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# Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem

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Contents

- ▶ **I | Introduction** ..... 3
  - 1.1. Mortality Rate of Vulnerable Alpine Ecosystem ..... 3
  - 1.2. The Declining and Analysis of Alpine Coniferous Forest ..... 4
  
- ▶ **II | Analysis of Researches into Different Effects of Conserving Alpine Coniferous Forest** ..... 9
  - 2.1. Effects of Temperature ..... 11
  - 2.2. Effects of Precipitation ..... 14
  - 2.3. Effects of Pests ..... 17
  - 2.4. Effects of Biogeochemical ..... 20
  
- ▶ **III | Analysis of Researched using Plant Growth Substances of Alpine Coniferous Forest** ..... 27
  - 3.1. Researches on Utilization of Various Plant Growth Regulators ..... 29
  - 3.2. Researches on Utilization of Plant Growth Substances and Jasmonic Acid ..... 29
  
- ▶ **IV | Limitations to Researches and Solutions** ..... 31
  - 4.1. Limitations to Researches ..... 33
  - 4.2. Solutions ..... 34
  
- ▶ **V | Future Research Direction and Summary** ..... 35
  - 5.1. Future Research Direction ..... 37
  - 5.2. Summary ..... 37
  
- ▶ **VI | References** ..... 39

Reference Materials

- Material 1. Categorization and Characteristics of Subalpine Zone ..... 47
- Material 2. Research and Analysis into Habitat of Vulnerable Alpine Ecosystem ..... 49



Table of Contents

<Graph I-1> Mortality and Analysis of Overseas Alpine Coniferous Forest ..... 7  
 <Graph II-1> Conservation and Adaptation Mechanism against Threats to  
 White Bark Pine Trees in Yellowstone National Park ..... 19

List of Figures

<Figure I-1> Korean Fir of Vulnerable Alpine Ecosystem ..... 3  
 <Figure I-2> Results of Dissertation DB Analysis related to Mortality due to Drought 4  
 <Figure I-3> Differences in Mortality Rate according to Altitude and Species ..... 5  
 <Figure I-4> Subalpine zone of Hallasan Mountain ..... 5  
 <Figure I-5> Theoretical Mechanism of Coniferous Tree Mortality due to  
 Climate Changes ..... 6  
 <Figure I-6> Picture of Korean Fir Forest in Good vs. Vulnerable Area ..... 6  
 <Figure II-1> Increase of Various Dangers of Tree Mortality due to  
 Climate Changes ..... 11  
 <Figure II-2> Comparison of forest mortality in the DACH based on NDVI region  
 analysis between 2003 and 2018. .... 12  
 <Figure II-3> Xylem Conductance of Damaged Branch (2018) ..... 12  
 <Figure II-4> Photos of Mortality by Types and Changes in Temperature/  
 Precipitation in Central Europe ..... 13  
 <Figure II-5> Analysis of Mortality Period of Pinyon pine due to High Temperatures ..... 13  
 <Figure II-6> Recent Extreme Drought in Canada ..... 14  
 <Figure II-7> Photo of Regions of Aspen Forest in Saskatoon, Canada and Mortality 15  
 <Figure II-8> Relationship between the Biomass Ratio and Mortality in Aspen ..... 15  
 <Figure II-9> Aerial Photo of Mortality of Jarrah Forest, Southwest of Australia ..... 16  
 <Figure II-10> Monthly precipitation (2010-2012) and drought sensitivity between the  
 two species ..... 16  
 <Figure II-11> Area of Tree Mortality in California between 2010 to 2015 ..... 17

# Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem

List of  
Figures

<Figure II-12> Conceptual Model in Interaction of white bark pine due to Climate Changes .....	17
<Figure II-13> Area of Tree Mortality due to Beetles in Western America in 2000 to 2012 .....	19
<Figure II-14> Mass Mortality of Korean Pinyon pine due to Bark Beetle of Northwest Region of America .....	20
<Figure II-15> Measuring Snow Depth .....	21
<Figure II-16> Measuring Snow Density .....	21
<Figure II-17> Measuring Snow Water Equivalent (SWE) .....	22
<Figure II-18> Photo of Mortality (A) and Mortality Progress (B) of Sitka Spruce at Beaver Creek .....	23
<Figure II-19> Monthly PLFC Ratio (top), Relationship between Soil Salinity, Ion and PLFC (below) .....	24
<Figure II-20> Correlation between PLFC (Percentage of Live Foliated Crown) and NSC (Nonstructural Carbohydrates) .....	24
<Figure II-21> Relationship between Mortality Rate and Microhabitat, Height and Canopy Openness .....	25
<Figure II-22> Relationship between Mortality Rate and Dominant Plantation Neighbor .....	26



## Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



- 1.1. Mortality Rate of Vulnerable  
Alpine Ecosystem
- 1.2. Declining and Analysis of  
Alpine Coniferous Forest

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# Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



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# I. Introduction

## 1.1. Mortality Rate of Vulnerable Alpine Ecosystem

- Tree mortality rates have increased globally since the late 1990s due to rising temperatures and drought associated with climate change (Allen *et al.*, 2010)
- By understanding the causes of decline in alpine coniferous forest globally and its conservation research trends to provide a conservation direction in protecting the vulnerable alpine ecosystem in Korea
- By researching the adaptation phenomena in response to vulnerable alpine ecosystem decline due to various environmental factors, to provide support for conservation and management measures

### 〈A Global Overview of Drought-induced Tree Mortality (Allen *et al.*, 2010)〉

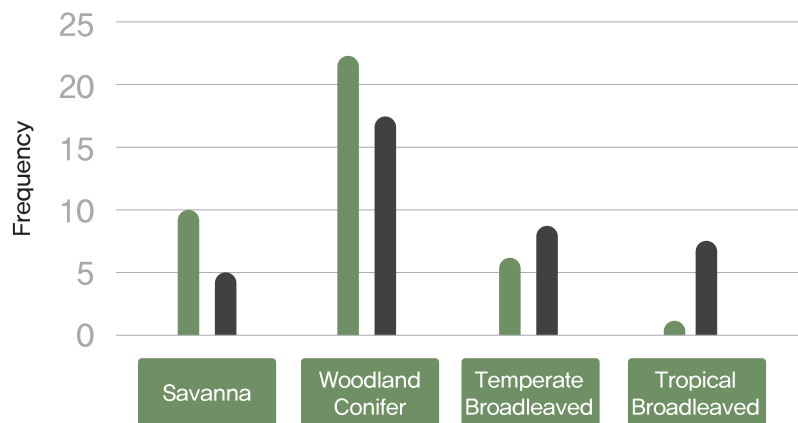
- In Asia, observed large-scale mortality of coniferous trees due to drought in China and Russia
  - Serious El Niño phenomenon caused 12–28% damages to Malaysia and 37–82% to Borneo rainforest of Indonesia
  - 20 to 50% tree mortality of Korean fir trees in Korea due to severe drought
  - Reported damages of 30% of *Juniperus procera* in Saudi Arabia, and approximately 400,000ha damages to spruce and pine forest of Russia
  - Tree mortality has affected approximately 113,000 ha of pine forests in Yunnan Province, China, and about 500,000 ha of Chinese red pine forests in Shanxi Province
- Increase of coniferous forest mortality (approx. 20%) due to repeated drought since 1970 in various regions of Europe including Switzerland, France, Poland and Greece
  - Serious damages reported due to drought in the following areas: Norway spruce forest in Norway, Calabrian pine forest in Greece, fir forest in Cephalonia, Scots pine forest in Switzerland, European black pine in Spain and others
- Widespread of mortality of pine, fir and spruce trees due to drought in North America centered around the western parts of the U.S.



<Figure I-1> Korean Fir of Vulnerable Alpine Ecosystem

## 1.2. The Decline and Analysis of Alpine Coniferous Forest

- High temperatures and drought are major drivers of decline, and coniferous forest biomes are particularly vulnerable to drought stress, resulting in rapid deterioration
  - According to research in mortality damages due to drought, coniferous trees are the most affected. The actual numbers are higher than the estimated number of damages
  - After a long-term ecology monitoring in North America; recent studies showed constant mortality rate of coniferous trees in western regions of U.S. from the 1970s

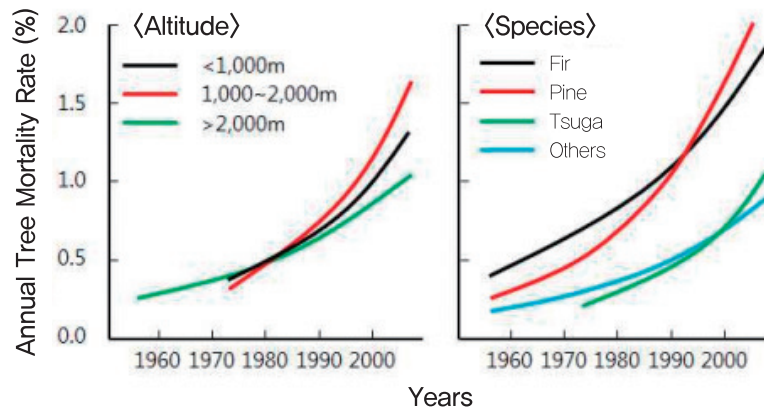


<Figure I-2> Results of Dissertation DB Analysis related to Mortality due to Drought

※ ISI Web of Science, actual number (green) vs model estimate (black) of mortality in different forests from 1986 to 2009.  
Source: Allen et al., 2010

- Effects of high temperature, drought stress and pest outbreak and forest fires
  - ※ Examples by region and types. Refer to table (Mortality and Analysis of Overseas Alpine Coniferous Forest)
  - Weakened pest defense of coniferous trees due to drought
  - Increase of survival, seed production rate and expansion of habitat of pest due to increasing temperatures
  - Frequent occurrence of major forest fires due to high temperatures during spring and quickened melting of snow
  - Increasing global carbon cycle imbalance
- Climatic stress increases forest fire severity and high temperature due to climate changes across Western U.S. with concurrent forest fire and pest damages (Van Mantgem et al., 2009)
  - The temperature in this region has been increasing at average of 0.3 to 0.4°C every 10 years, there is especially a relationship between the increase in coniferous tree mortality rate and a 0.5°C increase in temperature at high altitudes
  - Tree mortality is determined by a variety of factors such as drought, climate change stress such as temperature increases as well as pests, diseases, history of trees or physiological resistance (Miao et al., 2009)

- There is a clear correlation between prolonged drought and high temperatures; leading to decrease of physiological tolerance of trees and is affected more by illnesses and pests



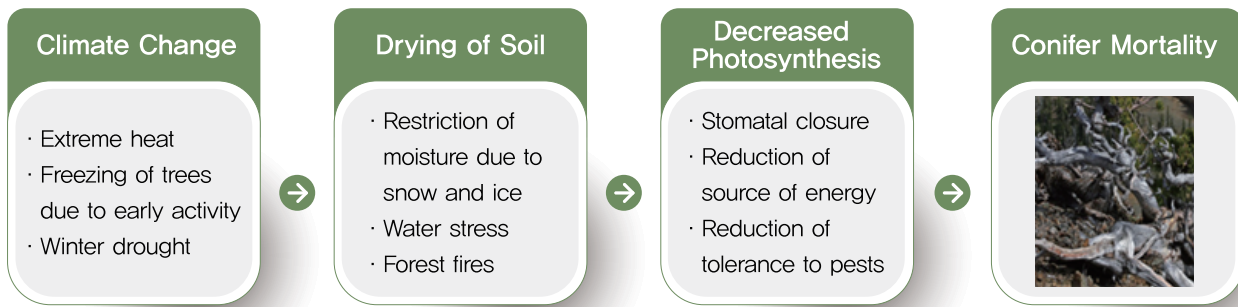
<Figure I-3> Differences in Mortality Rate according to Altitude and Species

