

Review

Future research trends of forest landscape degradation: The effect of changing status and use of rural road networks

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The degradation of forest landscape was mainly driven by anthropogenic disturbance at short temporal and small spatial scale. However, the execution (intensity or frequency) of anthropogenic disturbance was determined by the accessibility of road network connection. The passing effect of rural road network must be considered, when understanding on the degradation of forest landscape and selecting restoration measures for degraded forest landscape. The existing literatures deeply understood the influences of the natural passing effect on forest landscape degradation. And they, to a certain extent, also identified the function of huge road network to forest landscape degradation. But, rural road network more widely distributed, and its passing effect on forest landscape degradation involved less. Moreover, the evolution of the rural road network (e.g., change of use, renovation and expansion, new build) was greatly accelerated, due to land consolidation favoring to agricultural industrialization and new village construction helping to urbanization. Certainly, under such environment, the degradation of forest landscape will be greatly intensified. Therefore, the passing effect of rural road network was considered, when the study of forest landscape degradation carried out. And future priority field should focus on: the corresponding relationship between forest landscape degradation and the passing effect of rural road network was firstly identified. Secondly, underlying driving factors must be understood, as they determined the evolution direction of the above relationship. Finally, preferred recovery block and recovery model of degraded forest landscape were arranged through consultation with local residents together. The understanding of forest landscape degradation, under the function of the passing effect of rural road network, can provide the best path for the identification of degradation process and the selection of recovery strategy.

Key words: Forest landscape, degradation, passing effect, rural road network.

INTRODUCTION

Forest landscape plays an important role in sustaining the balance of global atmospheric carbon and oxygen and climate stability (Hellmann and Pineda-Krch, 2007).

However, forest landscape, with the high natural formation, was commonly controlled by the integration of natural succession and interference pattern, due to the

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high intensity of continuous disturbance of human activities (Lugo and Gucinski, 2000; Narayanaraj and Wimberly, 2012). This gradually led to the transition towards a simple stand structure, with the reverse development trajectory from natural forest, degraded natural forest, secondary forest, degraded forest, artificial forest to farmland (Quine and Watts, 2009). Consequently, the basement of forest landscape was usually damaged, and the high sensitivity of the response of forest landscape to anthropogenic disturbance mostly occurred (Nitschke and Innes, 2008; Albers and Robinson, 2013). Except for natural protected areas, natural forest landscape can only be found in high mountains and steep slope, where local residents had difficulties in carried out agricultural activities (Grainger, 2012).

Anthropogenic disturbance has been the main driving force of the evolution and conversion of forest landscape at short temporal and small spatial scale and the expansion or diffusion of interference, and its frequency of occurrence were often constrained by the accessibility of road network reflecting obvious post construction effect. Unfortunately, the existing literature is too much focused on the agglomeration and radiation of logistics and information exchange along large road networks in huge geomorphic units (Trombulak and Frissell, 2000; Wijewardana, 2008; Liu et al., 2008). Especially, the road network of county or above level possessing post-construction effect, clearly driving the occurrence of the heterogeneity and diversity of forest landscape, presented greater interest (Pfaff et al., 2013).

The patch use transformation of forest landscape driven by the rural road network (e.g., tractor road and production road) less caused researcher's interest and attention, due to the effect of rural road network on forest landscape possessing the following characteristics: local disturbance, occurrence concealment and effect hysteresis (Mon et al., 2012). The objectives of this study was to consider future research directions of forest landscape degradation, following the development of rural road networks, through refining existing literature on forest landscape degradation and post-construction passing effect, and summing up research progress made so far. The implication of this paper was to help people understand the mechanism of the forest landscape degradation, and to provide ideas for the restoration of degraded forest landscape in the future.

EXISTING PROGRESS OF PASSING EFFECT

Post construction effect resulted from the control drive of traffic accessibility to landscape evolution trajectory. Understanding forest landscape degradation must consider the evolution of traffic accessibility. People often say that forest landscape is being "cut in pieces", which was the most concentrated expression of above effect, concluding selective logging and usage alteration (Pfaff et

al., 2013). However, the study on post construction effect can be traced back to the significant function of huge valley and mountain on the passing of water vapor and runoff transmission under the background of large geomorphic units. Further, this effect is transferred to forest landscape, and will influence its health evolution and spatial difference distribution (Narayanaraj and Wimberly, 2013). High mountains presented significant obstacles to water vapor transport and human activity expansion (Li et al., 2007). But, only adaptive strategies could be taken to deal with this effect, due to mountain shape being not remodeled or changed in a short time.

