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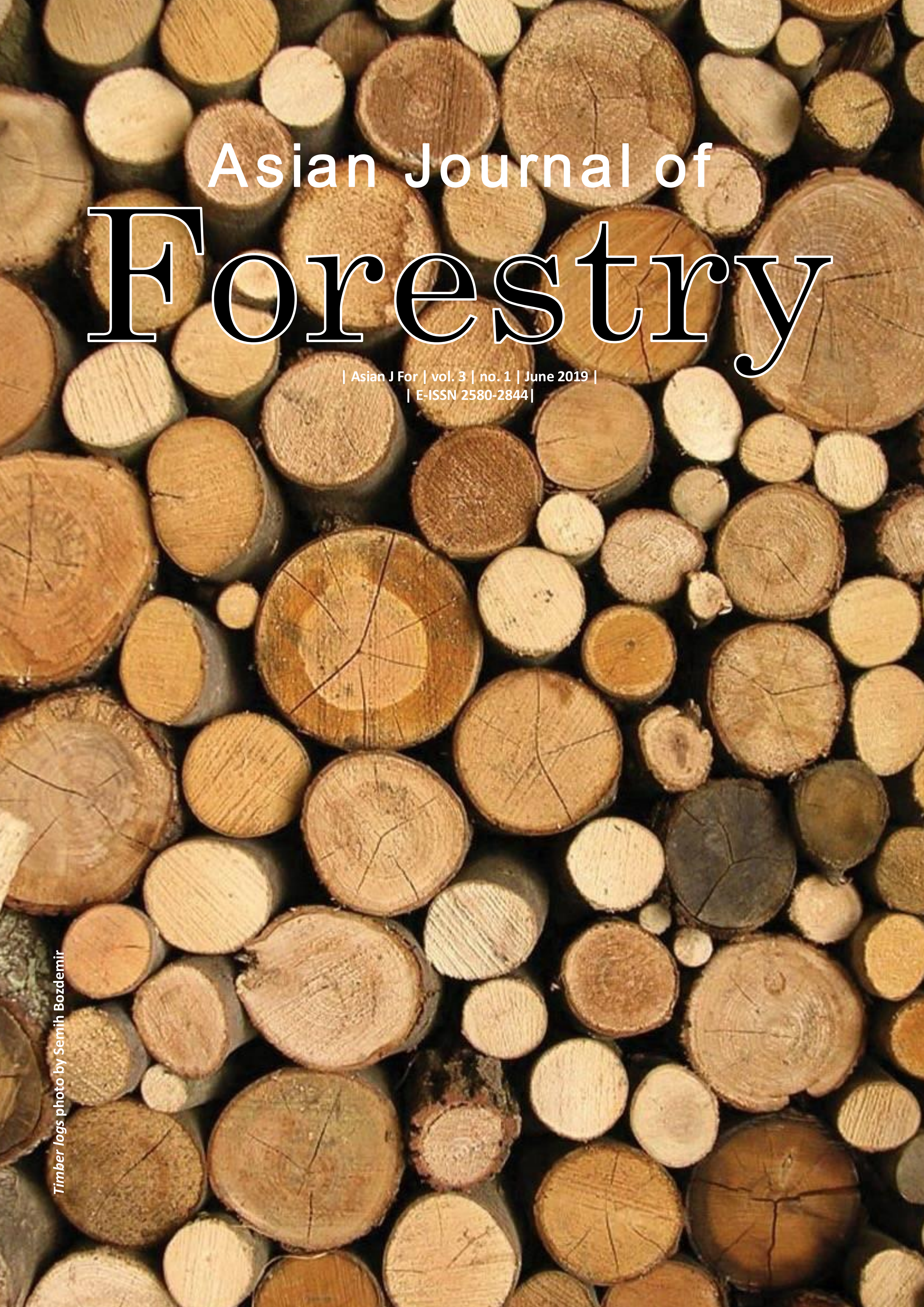

Timber logs photo by Semih Bozdemir

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Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds) Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th Annual Symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.) Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. www.molecularsystemsbiology.com. DOI:10.1038/msb.2008.24

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Analysis of the India-Myanmar timber trade

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Abstract. *Maria-Sube E, Woodgate G. 2019. Analysis of the India-Myanmar Timber Trade. Asian J For 3: 1-9.* Myanmar's forest cover declined by 1.8% annually between 2000 and 2015 as the result of on-going civil wars and institutional weaknesses. As Myanmar transitioned from military dictatorship, round log exports were banned in 2014. Until 2014, India was the most important importer of timber from Myanmar in terms of value, and the second most important in terms of volume, after China. This article assesses the value and volume of timber traded between Myanmar and India from 2010 until 2015. In addition to trade flows, the timber species and main actors involved in the timber trade are identified and the governance environment of trade is assessed. The paper goes on to investigate the impact of recent regulatory changes enacted by the Government of India and the prospects for the future of the India-Myanmar trade. The analysis showed that (i) from an economic perspective, the timber trade between the two countries, once active, is currently stalled. (ii) From a governance perspective, illegality occurs to a limited extent at the international border but probably happens to a greater extent at timber auctions in Myanmar. Finally (iii), from a social and environmental point of view, as infrastructure expands it will be crucial to include forest management and timber trade governance in discussions regarding border relations between the two countries.

Keywords: India, governance, Myanmar, timber, trade

INTRODUCTION

At the beginning of the 20th century, Burma (Myanmar) was famous worldwide for the science-based management of its teak forests and its high volume of exports (Woods and Canby 2011). However, successive government upheavals and on-going internal conflicts since independence have severely impacted the country's forests. From its independence in 1948 until the military coup in 1962, Myanmar's forests were managed according to colonial rules; after 1962, and in particular, after the civil uprisings in 1988, forests were logged unsustainably (Springate et al. 2016). Between 2000 and 2015, Myanmar experienced the third greatest loss of forest cover in the world, with an annual deforestation rate of 546,000 ha (equivalent to 1.8% of its forested area), behind only Indonesia and Brazil (FAO 2015a). In April 2014, the Myanmar government decided to ban the export of round logs. This was followed by a total logging ban from August 2016 until March 2017. The Environmental Investigation Agency commented that these measures 'give grounds for hope that Myanmar is entering a new era of forest management in which conservation and transparency, rather than the old model of extract and export, are at the fore' (EIA 2016a).

There is no undisputed definition of what illegal logging entails and no worldwide regulation to combat illegal logging. A recent definition (Kleinschmit et al. 2016, p.14) includes 'all practices related to the harvesting, processing, and trading of timber inconsistent with national and sub-national law'. Consumer countries have made bilateral or national efforts to reduce illegal logging and better manage forests internationally since the 1990s. Laws restricting imports of illegally harvested wood were passed in the United States with the 2008 Lacey Act and in the EU with the 2010 Timber Regulation. Such laws are slowly proving effective. In November 2016, a Swedish court ruled that a Singaporean trader's proof of legality for a shipment of Myanmar teak was not sufficient under the EU Timber Regulation (Forest Trends 2016). As a consequence, no Burmese teak can now be placed in the EU market (EIA 2016b).

Today, the rapidly expanding economies of China and India together represent 72% of global tropical log imports compared to just 28% in 2000 (Gan et al. 2016). In the case of Myanmar, the value of timber exports to China reached USD 621 million in 2013, of which more than 90% was thought to have been illegally logged (Woods 2013b). India was the main importer of timber from Myanmar until 2013 in terms of value, yet there is very little published research on this topic. There are also no studies yet investigating the impact of the recent timber export bans on the India-Myanmar timber trade. Therefore, this research aims to: quantify the value and volume of timber traded between Myanmar and India over the past 15 years; to identify where the timber transits between the two nations; and to assess the main actors involved and the species of timber traded. The main products to be studied are logs, sawn wood, veneer, and plywood. The governance of the trade will be analyzed, as well as recent changes in the India-Myanmar relationship context and the future prospects for the trade.

The information presented in this paper is expected to provide a better understanding on the issue of the India-Myanmar timber trade in this new global and bilateral context. It would answer the following questions: (i) What are the characteristics of the India-Myanmar timber trade since 2000? (ii) What are the economic, environmental and governance effects of the recent tightening of regulations on timber trade between India and Myanmar?

The paper develops as follows. A review of the literature surrounding forest management and timber production in Myanmar and the characteristics of the timber trade relationship between Myanmar and India, the materials and methods are explained. In the subsequent section, the results are presented and discussed.

MATERIALS AND METHODS

Quantitative research design

The quantitative research aimed to establish the volume, value, and flows of the India-Myanmar timber trade over the past 15 years. The analysis focused on all wood-based products other than paper and fuelwood, i.e., logs, sawn wood, veneer, plywood, and wooden furniture or ornaments, the main elements covered by Voluntary Partnership Agreements (VPAs) with the European Commission, called core VPA products. This scope facilitates comparisons with other sets of data.

Data were collected from three secondary sources: (i) the independent website www.flegtactionplan.eu, which collates information from open sources, such as the UN Comtrade database and Ministries of Commerce of importing countries; this source was used to compile Myanmar timber exports data and India's imports by country of origin; (ii) the UN Comtrade database, which contains official trade statistics shared by UN Member States; this source was used to cross-check Indian imports by country of origin in the flegtactionplan.eu website and to produce graphs of India's imports from Myanmar by wood product in terms of volume and value; (iii) The Directorate General of Commercial Intelligence and Statistics, Ministry of Commerce and Industry, Government of India; this source provided data regarding ports of entry of Indian imports. Data can only be obtained free for transactions within the last 24 months. Port of entry data was retrieved for imports of wood products from Myanmar and of wood products from all other countries in 2015.

Data were not altered, except the volume data for imports of logs, sawn wood, veneer, plywood, and other smaller wooden products. UN Comtrade provides weight data but not volume. In addition, volume of a wood product underestimates the volume of roundwood needed to make that product. Analysts calculate a roundwood equivalent. EU FLEGT conversion factors were used to transform data where necessary (Table 1).

Qualitative research design

The qualitative research aimed to answer questions related to the actors involved in the trade, the species that are traded, and the governance of the trade, as well as future prospects for this trade. Initial contacts were identified and these provided further informants, following a snowball sampling technique. Drawn from government, the private sector, academia, development partners and NGOs in India and Myanmar, 32 individuals were contacted for interviews between March and June 2017. Thirteen respondents accepted and were interviewed for durations ranging from 30 minutes to 2 hours. Protocols were prepared for semi-structured interviews for four respondent groups: Private sector, development partners, NGOs in India and NGOs in Myanmar.

Interviews with respondents based in India, took place between 10 and 19 April 2017, in New Delhi and Shillong, in the North East of India. Three interviews with India-based respondents also took place by telephone and one interviewee answered in writing. Interviews in Myanmar were all face-to-face. All but one respondent agreed to be recorded.

Qualitative data were analyzed using Dedoose Version 7.6 software. Themes within the interview transcripts were coded to identify trends in answers. Trends were not identified, given the diversity of respondents, but this exercise helped categorize the analysis regarding two topics: the governance of the sector and the future of the trade.

Some respondents stated that they did not wish to be named or to have their organizational affiliation revealed. This preference was therefore applied to all respondents, in order to avoid any issues with confidentiality. Table 2 details the sector and country of origin of respondents.

RESULTS AND DISCUSSION

Size of the trade: volume and value

In terms of volume, India imported on average 42% of Myanmar’s global timber exports between 2000 and 2015: in total 11.86 million m^3 Round Wood Equivalent (RWE) The value of Indian imports from Myanmar peaked in 2013 when they totaled more than US$700 million, and accounted for 31% of all of India's timber imports in that year. Myanmar was then the main source of timber in terms of value, ahead of Malaysia, for three years from 2011 to 2013. This peak was followed by a slight decrease in 2014, followed by a sharper decline in 2015 and 2016 (Figure 1).

India’s demand for timber had increased four times in value and doubled in volume since 2000. As can be seen in Figure 2, Malaysia was one of the main sources of timber for India in terms of value and volume since 2000. In 2016, Malaysia was the primary source in terms of value, while New Zealand represented the most important source in terms of volume. At the same time, India has diversified considerably its sources of timber with the growth in ‘other’ sources.

Wood products traded

Both in terms of value and volume, timber traded from Myanmar to India was predominantly composed of round logs until the export ban was announced in 2014, varying between 95% and 99% of the total value of the trade. Despite the round-log ban in April 2014, a significant volume of logs, more than 75% of the value of timber traded in 2015, were exported to India in one quarter. One

Myanmar-based interview respondent from an international organization explained that the log export ban might not have been well planned. In the run-up to the ban, many more trees were felled, to create stockpiles, which could be legally traded.

In 2015, the amount of timber traded plummeted by 61% in terms of volume (see Figure 3) and 79% in terms of value (Figure 4). The amount of logs exported is not zero, but small. The amount of veneer and sawn wood traded suddenly increased. Veneer represented 69% of the total value of timber traded in 2016 and sawn wood 24.5%.

Table 1. Roundwood Estimates (RWE) measures

Data	Weight to volume conversion
Determination of volume by weight	Multiply by 1.4
Fibreboard and sawn wood volume	Multiply by 1.8
Veneer and Mouldings volume	Multiply by 1.9
Plywood volume	Multiply by 2.3
Wooden furniture volume	Multiply by 2.8
Picture frames, ornaments, joinery volume or non-specified articles	Multiply by 2.5

Table 2. Profiles of respondents

Sector/country of operation	India	Myanmar	Total
Academic	2		2
Development Partner/ International Organisation	1	1	2
Government	1		1
NGO	2	2	4
Private Sector	2	2	4
Total	8	5	13

Note: Extracted from Dedoose 7.6

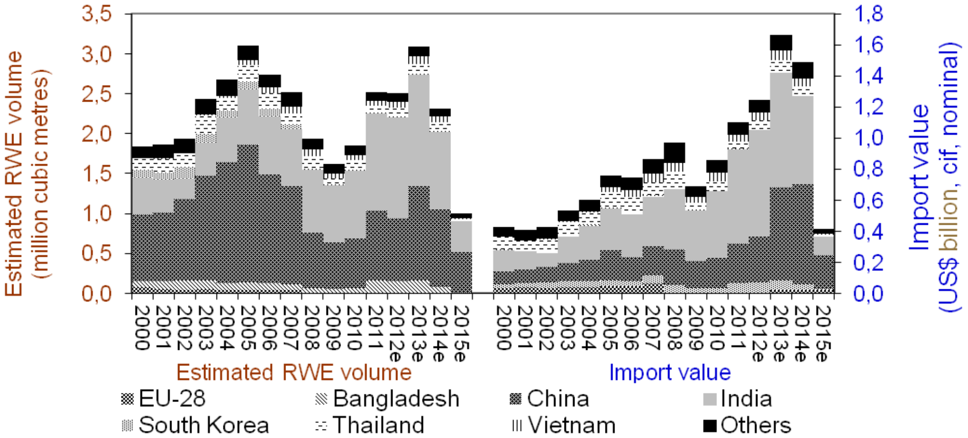

Figure 1. Imports of core VPA products from Burma (by importing country) based on declarations by importing country. Source: EU FLEGT Action Plan, data retrieved on 19 June 2017, http://flegtactionplan.eu/noneuimportsandexports.htm. The sources of the trade statistics used include: General Administration of Customs of the People's Republic of China (for China), Eurostat (for imports by EU member states), Import Statistics of Japan (for Japan), Korea Customs Service (for South Korea), Tradeline Philippines (for the Philippines), Directorate General of Customs (for Taiwan), Customs Department of the Kingdom of Thailand (for Thailand), United States International Trade Commission DataWeb (for the USA) and UN Comtrade

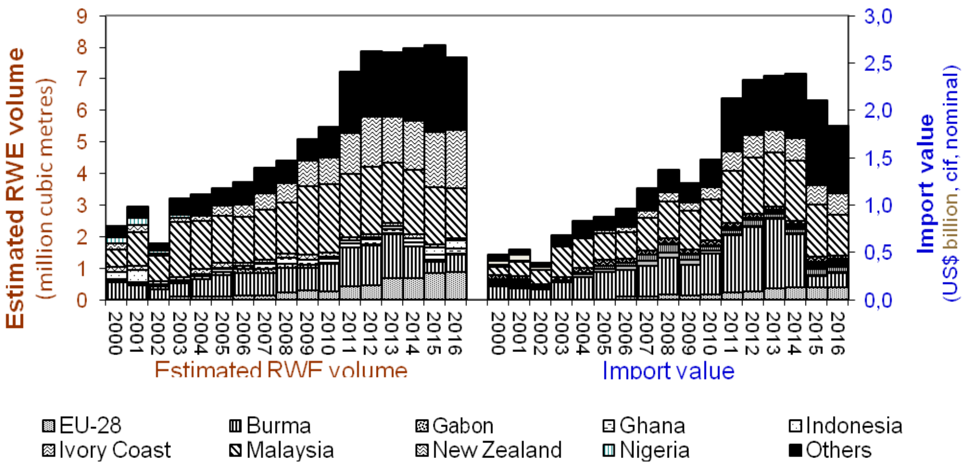

Figure 2. India's imports of core VPA products-by supplying country. Source: EU FLEGT Action Plan, data retrieved on 19 June 2017, http://flegtactionplan.eu/noneuimportsandexports.htm

Interviews revealed that in terms of species, Burmese teak, *Tectona grandis*, is highly appreciated by Indian traders. Interestingly, private sector respondents based in Myanmar did not mention teak; they focused on other species. Their prudence could be explained by the recent European sanctions. Burmese teak is not included on the IUCN Red List, nor in the CITES Appendices. Respondents with greater technical knowledge of the market, said gurjan, *Dipterocarpus* spp., as a preferred species for veneer and plywood. According to one private sector respondent operating in Myanmar, Myanmar exports 60 to 70% of its gurjan to India. Teak is mainly found in the forests of Sagaing. Several Dipertocarpus species are listed on the IUCN Red List as critically endangered, though they are not in the CITES Appendices. It can be difficult to tell these species apart in the trade, as gurjan may refer to a range of species. Desraj notes a similar phenomenon, noting that the Burmese name 'Kanyin' is actually 'rather loosely applied to probably a dozen species found throughout Burma' (1961). The third species mentioned is pyinkado, commonly called Ironwood (*Xylia xylocarpa*). It is used principally for construction and is not listed in the IUCN Red List.

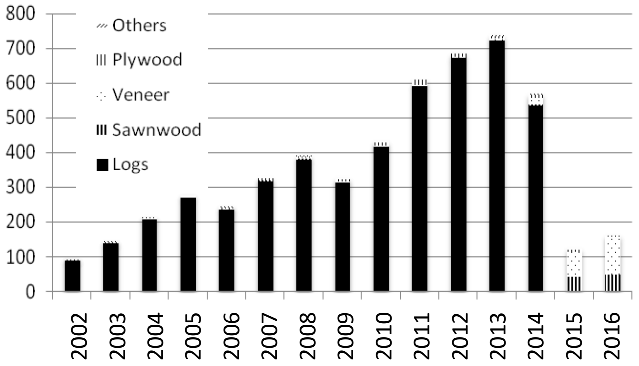

Figure 3. Imports of core VPA products from Myanmar to India in terms of value (millions of USD). Source: UN Comtrade from 2002 to 2016 for codes 4403, 4407, 4408, 4409, 4411, 4412, 4414, 4418, 4420, 940161, 940169, 940330, 940340, 940350, 940360

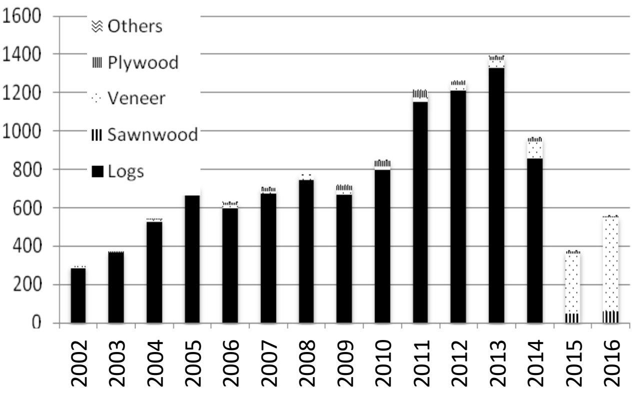

Figure 4. Imports of core VPA products from Myanmar to India in terms of volume in RWE. Source: UN Comtrade from 2002 to 2016 for codes 4403, 4407, 4408, 4409, 4411, 4412, 4414, 4418, 4420, 940161, 940169, 940330, 940340, 940350, 940360

Trade flows

Data could only be obtained for the year 2015 from the Indian Ministry of Commerce and Industry. As the roundwood ban had already been implemented that year in Myanmar and the nature of the wood products traded had changed significantly in that period, data were extracted for flows from Myanmar and for global ones.

While the main ports of entry for India's US$2.4 billion timber imports in 2015 were Kandla and Mundra, both located in Gujarat (Table 3), the main port of entry for timber from Myanmar was Cochin in Kerala (Table 4). Kandla has installed significant wood processing facilities at its port (ITTO 2013). Kolkata, was the third most important point of entry for imports from Myanmar in 2015, while it was much less important in terms of global flows. The headquarter of a plywood company called CenturyPly, which had a factory in Myanmar, is located in Kolkata. It is possible that round logs previously transited through Kandla and Mundra and that today, processed wood is transiting through Chennai and Kolkata.

"Other ports" are notable in both tables, for the flows from Myanmar and the global flows. As noted by a respondent operating in the private sector in India, Indian companies active in the timber sector were of small and medium size. Their flows were smaller and they might import their timber through smaller ports.

Table 3. Ports of entry into India of 'Plywood and Allied Products' and 'Other Wood and Wood Products' from all sources, Value in US Dollars, 2015

Port of entry	Value US$
Kandla	626,454,475
Mundra	342,825,976
Other Ports	234,847,090
Chennai	222,168,969
Tuticorin	210,253,986
Nhava Sheva	184,199,852
Kolkata	183,464,093
Delhi (ICD)	131,983,971
Cochin	91,966,107
ICD Bangalore	81,321,901
Marmagoa	46,747,885
New Mangalore	35,868,949
Visakhapatnam	16,436,599
Mumbai	7,459,761
Kakinada	3,987,957
Mumbai	3,574,142
Delhi Airport	2,855,270
Bangalore Airport	2,088,496
Hyderabad Airport	865,081
Chennai Airport	533,160
Petrapole Land	388,042
Kolkata Airport	110,251
Ahmedabad Airport	77,626
Kochi Airport	67,443
Seepz	26,593
SEZ Jamnagar (Reliance)	3,729
Raxaul Land	768
Paradip	455
Total	**2,430,578,627**

Note: Directorate General of Commercial Intelligence and Statistics, Ministry of Commerce and Industry, Govt. of India

An Indian private sector interviewee also noted the emergence of a large timber-processing zone in Orissa, which was corroborated by the press (The India Telegraph, March 2016). Orissa is situated on the coast of the Bay of Bengal, opposite Myanmar. Although the acquisition of the land for this processing zone seems to have delayed its launch, it is now going ahead. However, the port linked to this processing zone, Paradip, was still far from being the main port of entry of global trade and was not mentioned in the top 11 ports for Myanmar timber flows for 2015.

