European-wide ecosystem responses and their vulnerability to intensive drought

Chen, Q.

Summary

In recent years, Europe has experienced a series of extremely hot and dry summers (2003, 2010, 2013, 2015 and 2018). These droughts cause negative effects on vegetation growth, such as reducing photosynthesis and productivity of vegetation. Severe drought threatens the regular physiological functioning of vegetation and leads to vegetation mortality. Droughts are expected to increase in frequency, duration, and severity across wide regions in the coming decades, potentially increasing risks to the human system as a result of the disturbed ecosystems worldwide. This leads to major societal impacts, as forests provide essential ecosystem services to the human system. As such, reduced productivity and tree mortality can have a significant impact on not only on the ecosystem structure and functioning, but also on global biogeochemical cycles, and ecosystem services provision.

To mitigate these risks, it is urgent to build an understanding of ecosystem responses to drought and identify the most vulnerable ecosystems. Remote sensing, with its large-scale and long-term monitoring, has proven to have enormous potential in drought impact analysis. However, there remains a significant gap in our understanding of ecosystem responses to drought. Specifically, previous analyses focused on the long-term correlation between vegetation growth and drought as indicated by spectral indices. Such analyses fail to link individual drought characteristics to ecosystem damage features and therefore are not able to identify mechanisms of impacts. The research described in Chapter 2 addresses this limitation by developing a new framework to characterize drought events and the subsequent damage events in vegetation by their onset, duration and severity simultaneously. This allows the relationship between drought and vegetation damage to be analyzed in detail by establishing links between multiple drought characteristics and vegetation damage characteristics. This study showed the various vulnerability patterns of ecosystems in the Netherlands and Belgium during the 2018 drought. In summary, a multi-faceted framework to evaluate ecosystem vulnerability was proposed and tested in this study.

With this framework, a quantitative assessment was performed (described in Chapter 3) to evaluate the drought vulnerability of 21 ecosystem types across Europe. In general, the trend was to have earlier, longer and more severe damage when droughts were earlier, longer and more severe. However, this research also revealed that vulnerabilities to drought vary significantly across ecosystem types. Specifically, irrigated croplands are at extremely high risk when facing intensive droughts, while forests with high diversity show the lowest vulnerability against increasing drought conditions. Furthermore, most ecosystems showed a non-linearly exacerbating vulnerability to intensified droughts. With droughts likely becoming more widespread, prolonged, and extreme in the coming decades, it was summarized that mitigation strategies are necessary in particular for the most vulnerable ecosystems.

With the advanced capabilities of the multi-faceted framework to evaluate drought impacts on vegetation growth across Europe, a scientific understanding of plant regulatory strategies underlying drought resistance of ecosystems was investigated (described in Chapter 4). In this study, for the first time, remote sensing was utilized to detect drought strategies in ecosystems across Europe based on three key physiological aspects (stomatal, water content and carbon regulation), that are associated with the critical carbon and water regulation processes in plants. Divergent strategies were found in ecosystems during drought, including water saver vs. water spender, isohydric vs. anisohydric plants and biomass keeper vs. leaf shedder strategies. These strategies detected from remote sensing can provide real-time parameters to prediction models at large scales and facilitate future ecosystem management.

By linking plant strategies with physiological responses estimated from remote sensing, the impact of these plant strategies on tree mortality during drought was examined across Europe (described in Chapter 5). Here it was discovered that the early and high reductions in canopy water content and leaf area are associated with higher mortality in forests, which suggests these two indices can provide early warning signals for tree mortality. Hydraulic failure might have a large impact on forest mortality as a large number of dead trees with linked to a high reduction in canopy water content during the drought 2018 across Europe. This study highlights the potential of remote sensing in elucidating mortality mechanisms and provides the basis for predicting tree mortality on a large scale in response to climate change.

In conclusion, this thesis reveals European-wide ecosystem vulnerability based on ecosystem responses. As more frequent and severe droughts are expected in the future across many regions of the world, a wide range of ecosystems will become more vulnerable and even collapse because of high mortality. This thesis provides a number of suggestions for timely early warning and intervention possibilities for vulnerable ecosystems. Specifically, among forests, early and high reductions in canopy water content and leaf area can be used as early warning signals for tree mortality. Moreover, this thesis demonstrates the potential of remote sensing in monitoring ecosystem responses. Combining remote sensing for early and comprehensive monitoring of ecosystems will provide new possibilities and critical information for future drought prevention and management.