Monitoring Health of Forests: Locating Bark Beetle Infestations Using Satellite Images

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1 Motivation

Having had first hand experience in seeing how hard it is for forest owners to fight against bark beetle infestations, I was inspired to use my knowledge gained here in Edinburgh to try and find a creative solution to help local authorities address the issue. By using satellite images I want to develop a classification system that would be able to recognise areas affected by the beetle and help local authorities by providing coordinates of damaged locations.

2 Introduction

Forests are an important factor in preserving local as well as global ecosystems. They account for 75% of the gross primary production of Earth's biosphere, and contain 80% of Earth's plant biomass. Their importance has only increased with the rise of global warming awareness as they can maintain local climate and act as a natural shield against the spread of sahara and other less inhabitable geographical types which are spreading as a consequence of our ever-warming

Earth. However, forests are just like any other living organism, prone to various damaging factors, from natural disasters caused by heavy storms and droughts, to various infections and pests, such as bark beetles, which can take advantage of weak trees and grow in numbers to a degree when they can present serious issues even for healthy forests.
These attacks can seriously damage forests and recent outbreaks have shown unprecedented intensity, impacting the structure of the whole ecosystem. Since the late 1970s, irruptive outbreaks of these insects have affected millions of hectares of trees in North America and Europe, mainly focusing on conifer forests, with cascading consequences for ecological systems (Bentz et al. 2010; Seidl et al. 2014). These consequences are severe for the whole ecosystem - they have an immediate impact on the wild-life as the death of trees severely disrupts the food chain and decimates local populations and forces them to migrate. This can further expose the landscape to more critical changes - as the trees die, other sorts of vegetation can replace them. This means that the climate structure of the area can severely change, areas can become warmer as forests have served as a natural shield against the climate change.
Such attacks of course also represent a burden for the people, impacting various different levels of their lives, but most severe is the economic impact on the lumber industry.
The main predisposing factor causing the spread of aggressive bark beetles are extreme climatic conditions. Hurricanes, episodes of droughts, wildfires and storms destroy and weaken the trees to the extent that they become ideal breeding grounds for the beetles.
As trees become weaker, their immune system drops and so they become a much better prey for bark beetles and other pests. Once the population of beetles increases dramatically, they start posing a serious threat to the whole of the forest, including the healthy trees as their immune system is out-numbered by the attackers and cannot protect them anymore.

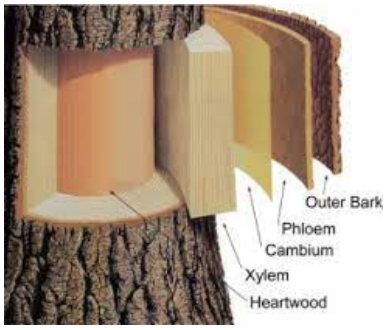
3 Bark Beetles

3.1 Who are they?

Bark beetles are tiny organisms, averaging approximately 5 millimeters in size. There are many different known species, many of which are not particularly harmful to forests as they only feed off the dying and unhealthy trees and contribute to the natural cycle of forests by helping with decomposition of dying trees. However, there are a handful of species, which are more aggressive and can feed on healthier trees, especially conifers. As the name suggests, the majority of beetles predominantly feed in the inner bark (phloem) layer of trees.

While some beetles breed in only one species of tree, there are some that can feed off almost any tree. Bark beetles often attack trees that are already weakened by disease, overcrowding, conspecific beetles, or physical damage. In

(a) Bark Beetle



(b) Tree structure

Figure 1: Showing the Bark Beetle in figure a, and the structure of the tree in figure b.

defense, healthier trees may produce sap, resin or latex, which often contain chemicals that can kill the beetles. Sap is one of the first lines of defense of pines against the beetles.
However, when in large numbers, the sheer number of beetles can overwhelm the tree's defenses which can lead to death of the tree.

