Chapter

Introductory Chapter: Vegetation Dynamics, Basic Phenomena, and Processes

Levente Hufnagel and Ferenc Mics

1. Introduction

Vegetation dynamics is the science about the concepts, theories, observations, and models that deals with changes in vegetation over time [1–4]. Changes in vegetation are a constant phenomenon on Earth. The simplest example of this is the appearance of weeds on a well-maintained lawn or the appearance of shrubs in an abandoned hayfield. Often the change is not so obvious, because the changes or the rearrangement of vegetation that is difficult to observe with the naked eye are slow compared to human life. Each vegetation patch changes dynamically, with every single plant eventually dying and being replaced by another. When environmental conditions change, including the opportunity of vegetation to influence its own environment, the balance between birth and death is disrupted. As a result, the relative proportion of plant species in the community will also change. The dominant species in the community largely determines succession, productivity, and stability, whereas the less abundant species determine the species richness of the community [5]. If the mortality rate exceeds the birth rate for a long period of time, the species becomes extinct and disappears from the community. New species are constantly being introduced from the area surrounding the vegetation patch, some of which may successfully establish if space is available. New species can also invade from the edges of patches, mainly vegetatively, by shoots and clones, which can also be a source of change in species composition. Largely spontaneously growing populations, evolving in accordance with the conditions of their habitat, form part of the ecosystem, along with external factors and other life forms [6]. Plant communities are assemblages of plant species that have evolved randomly throughout the history of the vegetation cover and then reorganized following the climate [7]. A plant community changes when there is a change in species composition, assuming that the community can be characterized based on the species composition.

Vegetation dynamics involve a range of processes, which can vary greatly in spatial scale, from the closure of stomas to the shift of entire biomes between geographical areas over centuries. Several researches are devoted to understanding and predicting how the physiological functioning and processes of individual plants, combined with each other, determine the structure, functioning, and dynamics of vegetation on large spatial scales. In order to study changes over time, of course, space and the spatial and physical properties of the vegetation have to be taken into account, the fact how vegetation exists in a given area at a given time. No two vegetation patches are exactly alike, the combinations and proportions of species are always changing [8].

2. Succession

Ecological succession has been a focus of research for almost a century. The process of succession can be studied from two perspectives: systems ecology and population ecology. In the latter case, there is a trend in the evolution of the system [9], and succession is a series of communities with a characteristic composition and characteristic ecological factors. In this approach, population dynamics is the dynamics of phytocoenoses. As a result, it is necessary to explain the fate of each phytocoenosis from the beginning to the equilibrium, or the fate of the phytocoenoses succeeding each other. Clements' [10] theory of the alternation of communities during succession is still the basis of several scientific works and theories. In contrast to the holistic approach, the individualistic approach emphasizes the importance of population processes in the biocoenosis dynamics when interpreting successional processes. Also, great emphasis is placed on disturbances, whether human or natural, and any influence that causes instability in vegetation [5]. Thus, succession can be interpreted at the ecosystem level according to one of the concepts. According to the other idea, succession is the consequence of the interaction between species as well as between species and the environment [11]. The latter results in the reproducibility of ecosystem structure and functioning. Taking into account data from population genetics and demography, succession is increasingly understood as a process of species replacement, with the role of individual species in vegetation change being related to life history strategy, growth, and reproduction [12]. In the past, these two theories were thought to be alternatives to each other; however, today they are rather complementary [13]. Long-term studies of the characteristics of certain plants, populations, and communities have led to the conclusion that it is correct to combine theories and seemingly contradictory methods in order to interpret successional processes [14]. In previous decades, there was a debate about whether succession could have only one endpoint, that is, whether it ends in a final climax community, or multiple climax communities could also be the result of a successional process [15, 16]. The concept of a more or less stable climax community was replaced by the idea that the relative frequency of changes decreases toward a supposed climax [17]; however, the climax itself also changes, and only the rate of change slows down but does not become zero [18]. In some cases, the changes may even be in the opposite direction [19]. The theoretically possible climax also changes in terms of species composition as a result of the changing climate, and new invasive species may appear [19]. The factors that influence succession vary in time and space [20]. With these constraints, vegetation approaches an endpoint, where only little change occurs, especially in terms of dominant species [21]. However, due to often irreversible changes caused by humans (e.g., [22, 23]), there may be changes in the species pool and vegetation structure, and the vegetation does not always reach the same hypothetical state [24]. Thus, there are several alternative endpoints.