Most notably, land border points of entry are not mentioned in these tables, although there are two border crossings with customs stations between Myanmar and India: Tamu, Sagaing, Myanmar to Moreh, Manipur, India and Rih, Chin State, Myanmar to Zokhawatar, Mizoram, India. There are two other trading points, located further north along the border, in Arunachal Pradesh (Nampong, India-Pangsu, Myanmar) and Nagaland (Avangku, India-Somara, Myanmar), according to the Indian Ministry of Commerce website; these trading points are either non-functional or were not officially recognized as of December 2016. As timber trade that does not transit through Yangon is illegal according to Myanmar law, more details will be provided on trade by land entry points in the following section about governance. One could suspect a large flow of illegal timber through the land border.

Main actors of the trade

Information about the actors of the trade, such as importers, exporters, and analysts of this trade, was gathered from interviews and the literature review. Interview respondents operating in Myanmar highlighted the importance of the national Government and the Myanmar Timber Enterprise in relation to facilitating the timber trade, while respondents operating in India only referred to Indian private companies, generally small and medium-sized enterprises.

Table 4. Port of entry into India of 'Plywood and Allied Products' and 'Other Wood and Wood Products' from Myanmar, Value in US Dollars, 2015

Port of entry	Value US$
Cochin	35,121,479
Other Ports	26,797,328
Kolkata	25,062,544
Mundra	23,113,924
Delhi (ICD)	11,343,073
New Mangalore	9,505,234
Nhava Sheva	7,768,011
Chennai	6,832,744
Visakhapatnam	5,765,737
ICD Bangalore	3,426,436
Tuticorin	3,385,327
Kandla	860,748
Mumbai	847
Total	**158,983,432**

Note: Directorate General of Commercial Intelligence and Statistics, Ministry of Commerce and Industry, Govt. of India

The Indian companies involved belong to a relatively new wave of Indian investors that emerged in the 1990s. They had limited links to the Indians who were already established in Myanmar before the Independence. One respondent operating in Myanmar in the private sector explained how the Indian private sector was helpful in bringing financing to the timber sector when Myanmar was isolated from the rest of the world due to economic sanctions and international pressure. Harvesting companies were not able to advance money to pay for transport or staff costs and no financing was available to cover these operating costs of timber extraction. According to this respondent, Indian operators would advance money informally to log extractors.

Some Indian companies, such as CenturyPly (ICICI Securities Limited 2015) installed processing factories in Myanmar just before the timber ban and it was hoped that other Indian companies would follow suit (ITTO 2015). However, the logging ban has put paid to such hopes and the future of the trade between the two countries is now in doubt. Myanmar was seen as the new production site for a growing Indian market, but this has now slowed down.

Governance

The India-Myanmar timber trade is partly illegal. Lawson estimates that 17% of India's imports are of illegal origin (2014, p. 2), while the EIA (2013) estimates that 72% of Myanmar's exports were illegal between 2000 and 2013. All thirteen respondents, except two closely linked to the Indian private sector, mentioned 'informality' when describing the India-Myanmar timber trade. However, the trade was not so obviously illegal as the China-Myanmar timber trade, which transited up to 94% (Woods 2015) via the land border of China and Myanmar. Respondents based in New Delhi or at the Myanmar-India border agreed that timber was passing by land, but that the quantities were not significant for two main reasons: first, the rules around the border trade had changed over the last decades and created confusion, secondly and most importantly, the border region was remote for both countries and lacked adequate roads to transport bulky wood products.

Trade links are indeed weak at the Myanmar-India border. India is the neighbor that exchanges the least with Myanmar by land, its trade representing 0.8% of Myanmar's border trade, with 66 million USD of exchanged value, behind Bangladesh with 1.5 billion USD of trade value at the border, and China with 3.8 billion USD. However, the unofficial Myanmar-India trade was estimated to be much higher, according to interviewees. The border trade was in favor of Myanmar; India imports mainly areca nut (the seed of *Areca catechu* and commonly referred to as betel nut), dried ginger, medicinal herbs, and also many electronic goods coming from Thailand and China, while Myanmar imports cumin seeds, wheat flour, and Indian cars. This trade differs from the general trade between India and Myanmar and responds to local needs in these isolated regions (Ministry of Commerce 2016).

Because of the lack of currency in Myanmar and the isolation of the region, barter trade was authorized in 1994 for an initial list of 22 commodities, mainly agricultural goods. Inhabitants of the border could exchange goods without the use of currency (Annexure 1 in Ministry of Commerce 2016). 'Minor forest products, excluding teak' was one of those commodities. This list was extended in 2007, 2008 and then 2012, reaching 62 items in total. In 2007, 'Wood in the rough, whether or not stripped of bark, timber, wood roughly squared, wood sawn or chipped lengthwise, sliced of a thickness exceeding 25mm' was added as a product that could be imported into India from Myanmar through barter trade (Annexure 2 in Ministry of Commerce 2016). In 2015, barter trade was abolished and normal trade was reintroduced (Annexure 3 in Ministry of Commerce 2016). This change has greatly confused local traders, according to an Indian academic based at the border. This respondent added that trade is ongoing, but since 2015 it is now entirely informal.

Interviewees from researchers from the university and the private sector based in the North-East of India revealed that timber passing the Indo-Myanmar border is traded informally and the trade is substantial, but far from comparable to the Sino-Myanmar trade. They explained that day-time trade consists mainly of imports from Myanmar, originating from China and Mandalay, while informal trade, such as timber, passes the border point at night. One respondent from academia added that there are at least four known points of illegal transit in Manipur alone. Another respondent from the Indian Government noted that Indian border traders originated mainly from Manipur. According to all North-East respondents, timber and medicinal plants transit both ways, from Myanmar into India, and from India, especially the resource-rich North-Eastern states, into Myanmar. Finally, they noted that Burmese timber is used locally in the North-East for house-building as it is cheaper than the alternatives and of good quality. Interviewees implied that illegal timber exports to India are most likely sourced from protected forests with bribes being paid to enter such lots in auctions or to pass through customs.

Timber is mainly imported by Indian companies via Yangon port. However, illegality may occur at other points, as explained by Springate et al. (2016). Timber that reaches auction points that Indian traders participate in, may originate from forests that were not supposed to be harvested. Furthermore, during the years when the AAC was exceeded, all Myanmar's timber extraction reporting was very different from its trade partners' statistics and 72% of the trade was estimated to be illicit. In addition, some respondents operating in Myanmar, especially from civil society, were doubtful about the legality of exchanges run by Indian companies, especially at auctions or at customs. Given the involvement of Indian timber traders in the financing of harvesting operations described above, they may have had unfair advantage in those circumstances. Other respondents in Myanmar, particularly those from the private sector, considered that Indian operators were under much greater scrutiny and could not afford to operate illegally, compared to Myanmar companies.

Prospects for India-Myanmar timber trade

The India-Myanmar timber trade is dependent on regulations in India and Myanmar, as well as the evolution of relations between the two countries. Respondents based in India were asked about the role of India as a large importer of tropical wood in the international timber trade, and whether civil society or the Government of India recognized the need for regulation to ensure legality and governance of the trade. Civil society has not acted on this topic in recent years and respondents from civil society and international organizations believed that with the current government, it was considered unlikely that they would in the near future. None of the respondents were aware of the WWF Global Forest and Trade Network, except one respondent who participated in its creation. However, the Government of India has shown some interest in timber trade governance, as regulations from export markets, such as the EU or the US, have strengthened. Indeed, according to one respondent working closely with the Indian private sector, the Ministry of Commerce expressed interest at the beginning of 2017 in establishing increased control of timber governance.

Respondents based in Myanmar were negative about the prospects of the timber trade in general. While some respondents from civil society celebrated the fall of the timber market, others, especially those from the private sector, regretted it, noting that not all actors are responsible for the current level of illegality in the sector. All respondents noted that the domestic market is suffering from the current situation. Legal timber does not seem to be available for domestic use, while demand is increasing in the construction sector in particular. As noted by respondents from civil society, while Myanmar is lacking skills and access to financing to develop a thriving wood processing industry, few incentives seem to be in place to develop it.

In this context, Indian companies are suffering. In 2017, the Myanmar government planned to grant timber extraction permits for 19,000 teak trees and 600,000 other hardwood trees; the two respondents from the private sector considered this to be very limited offering relative to industrial demand. One of them noted that an Indian plywood factory was currently functioning at 35% of its capacity. He added that Indian companies felt very disappointed by the recent changes. These two respondents were very negative about the prospects of the timber market in Myanmar in general. Indian companies say they are adopting a 'wait and see' strategy but it is unclear how long they can wait.

Unrest has dissipated over the past decade in most of the North East of India, but its people are isolated from the rest of India and its neighbors, especially Myanmar. The North East is composed of seven Indian states and is connected to the 'mainland' only via the Siliguri Corridor, which is only 27 km wide; a landlocked island of the Indian Union. All interview respondents based in the North East confirmed that insurgency had disappeared in almost all of the seven states of this geographical zone, although the states neighboring Myanmar are more unstable than those closer to the Siliguri Corridor. The 20-year period of unrest limited exchanges with the North East of India and increased its isolation. In general, Indians based in Assam or Meghalaya, which are closer to Bangladesh, had very limited knowledge about their Eastern neighbor. Few of the academics interviewed had taught Burmese students or met fellow Burmese professors in academic exchanges. This differs from U Thant Myint's description of Universities in Yunnan, China, where ‘several of the Chinese academics spoke Burmese well and were knowledgeable on the nitty-gritty of specific issues, [such as] cross-border trade' (2011).

One of the main points of disagreement between the people of the North East and the Indian Union in the 1990s was the management of natural resources and their land. The Sixth Schedule of the Constitution of India dealt specifically with the states of the North East, ruling local administration and land as well as forest management and acknowledging customary land tenure (Tiwari and Kumar 2008). Timber trade was banned in the North East in 1996 by a Supreme Court decision (Supreme Court of India, 1996). While the current legislation protects land rights and access to resources, its enforcement may vary as the North East opens to economic development.

India and Myanmar had strengthened their ties since the democratic opening of Myanmar in 2011; the Indian Minister of External Affairs was the first foreign dignitary to visit Myanmar when U Thein Sein's government took power. This link was reinforced with the accession of Daw Aung San Suu Kyi to power in 2016; India was the first foreign country she visited. Timber was recently discussed in top-level discussions when Myanmar's Minister of Commerce, U Than Myint and India's Minister of Commerce and Industry, Smt. Nirmala Sitharaman, met in May 2017 (ITTO, June 2017).

The Indian Government plans to improve the connectivity of the North-Eastern states and to connect India to Thailand via Myanmar. The construction of the India-Myanmar-Thailand tri-lateral highway had been discussed since the beginning of the 2000s (Engh 2016). It was formally agreed in 2012 at a meeting in Naypyidaw, Myanmar. Parts of the road have been completed in India and Myanmar; it was scheduled to be completed by 2020 (Ministry of External Affairs 2016). Another important connectivity project, the Kaladan multi-modal project would reconnect the ports of Sittwe, Myanmar, and Kolkata, India and beyond find a route to Mizoram via Myanmar’s Chin State, up the Kaladan river. It was also scheduled to be completed by 2020 (Lok Sabha 2017). Interview respondents based in the North East from all sectors were aware of these developments but expressed some doubts about them. First, having heard about these projects since 2000, some believe they would take longer than planned. Secondly, while these projects were presented as development opportunities, there were fears on both sides of the border about the important social and environmental changes, such as the impacts on forests.

The Kaladan project will connect Sittwe, the capital of Rakhine state, to Mizoram crossing Northern Rakhine. In August 2017, conflict broke out once more in Rakhine state, leading to the displacement of 650,000 Rohingya. India's Prime Minister, Narendra Modi, chose not to mention the Rohingyas during his state visit in September 2017 but expressed concern over ‘extremist violence' (The Hindu, 15 September 2017). It may be in India's interest to develop a pragmatic approach and not directly alienate the Myanmar government on this issue. However, this deeply entrenched conflict will not disappear without intervention. India has economic and diplomatic interests to support the Myanmar government in finding a peaceful and humane solution.

The two countries are becoming closer, both through infrastructure development and diplomatic ties. At the same time, India is likely to remain an accessible market for southeast Asian timber exporters, with fewer requirements than, for example, the EU. The decisions that the Government of Myanmar takes in the next two to three years will be crucial for Indian timber companies operating in Myanmar. While the legality of operations of Indian companies is questioned, their skills and access to finance could prove useful when developing a domestic timber industry. Increased connectivity along their land border will also have an impact on the rich natural resources in that area. In the context of increased road construction, the forests of Sagaing, which have supplied the Indian market over the past two decades, will require careful management if further forest degradation is to be avoided.

CONCLUDING REMARKS

Until 2014, India-Myanmar timber trade was the most important in terms of value for India and the second most important in terms of volume for Myanmar, after China. Between 2000 and 2015, India accounted for 42% of the volume of Myanmar’s timber exports. In terms of value, however, India’s imports from Myanmar were on average 55% higher than China’s on an annual basis.

Round logs were the preferred wood product in this trade and teak the preferred species, representing 95% and 99% of the total value of Myanmar exports until 2014. Burmese teak, pyinkado and gurjan were the preferred species. These are not listed in the CITES Appendices, but ‘gurjan’ includes several species listed as critically endangered on the IUCN Red List. Trade flows most probably transited from Yangon to the ports of Kandla and Mundra in Gujarat until 2013. The main actors of the trade were the Myanmar government, Myanmar Timber Enterprise, its sub-contractors and small and medium Indian enterprises.

After 2014 and the round log export ban enacted by the Government, India-Myanmar timber trade plummeted. Round logs are now being transformed into plywood or veneer by mills in Myanmar. Gurjan remains the preferred species for plywood and veneer. Burmese teak retains a reputation for great durability, but was not mentioned by private sector actors in Myanmar, possibly because of the recent European sanctions. Trade flows of these products have been transiting through Chennai port. After 2016 and the logging ban, Indian operators that invested in Myanmar have adopted a cautious but rather pessimistic 'wait and see' attitude.

The India-Myanmar trade was most likely partially illegal. Myanmar was considered as a high-risk country. Timber sold to Indian traders might not have originated from a forest where extraction was allowed, while timber auction might not be conducted fairly or transparently. However, the volume of timber crossing the Indo-Myanmar border, although substantial, was not comparable to that crossing the Sino-Myanmar border and catered mainly to local needs of the border regions. Illegality was most likely occurring in terms of forest designations, and at the final stages of the timber trade process: auctions and customs.

Although relationship between India and Myanmar was strengthening, in an attempt by both partners to temper the influence of China, timber trade, the second most import item traded by India until 2014, did not seem to be a major topic of discussion yet. However, it would be beneficial for both partners to explore this area jointly. Discussing how Indian companies could survive the governance changes of the Myanmar timber sector in the coming years could also prove useful for the domestic timber market of Myanmar. In addition, including sustainable natural resources management as a key point of discussion in the 'Look East' movement of India's external relations policy, may help increase the social acceptance of the large connectivity projects planned at the border.

The tensions in Northern Rakhine brought to the world's attention will be the main challenge that faces the democratically elected Myanmar government: finding peace for all, while sharing resources equitably. Ethnic minority groups, several of which were still at war, lived where many of the natural resources were located. Their lands were the most forested and were located near the borders of Myanmar's powerful neighbors: China and India. Managing forests in Myanmar is about peace and sharing natural resources among its various ethnic groups, as well as managing relations with its two giant neighbors.

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Tree species diversity and structural composition: The case of Durgapur Hill Forest, Netrokona, Bangladesh

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Abstract. *Rahman MdR, Rahman MdM, Chowdhury MdA, Akhter J. 2019. Tree species diversity and structural composition: The case of Durgapur Hill Forest, Netrokona, Bangladesh. Asian J For 3: 10-19.* Hill forest in Durgapur, Netrokona District, Bangladesh has been rarely studied to reveal its biodiversity information. This study aimed to assess tree species diversity and structural composition based on diameter and height class distribution in Durgapur hill forest (DHF). Tree inventory using stratified random sampling method was conducted during the period of October 2017 to May 2018 by establishing 42 sample plots with each plot had 20 m x 20 m in size. A total of 1436 stems of ≥5 cm DBH of 56 tree species belonging to 50 genera and 29 families were enumerated from the sampled area. Stem density was 855 stem ha^{-1} and basal area was 29.27 m^2 ha^{-1}. The Shannon-Wiener's, Margalef's, Simpson's and Pielou's diversity indices indicate that Durgarpur hill forest had a moderately diverse tree species and lower diversity in comparison to other natural forests of the country. The study showed that the most dominant 10 species have 58% of the total IVI (174.29 out of 300) in which *Acacia auriculiformis* showed the maximum Importance Value Index (51.02) followed by *Shorea robusta* (24.23). Number of individual tree species was the highest (49) in the height range of 7- <12 m whereas maximum (52) species were recorded in the DBH (cm) range of 5- <10 cm. *Acacia auriculiformis, Shorea robusta,* and *Tectona grandis* were found as the most dominant species based on hierarchical cluster analysis. The current study will be helpful for policymakers in formulating forest resource management plan for Durgapur hill forest.

Keywords: Diversity indices, Durgapur hill forest, importance value index, phytosociological characters, structural composition

Abbreviations: DBH: Diameter at Breast Height, BBS: Bangladesh Bureau of Statistics, DHF: Durgapur hill forest, IFESCU: Institute of Forestry and Environmental Sciences, University of Chittagong, BFRI: Bangladesh Forest Research Institute, BA: Basal Area, D: Density, RD: Relative Density, F: Frequency, RF: Relative Frequency, A: Abundance, RA: Relative Abundance, Rdo: Relative Dominance, IVI: Importance Value Index, PSP: Permanent Sample Plot, ANR: Assist Natural Regeneration.

INTRODUCTION

The diversity of plant species and structural composition plays a significant role in maintaining the integrity of forest ecosystems (Sajib et al. 2016; Rahman et al. 2017). Tree species diversity can serve as a proxy or indicator of the general pattern of the broader biological diversity of a forest. For example, a higher number of tree species is associated with a higher number of understory plants, or even animal diversity. Therefore, information on floristic composition, quantitative structure and diversity of tree vegetation is vital for understanding the functioning and dynamics of forest ecosystems (Reddy et al. 2008; Hossain et al. 2015). Such information is essential for sustainable use and management activities of a forest.

Bangladesh is situated in a transition between India and Myanmar (often so-called Indo-Myanmar) region. Because of the unique geophysical characteristics, the country has rich biological diversity containing about 5700 species of angiosperms (Nur et al. 2016). However, the depletion of native species was accelerating at an alarming rate due to the rapid deforestation and forest degradation (Hossain 2001). During the last few decades, some areas of natural forest in Bangladesh have been degraded due to anthropogenic activities, primarily by land encroachment (Rahman et al. 2017).

Undisturbed natural hill forests of Bangladesh are generally uneven-aged and multi-storied (Alam 2008). One of biologically important regions in Bangladesh is Durgapur hill forest located in Netrokona District. The district shares border with Garo Hills of India to the north and the biggest haor (swampy land) area of Sunamganj District to the east. A large variety of plants, including trees, grow in the district. As Durgapur hill forest of Netrokona is close to inland sal forest of Tangail-Mymensingh District, the species composition is almost similar in between the two districts whereas some of which are important for timber, such as sal (*Shorea robusta*), bot (*Ficus benghalensis*), tentul (*Tamarindus indica*), sada karoi (*Albizzia procera*), simul (*Bombax ceiba*) and aswatha (*Ficus religiosa*) (BBS 2013).

In government managed forests of Bangladesh, many researchers have investigated plant species diversity and forest stand structure (Nath et al. 1998; Nath et al. 2000;

Motaleb and Hossain 2011; Hossain et al. 2013; Feeroz and Uddin 2015; Hossain et al. 2015; Chowdhury et al. 2018a, b; Das et al. 2018). Recently, a taxonomic study was done by Rahman et al. (2017) concentrating on the flora of Madhupur National Park under different genera and families. Also, a clear understanding of forest stands parameters, i.e., diameter and height class distribution, and forest stocking are important for management strategies (Hossain et al. 2017). However, such scientific efforts are lacking in Durgapur Hill Forest (DHF), especially to reveal information regarding structural composition, plant diversity and conservation issues. Hence, the present study is conducted in DHF of Bangladesh aiming to assess tree species diversity and structural composition based on diameter and height class distribution. The results of this study will serve as baseline information to monitor changes in species composition and to undertake conservation and management activity of the hill forest in the future.

MATERIALS AND METHODS

Study area

The study area is located in the most northern part of Durgapur at the coordinates of 25˚7′30″ N and 90˚41′18″ E (Figure 1). Durgapur Upazila is a small city of Netrokona District, with an area of 293.42 km and consists of 7 unions. Durgapur is bordered by Meghalaya State of India to the north, Purbadhala and Netrokona Sadar to the south, Kalmakanda to the east, and Dhobaura sub-district to the west. There are three main rivers in Durgapur namely Old Someshwari, Kangsa and Someshwari.

Topographically, the study area is characterized by its large hillocks, known as ‘tilla' with irregular plain land. This area is located in the semi-drier part of Bangladesh. The highest temperature reaches 30°C during May and the coldest to around 10°C during January. The area has an average rainfall 2712 mm per year.

Data collection

Reconnaissance survey was conducted for planning of data collection with considerations of the accessibility of the forest, vegetation density and stratification, human settlement within the forest and fragmentation of the forest patches. Three transect walks across the study area were done.

The data collection was conducted from October 2017 to May 2018 to cover the whole study area. Stratified random sampling method was used for the inventory of the tree species. Sample plot with size of 20m × 20m was determined by applying the species-area curve of Caratti (2006) where a total of 42 sample plots were taken purposively. Sample plots were determined based on the area of the respected forest. Plots were taken both in natural and plantation forest patches having low, medium and dense tree cover. Position of each sample plot was then recorded using Ground Positioning System (GPS) device. Area of each plot was demarcated by measuring tape and rope. Plants having dbh ≥ 5 cm were recorded from the quadrats. Total height and diameter at breast height (dbh) of all trees inside the demarcated plots were measured using Suunto Clinometer and diameter tape respectively.

