14 The Impact of Cyclone Idai on Natural and Plantation Forests in the Eastern Highlands of Zimbabwe

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Abstract

The Eastern Highlands of Zimbabwe is home to a unique floristic diversity, which include exotic plantations of pines and eucalyptus, natural moist forests and dry forests. We assessed the impact of tropical cyclone Idai on natural and plantation forests. Normalized difference vegetation index (NDVI) was used to determine the changes in forest conditions. We also conducted a questionnaire survey in the study area to elicit perceptions of key informants. Results show a decrease in the NDVI values during the month of the cyclone. Results from surveys indicated that the impact of the cyclone varied across locations, with the relatively low altitude (≤1400 m.a.s.l.) areas being the most affected compared to higher altitude (>1400) sites. The impact of the cyclone was more on pines compared to eucalyptus species. *Pinus tecunumanii* had the largest proportion (expressed as % of total volume damaged) of 37% followed by *P. kesiya* (16%) and lastly *P. maximinoi* (12.3%). Our results indicate that plantation species responded differently to the impact of the cyclone and that low elevation sites suffered more impact than high elevation areas. We conclude that silvicultural management could provide cues for mitigating the impact of cyclones in plantation species.

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Keywords

Plantation forests · Natural forests · Cyclone Idai · NDVI · Eastern highlands

14.1 Introduction and Background

Tropical cyclones are extreme weather occurrences capable of causing human and animal fatalities and produce huge economic, environmental and social losses when they make landfall (Lugo, 2008). Most of the damages from tropical cyclones occur due to strong winds with high speeds and excessive rainfall totals which are also used to rank cyclone intensity (Bhowmik & Cabral, 2013). Depending on magnitude, tropical cyclones can have a long-term impact on forest structure, particularly on stem density, canopy structure and basal area of different forest types (Ibanez et al., 2018). Studies on the impact of cyclones on a global scale also indicate that

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tropical cyclones can also cause long-term disturbances to composition, structure and functioning of ecosystems (Le Page, 2016; Ibanez et al., 2018). However, the intensity of impact caused by cyclones on vegetation and forests has been shown to be strongly correlated with abiotic environmental factors such as soil type and topography (Suvanto et al., 2016). Research has shown that forests situated in high elevation areas and on windward slopes are more susceptible to damage by cyclones due to wind exposure, which causes tree mortality (Boose et al., 2004; Cortes-Ramos et al., 2020).

Remote sensing has been reliably used as a methodology for assessing the impact of cyclones at large spatial scales (Lee et al., 2008; Wang and Zhou, 2013; Negron-Juarez et al., 2014; Cortes-Ramos et al., 2020). Moderate Resolution Imaging Spectroradiometer (MODIS), Landsat data and vegetation indices such as normalized difference vegetation index (NDVI) derived from satellite imagery have been used in the assessment of disturbance patterns of forest disturbance post cyclone occurrence (Cortes-Ramos et al., 2020). Abbas et al. (2020) used NDVI satellite imagery data to assess the impact of a super-typhoon on secondary vegetation in Hong Kong and established that monoculture plantations in high and low elevation areas were severely affected by cyclones compared to open shrubland, open forests and grasslands.

In Zimbabwe, the forestry industry and its value chain, together with other related industries such as tourism, are key sectors that can potentially boost its economy and help in achieving sustainable development. The commercial forest plantation industry has historically been the mainstay of economic activity and the biggest employer directly and indirectly in Zimbabwe's Manicaland province. At its peak in the late 1990s, the industry directly employed 14,445 people and over 40,000 indirectly in downstream industries contributing 3% to the GDP (Forestry in South Africa, 2017). It has also been argued that the contribution of the forest sector to the national economy has been to a large extent under-valued because of the unobtainability of statistics from the informal sector which is significantly big in Zimbabwe (Mabugu & Chitiga, 2002).

On 14 March 2019, tropical cyclone Idai, with wind speeds of over 170 km/h and rainfall of up to 1000 mm in 24 h (category 4 cyclone), made landfall in Beira. The cyclone-affected parts of Malawi, Mozambique and eastern Zimbabwe with the Chimanimani district were the hotspot of impact. Tropical cyclone Idai left over 1000 people dead across the three countries, hundreds missing and along its path were economically, socially and ecologically important forests plantations and estates (RINA, 2019). Most studies done on the impacts of extreme external perturbations such as tropical cyclones on forests have focused mostly on coastal forests that are always the first to be hit by such events. The frequency and intensity of these tropical cyclones has been observed to be on the increase and are starting to hit further inland forests and plantations (Hoquea et al., 2017). The increasing frequency of these cyclones in the Eastern Highlands of Zimbabwe, which hosts high value forest plantations and a number of important forest biodiversity hotspots such as Vumba, Haroni and Chirinda rainforests, poses serious problems for forest management from the perspective of commercial plantations and forest biodiversity conservation programmes in general. However, there is no adequate risk and disaster management strategies in place in the local environment sector to mitigate against the increasing frequency and impact of such adverse weather phenomenon, despite cyclone Idai not being the first disaster to affect Zimbabwe (Chatiza, 2019; Chatiza & Manatsa, 2019). In-depth understanding of the pattern and intensity of disturbances on forest ecosystems caused by tropical cyclones is a critical step towards designing better management strategies. This is more so, especially in the wake of an observed increasing global trend towards enhanced demand for timber from tropical plantations (Varmola et al., 2005). Improved management practices will help in decreasing the vulnerability of livelihoods that depend on forest goods and services, especially the poor. It will also preserve the current potential of tropical forests as carbon sinks hence helping in the mitigation of the impacts of climate change (Hall et al., 2020). For forest and plantation experiencing episodes of tropical cyclones, studies of their role on ecosystem processes and patterns are a requisite for an in-depth understanding of ecosystem structure and dynamics (Chu, 2014).

With a special focus on tropical cyclone Idai on the Zimbabwean side, the chapter aims at unravelling the impacts of the tropical cyclone on natural and plantation forests. Specifically, the chapter aims at answering the following questions: How were forests and plantations impacted by the cyclone? What were the short-term impacts of the cyclone on canopy structure and tree mortality? What were the differential responses between tree species (floristic taxa) to the impacts of the cyclone? What were the impacts of the tropical cyclone on plantation and forest ecosystem productivity? By assessing the impact of cyclone Idai on forest ecosystems using a remote sensing methodology, the study contributes to a better understanding of how existing geographical conditions in the Eastern Highlands of Zimbabwe can inform adaptation and mitigation strategies for developing more resilient ecosystems to safeguard against losses in huge forest investments especially in the plantation forest sector.