Source: Van Mantgem et al., 2009

- Due to multiple factors such as increase of temperature during winter season, lack of soil moisture, interspecific competition, strong wind, typhoon and other extreme weather conditions of Korea's alpine regions
  - Subalpine conifer mortality due to spring drought where snow melts earlier than expected because of high temperatures during winter season
  - According to the future climate change predictions, the rise of temperature during winter is significant where precipitation is expected to be concentrated to summer seasons
  - Theoretically, the abnormal climate phenomena such as high temperatures during winter and spring drought, such phenomenon decreases soil moisture leading to decreased photosynthesis activity resulting in conifer mortality



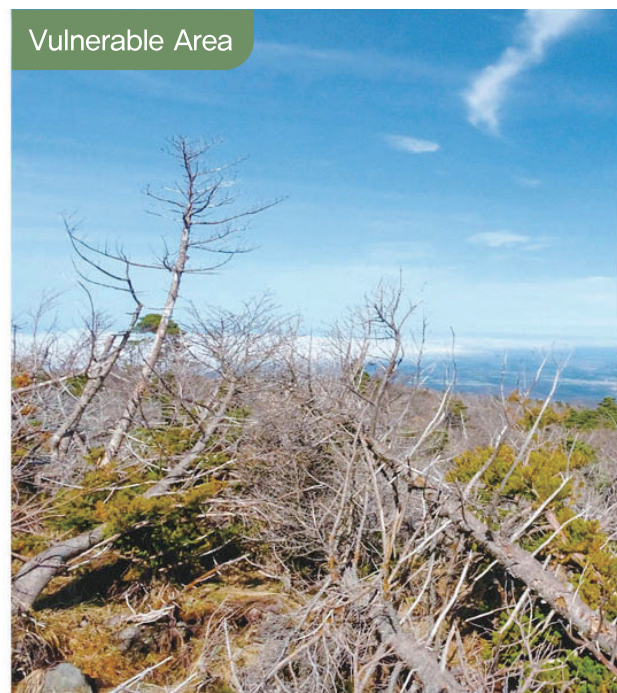
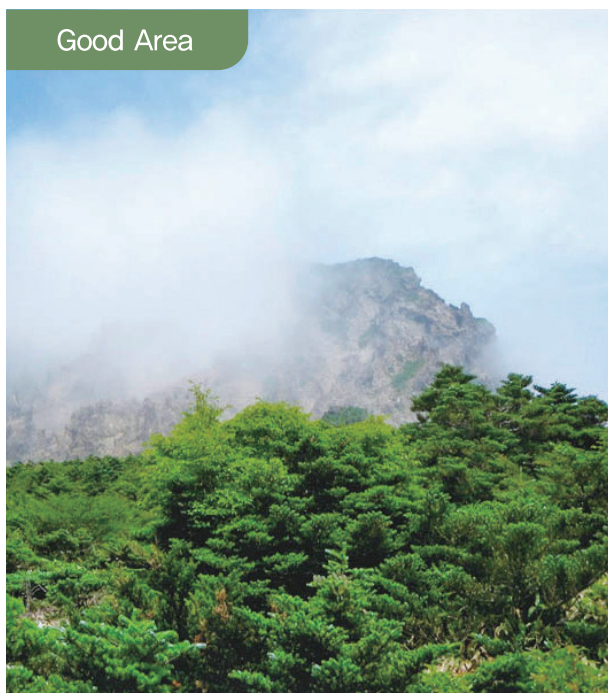
<Figure I-4> Subalpine Zone of Hallasan



<Figure I-5> Theoretical Mechanism of Coniferous Tree Mortality due to Climate Changes

*Source; National Institute of Forest Science, 2009. Visualization of forest fire due to global warming-Reasons of Mortality of Future Prospects Pine trees*

- Due to multiple factors such as increase of temperature during winter season, lack of soil moisture, interspecific competition, strong wind, typhoon and other extreme weather conditions of Korea's alpine regions
  - Increased tree mortality due to exposed roots and stem movement to grown trees in stony slopes
  - The species distribution differs according to the slopes of the valley, especially the rock crevices of north slopes are lower in temperatures and high humidity offers less stressful environment
  - Decrease of water damage due to inhibition of germination and blockage of light caused by increase of Northern bamboo and understories
  - Rapid population expansion of temperate deciduous forest (Mongolian oak, Miyama cherry and others) due to climate changes



<Figure I-6> Picture of Korean Fir Forest in Good vs. Vulnerable Area

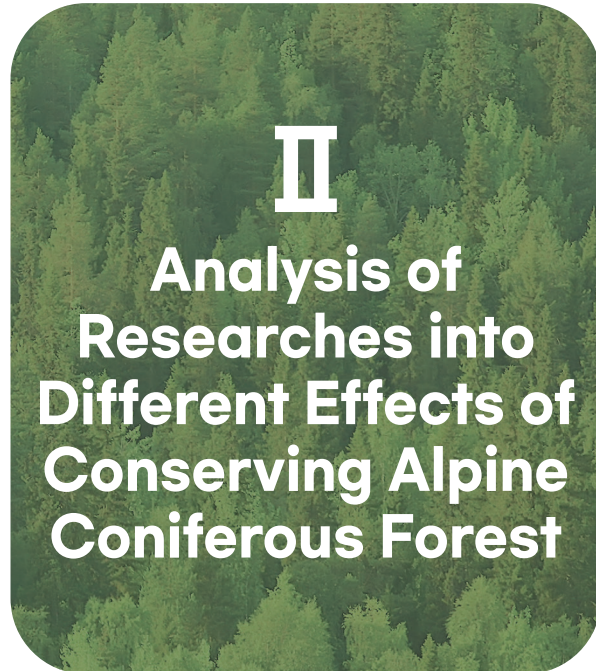
<Graph I-1> Mortality and Analysis of Overseas Alpine Coniferous Forest

	Target	Details
North America	White bark pine at Yellowstone National Park, Western U.S. ( <i>Pinus albicaulis</i> ) (Shanahan <i>et al.</i> , 2016)	<ul style="list-style-type: none"> <li>• Mortality due to effects between drought and size of trees, beetles and fungus</li> </ul>
	Large-scale coniferous forest at Rocky Mountain National Park, U.S. ( <i>Pinus albicaulis, pinus edulis</i> ) (Funk <i>et al.</i> , 2014)	<ul style="list-style-type: none"> <li>• Approximately 46 million acres of tree mortality due to beetles from 2000 to 2012</li> <li>• Proposed 6-stage guidelines in protecting forest resources</li> </ul>
	White bark pine, Alaska, U.S. (Barber <i>et al.</i> , 2000)	<ul style="list-style-type: none"> <li>• Declining tree growth through combined analysis of thickness of tree rings, density and carbon isotope profile</li> <li>• Limit to carbon absorption due to climate changes</li> </ul>
	Insect Outbreak, British Columbia, Canada (Kurz <i>et al.</i> , 2008)	<ul style="list-style-type: none"> <li>• Estimated 270MT of carbon emission due to forest mortality due to outbreak of beetles during 2000 to 2020</li> <li>• Major factor in climate changes related to carbon emission</li> </ul>
	Boreal Forest of Canada (Peng <i>et al.</i> , 2011)	<ul style="list-style-type: none"> <li>• Increased annual boreal forest mortality rate to 4.7% from 1963 to 2008</li> <li>• Significant difference between regions (west &gt; east)</li> </ul>
Europe	Norway spruce, Austria (Jandle R, 2020) (Honkaniemi <i>et al.</i> , 2020)	<ul style="list-style-type: none"> <li>• Relationship between pest outbreak, temperature and precipitation in the upper and lower regions</li> <li>• Analysis of drought vulnerability of spruce trees</li> <li>• Proposed forestation management of public, private and afforestation</li> <li>• Proposed methods of afforestation for different scenarios through landscape and climate resilience composition analysis</li> </ul>
	Spanish–French Pyrenees (Perez-Garcia <i>et al.</i> , 2013)	<ul style="list-style-type: none"> <li>• Predict the effects of climate changes in growth distribution of alpine and subalpine in 2080 by algorithm analysis</li> </ul>
	Norway spruce trees, Bohemian Forest Mountain, Germany (Štursová <i>et al.</i> , 2014)	<ul style="list-style-type: none"> <li>• Effects of surrounding ecosystem (soil, microorganism and fungus) and tree mortality due to beetle infestation</li> </ul>





## Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



## II Analysis of Researches into Different Effects of Conserving Alpine Coniferous Forest

- 2.1. Effects of Temperature
- 2.2. Effects of Precipitation
- 2.3. Effects of Pests
- 2.4. Effects of Biogeochemical

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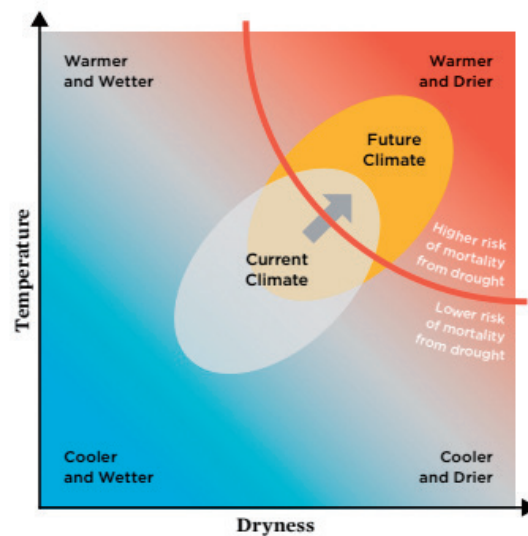


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## II. Analysis of Researches into Different Effects of Conserving Alpine Coniferous Forest

### 2.1. Effects of Temperature

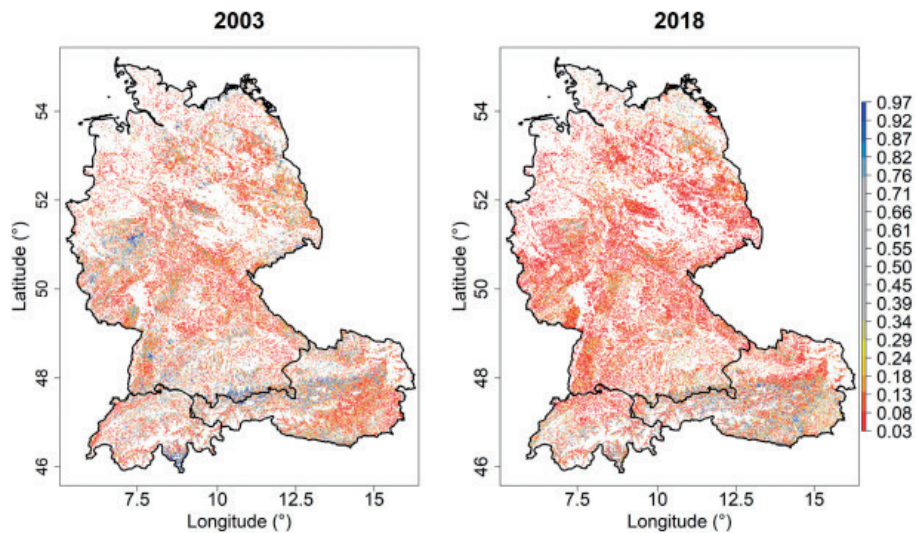
- Average temperature in U.S. after 1895, increased by 1.9°F where Rocky Mountains increased by 2.1°F; increasing the risks of forest (Funk *et al.*, 2014)
  - The speed of tree mortality increased due to high temperatures and dryness in Western regions
  - Rising temperatures result in warmer winters, reduced snow accumulation, earlier snowmelt, and increasingly dry summer conditions