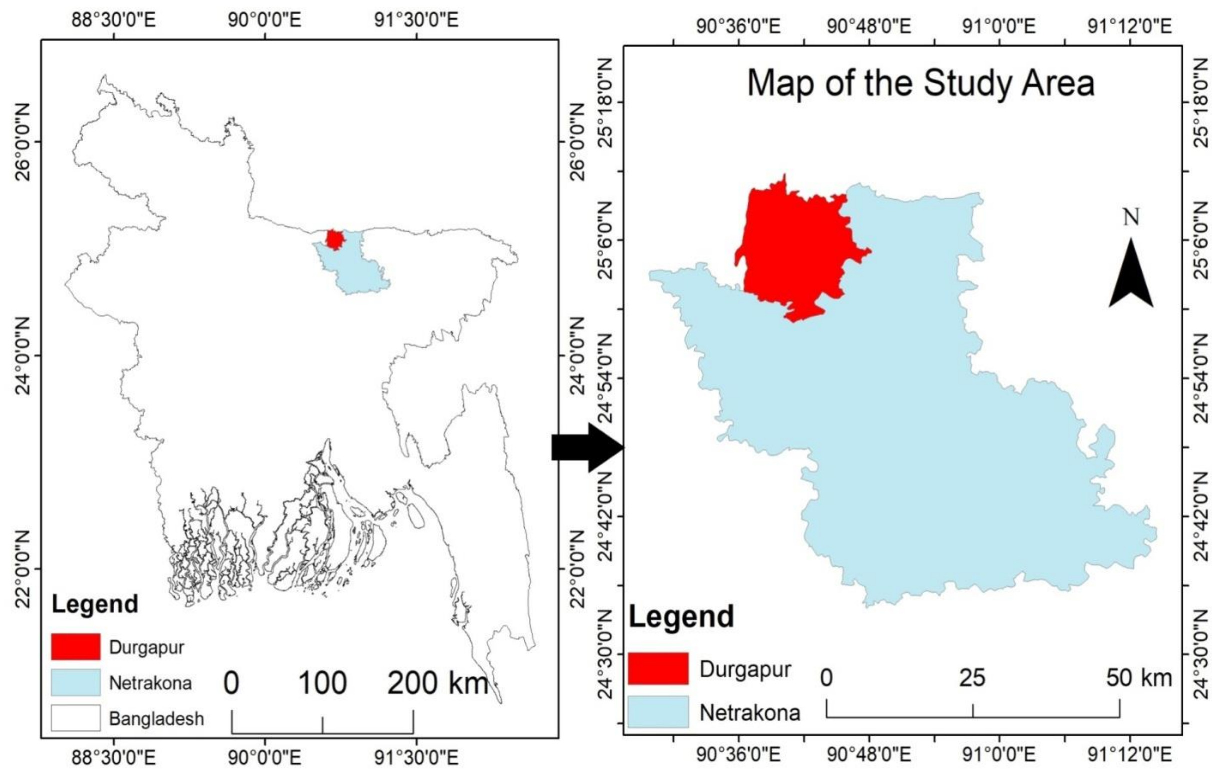

Figure 1. Map of the study area in Durgapur Upazila, Netrokona District, Bangladesh

For multi-stemmed trees, the bole dbh was measured below the forking (if height is 1.3 m from the ground) with each stem was considered as individual tree. Standard scientific method of dbh measurement was followed in other critical situations, i.e., buttressed stem, leaned tree, slope, etc.

Common tree species were identified directly in the field, while the samples of the unknown tree species were collected for the preparation of herbarium specimens and later those specimens were dried in the sun following standard scientific method. Consultation was done with published journals and reference books like Siddiqui et al. (2007) and Encyclopedia of Flora and Fauna of Bangladesh (Ahmed et al. 2008). Taxonomists from the Institute of Forestry and Environmental Sciences, University of Chittagong (IFESCU) and the Bangladesh Forest Research Institute (BFRI) also helped with species identification. Besides, the author's own collections, the herbarium specimens previously collected from Madhupur National Park, Tangail were also examined (Rahman et al. 2017).

Analysis of field data

The field data were compiled and analyzed to determine the density, relative density (RD %), frequency, relative frequency (RF %), abundance, relative abundance (RA %) and Importance Value Index (IVI). The equations used for calculating phytosociological characters are listed in Table 1 (Eq. No. 1-9). Besides, biodiversity indices such as Shannon's index, Simpson's diversity index, species evenness index, Margalef's index, etc., for the DHF were calculated and compared the findings with other studies in government managed forests of the country. The equations (Eq. No. 1-4) used for calculating biodiversity indices are listed in Table 2. Besides, hierarchical cluster analysis was done using computer software package SPSS.

Margalef's index (R) is high in communities that include a greater number of species and in which the number of individuals of each species decreases relatively slowly on passing from more abundant to less abundant ones (Margalef 1958). Shannon-Wienner diversity index value is maximum when the number of individuals of all species is equal; value is zero if there are only one species (Shannon-Wienner 1963). With Simpson's diversity index (D), 0 represents infinite diversity and 1, no diversity. Species Evenness index (E) also known as Shannon's equitable index, assumes a value between 0 and 1 with 1 being complete evenness (Pielou 1966).

Table 1. The list of equations used for calculating phytosociological characters of the vegetation

Phytosociological attributes	Formula	References
Basal area/ha (BA)	$BA = \frac{\sum \Pi \times D2/4}{\sum \text{Area of all quadrate}} \times 10000$	Shukla and Chandel (2000), Chowdhury et al. (2018b)
Density (D)	$D = \frac{a}{b}$	Shukla and Chandel (2000)
Relative density (RD)	$RD = \frac{n}{N} \times 100$	Misra (1968), Dallmeier et al. (1992)
Frequency (F)	$F = \frac{c}{b}$	Shukla and Chandel (2000)
Relative frequency (RF)	$RF = \frac{Fi}{\sum_{i=1}^{s}(Fi)}$	Misra (1968), Dallmeier et al. (1992)
Abundance (A)	$A = \frac{n}{c}$	Shukla and Chandel (2000)
Relative abundance (RA)	$RA = \frac{Ai}{\sum_{i=1}^{s}(Ai)}$	Shukla and Chandel (2000)
Relative dominance (D)	$RD = \frac{\text{Basal area of one species}}{\text{Total basal area}} \times 100$	Hossain et al. (2013), Chowdhury et al. (2018b)
Importance Value Index (IVI)	IVI = RD + RF + RA	Dallmeier et al. (1992), Shukla and Chandel (2000)

Note: D= dbh, a= Total no. of individuals of a species in all the quadrats, b= Total no. of quadrats studied, n= Total No. of individuals of the species, N= Total No. of individuals of all the species, c= Total no. of quadrats in which the species occurs, b= Total no. of quadrats studied, Fi = Frequency of one species, Ai= Abundance of one species

Table 2. The list of equations used for calculating biodiversity indices of the vegetation

Biodiversity indices	Formula	References
Shannon-Wiener's diversity index (H)	$H = -\sum_{i=1}^{n} P_i \ln P_i$	Shannon and Wiener (1963)
Margalef's species richness index (R)	$R = \frac{(S-1)}{LN(N)}$	Margalef (1958)
Simpson's diversity index (D)	$D = \sum_{i=1}^{n} P_i^2$	Simpson (1949)
Species (Pielou's) evenness index (E)	$E = \frac{H}{Ln(S)}$	Pielou (1966)

Note: H = Shannon-Wiener's diversity index, N = Total no. of individuals of all the species, Pi = Number of individuals of i^{th} species/Total number of individuals, S = Total number of species

RESULTS AND DISCUSSION

Results

Tree species composition

Tree is a vital element of any forest. A total of 56 species belongs to 50 genera and 29 families were recorded from the forest area. Mimosaceae was the most dominant family with 7 species and 4 genera followed by Arecaceae (4 species and 4 genera), Euphorbiaceae with 4 species and 4 genera and Combretaceae, Meliaceae, Myrtaceae, Moraceae, Rutaceae, Sapotaceae with 3 species each (Table 3).

Diversity indices

A total of 1436 individual stems were recorded from the Durgapur hill forest. The vacant area of the forest was covered with more or less mixed and mono plantations. Therefore, high stem density (855 stem ha^{-1}) was also found there. The Shannon-Wiener's index (3.18), species evenness index (0.79) Margalef's diversity index (7.57), and The Simpson's diversity index (0.07) was calculated for the study area (Table 4). The values of Shannon-Wiener and Margalef's diversity index indicate proficient presence of plant species in the area. Lower value of Simpson's index also stands for moderately diverse tree species.

Phytosociological characters of the tree species

Basal area, density, relative density, relative frequency, relative abundance, relative dominance and Importance Value Index (IVI) of the recorded tree species are shown in (Table 5). Fifteen dominant tree species accounted for 73.53% of the individuals (1056 out of 1436), 79.27% of the basal area, 73.53% of the relative density, 59.39% of the relative frequency, 54.05 % of the relative abundance, 79.26 % of the relative dominance and 68.53% of the IVI. Highest IVI was found for *Acacia auriculiformis* (51.02) followed by *Shorea robusta* (24.23), *Tectona grandis* (22.86).

Table 3. List of tree species found in the DHF with family name

Scientific name	Local name	Family
Acacia auriculiformis A. Cunn. ex Benth. & Hook	Akashmoni	Mimosaceae
Acacia mangium Willd.	Mangium	Mimosaceae
Aegle marmelos (L.) Corr.	Bel	Rutaceae
Albizia lebbeck (L.) Benth. & Hook	Kala Koroi	Mimosaceae
Albizia procera (Roxb.) Benth.	Shilkoroi,	Mimosaceae
Albizia richardiana (Voigt.) King &Prain	Raj koroi	Mimosaceae
Alstonia scholaris (L.) R. Br.	Chatian	Apocynaceae
Aphanamixis polystachya (Wall.) R.N. Parker.	Pitraj	Mimosaceae
Aporosa sp.	Kharjon	Euphorbiaceae
Aquilaria agallocha Roxb.	Agar	Thymeliaceae
Araucaria cunninghamii Sw.	Christmas tree	Araucariaceae
Areca catechu L.	Supari	Arecaceae
Artocarpus heterophyllus Lamk.	Kanthal	Moraceae
Artocarpus lacucha Buch.-Ham.	Borta	Moraceae
Averrhoa carambola L.	Kamranga	Oxalidaceae
Azadirachta indica A. Juss.	Neem	Meliaceae
Barringtonia acutangula (L.) Gaertn.	Hijal	Lecythidaceae
Bischofia javanica Blume	Kanjalbhadi	Euphorbiaceae
Bombax ceiba L.	Shimul	Bombacaceae
Borassus flabellifer L.	Tal	Arecaceae
Cassia fistula L.	Sonalu	Caesalpiniaceae
Chukrasia tabularis A. Juss.	Chickrassi	Meliaceae
Cryptocarya amygdalina Nees.	Ojha	Lauraceae
Dillenia scabrella Roxb. ex Wall.	Ajuli, Ajugi	Dilleniaceae
Diospyros blancoi A. DC.	Bilati gab	Ebenaceae
Elaeis guineensis Jacq.	Oil pulm	Arecaceae
Eucalyptus camaldulensis Dehnh	Eucalyptus	Myrtaceae
Ficus hispida L. f.	Dumor	Moraceae
Gmelina arborea Roxb.	Gamar, Jogi	Verbenaceae
*Grewia nervosa (*Lour.) Panigr.	Datoi	Tiliaceae
Haldina cordifolia (Roxb.) Ridsdale	Kaika, haldu	Rubiaceae
Lagerstroemia speciosa (L.) Pers.	Jarul	Lythraceae
Limonia acidissima L.	Kodbel	Rutaceae
Litchi chinensis Sonn.	Litchi	Sapindaceae
Madhuca longifolia (Koenig) MacBride	Mahua	Sapotaceae
Mallotus philippensis (Lamk.) Muell.-Arg.	Sinduri	Euphorbiaceae
Mangifera indica L.	Aam	Anacardiaceae
Manilkara zapota (L.) P. van Royen	Sofeda	Sapotaceae
Mimusops elengi L.	Bakul	Sapotaceae
Moringa oleifera Lamk.	Sajna	Moringaceae
Murraya paniculata (L.) Jack	Kamini	Rutaceae
Neolamarckia cadamba (Roxb.) Bosser	Kadom	Rubiaceae
Phoenix sylvestris Roxb.	Khejur	Arecaceae
Phyllanthus emblica L.	Amloki	Euphorbiaceae
Psidium guajava L.	Payara	Myrtaceae
Pterospermum acerifolium (L.) Willd.	Moos	Sterculiaceae
Samanea saman (Jacq.) Merr.	Raintree	Mimosaceae
Shorea robusta Roxb. ex Gaertn.f.	Sal	Dipterocarpaceae
Swietenia mahagoni Jacq.	Mahagoni	Meliaceae
Syzygium cumini (L.) Skeels	Kalojam	Myrtaceae
Tamarindus indica L.	Tentul	Caesalpiniaceae
Tectona grandis L. f.	Shegun	Verbenaceae
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Arjun	Combretaceae
Terminalia bellirica (Gaertn.) Roxb.	Bohera	Combretaceae
Terminalia chebula Retz.	Haritaki	Combretaceae
Ziziphus mauritiana Lamk.	Boroi	Rhamnaceae

Table 4. Density and tree diversity indices of the DHF

Parameters	Values for DHF
Density (stem ha^{-1})	855
Shannon-Wiener diversity index	3.18
Species evenness index	0.79
Margalef's diversity index	7.57
Simpson's diversity index	0.07

Table 5. Basal area, number of stems, relative density, relative frequency, relative abundance relative dominance, and Importance Value Index (IVI) for DHF

Scientific name	BA (m^2/ha)	Ind. stem no	RA (%)	RD (%)	RF (%)	RDo (%)	IVI
Acacia auriculiformis	7.19	289	7.18	20.13	6.26	24.64	51.02
Acacia mangium	1.01	49	1.85	3.41	4.11	3.46	10.99
Aegle marmelos	0.06	7	0.87	0.49	1.25	0.20	1.94
Albizia lebbeck	0.17	9	0.87	0.63	1.61	0.57	2.81
Albizia procera	0.58	33	0.96	2.30	5.37	1.99	9.65
Albizia richardiana	0.57	23	2.86	1.60	1.25	1.96	4.81
Alstonia scholaris	0.39	26	1.03	1.81	3.94	1.33	7.07
Aphanamixis polystachya	0.29	26	1.03	1.81	3.94	0.99	6.74
Aporosa wallichii	0.04	6	1.74	0.42	0.54	0.14	1.10
Aquilaria agallocha	0.70	65	3.77	4.53	2.68	2.39	9.60
Araucaria cunninghamii	0.02	1	0.87	0.07	0.18	0.06	0.31
Areca catechu	0.04	3	0.87	0.21	0.54	0.14	0.88
Artocarpus heterophyllus	0.40	27	0.98	1.88	4.29	1.36	7.53
Artocarpus lacucha	0.29	19	1.03	1.32	2.86	0.98	5.16
Averrhoa carambola	0.13	6	0.87	0.42	1.07	0.43	1.92
Azadirachta indica	0.37	28	1.62	1.95	2.68	1.27	5.91
Barringtonia acutangula	0.14	11	1.06	0.77	1.61	0.46	2.84
Bischofia javanica	0.25	16	0.99	1.11	2.50	0.85	4.47
Bombax ceiba	0.46	22	1.13	1.53	3.04	1.59	6.16
Borassus flabellifer	0.08	10	2.90	0.70	0.54	0.26	1.49
Cassia fistula	0.61	22	1.59	1.53	2.15	2.10	5.78
Chukrasia tabularis	0.61	46	1.91	3.20	3.76	2.10	9.06
Cryptocarya amygdalina	0.04	3	0.87	0.21	0.54	0.12	0.86
Dillenia pentagyna	0.05	3	0.87	0.21	0.54	0.17	0.91
Diospyros blancoi	0.01	1	0.87	0.07	0.18	0.02	0.27
Elaeis guineensis	0.16	4	1.16	0.28	0.54	0.55	1.36
Eucalyptus camaldulensis	2.81	97	2.56	6.76	5.90	9.61	22.27
Ficus hispida	0.29	25	1.81	1.74	2.15	0.99	4.88
Gmelina arborea	0.49	29	2.10	2.02	2.15	1.66	5.83
Grewia nervosa	0.35	31	3.85	2.16	1.25	1.18	4.59
Haldina cordifolia	0.42	25	1.81	1.74	2.15	1.44	5.33
Lagerstroemia speciosa	0.09	7	1.01	0.49	1.07	0.29	1.85
Limonia acidissima	0.08	4	3.48	0.28	0.18	0.26	0.71
Litchi chinensis	0.08	5	2.17	0.35	0.36	0.26	0.96
Madhuca longifolia	0.00	1	0.87	0.07	0.18	0.01	0.26
Mallotus philippensis	0.31	40	3.16	2.79	1.97	1.06	5.81
Mangifera indica	0.24	11	3.19	0.77	0.54	0.81	2.11
Manilkara zapota	0.03	1	0.87	0.07	0.18	0.09	0.34
Mimusops elengi	0.09	5	1.09	0.35	0.72	0.30	1.36
Moringa oleifera	0.06	5	0.87	0.35	0.89	0.21	1.45
Murraya paniculata	0.01	1	0.87	0.07	0.18	0.05	0.29
Neolamarckia cadamba	0.31	11	0.74	0.77	2.33	1.06	4.16
Phoenix sylvestris	0.01	1	0.87	0.07	0.18	0.04	0.29
Phyllanthus emblica	0.08	4	0.87	0.28	0.72	0.26	1.25
Psidium guajava	0.03	4	1.16	0.28	0.54	0.10	0.91
Pterospermum acerifolium	0.12	8	2.32	0.56	0.54	0.40	1.49
Samanea saman	1.01	18	1.96	1.25	1.43	3.45	6.14
Shorea robusta	2.51	173	7.52	12.05	3.58	8.61	24.23
Swietenia mahagoni	0.53	24	3.48	1.67	1.07	1.81	4.55
Syzygium cumini	0.01	1	0.87	0.07	0.18	0.03	0.28
Tamarindus indica	0.37	10	0.97	0.70	1.61	1.28	3.59
Tectona grandis	3.45	97	3.51	6.76	4.29	11.81	22.86
Terminalia arjun	0.01	1	0.87	0.07	0.18	0.02	0.27
Terminalia bellirica	0.19	12	1.16	0.84	1.61	0.66	3.10
Terminalia chebula	0.61	23	1.33	1.60	2.68	2.10	6.38
Ziziphus mauritiana	0.02	7	0.87	0.49	1.25	0.06	1.80
Total	29.27	1436	100.00	100.00	100.00	100.00	300.00

Note: BA= Basal Area, RD= Relative Density, RF= Relative Frequency, RA= Relative Abundance, RDo= Relative Dominance and IVI= Importance Value Index

Structural composition based on height classes

The vertical profile of a forest provides a clear concept of forest stratification. In the study we assigned six height classes considering total height of the tree individuals of different species with interval of 6 m. The six height classes were, 2- <7 m, 7- <12 m, 12- <17 m, 17- <22 m, 22- <27 m, and 27- <32 m. The distribution of individuals among different height classes showed a positively skewed curve, indicating a relatively stable population structure and regeneration status. Patterns of height (m) class distribution shows general trends of population dynamics and recruitment process to the maximum species in DHF. It was found that both the number of species and number of individuals decreased regularly with the increasing of total height. Both the number of tree species and number of individuals (56 species; 1436 individuals) were highest in the height range of 7- <12 m and lowest (2 species) in height range of 27- <32 m (Figure 2).

Vertical structure of some dominant tree species

Height classes of trees are shown in Figure 3 (A-D) and Figure 3 (E-J). Figure 3 (A-D) is the representative of exotic species and Figure 3 (E-J) is the representative of native species. The study reveals that exotic species possessed mainly in first four height classes, i.e. *Acacia auriculiformis*, *Acacia mangium*, *Tectona grandis* except for *Eucalyptus camaldulensis*. However, the maximum height class for exotic tree species was found 2- <27 m range.

In case of native species, *Shorea robusta*, *Bombax ceiba*, and *Aquilaria agallocha* were found in four height classes whereas *Cassia fistula*, *Azadirachta indica,* and *Chukrassia tabularis* was present in three height classes.

Structural composition based on DBH classes

The distribution of individuals among different DBH (cm) classes shows a reverse J-shaped curve (Figure 4). It indicates progressive decrease of tree individuals in larger tree size classes. The number of species and tree individuals was found to decrease with increasing diameter with very little exception. Both the tree species and individuals were maximum (52 species, 534 individuals) in 5- <10 cm dbh range and minimum (2 species, 4 individuals) in 45- <50 cm dbh range (Figure 3). As the dbh increases, both the number of species and number of tree individuals decrease. It indicates incidence of illegal felling of mature and economically important trees in the area. The higher number of trees in lower size classes also indicates recent initiatives for conservation, protection, and improvement of the forest.

Distribution of some dominant tree species in different diameter classes

Diameter classes of trees are shown in Figure 5 (A-D) and Figure 5 (E-J). Figure 5 (A-D) is representative of exotic species and Figure 5 (E-J) is the representative of native species. In case of native species, *Shorea robusta* and *Terminalia chebula, Cassia fistula, Alstonia scholaris* were found in maximum dbh class with the highest density in the first and second class decreasing with increasing dbh class forming inverted J shape.

In case of exotic species, the diameter class distribution of *Acacia auriculiformis*, *Acacia mangium*, *Shorea robusta*, *Eucalyptus camaldulensis*, etc. showed a reverse shape J-curve with a sharp drop in the higher diameter classes. The sharp decline and very low representation in the higher diameter classes depict illegal felling in the DHF. The presence of some large trees and the prevalence of small to medium size individuals also represent that the forest is in a second development stage.

Hierarchical cluster based on the dominant tree species in the Durgapur hill forest

The study revealed tree species of DHF are grouped into four hierarchical clusters (Figure 4). *Acacia auriculiformis* was the most dominant species followed by *Shorea robusta, Tectona grandis, Eucalyptus camaldulensis* and the member of first cluster. Then *Samanea saman, Cassia fistula, Haldina cordifolia, Gamlina arborea,* etc. were the second most dominant species and the member of second cluster. Other species under this research form rest of the clusters (Figure 4). However, it is obvious that the dominated tree are exotic species. This indicates that the area is gradually converted with plantation activities.

