Journal of Institute of Science and Technology, 24(2), 1-6 (2019)
ISSN: 2469-9062 (print), 2467-9240 (e)
Doi: http://doi.org/10.3126/jist.v24i2.27243

Review Article

CANOPY RESEARCH IN NEPAL HIMALAYAS: OPPORTUNITIES AND CHALLENGES

Mohan P. Devkota

Botany Department, Amrit Campus, Tribhuvan University, PO Box 102, Thamel, Kathmandu, Nepal
Corresponding author: mistldevkota@yahoo.com

*(**Received:** July 3, 2019; **Revised**: October 31, 2019; **Accepted:** November 1, 2019)*

ABSTRACT

Despite a rapidly expanding interdisciplinary field worldwide, forest canopies of Nepal Himalayas are yet to be explored and the national conservation strategy still has to recognize the importance to identify it as an essential domain of canopy dwelling animals and plants. In the last few decades canopy science has emerged as a new discipline with more interdisciplinary and large-scale research possibilities are coming including canopy-atmosphere interactions, structural and functional aspects of canopy on biodiversity are a few among them. Canopies are important in supporting high terrestrial diversity and providing goods and services. Diverse rural mountain societies not only depend on goods and services provided by canopy but it also provides opportunities to explore sustainable use of resources for local livelihood generation. New frontiers of forest canopy research can also provide inputs to understand the potential impacts of climate change on the changing availability of goods and services affecting rural communities of Nepal. Yet, it still remains one of the unexplored and overlooked areas in the biodiversity sector of Nepal. Here, the opportunities of canopy research in Nepal Himalayas and various challenges associated with this are reviewed.

Keywords: Forest canopy, Canopy biodiversity, Canopy conservation, Ecotourism, Himalayas

INTRODUCTION

The world of canopy science, which provides many aspects of research in diverse habitats, is a rapidly expanding interdisciplinary field engaging numerous scientific disciplines and applying them to unlock the mysteries of the world's forests and treetops by providing pedestals that integrate all fields of scientific investigation. Research in this diverse area of study ranges from canopy biodiversity, discovery of new species, documentation of life histories to broad investigations on nutrient cycling patterns, sophisticated population modeling, and ecological impacts in a rapidly changing world. Forest canopies are fascinating habitats harboring rich and unique creatures, many of which are still unknown to science.

Work on this challenging frontier only began with earnest in the early 1980s and has already substantially changed our understanding of key ecosystem processes. Forest canopies not only support high terrestrial biodiversity, but also represent a critical interface between the atmosphere and the earth. They also provide goods and services to support diverse human communities and offer opportunities to explore sustainable use of resources for local livelihood generation. Besides, the canopy can also act as a hook for sustainable use, such as canopy ecotourism and education, and outreach.

The importance of plants that dwell in forest canopies are increasingly recognized in relation to understanding biodiversity. Canopy-dwelling plants contribute substantially to overall forest biodiversity and bio-complexity by providing resources for arboreal vertebrates, invertebrates and microbes, by participating in nutrient and water cycling, gas and energy exchanges (Nadkarni *et al*., 2001). The forest canopy is a functional interface between a rich and complex biological habitat and the atmosphere across more than a quarter of the global land surface.

Canopies are characteristic feature of the land surface of our plant. The total foliage surface area of the terrestrial vegetation (644×10^6) is greater than the surface area of the entire earth (510×10^6) (Whittaker & Likens, 1974). Researchers have viewed the canopy in various ways: (i) as a *place* (whose location can be defined, either by reference to relative height, by the proximity of non-forest conditions, or even by the difficulty of access); (ii) as a *set of conditions* (a medium with structural limits or environmental boundaries); or (iii) as an *interface* between two environments, the atmosphere and biosphere (Nadkarni *et al*., 2011).

Definition and importance of canopy studies

The forest canopy has been called "the last biotic frontier" (Erwin, 1988). It presents a habitat conducive to the evolution of literally thousands-perhaps millions-of species of plants, microorganisms, insects, birds, and mammals that are rarely or never encountered on the forest floor. The forest canopy is a structurally complex and ecologically important subsystem of the forest. It is defined as "the aggregate of all crowns in a stand of vegetation, which is the combination of all foliage, twigs, fine branches, epiphytes as well as the interstices (air) in a forest" (Parker, 1995) and plays a significant role in the maintenance of biodiversity and the provision of local and global ecosystem services (Ozanne *et al*., 2003).

