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Master thesis

Mortality Dynamics Across Time and Site Class Gradient

Master in applied Ecology

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Abstract

Forest poses an important role by providing multiple ecological services such as regulating climate, recycling nutrients and carbon- storing etc. These services are highly dependent on the existing forest dynamics which is largely determined by tree mortality. Tree mortality is caused by many factors such as warming climate, drought, fire, competition, wind, pest attack etc. The study tries to aim of the study is to quantify and compare the rate of mortality across time on forest types of Norway. For this, secondary data from Norwegian National Forest Inventory data (2004 –2018); both plot and tree data were used for the study. The analysis was performed using R computing statistical tool. To be more specific, the mortality value was relative to the volume without bark was quantified on the base of DBH class, site index, volume, and basal area.

Based on the analysis, three dominant trees i.e. (spruce, pine, and common birch) are estimated to have the highest volume loss (mortality) of 4.12 m^3/ha with an annual mortality rate of 0.2753 m^3/ha /yr. This shows that the mortality rate is low compared to other European countries. While going through the stand types, spruce has the highest mortality rate 0.51 m^3/ha/yr, whereas pine and common birch have the mortality of 0.32 m^3/ha/yr and 0.24 m^3/ha/yr respectively. Considering the different factors, the annual tree mortality estimates that the decline of tree numbers is relatively in low rate in comparison to the European tree mortality rates). The mean DBH (17.4 cm), basal area (0.031 m^2) and volume for Pine dominated stands (237 m^3) is greater than spruce and birch dominated stands. The tree mortality at high site quality is over 0.6 m3/ha greater on average than medium and high site quality mortality volume. The high-quality site has an average of 2.68 ± 5.81 m^3/ha tree mortality, whereas, the medium and low site quality observed tree mortality of 2.09 ± 5.19 m^3/ha 1.88 ± 4.93 m^3/ha, respectively. The error bar on site quality over mortality shows that majority of stand volume over other site quality is significantly not different. Thus, further statistical analysis is required to identify the significance of the data on site quality in different stand types over mortality.

Key words: Forest Inventory, Stand Volume, Site quality, Tree Mortality, Forest.

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1. Introduction

Forest are dynamic ecosystems, contributing to the well-fare of the society by providing various important services categorized into three main types i) Provisioning services, constitute forest products such as food, fibre and water ii) Regulating services , includes regulating climate recycling nutrients, protection from the natural hazard like flooding and landslides iii) Cultural services, are not materialistic but very essential to the humankind such as recreation, enjoyment and spiritual and religious (Birkhofer et al., 2015; Haines-Young & Potschin, 2010; Massad et al., 2015; Mönkkönen et al., 2014). In addition, forests provide a shelter to a wide range of biodiversity (Zanchi & Brady, 2019) which, accounts for more than 80 % of the Earth's terrestrial biodiversity (Gardner et al., 2009). Similarly, the forests of Norway account for 2/3rd of terrestrial species including a large number of threatened and near threatened species (Bevanger, 2018). Therefore, forest are very important biological entity for the sustainability of the societies (Daniels et al., 2011). However, to maintain the forest sustainably it is important to understand the factors influencing the structure and function of the forest ecosystem. Among various other factors growth, regeneration, and mortality are the most significant process influencing the forest dynamics (Boyden, Binkley, & Shepperd, 2005; Moeur, 1993; Youngblood, Max, & Coe, 2004).

Tree mortality is caused by the result of various physiological, pathological and entomological processes (Sims, Mändma, Laarmann, & Korjus, 2014; Yang, Titus, & Huang, 2003). Warming climate, drought, fire, and wind are the abiotic factors and competition, pest attacks are some of the biotic factors that causes tree mortality (Brando, Oliveria-Santos, Rocha, Cury, & Coe, 2016; Heineman et al., 2015; Jolly et al., 2015; McDowell et al., 2018; Walton, Poudyal, Hepinstall-Cymerman, Gaither, & Boley, 2016). Likewise physical factors include wind, landslide, ice glazing or snow loading result in the long-term changes in the forest's structure and availability of resources(Lutz & Halpern, 2006). Mortality due to competition is more noticed in small trees (Hurst, Allen, Coomes, & Duncan, 2011) due to limited availability of the resources and high productivity (Ruiz-Benito, Lines, Gómez-Aparicio, Zavala, & Coomes, 2013) and also depends on the available biotic and abiotic factors (Wu, Franklin, Liu, & Lu, 2017). It is observed in Europe that 53% of the total tree mortality is caused by storm , 16% from fire, 3% from snow, 5% and 10% from the abiotic and biotic causes respectively and the rest 7% is from unidentified causes (Csilléry et al., 2017; Schelhaas, Nabuurs, & Schuck, 2003). Whereas, Franklin, Shugart, and Harmon (1987) recorded that 33-46% of mortality in conifer forests was result of wind related causes. Similarly Bashir and MacLean (2015) estimated 39-55% wind throw mortality in balsam fir Spruce stands. Furthermore, mortality increases with the age of the tree due to decreases in its physiological functions like photosynthesis and increase in respiration (Luo & Chen, 2011; Speckman et al., 2015). This signifies that tree mortality varies with environmental factors, species type and stand dynamics (Bashir & MacLean, 2015; Colford-Gilks, MacLean, Kershaw Jr, & Béland, 2012).