Large valley possessed clearly transfer effect to the transmission of water vapor and runoff, and the extension of human activities (Wijewardana, 2008). The agglomeration of town and rural settlements, and the occurrence of various land-use activities, often focused on the valley area, or gathered in the interchange of main traffic routes, and usually extended along valley trend or traffic network development direction. Finally, the transfer effect of large valley had great disturbance to forest landscape, which distributed around valley area and main traffic routes (Li and Zhang, 2010). Moreover, for reducing the influence of transfer effect on forest landscape degradation, the way environmental impact assessment was often adopted to evaluate the destruction scene of forest landscape induced by human activities. At the same time, response or adaptive measures could be provided to recover degraded forest landscape.

The roads are the channels of artificial landscape and the transmission belt of economic development. They were mostly built for economic purposes (that is, economic development, traffic). Moreover, they widely distributed, were rapidly built, and deeply impacted their surrounding landscape. Zong et al. (2003) considered that the roads affected 15 to 20% area of global terrestrial ecosystem, depending on five functions (e.g., channel, barrier, filtration, habitat, source and sink). The effects of roads on forest landscape degradation presented the following two aspects: transient interference in the process of construction and potential, long-term and slow interference in the process of operation (Liu et al., 2008; Freitas et al., 2012). The former promoted forest landscape degradation being "point" or "strip" patterns, while the latter resulted in the occurrence of forest "island" or the reduction of forest ecological integrity.

China's road construction has been rapidly speeded since 1990s. Especially, backbone road network basically formed after the adjustment of the important development strategy at the national level (e.g., Western development, Northeastern old industrial base reconstruction and Midlands rise). With this correspondence, the study of the impact of the transfer effect of roads on surrounding forest landscape was mainly focused on county or higher level road network, while rural road network was seldom involved.

However, a large number of rural road network that directly helped agricultural production, farmer's trip and rural life obtained rapid development, associating with the promulgation of the policies aiming at the issues of "agriculture, rural areas and farmers", e.g., rural-urban integrated development, new rural construction and land consolidation. Although the impact of rural road network on the degradation of forest landscape also depended on the road grade and the distance from the roads, and the connecting or adjoining degree of rural road network with the main roads, more emphasis on the transfer of tractor road and production road to natural landscape availability (Tang et al., 2010; Sonwa et al., 2012). That is, the effect of low grade roads on the degradation of forest landscape was the most direct and most significant. As we know, rural road network connecting the radius of residence and production, itself with narrow pavement, was only suitable for small agricultural vehicles or pedestrians. But, the influence of the transfer effect induced by low grade roads on the degradation of forest landscape generally strengthened, along with the upgrade of road level (Agbenyega et al., 2009; Mon et al., 2012).

The more important, public welfare forest was protected by ecological compensation measures at the national or regional level (Yin and Xu, 2002). The direct effects of large traffic network on forest landscape was relatively weak, the trend of forest landscape degradation has been basically controlled. However, forest landscape scattering in the farmland was faced with the threat of further development or transformation under the impact of rural road network (Ali et al., 2005; Avon et al., 2013). Because this part of forest landscape was non-public welfare forest. Certainly, not only lack of adaptable protection policies limiting the development behavior were arranged, but also no appropriate compensatory measures encouraging participation protection were formulated. The rural road network not only was carrying the direct function of residents' disturbance behavior to scattered forest landscape, but also was a carrier of the implementation of forest conservation policy at the national and regional scale (Freitas et al., 2010; Sonwa et al., 2012). Hence, it was necessary to understand the impact of the road status and use effect on forest landscape degradation through selecting the rural road network as the object.

The impact of rural road network on forest landscape was the explanation or decomposition of the function of the use effect of large road network on forest landscape degradation at the national or regional level. However, the influence of large road network on forest landscape at the national or regional level was the concentration or accumulation of the stress of the use effect of rural road network on forest landscape degradation. Namely, the disturbance scenarios of forest landscape around large road network at the national or regional level could rely on the accumulation of the use effect of a number of rural

road networks connecting with large roads by the way of coupling interaction. Identifying the above effects of rural road network can serve macro decision-making for protecting forest landscape at the national or regional level.