The increasing research and the growing body of canopy knowledge, is helping us to understand: (i) the tremendous biodiversity in canopies, (ii) the relationship between forest canopy structure and function, (iii) the exchange of matter and energy with the atmosphere, and (iv) the control of forests over climate (Bonan, 2008). These issues relate to some of the most pressing environmental topics today: the loss of biodiversity, the functional role of forests to provide ecosystem services, and mitigation of global and regional climate change due to human activities. Research approaches have become more experimental and predictive in orientation (Winkler *et al*., 2005) having great promise for the integrative, comparative, and predictive work that marks a mature science. This growing understanding has also created increased public interest in canopies and forests, with ramifications for conservation, environmental education, and ecotourism (Moffett, 1993).

Canopy research in 21st century

Thirty years ago, the canopy was considered an insignificant part of the forest ecosystems with little scientific attention beyond a few taxonomists specializing in arboreal biota. The development of three technological innovations coincided with the subsequent rapid growth of canopy studies: (i) mountain climbing methods, fogging techniques, and construction equipment to facilitate access (Erwin, 1982; Moffett & Lowman, 1995) (ii) easy-to-use equipment for making whole canopy measurements of material and energy exchanges with the atmosphere (Baldocchi *et al*., 1988), and (iii) methods to measure the structure of whole canopies (Gonzalez *et al*., 2010).

Canopy study is becoming a data-rich discipline that bears on many fields of science and environmental issues. Canopy-dwelling plants (epiphytes) constitute up to half the total plant diversity of some wet tropical forests and provide crucial resources for a host of arboreal birds and animals (Nadkarni & Matelson, 1989). Recent researches from numerous tropical and temperate canopies documented that canopy invertebrates exhibit a tremendous amount of diversity and 'endemism' in the canopy (Nadkarni, 2001 and the references there in). Canopy structural elements such as foliage and twigs account for a tremendous 'sieving' effect of fog in some forests, causing wind-borne precipitation and its accompanying nutrients and pollutants to be deposited locally (Coxson & Nadkarni, 1995). Canopy dwelling organisms can serve as indicator organisms to monitor changes in global climate and atmospheric conditions as they live in the atmosphere-forest interface (Lugo & Scatena, 1992; Benzing, 1998). Many important forest–atmosphere interactions such as photosynthesis, respiration, carbon flux, and water and nutrient cycling mainly take place in this region as the forest canopies are at the interface between the forests and the atmosphere thus fostering many ecosystem processes (Lowman & Nadkarni, 1995).

On a global level, we need to know how plant–atmosphere interactions are likely to be affected by the changing global process. Changes in plant-atmosphere interactions can have cascading effects on animals which interact with plants as well as with the atmosphere. Recently, such issues have become increasingly important in the context of global climate change scenarios.

Tropical canopy biologists are at the threshold of exploring a new frontier, with new perspectives and newer approaches. With rapidly accumulating knowledge there are immerging opportunities to address fundamental questions concerning biodiversity such as: Does the distribution of canopy-dwelling species match with those near the ground across large spatial and temporal scales? What is the role of canopies of different structures in canopy atmosphere interactions? What is the level of productivity, carbon sequestration across spatial scales or more simply, does one forest canopy sequester more carbon than other types in different regions? In the meantime canopy understory interactions are also not clearly understood. Does herbivory reduce the productivity of the trees or does it actually promote nutrient cycling? Many such questions will be addressed in the future, as canopy science becomes a more integrated discipline and does not remain only a biologist's last frontier. Thus, canopy science has now emerged as a recognized field and is progressively evolving as a distinct discipline.

Phyto-geographical significance of Nepal for canopy research

Nepal lies in the cross road of various floristic regions of Asia, where the drier Western and Central Asiatic floral provinces meet with the more humid Sino-Japanese province. The South East Asiatic provinces penetrate into the foot hills of eastern Nepal while the African-Indian desert province is attenuated towards the western parts of the country. The southern part of Nepal with its flat plains is typical of the Indian province. The division between the boreal forest region (Paleartic realm) and the paleotropical floral region (Oriental realm) runs along the Himalayan region from east to west (Shrestha & Joshi, 1996). These features make Nepal extremely rich in terms of diversity in proportion to its size.

