（第3号様式）(Form No. 3)

学 位 論 文 要 旨
Dissertation Summary

氏 名: (Name) PHAM VAN HIEU

論 文 名: (Dissertation Title) Analysis of ecological functioning of restored mangrove ecosystem in North-Central Vietnam
中央ベトナム北部における再生マングローブ林の生態機能に関する研究

Mangroves are one of the most productive forests located at the upper intertidal coastline in tropical and subtropical latitudes. Mangroves provide essential ecosystem services such as sequestering large quantities of carbon, exporting organic matter to coastal waters, nursery habitats for coastal species, protection of coastal areas from erosion, flooding, catastrophic events and forest resources for coastal communities. The organic matter exported from mangrove forests to nearby ecosystems both inland and offshore are important food sources. In recent decades, mangrove forests have been suffered from land conversion for aquaculture, agriculture, and urbanization, causing a massive degradation of mangrove forests and loss of their ecosystem services. Therefore, mangrove restoration is considered as a solution to reverse the declining trend in mangrove forest areas. However, the ecological function of restored mangrove forests, particularly in ecosystem carbon (C) storage and organic carbon (OC) accumulation, and food sources for benthic invertebrates are still not well working. Addressing these gaps will be allowed for more detailed assessment of the ecological function of restored mangrove ecosystems and strengthened understanding of OC fluxes and budgets in the coastal area. It provides the scientific information on conservation and restoration of mangrove forests in the coastal developing countries, such as Vietnam. Thus, the study has aimed at clarifying the ecological function of restored mangrove ecosystems by the analysis of ecosystem OC storage and OC dynamics in different mangrove species (*Kandelia obovata* and *Sonneratia caseolaris*), different forest ages (from young to older forests), and different tidal range (from low to high tidal elevation) in Hau Loc mangrove forests (HLMF), Thanh Hoa Province, North-Central Vietnam. The investigation of ecosystem C storage, OC content, sediment properties, and stable isotope signatures of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) have been combined to solve the questions: **(1)** How do restoration activities influence on the sediment OC and ecosystem C storage in the restored mangrove ecosystems? **(2)** What is the roles of mangrove restoration in

contributing a significant proportion of OC to the sediments, and which factors control the accumulation of mangrove-derived organic matter in the mangrove sediments? **(3)** How will benthic invertebrate communities and their diet composition change in restored mangrove forests?

The present study is composed of five chapters, of which the main findings are outlined as follows:

(1) Restored mangrove forests enhance ecosystem carbon storage and sedimentary organic carbon: The ecosystem C storage in five different-aged restored mangrove forests and a mudflat in Hau Loc was estimated by measuring the above-ground biomass of trees, understory vegetation, downed woody debris, and the below-ground biomass of roots, OC in the sediment cores and overall depth. The mean above- and below-ground C stocks (mean ± SE) of these forests ranged from 12.7 ± 2.4 to 107.5 ± 10.7 MgC ha^{-1}, and 103.8 ± 2.9 to 412.4 ± 6.5 MgC ha^{-1}, respectively. The ecosystem C storage of mangrove forests tended to increase with forest age, varying between 201.3 ± 4.3 and 519.9 ± 12.5 MgC ha^{-1}, with an overall mean of 310.3 ± 21.3 MgC ha^{-1} and was relatively lower than those of mangrove forests in the Mekong Delta, Vietnam and other mangroves worldwide. These results indicated that the oldest mangrove forest was potentially successful in recruitment and confirmed the efficiency of the restoration programs. The increase of the OC content and ecosystem C storage from the recent planted to the maturity stage of restored mangroves forests was a result of higher biomass production following forest development, including root in the young forests or both leaf litter and root, and OM derived from previous mangrove vegetations in the old forests. Also, the position of stand in the intertidal zone well influenced on litter accumulation or deposition of materials on the forest floor under tidal inundation and flushing, resulting in a low OC content in the mudflat and the young mangrove forests, and a higher OC content in the older mangrove forests. Therefore, mangrove restoration programs should be paid attention to as a potential solution for increasing ecosystem C storage and sediment OC, and as a major component of coastal ecosystems management and mitigation strategies in climate change.