In addition, Site index is one of the major factors in determining the mortality of the forest (Fontes et al., 2003).Site index has a direct impact on the productivity and mortality of the forests (Aertsen, Kint, Van Orshoven, Özkan, & Muys, 2010). Better site condition has less mortality, rapid growth on the young forest, production of high timber volume and helps on yield modelling (Fontes et al., 2003; Yu et al., 2017). Along with this, a better understanding of the site index helps to improve the forest management (Bravo & Montero, 2001).Davidson, Gottschalk, and Johnson (1999) and Bontemps and Bouriaud (2014) provide the evidences that site index is an important factor for tree mortality which has directly impacted tree mortality by making both individual and whole stand vulnerable and cause mortality in large scale.

Tree mortality also plays an important role in the forest development and yield production (Adame, Del Río, & Cañellas, 2010). Most of the mortality is observed in mature trees (Coomes & Allen, 2007) , which reduces timber production (Anderegg, Kane, & Anderegg, 2013),. Bashir and MacLean (2015, p. 9) have also explained that mortality increased in older Balsam Fir dominated mixed wood and soft wood stands. Although tree mortality is economically undesirable but provides various ecological (Anderegg, 2013). Tree mortality has a special role in providing regeneration niches (Lawton & Putz, 1988) by creating gaps (growing space) (Adame et al., 2010; Trumbore, Brando, & Hartmann, 2015) and provides suitable seedbeds (nurse logs) and also help in exposing mineral soils (Lännenpää, Aakala, Kauhanen, & Kuuluvainen, 2008). Tree mortality has a significant role in shaping forest structure by contributing deadwood, affecting light and nutrients availability(Bashir & MacLean, 2015; Ruiz-Benito et al., 2013). Therefore, it is important to quantify mortality losses because tree mortality has the direct impact on the timber production and alter ecosystem services and forest dynamics. It will be helpful for the policy maker and new researcher. This will also be useful to the practitioner working with promoting and protecting forest. Along with this, this will be helpful in the managerial aspect of the forest. In addition, Climate change is already evident (Karl, Melillo, Peterson, & Hassol, 2009) and it will exacerbates the extreme events like forest fire, drought, pest attack (Allen et al., 2010) which can cause more tree mortality and alter forest ecosystem (Karl et al., 2009).

To this context, it becomes very important globally as well as in the Norwegian forests to understand the most stochastic, and irregular phenomenon of tree mortality. Therefore, in this study I attempted to quantify the mortality dynamics of most dominant forest types in Norway, with specific objectives as to 1) quantify the pattern of tree mortality for three prominent forest types across measurements periods 2) analyses the variation in tree mortality among three forest types across the site quality gradient.

2. Methodology

2.1 Study area

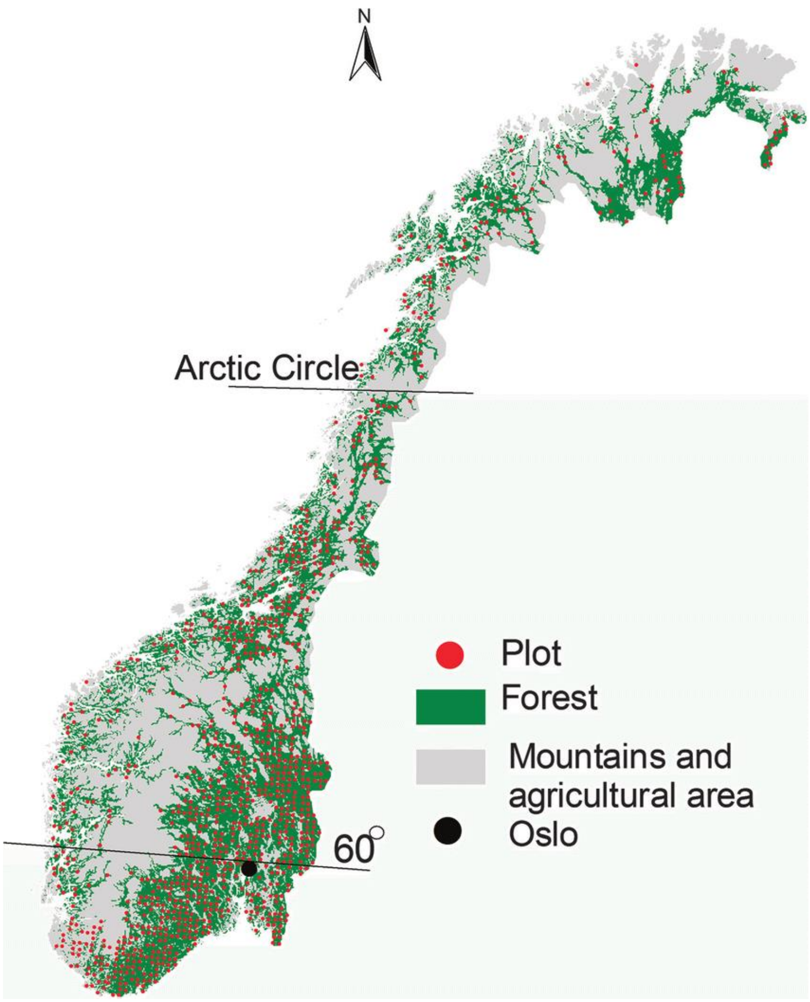
Norway has 323,808 km^2 of land, where forest area accounts for 121043 km^2 (37.4%) and, around 27% of the Norwegian forest are productive forest (Rognstad & Steinset, 2012).The Norwegians forests are classified into three main types i) coniferous evergreen forest ii) Broad-leaved forest and iii) Mixed Forest. Common Birch (*Betula pendula*), Norway Spruce (*Picea abies*) Scots Pine (Pinus Sylvestris), Red alder, Rowen, Aspen, Oak are some of the common tree species found in the forest of Norway. Norway spruce (44 %), Scots pine (31%) , and common birch (25%) are the dominant species by volume and economic importance (Schumacher, Hauglin, Astrup, & Breidenbach, 2020). Norwegian forest contains a timber volume of 978 million cubic meter with an annual increment of about 25 million cubic meter, whereas annual loss is about 68.4 kha of natural forest (Statistics Bureau Norway, 2021). The tree line is about 1100 masl in southern Norway, whereas, on Northern side, it is around 130 masl (Schumacher et al., 2020). The climatic condition of Norway is complex as the country is stretched hugely from the North-South direction (Ketzler, Römer, & Beylich, 2021). The average annual temperature ranges from a warmer 7 ^{o}C on the west coast to the freezing – 3 ^{o} C in the northern inland areas and the average annual precipitation is 1600 mm (1971-2020) which is expected to increase by 8 % by the end of the century (Ketzler et al., 2021).