Discussion

Floral inventory is a prerequisite for fundamental research in community ecology, and for modeling patterns of species diversity and understanding species distribution patterns (Das et al. 2018). The tree species composition of DHF (56 tree species, 50 genera, 29 families) is closer to that found in tropical forests, for example, 50 tree species in Rampahar Natural Forest Reserve (Chowdhury et al. 2018a), 52 tree species in Kaptai National Park (Rahman et al. 2016), 62 tree species in Tankawati natural forest (Motaleb and Hossain 2011). However, DHF possessed lower tree species in comparison to 107 tree species in Kamalachari natural forest, Rangamati and Bandarban borderline (Hossain et al. 2015), 153 tree species in Tropical Forest of Eastern Ghats, India (Reddy et al. 2011) and 93 tree species in Chunati Wildlife Sanctuary (Nath et al. 2016).

As plantation activities are increasing in study area, the stem density (855 stems ha^{-1}) is higher than 709 stems ha^{-1} in tropical forest of Eastern Ghats, India (Reddy et al. 2011). But the number is lower than a study by Haider et al. (2013) in natural forests of Moulvibazar in Sylhet Forest Division where they recorded 1,051 tree individuals per ha, belonging to 81 species, 59 genera and 33 families. The basal area (29.27 m^2 ha^{-1}) of DHF is lower than that of 47.02-62.16 m^2 ha^{-1} in Tankawati natural forest of Chittagong South Forest Division (Motaleb and Hossain 2011). Besides, it is higher than 16.88 m^2 ha^{-1} revealed by Rahman et al. (2000) and 21.10 ± 2.62 m^2 ha^{-1} found by Hossain et al. (2015). The moderate number of tree species with higher stem density but lower basal area indicates that the forest area is suffering from deforestation.

The IVI value indicates a complete picture of phytosociological character of a species in the community. The study showed that the most dominant 10 species have 58% of the total IVI (174.29 out of 300), where the dominant tree species were *Acacia auriculiformis, Shorea robusta*, *Alstonia scholaris Tectona grandis*, etc. However, Hossain et al. (2015) showed that the most dominant 10 species have 34.67% of the total IVI (104 out of 300) and the amount is less than present findings.

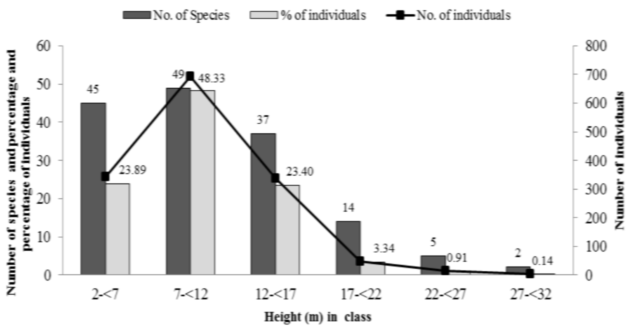

Figure 2. Distribution of tree species, % of tree individuals and individual number in different height (m) classes of DHF

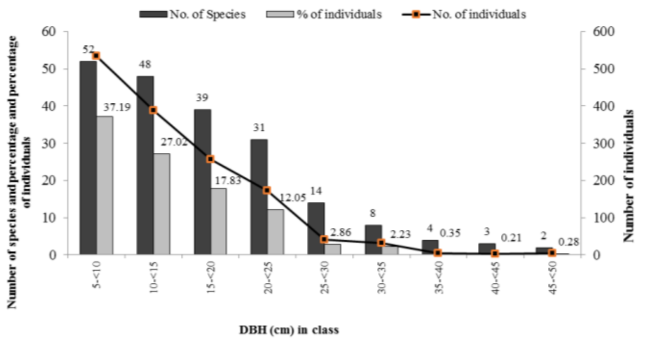

Figure 4. Distribution of tree species, % of tree individuals and individual number in different DBH (cm) classes of DHF

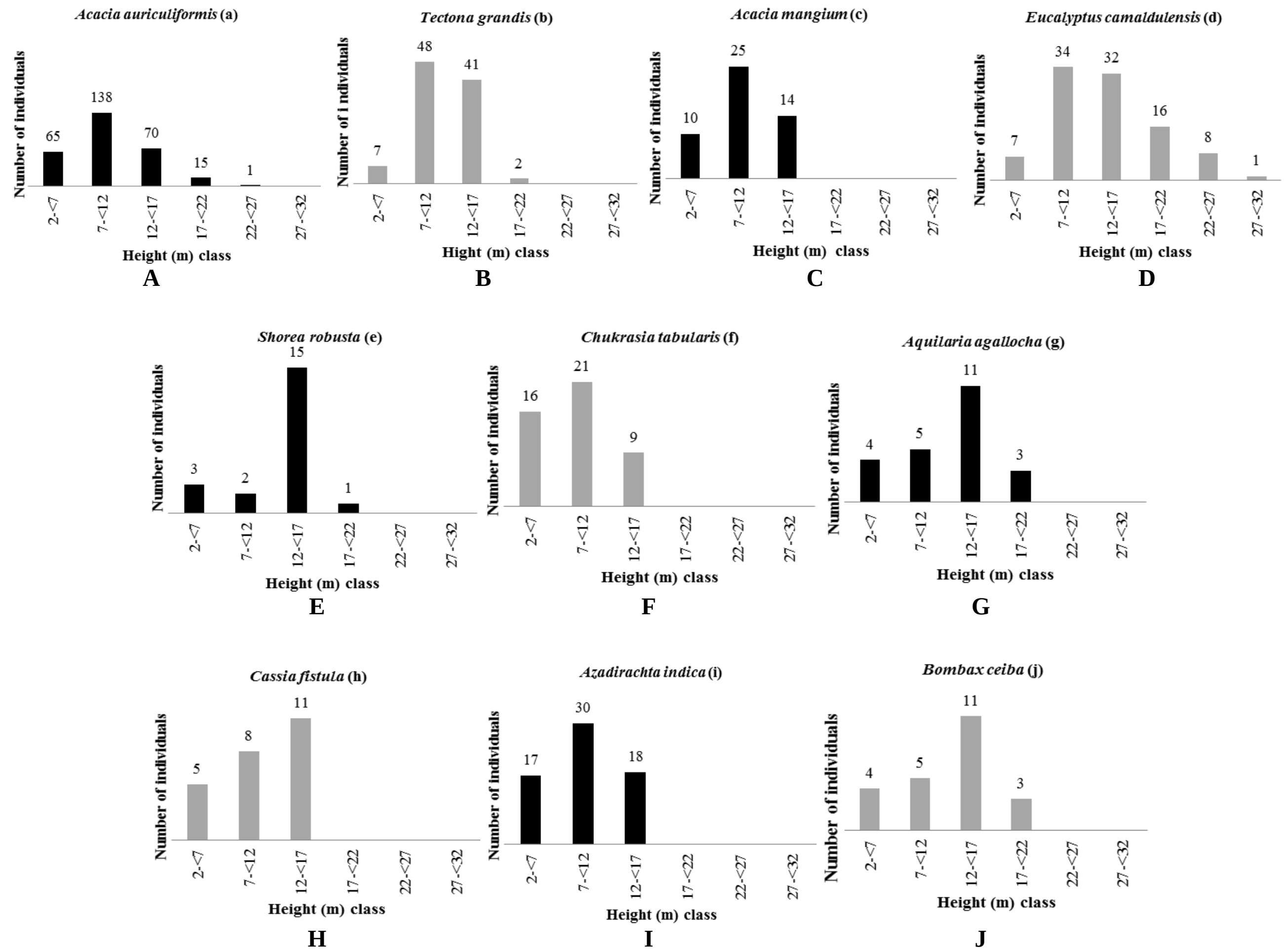

Figure 3. A-D. Height class distribution of some exotic tree species in DHF. E-J. Height class distribution of some native tree in DHF

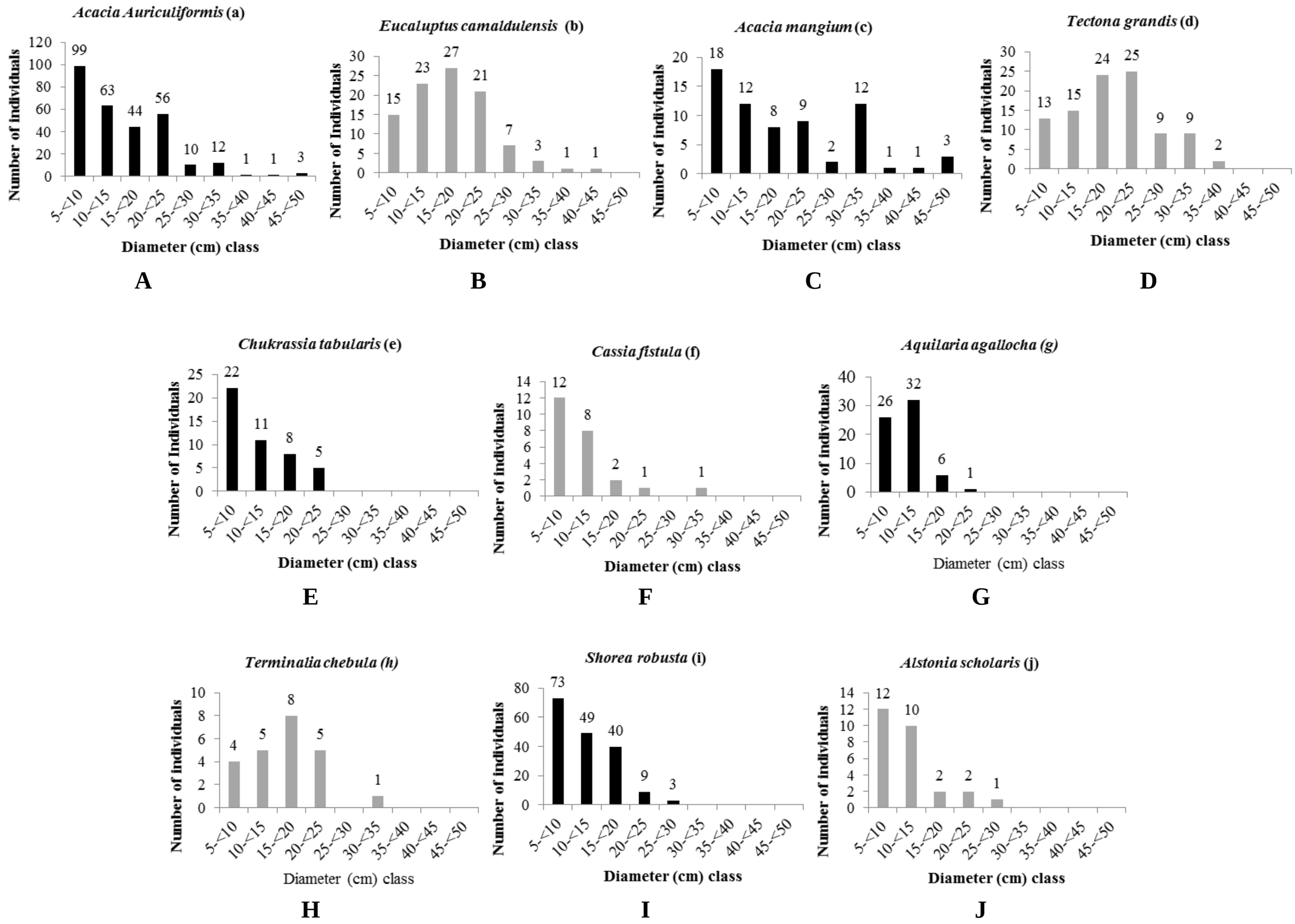

Figure 5. A-D. Diameter (cm) class distribution of some exotic tree species in DHF. E-J**.** Diameter (cm) class distribution of some dominated tree species in DHF

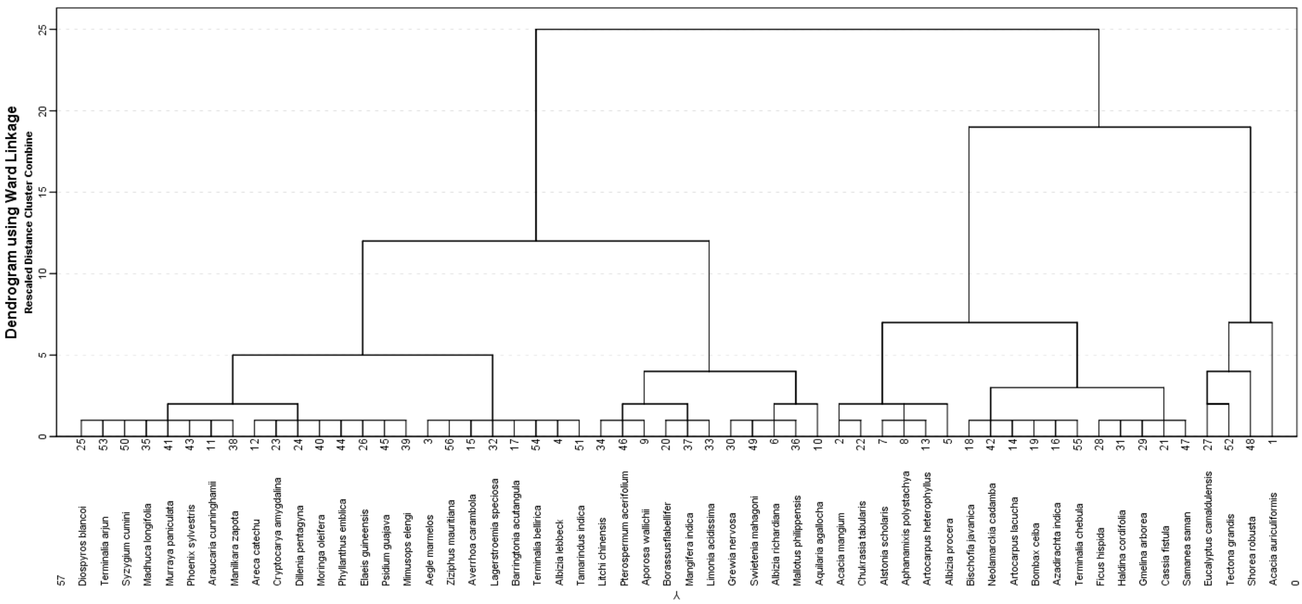

Figure 4. Hierarchical cluster of the tree species in DHF

The maximum number of species (52) and percentage of tree individuals (37.19%) was found in the DBH range of 0.5-<10 cm, whereas the maximum number of species (88) and percentage of tree individuals (66.02%) was found in the DBH range of 10.1-<20 cm in Kamalachari natural forest of Chittagong south forest division (Hossain et al. 2015) and nearly 90% trees were belonging to 5- to 15-cm dbh class recorded form Chunati Wildlife Sanctuary (Nath et al. 2016). Besides, DBH range of 20.1-<30 cm possessed both highest (58 species) number of species and percentage (29.69 %) of tree individuals in Tankawati Natural Forest Reserve of Chittagong (South) Forest Division, Bangladesh (Motaleb and Hossain 2009). Again, Hossain et al. (2015) revealed the number of tree species, tree individual percentage, and their number were highest (97 species, 77.99%, 404 individuals) in the height range of 4.5-14.4 m. Present study found that *Eucalyptus camaldulensis, Areca catechu, Averrhoa carambola, Elaeis guineensis, Tamarindus indica, Terminalia bellirica, Neolamarckia cadamba* dominated the upper canopy. The height class distribution indicates that Durgapur hill forest is a relatively well-stratified forest.

The Shannon-wiener diversity index of 3.18 is lower than that of 3.25 in Tankawati natural forest of Chittagong (South) Forest Division, 4.01 in Komolchori VCF of Khagrachari (Chowdhury et al. 2018) and 4.27 in Garo Hills of India (Kumar et al. 2006) where, but is very closely related with Chunati Wildlife Sanctuary (3.15) (Nath et al. 2016). Margalef's index (7.57), lower value of Simpson's index (0.07) and Species evenness index (0.79) indicate less species diversity in DHF in comparison to other natural forests of the country. However, it is alarming that the forest area is now dominated by some exotic species which should be rejuvenated with the native flora.

In conclusion, the study revealed that Durgarpur hill forest had a moderately diverse tree species along with stratified tree populations. The IVI values revealed economically and ecologically most important tree species in the forest and those to be prioritized for conservation. The height class distribution indicates occurrences of illegal removal of trees from the forest. The dbh class distribution shows that some species are in poor regeneration status may be due to human disturbance and livestock grazing. Collection of sun-grass, intentional burning, and encroachment caused extensive loss of regenerated seedlings of important native tree species in the last decades. It is therefore recommended to establish some Permanent Sample Plots and Assisted Natural Regeneration plots, and adopt species-specific conservation measures to enhance regeneration status and tourism potentials of DHF. Special conservation measures both *ex-situ* and *in-situ* methods may be initiated to conserve the rare native plant species in this area. Improved law and policy, livelihoods and incentives and capacity building may be considered for the area adjacent people. Also, regular community patrolling should be done to stop the theft of valuable timber. Different encroachments like inhabitation, agricultural expansion, hunting, shooting, illegal cutting, fuelwood collection, etc. were seen in the forest during field data collection. Therefore, such detrimental activities must be stopped immediately, otherwise, those will make the area more fragmented and reduce natural forest restoration capacity.

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Color modification and homogenization of sugi wood (*Cryptomeria japonica*) by steaming

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Abstract. *Tolvaj L, Banadics EA, Tsuchikawa S, Mitsui K, Preklet E. 2019. Color modification and homogenization of sugi wood (Cryptomeria japonica) by steaming. Asian J For 3: 20-24.* Color modification and homogenization in wood by steaming is common technique to improve wood attractiveness, yet for some species, the knowledge on such treatment is lacking. This study aimed to investigate the effects of steaming on colors creation and homogenization on sugi (*Cryptomeria japonica* D. Don) wood. Sugi wood samples were steamed applying broad range of steaming time (0-20 days) at 90 and 110°C steaming temperatures. The color change was monitored objectively using the CIE Lab color system. A wide range of colors was created by steaming between the initial color and light brown color depending on the steaming time and temperature. The initial color of earlywood and latewood within sapwood and heartwood covered a wide range of hues. The initial redness and yellowness values ranged from 4.3 to 17.3 and 21.4 to 31.6 units, respectively. Steaming produced excellent color homogenization and increased saturation. After 9 days of steaming at 110°C, redness values converged, falling between 11.6 and 12.7 units. The yellowness values increased and also converged. After 9 days of steaming at 110°C the yellowness values were between 31.6 and 33.5 units. The color saturation of the examined tissues increased considerably and was also showed homogenized. After 9 days of steaming at 110°C, the saturation values were between 34.1 and 35.6 units (the initial values were between 22.6 and 32.1). It was difficult to differentiate the sapwood and heartwood at the end of the steaming process at 110°C.

Keywords: Color homogenization, color modification, color saturation, steaming, sugi wood

INTRODUCTION

Various types of timber utilization require different wood characteristics since not all properties of wood suit a particular purpose. Yet, in many cases, unfavorable properties can be improved by modification of the wood material. In terms of appearance, not all wood species have attractive colors. For example, the hue of wood between red and yellow gives us a feeling of warmness. Some species exhibit a white-greyish color without a marked texture, while some other species have disturbingly inhomogeneous coloring.

As technology developed, the disadvantages of unfavorable color in wood can be modified by steaming. The industrial application of steam treatment to change the color of wood started in the second half of the last century with the most frequently steamed species were Beech and black locust. The development in wood-coloring technology was largely supported by scientific research in which systematic efforts to discover the specific effects of steaming treatments for individual wood species started 30 years ago.

Up till now, the steaming behavior of black locusts has the most detailed literature. Some of the most relevant publications concerning the steaming behavior of black locusts were Tolvaj and Faix (1996); Molnar (1998); Tolvaj et al. (2010); Dzurenda (2018a). Based on these studies, the unattractive and highly inhomogeneous greenish-yellow color of black locust could be modified to resemble a chocolate brown color. Fewer studies are available concerning the investigation of the steaming behavior of beech than for black locusts (Milic et al. 2015, Geffert et al. 2017). Beech is usually steamed to turn its whitish-grey initial color into a more attractive reddish hue. The color difference between the white and red heartwood of beech can also be minimized by steaming (Tolvaj et al. 2009).

There are fewer publications regarding the steaming properties of species other than beech and black locust. Among such publications, Varga and van der Zee (2008) studied the alteration of some mechanical and physical properties of two European and two tropical hardwood species caused by steaming. Straze and Gorisek (2008) and by Dianiskova et al. (2008) investigated the possible color variations of cherry wood generated by steam treatment. Other studies (e.g., Tolvaj and Molnar 2006, Todaro et al. 2012 a,b, Csanady et al. 2015) found that steaming can reduce the great color difference between sapwood and heartwood of Turkey oak. Recently, Banadics and Tolvaj

(2019) studied the color change of poplar (*Populus x euramericana cv. pannonia*) by steaming to obtain attractive colors suitable for various indoor applications. Steaming was also found to be a proper technique to turn the naturally unattractive color of poplar wood to a pleasant brown color. The steaming was able to double the color saturation, which is a significant result in terms of industrial application. The treatment increased both redness and yellowness values and reduced the lightness. Dzurenda (2017, 2018b) investigated the steaming behavior of oak and maple wood to get attractive brown color.

It is hard to find results in the literature regarding the color modification of softwoods by steaming. Among the limited literature, Tolvaj et al (2012) did steaming experiment on Scots pine and spruce samples by applying board range of steaming times (0-22 days) and the temperatures between 70 and 100°C. The result showed that wide ranges of colors were created between the initial and light brown colors. These new colors were similar to those of aged indoor wooden structures and furniture. Another study by Kaygin et al. (2014) investigated surface quality and hardness of eastern red cedar as function of steaming time and temperature.

Until now, there is limited trial to look at the effect of steaming treatment of colorization of sugi (*Cryptomeria japonica* D. Don) wood. In its raw materials, the color of sugi timber is highly inhomogeneous. Its heartwood is much darker and redder than the sapwood. As such, this study aimed to investigate the effects of steaming on color homogenization of sugi wood and to find all of the possible colors created. The created diagrams are useful for finding the proper steaming treatments if a specific color is required.

MATERIALS AND METHODS

Sugi (*Cryptomeria japonica* D. Don) samples were prepared for the steaming tests. The size of each specimen sample was 150x20x10 mm. The largest surface contained only earlywood or latewood (tangential surface). Half part of the specimens was sapwood, and the other half part was heartwood. The average moisture content of the samples was 9.1% before the steaming process.