The study of the impact of the use effect of road network on forest landscape was being transferred from large road network at the national or regional level to rural road network. It is often easier to develop or disturb local area where the density of rural road network was higher, and this development or disturbance usually extended along roads (Hickey and Nitschke, 2007). Where the density of rural road network was higher, the accessibility was better. In this region, the degree of influence of anthropogenic disturbance for pursuing maximum economic yield was stronger. Thus, forest landscape near rural road network was easily developed as farmland or woodland. Even then, some hidden intrusion or implicit damage was carried by farmers who replanted local precious species into natural forest landscape. The consequence of development and invasion resulted in the loss or damage of the ecological functions of forest landscape (Nagendra, 2012). Moreover, the effect of this loss or damage did not appear in a short time, while it presented regional effect with the help of local accumulation magnification.

FUTURE DIRECTIONS OF ROAD STATUS AND USE EFFECT

Forest landscape reflected the clear vulnerability characteristics, resulting from the overlap of ecology and economy, and the frequent disturbance of human activities in the key forest areas (Nitschke and Innes, 2008). However, most of them were controlled by the morphology of rural road network induced by the disturbance of human activities (Freitas et al., 2012). Identifying road use effect associated with the accessibility media of rural road network not only contributed to the understanding of the degradation process of forest landscape, but also favored the recovery scheme of degraded forest landscape.

Most of the influence of rural road network on forest landscape presented was corresponding to "channel", and no way was equal to "barrier". Namely, the impact of rural road network on forest landscape played only a "channel" for local residents whose perturbation behavior could be touched or not (Van de Walle, 2002). But, the extent of the influence only expanded outward along roads with the characteristics of local sporadic "point" shape, and performed for the spatial jump of interference. Rural road network altered or modified the effect of large road network on forest landscape, and it determined the possibility of forest landscape conversion. The conversion of forest landscape that was much closer to the road was earlier, due to the demand of farmers' traffic, crop's

harvest and agricultural goods' transportation. Moreover, the comprehensive effect of forest landscape fragmentation or correction was more obvious. Forest landscape that occurred around rural road network was used first or concerted with the patterns of "point" or "strip" shape along the both sides of road, when no major road network occurred in this region. There was a significant positive correlation between the reduction of forest landscape and the distribution of rural road network. This correlation expanded outward along the two sides of rural road network accessibility corridor. The consequence of expansion resulted in the decrease of forest landscape. Even then, shrub was very rare in this region. Further, it induced the damage of the function of soil and water conservation of forest landscape along rural road network (Neary et al., 2009). Under such environments, a high risk of ecological signal was released: parts of roads were seasonal being used in the dry season only. In turn, the passing effect of rural road network was greatly reduced.

The degradation of forest landscape presented the patterns of sporadic and isolated "point" shape, with the single, stability and chronic characteristics, when the rural road network was sparse. However, local residents often developed the larger range along the two sides of roads through the stronger disturbance action, along with the development of rural road network. Thus, the degradation of forest landscape gradually evolved towards "strip" shape, and the degraded patches of "point" and "strip" shape obviously appeared. Finally, the degradation of forest landscape showed strong diffusion convergence effect.

The disturbance of "strip" shape of local farmers to forest landscape would move with the feature of "skirt strip" shape along the foot of the mountain upward, resulted from the grid development of rural road network, when meeting with undulating micro topography. Then, the consequence of "skirt strip" shape disturbance drove the formation of a large number of forest landscape "islands" (Rotherham, 2007). Below the mountain where is easy to close, with the following characteristics, e.g., good accessibility, fertile and thick soil, good matching between water and soil resources, and low risk for production investment. Under such environment, part of forest landscape was firstly used for farmland and artificial woodland.

Moreover, accessibility determined by rural road network, relying on the point, corridor and superposition effect of point-corridor-network, induced that "isolated island" gradually atrophied, and "strip" gradually widened and lengthened connecting "isolated islands" (Sonwa et al., 2012). Consequently, the ecological integrity of local forest landscape was damaged. Certainly, once the signs of forest landscape degradation or ecological integrity damage occurred at the regional scale. At this time, in the location, long-term human disturbance must occur terribly, and evoked amazing patch fragile of forest

landscape that was difficult to restore in the short time. Thus, the important role of forest landscape played in the balance of global atmospheric carbon and oxygen, and climate stability, was influenced by the accumulation of forest landscape degradation through the local to regional approach.