Dipterocarps in Terai region; Pine forest in the west and *Schima-Castanopsis* forest in the east and centre of Mahabharat and middle mountains; various oaks, rhododendron, magnolias and laurels in further higher elevation dominate the vegetation. According to ICIMOD/MoEST (2007) Nepal's rich biodiversity is composed of 6391 angiosperms flora, with 25 species of gymnosperms, 2000 species of lichen, 1822 species of fungi, 853 species of bryophytes, 534 species of ferns and fern allies, similarly 651 species of butterflies, 785 species of moths, 195 species of herpetofauna, 874 species of birds and 185 species of mammals are faunal species. Similarly, there are 377 orchid species (Rajbhandari & Dahal, 2004) and 20 mistletoe species (Devkota & Glatzel, 2005; Devkota & Koirala, 2005; Devkota & Ikeda, 2013).

Likewise, Devkota (2013) has reported that forest canopies of sacred groves of Kathmandu Valley have supported 45 % of mistletoe diversity reported from the country. Thirty five different forest types (Stainton, 1972) and 136 different ecosystems in 8 ecological regions (Dobremez, 1972) have been identified in Nepal which has resulted into a great variety of habitats. Sudden variations in altitude, climate and topography create diverse habitats and ecosystems, challenging the researchers in natural sciences and also for the enthusiastic dwellers and trekkers interested in nature. Thus, Nepal offers unique opportunity to explore and study the canopy biodiversity of many phytogeographical/ zoogeographical provinces in a small territory of 147,181 km^2.

The need for canopy research in Nepal Himalayas

It has been estimated that forest canopies support about 40 % of extant species of which 10 % are predicted to be canopy specialists (Hammnod *et al*., 1997; Rodgers & Kitching, 1998; Novotny *et al*., 2002). In some tropical forests canopy biodiversity make up one-third to half of total species richness (Gentry & Dodson, 1987; Kelly *et al*., 1994). Madison (1977) has estimated that epiphytic vascular plants comprise 10 % of all vascular plant species and 70 % of all orchid species (Gentry & Dodson, 1987). Biodiversity locked up in the canopy can be exceedingly large, as much as 50 % or more of an ecological community (Erwin, 1983). In the past, very few studies have been carried out that have examined interactions between canopy plants and animals. Devkota and Kunwar (2006) have studied the role of mistletoe birds in pollination and dispersal of *Scurrula* (mistletoe) species in Kathmandu Valley. Similarly, Adhikari *et al*. (2012a), Adhikari *et al*. (2012b), and Adhikari & Fischer (2011) have examined the distribution pattern of orchids with human impact gradient in the Kathmandu valley. Nepal's rich biodiversity with one biodiversity hot spot in the Eastern Himalayas, Kangchenjunga Area, provide excellent opportunity for canopy research in wide variety of ecosystems from Terai to high Himalaya. Yet almost all the biodiversity assessments in Nepal have been conducted in the terrestrial level and much more remained to be examined in the forest canopies of Nepal. Nepal has high potentiality for carrying out canopy research despite many challenges associated in inaccessible mountainous terrain.

Opportunities

Forest canopies of various vegetation types in diverse ecosystems that provide great varieties of habitats harbouring rich floral and faunal diversity need to be explored in Nepal. Besides, diverse rural societies are supported by canopies in various ways, providing goods and services. But, in Nepalese context we do not know (i) how much floral and faunal diversity is supported by canopies in the Himalayas, (ii) their role in providing regulating and supporting ecosystem services that promote mitigation of and resilience to climate change in the Himalayas; (iii) the potential impacts of climate change on those services and the provision of services to rural communities of Nepal, (iv) role of canopies generated opportunities to explore sustainable use of resources to support and generate local livelihood, and (v) sustainable use of canopy in ecotourism, education and outreach.

Canopy outreach and education may prove to be an important hook for inspiring young graduates to seek careers in science, for giving citizen's scientists opportunities to understand principles in ecology, and to serve as a communication platform for policy makers. In several ways, forest canopies are in the front line in the fight against climate change. Policy makers of Nepal can be increasingly made aware of the potential role of forests in both mitigating and adapting to climate change, which is an urgent need to fight against climate change. Understanding of the functioning of canopies and appreciation of the resulting services of fundamental importance can be understood to our ability to guide policies on conservation and sustainable management of forest resources.

Canopy research in Nepal has high potential to open new collaborative opportunities for Nepalese scientists with rest of the world, whereas ecotourism with canopy walkways will create new livelihood opportunities for rural communities. Tourism activities such as paragliding and zip flyer, in Pokhara and Dhulikhel are very good examples to raise environmental awareness in ecotourism destinations which are often located in remote areas by avoiding negative ecological and socio-cultural effects.