Table 1: Land cover percentage in Norway (Statistics Norway, 2020)

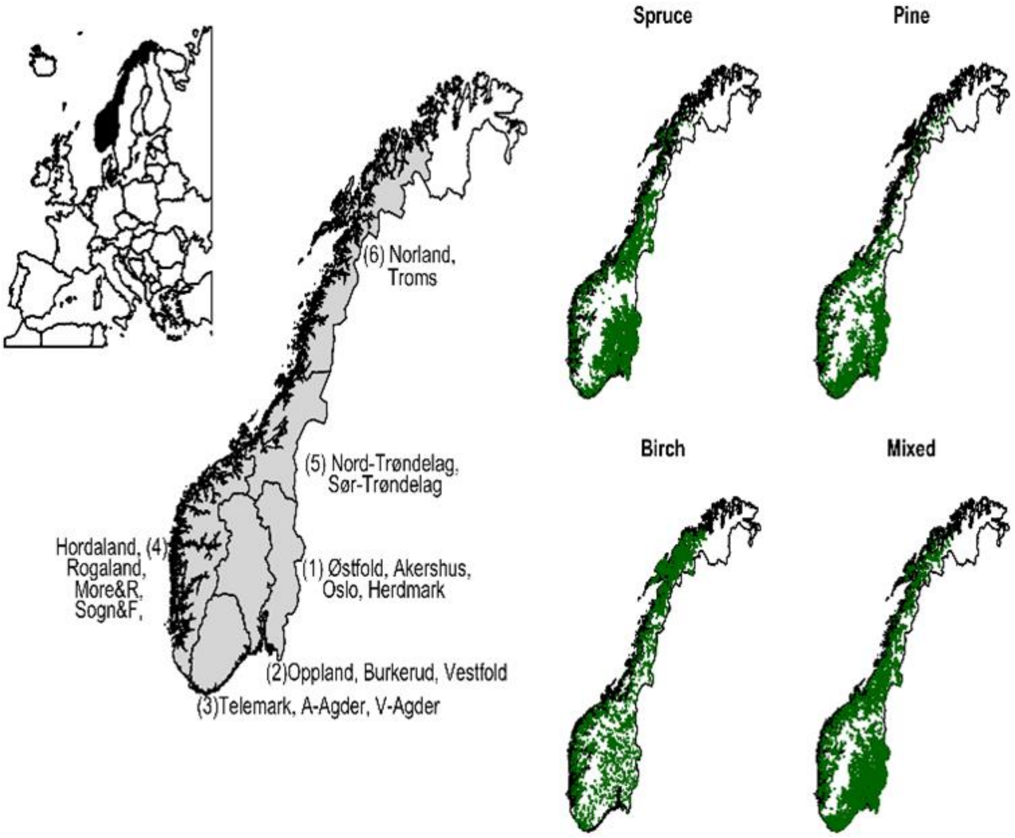
Land use type	coverage %
Built up Area	1.7
Agricultural land	3.5
Forest	37.4
Open firm ground	37.6
Wetland	5.3
Bare rock gravel and blockfields	7.4

Permanent snow and glaciers	0.8
Inland waters	6.2

Figure 1: (a) Map of Norway showing the forested areas and grid plots (b) Map showing the dominant tree species in different geographical locations (Strand, Callesen, Dalsgaard, & de Wit, 2016).



(a)

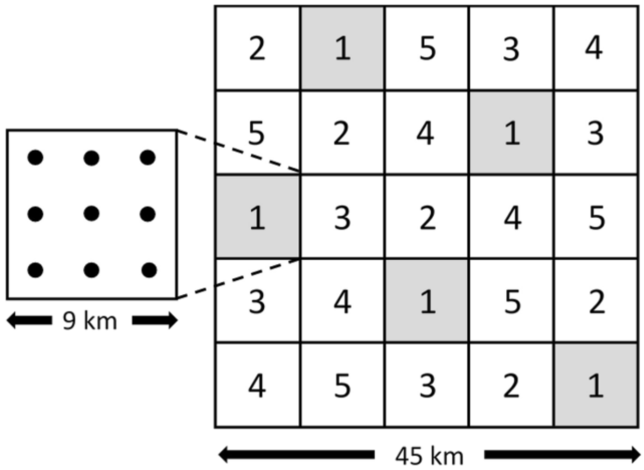


(b)

2.2 Norwegian National Forest Inventory (NNFI)

The Norwegian National Forest Inventory (NNFI) was established in 1919 (Dalen, 2019). The Norwegian Institute of Bio-economy research is responsible for carrying out the National Forest Inventory of Norway (Martin Bollandsås, Buongiorno, & Gobakken, 2008). Forest Inventory is conducted nationwide on a periodic basis in every five years using permanent sample plots. Each year 20% of the sample plots are visited (Breidenbach, Antón-Fernández, Petersson, McRoberts, & Astrup, 2014). The inventory provides important information on i) the development of Norway's forest resources such as forest types, growth, condition of the forest, and ii) stand ages. These data are considered key for the National policy development for sustainable forest management and various research purposes. Additionally, the collected data is also used to estimate the timber supply. In regard to the permanent sample plot grid, the total number accounts for 22,008, inclusive of all the land used types (Breidenbach, Granhus, Hylen, Eriksen, & Astrup, 2020). To control the influence of topography, Norway is represented in Latin square. Each Latin square has 5*5 = 25 blocks, each with an area of 81 km^2. Out of 25 blocks, each block contains nine plot locations on the 3 km* 3 km grid (Viken, 2018, p. 9 figure 3).