The obstructing effect of micro topography was very obvious in which rural road network was less. The spatial distribution of forest landscape presented significant difference, associating with the distance from the roads. However, the obstructing effect of original micro topography was broken, and forest landscape was heavily changed, along with the increase of the density of rural road network. Along the accessibility of rural road network radiating outwards, the strengthen degree that forest landscape was disturbed was generally slowed. Thus, for forest landscape, large patches controlled the dominant position, its patches' area increased, and its diversity index decreased. Accordingly, in the reachability scope, traffic was the more convenient, and the use of original forest landscape transformed. The process of forest landscape transformation was more complicated, and showed the number of patches was much more, the middle trajectory being difficult to identify. Certainly, the difficulty was much greater, if this part of the forest landscape was restored to near natural condition (Basu and Nayak, 2011).

In future scenario, the trend of the function of the accessibility induced by use effect on the further fragmentation of forest landscape was very clear. The area of large patches continued to shrink, and the number of small patches continued to increase. At the same time, the shape of large patches tended to be broader and the diversity tended to be simple (Bahadur, 2011). The ecological effects of forest landscape fragmentation caused habitat loss, the edge effect of fragmentation also seriously impaired the ability of maintaining the quality and population of forest landscape.

Human disturbance was blocked, and the ecological integrity of forest landscape was maintained relatively well, due the obstructing of micro relief where rural road network was absent. However, the construction of rural road network made the accessibility better and anthropogenic disturbances spread. The damage of forest landscape ecological integrity often occurred. But, the particularity of forest landscape site resulted in human disturbance was very frequent along both sides of rural road network. The consequence of perturbation led to the loss of a large amount of forest ecological information, and economic development into a vicious spiral circle. That is, the maintenance of forest landscape ecological integrity was facing double choice of economic development and ecological protection. Their balance became the most important problem at present, adapting to and coping with global climate change.

The World Bank considered that international or

interregional developed areas should include the protection of the forest landscape of poor areas. The framework of the international climate convention: "The Kyoto Protocol" and IPCC's "fourth report on climate change" also analyzed economic development, CO₂ emissions, afforestation or reforestation. Carbon trading was promoted by the rapid development of economy under the background of global climate change. But, ultimate measures for solving global climate change were the restoration of degraded forest landscapes. However, the current framework of carbon trading still consider afforestation and reforestation as a basic way of forest carbon sink, and ignores the huge potential value of the increase in carbon sink from degraded forest landscape restoration and need for a simple carbon sequestration accounting. In fact, afforestation, reforestation, and restoration of the ecological function of existing degraded forest landscape, possess the absorptive effect of atmospheric CO₂. Moreover, the restoration of degraded forest landscape had obvious advantages, either the investment of capital or management, or the occurrence of landscape effect in time, compared with the afforestation and reforestation. Currently, the main problem lies in the lack of accurate understanding to the complex process and core mechanism of degraded forest landscape. And, it was just the basic premise for efficient, accurate accounting the carbon effect of forest landscape restoration. Under such environment, the explanation of the use effect for forest landscape degradation and restoration was in line with the future demand of national economic strategy and the interest of present international research.

In addition, the central government work report, the central document and the new government's policy in 2013 also took agricultural industrialization, industrial new village and new village urbanization as strategic task for the next 10 years. The key issues of these documents were to implement the appropriate concentration of farmers contracted land and rural residential land, and to strengthen the infrastructure facilities. Especially, the density and level of rural road network was one of the key considerations. The density and level of the existing rural road network could not meet the demand of the development of new agricultural industrialization and new rural construction. Rural road system needed a new layout, and upgrading of rural road design standards. Moreover, the original transit road lost the previous meaning, due to the emergence of a large number of hollow, abandoned or unused villages. And it had gradually evolved into a village road and production road, and some where even abandoned. Certainly, the construction of new village residents gave rise to the emergence of a new road type. Under the process of contracted land and rural residential land focused on, the number of patches greatly reduced, and the area of single patch increased. Thus, the original production roads aimed at helping to local residents living or farming

would no longer exist, after the number of patches reduced. Originally, the region where the trunk road was rarely planned, and road density increased for the efficient transport of agricultural goods.