14.2 Literature Review

The destruction and disturbance of forests and plantations by tropical cyclones has got a direct bearing on the achievement of the 2030 Agenda for Sustainable Development in the affected areas. Forest and plantation ecosystems specifically relate to sustainable development goal (SDG) 15 which seeks to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combating desertification and halting and reversing land degradation and biodiversity loss (UN, 2015). Target 15.1 of SDG 15 specifically encourages that by 2020 there should be conservation, restoration and sustainable utilization of terrestrial and inland freshwater ecosystems that include forests, wetlands and mountains (Inter-agency and Expert Group on SDG Indicators-IAEG-SDG, 2019). Target 15.2 further promotes by 2020, the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation (ibid). SDG 6 also links directly and indirectly with the other 16 SDGs since they are integrated and inseparable balancing the three pillars of sustainable development. For example, conservation of forests links well with SDG 13 which deals with climate action since they constitute a significant carbon sink. Forests and plantations also provide ecosystem services that can be regarded as being key in supporting livelihoods of local communities, for example SDG 1 and 2 which deal with eliminating extreme poverty and hunger.

14.2.1 Impact of Cyclones on Natural and Planted Forests

The frequency and intensity of tropical cyclones is projected to be on the rise as a result of the increasing warming of sea surface temperatures due to climate change (Teng-Chiu et al., 2020). Tropical cyclones are therefore considered among the most important disturbance agents that cause economic losses and substantial damage and disturbance in forests (Suvanto et al., 2016; Latifah et al., 2017; Hall et al., 2020; Taylor et al., 2020). Tropical cyclones can affect tree species composition, succession, structure and subsequently impact on terrestrial carbon sequestration (Boutet & Weishampel, 2003). Noticeable effects of cyclones on both natural and planted forests include direct damage to the stem, branches and foliage of trees and at times complete uprooting of trees (Turton, 2008; Ibanez et al. 2019). According to Taylor et al. (2020), forest tree species composition is a major determinant of different types of disturbances that affect forest ecosystems. The associated disturbances to forest ecosystems can also intensify vulnerability to other disturbances such as wildfire, landslides, soil erosion and insect pests (Vozmischeva et al., 2019; Krauss & Osland, 2020). For example, increases in tree mortality due to tropical cyclones may lead to massive conversion of living biomass to dead fuel load that may increase the risk of wildfires in forest ecosystems as well as reduced capacity of the forest to act as a carbon sink after salvage logging (Vozmischeva et al., 2019). Severe storms in Germany in the 2004/05 season affected forests in national parks leading to a severe bark beetle outbreak (Muller & Job, 2009). Such interactions between extreme climatic events and forest response need to be understood further given the importance of forests.

14.2.2 Differential Responses Between Tree Species (Floristic Taxa) to the Impacts of Cyclones

The selective damage caused by the disproportionate effect of cyclones on big trees results in lower canopies and higher stem densities (Ibanez et al., 2019). Natural forests are generally regarded as more tolerant to disturbance from a number of natural agents (including cyclones) compared to planted exotic forests (Gadgil & Bain, 1999; Abbas et al., 2020). Contributory factors to native species' tolerance to disturbances are largely attributed to adaptability to local climate and abiotic conditions which enhances chances of native species to better survive disturbance compared to exotic monocultures (Abbas et al., 2020). To support the hypothesis of differential responses between species, studies in the Caribbean have shown that there is a negative relationship between wood density and cyclone-driven tree damage (Zimmerman et al., 1994; Van Bloem et al., 2006; Teng-Chiu et al., 2020). High wood density hardwood species which comprise of a wide range of native tree species and a few commonly planted exotic species such as the eucalyptus are expected to withstand cyclone damage better than softwood species such as conifers (pines) which are generally characterized by low wood density. The local commercial plantation forest statistics in Zimbabwe indicate that pines constitute about 70% of the plantation species in the commercial plantation forestry sector (TPF, 2019). Such species composition leaves the local plantation forest sector more vulnerable to severe damage in the event of a cyclone. Chu (2014) has however observed forest ecosystems to be complex, adaptive and undergo change due to continued physical and biological disturbances. This then brings about the importance of understanding how these ecosystems maintain equilibrium within the system boundaries after disturbances. According to Hall et al. (2020), forests established in high elevation areas are more prone to damage from the effects of cyclones due to the association of high elevation landscapes with high rainfall and strong winds.

14.2.3 Impacts of the Tropical Cyclone on Plantation and Forest Ecosystem Productivity

The primary purpose of most plantations is for harvesting timber for use in various purposes, which include construction where it is used as round poles, or rough sawn timber. Cyclones can impose huge losses in terms of timber quality through stem breakages, which render the timber not fit for purposes. For example, in 2005, hurricane Katrina caused a total loss of 2.23 million ha of timber in the four coastal states in the United States estimated at between $1.4 billion and $2.4 billion (Stanturf et al., 2007). Tropical cyclone disturbances have a direct impact on forest ecosystem productivity. Tropical cyclones impact on ecosystem goods and services such as fruits, medicines, recreation, and aesthetic value derived from both native and planted forests. According to Hutley et al. (2013), disturbance as a result of cyclones occur over large areas leading to forest ecosystem carbon dynamics arising from spatial and temporal mosaic of carbon sources and sinks. To illustrate the magnitude of forest disturbances by cyclone, a case study of the impact of hurricane Katrina on the Gulf Coast forests in the United States showed that a total of 105 tera grams of carbon, equivalent to the net annual United States carbon sinks, were lost as a result of a single disturbance (Chambers et al., 2007). Ecological models for assessing forest disturbances indicate that high levels of forest disturbance by cyclones affect regenerative capacity of a forest, which leads to suppressed recruitment and growth of woody components (Werner & Prior, 2013; Hutley et al., 2013). Net primary productivity (NPP) is one of the commonly used indicators for assessment of tropical cyclones on forest ecosystem productivity. Research conducted in Florida on the impact of hurricane Wilma showed that NPP losses as a result of defoliation ranging from 5.53 to 7.84 Mg C ha^{-1} $year^{-1}$ were recorded (Tess et al., 2017).