Figure 2: The Latin square design of the NFI.



The data consists of the information on the stand, such as tree height, diameter at breast height (DBH), tree species, topography, land use pattern, tree mortality, soil type, site quality etc. (Lehtonen, 2005). In the lowland region, NFI took data on 3 km * 3 km systematic grid, whereas 3 km*9 km in the dominated low productive mountainous region (Schumacher et al., 2020). Circular plots with an area of 100 m^2 were used between the year 1986 and 1993 and later from the year 1994 it was increased to 250 m^2 (Sharma & Breidenbach, 2015). Circular plots with an area of 250 m^2 (8.92 m radius) were used to measure the variable such as tree volume, biomass as well as dominant species type (Breidenbach et al., 2020). The height of ten trees per plot was measured with a hypsometer and, if the plot contains more than ten trees, then relascope (proportional to stem basal area) were used to choose the sub-sample of ten trees based on the target sample i.e., ten trees/plot. The other unmeasured tree height were calculated by the models calibrated using the data from the already measured trees (Rahlf, Breidenbach, Solberg, Næsset, & Astrup, 2017). Calipers were used to measure the diameter at breast height (DBH) of all living and standing dead trees (Breidenbach & Astrup, 2012). Volume of each trees were calculated by using allometric functions, when height and DBH of each trees were known (Breidenbach & Astrup, 2012; Breidenbach et al., 2020). On the other hand, the site index value was based on the dominant tree height at a base age of 40 years. It was recorded as a site variable with a range of 3m. For example, if the dominant height of the trees at 40 years breast height is between 13.5 m – 16.5 m, the site index value is 10 (Breidenbach et al., 2020). Dead and live trees were calculated during the establishment of the plot (Eid & Tuhus, 2001) and the deadwood volume were calculated in 250 m2 plot using line transect sampling (Breidenbach et al., 2020) The detailed methods of data collection and the NFI design can be found in (Breidenbach et al., 2020; Hylen, 2013; Viken, 2018).

The various modern technologies such as Airborne Laser scanner discrete return LIDAR (light detection and ranging) etc. (Strand, Callesen, Dalsgaard, & de Wit, 2016) are also being used in the forest inventory in Norway (Næsset, 2014).

2.3 Data Analysis

Norwegian National Forest Inventory data (both plot and tree data) was used for this study. The data was taken for the period of 2004 to 2018. The measurement was from the year 2004-2008 (Measurement 1), 2009-2013 (Measurement 2) and 2014-2018 (Measurement 3). The data consists of 645823 individual trees. Out of total observation 609477 (90%) of the individual trees were alive and remaining 36,346 (6%) were dead. While going through the data, I found out that the dominant species during the measurement period were spruce (43%), common birch (40%) and pine (16%). The total number of sample plots of the inventory accounted for 9249 plots. Since, I am concerned with the mortality of the tree, the condition of the tree, either dead or alive was identified by going through each plot and each tree ID in each measurements period. The tree was considered dead when the tree is i) completely lying ii) partly alive + removed iii) living outside the plot iv) vividly projected v) partly died + lying deadwood vi) partly dead + removed vii) partly alive viii) removed ix) status is not identified. The sample plot was identified for the analysis of the species abundantly found in it. For example, If the plot contains 70 % or more than the volume of spruce species then the plot was considered as spruce dominated (Eid & Tuhus, 2001) and, same applies for pine and common birch . Out of 9249 plots, 4743 plots contain dead trees. Among 4743 dead plots, 2655 (56%), 1435 (30%) and 653 (14%) plots were common birch, spruce and pine dominated, respectively. More than half of the dead plots were common birch dominated. The analysis was performed using R computing statistical tool (package = ggplot2, package=dplyr, package=tidyverse) referred by Team (2020). The mortality volume relative to the volume without bark was quantified based on DBH class and site quality index. The data was formatted by using omit tools to avoid the non-available data (missing symbols and numbers). The site quality was classified into three main categories based on productivity levels. The site classes were low (0-12), medium (12-20), and high (>20). The descriptive statistical analysis has been done with a package ("datarium").

3. Result

3.1 Descriptive statistics for three stand types:

The descriptive summary statistics for all three stand types were calculated (Table 2). The mean DBH, basal area and volume for pine dominated stands is greater than spruce and birch dominated stands. The average DBH of pine dominated stands with 17.4 cm DBH is little higher (2 cm) than the spruce dominated stands, whereas 7 cm than common birch stands. The Spruce stands possess the maximum of 90 cm DBH with minimum of 5 cm for all stand types. The average basal area of pine is little over than other stand types, with mean value of 0.031 ± 0.033 m^2 of basal area. The maximum stand volume is 237 m^3 for pine dominated stands.

Table 2: Mean, standard deviation and range of different variables (DBH, Basal area and stand volume) for all stand types.