<Figure II-1> Increase of Various Dangers of Tree Mortality due to Climate Changes

Source: Funk *et al.*, 2014

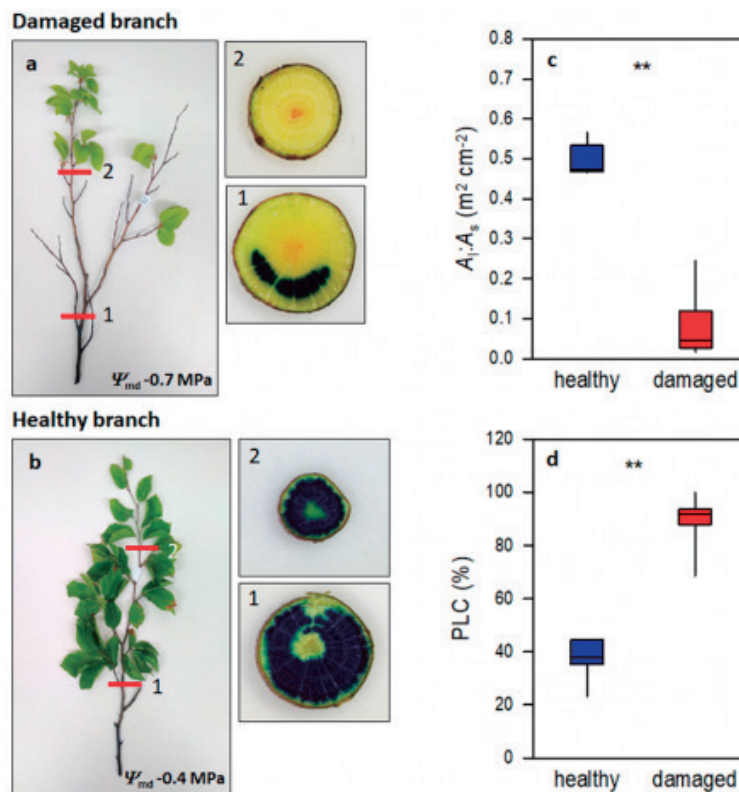
- Wide range of tree mortality due to extreme heat and summer drought in \*DACH region(Germany, Austria, Switzerland) in Central Europe, 2018 (Schuldt *et al.*, 2020)
  - \* First letters of representative German-speaking countries (D: Deutschland; A: Austria; CH: Switzerland, Latin: Confoederatio Helvetica)
    - Increase of 3.3°C during months of April to October compared to previous years (1961 – 1990) and increase of 1.2°C compared to record-breaking summer of 2013
    - The precipitation was also at its lowest compared to previous years and there has been a constant decline in Climatic Water Balance (CWB–potential evapotranspiration) since the 1960s
    - Early discoloration and leaf senescence of European beech trees (*Fagus sylvatica*), a deciduous tree species and signs of leaf discoloration in coniferous tree species Norway spruce trees (*Picea abies*) and Scots pine trees (*Pinus sylvestris*) over a wide area
      - The biggest impact was the mortality of Norway spruce trees, European beech trees, Scots pine trees, European silver fir (*Abies alba*) and oak trees (*Quercus petraea*, *Quercus robur*)
    - Through a NDVI video of 2003 and 2018, an analysis and research data of forest region of DACH region showed a serious phenomenon of tree mortality in 2018



<Figure II-2> Comparison of forest mortality in the DACH region based on NDVI analysis between 2003 and 2018

Source: Schuldt et al., 2020

- Compare and contrasting of xylem of European beech trees that went through extreme heat and drought over 3 different regions; Basel, Zurich and Schaffhausen in Switzerland, 2018
- Confirmed decline in conductance of xylem in damaged European beech trees

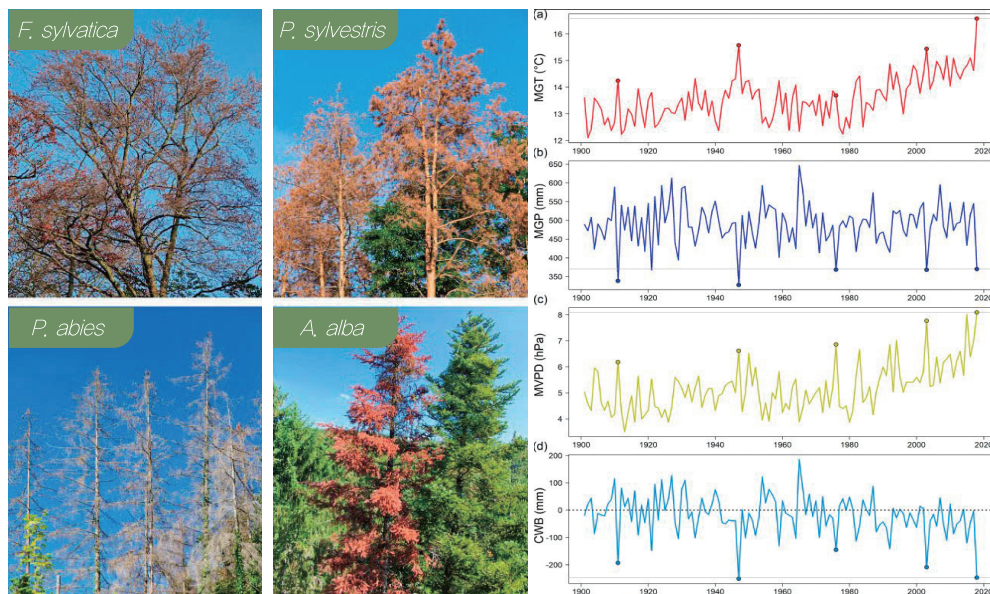


<Figure II-3> Xylem Conductance of Damaged Branch (2018)

※  $A_1:A_2$ : leaf-to-sapwood area ratio, PLC: percentage loss of conductance

Source: Schuldt et al., 2020

- Increase of mortality rate due to damages to metabolism due to high temperatures and vulnerable to invasion of insects and pathogens as well as large-scale beetles for the following year
- The number of infected tree with pathogens due to high temperatures in Switzerland from 2005 to 2019 reached 1 million cubic meters



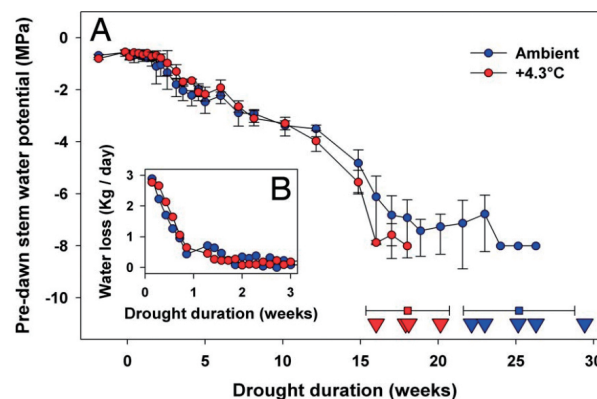
<Figure II-4> Photos of Mortality by Types and Changes in Temperature/Precipitation in Central Europe

MGT: Mean growing season air temperature	MGP: Mean growing season precipitation
MVPD: Mean vapour pressure deficit	CWB: Climatic water balance

Source: Schuldt et al., 2020

• Tree mortality of Pinyon pine (*Pinus edulis*) due to temperature (Adams et al., 2009)

- 28% high mortality rate of Pinyon pine grown at high temperature (approximately 4°C) compared to the control group
- The mortality period during drought caused by high temperature was 25 weeks (blue triangle) for control group. However, it was 18 weeks (red triangle) for high temperature group
- Caused by carbon deficiency due to respiratory overload (increased respiratory rate caused by high temperatures)

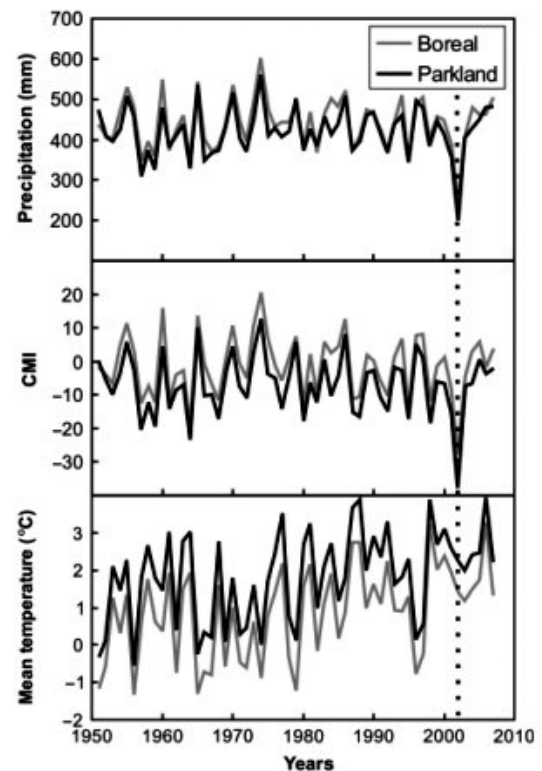
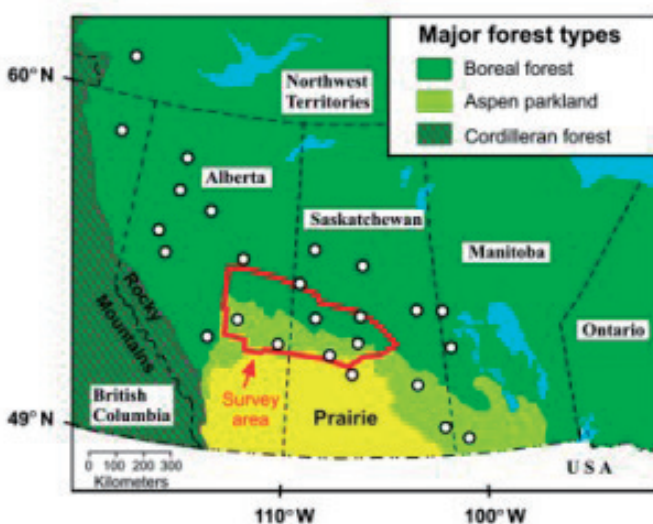


<Figure II-5> Analysis of Mortality Period of Pinyon pine due to High Temperatures