All steaming temperatures and steaming times were represented by a series of 10 samples and 10 randomly chosen points were used for color measurement on each sample. The steaming was carried out in a steaming chamber at 100% relative humidity at 90 and 110°C. Wood specimens were placed in a large pot with distilled water for conditioning the air to generate 100% relative humidity. At 110°C the pot was able to maintain the pressure. The pots were heated in a drying chamber to the indicated temperatures. The steaming process started with four hours of heating. The temperature was regulated automatically around the preset values with a tolerance of 0.5°C. Specimens were removed after 2, 5, 9, 14 and 20 days of steaming, respectively. The wood specimens were conditioned for one month both before and after steaming at room temperature before the color measurements (laboratory condition).

The color of the wood specimens was measured before and after steaming. Measurements were carried out with a colorimeter (Konica-Minolta 2600d) on the tangential surface. The color values of earlywood and latewood were determined separately. The CIE-Lab color measurement system was applied, and 10 randomly chosen dots were measured on each sample. The L*, a*, b* color coordinates were calculated based on the D_{65} illuminant and 10° standard observer with a test-window diameter of 3 mm.

RESULTS AND DISCUSSION

The tissues of sugi (*Cryptomeria japonica*) have highly varying color hue and lightness characteristics. The initial average color data of the investigated samples are presented in Table 1.

Heartwood was much darker than sapwood. Earlywood in sapwood, especially, was much lighter than in all other tissues. Latewood in sapwood had the same lightness as did earlywood in heartwood. The darkest tissue was the latewood in heartwood. The border between the dark and light portions was usually sharp.

The redness of sugi wood showed the greatest diversity among the tissues. Latewood in sapwood and earlywood in heartwood were more than two times redder, and latewood in heartwood three times redder than the earlywood in sapwood. There were moderate differences among the tissues in yellowness. These great color differences can be diminished by steaming. The standard deviation (SD) values were small, showing a high degree of color homogeneity within the earlywood and the latewood, respectively.

Figure 1 presents the redness change caused by steaming at 90°C. The color dots of all tissues converged with elapsed steaming time, representing color homogenization. The color homogenization continued up to the 14^{th} day of steaming. During this steaming period, the initial redness value difference among the tissues (13 units) was reduced to 2.5 units. The redness of the two types of earlywood was equal after 14 days of steaming, and the same happened for the latewood as well. However, the final values of redness (after 20 days) were different for earlywood and latewood.

Table 1. Initial color data of different tissues of sugi wood (average and standard deviation SD). S=sapwood, H= heartwood, E= earlywood, L= latewood

	L*	SD	a*	SD	b*	SD
SE	81.07	1.93	4.99	0.90	21.80	1.11
SL	71.02	2.00	11.69	1.35	30.43	2.63
HE	71.25	1.73	12.46	1.01	23.48	1.16
HL	62.20	2.09	16.45	1.37	27.42	1.84

Steaming at 110°C caused similar redness change as steaming at 90°C, but the redness change was more intense during the first two days of steaming (Figure 2). At this temperature, homogenization was achieved after the first nine days of steaming. The redness difference among the tissues was only 1.2 units after nine days of steaming. This finding suggests that if we want to steam sugi wood for color homogenization, nine days are sufficient to achieve maximum homogenization. From an industry point of view, the proper steaming time is five days for color homogenization. The redness change is negligible after this period of steaming at 110°C. It is better not to homogenize the color completely. The unique color harmony in wood is produced by moderate color differences between earlywood and latewood. Applying the proper steaming time and temperature, optimal color harmony may be generated.

The redness values were almost constant in most parts of the applied steaming period (between 5 and 20 days). This is a highly important result. It means that the chromophore chemical groups creating redness are stable during the thermal treatment at 110°C, and even more stable at ambient temperatures during everyday usage. The color shift is related to the alteration of conjugated double-bound chemical systems. These bounds can be found in the lignin and the extractives. Thus, the color changes in the examined temperature range originated mostly from the alteration of the extractives. Previous research showed that flavonoids play a significant role in the discoloration of wood (Csonka-Rákosa 2005).

The steaming results of wood species other than sugi (black locust, beech, Turkey oak) indicated that the red color created by steaming was not stable above 100°C (Tolvaj et al. 2009, 2010, Tolvaj and Molnar 2006). The high temperature degraded the newly generated chromophore molecules, and the steam leached out part of these colored chemical compounds from the samples, resulting in the decrease of a* values. In contrast, the experiments showed that the chromophore groups of sugi were stable during the 20 days of steaming at 110°C. The color stability for sugi wood is an important advantage when steaming.

Figure 3 presents the yellowness change caused by steaming at 90°C. The color dots of all tissues converged, representing color homogenization. The color homogenization continued up to the 14th day of steaming. During this steaming period, the initial yellowness value difference (9 units) was reduced to 3.1 units. In contrast to redness, the yellowness of the two types of tissues of sapwood was almost equal after 14 days of steaming, and the same happened for the heartwood as well. However, the end values (after 20 days) were different for sapwood and heartwood.

The yellowness change at 110°C was different from the change at 90°C (Figure 4). Most of the yellowness change happened during the first two days of steaming. The yellowness of sapwood hardly changed after this period and the yellowness value of heartwood slightly increased during the further steaming process. The average yellowness end value at 110°C (33.5 units) was much higher than at 90°C (27.3units).

The lightness difference among the tissues was 18 units at the beginning of steaming (Figure 5). The lightness values decreased continuously with elapsed steaming time at both temperatures. The difference between the effects of the two temperatures was only that the 90°C temperature resulted in smaller (6 units) lightness homogenization than the 110°C (11 units).

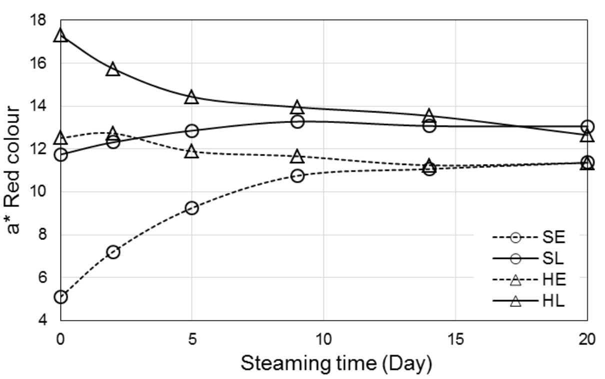

Figure 1. The redness change of different tissues during steaming at 90°C. (S=sapwood, H=heartwood, E=earlywood, L=latewood)

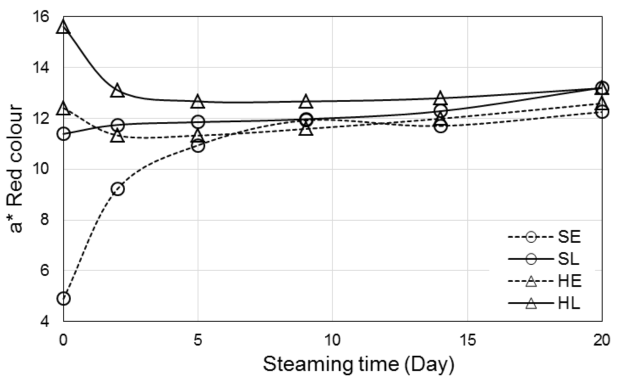

Figure 2. The redness change of different tissues during steaming at 110°C. (S=sapwood, H=heartwood, E=earlywood, L=latewood)

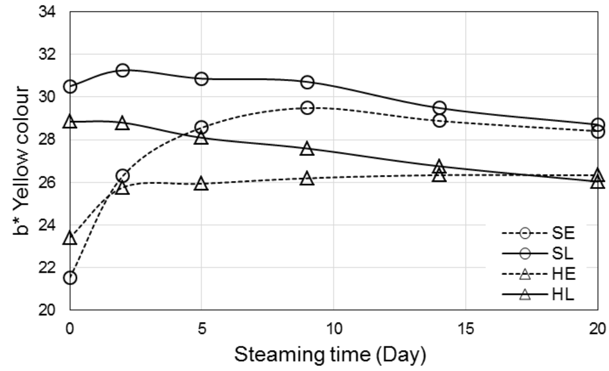

Figure 3. The yellowness change of different tissues during steaming at 90°C. (S=sapwood, H=heartwood, E=earlywood, L=latewood)

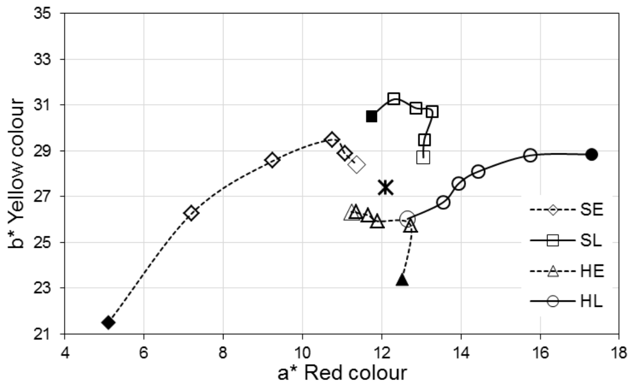

Figure 6. The color dots' locations on the b*-a* plane during steaming at 90°C. (Filled marks mean unsteamed)

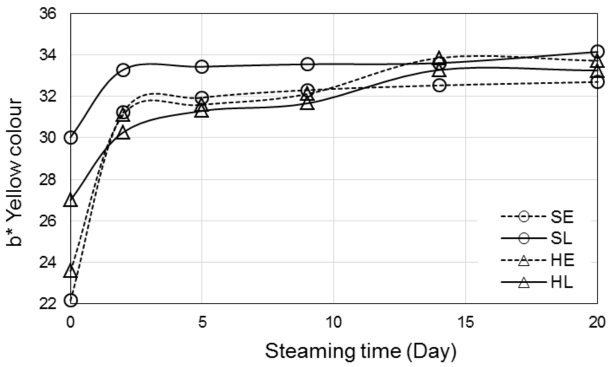

Figure 4. The yellowness change of different tissues during steaming at 110°C. (S=sapwood, H=heartwood, E=earlywood, L=latewood)

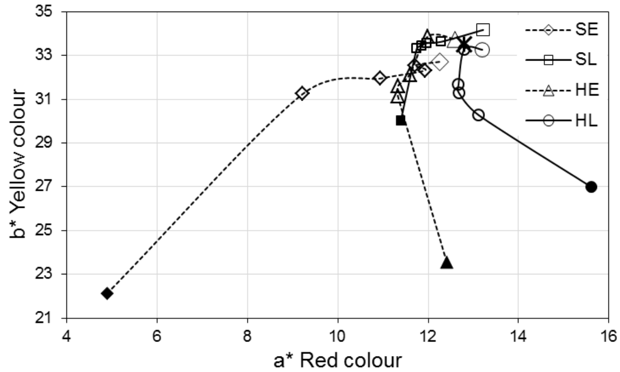

Figure 7. The color dots' locations on the b*-a* plane during steaming at 110°C. (Filled marks mean unsteamed)

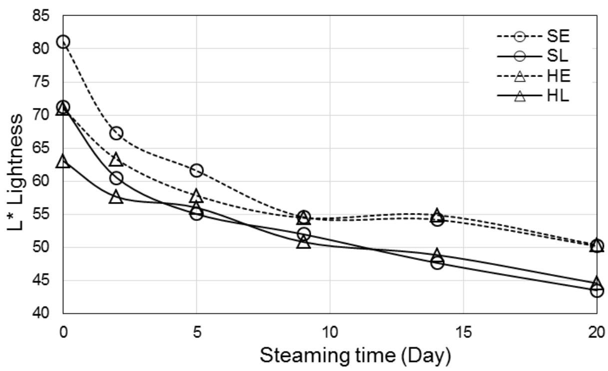

Figure 5. The lightness change of different tissues during steaming at 110°C. (S=sapwood, H=heartwood, E=earlywood, L=latewood)

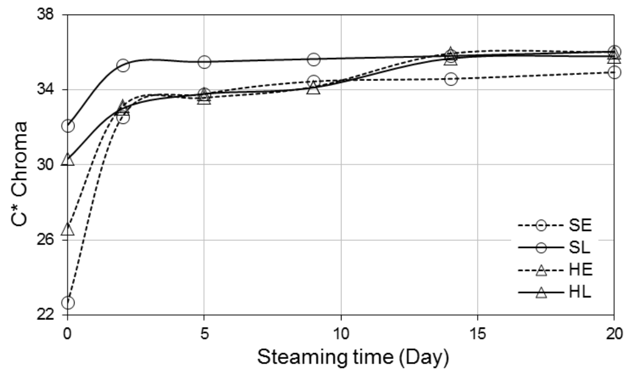

Figure 8. The change of color saturation for different tissues during steaming at 110°C. (S=sapwood, H=heartwood, E=earlywood, L=latewood)

The homogenization effect of steaming can be visualized by plotting the color dots on the a* -b* plane. Figures 6 and 7 show the colors generated by steaming at 90°C and 110°C, respectively (Filled marks represent the color dots of samples before steaming). The initial color dots are evidently far from each other. The color dots converge during the steaming process, towards a center dot. The coordinates of this center dot were; a*=12.1 and b*=27.4 units. The distances among the dots decreased representing the homogenization.

Similar changes were visible when sugi wood was steamed at 110°C (Figure 7). The changes were large during the first two days of steaming. The direction of changes differed compared to the effect of steaming at 90°C. The color dots moved towards a common point, but this point was not in a central position. This happened because the redness values increased considerably, elevating the color dots on the chart during the steaming. The middle point of the final color dots is located on the top of the diagram; its coordinates are a*=12.8 and b*= 33.5 units. The color dots were close to each other after the 5th day of steaming, representing color homogenization.

The chroma is also an important parameter because it represents the saturation of the given color. High saturation means that the color is vivid. Low saturation represents a dull color. The values of chroma hardly changed during steaming at 90°C. The only exception was the earlywood part in sapwood. Its chroma increased continuously during the first nine days of steaming and remained constant after that. All tissues became more saturated in color during the steaming at 110°C (Figure 8). Most of change happened within the first two hours of steaming. The chroma of earlywood increased much more than the chroma of latewood in sapwood as well as heartwood. The chroma hardly changed after the second day of steaming. Only the tissues of heartwood showed some increase in chroma after the second day of steaming. This result is important for the wood industry, because a more saturated color is generally more acceptable for humans than a dull color.

In conclusion, the color of sugi wood is highly inhomogeneous. It has light earlywood in sapwood. The color of latewood in sapwood has similar color to the earlywood in heartwood. This color is darker and much redder than the color of earlywood in sapwood. The latewood in heartwood has the darkest and most reddish color. Steaming was able to reduce these large color differences. A wide range of colors was created by steaming between the initial color and brown color depending on the steaming time and temperature. The color homogenization was so successful that it was difficult to differentiate between the sapwood and the heartwood by naked eye at the end of the steaming process. The effective steaming time for color homogenization was nine and two days at 90°C and 110°C, respectively. The chroma of all tissues increased considerably by steaming at 110°C, showing that steaming generated saturated color. The color data of steamed sugi wood are useful to find out the appropriate steaming parameters for achieving a specific color and color harmony.

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Restoration and rehabilitation potentials of the remnant natural forests of Himchari National Park (HNP), Cox's Bazar, Bangladesh

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Abstract. *Hossen S, Hossain MK, Uddin MF. 2019. Restoration and rehabilitation potentials of the remnant natural forests of Himchari National Park (HNP), Cox's Bazar, Bangladesh. Asian J For 3 : 25-30.* Himchari National Park (HNP) in Cox's Bazar, Bangladesh has been threatened by various anthropogenic activities, yet there are opportunities that the remaining vegetation can regenerate either naturally or with assistance. This study aimed to investigate the process of forest regeneration in Himchari National Park by looking at the state of regenerating vegetation, its community composition and biodiversity indices. As many 51 stratified random sample quadrats (20 m x 20 m) were surveyed. The result showed that natural vegetation (dbh ≥ 5cm) was found in dominance in 16 plots, equaling 31% of the total 51 plots sampled. The highest number of regenerated seedlings was *Grewia nervosa* (12.37%) followed by *Acacia auriculiformis* (8.95%). The maximum Importance Value Index (IVI) of regenerated seedlings was found for *Grewia nervosa* (26.43) followed by *Acacia auriculiformis* (20.27). The Shanon-Wiener's diversity index, Shanon's maximum diversity index, species evenness index, Margalef's diversity index, and Simpson's diversity index were 3.166, 3.714, 0.853, 6.03 and 0.057, respectively. Maximum coverage of natural regeneration was observed in the sampled plots of natural and plantation forest types rather than remnant natural forests or patches. Based on result, we recommend: (i). Evaluation of forest harvesting impacts on the forest ecosystems, (ii). Development of rehabilitation methods on logged-over forests and degraded forest lands, (iii). Development of silvicultural techniques on plantation and degraded lands, (iv). Network on the restoration and rehabilitation of degraded forest ecosystems.

Keywords: Degradation, National Park, regeneration, rehabilitation, restoration

INTRODUCTION

Forest degradation, from the perspective of vegetation cover, can be defined as a state of vegetation disturbance when the canopy is opened to form gap and plant succession process is disturbed (Kobayashi et al. 1999). It can be caused by natural disasters and human activities with major factors of forest degradation are agricultural exploitation, commercial logging, and wildfire (Mori et al. 2000). Such activities become a trigger for deforestation and land conversion to other forms of utilization, such as monoculture plantations, human settlements and so on (Kobayashi 1988, 1994).

Forest degradation affects forest ecosystems in various ways, including biodiversity loss, reduced capacity to regulate water, soil erosion, and greenhouse gas emission. Along with deforestation, forest degradation in tropical regions are the major contributors to global warming because both phenomena release a large amount of greenhouse gas emissions, such as carbon dioxide, methane, and nitrogen oxide, while at the same time reducing the capacity to sequester carbon dioxide through photosynthesis as the vegetation lost or degraded (Kira 1991; Uchijima 1991).

In Bangladesh, forests play an important role in various aspects including biodiversity conservation, carbon sinks, soil and water conservation, wildlife conservation, timber production and fulfillment of the needs of local people. Yet, many forests in Bangladesh are currently pressured by deforestation and forest degradation. As a results, Rahman et al. (2000) and Hossain (2001) stated that the depletion of native species is accelerating at an alarming rate due to the rapid loss and degradation of forests of the country. Numerous plant species are also at risk of being lost in all or part of their distribution ranges because of reduction in their population number due to overexploitation (Das 1987). Nonetheless, the extent of biodiversity loss in Bangladesh is not exactly known due to very poor database and is often based on scarce information (Hossain et al. 2004). As such, there is an urgent need to effectively protect and manage the existing natural forests in Bangladesh for the future generation (Hossain 2004). In addition, forest rehabilitation is also required to restore the degraded forest in Bangladesh.

Forest rehabilitation can be defined as coordinated measures to recover vegetation in deforested and degraded forests to maximize forest functions to satisfy human needs. Forest rehabilitation can be done by intended planting (active rehabilitation) or letting the remained vegetation proceed with natural regeneration (passive rehabilitation). While most understanding of forest rehabilitation is centered on intended planting activities, natural regeneration is essential for preservation and maintenance of biodiversity in natural forests (Hossain et al. 2004; Rahman et al. 2011). Knowledge about the pattern of natural regeneration is also important to answer the basic question of forest management (Hossain et al. 1999).

Himchari National Park (HNP) is located in southeastern region of Bangladesh, comprising an area of 1729 ha. It was established in 1980 and is very important due to its proximity to Cox's Bazar tourist city. Previously, this forest area was rich in floral and faunal diversity, number of waterfalls, streams cascades down towards the sandy beach on the west. Unfortunately, the national park was pressured by various factors like encroachment, illegal felling, and conversion of land into agriculture and betel leaf cultivation (Hossen and Hossain 2018). Nowadays, there is an increasing awareness to recover forest conditions in Himchari National Park through forest rehabilitation, yet limited information is available regarding the processes of regeneration. As such, this study aimed to investigate the process of forest regeneration in Himchari National Park by looking at state of regenerating vegetation, its community composition, and biodiversity indices. The results of these biodiversity monitoring and evaluation efforts are essential for taking effective conservation measures of the protected area immediately.

MATERIALS AND METHODS

Study area

Himchari National Park (HNP) geographically lies at $21^0$35' to $21^0$44`N and $91^0$98` to $92^0$05' E. It is located on the outskirts of Cox's Bazar city extending from Lighthouse para on the north to Rejhukhal on the south. It encompasses three unions namely South Mithachari, Jhillonja and Khuniapalong. The national park was established on 15th February 1980 through the decree of section 23 (II) of Bangladesh Wildlife Preservation Act 1974 by the Government of the People's Republic of Bangladesh with an area extent of about 1729 ha (4,271.15 acres). At the establishment, it consisted of three forest blocks namely Bhangamura Reserve Forest (872 ha), part of Chainda Reserve Forest (62 ha), and part of Jhilongja Protected Forest (795 ha). Currently, the national park covers four forest landscapes namely Kolatoli (872 ha), Chainda (62 ha), Jhilongja (450 ha), and Link Road (345 ha). The total area of the Protected Forest (PF) is about 10,849 ha of which 1,729 ha core zone, 5,247 ha buffer zone, and 3,873 ha private land (Figure 1). It is under the jurisdiction of Cox's Bazar South Forest Division within Cox's Bazar District.

Method and sampling design

The study was conducted from January 2017 to May 2018. The composition and diversity of the tree species in HNP were assessed through stratified random sampling using quadrat method applied separately for tree species. A total of 51 plots from four blocks were taken. The number of quadrats was fixed with plot size of 20 m x 20 m to have a sampling intensity of 0.117%.

For regeneration study, 5 m × 5 m subplots were taken at the center of each sample plot, and thus a total of 51 regeneration subplots were studied from the study area. All the sample plots were demarcated, and then all the tree species, including seedlings and saplings in each plot were identified and recorded with the help of taxonomists and local people. The relative density, relative frequency, relative abundance, and Important Value Index (IVI) were calculated following Shukla and Chandal (2000). Different biological diversity and richness indices (e.g., Species diversity index, Margalef's, Shannon-Wiener, Simpson's diversity index, etc.) were analyzed following Kent and Coker (1992), Margalef (1958), Michael (1990), Odum (1971), Pielo (1995), Shannon-Wiener (1963), Simpson (1949) and Hossain and Hossain (2014) to get a picture of regenerated seedlings in HNP. Family relative density and family relative diversity were calculated following Rahman et al. (2011). Empirical data were analyzed using MS Excel. The equations are presented below.