Variables	Common Birch No. of Plots (2655)				Pine No. of Plots (1435)				Spruce No. of Plots (653)			
	N	Mean (SD)	Min	max	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max
DBH (cm)	13943	10.0(4.99)	5	67	4967	17.4(9.62)	5	66	17436	15.2(8.78)	5	90
Basal area (m^2)	13943	0.01(0.012)	0.002	0.35	4967	0.031(0.033)	0.002	0.34	17436	0.024(0.029)	0.002	0.64
Volume (m3)	9559	1.36(2.54)	0.114	56.3	1714	3.4(9.14)	0.12	237	5965	2.85(6.5)	0.12	105
Site Quality	13835	11.5(4.27)	6	26	4916	12.9(3.56)	6	26	17299	15.1(4.33)	6	26

3.2 Mortality across the measurement period

In this study, the average overall mortality (m^3/ha) for the dominant species pine, spruce and common birch was 4.12 m^3/ha between 2004 – 2018 in Norway. The average mortality volume found as 0.2753 m^3/ha /yr. It is evident that mortality rates vary with species, DBH class, site index and basal area and stand volume. Norway Spruce (*Picea abies*), pine (*Pinus sylvestris)* Common Birch (*Betula pendula)* dominated stands types were selected for further analysis. Spruce had the highest mortality rate (0.37 m^3/ha/yr) as compared to pine and common birch. Common Birch had the lowest mortality volume (0.19 m^3/ha/yr). Between the three measurement periods, the highest mortality is found in Measurement 2 (M2) 0.529 m3/ha/yr followed by Measurement 1 (M1) 0.151 m^3/ha/yr and Measurement 3 (M3) 0.145 m^3/ha/yr (Table 3).

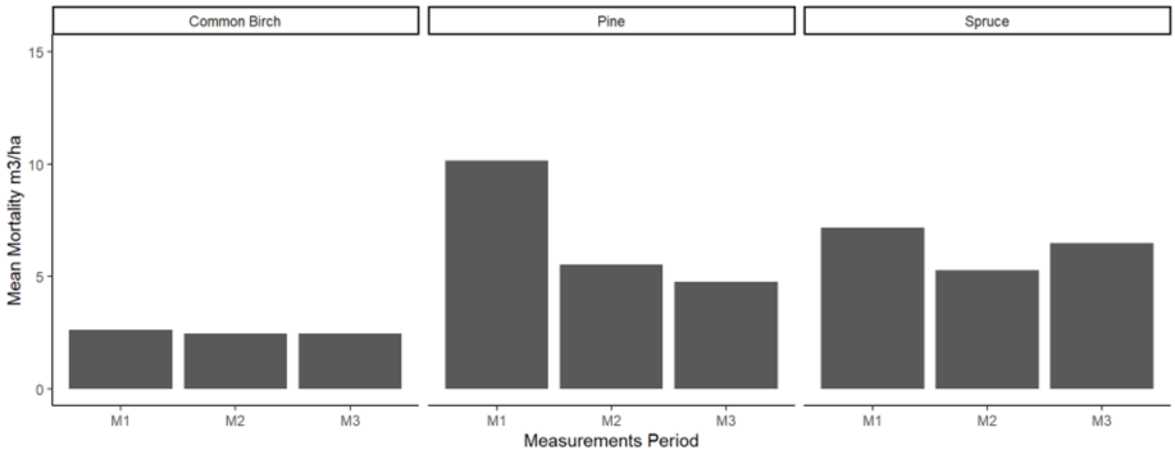
Table 3:showing mean mortality (m3/ha) of species and measurements period between 2004-2018

Variable	Species			Measurements period		
	Common Birch (N= 2655)	Spruce (N=1435)	Pine (N=653)	M1 (N=938)	M2 (N=1414)	M3 (N=2391)
Tree mortality (m3/ha)	0.190	0.370	0.265	0.151	0.529	0.145

[*M1=2004-2008, *M2=2009-2013 *M3=2014-2018 and N (No. of plots)]

In the measurements period M1, M2 and M3, the highest mortality was observed in the pine dominated stands i.e., 10.14 m^3/ha, 5.52 m3/ha and 4.75 m^3/ha, respectively; and the lowest in common birch (2.62 m^3/ha, 2.47 m3/ha and 2.45 m^3/ha) respectively (Figure 3). The mortality of pine had decreased in each measurement periods, whereas spruce mortality rate was decreased in M2 and again increased in M3. In common birch, stands the mortality was highest in M1 and almost similar in M2 and M3.

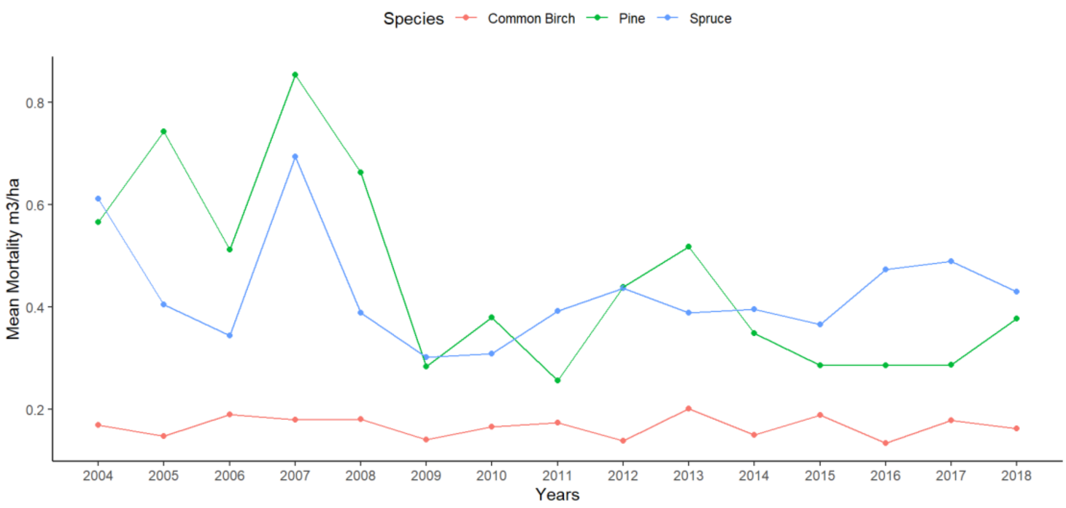
Figure 3: Mean Mortality (m3/ha) within Species in Norway between the Measurements periods