Source: Adams et al., 2009

## 2.2. Effects of Precipitation

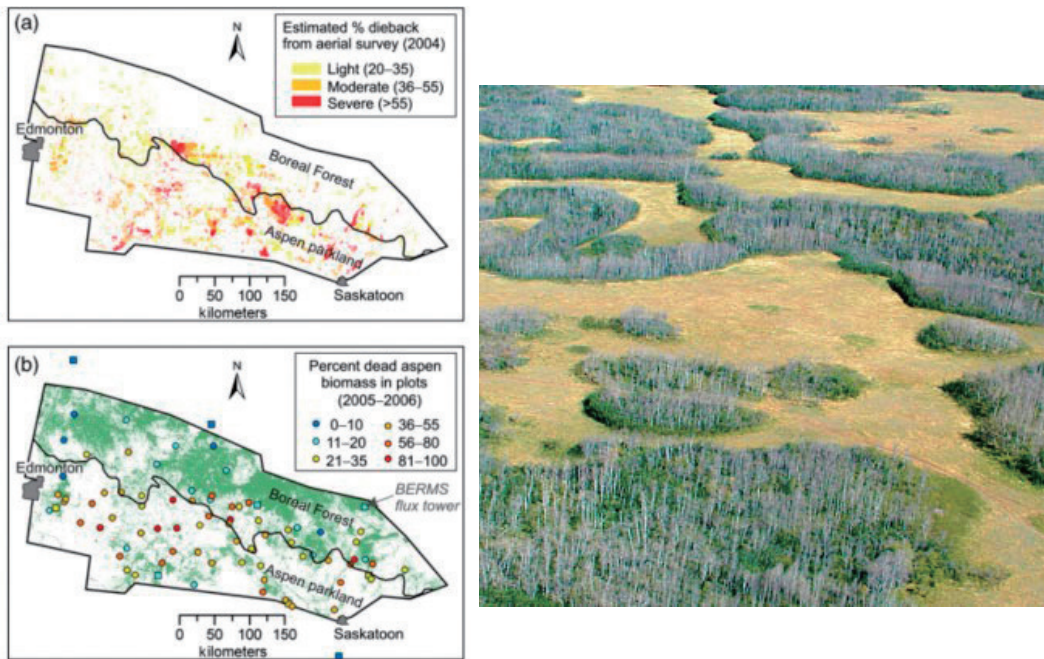
- After a research survey of 11.5Mha of Aspen forest, a broadleaved forest which is the boreal forest of Canada, total biomass loss due to tree mortality was estimated at 45 Mt (Michaelian *et al.*, 2011)
  - The main factor in decline of Aspen\* forest after 4 years (2005–2006) was severe drought (less than 50% of average precipitation) in 2001 to 2002
  - \* Most common species in North America where it is the most dominant broadleaved trees in Canadian boreal forests
- Importance of drought on the Northern Forest Carbon Cycle
  - Over 35% of dead biomass
  - Majority of biomass mortality occurred in the parks and southern edge adjacent to the boreal forests
  - Approximately 45Mt Broadleaved forest mortality (mostly Aspen) (relevant to 20% of overall biomass)
  - The estimated biomass mortality (29Mt) due to drought in the survey area, this corresponds to approximately 14Mt of total carbon content based on Aspen carbon content of 47% (approximately 7% of carbon pool of Canada's annual carbon emission)



<Figure II-6> Recent Extreme Drought in Canada

※ Drought-affected regions in Western Canada (red line, left) and climate trends in the survey area from 1950 to 2007  
 (vertical dotted line shows extreme drought period from August 2001 to July 2002, right)  
 Source: Michaelian *et al.*, 2011

- Serious forest mortality due to multiple factors such as damages to leaves and branches due to insects and fungus caused by drought

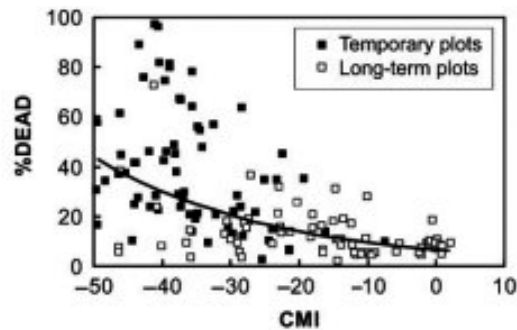


<Figure II-7> Photo of Regions of Aspen Forest in Saskatoon, Canada and Mortality

※ Total area of Aspen forest showing the mortality in Western Canada region affected by drought in 2004 (a) and biomass ratio of aspen tree mortality in the survey area from 2005 to 2006 (b) (left), Aerial photo of serious Aspen mortality (right)

Source: Michaelian et al., 2011

- The biomass rate of Aspen trees in Western Canada is a region most severely affected by the drought. In other words, region with the lowest CMI (Climate Moisture Index) is most affected



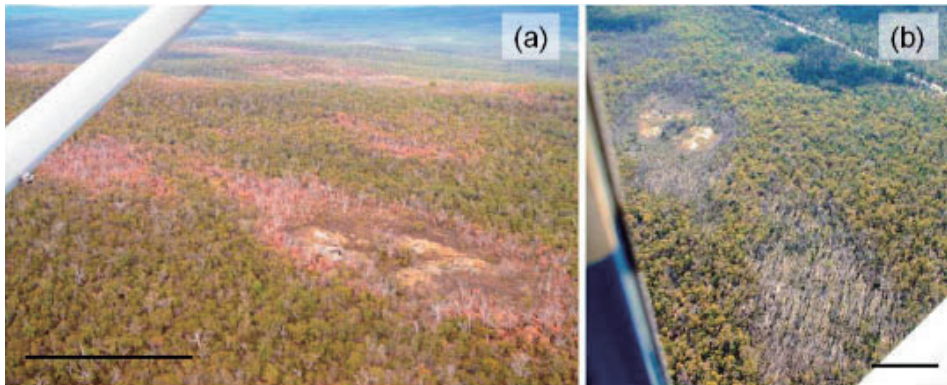
<Figure II-8> Relationship between the Biomass Ratio and Mortality in Aspen

※ Biomass (%DEAD) ratio of Aspen mortality between 2005 and 2006 in relation to the seriousness of drought based on the minimum annual value of CMI during the climate from 2000 to 2005

Source: Michaelian et al., 2011

- More than 70% mortality over an area of 16,500ha at the Jarrah forest of Southwest of Australia due to drought in 2011 (Ruthrof et al., 2015)
  - Compare and contrast of initial reaction of Eucalyptus (*Eucalyptus marginata*) and Corymbia (*Corymbia calophylla*) tree species that grow in highlands of (Northern Jarrah Forest) (NJF) after a drought
  - Sensitivity difference in drought stress of vegetation according to closure of pores, the difference in transpiration rate and vegetation soil environment
  - After 3 months of drought, Eucalyptus showed worsed mortality patterns than Corymbia

- Predicted changes to plant growth due to increased frequency of droughts
- The ability to close pores is higher for *Corymbia* than *Eucalyptus* during the initial stages of drought

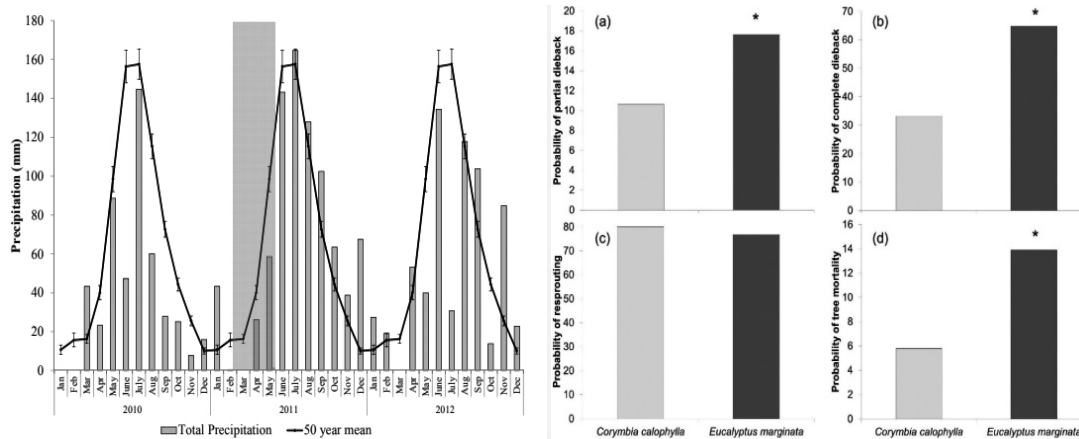


<Figure II-9> Aerial Photo of Mortality of Jarrah Forest, Southwest of Australia

※ Aerial photo of Northern Jarrah (*Eucalyptus marginata*) in Southwest Australia after 3 months (a) and 16 months (b) after the drought (scale bar; approximately 200 m)

Source: Ruthrof et al., 2015

- *Eucalyptus* (*Eucalyptus marginata*) are more vulnerable in land with limited access to underground water during a long-term drought
- *Corymbia* (*Corymbia calophylla*) possess strong resistant characteristics against drought compared to *Eucalyptus* (for example, controlling the osmotic pressure etc.)

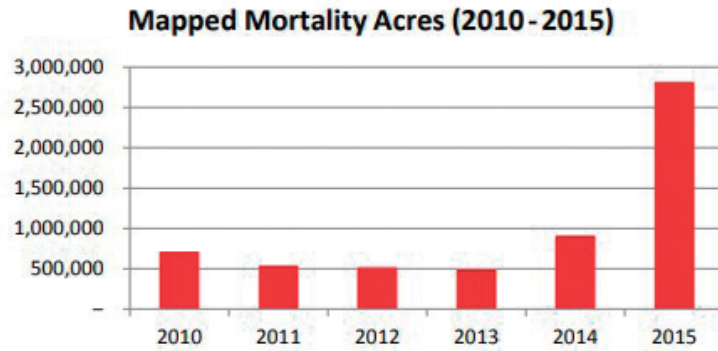


<Figure II-10> Monthly precipitation (2010-2012) and drought sensitivity between the two species

※ Compare and Contrast of Monthly precipitation and average monthly precipitation of Perth, West Australia (left) and mortality of *Corymbia* (*Corymbia calophylla*) and *Eucalyptus* (*Eucalyptus marginata*) (a) Partial crown mortality rate, (b) total mortality rate, (c) post-mortem germination, (d) total mortality due to drought in the Northern Jarrah Forest, Western Australia (right)

Source: Ruthrof et al., 2015

- Tree mortality in 2015 with approximately 29 million trees over 3 million acres of west region of Nevada, Sierra, South California of U.S. (USDA Forest Service, 2016)
  - Caused by severe drought, bark beetle and high tree density over the course of 4 years

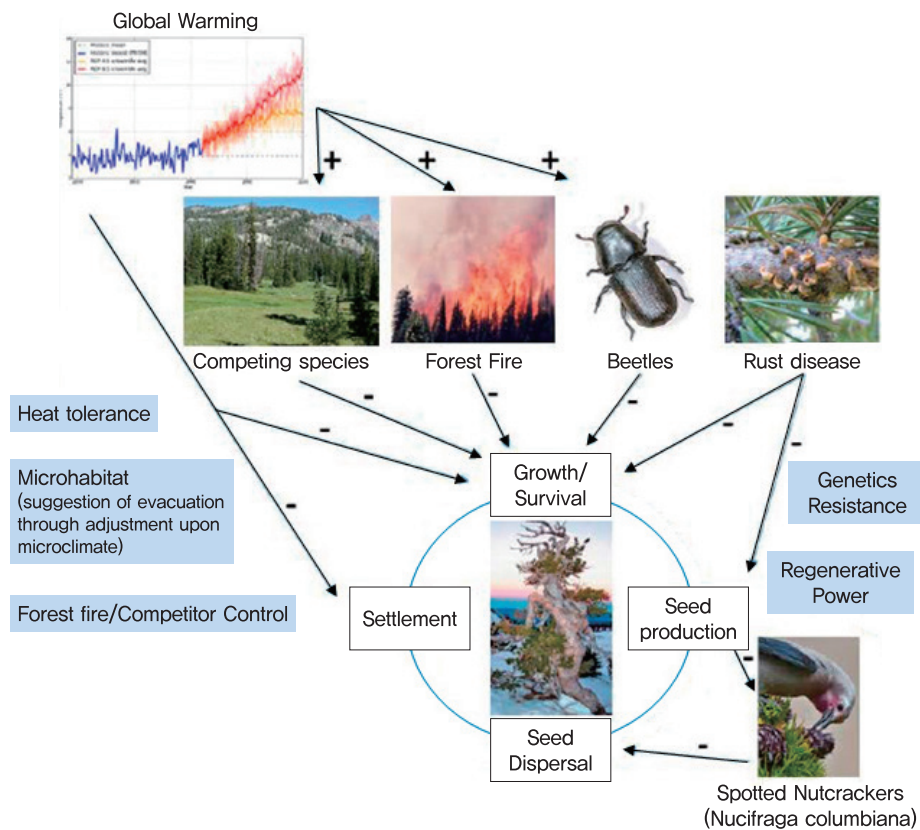


<Figure II-11> Area of Tree Mortality in California from 2010 to 2015

Source: USDA Forest service, 2016

### 2.3. Effects of Pests

- More than 50% tree mortality of white bark pine at Yellowstone National Park, U.S. from 1990 to 2007 (Hansen *et al.*, 2016)
  - Predicted to threaten 66% of habitats of white bark pine in the next 100 years