3. Vegetation and climate change

The distribution, phenology, and productivity of vegetation are highly sensitive to changes in climate, which affects all ecosystems on Earth [25]. Vegetation shifts in terms of altitude and geographical latitude due to rising temperatures, and the vulnerability of many ecosystems increases [26–28]. Higher temperatures cause the growing season to start earlier in spring and last longer in temperate regions [29]. Production increases at higher latitudes, while in arid areas and desert regions, it tends to decrease further from the current low values [30]. Increasingly severe drought and fires also increase the destruction of vegetation [31]. Shifts in phenological phases (e.g., [32]) also result in changes in albedo, vegetation conductance, surface roughness, and the fluxes of water, energy, carbon dioxide, and volatile organic compounds [33].

Global warming causes glaciers to recede more and more and the free surface left behind is eventually covered by plants. Such primary succession means the colonization of previously unvegetated land and is one of the most important concepts [34]. During the process, pioneer plants colonize and stabilize the surface. A specific pattern of colonization and extinction can be observed in the community controlled by biotic and abiotic factors [35]. The structural complexity of the plant community is gradually increasing, and along with this, the biomass, production, species numbers, and the interactions between them are doing so [36]. When Krakatoa erupted in 1883, the entire island was sterilized, leaving no trace of the former soil and vegetation on the completely transformed island (Docters [37]). After the eruption, the area was covered by a nutrient-rich layer of vitric tuff (hypersthene-augite), which provided a suitable medium for plant roots, although no organic matter was present in it yet. The first colonizing species to appear were blue-green algae, forming a coating on the surface. Then the pteridophytes came, as they could reach the island in the easiest way with their spores dispersed by the wind. These were followed by seeds floating on the water. Finally, species spread by animals arrived. Today, there is even forest on the island; however, the vegetation is not as species-rich as in the area not affected by the disaster. The species present are not those typical of the climax community, the succession is ongoing and far from reaching the status of the characteristic tropical forests there, not disturbed by humans [38]. Succession also resumes after the abandonment of agricultural land, however, this is secondary, as these are not sterile areas, plants and other organisms had been present previously as well, but the cessation of human activity causes the process to resume, changing the resilience of the system and its response to external influences [39].

During succession, the microclimate and the physiognomy of the vegetation change [40]. The complexity of vegetation determines the diversity, species composition, and abundance of animal communities [41]. Some animal species are associated with vegetation of a certain complexity, where certain resources occur, such as prey animals, seeds, fruits, and shelter [42]. Forest loss also has the effect of increasing the visibility of animals, both prey and predators. This leads to a change in their behavior, for example, the cohesion of flocks of birds is reduced [43]. The changes also apply, of course, to microorganisms. During vegetation degradation, carbon dioxide efflux increases due to soil respiration, because respiration continues without photosynthesis, that is, carbon dioxide fixation as well, so there is nothing to counteract this [44]. In a healthy ecosystem, carbon accumulation is rather typical, with carbon dioxide getting into vegetation and soil. As a consequence of the activity of microorganisms, carbon is released back into the atmosphere as carbon dioxide. During the degradation of vegetation, the transformation of soil organic matter into carbon dioxide predominates [45]. During succession, the amount of carbon dioxide sequestered increases due to the increasing amount of photosynthesizing plants, while net carbon dioxide efflux decreases [46]. The changing vegetation depends on the soil microbiome network and regulates the community composition and, through this, the productivity of the whole system during succession. A resistant microbiome community also promotes the process of succession [47].

Vegetation degradation refers to a temporary or permanent loss of biomass, production, species richness, cover, and structure [48]. The definition includes not only quantitative but also qualitative change. This also includes the appearance of species that are less favored by grazing animals and less nutritious due to changing species composition in grazed areas [49]. Changes in vegetation are the result of a wide range of variables, from adaptation to changing conditions, through disasters, to human activities [50]. Therefore, it is very important to distinguish natural variation from human-induced changes [51]. Vegetation degradation is a worldwide phenomenon, very often caused by false human management practices or climate change [52]. NPP is the highest in the tropics, accounting for up to one-third of the total global NPP, and its dynamics are therefore very important in the geochemical cycle of carbon [53]. Human activity and climate change are causing the loss and variability of natural vegetation cover and NPP, so any action to combat climate change is crucial to prevent further deterioration of vegetation and desertification [54]. Due to land use and rapid urbanization, significant areas are losing natural vegetation [55]. As urbanization increases, the vegetation index also decreases, however, vegetation is present in the metropolitan area as well [56]. Changes in vegetation dynamics are closely related to climate change and human activities, so continuous monitoring of the dynamics and the prediction of changes are crucial tasks [57]. The extent of desertification in inner Mongolia reached 620.000 km^2 by 2009, which is more than 50% of the area [58]. Fire is also a force that can strongly shape the vegetation pattern. It is an extremely important component of terrestrial ecosystems and has the potential to greatly alter vegetation structure and distribution, carbon, and other element cycling, as well as water and energy budgets [59]. Fires release large amounts of gases and aerosols into the air, which then affect radiation reaching the surface and the climate [60]. The planned lighting of fires in forests and rangelands has been common practice for thousands of years, from hunting and gathering societies to modern-day farmers. Burned forests are converted into pastures, and in the pastures, the emergence of shrubs and trees is prevented. The biomass and species diversity of herbaceous plants increases in regularly burned pastures. After the fire, grazing ungulates influence succession and species composition [61]. Regular fire burning and grazing result in a diverse, mosaic vegetation pattern with different stages of succession, increasing the spatial heterogeneity of the landscape, which in turn leads to greater species richness [62]. In developed countries, however, fire is rarely used as a means of shaping vegetation, and roads and other infrastructure also contribute to a lower incidence of fires than in less developed countries and in the pre-industrial era [63].