During the measurements period 2004-2018, pine spruce and common birch dominated stand types showed different mortality trends. Common Birch had the lowest mortality during all the measurement periods in comparison to other forest types. Mean mortality of the common birch falls between 0.189 m^3/ha and 0.138 m^3/ha. For common birch, the highest mean mortality is in the year 2015, and the lowest is in the year 2012. Pine and spruce showed fluctuations in the mean mortality between the years. The mean mortality of the pine is 0.566

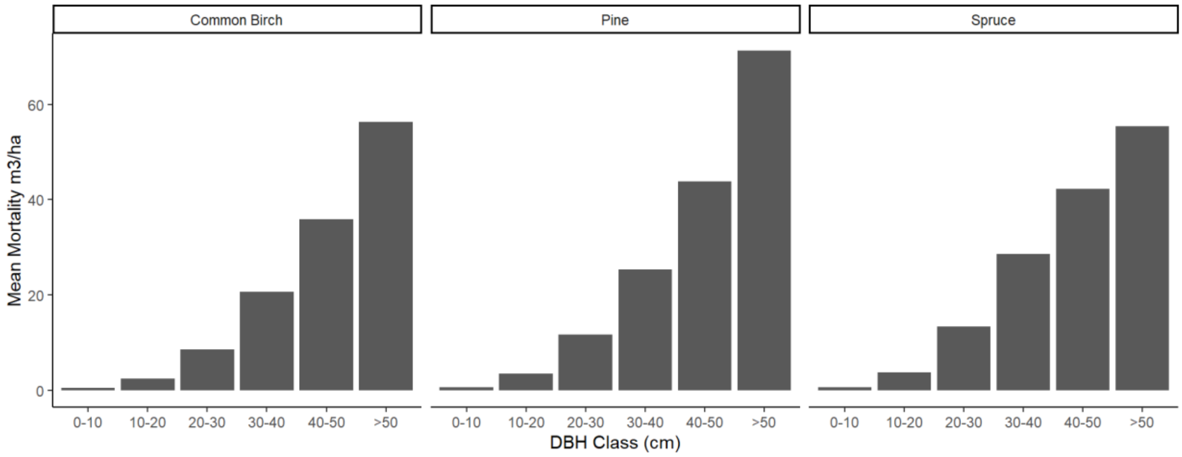
m^3/ha at the beginning of the measurement year 2004 and is 0.377 m^3/ha at the end of the measurement year 2018. Whereas the highest mortality rate of the pine is 0.853 m^3/ha in the year 2007 and, the lowest is 0.256 m^3/ha in the year 2011.

Figure 4:Mean mortality (m3/ha) of three dominant stand types in Norway from the year 2004 to 2018.



During the measurement period from the year 2004 – 2018, the average mortality is highest in the DBH class >50, with mortality of trees accounting for 105.2235 m^3/ha and the lowest was in the DBH class 0-10 (0.608 m^3/ha). Pine dominated stands had average highest mortality of 153.480 m^3/ha, in the DBH class >50, similarly spruce and common birch stands had highest average mortality (55.414 and 56.280 m^3/ha), respectively in the DBH class >50. The mean mortality value is almost negligible in the DBH class 0-10 in comparison to other DBH classes across all stand types. The result shows that with increase in DBH the tree mortality also increases. The Pine dominated stands incurred higher mortality as compared to spruce and common birch stand types. In the DBH class >50, the pine mortality is three times greater (153.48 m^3/ha) than common birch dominated stand types (56.28 m^3/ha).

Figure 5: Mean mortality (m3/ha) by DBH class (cm) among three prominent stand types in Norway.



3.3 Mortality across site quality

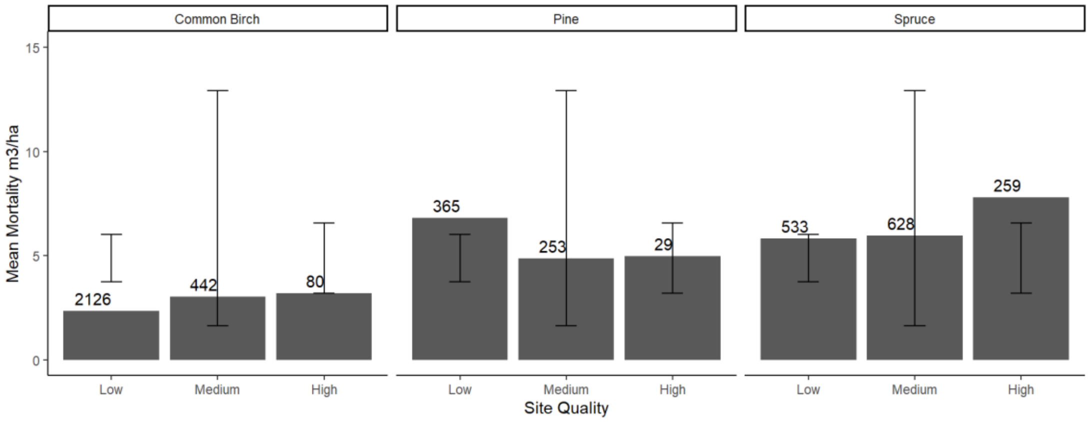
The stand variables (DBH, basal area and volume) average is found to be greater in high site quality, followed by medium site quality and so on. The tree mortality at high site quality is over 0.6 m3/ha greater on average than medium and high site quality mortality volume. The high-quality site has an average of 2.68 ± 5.81 m^3/ha tree mortality, whereas, the medium and low site quality observed tree mortality of 2.09 ± 5.19 m^3/ha 1.88 ± 4.93 m^3/ha, respectively. DBH and basal area at high quality forest areas is (14.6 ± 8.73 cm and 0.023 ± 0.029 m2) greater than medium and low site quality. The total number of observations is found to be higher in low site quality than in medium and high site quality.