<Figure II-12> Conceptual Model in Interaction of white bark pine due to Climate Changes

※ Climate change directly influences establishment, growth, survival, seed production, and dispersal, and indirectly affects biochemical interactions that ultimately influence the survival of whitebark pine

Source: Hansen *et al.*, 2016

- White bark pine, WBP, *Pinus albicaulis*
  - Major constituent of alpine and subalpine forest of western mountains of North America, a significant subalpine species due to climate change
  - Decline in numbers due to mountain pine beetle (*Dendroctonus ponderosae*) and Eastern white pine blister rust
  - 53% white bark pine exists in Greater Yellowstone Ecosystem (GYE)
- Multiple factors threaten the persistence of whitebark pine under ongoing climate change

① Climate	② Competition
<ul style="list-style-type: none"> <li>· It is estimated that the average annual temperature of GYE will increase 3 to 7°C until the end of this century and snowfall rate in the subalpine regions will reduce by 20%</li> <li>· Out of the 8 species of coniferous trees in North Rocky Mountains, white bark pine trees are most susceptible to climate changes</li> </ul>	<ul style="list-style-type: none"> <li>· Competition among lodgepole pine, Douglas fir, subalpine fir, Engelmann spruce, and other species</li> <li>· According to the future climate scenario, subalpine fir is most adaptable to the high altitudes of GYE where it will compete with white bark pine</li> </ul>
③ Forest Fire	④ Mountain Pine Beetle
<ul style="list-style-type: none"> <li>· High mortality rate of white bark tree due to increase of serious fires in western regions of Montana</li> <li>· It is predicted that the frequency and size of the fires will gradually increase in the GYE region</li> </ul>	<ul style="list-style-type: none"> <li>· A native species that periodically invaded the western forest in the past caused serious mortality to the western pine species</li> <li>· Increase of disease outbreaks due to 1 year of lifestyle due to warmer winter and high temperature summers recently</li> <li>· More than 50% suffered from mortality at 95% of habitat of White bark pine habitat over the period from 1999 to 2007</li> <li>· According to future forecast, the white bark pine area of GYE will become more climate-friendly to Mountain pine beetles</li> </ul>
⑤ White pine blister rust	⑥ Seed Predation and Dispersal
<ul style="list-style-type: none"> <li>· Invasive pathogen (originally from Asia) that entered North America in 1910</li> <li>· Found in overall distribution of white bark pine trees and shows the worst numbers in northwestern regions of Rocky Mountain as the pathogen prefers cool and humid environment</li> <li>· It is predicted that the infection rate will reach 20–30%, and that the infection will spread to the rest of the area within the next 20 years</li> </ul>	<ul style="list-style-type: none"> <li>· It will spread by spotted Nutcrackers (<i>Nucifraga Columbiana</i>)</li> <li>· If seed production decreases due to the death of white bark pine, seed dispersal becomes difficult due to migration of spotted nutcrackers</li> </ul>

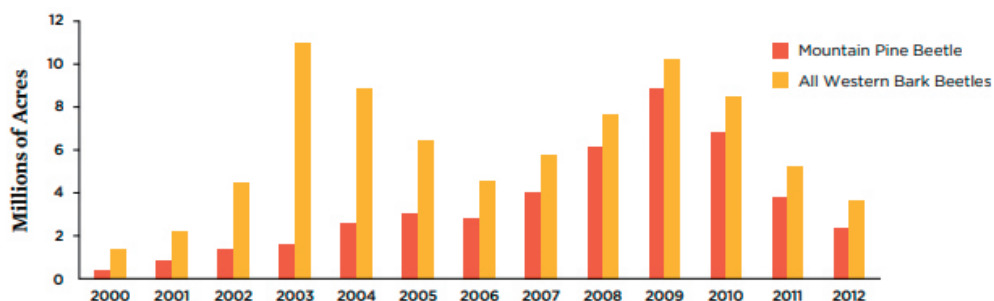
- Limiting factors in whitebark pine habitats, including climatic maladaptation, interspecific competition, forest fires, mountain pine beetles, and whitebark pine needle rust
  - Any climate changes that exceeds the natural scope of tolerance directly affects the settlement, growth and survival of white bark pines
  - Competitive species, forest fire, mountain pine beetles and needle rust has a direct negative influence on the growth and seed production of white bark pine
- Yellowstone National Park Committee is in progress with implementing protection measures based on survival and adaptability ecosystem of white bark pines

<Graph II-1> Conservation and Adaptation Mechanism against Threats to White Bark Pine Trees in Yellowstone National Park

Threat Factors	Adaptation Mechanism
Climate Change	Increased tolerance to climate change
Resistance to climate change (tolerance)	Improving the competitive relationship and increasing survival rate by increasing resistance
Interspecific Competition	White bark prefers moderate occurrences of fire
Forest fire	Mid-size trees (diameter at breast height 18~25m) possesses high tolerance
Pine Bark Beetle	Acquired disease resistance through natural/artificial methods
White bark pine needle rust	Algorithm analysis of alpine and subalpine vegetation in 2080

Source: Hansen et al., 2016

- **Tree mortality worth 460,000 acres in the western U.S. region from 2000 to 2012 (Funk et al., 2014)**
  - The main cause is the mountain pine beetle and the number increased in 2003 to 2005
  - Due to high temperature and drought stress resulting in weakening of the tree's defense system as well as shortened seed production period due to increase in temperature during winter season leading to infection trees in the higher altitude region and rapidly spread



<Figure II-13> Area of Tree Mortality due to Beetles in Western America from 2000 to 2012

Source: Funk et al., 2014

- **Mass mortality of pinyon pine due to pine bark beetles in south western U.S. (Allen-Reid et al., 2008)**
  - From 2002 to 2003, approximately over 1 year period; approximately 40 to 80% of pinyon pine trees suffered from mortality in New Mexico, Arizona, Colorado and Utah regions of the U.S. (more than 1,2 million ha of damages)
    - The damages started from 2000 to 2003 by Pine shoot beetle started to spread rapidly
    - The leaves changed to brown colors and dropped off where there were mix of pine trees and juniper trees affected by such damages. As species with slow growth rate, it will be difficult to restore to its original condition over the next several decades

- The mass mortality damage was caused by pine bark beetles, however depending on the growth status and landscape of affected areas; pests affected the damaged area where Colorado suffered damages from two types of pests



<Figure II-14> Mass Mortality of Pinyon pine due to Bark Beetle of Northwest Region of America

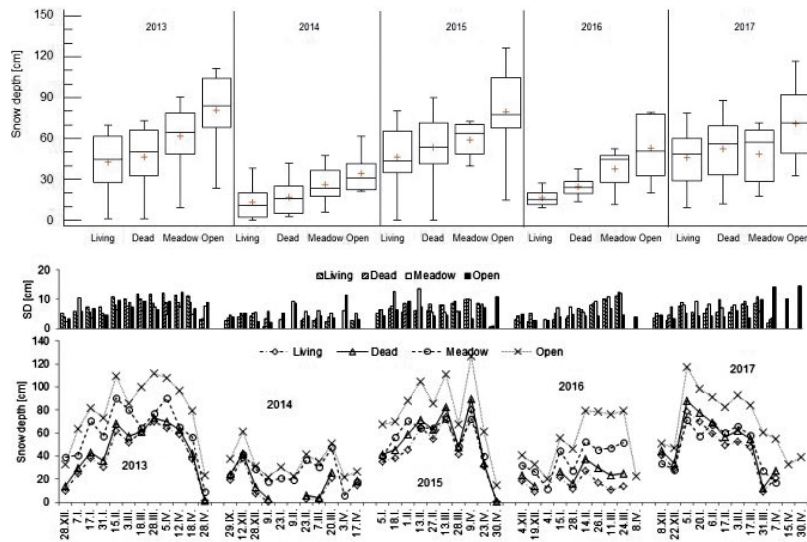
※ Pinyon pine mortality due to surrounding pine bark beetles in Jemez Mountains, New Mexico region (Photo from left: October, 2002; Right: May, 2004)

Source: Jensen, 2005

## 2.4. Effects of Biogeochemical

### • Analysis of effects between snowfall, snowmelt and mortality of Norway spruce in Slovakia (Bartik *et al.*, 2019)

- Norway spruce (*Picea abies*) that are the most dominant coniferous trees that consists of at least 40% of Slovakia forest faced the risk of extinction
- By analyzing the changes in snowfall characteristics (snow depth, density and Snow Water Equivalent [SWE]) during winter season from 2013 to 2017 (5 years) of Tatra mountains, Western Slovakia, studying the effects of dead wood has on snowfall and snowmelt
  - Categorizing 4 sites: The snow depth, density and SWE of Living, Dead, Open and Meadow
  - Confirmed significant differences in the living and dead sites after three winter seasons



<Figure II-15> Measuring Snow Depth

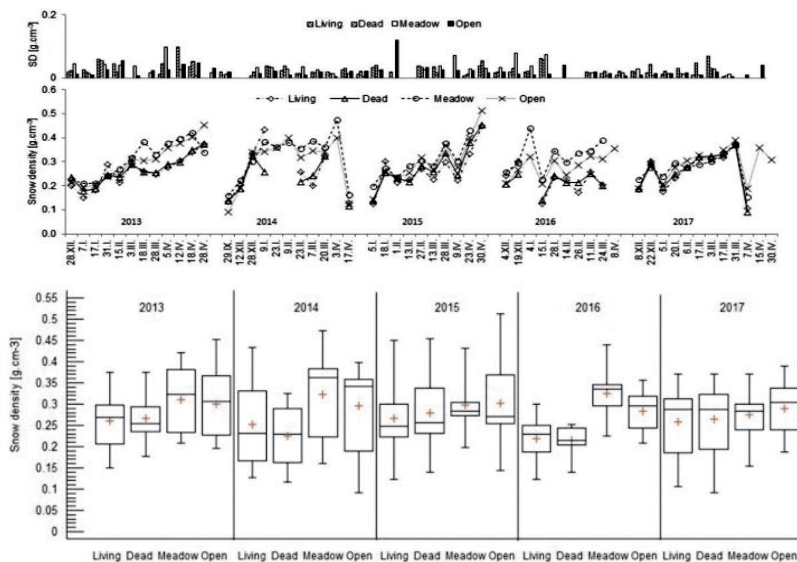
※ Average snow depth of all days and every regions with a winter measurement from 2013 to 2017 (5 years) and the snow depth for the whole of winter (below)

※ Snow Depth: Differs according to the climate conditions of winter of various sites such as wind, solar radiation (meadow had the most effect) where it increased in the order of Living<Dead<Meadow<Open

Source: Bartik et al., 2019

– After the degeneration of the forest (2013–2014), the snow depth, density, snow melt and SWE of forest mortality is high (increased by 25%)

· Snowmelt has increased by 16% since the first winter in 2013, with the cause estimated to be an increase in radiant heat