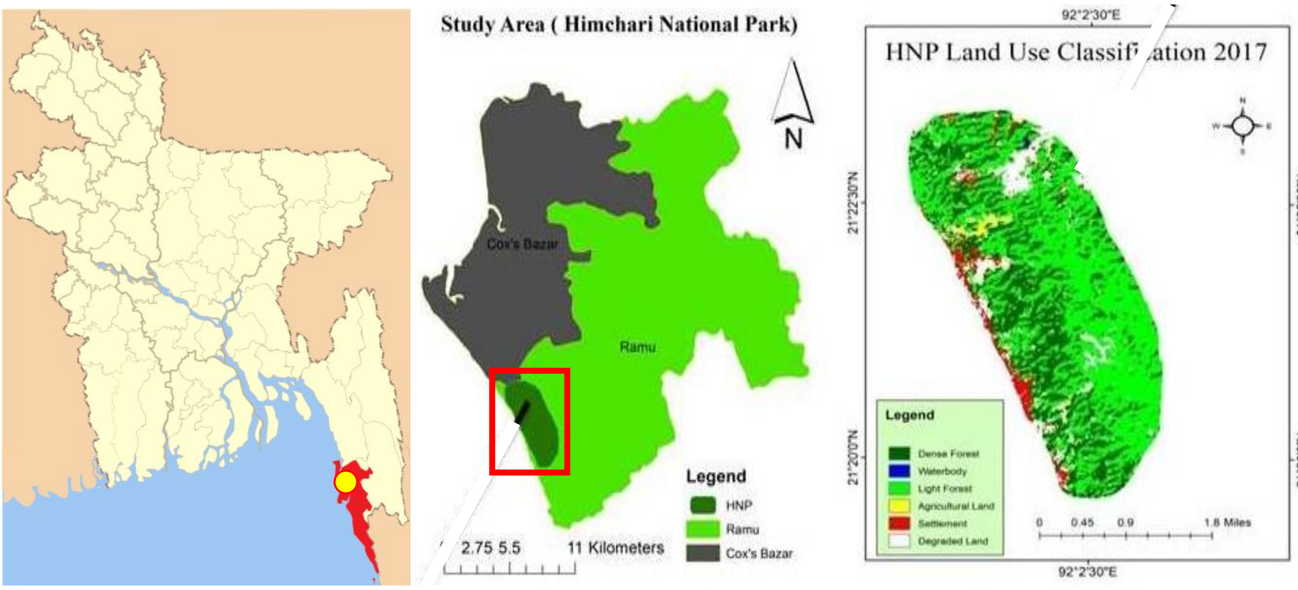

Figure 1. Map of the study location and land use classification of Himchari National Park (HNP), Cox's Bazar District, Bangladesh

$$\text{Density of a species} = \frac{\text{Total no.of individual of a species in all the quadrats}}{\text{Total no.of quadrats studied}}$$

$$\text{Relative density} = \frac{\text{Total no.of individual of the species}}{\text{Total no.of individuals of all the species}} \times 100$$

$$\text{Frequency of a species} = \frac{\text{Total no.of individual of quadrats in which the species occurs}}{\text{Total no.of quadrats studied}}$$

$$\text{Relative frequency} = \frac{\text{Frequency of one species}}{\text{Total frequency}} \times 100$$

$$\text{Abundance of a species} = \frac{\text{Total no.of individual of a species in all the quadrats}}{\text{Total no.of quadrats in which the species occured}}$$

$$\text{Relative Abundance} = \frac{\text{Abundance of one species}}{\text{Total abundance}} \times 100$$

IVI = Relative Density + Relative Frequency + Relative Abundance

Species diversity index, SDi = S/N

Margalef's/ Species richness index index, R = (S-1)/ Ln (N)

Shannon-Wienner's diversity index, $H = -\sum_{i=0}^{n} Pi \ln Pi$

Shannon's maximum diversity index, Hmax =Ln (S)

Simpson's diversity index, $D = \sum_{k=0}^{n} Pi^2$

Dominance of simpson index, D´= 1-D

Simpson's reciprocal index, D_r= 1/D

Species evenness index, $E = \frac{H}{Ln(S)}$

Family relative density, FRD (%) = N_f/T_i X 100

Family relative diversity index, FRDI (%) = N_s/T_s X 100

Family importance value (FIV) = FRD + FRDI

Where,
H : Shannon-Wiener's diversity index
N_f : No. of individual in a family
N : Total no. of individuals of all the species
P_i : Number of individuals of one species/ Total number of individuals
T_i : Total number of individuals
N_s : No. of species
T_s : total number of species.

RESULTS AND DISCUSSION

State of vegetation regeneration in HNP

Of the 51 sampled plots, the dominance of natural vegetation was found in 16 plots (31%), while the remaining plots were dominated by natural and planted vegetation (15 plots, 29%), planted vegetation (8 plots, 16%), mixed plantation (7 plots, 14%), enrichment plantation (2 plots, 4%), coppice and plantation (2 plots, 4%) and coppice and natural vegetation (1 plot, 2%) (Figure 2). The natural regeneration was mostly observed in the sample plots of natural and plantation forest types rather than remnant natural forests. This result implies that the vegetation in HNP is regenerating mainly through artificial means than natural processes.

Family composition of regenerating vegetation in HNP

A total of 760 tree seedlings of 41 species under 21 families were recorded from the sampled areas. About 57.14% (12) families were represented by only one species and 14% (3) by more than two species. Families with the largest number of species were Moraceae and Myrtaceae with 5 species followed by Mimosaceae (4), Caesalpiniaceae (3), Combretaceae (3), and Meliaceae (3) (Table 1). Family with the highest relative density was Myrtaceae (14.34%) followed by Dipterocarpaceae (12.37%). Myrtaceae and Moraceae also had the highest relative diversity (12.12%) followed by Mimosaceae (9.76%). Family with the highest Family Importance Value (FIV) was Myrtaceae (26.54) followed by Mimosaceae (21.99), Moraceae (21.54), Dipterocarpaceae (17.25), and Tiliaceae (14.81) (Figure 3).

Species composition of regenerating vegetation in HNP

The community composition of regenerating vegetation at species level in Himchari National Park (HNP) was studied on the basis of the density, relative density, relative frequency, relative abundance and Importance Value Index. Species with the highest relative density were *Grewia nervosa* 12.37% (94) followed by *Acacia auriculiformis* 8.95% (68) and *Syzygium fruticosum* 8.82 % (67). The lowest number of seedlings was recorded for *Ficus microcarpa* 0.13% (1) followed by *Terminalia chebula* 0.26% (2), *Terminalia bellirica* 0.26% (2), and *Syzygium firmum* 0.26% (2) (Table 2).

Table 1. Family composition, number of species, number of individuals under each family, family relative density (FRD), family relative diversity index (FRDI) and family importance value (FIV) index of the regenerating trees in HNP, Cox's Bazar District, Bangladesh

Family	No. of species	No. of seedlings	FRD (%)	FRDI (%)	FIV
Anacardiaceae	2	25	3.29	4.88	8.17
Apocynaceae	1	7	0.92	2.44	3.36
Caesalpiniaceae	3	17	2.24	7.32	9.55
Casuarinaceae	1	23	3.03	2.44	5.47
Clusiaceae	1	3	0.39	2.44	2.83
Combretaceae	3	19	2.50	7.32	9.82
Dipterocarpaceae	2	94	12.37	4.88	17.25
Elaeocarpaceae	1	10	1.32	2.44	3.75
Euphorbiaceae	1	9	1.18	2.44	3.62
Fabaceae	1	18	2.37	2.44	4.81
Lythraceae	1	11	1.45	2.44	3.89
Magnoliaceae	1	2	0.26	2.44	2.70
Meliaceae	3	45	5.92	7.32	13.24
Mimosaceae	4	93	12.24	9.76	21.99
Moraceae	5	71	9.34	12.20	21.54
Myrtaceae	5	109	14.34	12.20	26.54
Oxalidaceae	1	2	0.26	2.44	2.70
Rhamnaceae	1	26	3.42	2.44	5.86
Rubiaceae	1	14	1.84	2.44	4.28
Tiliaceae	1	94	12.37	2.44	14.81
Verbenaceae	2	68	8.95	4.88	13.83
	41	760	100	100	200

Table 2. Phytosociological characters of the regenerating tree species in HNP, Cox's Bazar District, Bangladesh

Scientific name	Local name	No. of seedlings	RD (%)	RF (%)	RA (%)	IVI
Acacia auriculiformis A. Cunn. ex Benth. & Hook.	Akashmoni	68	8.95	8.42	2.90	20.27
Acacia mangium Willd.	Mangium	5	0.66	1.10	1.63	3.39
Albizia procera (Roxb.) Benth.	Sada Koroi	4	0.53	0.37	3.92	4.81
Alstonia scholaris L.	Chatim	7	0.92	1.47	1.71	4.10
Artocarpus chama Buch.-Ham.	Chapalish	2	0.26	0.37	1.96	2.59
Artocarpus heterophyllus Lamk.	Kanthal	29	3.82	4.03	2.58	10.43
Averrhoa carambola L.	Kamranga	2	0.26	0.37	1.96	2.59
Azadirachta indica A. Juss.	Neem	18	2.37	3.30	1.96	7.62
Butea monosperma (Lamk.) Taub	Palash	18	2.37	1.83	3.53	7.73
Caesalpinia pulcherrima L.	Radhachura	3	0.39	0.37	2.94	3.70
Cassia fistula L.	Sonalu	5	0.66	0.73	2.45	3.84
Casuarina equisetifolia Forst.	Jhau	23	3.03	2.93	2.82	8.77
Delonix regia Rafin.	Krishnachura	9	1.18	1.10	2.94	5.22
Dipterocarpus turbinatus Gaertin.	Telia Garjan	63	8.29	5.49	4.12	17.90
Elaeocarpus tectorius (Lour.) Poir	Jalpai	10	1.32	1.83	1.96	5.11
Eucalyptus camaldulensis Dehnhardt.	Eucalyptus	2	0.26	0.37	1.96	2.59
Ficus benghalensis L.	Bot	2	0.26	0.37	1.96	2.59
Ficus hispida L.f.	Dumur	37	4.87	5.86	2.27	12.99
Ficus microcarpa L.f.	Puti Bot	1	0.13	0.37	0.98	1.48
Garcinia cowa Roxb. ex DC.	Kao	3	0.39	0.37	2.94	3.70
Gmelina arborea Roxb.	Gamar	36	4.74	3.66	3.53	11.93
Grewia nervosa (Lour.) Panigrahi	Assargola	94	12.37	10.99	3.07	26.43
Lagerstroemia speciosa (L.) Pers.	Jarul	11	1.45	1.83	2.16	5.43
Mangifera indica L.	Aam	20	2.63	3.66	1.96	8.25
Mangifera sylvatica Roxb.	Uri Aam	5	0.66	1.10	1.63	3.39
Michelia champaca L.	Champa	2	0.26	0.37	1.96	2.59
Neolamarckia cadamba (Roxb.) Bosser	Kadam	14	1.84	2.56	1.96	6.37
Phyllanthus emblica L.	Amloki	9	1.18	1.47	2.20	4.85
Psidium guajava L.	Peyara	36	4.74	6.23	2.07	13.04
Samanea sam (Jacq.) Merr.	Raintree	16	2.11	2.56	2.24	6.91
Shorea robusta Roxb. ex Gaertin. f.	Sal	31	4.08	3.66	3.04	10.78
Swietenia mahagoni Jacq.	Mahagoni	4	0.53	0.73	1.96	3.22
Syzygium cumini (L.) Skeels	Kalo Jam	2	0.26	0.37	1.96	2.59
Syzygium firmum Thw.	Dhaki Jam	2	0.26	0.37	1.96	2.59
Syzygium fruticosum DC.	Puti Jam	67	8.82	5.49	4.38	18.69
Tectona grandis L.f.	Segun	32	4.21	3.30	3.48	10.99
Terminalia arjuna (Roxb. ex Dc.) Wight & Am.	Arjun	15	1.97	2.20	2.45	6.62
Terminalia belliria (Gaertin.) Roxb.	Bohera	2	0.26	0.37	1.96	2.59
Terminalia chebula Retz.	Haritaki	2	0.26	0.37	1.96	2.59
Toona ciliate Roem.	Suruj	23	3.03	4.03	2.05	9.10
Ziziphus mauritiana Lamk.	Boroi	26	3.42	3.66	2.55	9.63
		760	100	100	100	300

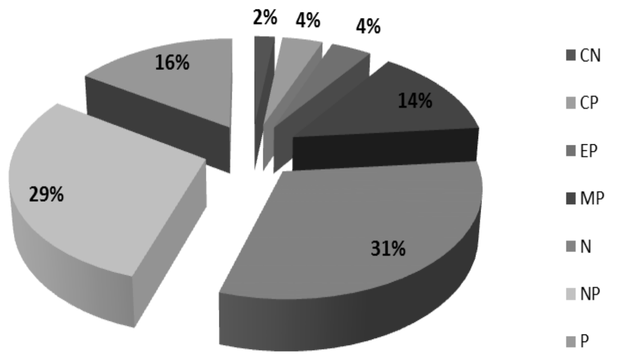

Figure 2. State of vegetation regeneration in HNP, Cox's Bazar District, Bangladesh resembled by the proportion of the 51 sampled plots across various vegetation types. Vegetation type: CN: Coppice and Natural, CP: Coppice and Plantation, EP: Enrichment Plantation, MP: Mixed Plantation, N: Natural forests, NP: Natural and Plantation and P: Plantation

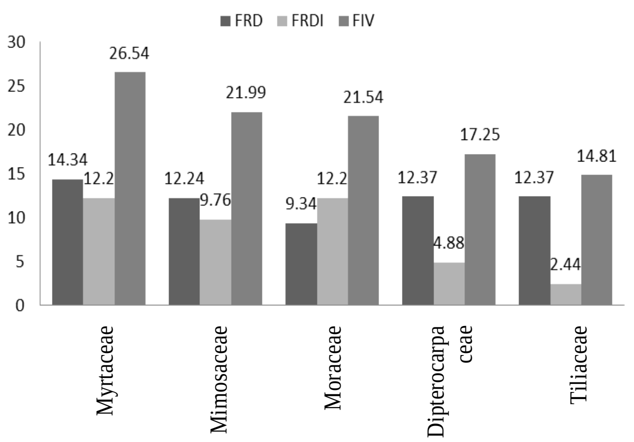

Figure 3. Family relative density, family relative diversity, and family importance value of some dominant tree families in HNP, Cox's Bazar District, Bangladesh

Recommended strategies for restoration and rehabilitation of degraded natural forests of HNP

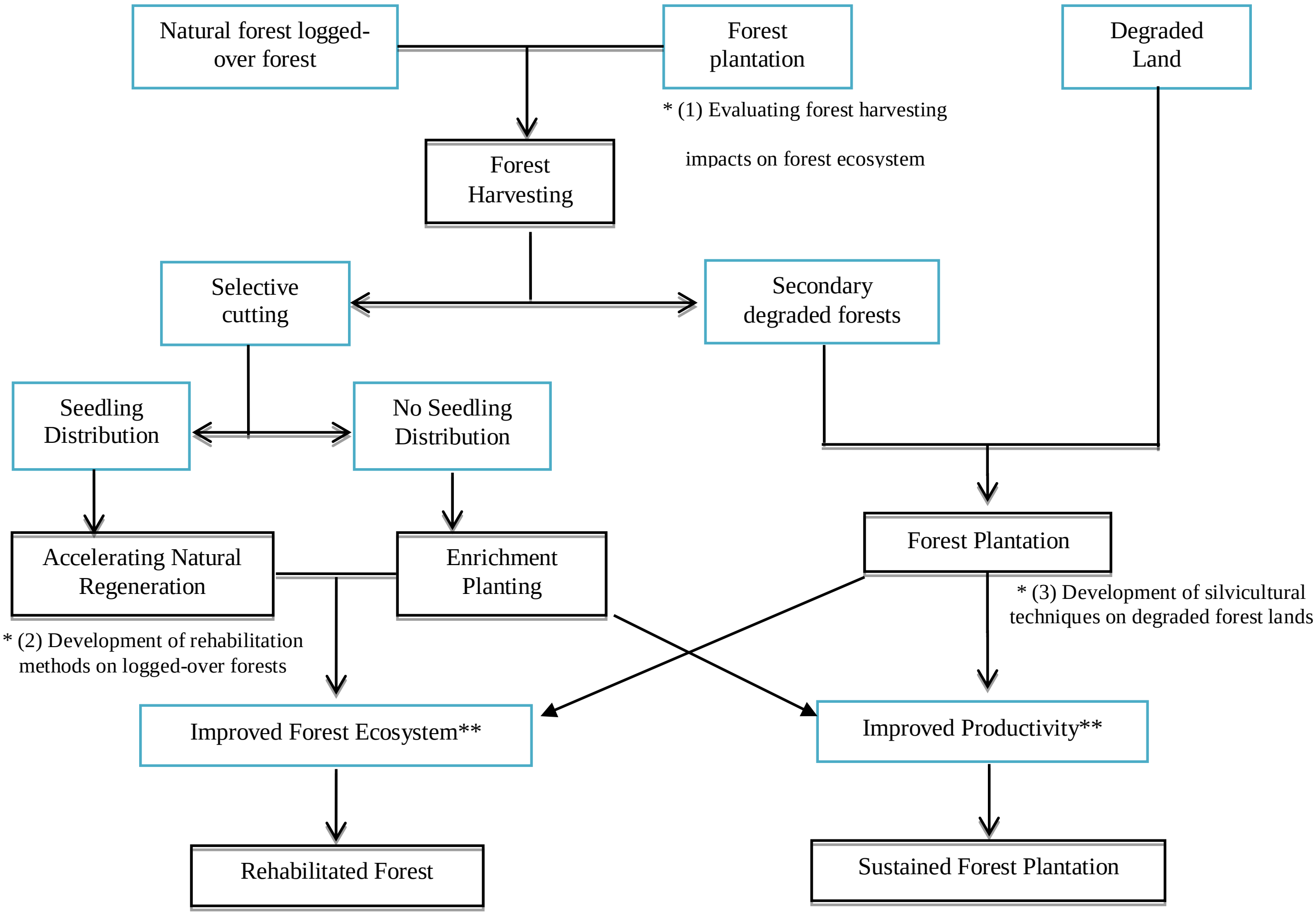

Figure 4. Proposed restoration and rehabilitation strategies for remnant natural forests in HNP, Cox's Bazar District, Bangladesh. Note: *Actual target is development of adequate techniques. ** Final target is conservation of biodiversity and environment of forest.

Maximum relative density was recorded for *Grewia nervosa* (12.37%) followed by *Acacia auriculiformis* (8.95%), *Syzygium fruticosum* (8.82%), *Dipterocarpus turbinatus* (8.29%). Maximum relative frequency was recorded for *Grewia nervosa* (10.99%) followed by *Acacia auriculiformis* (8.42%), *Psidium guajava* (6.23%). The highest relative abundance was *Syzygium fruticosum* (4.38%) followed by *Dipterocarpus turbinatus* (4.12%). The maximum Importance Value Index (IVI) was found for *Grewia nervosa* (26.43) followed by *Acacia auriculiformis* (20.27), *Syzygium fruticosum* (18.69) (Table 2).

Biodiversity indices of regenerating vegetation in HNP

The study revealed that the value of species diversity index in the whole surveyed area was 0.054. The Shanon-Wiener's diversity index in the area was 3.166 with Shanon's maximum diversity index of 3.714. The species evenness index was 0.853, Margalef's diversity index was 6.03 and Simpson's diversity index was 0.057. The values of Dominance of Simpson's index and Simpson's reciprocal index of HNP were 0.943 and 17.544 respectively (Table 3). The values of Shanon-Wiener and Margalef's diversity index indicate adequate presence of tree species in the area. Lower value of Simpson's index is also indicator for diverse tree species.

The results of this study showed that the phytosociological attributes of regenerating vegetation in the HNP are comparable to other tropical forests (Figure 4). The values of these variables indicate that even though the forest in HNP had been degraded and deforested severely, but it harbors a rich diversity of tree species. These forests had been under great anthropogenic pressures, indicated by fragmentation and land conversion into other land uses including agriculture, betel leaf, and houses. The natural regeneration coverage, composition and density reveal that the forests still have revival capacity and variety of trees have been growing from seeds and root suckers.

Although their natural regeneration was present, cutting of seedlings and saplings particularly by fuelwood collectors and betel leaf cultivators imposed threats on new recruitments. Many local people living in and around the national park area are dependent on the forests for their livelihood and daily necessary goods. Conflicts regarding land need to be resolved to protect trees and natural regeneration.

Table 3. Biodiversity indices of regenerating vegetation in HNP, Cox's Bazar District, Bangladesh

Parameters	Total for HNP
Species diversity index (SDi)	0.054
Shanon-Wiener's diversity index (H)	3.166
Shanon's maximum diversity index (Hmax)	3.714
Species evenness index (E)	0.853
Margalef's diversity index (R)	6.03
Simpson's diversity index (D)	0.057
Dominance of Simpson's index (D')	0.943
Simpson's reciprocal index (Dr)	17.544

Finally, it can be concluded that although the condition of the forest is poor, but still there is some hope as shown by the rich number of regeneration and potential of rehabilitation in the remnant natural forest. It is suggested that the results of these studies will contribute to the sustainable use of forest resources and environmental conservation. If it is possible to protect the national park in the current state with effective measures of diverting the forest-dependent people towards non forest-related livelihood alternatives or reducing dependency on the forest, there is a greater possibility of this forest to develop into a better quality forest in the future.

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Abundance, distribution and conservation threats of African wild dog (*Lycaon pictus*) in the Loliondo Game Controlled Area, Tanzania

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Abstract. *Masenga E, Hasan SN, Japhet K. 2018. Abundance, distribution, and conservation threats of African wild dog (*Lycaon pictus*) in the Loliondo Game Controlled Area, Tanzania. Asian J For 2: 31-41.* African wild dog (*Lycaon pictus*) is of high conservation importance due to its few populations remaining while it is threatened with various factors. Assessment of abundance, distribution, and conservation threats to African wild dogs was conducted in Loliondo Game Controlled Area (LGCA), northern Tanzania. Specifically, the study focused on determining population size and structure, spatial distribution, attitudes of local people towards wild dogs and wild dog conservation and threats impacting the species. Semi-structured interviews, diurnal random searches, internal and external examinations of wild dogs carcasses examined, and night transect surveys were employed. Eight packs with a total of 132 recognized individuals at an average pack size of 16.50 ± SD 7.50 individuals were recorded. Pack sizes of 3 individuals were reported to be sighted mostly and of all respondents (n= 210), only 26% were able to recognize wild dog sexes. The density of both known and unknown wild dogs was 0.19 animals/km^2, higher compared to other carnivores. In terms of distribution, most of the packs were concentrated in the northern part as compared to the central and southern parts of LGCA. The species was observed to occur most in woodland types of vegetation. Interestingly, 55.30% of respondents showed a positive attitude towards wild dogs and wild dog conservation despite that 52.90% of respondents dismissed lack of any conservation action or strategy in place towards conserving the species. However, poisoning and Canine Distemper Virus were identified as the main threats. Therefore, conserving African wild dogs in LGCA requires multi-approach conservation efforts (i.e. awareness rising to community, fitting radio telemetry to the dogs, and threats management interventions) due to nature of the species.