Table 4: Mean, standard deviation and range of different variables (DBH, Basal area and stand volume) in all site quality index.

Site Quality	**Low No. of Plots (3024)**				**Medium No. of Plots (1323)**				**High No. of Plots (368)**			
Variables	N	Mean (SD)	Min	max	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max
DBH (cm)	16334	12.8(7.76)	5	67	14639	13.9(8.43)	5	90	5077	14.6(8.73)	5	63.5
Basal area (m^2)	16334	0.018(0.024)	0.002	0.352	14639	0.021	0.002	0.636	5077	0.023(0.029)	0.002	0.317
Volume (m3)	9229	1.88(4.93)	0.114	237	5683	2.09(5.19)	0.12	105	2194	2.68(5.81)	0.12	95.3

The stand type dominated by spruce possess the highest mortality of 7.789 m^3/ha on average in high site quality. In contrast, pine recorded mortality of 6.80 m^3/ha in low site quality. Whereas, common birch with tree mortality of 3.20 m^3/ha on a high site quality index is greater than medium and low site quality. Figure 6 shows that the standard error bar is shorter at the low- and high-quality sites in comparison to medium site quality across all stand types.

Figure 6: Mean mortality (m3/ha) by Site quality index within different species in Norway between 2004-2018.



Spruce and common birch observed highest mortality in high site quality forest sites, whereas pine with highest mortality resulted in low site quality index. The high site quality of spruce and common birch has the average stand volume of 3.42 ± 6.81 m^3ha and 1.12 ± 2.45 m^3/ha tree volume, respectively. And the low site quality of Pine having 4.41 ± 12.3 m^3/ha on average tree volume. Table 5 shows that pine have highest average DBH (18.6 ± 10.0 cm) in low site quality index whereas, common birch observed lowest average DBH (9.9 ± 5.19 cm) in high site quality index.

Table 5: Mean, standard deviation and range of variables (DBH, basal area and volume) of species across observations.

Site Quality = Low	**Spruce No. of Plots (533)**				**Pine No. of Plots (365)**				**Common Birch No. of Plots (2126)**			
Variables	N	Mean (SD)	Min	max	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max
DBH (cm)	5028	15.2(8.44)	5	55.5	2321	18.6(10.0)	5	66	8985	10.0(4.9)	5	67
Basal area (m^2)	5028	0.024(0.027)	0.002	55.5	2321	0.035(0.035)	0.002	0.342	8985	0.01(0.012)	0.002	0.352
Volume (m3)	1723	2.86(6.17)	0.12	55.2	731	4.41(12.3)	12.3	0.12	6775	1.36(2.43)	0.114	56.3

Site Quality = Medium	**Spruce No. of Plots (628)**				**Pine No. of Plots (253)**				**Common Birch No. of Plots (442)**			
Variables	N	Mean (SD)	Min	max	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max
DBH (cm)	8482	15.0(8.85)	5	90.0	2345	16.3(9.09)	5	53	3812	9.97(5.11)	5	48
Basal area (m^2)	8482	0.024(0.03)	0.002	0.636	2345	0.027(0.03)	0.002	0.221	3812	0.01(0.013)	0.12	0.181
Volume (m3)	2777	2.51(6.5)	0.154	105.0	849	2.39(4.53)	0.16	50.1	2057	1.4(2.89)	0.12	50.8

Site Quality = High	**Spruce No. of Plots (259)**				**Pine No. of Plots (29)**				**Common Birch No. of Plots (80)**			
Variables	N	Mean (SD)	Min	max	N	Mean (SD)	Min	Max	N	Mean (SD)	Min	Max
DBH (cm)	3789	15.8(9.01)	5	63.5	250	15.7(9.39)	5	50.2	1038	9.9(5.19)	5	46.2
Basal area (m^2)	3789	0.026(0.031)	0.002	0.317	250	0.026(0.033)	0.002	0.198	1038	0.01(0.014)	0.002	0.168
Volume (m3)	1416	3.42(6.81)	0.12	95.3	122	2.54(4.2)	0.273	23.5	656	1.12(2.45)	0.12	33.0

4. Discussion

Tree mortality is a fundamental driver of forest ecosystem but highly completed process (Neumann, Mues, Moreno, Hasenauer, & Seidl, 2017). The studied was carried out with a goal to understand complexity of tree mortality so that the proper forecast of the forest development can be estimated, and forest could be managed properly for receiving different forest ecosystem. In the study, I quantified and compared the rate of mortality across time and influence of various factors such as DBH, site index. The focus was to see this change on the dominant forest types of spruce, pine, and common birch. For the quantification, the data are drawn from the Norwegian National Forest Inventory (NNFI) from the inventory period 2004 -2018. This study could not include all the forest factors into consideration due to insufficient (scarcity) of data.

The pine had a stand volume (3.4 ± 9.14 m^3/ha) greater than common birch (1.36 ± 2.54 m^3/ha) and Spruce (2.85 ± 6.5 m^3/ha). The higher standard deviation of pine indicates that pine stand volume is more dispersed than the average of spruce and common birch stand volume. Here spruce standard deviation of 6.5 m^3/ha is more closer grouping to the mean 2.85 m^3/ha. It is found that the average stand volume of spruce is found to be more consistent than other stand type. It also supports the result.