14.2.4 Remote Sensing as a Tool for Assessing Cyclone-Induced Damage in Forests

Field-based methods for assessing the damage imposed on forest and plantation ecosystems by tropical cyclones are both expensive, time consuming and rarely have the required before impact data (Hoquea et al., 2017). Remote sensing has evolved as an effective tool for monitoring and analysing changes in forested areas due to tropical cyclones disturbance (Hall et al., 2020). The main advantages of using satellite remote sensing are that it enables the observation of forests in places where human access is limited; it gives the state of the forests before and after the tropical cyclone impact and availability of sensors with both high spatial and temporal resolutions (Wang et al., 2010). This enables efficient damage assessment and identification of disturbance hotspots within forests and plantations. MODIS and Landsat are some of the remote sensing tools that have gained wide recognition in the study of the impact of cyclones (Negron-Juarez et al., 2014).

This literature review provided an overview of how biotic factors such as tree species attributes and abiotic factors such as topography and silvicultural conditions determine the impact of cyclones on forests and forest ecosystems. This theoretical basis from literature provides an important basis for understanding how forests ecosystems adapt to disturbances over time.

14.3 Materials and Methods

This section provides an overview of the study area and details on the tools used in the collection and analysis of data.

14.3.1 Study Area

Figure 14.1 shows the study area, mainly the eastern districts that have forests and plantations affected by tropical cyclone Idai. The eastern parts of Zimbabwe close to the border with Mozambique were the most affected by tropical cyclone Idai. These include the Mutare, Chimanimani, Mutasa, Nyanga and Chipinge districts. The study area has got a combination of both exotic and natural forests and plantations. Forestry and tourism are the mainstay of the local economy, and the forest estates in the area include: Martin, Lionhills, Chisengu, Tarka and Glencoe Forest Lands administered by the Zimbabwe Forestry Commission. Others include Vumba North and South, Banti, Bonga, Rusitu, Selbourne, Mtarazi, Mukurupini, Chirinda, Ngungunyana, Silver streams and Charter forests.

The individual forest establishments range in size from less than one hectare to thousands of square kilometres in size. The plantations are made up of exotic species of pines, eucalyptus and the black wattle and used mainly to produce timber, poles, pulp, paper, tannin and furniture. Natural rainforests occur at the Vumba, Rusitu and Chimanimani mountains with the Chirinda forest in Mount Selinda, Chipinge being the southernmost rainforest in Africa. The main summer rainfall season is from October to March but on the high mountains can occur throughout the year. Annual rainfall totals range from 1500 to 2000 mm/year. The dry season is not as marked here as it is on the other parts of Zimbabwe.

14.3.2 Methods

The study used a mixed methods approach using remote sensed data and surveys (key informants and questionnaire) supported by post cyclone

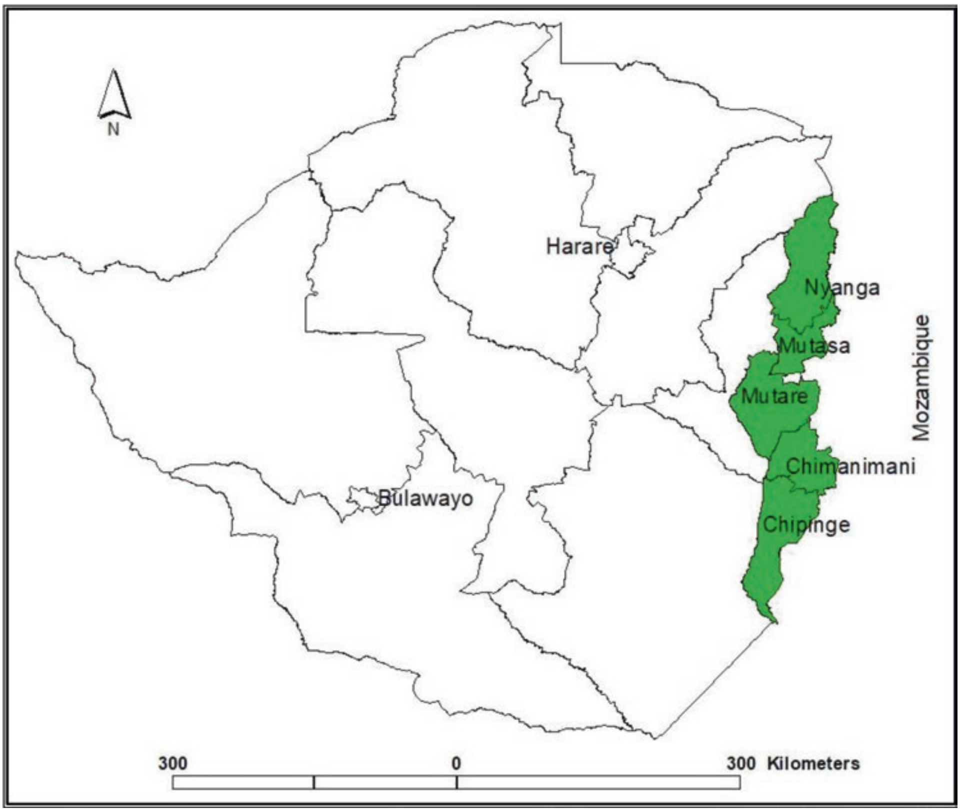

Fig. 14.1 Study area
Source: Authors

assessment data collected by the Forest Research Centre in the field. MODIS satellite was used in the study to determine the level of disturbance of forests and plantations before and after the tropical cyclone. Decadal normalized difference vegetation index (NDVI) composites for the affected forests were derived from time-series MODIS imagery of the area for the 2018/2019 season. Decadal NDVI composites average the condition of vegetation in an area over periods of 10 days throughout the season. Sudden disruptions in vegetation productivity can be observed by sudden reductions of NDVI values over a decad. The chosen downloaded wavebands were those in the red and near-infrared (NIR) category of the electro-magnetic spectrum. The wavebands have a spatial resolution of 250 m*250 m. The MODIS sensor was chosen because of its high temporal resolution, which makes it easy to detect changes in vegetation over short periods of time.