Keywords: Distribution, conservation, Loliondo, *Lycaon pictus,* Tanzania

INTRODUCTION

The African wild dog (*Lycaon pictus*) is one of the world's most endangered large carnivores (Woodroffe et al. 2004) and yet of high value to Africa's tourism industry (Lindsey et al. 2007). The reason for its current conservation category is the small population size and ongoing decline (Woodroffe et al. 2004). In the wild, fewer than 8000 individuals remain, spread across a small number of fragmented populations (IUCN/SSC 2008).

Although the highest densities of the wild dog have been recorded in wooded savannah (Creel and Creel 2002), their populations have also been recorded in habitats as diverse as short grasslands, montane forests (Dutson and Sillero-Zubiri 2005) and mangroves (McNutt et al. 2008). Historically, the species was once distributed across the African continent, absent only from the jungles and deserts (Woodroffe 2004; McNutt et al. 2008). Today, African wild dogs remain uncommon even in essentially less disturbed wilderness, apparently due to negative interactions with larger carnivores and livestock predation (Creel and Creel 1996; Mills and Gorman 1997; Woodroffe et al. 2005).

All large carnivores need large areas to survive hence African wild dogs need larger areas than almost any other terrestrial carnivore species anywhere in the world (Woodroffe et al. 2005). However, dramatic range reductions resulting from extensive habitat loss and persecution mean that they now occupy just 7% of their historical range (Woodroffe 1997; IUCN/SSC 2008). Frequently reported major causes for the decline of the species to include habitat loss, persecution, competition with other carnivores, low prey availability, and contagious diseases particularly rabies and canine distemper (Alexander and Appel 1994; Woodroffe and Ginsberg 1998; van de Bildt et al. 2002). Other causes are snares and roadkill (Woodroffe et al. 2004), and low genetic variation within a population over time (Oliver 2009).

The aims of the study were (i) To determine population size and structure of African wild dogs; (ii) To assess the spatial distribution of African wild dogs; (iii) To determine and assess threats impacting African wild dogs; (iv) To determine attitudes of local people towards the wild dogs and wild dog conservation.

MATERIALS AND METHODS

Study area

Location

The study was conducted in Loliondo Game Controlled Area (LGCA), which falls within the Serengeti Ecosystem in northern Tanzania. In addition, African wild dogs in adjacent protected areas, i.e. NCAA and Maasai Mara, were studied. Loliondo Game Controlled Area (Fig. 2) lies within the Maasai ancestral lands between latitudes 2° 5' 00" and 2° 2' 60" S; and longitude 35°61'67" and 35° 37' 00" E. It encompasses an estimated area of 4000 km^2, roughly one-third of the area of Serengeti National Park. There are no physical barriers separating the LGCA from the bordering protected areas.

Climate and vegetation

Generally, the climate is warm and dry, coolest from June to October, with a mean annual temperature of 20.8°C, which is often less than the diurnal variation (UNEP 2008). The average annual rainfall varies between 400mm and 600mm (Homewood et al. 2001). However, LGCA exhibits a bi-modal rainfall pattern with peaks occurring in December and April and a total of 400-1200mm per annum (Norton-Griffiths et al. 1975).

The vegetation in LGCA varies from open woodland to short grass plains. The northern part is primarily of open woodlands on rolling hills, interspersed with rocky outcrops. It consists of a mosaic of *Acacia drepanolobium* in black cotton soils, high altitude forests of Pencil cedar, long grass plains dominated by *Acacia gerardii*, *Rhus natalensis*, *Euclea divinorum*, and *Acacia hockii* tree species (Homewood et al. 2001). The forests are mostly situated on the hilltops or along watercourses in valleys. The mountain forests are classified as closed evergreen forests, which contain major tree species such as *Fagaropsis anglolensis (Olmoljoi), Olea welwitschii (Ololiondo)* and *Juniperus procera (Oltarakwa)*. Acacia species are dominant in open scattered valley forests (Ojalammi 2006). Short grass plains with a high net primary productivity during rains (Sinclair et al. 2002) are present to the South converging into *Acacia/Commiphora* woodland. The short grass plains are important breeding grounds of Wildebeest (*Connochaetes taurinus*). In the central part, and in and around the Sonjo area, there are mountains with steep slopes and densely vegetated gullies. In the south, the Gol Mountains give way to the short grass plains (Sinclair et al. 2002).

Wildlife

Loliondo is an important part of the semi-annual migratory route of millions of wildebeests and other ungulates northward into the Maasai Mara Game Reserve and Amboseli National Park in Kenya between April and June, and returning southward between December to January every year. The survival of the Ngorongoro-Serengeti-Maasai Mara ecosystem and the wildlife it supports is highly linked to the existence and health of Loliondo (Homewood et al. 2001). The Gol Mountains and Sanjan Gorge are important nesting refuges for Rüpell's Griffon Vulture (*Gyps rueppellii*) and White Backed Vulture (*Gyps africanus*) both of which are near-threatened (Ojalamini 2006). Carnivores such as African wild dog (*Lycaon pictus*) (endangered) and cheetah (*Acinonyx jubatus*) (threatened) are present (Sinclair et al. 2002).

Attributes of the human communities

The human population density in the eastern part of the ecosystem (LGCA) decreases from north to south with the highest density is found close to Kenyan border and around Wasso and Loliondo towns in the north, and the lowest density is in the Gol Mountains area in the south, where there are mainly seasonal settlements of nomadic Maasai (Masenga and Mentzel 2005). Currently, the human population of Loliondo District is estimated at 176,607, of which 85,684 are males and 90,923 are females. The estimate is computed using 4.5% annual growth rate (NDC 2009). Human activities such as settlement, cultivation (including mechanized commercial farming), pastoralism, tourism, and licensed hunting are permitted (Homewood et al. 2001) in the area. The economic activities of local communities include agro-pastoralism, with more of them engaged in livestock keeping (about 80%) and small-scale agriculture (13%) production system (NDC 2009).

Overall, there were 16 study villages in the studied areas even though the semi-structured interviews were limited to only 6 villages. The age structure (in years) of respondents consisted of four categories: 31-40 (5%), 41-50 (26%), 51-60 (38%) and > 61 (23%). However, 8% of individuals had no knowledge at all of their ages. Majority of respondents (126; 60.80%) had primary school education whereas 50 respondents (23%) had no formal education. Other education categories were standard twelve year with 26 respondents (12.40%), diploma 7 respondents (3.30%), and University education 1 respondent (0.50). Numbers and corresponding percentages for the sex of respondents interviewed are summarized in Table 1.

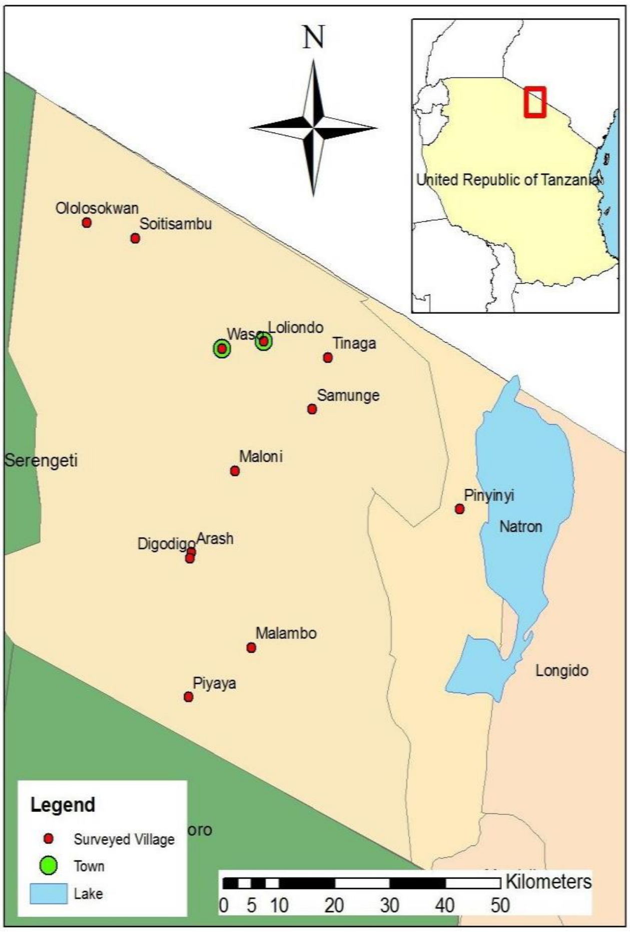


Figure 2. Map of Loliondo GCA showing surveyed villages 2009

Table 1. The distribution of the respondents by village in respect of sex

Respondents	Villages					
	Ololosokwan	**Soitsambu**	**Piyaya**	**Malambo**	**Digodigo**	**Samunge**
Male	30 (86%)	34 (97%)	33 (94%)	26 (74%)	17 (49%)	27 (77%)
Female	5 (14%)	1 (3%)	2 (6%)	9 (26%)	18 (51%)	8 (23%)
Total	35 (100%)	35 (100%)	35 (100%)	35 (100%)	35 (100%)	35 (100%)

Data collections

Primary data were collected based on three methods namely, diurnal random search of wild dogs, systematic night field surveys, internal and external examination of wild dogs carcasses, and semi-structured interviews. This approach was necessary due to rarity of the subject animal. Secondary data were obtained from unpublished reports and journal publications at Tanzania Wildlife Research Institute (TAWIRI) and at Sokoine National Agricultural Library (SNAL).

Population size, structure, and distribution of wild dogs

Diurnal random searches of wild dogs were conducted in areas historically known to have wild dogs. The searches were made by a team comprising of the researcher and enumerators (persons trained to locate wild dogs and make records). Pack sizes, age, and sex of sighted individuals and positions were recorded for each pack encountered. Positions were recorded with the aid of a handheld Global Positioning System tool (GPS-Garmin 12) for mapping distribution. Photographs were taken using a high-resolution camera (8.0 megapixel) for subsequent individual/pack identification (IDs). A binocular was used to aid determination of pack sizes and individual/pack identification where possible. Also, habitat/vegetation types were identified, and den sites and number of pups together with any incidence of wild dog attack by other carnivores were recorded.

Systematic night field surveys of carnivores along four major roads (Piyaya plain-Piyaya Suyan campsite, Maloni village centre-Samunge Hahara sub-village, Malambo Lake Natron junction-Malambo village center and Gol road junction-Nasera rock) were employed. A total of 20 km along each road were surveyed. In this case, each road was treated as a transect. Transects were driven at a fixed speed of 20 km/hr (Buckland et al. 2001), with two observers and one recorder seated at the back of a Land Rover station wagon. Each observer scanned one side of the road using a handheld spotlight. Name of carnivore species, group size, side of the road (right/left), the perpendicular sighting distance, position, time of sighting, and kilometer driven was recorded every time a carnivore species was seen.

Peoples attitudes towards wild dogs and threats of wild dog conservation

Attitudes. The purposive sampling technique was used to select six villages from the government register book in which to conduct interviews. The villages selected were Ololosokwan, Soitsambu, Piyaya, Malambo, Samunge, and Digodigo. The sampling unit, in this case, was a household. According to der Gier (2004), sample size should be at least 30 to 50 to ensure adequate representation of the population. Therefore in this study, the sample size was 35 households per village. Simple random sampling design was used to obtain the households sampled. The design is preferred over other designs because it gives each unit in the population an equal probability of being selected, and all choices are independent of one another. Under this method, the whole population is taken as a single composite unit (Sancheti and Kapoor 2007). Subsequently, semi-structured interviews with household representatives from villages surrounding the study area were employed. Respondents included three *Ilgwanak* (Head of Maasai traditional norms of different age groups) and five key informants per village (i.e. village executive officer, village chairman, village environment committee officer, village game scout officer, and teacher). The information regarding merits and demerits of wild dogs, conservation threats of wild dogs, activities/sources of threats, and mitigation of threats on wild dog conservation were focused. The survey had four main sections: (i) Respondent characteristics, (ii) African wild dog general information, (iii) Main threats facing wild dog populations, and (iv) Attitudes of local communities towards conservation of wild dogs.

Threats. Internal and external examinations of wild dog carcasses encountered during the survey were conducted and recorded. Some fresh carcasses were found near water sources suggesting mortality occurred few days ago before they were discovered. These carcasses looked very dehydrated, brownish, and swelling under the tails in most cases with open recta (evidence of severe bloody diarrhea). Eleven out of 23 fresh carcasses collected were examined for the cause of death.

The lungs appeared reddish-brown to black with extensive hemorrhages with consolidation in parts of the lobes with or without emphysema. The diaphragmatic muscles were congested with reddish to brown discoloration. The livers were slightly enlarged with thick margins and dark in color with portions of cooked-like appearance. The spleen was enlarged with thick margins, and evenly distributed dark and brown patches on both sides. In some cases, kidneys were only congested; however, in others, they appeared enlarged with evidence of hemorrhages on cut surfaces. The stomach was empty in most of the carcasses while only few had scanty brownish watery contents. The thoracic cavity was filled with reddish to brown colored fluid (sanguineous fluid or fibrin) and there was congestion in the inner surfaces of the chest cavity (pleura).

Visceral organs including lungs, heart, intestines, liver, spleen, kidneys, lymph nodes, salivary glands, and brain were collected and examined. These samples were used for screening of Canine Distemper Virus. Tissue samples in duplicates were preserved in glycerol saline, 10% buffered formalin, ethanol, methanol, and RNA later, and thereafter the samples were frozen. Only tissues preserved in glycerol saline were used for bacterial culture. In addition, 10% buffered formalin, ethanol and methanol were used to fix tissues for histopathological examination whereas tissues in RNA were used for virus isolation and sequencing.

Data analysis

Population size, structure, and distribution

The data from the systematic night field surveys of carnivores including wild dog were prepared and summarized in Microsoft Office Excel 2003. The summaries were average pack size, minimum, and maximum pack size and age ratios. Similarly, the population size of carnivores other than the wild dogs was estimated in the excel sheet following Davis and Winstead (1980):

$P = AZ/2YX$, where; P = population size A = Total study area

Y = Mean perpendicular sighting distance X = total length of all transects and

Z = Total number of animals counted

The density (D) of wild dogs was computed by dividing the population size (N) by the size of the survey area (A) (Wilson et al. 1996). The density of other carnivores was computed using the strip width transect for density estimate using line-transect (Buckland et al. 2001). On the other hand, data from random searches were collated in ArcGIS 9.2 (ESRI 2006) to map spatial distribution of the packs and habitat types for the wild dogs.

Attitudes and threats of local people towards wild dogs

The data generated through semi-structured interviews were translated from *Kiswahili* into English and categorized into themes and sub-themes, each of which was assigned an identification code for easy analysis. Descriptive analyses were employed in the Statistical Package for Social Sciences for Windows (SPSS 16). Relative importance of each threat was obtained by scoring and ranking technique (Kajembe and Kessy 2000). Other results were summarised in tables and graphs.

Later on, tissue samples were submitted to the Government Chief Chemist (GCC) in Dar es Salaam for toxicological analysis. Samples that were fixed in 10% buffered formalin were submitted for histopathological examination. The tissues were first processed routinely, embedded in paraffin, sectioned at 4µm and stained with hematoxylin-eosin (H and E). Few samples preserved in RNA later were used for the molecular analyses.

The messenger Ribonucleic Acid (mRNA) was isolated from two wild dog samples and Reverse transcriptase-polymerase chain reaction (RT-PCR) was performed. *Morbillivirus* specific primers that amplify a region of the Pgene (P1: 5’-ATGTTTATGATCACAGCGGT-3’ and P2: 5’-ATTGGGTTGCACCACTTGTC-3’) (Barret et al. 1993) as well as primers homologous to sequences of the Fgene (FC1: 5’ GGACTGATAATGTCCATTA-3’ and FC2: 5’-ATAGCTTTGTTAGACTGTT-3’) were used (Liermann et al. 1998). The phylogenetic sequence on a 388bp fragment of a P gene was analyzed and the joining trees were generated using Tamura Nei parameter with 1000 bootstrap pseudo-replications (Kumar and Tamura 2004).

RESULTS AND DISCUSSION

Population size and structures of wild dogs

Over 75% (n = 160) of the respondents from household interviews admitted having had seen wild dogs. Whereas, 24% (n = 50) respondents had not reported seeing wild dogs. The "yes" or "no" answer depended on how long a respondent had lived in the area by the time of survey, meaning that respondents who had shifted to the area in recent years had less chance of having sighted the animal compared to those who had lived in area for over five years.

Respondents reported having had sighted African wild dogs in groups of varying sizes (Table 2, Fig. 3). However, villagers in Piyaya and Malambo villages had an opportunity to see 4 of the 5 pack size categories whereas those in Soitsambu and Samunge saw the least number of pack size categories (Fig. 3). Overall, larger pack sizes, i.e. 21-30, 31-40 and those with individuals >40 were rarely seen compared to those with individuals between 1-10 and 11-20 with most pack sighted with 3 individuals (Table 2). Apparently, majority of respondents were unable to recognize sex of a wild dog as only 55 respondents (26%) of all respondents were able to recognize only 2 adult males with the other 8 respondents (4%) recognizing only 3 sub-adult females.

During the diurnal random searches for African wild dogs, a total of 8 packs were recorded in the area and given names depending on the pack's place of residence. The Tinaga pack was found to consist of 19 adult dogs whereas the Losoito pack in the central part of Loliondo had 15 sub-adult dogs. Also, 6 den sites were found with the number of pups ranging between 2 to 4 (Table 3) making a total of 132 individuals. The size of known packs ranged from 4 to 25 individuals with an average pack size of 16.50 ± SD 7.50 (CI, 0.50) animals. The pack sizes of known and unknown packs pooled together varied from 1-30 with average packs sizes of 9 ± SD 5.70 (CI, 0.20).

Table 2. African wild dog pack sizes reported by respondents in six studied villages LGCA 2009

Pack sizes	1-10	11-20	21-30	31-40	>40	Total
Respondents (N)	122	25	5	5	3	160
Percentage (%)	76%	16%	3%	3%	2%	100%

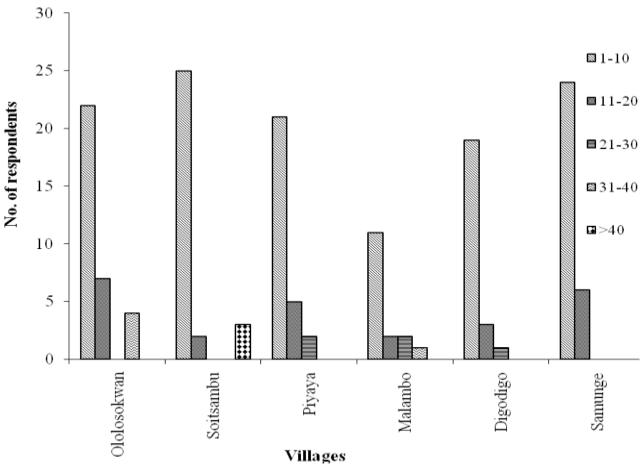


Figure 3. African wild dog pack sizes reported in six study villages in the LGCA 2009

Table 3. The sizes and age structures of known packs of wild dogs in the study area as identified during diurnal random searches in Loliondo Game Controlled Area 2009

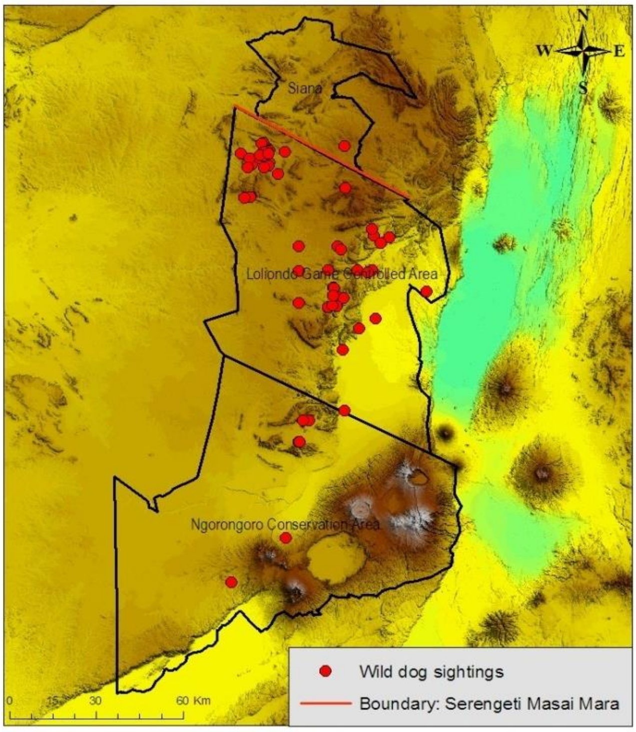
Pack name	Age structures		Pack size	
	Adult	Sub adult	Pups	Total
Losoito	8	15	2	25
Malambo	10	4	4	18
Masosu	8	0	4	12
Ololosokwan	7	7	4	18
Parimangati	17	6	0	23
Samunge	3	1	0	4
Tinaga	19	0	4	23
Yasimdito	6	0	3	9
Average	9.75	4.13	2.63	16.50
Total	78	33	21	132

Spatial distribution of African wild dog, population estimates and densities of other carnivores sighted during random searches

Wild dogs were sighted inside and outside LGCA (Figure 4) and their pack sizes were recorded in various habitats/vegetation types (Figure 5). Sightings outside LGCA consisted of one sighting in the Maasai Mara, Kenya, and five sightings in Ngorongoro Conservation Area (NCA).