(2) Restored mangrove forests are predominant organic carbon source for the sediments: The stable carbon isotope signatures ($\delta^{13}C$) of core and surface sediments and organic carbon sources such as mangrove litter (termed as autochthonous sources) and marine phytoplankton (termed as allochthonous sources) were analyzed for examining sources and contribution of mangrove-derived organic matter to sedimentary organic carbon (SOC). The sediment $\delta^{13}C$ values considerably decreased with forest age, was from −24.7 ± 0.1 to 27.4 ± 0.1‰ and from −25.1 ± 0.1 to −26.2 ± 0.1‰ for core and surface sediments, respectively. The sediment cores $\delta^{13}C$ values decreased progressively with depth in the mudflat and the *S. caseolaris* forests, while a reverse trend was observed in the *K. obovata* forests. The $\delta^{13}C$ values of POM increased from the upstream to the mouth of the river, which was considered as the $\delta^{13}C$ values of marine phytoplankton, while $\delta^{13}C$ values of mangrove litter were lower than previously reported for mangrove leaves in the Northern Vietnam. The outputs from mixing model indicated that the mangrove-derived organic matter contributed from 45.8 to 64.1%, and from 36.3 to 82.4% to the source of SOC in the core and surface sediments, respectively, and significantly increased following forest age. The maturity of mangroves forest supplied more production of mangrove roots with a rapid decomposition rate of the mangrove-derived OM at the high intertidal zone, and it led to more depleted in $\delta^{13}C$ signatures in the old mangrove forests. The inundated conditions depending on the position of mangrove forests influenced on the accumulation of mangrove litter with low $\delta^{13}C$ signatures and deposition of organic matter from marine phytoplankton with higher $\delta^{13}C$ signatures on the forest floor, causing more enriched $\delta^{13}C$ values in the young mangrove plantations and the mudflat. These results pointed out the importance of restored mangrove forests as C sources for the sediments and proved the role of mangrove restoration programs in C cycling in the coastal regions.

(3). Restored mangrove forests supply the food sources for macro-invertebrates: Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios of potential food sources and benthic invertebrates including gastropods, crabs, bivalves, polychaetes, shrimps and mantis shrimps were used to identify the change in the diets of consumers in mudflat and various aged restored mangrove forests in the HLMF. The potential food sources for benthic invertebrates varied among differently aged forests, including sediment organic matter (SOM), particulate organic matter (POM), benthic microalgae (BMA) and marine phytoplankton (Phy); and SOM, POM, BMA and mangrove leaves (Man) in the mangrove forests. The isotope signature of food sources tended to increase from mangroves forests to mudflat, reflecting the influence of forest maturity and the position of forest in the intertidal zone, which related to tidal conditions. The crabs and gastropods communities had a broad range in $\delta^{13}C$ and $\delta^{15}N$ signatures among species and forest ages, whereas the bivalves, polychaetes, and shrimps and mantis shrimps communities showed a narrow range of them. The difference of actual isotope composition between food sources and consumers and the mixing model analysis indicated that the benthic invertebrates of the mudflat mainly consumed on a mixing of BMA and Phy. However, a combination of BMA and SOM was the primary organic source for the benthic invertebrates of the mangrove forests, with a higher contribution of organic sources in the old forests. The dense tree canopy in the old planted mangroves created more dark shades for the development of BMA on the forest floor, and thus led to the alternative of the diet composition of benthic invertebrates among the mudflat and the mangrove forests. Moreover, the difference in assimilated food sources of benthic invertebrate between mangroves and non-vegetated mudflat was driven by tidal import and export, and accumulation of SOM deposition on the forest floor, which associated with the location in the intertidal zone. The assimilated food sources of crabs in the present study were not consistent with the results of the earlier studies, and it could be clarified by the difference in the application of trophic discrimination values, the feeding practices, and the assimilation efficiency of mangrove crabs. This study is vital for assessing potential effects of mangrove restoration activities on local benthic invertebrate communities, as well as for evaluating the success of mangrove restoration programs.

(4). Recommendation for future studies on the ecological functioning of restored mangrove ecosystems: This study showed the functions of restored mangrove forests in enhancing ecosystem C storage and sediment OC, was the predominant contribution of mangrove-derived organic matter to the sources of SOC and supporting food sources for benthic invertebrate communities. However, the decomposition of mangrove leaf litter was a major component in the OC dynamics, and roles of restored mangrove forests in the provision of food sources for fishes and nearby habitats, have not yet been addressed in the present study. Although the sea-level rise has positive effects on death and degradation, and changes in habitat conditions of coastal ecosystems, the functional role of restored mangrove forests in adaptation to changes in sea level has not been studied. Hence, the future studies should measure rates of elevation change and sediment accumulation rates in restored mangrove ecosystems for understanding the benefits of mangrove restoration programs in controlling sediment elevation to mitigation and adaptation to climate change and sea-level rise.