NDVI was used to determine the changes in forest conditions before and after cyclone Idai (Eq. 14.1). NDVI is the most widely used vegetation index for ecosystem monitoring and multi-temporal changes in vegetation structure. NDVI calculations are useful for classifying land cover and detecting the dynamics of vegetation (Running, 2007). NDVI was chosen for the study because it is less affected by topographical factors and illumination than other vegetation indices (Riera et al., 1998). The NDVI was computed as:

$$\mathrm{NDVI} = \frac{\mathrm{NIR}\sigma - \mathrm{Red}\sigma}{\mathrm{NIR}\sigma - \mathrm{Red}\sigma} \qquad (14.1)$$

where NRIσ and Redσ represent the reflectance in NIR and Red wavebands, respectively (Abbas et al., 2020). The NDVI values range from −1.0 to 1.0, with high values related to high levels of live photosynthetic and healthy vegetation and lower values associated with sparse vegetation or unvegetated areas. Negative values mainly represent snow or water; thresholds close to zero mainly represent bare areas, sand and rocks. NDVI values between 0.2 and 0.3 represent shrub and grasslands while values from 0.6 to 0.8 indicate thick forests.

3D satellite images for Forest Research Centre's research sites were downloaded using Terrain2STL online software application. The latitude (19°48′ 0.00″S) and longitude (32°52′0.01″E) for Chimanimani was used in the Terrain2STL application to locate Chimanimani on Google Map and then zoomed to the individual Forest Research Centre's (FRC) research sites namely Cashel, Chisengu, Martin and Tarka forests. Site elevation details (altitude) used in the analysis were also obtained from Terrain2STL.

A questionnaire survey was also carried out in the Chimanimani and Chipinge districts to access the opinions of respondents on the impact of the cyclone on forests and plantations. Purposive sampling was used to recruit participants of the questionnaire and targeted households that had been impacted by the cyclone. A total of 219 questionnaires were administered. In-depth interviews with key informants as well as direct field observations were also used to gather additional information on the impact of the cyclone on the forests in the area. Key informants included officials from the Forestry Commission of Zimbabwe, Local Traditional Leadership, Environmental Management Agency and Agricultural Extension Workers. They provided a chance to validate the information obtained from remote sensing and also to gather additional information difficult to obtain from Earth observation data. Data triangulation was further achieved through data sourced from the Forest Research Centre on their assessment of extent of damage caused by cyclone on their research trials.

14.4 Findings

This section presents results from the study. It shows how the forest landscape in the study area was affected by cyclone Idai from a remote sensing perspective using NDVI and also from an observation data in the field which shows how plantations and natural forests were impacted by the cyclone. The section is organized as follows.

Firstly, a presentation of a general overview of the impact of cyclone Idai on forest cover using NDVI to show changes in vegetation cover before, during and after the cyclone period is provided. It also presents findings from empirical data collected by the FRC showing how plantations (represented by various research trials across FRC research sites) were affected by cyclone Idai. Secondly, the section presents qualitative data from interviews and questionnaires administered to respondents in the study area to provide perceptions of respondents on the impact of the cyclone on vegetation and forest resources. These findings are then discussed with reference to literature and experiences from similar extreme weather occurrences in other parts of the world.

14.4.1 Normalized Difference Vegetation Index

Figure 14.2 shows average decadal NDVI values for forests in Chimanimani, Nyanga, Chipinge and Mutare districts in the 2018/2019 season. For all the districts, the second decad of March 2019 showed a sudden decline in NDVI values. This shows that there was a sudden disturbance to the forests in these areas given the fact that all had been showing progressive increases in biomass from December 2018. The sudden drop in biomass in the second and sometimes third decads of March 2019 also coincided with the occurrence of cyclone Idai and its aftereffects.

The biggest drop in biomatter was recorded in the Chimanimani district where NDVI values fell from 0.73 to 0.62 for the second and third decads of March 2019. A drop of 0.11 in the value of NDVI may seem small, but on the ground it signifies a significant decline in biomatter and productivity. This is because the relationship between NDVI and vegetation productivity is not linear but exponential. The vegetation showed some signs of recovery in the last decad of March and in the first decad of April but never recovered to cyclone pre-impact levels. All other districts as

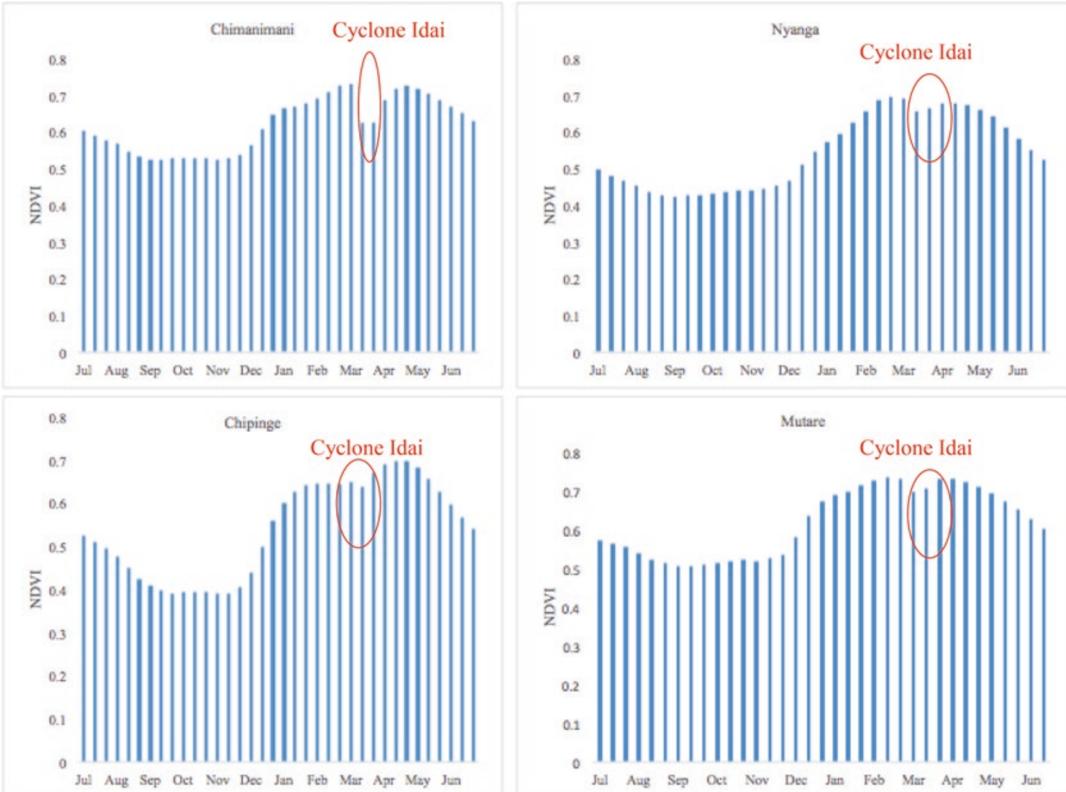

Fig. 14.2 Decadal NDVI values for Chimanimani, Nyanga, Chipinge and Mutare forests in the 2018/19 season
Source: Authors, data from MODIS images

shown in Fig. 14.2 show a similar pattern except that the reduction in biomatter was not as great as the one observed in Chimanimani. The least drop in forest damage was observed in Chipinge where there was a slight drop in the second decad of March 2019.