Climate plays a central role in the distribution of vegetation and plant species. Climate change could lead to significant changes in the distribution of vegetation across the globe in the coming decades and centuries [64]. Plenty of research focuses on estimating the impact of climate change on vegetation, also in light of research data on past climate changes [65]. In the near future, the impact of climate change will be comparable to changes at the glacial-interglacial boundary, causing significant changes in vegetation properties as well [66]. By the end of the century, average annual temperatures will have increased by 1.8–4°C, and by up to 6.4°C in the case of high emissions, compared to the 1980–1999 average [64]. The temperature increase will be the greatest around the poles, with a range of 5–8°C according to the A1B scenario [64]. The spatial shift of the climate could reach an average of 0.42 km per year, it could be slightly slower in mountainous areas (0.08 km per year) and faster in lowland areas (1.26 km per year) [67]. Associated with this, there will be a number of changes in the environment. Snow cover will decrease, permafrost will thaw, the frequency of weather anomalies will increase in terms of temperature and precipitation, the frequency and intensity of tropical cyclones will increase, and the direction of extratropical storms will shift toward the poles, where precipitation will increase but it will decrease further at the tropics [64]. The rise in carbon dioxide concentrations and sea level are directly linked to this. These changes will have drastic impacts on plant populations as well, both indirectly and directly [68, 69]. According to all scenarios, these changes and their consequences will continue in the coming centuries [64]. Changes in vegetation structure are difficult to predict because changes in climate are followed by changes in vegetation with a lag [70], probably with very complex dynamics.

4. Human effects and conservation efforts

Nowadays, one-third of the human population is already feeling the negative effects of degradation, which include soil erosion, salinization, draining of marshes and bogs, and deforestation [71]. There are already more than 500 million hectares of degraded forests in the tropics and this area is steadily increasing [72]. Deforestation is caused by economic, demographic, technological, and political factors [73]. In total, 52% of the felled timber becomes lumber, 31% firewood and charcoal, 9% is the victim of an uncontrolled fire, and 7% is lost due to grazing [74]. Every biome is losing NPP due to human activities, with a degraded area reaching 2.7 billion hectares worldwide [75]. In abandoned areas, vegetation is able to regenerate. This is often done deliberately as part of a rotation system in order to regenerate soil nutrients [76] or in response to socioeconomic impacts, which alter profitability, access to labor, capital, and markets [77]. Secondary forests appear in the place of previously deforested forests, and their area increased in Brazil from 10 to 17 million hectares between 2004 and 2014, which is very important from the viewpoint of the situation of rainforests in the twenty-first century [78, 79]. Today, there are several programs to restore the original natural vegetation. Theoretical knowledge of the succession process in a given location and consideration of climatic conditions allow decision-making in order to achieve the goal of restoring a given area to a near-natural state or a condition desired by the human community [80]. During the restoration program, vegetation should be monitored continuously. The data obtained as a result of monitoring provide feedback, which can be used to adjust predictions and modify plans if necessary. In addition, monitoring can be the basis for other scientific work, increasing our knowledge of succession and vegetation dynamics. In order to control succession, it is important to know, for example, when it is time for the emergence of desirable species or for their artificial dispersal. What will their mortality be due to the competition? How to reduce harmful abiotic effects? The spread of emerging undesirable adventitious species also needs to be controlled or they have to be eradicated [81]. An adequate response to ongoing degradation is often lacking due to missing adequate knowledge of the causes that trigger it. Even measures that have been initiated are not always successful if the process of degradation itself and the underlying causes are not linked. In the absence of appropriate countermeasures, vegetation cover and soil nutrients may disappear [82].

Author details

Levente Hufnagel[1]* and Ferenc Mics[2]

1 Ecotheology Research Group of John Wesley Theological College, Budapest, Hungary

2 Department of Environmental Security, John Wesley Theological College, Budapest, Hungary

*Address all correspondence to: wjlf.hu@gmail.com

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