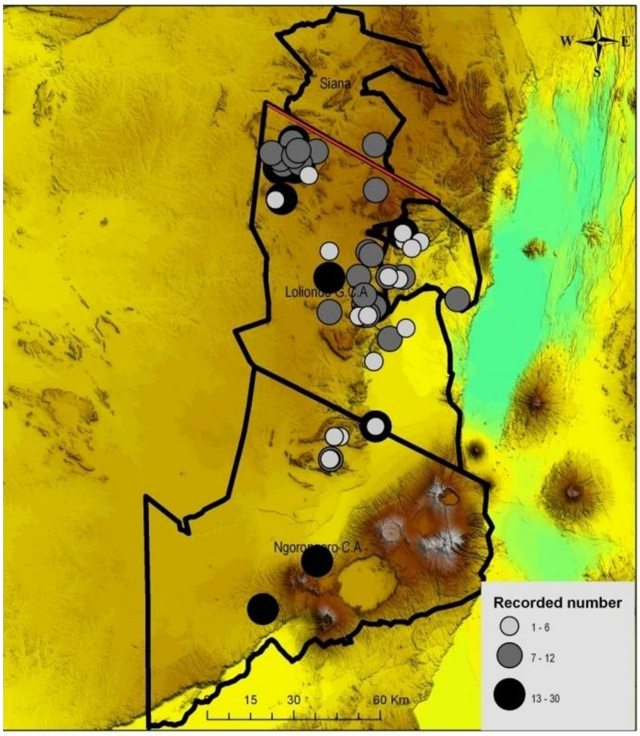
During the wild dog diurnal random searches, five categories of habitat were recorded (Fig. 6). The sightings were overlaid on the vegetation types to show the wild dogs sighted in different habitat types such as shrubland (n = 2), woodland (n = 46), grassland (n = 17), bushland (n = 12) and anthropic landscape (n = 5) (Figure 7).

During the systematic night transect survey, neither lion nor wild dogs were recorded. Other small and large carnivores were counted and their population estimates are presented in Table 4. The densities of all carnivores recorded were calculated (Table 5) without carnivores with observation less than 5. However, the density for wild dogs itself was 0.19 animals/km^2 for the whole surveyed area.



Map datum and Projection: Arc 1960, Zone 36S; Data source: Wild dog Project 2009; Map drawn by Masenga

Figure 4. Spatial distribution of wild dogs in LGCA and the adjacent environs based on sightings during the diurnal random searches (Map background SRTM)



Map datum and Projection: Arc 1960, Zone 36 S; Map drawn by Masenga

Figure 5. Different pack sizes as sighted in various localities within and outside LGCA during the diurnal random searches in 2009 (Map background SRTM)

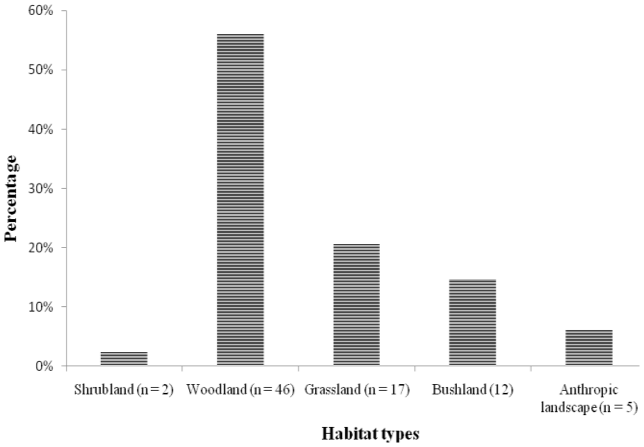


Figure 6. Relative occurrences of the African wild dogs in various habitats in LGCA 2009

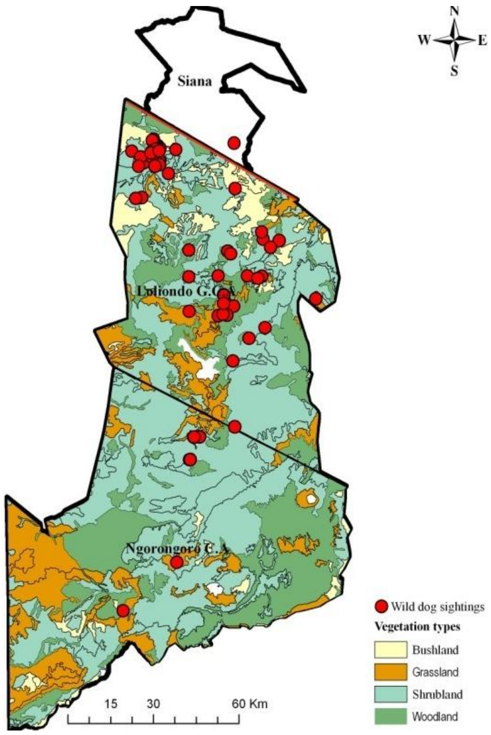


Figure 7. Wild dogs sighting in various vegetation types in LGCA and its adjacent areas (Map background SRTM)

Attitudes of local people towards wild dogs and wild dog conservation

Respondents had varied opinions regarding presence of wild dogs within their area. Over one-third (40%) showed a negative attitude towards the wild dog for reasons such as fear of livestock predation and human attack. The positive attitude towards the animal (55.3%) such as very happy about wild dogs and the animal is good for tourist attraction but difficult to see (Table 6). Such positive statements were based on the understanding that the animal was rare and therefore important for income generation and employment in tourism industry.

Table 4. Small and large carnivores other than wild dog and lion that were counted in LGCA during the estimate of each species night surveys and the corresponding

Month/ species	Counts	Estimates
January 2009		
Black-backed jackal	1	4800
White-Tailed Mongoose	7	5600
Domestic cat	1	4800
February 2009		
Black-backed jackal	4	6400
Golden Jackal	3	4000
Spotted hyaena	2	9600
Bat Eared Fox	2	1600
March 2009		
Golden Jackal	3	27600
Spotted hyaena	2	9600
White-Tailed Mongoose	7	13070
Bat Eared Fox	27	35100
Black-backed jackal	1	1600
April 2009		
Bat Eared Fox	10	18000
Serval cat	2	800
May 2009		
Bat Eared Fox	7	44800
Aardvark	1	3200
Striped hyaena	1	3200
Wild cat	1	800
August 2009		
Golden Jackal	3	20800
Bat Eared Fox	6	28800
African civet	1	4800
September 2009		
Golden Jackal	3	21600
Bat Eared Fox	2	11200
October 2009		
Wild cat	1	6400
Golden Jackal	1	6400
Bat Eared Fox	3	19200
November 2009		
White-Tailed Mongoose	2	12800
Domestic dog	1	1600
Wild cat	1	4800
Golden Jackal	1	3200
Bat Eared Fox	1	3400

Table 5. Summary of frequency of carnivore sightings and densities from January-November 2009

Species	Counts	Density (animals/km^2)
Bat-eared fox	58	0.07
Black-backed jackal	6	0.01
Golden jackal	14	0.02
White-tailed mongoose	16	0.02

Table 6. Local communities' attitude towards wild dogs occurring on their land in the LGCA 2009

Respondents feeling	Number of respondents	Percentage
Dangerous to livestock	77	36.70
Very happy	68	32.40
A good for tourist attraction	39	18.60
Good but they are difficult to see	9	4.30
Fear them	7	3.30
Feel normal (Not afraid of the dogs)	10	4.80
Total	210	100.00

Table 7. Local communities initiatives towards wild dog conservation in the LGCA 2009

Initiatives	Number of respondents	Percentage
Rising conservation education	76	36.10
Encourage villagers to do wild dog watching	13	6.20
Village should formulate by-laws to safeguard the animal	10	4.80
No effort made to conserve wild dogs	111	52.90
Total	210	100.00

Table 8. Summary of responses to the question regarding threats to wild dogs in LGCA 2009

Type of threat	Number of respondents	Percentage
Don't know	74	35.20
Moved away from the area	35	16.70
Climate change	33	15.70
Livestock and human population increase	22	10.50
Persecution	17	8.10
Decline of preferred prey	16	7.60
Diseases e.g. Rabies	9	4.30
Less pups borne	4	1.90
Total	210	100

Nevertheless, majority of community members (52.9%) were disappointed by the fact that no conservation initiatives were in place to conserve this rare and endangered animal. In contrast, less than 10% (6.2%+4.8%) of respondents reported presence of a minimum level in place of initiatives for the conservation of this rare animal as implied by statements such as "advocate wild dog watching and formulation of by-laws" (Table 7).

Threats to wild dog conservation

Ultimate and proximate threats

During the interview, a total of 210 respondents responded to the question regarding threats to survival of the African wild dog. The responses were rendered into 9 groups of threats. But, majority of respondents appeared to have no idea about the probable cause for wild dog decline (Table 8).

Poisoning

The results from the local laboratory (GCC) detected presence of organ phosphorus pesticides in liver, kidneys, and spleen in 4 of 23 wild dog carcasses that were suspected of poisoning. However, lungs, intestines, and stomach had no trace of organophosphorus pesticides.

Diseases

The histopathological examination of liver, spleen, lung, heart, kidney, and brain revealed moderate to severe multi-lobular suppurative to necrotizing bronchopneumonia. In addition, there was extensive intra-alveolar and interstitial infiltration with mononuclear inflammatory cells. Epithelial lining cells of bronchi and bronchioli contained clearly visible eosinophilic intracytoplasmic inclusion bodies. There was also multi-focal moderate to severe interstitial pneumonia in some animals with formation of multiple syncytial cells. Occasionally, marked interstitial edema with some intra-alveolar hemorrhages and fibrin deposits were observed.

Some neutrophilic granulocytes were observed indicating secondary bacterial infection. These findings are consistent with canine distemper virus (CDV) infection.

The RT-PCR amplification and Sequencing together with phylogenetic analysis of amplified P-gene fragment of size 388bp obtained from the liver, spleen, lung, heart, kidney, and brain demonstrated a CDV strain closely related to CDV strains previously described for lions, spotted hyenas and bat-eared foxes in Serengeti National Park, and those described for domestic dogs outside the park and wild dogs held in captive breeding program in Mkomazi Game Reserve. Some neutrophilic granulocytes were also observed indicating secondary bacterial infection.

Discussion

Population size and structures of wild dogs

African wild dog is among large carnivores now endangered second to Ethiopian Wolf (Woodroffe et al. 2005). Therefore, their occurrence in any area draws attention to their conservation. LGCA which has a remnant population is among the remaining core areas in the Serengeti ecosystem. The sightings have been known to the local communities living in the area as resident individuals. The wild dog packs sizes of 1 to 10 individuals were reported in all studied villages whereas packs with >40 individuals were reported in only one village. However, respondents have no idea about the number of packs seen in the area due to inability to recognize individuals of various packs. Pack sizes were defined as the number of adults of ≥1 year of age (McNutt and Silk 2008). Results of this study, therefore, correspond to previous reports in the same ecosystem (Burrows 1995) that wild dogs are still seen in small pack sizes.

Formerly, the SNP supported several wild dog packs though the densities had never been high (Creel and Creel 2002; Woodroffe et al. 2004; IUCN/SSC 2008). This study reports 8 packs, comprised of 132 individuals. This population size is lower compared to previous estimates for known packs in Tanzania, except for the wild dog pack in the Maasai Steppe, which was reported to have only 8 packs (n = 70 individuals) (TAWIRI 2009). According to Creel and Creel (2002) and IUCN/SSC (2008), Katavi had 17 packs making 200 individuals; Kigosi-Moyowosi 33 packs making 400 individuals; Rungwa-Ruaha 35 packs making 500 individuals and Selous 50 packs constituting 880 individuals. The present study on both known and unknown packs in LGCA range from 1 to 30 with average pack size of 9.10 ± SD 5.70 (n = 82) which does not concur with the other findings. In Luangwa protected area complex (48,180 km^2) in Zambia probably holds the second largest wild dog population in Africa with mean pack size of 8.80 ± SD 5.10 (n=24) with a pack size ranging from 1 to 27 (Somers et al. 2008). Similarly, wild dog pack sizes in Northern Botswana varied from 2 to 30 adults, with an average pack size of 10.40 ± SD 5.40 (n = 84) (McNutt and Silk 2008). The lower mean pack size in this study was contributed by communities disturbing the dogs so the dogs dispersed widely.

The current recorded population size of wild dogs is larger compared to what has been reported previously by Masenga and Mentzel (2005). The observed increase is linked to relatively lower carnivore populations as reported in this study. However, during the study period, there was no wild dog recolonization inside Serengeti Park. This is probably due to increased hyena and lion numbers in the Serengeti National Park causing high interspecific competition (Woodrofe et al. 2004).

Spatial distribution of African wild dog, population estimates and density of carnivores other than African wild dog

Wild dogs in LGCA were found concentrated in the northern part. But they were sparsely distributed in the central part and scattered in the southern part. The order and magnitude of sightings of wild dog packs in different vegetation types of LGCA with most sightings in the woodlands (Fig. 6) are comparable to findings in Selous Game Reserve whereby wild dogs were also found to prefer woodland and bushland due to good cover (Creel and Creel 2004). However, sightings of the same wild dog packs in LGCA and NCAA, Tanzania, and Maasai Mara, Kenya suggest that wild dogs in Loliondo can also use other areas of the Serengeti Ecosystem.

Habitat variation in LGCA (i.e. woodland, shrubland, bushland, and anthropic landscapes) in combination with hills and rock outcrops possibly contributes to the tendency of wild dogs to concentrate more in the area. In other studies showed that in Ethiopian Montane forest and East African mangrove in Ijara-Lamu in Kenya are one of ecological habitat uniqueness of wild dogs confirmed to occur (Dutson and Sillero-Zubiri 2005; IUCN/SSC 2008). Other factors could be the influence of wildebeest migration that occurs between December and May every year on the Southern part of Serengeti ecosystem (Holdo et al. 2010). The migrating animals could be a good source of food supply to the wild dogs in the area. Contrary, studies in Hwange National Park, north-western Zimbabwe reported wild dogs to occur most in deciduous tree savanna, which constituted about 45% of the entire range (Rasmussen et al. 2008).

The results from the systematic night transect survey revealed few counts for all carnivores with a special case of no wild dogs and lion sightings. The probable cause for not sighting wild dogs could be the activity pattern of the species, being more active during the day than at night. However, absence of lions during the counts may be associated with Maasai culture to kill lions as part of *"Moran"* prestige or moved to other areas. In Simanjiro lion has been killed by humans and they moved away from adjacent boundary to Tarangire national park (Kissui 2008).

The low numbers for other carnivores despite being lower than that of wild dogs could be due to high densities of livestock and human increased demand for cultivation (Ojalammi 2006) as well as drought during the survey period. In this study, the presence of low numbers of both large and small carnivores during the night surveys suggested that competition during wild dogs hunting would be low thus reducing inter-specific competition. Results of the study in Laikipia-Kenya showed that low densities of small carnivores allow for increase in wild dog population as they avoid inter-specific competition with lions (Woodroofe et al. 2005) by avoiding lion and hyenas home ranges. These findings are in line with the present study. Nevertheless, other findings reported that wild dog can coexist with people only under right circumstances such as high density of prey ungulates (Treves et al. 2004), low densities of domestic dogs, and human (Woodroofe et al. 2004; Creel and Creel 2004).

The overall wild dog density (known and unknown packs) in this study area was 0.19 animals/sq km. By comparison, the density of adult wild dogs was 0.0195 adults/sq km which is relatively lower than what has been recorded in Selous Game Reserve, 0.04 animals/sq km (Creel and Creel 2002) and 1.6 adults/sq km in Hluhluwe-iMfolozi Park (Somers et al. 2008). However, the adult population density on the Serengeti plains over 13 years averaged 0.01 animals/sq km (Burrows 1995) which is lower than what has been recorded in this study.

Attitudes of local people towards wild dogs and wild dog conservations

The results from respondents revealed that majority had negative attitude on wild dog presence on their land. This was due to wild dog attacks on their livestock. However, livestock depredations by wild dogs were said to peak during dry season. During this time of the year when migratory herbivore species particularly wildebeests are away, livestock is concentrated in habitat patches with few types of grass remaining. Consequently, livestock serves as cheap and easily available prey. Presence of wildebeest migration in the area during wet season implies high abundance of prey thus wild dogs switch their feeding preference from livestock to wildebeest and other wild prey, which reduces the wild dog-human conflict. However, the retaliatory actions by local communities versus wild dogs persist following the negative attitude already developed (Marker et al. 2003). The negative attitude by livestock keepers and ranchers towards wild dogs is due to economic loss they cause (Woodroffe et al. 2005; Lindsey et al. 2005).

The local communities realize that wild dogs are rare and important for the tourism industry. The family members who were engaged directly in taking tourists to watch wild dogs gained incentives for wild dog viewing from tourists. In addition, tour operators offer employment to members of local communities with experience in areas where wild dogs use mostly. The benefit-sharing through wild dog as an asset between local communities and tourists/tour operators, have been observed in the Ololosokwan, Soitsambu and Piyaya villages. Based on these kinds of values, local communities who are beneficiaries may develop a positive attitude toward wild dogs and wild dog conservation. Therefore, understanding local community attitudes towards carnivores including wild dog may contribute to better management and identification of carnivores ecology, behavior, and conservation status through integrating local communities in management (Dickman 2005).

Increased education and outreach activities regarding wild dog conservation would also be beneficial to conservation. The observed positive contact between local communities and tour operators was indicative of improved attitudes towards the wild dog, demonstrating that such contact can have clear benefits. Although some conservation education programs have been established for schoolchildren to visit the Serengeti National Parks, this has little relevance to nomadic pastoralists. Still, it would be valuable to develop similar schemes with pastoralists, and to use these programs to highlight the presence of wild dogs in their area, with the aim of improving attitudes not only towards the wild dog, but also towards other wildlife species.

Although wild dog is an endangered species, this study showed that majority of respondents felt that there were not yet any conservation initiatives in place to serve the species. This was due to lack of Government conservation guidelines for the species in Tanzania. The community opinion on the inspire community to kill the dogs, awareness-raising and provision of community conservation education are of importance to serve the species. The action plan for wild dog conservation has identified priority areas for species conservation but rather has not emphasized on formulation of by-laws to safeguard the species conservation (TAWIRI 2009). In Kruger National Park, tourist volume is high and almost 75% of guests are willing to pay to see wild dogs. These revenues are potentially sufficient for conservation initiatives in the country (Lindsey et al. 2005). However, in LGCA wild dog watching campaign and formulation of by-laws were not in place as suggested by respondents. Therefore, in order to ensure sustainable conservation initiatives for the species in LGCA, raising conservation awareness needs to be emphasized.

Threats to African wild dog populations

It is, however, important to understand immediate and ultimate threats to wild dogs. Results suggest that immediate wild dog threats were not known to a greater proportion of local community, therefore aspect such as dog emigration and weather change was viewed by respondents as the ultimate threats. Their notions about the threats were based on their knowledge of the ecology of the species, which include their wide-ranging behavior. It is documented that wild dogs require large home ranges to support viable populations (Creel and Creel 2002; Woodroffe et al. 2004).

The respondents mentioned human and livestock population increase, persecution, decline of preferred prey, diseases, and fewer pups borne as threats to wild dogs. However, habitat fragmentation has caused decline of wild dog home ranges to extend beyond reserve borders, leading to increased mortality risk due to persecution by humans, and poaching activity such as snares which can cause considerable death to dogs (IUCN/SSC 2008). Woodroffe et al. (2005) also pointed out that indiscriminate killing of wild dogs by game rangers may be led to its population decline. With high proportion of dogs killed by people, human induced mortality has been identified as threat to wild dogs as it appears to increase due to decline in monitoring intensity (Woodroffe et al. 2004).

One pack in the study area continues to decline as a result of ongoing conflict with humans. The conflict between wild dogs and human has led to intentional poisoning of the dogs due to wild dog attacks on their livestock. This has resulted in death of 65% of Parimangati packs due to poisoning in Ololosokwan village. The poison used contained organophosphate compounds that are found in cattle dip for killing ticks on livestock. The magnitude of mortality identified in this study was similar to that reported by Woodroffe et al. (2004) for other wild dog populations elsewhere in Africa, for which poisoning itself contributed about 8% of the population. Poisoning of wild dogs in LGCA is done in secrecy because for the Maasai it is an abomination to kill wild dogs. Therefore, most poisoning incidences were not reported (IUCN/SSC 2008).

The wild dog appears to be susceptible to many diseases; particularly canine distemper virus that has been confirmed to kill considerable population of the Parimangati pack. In Mkomazi Game Reserve, Tanzania, Canine Distemper outbreak caused death to a captive-bred population, 49 out of 52 individual dogs died between December 2000-February 2001 (Marco et al. 2002).

The histopathological lesions described in the result section were consistent with the gross pathological examination suggesting that the pathological changes were due to viral and secondary bacterial infection. Detection of genetic material for CDV by RT-PCR can be a result of circulating antigens from previous exposure to CDV (Goller et al. 2010). However, it is unlikely for the non-infectious antigens to cause pathological lesions with intra-cytoplasmic inclusion bodies which are pathognomonic for clinical CDV infection. The secondary bacterial infection probably exacerbated the severity of CDV infection. The detected CDV strain in the recent infection is similar to previously described strain in wild carnivores suggesting that the virus is still circulating in an unknown reservoir within the Serengeti ecosystem.

Conclusion

From this study, it is not easy to draw up conclusion of the small pack sizes recorded during the diurnal random searches and reported by the respondents. However, some more in-depth information (pack recruitment and, birth and death rate within and among pack members) are required to explain the presence of the low population sizes. The information provided shows that the wild dogs in the LGCA are magnificent carnivores among others as they had not been sighted in the Serengeti National Park which has potential for tourists during the study period.

The findings indicate that the spatial distribution of wild dogs formed access for wild dog game viewing in the area by tourists. Although, the nature of the wild dogs to prefer more woodland habitat types may obscure the visibility of the animal when searched by the people. Also, the nature of protected areas (game reserves) allowing the co-existence of mankind and wildlife in the natural settings poses a challenge wild dogs sighting. Thus most of these sightings were not close to human settlement (i.e. in areas close to human settlement such Sonjo area less sightings were reported compared to Maasai area with a vast land unoccupied by humans). In addition, the night transect surveys showed the presence of more sightings of small carnivores compared to large carnivores, suggesting that large carnivores were persecuted and as the result, they avoid human areas.

In terms of attitudes of communities towards wild dog conservation much need to be done to improve coexistence between human and wild dogs. Most likely the tendency of local communities to dislike the presence of this endangered species on their land is not promising for the species future survival. Since, there is no effort in place to conserve the species by the communities there is no hope for the sustainable utilization of the species in order to improve the community livelihood.

Most of the threats faced by wild dogs in this study are hazardous to the future survival of the species. The combination of poisoning and diseases is a great challenge to conserve the species in the area. This is contributed by the nature of the species behavior as they range widely and make it easier to continue contact with human activities which may lead to conflict with the wild dogs as the result of persecution may increase. In terms of diseases, wild dogs range widely and they are exposed more to disease transmissions such as CDV and rabies when affecting the pack.

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