14.4.2 Impact-Location Differentiation and Cross-Location Analysis

Results across the Forest Research Centre's five research sites indicate that the impact of the cyclone was not uniform across research sites (Table 14.1). More field trials were damaged in Tarka (with 6 out of 11 trials) and Cashel research sites (with 4 out of 9 trials) having been damaged, while Ngungunyana and Chisengu had fewer trials damaged. Martin research site had no trials damaged.

Figure 14.3 shows that the variation in altitude across the sites might have mitigated the impact of the damage on research trials. Martin research site, which has the highest altitude of 1800 m.a.s.l., had no trials damaged while the other sites with slightly lower altitude had more trials damaged. The altitude range for trials at Tarka with the highest number of trials affected ranges from 1200 m.a.s.l. to 1600 m.a.s.l. while that of Cashel with the second ranking damage impact has an altitude range of 1400 m.a.s.l. However, for Cashel the trials are located mostly in the lower altitude range of 1400 m.a.s.l. Martin forest is situated towards the Mozambican side of Chimanimani but on leeward side which protects the site from the strong Mozambican winds unlike with Tarka which is on the windward side of the Mozambican air current. This probably

Table 14.1 Extent of cyclone damage in the five research sites under the Forest Research Centre

	Status						
	Damaged				Undamaged		
Site	No. of trials damaged	Area (Ha)	Mean age (years)	Volume (m^3)	Area (Ha)	No. of trials	Mean age (years)
Cashel	4	11.42	28.5	1852.2	16.11	5	30.2
Ngungunyana	1	1	36	200	32.61	8	25
Chisengu	2	4.9	36	200	21.79	10	11.3
Tarka	6	14.73	32.3	1007.4	9.35	5	26
Martin	0	–	–	–	9.39	4	23.2
Total	**13**	**32.05**		**3259.6**	**89.25**	**32**	

Source: Authors, data from Forestry Commission of Zimbabwe

explains why there were no damages on trials at Martin. Although the lower altitude range for Martin research site is also 1400 m.a.s.l., the trials are mostly concentrated in the high-altitude range of 1800 m.a.s.l.

It was also observed by key informants that regardless of the tree species in the plantations, those that had just been thinned and pruned suffered more damage from the cyclone compared to those that were not. Figure 14.4 shows the extent of damage to natural forests and plantations by cyclone Idai as observed by the participants of the questionnaire survey. Close to 70% of the participants viewed the damage as being severe, while 18% indicated the damage as being moderate.

Key informants attributed most of the damage to high wind speeds, heavy rainfall and landslides that were induced by the tropical cyclone. Most of the damage that occurred on commercial plantations was due to windthrow, which resulted in trees being uprooted or broken by wind action with the breakage occurring on the tree bole (trunk).

Most of the participants observed a similar extent of damage between exotic and indigenous tree species (Fig. 14.5). This was highlighted by about 62% of the participants, who highlighted that as long as the forest was in the path of the impact, the damage was not significantly different between native and indigenous forests. Damage was mostly done on trees and forests on or below areas that had slope angles ranging from 65° to 85°. These slopes mostly collapsed and triggered landslides which destroyed everything on their path. It was however noted that very few places afforded the participants a chance to compare the differences in damages between exotic and indigenous tree species because most places have only one type of forest not both. Close to 15% (Fig. 14.5) of the participants viewed indigenous forests as being the most damaged. These singled out riverine forests as being the most damaged as they were located close to rivers which flooded, widened and in the process carried huge boulders that decimated riparian forests. About 10% observed the exotic forests to be impacted the most by the tropical cyclone. These were mostly participants from the commercial farming areas and forest estates. They observed that in total 1009 hectares of exotic wattle, gum and pine plantations were completely destroyed during tropical cyclone Idai.

14.4.3 Silvicultural Aspects of the Forest Ecosystem (Composition, Health and Quality of Forests)

Figure 14.6 shows the size of trees observed by the participants to have been damaged more within forests during cyclone Idai. About 59% of the participants highlighted that trees of all sizes and age where equally damaged during the tropical cyclone Idai. Close to 26% of the participants