The study result showed that overall tree mortality 4.12 m^3/ha and 0.2753 m^3/ha/yr were observed for Norwegian forest during the last two decades. The mortality rate of Spruce is significantly higher as compared to the other two stand types. Whereas, common birch showed the lowest mortality. The overall mortality rate was in the increasing trend until 2008 i.e., the first measurement period where the average mortality was 1.81 m^3/ha. However, for the next two measurement periods (M1 and M2) the average mortality volume 1.431 m^3/ha and 1.437 m^3/ha were found respectively, which is slightly lower than the first measurement period. From 2004 till 2018, Spruce had the highest mortality rate throughout all the years, and the trend of the tree mortality were almost similar during all the years. Whereas, the average mortality volume ranges between 0.138 m^3/ha and 10.098 m^3/ha.

In the study, the influence of different factors such as (DBH, basal area, volume and site index) on tree mortality. The mortality rate varies on the species with different factors: i) 0-10 cm had the lowest mortality whereas the highest in the DBH class > 50 (ii) the high site quality index had the highest mortality volume 17.171 m^3/ha, where Spruce having high site quality index had highest mortality volume 7.789 m^3/ha and common birch having low site quality index had lowest mortality volume 2.31 m^3/ha. The error bar (figure 5) shows that majority of stand volume over other site quality is significantly not different. Therefore, I can't say that spruce having highest mortality volume overall site quality and species. Likewise, the error bar on the common birch in low site quality index reflects the same result as above. That means the overall mortality volume of common birch over other site quality index and species is significantly not different. So, I can't also say that common birch having lowest mortality volume overall site quality. For the conclusion, more statistical analysis is required.

Site quality index is considered as one of the most important indicators (factor) in determining mortality. It gives the idea about the quality of the soil or the quality of the site (Eid & Tuhus, 2001; Kahle, 2008). Furthermore, it helps in determining the forest growth and yield modelling. It has been seen that site index doesn't follow one regular pattern (Davidson et al., 1999), which is also one of the findings of this research as well. For an instance, mortality is low on medium site quality and higher on the high site quality. This result in line with the previous studies where mortality is seen higher on high quality site and lower on low quality site (Chen, Krestov, & Klinka, 2002; Eid & Tuhus, 2001; Sharma & Breidenbach, 2015). The site with good quality provides the right environment for the growth of the tree.

For all three dominant tree stand types (pine, spruce and birch) the mortality is quantified. The overall mortality volume during the study period in Norway is 0.275 m^3/ha/yr is low compared to the other European countries for example; forest of Italy's mortality 2.25 m3/ha/yr (Bertini, Ferretti, Fabbio, Raddi, & Magnani, 2019) and to the Finish forest mortality is 0.56 m^3/ha/yr (Valkonen, Aulus Giacosa, & Heikkinen, 2020). The overall annual mortality volume in the Europe is 0.50 m^3/ha/yr (Neumann et al., 2017). In Norway the tree mortality is less than half compared to overall average tree mortality in the European forest. The overall mortality in Norway is low because the government data shows that a massive number of trees, more than 60 million, were planted annually in the period of 1955-1992 with a peak of more than 100 million planted annually in the 1960's and annual feeling are much lower than the annual increment (Norwegian Ministry of Climate and Environment, 2020). To support this fact, the result clearly shows that the high site quality stand has high mortality volume, and the low site quality index has low mortality volume. In addition to that, the government of Norway has enacted a strong and active Forest policy for the past 60 – 70 years, which supported improving forest management and helped in lowering the mortality (Norwegian Ministry of Climate and Environment, 2020, p. 12). In this study, among the three dominant stand, spruce has the highest mortality. Similar findings were observed by Bashir and MacLean (2015), while studying Balsam Fir and Spruce dominated stand types. Contrary to our results, Etzold et al. (2019) have low Spruce mortality. Spruce mortality in Norway is high as these species are climate -sensitive and could not withstand extreme climatic events like drought, storm and extreme cold weather (Kolář, Čermák, Trnka, Žid, & Rybníček, 2017; Lännenpää et al., 2008). Therefore, high dominance of Spruce in Norwegian forest can be another reason for highest Spruce mortality.

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5. Conclusion

The research showed that mortality is an important, stochastic yet complicated phenomenon. Among the three dominant species in Norway, spruce dominated plot has the highest mortality. And the overall mean mortality volume had found in the measurement period of 2009 – 2013. The DBH, basal area, stand volume, and site quality condition significantly affects the stand volume loss (mortality volume) overall stand types. The results also conclude that the high site quality had the highest mortality volume low site quality had the lowest mortality volume. The stand type Spruce had the highest mortality volume on high site quality, and common birch showed the lowest mortality on low site quality.

So, Spruce should be taken into consideration by the researcher, planners, and management officers. The overall mortality is low in Norway compared to other European countries because Norway has a strong Regulation when it comes to forest management. Management can increase the productivity of the forest by introducing various highly productive major such as adding fertilizer to the soil, introducing the fastest growing plants, and introducing various sustainable programs. The authority should be more concerned with the forest mortality as it has a larger impact on the forest function, which can alter regional as well as the global environment. Mortality of the forest can also define the health status of the forest. Lowering the forest mortality means improving our ecosystem services.

It is highly recommended to carry out the research with a focus on identifying the specific ecological factors which caused the high tree mortality with high volume mass trees. The policymakers should also focus on highlighting the forest management approaches which will address the higher tree mortality volume of the high stand volume.

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