Challenges

Nepal has 40.36 % of its land covered by forest, spreading over 5.96 million ha area, (DFRS, 2015) but it is facing severe threat due to increasing demand of agricultural land, timber, fuel wood and fodder, and encroachment of forest area for settlements. It has been estimated that country has lost 1.2 million hectares of forest between 1990 and 2005 representing about 25 % of its total forest cover (FAO, 2005). Primary forest cover diminished as well, falling by nearly 11 % during that period. While overall deforestation rates have fallen since the 1990s, rates of primary forest loss have increased significantly (FAO, 2005). If the current deforestation rate is not reduced to significant level and control measures are not immediately implemented, it can be predicted that the country will lose its most vital forest resources from Terai to mountains, except in protected areas. Thus, deforestation, fragmentation and land degradation of habitats can be considered as the greatest threats to Nepal's biodiversity. Although community forestry is considered as one of the most successful forestry program that covers approximately 1.8 million hectors in Nepal (DoFSC, 2019), it does not significantly contribute in biodiversity conservation as it has converted national forest to less diverse regular forest by altering plant community composition (Poudel, 2009; Baral & Katzensteiner, 2009; Shrestha *et al*., 2010).

Canopy studies cannot be carried out without adequate safe-climbing gears to access the forest roof. Considering the present research facilities available in Nepal, canopy study is very challenging as it requires high-tech equipment such as tree climbing gears, walkways, cranes, balloons, towers with interconnected walkways and airships. Purchase or establishments of these costly equipment/methods for canopy research will demand lots of money which may impede the spirits of pioneering researchers in Nepal. Lack of experts within the country is another problem but collaborative work can be very beneficial in carrying out the canopy research in Nepal which will also help in developing trained Nepalese manpower for future research.

In this rapidly changing world of conservation with new emerging scientific methods and approaches, the National Biodiversity Strategy and Action Plan: 2014-2020 has inadequate methods of biodiversity conservation and was unable to identify new areas, methods and systematic approach in determining country's capacity and developing implementation modalities for biodiversity conservation which has negatively impacted prioritization, operation, implementation, and ability to monitor performances at the program/project level (GoN/MoFE, 2014). Therefore, Nepal needs to revise its strategy and prioritize its fields of biodiversity study, initiate international cooperation and develop conservation strategy in new areas with effective implementation plans.

Need for canopy conservation

Ecosystem goods (such as food) and services (such as interception of water and pollination) are the benefits that human populations derive, directly or indirectly, from the canopy. However, outside the scientific community, few people understand about these benefits, and a need to generate awareness about canopies is essential for forest conservation. The canopy-access systems, if established, can be a versatile tool to generate awareness. Similarly, canopy access in reserve forests with lesser protection status could also be used for eco-tourism with restrictions, to complement the dearth of funds. Part of the funds could be directed to the welfare schemes of forest-dependent communities.

Forest canopy studies can provide compelling reasons supported by scientific data to encourage conservation of forests by highlighting our diverse canopies and their contribution to the global-change process such as climate change. Since canopies buffer the earth surface from the vagaries of extreme weather patterns, it can have a significant effect on soil and water conservation and can give useful inputs to the forest and other related departments which can use the knowledge to protect and enhance biodiversity conservation. Canopies can be a wonderful place to deliver any conservation message and build a lasting impression of forests on young minds.

Arboreal plants provide many opportunities and challenges for biologists from many disciplines, and because these plants have no access or sporadic access to terrestrial soil, they make excellent experimental subjects to study physiology and stress. Canopy plants warrant attention for the roles they play in forest dynamics, which affect biodiversity, productivity, and nutrient cycling. Lichens and mosses are very important components of canopy and are very susceptible to air pollution metal ion deposition (Rhoades, 1995). They have been successfully used by few studies as bio-indicators to monitor air pollution in Kathmandu Valley (Shakya *et al*., 2004; Chettri *et al*., 2001).