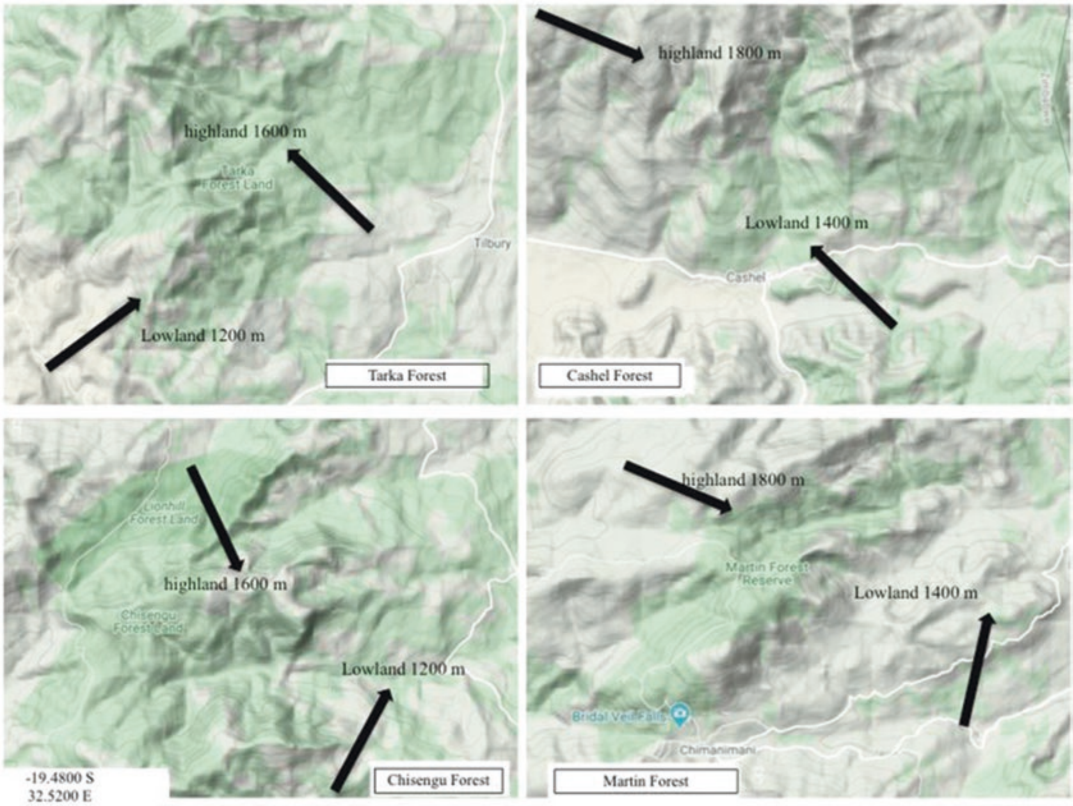

Fig. 14.3 Raised Relief Maps showing spatial distribution of forest plantations and research trials in four sites namely Tarka Forest (top left); Cashel (top right); Chisengu Forest (bottom left) and Martin Forest (bottom right)
Source: Authors

highlighted that it was mainly the older trees that suffered as a result of the cyclone. Key informants highlighted that older trees usually are not flexible enough to bend and twist without breaking when compared to the younger tree; hence, they were more vulnerable to windthrow during cyclones. At Rathmore estate, for example, close to 30 ha of mature pine which was ready for harvesting was completely destroyed by landslides and also washed away by flowing flood waters. The small- and medium-sized trees were not much affected by the cyclone except for those close to flooded river systems. The wind did not do much damage to them because of their flexibility and ability to get back to their position after bending and twisting.

The Forest Research Centre trials in Muguzo (in Chimanimani) also experienced damage to various levels on pine and eucalyptus species. *Pinus tecunumanii* accounted for the highest volume of damaged trees with 37.4% of the total volume of trees damaged, followed by *P. kesiya* (16%) and *P. maximinoi* (12%). *Eucalyptus grandis* and *E. maculata* suffered more damage in the eucalyptus category. The mean age of damaged trials ranged from 11 to 38 years, with most of the trials affected being above 20 years of age. However, results also indicated that the majority of trials that remained undamaged by the cyclone were also above the 20-year age range. Table 14.2 shows the impacts of cyclone Idai damage on research compartments in Muguzo Research Station in Chimanimani.

The most severely damaged indigenous forest in the study area was the Marirwa forest. The damage was mostly for trees within the waterways and those on slopes affected by landslides. The forest suffered more damage compared to

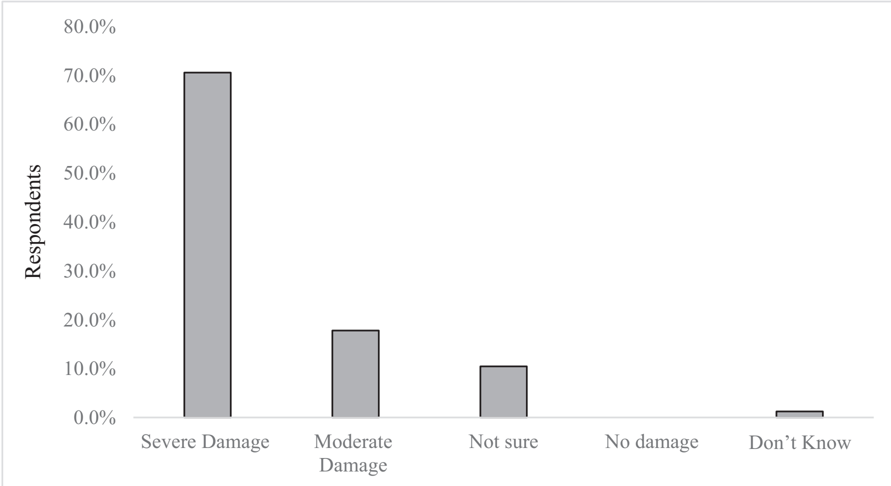

Fig. 14.4 Perceptions of respondents on the extent of damage on trees
Source: Authors

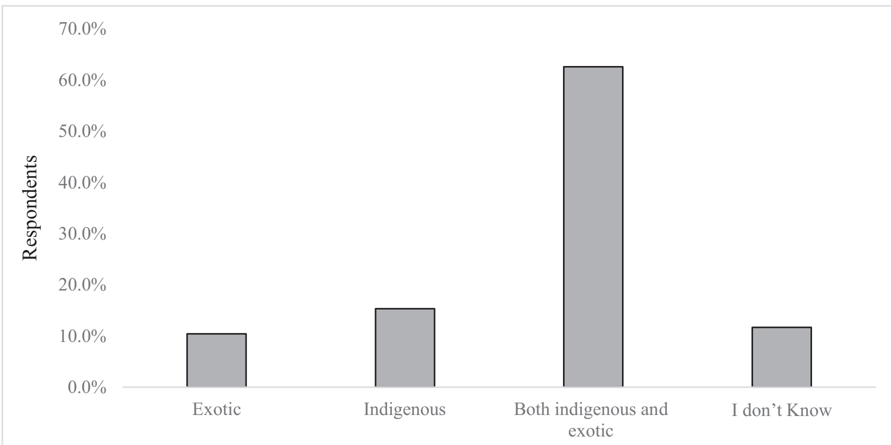

Fig. 14.5 Perceptions of respondents on the damage caused by cyclone on native trees as compared to exotic trees
Source: Authors

other indigenous forests like Chirinda rainforest and Bonga and Rusitu because it is mainly located on steep slopes which suffered mass movement. Most key informants observed the greatest damage on indigenous forests as having occurred along the river courses. Most rivers especially in Chimanimani widened up to contain the huge volumes of water which were intermixed with boulders. Of note is the fact that most riverine forests suffered close to 90% damage, and there is a high probability of having lost most of the endemic tree species in the process. Some of the most wiped-out trees include the *Syzygium guineense* or waterberry, and the most resilient tree within riverine forests include the *Ficus sycomorus* (sycamore fig) and the *F. chirindensis* (Chirinda fig) all of which have long root systems that can grow up to 50 m.