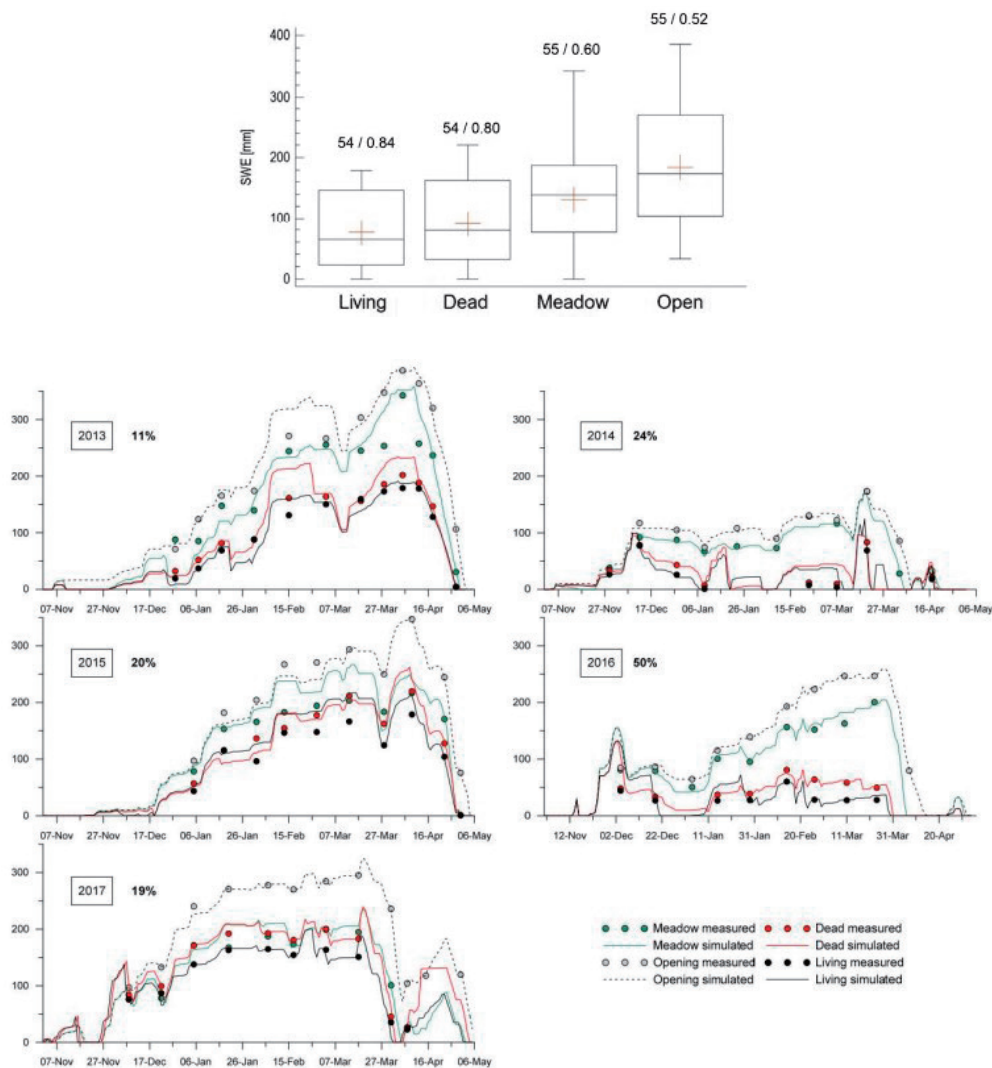
<Figure II-16> Measuring Snow Density

※ Snow density and changes within the site illustrated using standard density (above) and snow density for whole winter (below)

※ Snow Density: Due to warmer winter in 2014, the volatility is significant due to rapid increase and decrease Open sites usually showed higher numbers

There are differences in forest and open sites, however, is not statistically significant

Source: Bartik et al., 2019



<Figure II-17> Measuring Snow Water Equivalent (SWE)

※ The measured SWE value [cross is the average arithmetic, the numbers on top of the graph shows measured counts (54-55) and coefficient variation (0.52-0.84) (above) and the measured SWE and simulation value during the winters of 2013-2017 [distribution rate of SWE value of dead forest showed higher rate than average SWE during forest winter season] (below)

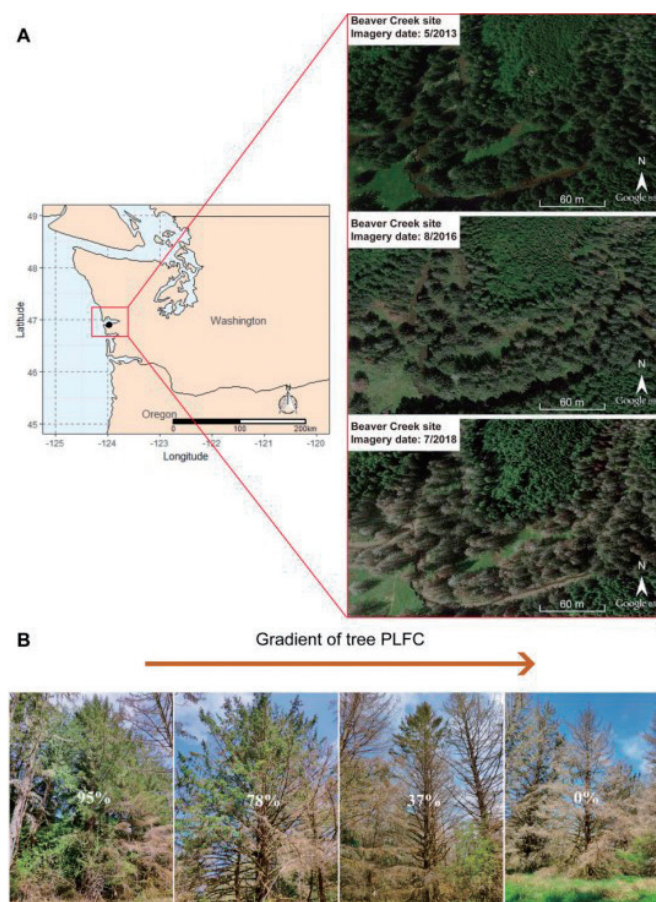
※ Value of Snow Water Equivalent (SWE, time in which snow starts to melt and its duration): increased in the respective order of Living<Dead<Meadow<Open

The snowmelt intensity of dead forest is 25% more higher than the Living  
Open sites has 31% higher melted snow than meadow site and 60% higher than Living and Dead forest sites.

Source: Bartik et al., 2019

- Increase mortality rate due to exposure of salt water of Sitka spruce (*Picea sitchensis*) at beach forest located in western Washington, U.S. (Zhang et al., 2021)
  - Coastlines are known as the weakest and most vulnerable ecosystem to climate change
    - Threatens coastal forest with low altitude
    - Reduction of tree growth (decreased crown leaves and broadleaved tree canopy ratio) and difficulties in regeneration resulting in forest mortality
    - Negative impact on the biogeochemical cycle due to vegetation, flow of water/carbon and changes in sediment transportation

- Analysis of mechanism related to rising of sea level due to climate change and mortality of Sitka spruce (*Picea sitchensis*) of coastal forest due to climate change
  - Studied the Sitka spruce (*Picea sitchensis*) of Beaver Creek coastal forest, Pacific Northwest of the U.S.
  - After removing the causeway in 2014 caused exposure to soil salinity due to invasion of tide and sea water
  - 78% of whole trees suffered from mortality within 4 years
- The major cause of mortality was due to leaves falling off resulting in decreased carbon fixation where it caused carbon deficiency as a result of constant depletion of Nonstructural Carbohydrate (NSC)\*
- \* Nonstructural Carbohydrate: Important role in growth and survival of plants where primary metabolic energy is stored in plant tissues in the form of sugar and starch
- Increased tree mortality due to climate change – induced sea-level rise, increased soil salinity, decreased precipitation, warmer summers, and multiple interacting factors

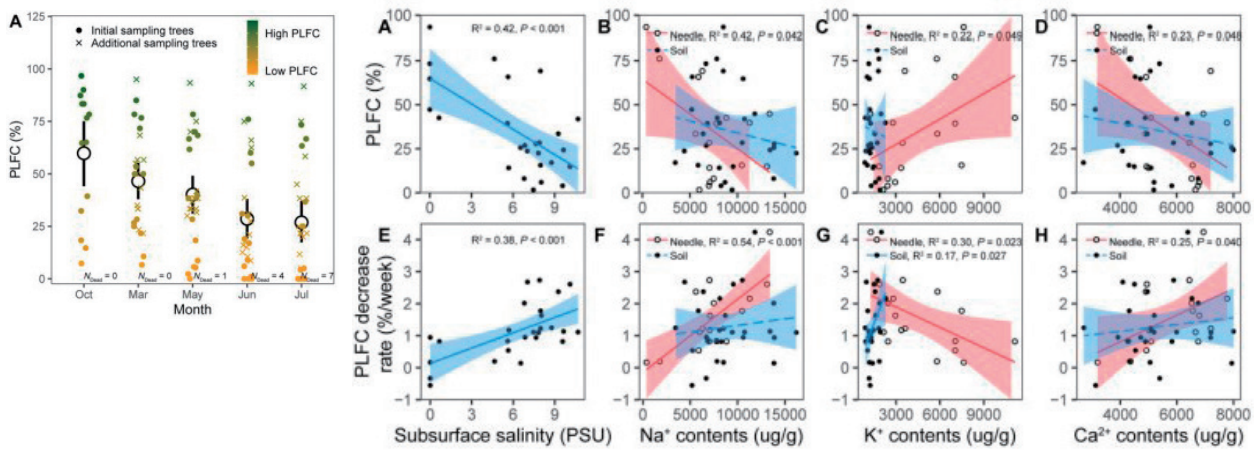


<Figure II-18> Photo of Mortality (A) and Mortality Progress (B) of Sitka Spruce at Beaver Creek

※ Estimation of tree mortality rate and its location. It is located at Beaver Creek, Washington State, in the Pacific Northwest of the U.S. (spruce trees in this location is suffering from mortality as seen in the above satellite photo after the causeway is removed in 2014) (A). Example of measurement of tree mortality rate (%) (B)

Source: Zhang et al., 2021

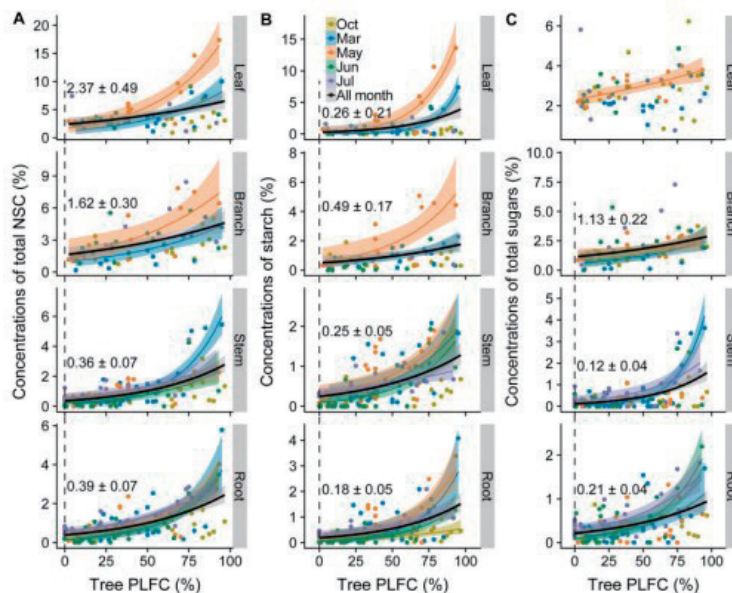
- The ratio of Percentage of Live Foliated Crown (PLFC)\* reduced to 66% from October 2018 to July 2019
  - The reduction of PLFC, increases soil salinity, sodium and calcium content in leaves and reduces potassium content
- \* Percentage of Live Foliated Crown (PLFC): the ratio of leaves on a tree



<Figure II-19> Monthly PLFC Ratio (top), Relationship between Soil Salinity, Ion and PLFC (below)

※ Tree PLFC changes over time (above) and correlation between leaf/soil salinity and mortality rate (below)  
 Source: Zhang et al., 2021

