Summary

The formation of the wind damages (windthrow, blowdown) is controlled primarily by the occurrence of high-speed winds. Due to the strong wind impact, the tree can be broken or uprooted. In the 1st type of tree mortality, there are only minor geomorphic and pedogenic consequences. In the 2nd type of tree mortality, some of the soil material attached to its root system is lifted and deposited on the ground surface in the form of a root plate. These forms are unstable and subsequently deteriorate, leading to the formation of pit-mound topography, i.e., adjacent pit-mound pairs of various density per ha, where each pair represents remnants of one root plate. The tree uprooting process and its outcomes can be considered an expression of biomorphodynamics, i.e., changes in landforms, activity of geomorphological processes, and transport caused by living organisms.

The wind-driven forest damage, together with resulting landforms (root plates, pit-mound topography) can be studied in different spatio-temporal scales, with the use of various techniques and approaches, such as field mapping, soil sampling, geophysics, dendrochronology, and using digital approach through remote sensing (RS). The advantages of employing remote sensing over other approaches are: 1) substantial volume of RS data collected nowadays by national agencies, out of which a large part is available in an open domain, 2) the RS data consistency supporting a large variety of strategies, workflows, and analytical and modeling scenarios, and 3) defined intervals of RS data acquisition enabling analysis of the phenomena changeability over time.

The main objective of the thesis is to develop a quantitative and qualitative methodology for using remote sensing data to assess the impact of windthrows on the slope biomorphodynamics. This methodology was proposed for three components required in the analysis of wind-related biomorphodynamics, i.e., windthrow areas, root plates of fallen trees, and pit-mound topography. The author tested whether the RS data can be effectively applied to map these components with a high spatial precision, on the level of accuracy enabling to decipher the environmental aspects of the wind - trees - relief and soils interactions. Research was carried out for the mid-latitudes mountainous coniferous forests of the Polish Carpathians (Babia Góra National Park and Gorce National Park) and the American Rocky Mountains (Colorado Front Range).

The blowdown mapping in the Rocky Mountains was based on the change detection using pre- and post-event images. Using the change vector analysis, changes between images are described using two parameters: magnitude, representing the amount of change, and direction, referring to the type of change. The author computed the differential image composed of 12 bands, and then calculated *mgt* and *drct* rasters for 66 possible pairs of differential image bands. Different *mgt* and *drct* thresholds were tested to provide the best possible accuracy and the lowest false positive rate (FPR). The final result was obtained by combining the direction and magnitude rasters. The most effective output was based on Sentinel-2 band pairs 11 and 12, together with $40° < drct < 47°$ and

mgt > 0.1, having the TPR of 66.04% and FPR of only 0.89%. These results can be adjusted to higher TPR, however this is connected with the FPR increase.

Both root plates and pit-mound detection were based on LiDAR data and the raster models derived from them. For root plates, analyses were carried out in the 0.25 m resolution, while for pit-mound topography three DTMs with resolutions of 0.1, 0.25 and 0.5 m were tested. For root plates, the author created the differential model (DM) representing the height of root plates, fallen trunks, and dense understory vegetation by 1) creating the Digital Surface Model (DSM) through interpolation of the points being the last returns of the laser beam with a normalized height < 2 m, and 2) subtracting the DTM. For both methods the position of forms was extracted using closed contour lines, and applying various classification methods. For treethrow pits and mounds, the objects were labeled basing on the location of the highest and the lowest points within the closed contour line polygons. For root plates, the closed contour line polygons were labelled as "root plates" or "artefacts" using a set of parameters computed for each polygon and comparing multiple filtering rules to select the most effective one. Regarding the biotransport, the author proposed two approaches to estimate the volume of root plates using the above-described differential model. Having the most accurate root plate boundary, the volume was estimated using the contour lines (CNT) or zonal statistics (ZS) approach. The results were validated using root plate volumes calculated based on the field measurements (FM) and the equation for the volume of a half ellipsoid. This allowed to calculate the volume of the soil volume transported within root plates of uprooted trees. All described workflows were automated using R programming language. The root plate detection rate was 79.1%, 71.2% and 70.3% for three investigated 100x100 m study plots, respectively. The root plate volumes computed with the RS-based approaches were in a similar range to the ones estimated using the field data. The mean calculated biotransport was the highest when using ZS, lower for CNT, and the lowest for FM. Pit-mound pairs detection rate was at the level of 90.6% and 85.7% for two study areas, whereas the highest detection rate for pits reached 96.9 – 95.2%, and for mounds – 93.8% - 90.5%.

The methods proposed in this thesis are novel in several aspects, which include: 1) proposing the root plates and pit-mound topography mapping workflows based on LiDAR data, 2) developing the techniques of single root plate volume estimation, based on LiDAR data, 3) implementing the change vector analysis for the blowdown detection for the first time in North America, 4) preparing scripts in R programming language to automate all the workflows, and 5) presenting the detailed exploration and evaluation of factors affecting the quality of these methods outputs. The presented environmental insights contribute to the fields of geomorphology, soil science, and forest ecology through: 1) exploring and explaining the spatial distribution patterns of root plates and pit-mound topography, 2) quantifying the biotransport driven by tree uprooting, and 3) providing the analysis of to-date unexplored 2020 wind event in the Colorado Front Range.

Keywords: windthrow, tree uprooting, biomorphodynamics, LiDAR, Sentinel-2, change vector analysis, R programming