Water stress is a major limiting factor for plants inhabiting the crowns of trees. A rise in global temperatures may have an impact locally on the relative humidity of some forest canopies affecting local canopy communities. Because of their small size, high degree of endemism and frequent microsite specificity, epiphytes may be more vulnerable to human-induced disturbance than terrestrial plants. Their conservation, in such stress condition, can be achieved as discussed by Lowman and Nadkarni (1995). Large canopies of older trees in forests act as a habitat for certain sensitive canopy species as shown by Nadkarni *et al*. (2001). Loss of such single tree can be a great loss to canopy diversity, however there are no records of a specific canopy plant extinction in modern times (Nadkarni *et al*., 2001). Gradstein *et al*. (1989) suggested that relatively small reserves containing a diversity of life zones should suffice to conserve cryptogam biodiversity if the reserve is large enough to maintain a viable population of host trees.

There is more to be explored and examined in the canopies of Nepalese forests. Nepalese biodiversity could get a new estimate if we begin to document the lesser known taxa in the canopy. It is already late for Nepal to initiate a program to investigate this 'unexplored biosphere', to fulfill its commitments made under CDB.

Processes such as plant–animal interactions, canopy–understory interactions, canopy atmosphere interactions are also vital areas of research. Nadkarni and Rodrigo (2002) had demonstrated the canopy epiphytic community in montane forests of Monteverde as an effective biotic tool for detecting the global climate change. Perhaps, our canopy may also harbor such indicators yet to be identified. In conclusion, canopy science can lead us to the heights of exciting research possibilities which are hard to visualize from ground based observations and imagination.

REFERENCES

Adhikari, Y. P., & Fischer, A. (2011). Distribution pattern of epiphytic orchids *Rinchostylis retusa* under strong human influence in Kathmandu Valley, Nepal. *Botanica Orientalis*, *8*, 90-99.

Adhikari, Y. P., Fischer, A., & Fischer, H. S. (2012a). Micro-site conditions of epiphytic orchids in a human impact gradient in Kathmandu Valley, Nepal. *Journal of Mountain Science*, *9*, 331-342.

Adhikari, Y. P., Fischer, H. S., & Fischer, A. (2012b). Host tree utilization by epiphytic orchids in different land-use intensities in Kathmandu Valley, Nepal. *Plant Ecology*, *213*, 1393-1412.

Baldocchi, D. D., Hicks, B. B., & Meyers, T. P. (1988). Measuring biosphere atmosphere exchange of biologically related gases with micrometeorological methods. *Ecology, 69*, 1331-1340.

Baral, S. K., & Katzensteiner, K. (2009). Diversity of vascular plant communities along a disturbance gradient in a central mid-hill community forest of Nepal. *Banko Jankari*, *19*(1), 3-10.

Benzing, D. (1998). Vulnerabilities of tropical forests to climate change: the significance of resident epiphytes. *Climatic Change*, *39*, 519-540.

Bonan, G. B. (2008). Forests and climate change: forcing, feedbacks, and the climate benefits of forests. *Science*, *320,* 1444-1449.

Chettri, M. K., Thapa, K. B., Poudel, K., & Acharya, B. (2001). Bio-monitoring of toxic heavy metals in Kathmandu Valley using lichens. *Ecoprint*, *8*, 69-75.

Coxson, D. S., & Nadkami, N. M. (1995). Ecological Roles of Epiphytes in Nutrient Cycles of Forest Ecosystems. In M. Lowman & N. Nadkarni (Eds.), *Forest canopies* (pp. 495-564). San Diego, California: Academic Press.

Devkota, M. P. (2013). Sacred Groves as Sanctuaries for Mistletoe Conservation in Kathmandu Valley. In M. Lowman, S. Devy & T. Ganesh (Eds.), *Treetops at risk: Challenges of global canopy ecology and conservation* (pp. 405-414). New York: Springer.

Devkota, M. P., & Glatzel, G. (2005). Mistletoes of Annapurna conservation area, central Nepal Himalayas. *Journal of Japanese Botany, 80*, 27-36.

Devkota, M. P., & H. Ikeda. (2013). A new record of *Tolypanthus involucratus* (Loranthaceae) from Nepal. *Journal of Japanese Botany, 88,* 188-190.

Devkota, M. P., & Koirala, A. K. (2005). New record of mistletoe *Viscum monoicum* Roxb. ex DC. (Viscaceae) from Nepal Himalaya. *Journal of Japanese Botany*, *80*, 56-57.

Devkota, M. P., & Kunwar, R. M. (2006). Pollination and dispersal of three *Scurrula* species (Loranthaceae) in Godawari area of Kathmandu Valley, Nepal. *Indian Journal of Botanical Research*, *2*(2), 115-128.