Canopy structure damage was observed to be minor for indigenous tree forest when compared to exotics and even more critical was the damage on the thinned plots compared to those not

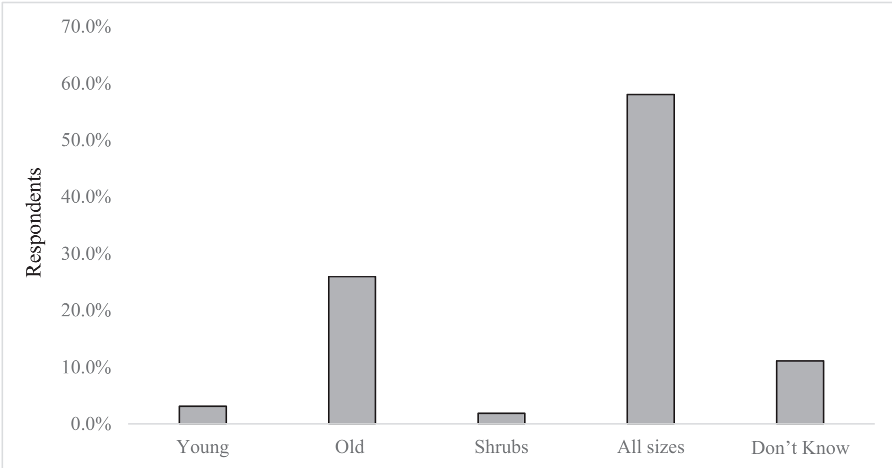

Fig. 14.6 Sizes of tree mostly damaged
Source: Authors

thinned. Indigenous trees generally have lower canopies which extend horizontally as an adaptation to wind damage; hence, this probably explains the low impact experienced on indigenous trees compared to exotic species with high, vertically extending canopies. Indigenous trees in the area include the *Brachystegia spiciformis* (Musasa) and the *Julbernardia globiflora* (Munhondo) and muuzhe (*Brachystegia tamarindoides*) survived though damaged. Figure 14.7 shows some of the observed damage on forests in the Chimanimani district due to windthrow, river widening and landslides.

14.4.4 What Were the Impacts of the Tropical Cyclone on Plantation and Forest Ecosystem Productivity?

Tropical cyclone Idai did not only damage the physical forests, but washed away access roads leading to the plantations , and in the process reducing the chances of salvage operations to recover wood from the damaged forests. The culverts and drainage systems within the forest estates were also destroyed and, in some cases, huge gulleys were formed bringing the need for expensive environmental restoration to prevent further degradation to the environment. One of the largest sawmills in the country at Rathmore estate was completely washed away during the cyclone and nothing from it was recovered; hence, timber producers who were using it found themselves travelling longer distances to process their harvest. Access to markets for processed timber was also not possible because the area had been cut off from the rest of the world through a series of damaged bridges and roads. The damage done by the cyclone to the forest and related infrastructure left the industry and ecosystems vulnerable to further damage if similar or even less magnitude events occur in future.

Equally affected by the cyclone and the damage it induced on forests were the livelihood of hundreds of local community members who relied on beekeeping and honey production. Most of the respondents noted a significant decline in the population of bees and the amount of honey produced after the impact of the cyclone. Some of the key informants argued that most of the trees providing the flowers and nectar for bees to produce honey were significantly damaged by the cyclone.

Table 14.2 Effect of cyclone Idai damage on research compartments in Muguzo Research Station

	Status						
	Cyclone-damaged trials				Undamaged trials		
	Mean				Mean		
Species	Area (Ha)	Age (Years)	Volume (m^3)	% Volume	Area (Ha)	Age (Years)	No. trials
E. citriodora	–	0	–	0	6.3	34	1
E. cloeziana	1.18	2.5	82.6	2.5	–	–	0
E. grandis	1.97	10.0	324.7	10.0	2.96	33	2
E. maculata	2.53	5.4	177.1	5.4	2.53	33	1
E. pyrocarpa	–	0	–	0	2.54	25.5	4
E. saligna	–	0	–	0	3.17	24	1
E. pilularis	0.55	3.6	116.2	3.6	3.19	22.67	3
Liquidambar stryaciflua	4.71	9.4	306	9.4	–	–	0
P. kesiya	4	16.0	520	16.0	1.89	38	1
P. elliottii	–	0	–	0	1.02	33	1
P. greggii	–	0	–	0	2.61	24	1
P. maximinoi	1	12.3	400	12.3	3.25	5.5	5
P. patula		0		0	1.79	32	5
P. oocarpa	1.32	3.4	112.2	3.4	–	–	0
P. taeda	–	0	–	0	1.86	33	1
P. tecunumanii	2.03	37.4	1220	37.4	4.67	19.67	7
TOTAL				100			**32**

Source: Authors, data from Forest Research Centre Cyclone Damage Assessment Report

14.5 Discussion

In this section, we discuss the findings on the impact of cyclone Idai on natural and plantation forest ecosystems. We begin our discussion by a focus on what lessons can be learnt for forest management with regards to mitigating impacts of cyclone damage and associated natural disasters such as strong winds which can cause serious negative impacts, particularly on planted forests by virtue of them being subject to intentional or deliberate design. A number of silvicultural operations such as thinning on spacing management and site species matching are designed to achieve maximum productivity in plantation forestry. These same practices can also be employed to mitigate risk from natural disasters such as cyclones. We then centre our discussion on the impacts caused by Cyclone Idai on productivity of forest ecosystems, however without dwelling much on detailed economic aspects as this is beyond the scope of this study. We consider the role of both planted and natural forests as carbon sinks an important ecosystem function that is under the spotlight in view of the disturbances by cyclone Idai. Large tracts of undisturbed woodland or forest have potential for climate change mitigation under the Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiatives which are being promoted locally by various donor organizations in partnership with the government of Zimbabwe. Exotic plantations have also been indicated to be potential carbon sinks as they sequester significant amounts of carbon as standing trees before they are felled into timber where they also continue to lock carbon for long periods of time (Montagnini & Porras, 1998; Liao et al., 2010; Moroz et al., 2020). We conclude our discussion by focusing on how the cyclone impacted on a pertinent aspect of forest productivity which is germplasm for forest regeneration which was affected by the cyclone. We discuss this in the context of forest management, particularly in the plantation forest sector.

