学　位　論　文　内　容　の　要　旨/Dissertation Abstract

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学　位　論　文　題　名/Title of Dissertation

Influences of abiotic and biotic factors on plant-plant facilitation toward forest restoration
（森林再生に関わる植物間の促進作用への非生物的・生物的要因の影響に関する研究）

Forests are among the most extensive terrestrial ecosystems, supporting diverse ecological functions. In recent decades, the increasing frequency of extreme climatic events driven by global climate change, coupled with disturbances from human activities, places forests at risk of degradation. After disturbance, the natural regeneration process begins with the recruitment of plant seedlings. The dynamics of the seedling stage are considered crucial for determining subsequent vegetation recovery patterns. However, seedlings are likely to be highly susceptible to harsh environments after disturbances. Furthermore, interactions among seedlings, influenced by both biotic and abiotic environmental factors, shape the trajectory of forest restoration and determine the composition and structure of future stands.

Facilitation among plants, either directly or indirectly, can enhance the performance of the interacting participants. Compared to natural forests, disturbed sites experience stronger environmental stress, under which plant facilitation is more likely to be critical for seedling colonization success and performance. Severe forest disturbance events, such as landslides and the ongoing soil erosion that follows, create new environmental conditions in the disturbed areas. However, whether facilitation occurs among newly recruited seedlings following disturbance, how such facilitation is shaped by environmental conditions, and its ecological consequence towards restoration remain unclear. In my doctoral research, I investigate how the new biotic and abiotic conditions following landslides influence the process of facilitation during seedling regeneration, aiming to uncover insights for forest restoration and management. Specifically, by combining field surveys and common garden experiments, I conducted the following three studies.

In Chapter 2, I am dedicated to clearly illustrating in the post-landslide area, how the initial spatial distribution of seedlings emerges, and how those abiotic and biotic environmental conditions, i.e. neighboring seedlings' interactions and rill erosion, influence seedling performance. Based on a replicated artificial landslide experiment (i.e., ALES), in the first growing season after the disturbance, I monitored the seedlings' performance and recorded the rill erosion. This study indicated that, in the post-landslide area, newly recruited seedlings primarily exhibited spatial clustering with conspecific neighbors and demonstrated significantly higher abundance around rills. At the scale of several centimeters, proximity to conspecific and heterospecific neighbors significantly enhanced focal seedling survival and growth. The survival of seedlings near rills decreased, and this response varied by species. Interactive effects of plant facilitation and rill erosion on tree seedling colonization toward restoration have been validated. The proximity of a seedling to heterospecific neighbors attenuated the negative influences of being near rills. This study suggests that there were conspecific and heterospecific facilitative effects on seedling survival at this post-landslide habitat, but the relative importance of the two effects could be dependent on the degree of rill erosion. This study inspired the understanding that the effects of plant-plant facilitation, together with the fine-scale geomorphological heterogeneity, shape seedling performance, thereby influencing the forest restoration process.

In Chapter 3, I aimed to elucidate the genetic properties of the newly recruited seedlings and their effects on seedling performance. In particular, the following questions were addressed: 1) are there population differentiations among spatially proximate disturbance sites after landslides, 2) how landslide scars and subsequent rill erosion shape the genetic structure of seedling populations, and 3) how genetic relatedness among seedlings influence their performance. By using the same ALES sites of Chapter 2, I examined the genetic structure of the dominant seedlings, *Abies sachalinensis* (F.Schmidt) Mast. (Pinaceae), in each landslide site. I extracted genomic DNA from 292 seedlings and performed MIG-seq. This study indicated that the genetic structure of three spatially proximate seedling populations exhibited significant differentiation, suggesting strong dispersal limitations. These dispersal limitations, coupled with fine-scale spatial structures within the patches, contributed to the low genetic diversity of the within-site seedling populations. Due to the greater niche overlap, resource competition could happen among seedlings with close genetic relatedness. I found the tendency of the negative association of neighbor relatedness and growth. This study suggests that the restoration management of disturbed sites should consider the dispersal capacity of surrounding tree species and the genetic structure of source populations. Building upon natural succession, and supplementing it with strategies to control the genetic diversity of restored populations may provide valuable insights for forest restoration.

In Chapter 4, I explored how species diversity-ecosystem functioning relationships are influenced by soil microorganisms and intraspecific genetic diversity. In parallel, how this species diversity, in turn, shapes the composition of soil microorganisms (i.e., fungi and bacteria). I conducted a common garden experiment to control intraspecific genetic diversity by combining seedlings from different origins and to regulate soil microorganisms by inoculating natural soil collected from beneath maternal trees or commercial Akadama soil. In fact, the composition of microbe communities was significantly affected by the soil inoculation treatment. Both soil inoculation treatment and genetic diversity treatment influenced the sign and strength of species diversity effects on ecosystem functioning. The presence and absence of natural soil microorganisms affected the selection effects of species diversity. Moreover, increasing genetic diversity improved the complementarity effects of species diversity on ecosystem functioning. The effect of natural soil inoculation on the relationship between species diversity and ecosystem functioning was stronger than the effects of intraspecific diversity. Furthermore, changes in fungal community composition from the start to the end of the study were driven by whether planted tree seedlings were in polyculture or monoculture. My results indicated that plant species diversity could also play a critical role in the restoration of soil microbial communities, which may feedback to the subsequent ecosystem functioning. Overall, this common garden study suggests that an increase in the genetic diversity of plants could strengthen the positive association between species diversity and ecosystem functioning. It should also be noted that the management of soil inoculation or microbe communities could much enhance species diversity effects. Toward a long-term forest restoration project, soil properties should be tailored to the local plant community composition and the stage of restoration, as soil inoculation during the early successional stages may disproportionately boost the performance of dominant seedlings.

In summary, during the natural regeneration process of plants after disturbance, the fine-scale spatial and genetic structure of seedlings, small-scale topographic heterogeneity, and other ecosystem participants such as soil microorganisms collectively shape plant facilitation. Furthermore, my research pioneeringly reveals the interactive effects of plant species and genetic diversity on ecosystem functioning. Species diversity fosters plant-soil feedback, while increased genetic diversity further promotes the relationship between species diversity and ecosystem functioning. In future forest restoration management, natural regeneration of local populations, supplemented by the manipulation of new biotic and abiotic factors, will benefit the long-term development of restored communities.