- NSC of all structure in March and May reduced with the decline of PLFC
- When the PLFC declines from 100% to 0%, the NSC value of a tree showed greater reduction in stem and roots (88% and 85.1%) than compared to leaves and branches (64.9% and 66%)
- The total starch value significantly reduced in all structures [leaves (94%), branches (73.2%), stem (81.6%) and roots (89%)] with the decline of PLFC



<Figure II-20> Correlation between PLFC (Percentage of Live Foliated Crown) and NSC (Nonstructural Carbohydrates)

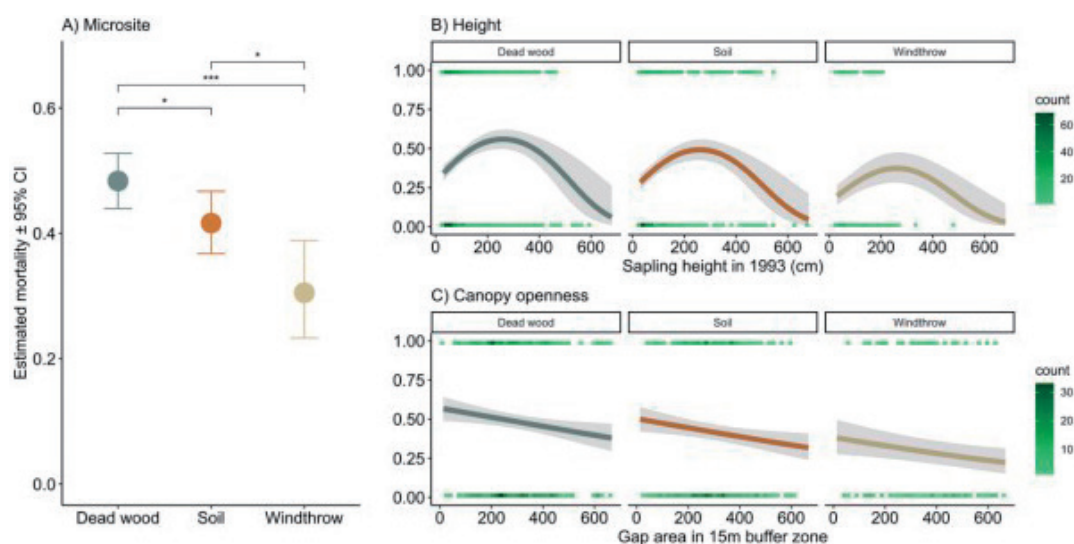
※ Relationship in the concentration of PLFC of leaves, branches, stem and root and total NSC (A), Starch (B) and soluble sugar (C). The colors of each panels are samples Months: October (Brown), March (Blue), May (Orange), June (Green), July (Purple), all of the months (Black line)  
 Source: Zhang et al., 2021

- Mortality due to exposure to salinity: increase of soil salinity, decrease of precipitation and multiple factors of a warm summer
  - If the condition of the crown is poor, the damages to the leaves are accelerated (if leaf ratio is low, it accelerates the decline of crown)
  - Reduced carbon fixation and using of stored carbon due to reduced leaf area
  - The constant decline of saved NSC increases the vulnerability of trees (25% or less PLFC resulted in decline in tree growth during dry summer)
  - The analysis of tree starch can be used as an indication for survival period and carbon deficiency due to exposure to seawater (starch, unlike sugar, will be depleted in all structures of dead trees)

• **Analysis of sapling mortality for 25 years at Norway spruce tree microhabitat\* at Carpathian, western Poland (Holeksa *et al.*, 2021)**

\* Microhabitat: crevices, under canopies, unobstructed soil, rotten wood and various landscapes

- Analysis of Mortality Rate of 1,304 saplings of Norway spruce tree over a period of 25 years of Babia Gora National Park at Carpathian Mountains, western Poland
  - Lack of research into long-term survival of young cases due to dead trees in a micro space
  - Categorization of microhabitat: dead trees, soil (undisturbed soil), mounds with strong winds
- Analysis Results of Mortality Rate of Norway Spruce Trees
  - Microhabitat: Dead Trees (49%) > Undisturbed Land (41%) > bank of ground (30%)
  - Height of Sapling: highest death rate (56%) for mid-sized sapling at 200 to 300 cm
  - With the increase of opening of canopy, the mortality rate decreased (effects of isolation and milk weed; increase of temperature due to direct sunlight and animals such as deer are unable to approach easily)

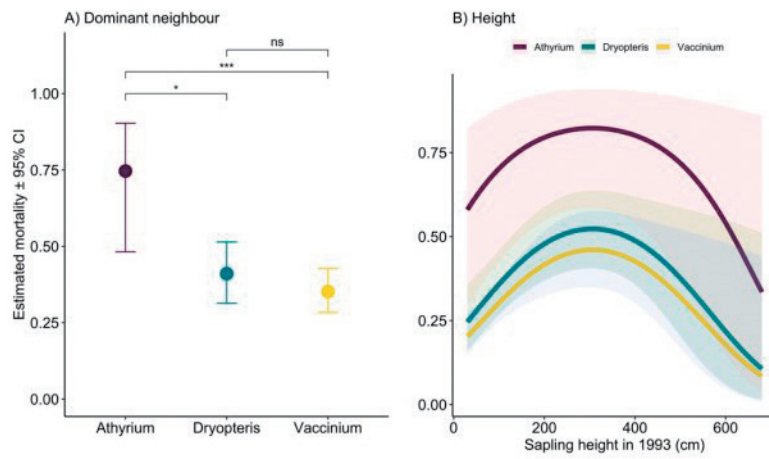


<Figure II-21> Relationship between Mortality Rate and Microhabitat, Height and Canopy Openness

※ Microhabitat, height of sapling, openness of canopy and mortality rate of Norway spruce sapling  
Overall microhabitat type (A), Tree Seedling Height (B), Canopy Openness (C)

Source: Holeksa *et al.*, 2021

- Mortality Factors of Norway spruce tree: green plantation on surface, canopy crevices and effects of proximity to trees



<Figure II-22> Relationship between Mortality Rate and Neighboring plant species

- ※ The mortality rate of Norway spruce saplings are related to neighboring plant species and the height of the sapling
  - ※ Plant Type: lady fern (*Athyrium distentifolium*) (76%) > Broad buckler fern (*Dryopteris dilatata*) (41%) > Bilberry (*Vaccinium myrtillus*) (35%) > neighboring plantation around *Athyrium distentifolium* is isolated
- Source: Holeksa et al., 2021



## Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



III

### Analysis of Researched using Plant Growth Substances of Alpine Coniferous Forest

- 3.1. Researches on Utilization of Various Plant Growth Regulators
- 3.2. Researches on Utilization of Plant Growth Substances and Jasmonic Acid

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## III. Analysis of Researched using Plant Growth Substances of Alpine Coniferous Forest

### 3.1. Researches on Utilization of Various Plant Growth Regulators

- **Applications in studies of coniferous tree growth and development**
  - Conditional research in root growth of Norway spruce trees (size of roots, types and concentration of auxin hormones, its processing methods) (OuYang *et al.*, 2015)
  - Comparative analysis of indole-3-acetic acid, gibberellin, and kinetin treatments in 3- and 16-year-old Norway spruce trees (Bleymüller *et al.*, 1976)
  - Showed significant growth with gibberellin treatment on White spruce aged 3 years (Galeano and Thomas, 2021)
- **Utilization in Somatic Embryo Development Researches of Coniferous Trees**
  - Somatic embryo technology was first introduced in 1965 with broadleaf tree species, Sandalwood (*Santalum album*), and in 1985 with coniferous species, Norway spruce (*Picea abies*)
  - Inducing somatic embryo development of *P. nigra* and *Abies* (Salaj *et al.*, 2019)
  - Development of experimental methods using optimum conditions for tree embryos of Nordmann fir (*Abies nordmanniana*) (Nawrot-Chorabik, 2016)
  - ※ Somatic Embryo: cell extracted during the developmental process with ability to differentiate into plant, its extraction method of somatic embryo is widely used in plantation production

### 3.2. Researches on Utilization of Plant Growth Substances and Jasmonic Acid\*

\* Substance that activates plant defense caused by biotic stress such as insects and fungal pathogens as well as abiotic stressors such as high temperature, drought and others.

- **Defense Role to Coniferous Tree Pests**
  - By treating seedlings and mature trees of Norway spruce with jasmonic acid, it increases pest resistance substances, increase of survival rate against pathogenic infections and extermination of beetles (Kozłowski *et al.*, 1999; Zeneli *et al.*, 2006; Schmidt *et al.*, 2011; Mageroy *et al.*, 2020)
  - By treating Scots pine (*Pinus sylvestris*) with jasmonic acid to create chitinase\* genes (Kanberga-Siliga *et al.*, 2017)
  - \* chitinase: enzyme that dissolves the external walls of fungus
- **Role in increasing stress tolerance to environmental stress of coniferous plants**
  - By replacing dark method\* with jasmonic acid for nursery in North America and Scandinavia for delaying growth and increasing tolerance to low temperatures (Fedderwitz *et al.*, 2020)
  - \* Promotes the growth of seedlings by providing a continuous night-like conditions
  - By treating seedlings of Red pine (*Pinus resinosa*) with jasmonic acid, not only does it promote pest resistance but also increases tolerance to low temperature stress (Connolly *et al.*, 2018)

– Jasmonic acid treatment on White spruce (*Picea glauca*) and through induced experiment of dryness stress test, analyzed the relationship between climate change and mortality due to pests (Perreca *et al.*, 2022)

• **Tolerance effects of environmental stress in various plants**

– Confirmed tolerance to low temperatures in Thale cress (*Arabidopsis thaliana*) (Hu *et al.*, 2017), tolerance to dryness in rice (Fu *et al.*, 2017), beans (Mohamed *et al.*, 2017) and broccoli (Wu *et al.*, 2011), and tolerance to high temperatures in rye grass\* (Su *et al.*, 2021)

\* Low-temperature adapted plant used mainly as feed for livestock



## Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



4.1. Limitations to Researches

4.2. Solutions

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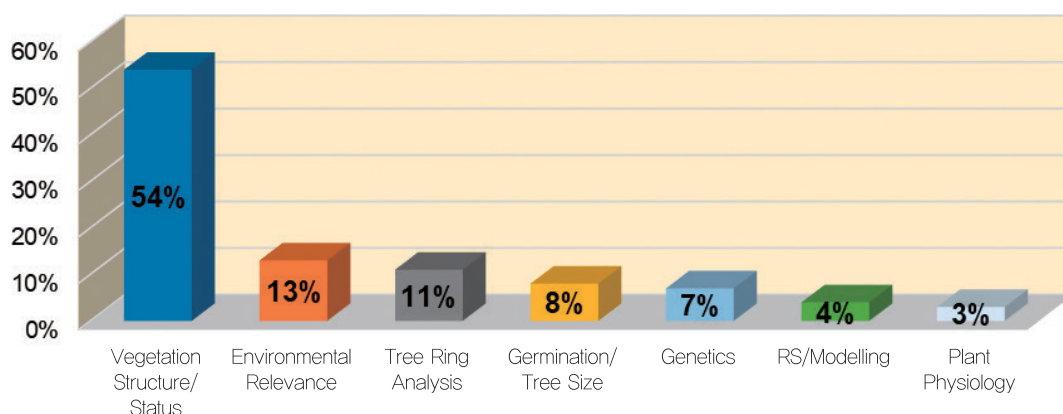
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## IV. Limitations to Researches and Solutions