3.2 Life Cycle

Bark beetles go through four stages of life: egg, larvae, pupae, and adult - similar to the one of a butterfly. Generally, adults bore into a tree and lay their eggs in the phloem of the tree, which usually occurs at the end of Summer. Once the eggs hatch, the larvae then live in the tree, feeding on the living tissues below the bark, often leading to death of the tree by cutting the water supply. At the end of the larvae stage chamber-like structures are constructed under the bark which serve as a place for the pupae to overwinter until they are ready to emerge as adults, which then repeat the process.

3.3 Attack on Trees

As it was explained above, the beetles attack the tree by feeding on the inner bark and as they consume enough of the inner tissue it girdles the tree, and cuts off the spread of water and nutrients. There are three stages of drying out the trees as a consequence to the bark beetle attack. The initial stage of the attack is the so-called green-attack stage, where the crown of the tree visually still looks healthy, although by the time of attack, the tree is already weakened. Red-attack stage begins when the crown becomes thinner and the needles change their colour to yellow or red-brown, which is the consequence of

the cut off water supply. Then follows the gray-attack stage when the needles fall off completely and the tree dries up. During these attacks the trees would fight back against the beetles by releasing sap, resin or latex, which contain chemicals fatal for the beetles.

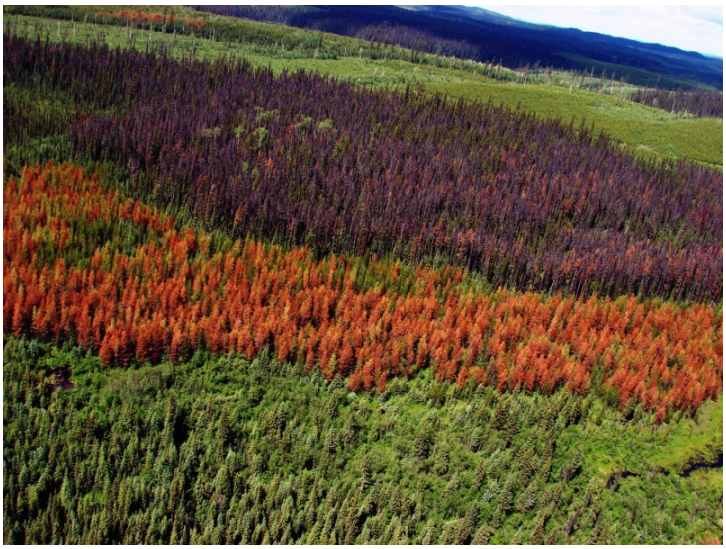


Figure 2: Forest infestation: red-attack and grey-attack.

4 Background

In Slovenia the legislation puts the responsibility of keeping forests healthy in the hands their respective owners. It aims at preventing outbreaks of pests and various diseases by ensuring the landowners will prevent such spreads early on. While the aim is very important and helpful, there is no efficient way of keeping track whether the owners have complied with the legislation or not. The only way for the local authority to do that is to send people in forests where they manually mark weakened and broken trees that need removal, and later to check them manually again.

4.1 Current Solutions

From the research conducted to date, I have not found any solution that allows local authorities to track bark beetle infestations solemnly using satellite images. There are several papers available showing how satellite images can be used but in cooperation with the airborne data obtained from planes that flew across different regions at different heights. However, flying a plane across a desired

field can be rather pricey, especially if the whole of the land needs to be covered. It does not surprise then that the local authorities still use the manual marking and locating rather than any sort of software. However, the models developed with this approach have shown some very impressive results, especially because they have been able to start recognising trees that are in 'green-attack' phase, meaning that they have not started changing colour yet.

4.2 Idea

In my dissertation I would like to research if there is a possibility of using publicly available satellite images for developing a classification model that can distinguish bark beetle infestation locations across the forests. So far I have been discovering resources that I could potentially use for accessing satellite images and have applied for their student packages that allow full functionalities of the platform. I am currently in the process of locating areas that have been affected by bark beetle infections in the past so that I could then learn how to access that specific region at a particular time frame in the past when the bark beetle outbreak was actively happening. Once the data is collected I will then need to label it manually using proposed tools.