Fig. 14.7 Forest damage due to windthrow, river widening and landslides
Source: Authors

14.5.1 What Lessons Can Be Learnt for Forest Management?

The high tree mortality observed in research trials could be attributed to a number of factors. One of the factors relates to the attributes of plantation species derived from silvicultural management practices that are meant to promote fast growth rates to achieve high gains in height and volume in shorter rotations (Jacobs et al., 2004; Rossi et al., 2017). However, some of these gains from silviculture such as high (vertical) forest canopy structure can make trees more prone to wind damage. Wind damage occurs 'when the overturning moment caused by the wind exceeds the maximum resistive moment that the tree can provide' (Moore & Somerville, 1998: 27). An explanation to our results which show that pines, for example *P. tecunumanii*, were more prone to damage than eucalyptus, can be derived from the genetic attributes of some of these species in relation to wood density properties. Eucalyptus is in the category of hardwoods and generally has denser wood than pines which are in the softwood category. Therefore, their ability to withstand wind pressure would be different. Besides the type of tree under consideration, the impact caused by winds on trees is also related to topography, which has a strong bearing on airflow especially in mountainous terrain (Moore & Somerville, 1998).

P. maximinoi and *P. tecunumanii* are relatively fast growing species that have recorded impressive gains in volume and height attributes in research trials at the Forest Research Centre (Nyoka, 1994; Nyoka et al., 2010) Research findings on *P. maximinoi* in Zimbabwe indicate that it is well adapted to Chisengu conditions where it has performed well compared to other research sites in the country (Nyoka, 1994). This could further explain the trend observed from the results in the study (Table 14.2) which indicates more susceptibility to damage of these fast-growing species because of their height which exposes their canopies to the effect of high-speed winds. The intensive damage to these pine tree attributed to the fact that it becomes very brittle/inelastic when it matures, therefore vulnerable to windthrow during the tropical cyclone.

Although our study did not manage to obtain actual tree height and diameter measurements of the affected trees, literature indicates a strong correlation between tree size (diameter at breast height) and wind damage. A study by Rossi et al. (2017) indicated that trees with large diameters of between 70 cm and 90 cm are more prone to uprooting by strong winds compared to trees of a smaller size. Our findings from trees in research trials agree with these observations which show that most trials that were damaged by cyclone Idai were in the age range of 29–36 years compared to the age range of 11–30 years for the undamaged trials (Table 14.1). Thinning and pruning silvicultural operations which are conducted to maximize yield and quality of timber may also expose trees to wind damage during cyclones. Thinning regimes, especially at 50%, reduces the final standing volume (stems per hectare) and widens the inter-row spacing between stems resulting in free passage of heavy wind in the event of a cyclone; hence, more damage is likely to be encountered.

14.5.2 Effect of Cyclone Damage on Forest Productivity

The impact of cyclone Idai's trail of damage on forest productivity can be viewed from an ecosystem and an economic productivity perspective. From an ecosystem perspective, literature indicates that catastrophic events such as cyclone damages on plantations can have a beneficial contribution on forest biodiversity, for example by diversifying reptile and bat communities in exotic plantations (Kirkpatric et al., 2017; Jimenez et al., 2020). This is a beneficial ecosystem function that can be attributed on cyclones, especially in the plantation estates where there is a dominant monoculture of a few pines or Eucalyptus species. However, cyclones can also degrade another important ecosystem function of forests, that is, their ability to store carbon. A review of literature indicates that the role of plantations as carbon sinks is gaining more recognition despite their short rotations compared to their native species counterparts (Chang et al., 2017; Nguyen, 2017). From an economic perspective, the productivity of a natural or planted forest is mainly considered in terms of providing merchantable products such as wood and non-wood products. In terms of wood products such as timber harvesting, the effects of cyclones are not desirable as they cause economic losses.

14.6 Conclusions and Recommendations

Forests in the eastern districts of Zimbabwe showed disturbance due to tropical cyclone Idai. The hotspot of damage was in the Chimanimani district. The extent to damage was observed to be severe for most forests. Both indigenous and exotic forest were damaged, but some species showed more damage compared to others. The pine plantations and the riverine forests were the most damaged and landslides caused the most damage to indigenous forests than windthrow. All sizes of tree suffered damage, but the mature ones suffered more compared to the younger trees.

From the study, it is evident that the impact of cyclone Idai on the forests and the forest sector is multi-dimensional. The productive capacities of the forests both in terms of meeting ecosystem and socio-economic demands were negatively impacted. Enabling services of the Forest Research Centre to the plantation forest sector were also negatively impacted by cyclone Idai, to the extent that long-term shortages of germplasm for certain plantation species is likely to persist in the short to medium term. Although the impact was huge, important lessons were also learnt in terms of how silvicultural management aspects can provide insights on managing future natural disasters. Canopy structure, tree size and topography are important factors to consider in building resilience and spreading risk from cyclone damage particularly in the plantation sector. Another important lesson is that the cyclone damage in the natural and plantation forest has deposited a huge fuel load, which if not properly managed may increase the risk of fires, further worsening the woes on the already ailing sector. Fire management plans need to take into consideration the surge in the fuel load and develop suitable mitigatory measures.

In the light of the results, several recommendations can be made. There is need for a proper quantification of biomass and carbon stocks of the natural forest ecosystems in the Eastern Highlands, particularly Chimanimani, to inform national climate mitigation and adaptation strategies which rely on such data. For example, the Low Emission Development Strategy (LEDS) and the Nationally Determined Contributions (NDCs) spearheaded by the Climate Change Department under the Ministry of Environment Climate Tourism and Hospitality Industries. Given the importance of forestry and plantations as an industry in Zimbabwe and their ecological significance, the sector will need external assistance if it is to fully recover from the impacts of the tropical cyclone. The industry will struggle to fund itself out of this damage given the fact that it was already in distress before the cyclone and that operations stopped for a while during the post disaster phase.

Given the fact that the forests are along a known cyclone path and once in a while they hit the area, the forestry industry must take necessary steps to adapt to extreme events. Cyclone Idai left the forests and plantations vulnerable to future extreme events and other external perturbations; hence, the industry has no choice but to be climate smart. It is recommended in terms of cultivation and drainage that there must be use of appropriate cultivation techniques for the soil and site conditions to ensure that there is adequate provision rooting depth of trees. We recommend the selection and planting of resilient tree species especially on areas facing the direction of the wind and careful thinning on exposed sites and sometimes practicing a non-thinning regime on sites vulnerable to windthrow. There is also need for avoiding excessive openings for roads, turning points and entrances within the forests.

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