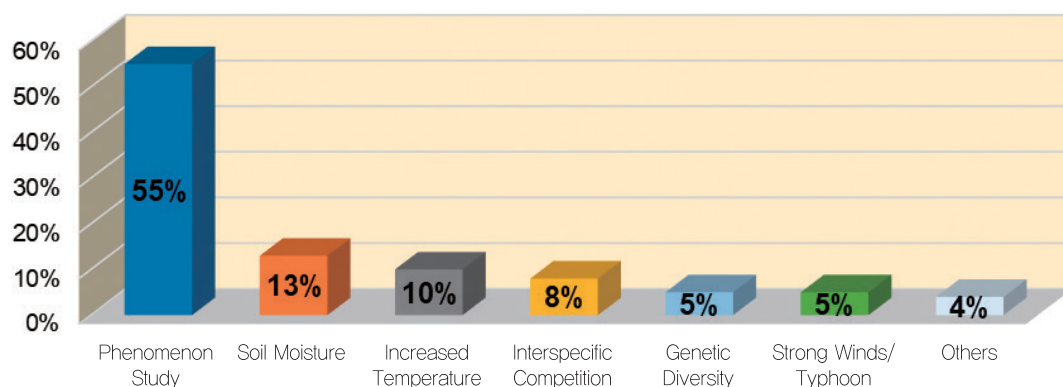
### 4.1. Limitations to Researches

- Supplementary research into response and conservation measures for the cause of decline of subalpine coniferous forest conducted on the vegetation structure and status as well as field surveys are necessary (analysis of 83 research papers and thesis papers)

Categorization according to research methods of alpine coniferous forest



Prepare adaptation methods by analyzing the various causes of decline of vulnerable species to climate change



Source: Ecosystem Adaptation Team, National Institute of Ecology, 2015

- Further study into conservation methods of vulnerable alpine ecosystem through expansion of research in vulnerable species to climate changes are required
- Prepare adaptation methods by analyzing the various causes of decline of vulnerable species to climate change

## 4.2. Solutions

- Genetic-level research across habitats for conserving vulnerable ecosystems under environmental change
- Habitat restoration and alternative habitat conservation strategies using adaptive conditions for vulnerable alpine ecosystems
- Expanding supplementary research on vulnerability assessment and conservation strategies for vulnerable alpine ecosystems—such as yezo spruce (*Picea jezoensis*) and Khingan fir (*Abies nephrolepis*)—based on adaptation studies of Korean fir (*Abies koreana*)
- Permanent conservation and climate-adaptive species development for vulnerable alpine ecosystems, including *Abies koreana*



## Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



# Future Research Direction and Summary

5.1. Future Research Direction

5.2. Summary

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# V. Future Research Direction and Summary

## 5.1. Future Research Direction



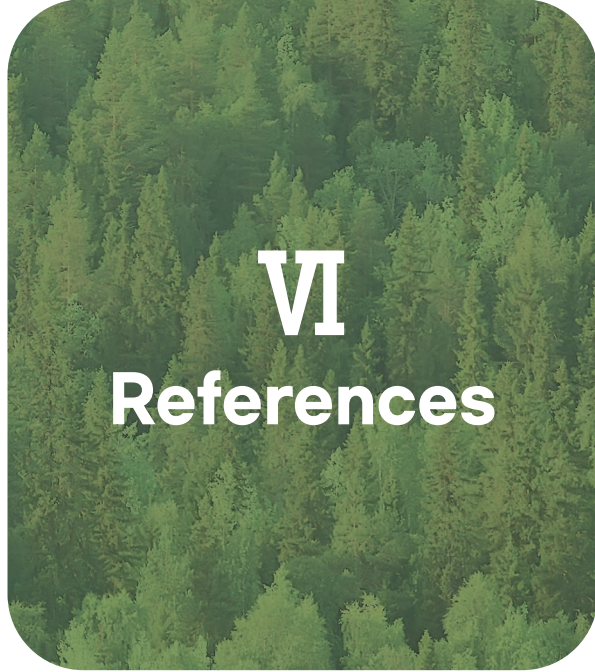
## 5.2. Summary

- Subalpine coniferous forests are rapidly declining all over the world due to climate change causing weakened defense system together with insect infestation
- Plant growth substances contribute to the growth and development of coniferous trees, while jasmonic acid enhances defense against pests and improves tolerance to environmental stress
- In order to conserve the vulnerable subalpine ecosystem due to climate risks, further researches into utilizing plant growth substances is absolutely necessary
  - Further development and application of technologies for inducing somatic embryogenesis through tissue culture
  - Development of adaptive technology by establishing an enhancement conditions for resistance to environmental stress





## Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



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## Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



# Reference Materials

Materials 1

Materials 2

NATIONAL INSTITUTE OF ECOLOGY

# Analysis of Research Trends in Conservation Technology for Vulnerable Alpine Ecosystem



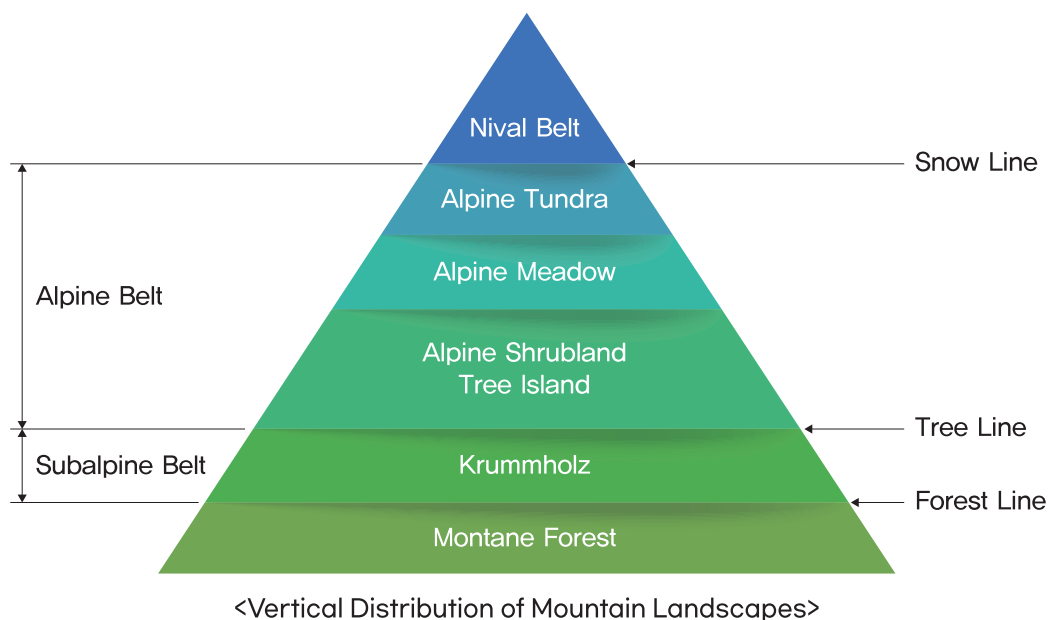
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NATIONAL INSTITUTE OF ECOLOGY

# Reference Materials

## Material 1. Categorization and Characteristics of Subalpine Zone

### ■ Categorization and Characteristics of Subalpine Zone

- It initially started with American ecologists, **Weaver and Clements (1983)**, who classified the forests into coniferous forests of uplands and **boreal forests** of extreme low temperatures
- Usually, it is differentiated into mountain forests, subalpine and alpine zones; however, it is necessary to classify it by considering the regional vegetation status, climate, ecosystem structure and characteristics



### ■ Definition of Subalpine by Regions

- Europe: Areas with below the timberline with less than 5 m tall **scrubs** and birch trees due to stunted growth caused by the climate (**EU, CORINE; Coordination of information on the Environment**)
- U.S.: Evergreen conifers such as spruce, fir and pine trees dominates the region where its elevation is at approximately 2,900 to 3,500 m (Colorado region) with short season growth. The climate is characterized by heavy snowfall, low temperatures and strong winds (**USDA: United States Department of Agriculture**)
- Japan: Lies in between high altitudes and mountains where its elevation is approximately 1,700 to 2,500 m in central Honshu, mainly consisting of conifer trees such as fir species (environmental)

## ■ Climate Change and Subalpine Ecosystem

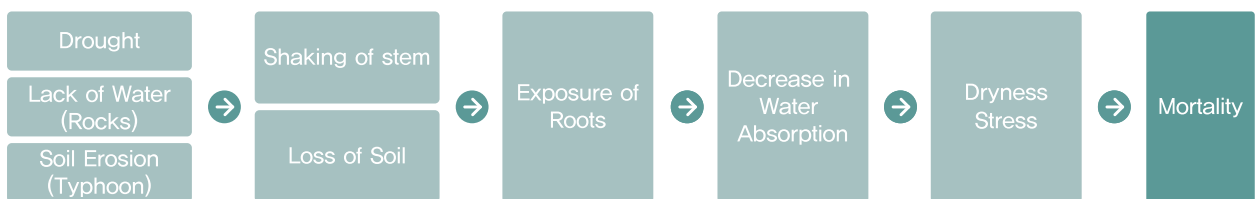
- Subalpine regions, along with polar regions, are an ecosystem that is sensitive to changes in the climate where many species have smaller distribution resulting in many classified as endangered and/or exotic
- Many that live in the subalpine regions have been adapted to living in low temperatures for a long time therefore a sudden rise in temperatures can be a serious complication for growth
- Due to extreme climate change such as extreme heat, typhoon, flooding; it not only increases the likelihood of damages from flooding and landslides. Also, it is predicted that temperature rise increases the activity scope of pests which will only add to the existing problem

## Material 2. Research and Analysis into Habitat of Vulnerable Alpine Ecosystem (Hallasan)

### ■ Effects of Stony Slope

- After growing into saplings in the stony slope regions, they had difficulties in growing into a mature tree due to difficulties resulting in tree mortality
- Due to drought, lack of water, soil erosion (wind, typhoon) and unstable roots leading to exposure of roots resulting in tree mortality

※ Stony Slope: a rocky habitat with weak soil and lack of organic matters



Typical stony slope  
(Youngsil, Hallasan)



Dead trees in stony slopes  
(roots above rocks)



Alive trees in stony slopes  
(roots between rocks)

### ■ Effects of Slopes

- The death rate of Korean fir (*Abies koreana*) trees on the east slope (Jindallaebat) and west slope (Yeongsil) with a slope less than 20° increases rapidly due to wind, snowfall and dry air. The distribution of trees varies depending on the slope of the valley.



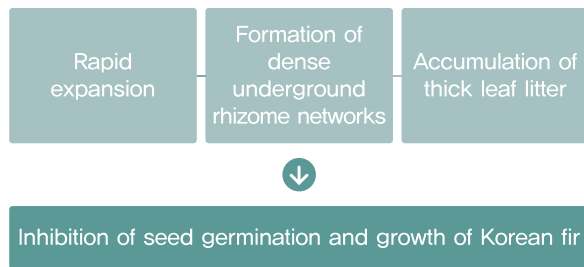
Dead trees on west slope of Hallasan



Distribution of trees according to slopes of valley

## ■ Effects of Jeju dwarf bamboo (*Sasa quelpaertensis*)

- Mostly distributed between 600 and 1,700 m on Hallasan Mountain; its rapid expansion driven by global warming poses a threat to biodiversity.
- Korean fir (*Abies koreana*) seedlings are commonly found on gentle slopes (5° – 20°), but their growth is inhibited by dense coverage of Jeju dwarf bamboo.



Jeju dwarf bamboo and Korean fir in an alpine zone

## ■ Expansion of temperate forest species

- Expansion of pine forests driven by northward shifts of southern distribution limits and upward movement in elevation due to climate change.
- Rapid increase in temperate deciduous forest species (e.g., Japanese oak and wild cherry) in alpine regions as a result of climate change.



Rapid growth of pine trees above 1,600 m above sea level



Increase in temperate deciduous forests in alpine zones



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