DFRS (2015). *State of Nepal's forests*. Forest Resource Assessment (FRA), Department of Forest Research and Survey (DFRS), Kathmandu, Nepal, p. 521.

Dobremez, J. F. (1972). Les grandes divisions phytogeographiques du Nepal et de l'Himalaya. *Bulletin de la Société Botanique de France, 119,* 111-120.

DoFSC. (2019). Community Forestry, Department of Forest and Soil Conservation, Ministry of Forest and Environment, Government of Nepal. Retrieved from http://dof.gov.np/dof_community_forest_division/community_forestry_d on July 1, 2019.

Erwin, T. L. (1982). Tropical forests: their richness in Coleoptera and other Arthropod species. *Coleoptera Bulletin*, *36*, 74-75.

Erwin, T. L. (1983). Tropical forest canopies, the last biotic frontiers. *Bulletin of Entomological Society of America*, *29*, 14-19.

Erwin, T. L. (1988). Biodiversity. In E. O. Wilson (Ed.), *The tropical forest canopy: The heart of biotic diversity* (pp. 123-129). Stanford, California: Stanford University Press.

FAO. (2005). *Nepal country report; Global forest resources assessment*. Country Report No. 192. Rome, p. 42.

Gentry, A. H., & Dodson, C. H. (1987). Diversity and biogeography of neotropical vascular epiphytes. *Annals of the Missouri Botanical Gardens, 74*, 205-233.

GoN/MoFSC. (2014). *Nepal national biodiversity strategy and action plan: 2014-2020*. Government of Nepal, Ministry of Forest and Soil Conservation, Kathmandu, Nepal, p. 232.

Gonzalez, P., Asner, G. P., Battles, J. J., Lefsky, M., Waring, K. M., & Palace, M. (2010). Forest carbon densities and uncertainties from Lidar, Quick Bird, and field measurements in California. *Remote Sensing of Environment, 114*, 1561-1575.

Gradstein, S. R., van Reenen, G. B. A., & Griffin, D. (1989). Species richness and origin of the bryophyte flora of the Colombian Andes. *Acta Botanica Neerlandia, 38,* 439-448.

Hammond, P. M., Stork, N. E., & Brendell, M. J. D. (1997). Insect Sampling in Forest Ecosystem. In N. E. Stork, J. Adis & R. Didham (Eds.) *Canopy Arthropods* (pp. 184-223). Chapman & Hall, London.

ICIMOD/MoEST. (2007). *Nepal biodiversity resource book: Protected areas, Ramsar sites and world heritage sites*. ICIMOD and MoEST, Government of Nepal, p. 161.

Kelly, D. L., Tanner, E. V. J., NicLughada, E. M., & Kapos, V. (1994). Floristics and biogeography of a rain forest in the Venezuelan Andes. *Journal of Biogeography, 21,* 421-440.

Lowman, M. D., & Nadkarni, N. M. (1995). *Forest canopies* (1st ed.). San Diego, California: Academic Press.

Lugo, A. E., & Scatena, F. (1992). Epiphytes and climate change research in the Caribbean: A proposal. *Selbyana, 13*, 123-130.

Madison, M. (1977). Vascular epiphytes: Their systematic occurrence and salient features. *Selbyana, 2*, 1-13.

Moffett, M. W. (1993). *The high frontier-exploring the tropical rainforest canopy*. Cambridge: Harvard University Press, p. 267.

Moffett, M. W., & Lowman, M. D. (1995). Forest Canopies. In M. D. Lowman and N. M. Nadkarni (Eds.). *Canopy access techniques* (pp. 3-26). New York: Academic Press.

Nadkami, N. M., & Matelson, T. M. (1989). Bird use of epiphyte resources in Neotropical trees. *Condor, 69*, 891-907.

Nadkarni, N. M. 2001. Enhancement of forest canopy research, education, and conservation in the new millennium. *Plant Ecology, 153*, 361-367.

Nadkarni, N. M., & Rodrigo, S. (2002). Tropical forests: Past present future. In: *Proceedings of Association of Tropical Biology*, Panama.

Nadkarni, N. M., Mervin, M. C., & Nieder, J. (2001). Forest canopies, plant diversity. *Encyclopedia of Biodiversity, 3*, 27-40.

Nadkarni, N. M., Parker, G. G., & Lowman, M. D. (2011). Forest canopy studies as an emerging field of science. *Annals of Forest Science, 68*, 217-224.