Certainly, the road was wasted, and its use was changed. The change of the changing use effect of road must occur, and the degree of degradation of forest landscape resulting from this changed (Rotherham, 2007). The road use effect was terminated, associated with road abandonment. Thus, the degradation of forest landscape also stopped. The use effect greatly reduced due to the conversion from tractor to production road, and the degradation degree of forest landscape also obviously weakened. But, the change of use effect, resulted from improving road construction standards or new roads, also induced the change of the degree of degradation of forest landscape. The changed status and use effect when road construction standards were promoted from production to tractor road would greatly enhance, and the response of forest landscape degradation on it was more obvious. The use effect suddenly occurred due to new road building and the degradation of forest landscape also appeared.

Hence, the study of degraded forest landscape in the future must consider the impact of the passing effect of rural road network on it, meeting new rural construction, modern agricultural development and protection of forest landscape embedding in farmland. This meets the requirement of restoring forest landscape, dealing with global climate change and transforming economic development mode.

FUTURE RESEARCH IDEA OF CHANGING STATUS AND USE EFFECT

The study of forest landscape degradation considering the effect of use of rural road network was to understand the response of forest landscape degradation on it, and plan the recovery strategy of forest landscape sustainable utilization in the future. Therefore, the key scientific problem to be solved included: How to find out the dynamics of forest landscape patch and the changes of use effect, and understand the relationships between them? How to identify the driving intensity of the response of the conflicts of different interests groups on the use effect? How to arrange the landscape restoration scenarios, to set the priority recovery block, and to construct sustainable utilization mode?

The research objectives need to aim at four aspects: 1. Understanding the spatial differences of the trajectory of forest landscape degradation induced by the use effect of rural road network, and analyzing the impact and function process of the evolution of use effect on these differences; 2. Identifying the conflicts of different interest groups caused by the use effect of rural roads, and finding out the specific driving process and future

possible trend of these conflicts to forest landscape degradation; 3. Simulating the future scenarios of forest landscape restoration under the constraints of ecological integrity, considering the use effect, and determining priority block of landscape restoration; 4. The content arrangement needs to integrate the framework of pattern, process, driving forces and measures, and answer the relations between forest landscape degradation and use effect of rural road network. Specifically, the future research must identify the use effect of forest landscape degradation and restoration by means of rural road network transferring or diffusing human disturbance. At the same time, the trajectory and characteristics of forest landscape degradation should be analyzed. And the relationship between this trajectory and the use effect of rural road network should be assessed. On the basis of above researches, the underlying potential driving factors can be understood. In addition, the future trend of the function and response of different interests groups on the use effect of rural road network should be investigated. Finally, the appropriate scenario of the restoration of degraded forest landscape needs to be simulated.

The analysis methods need to integrate high resolution remote sensing data (e.g., aerial photos, SPOT, Quickbird, etc.) and non-remote sensing data (e.g., household interviews, historical statistics, field survey, etc.). Quantitative mathematical method (e.g., CLUE-S, strength of interference effect, ecological time limit, logistic regression, multi-agent, ecological fragmentation degree, etc.), and patch dynamics atlas featured the spatial distribution of forest landscape, are used to calculate and simulate the response of forest landscape patch atlas on the change of the passing effect of rural road network.

Completing of the above ideas, the key technology that must be solved is: 1. Quantitative technique by which the relationship between the degradation of forest landscape and the use effect of rural road network should be analyzed; 2. Recognition technique by which driving factors impacting forest landscape degradation are understood, considering the influence of the use effect of rural road network. The technical difficulty that must be resolved: 3. Distinguishing what extent the influence of the use effect of rural road network on the degradation of forest landscape will appear? Otherwise, the relationships between the degradation of forest landscape and the passing effect of rural road network is very difficult to find; 4. How to use the use effect of rural road network to restore degraded forest landscape. Otherwise, the sustainable utilization mode of degraded forest landscape may not achieve.

CONCLUSIONS

The study of the impact of the use effect of road network on forest landscape degradation is shifting from large road at the national or regional level to rural road

network. The spatial distribution of forest landscape degradation presented strong heterogeneity, resulting from the difference of the status and use effect of rural road network. However, understanding the impact of the use effect of rural road network on forest landscape degradation must first be determined using the relationships between them, and find out the reason of forest landscape degradation, under the influence of the changing use of rural road network. Moreover, the future evolution trend of rural road network, and the future scenarios of forest landscape degradation induced by the changing use passing effect of rural road network should be quantitatively simulated. Finally, the future restoration scheme of degraded forest landscape should be determined by consulting with the local inhabitants, considering the use effect of rural road network. However, completing this research idea and direction, the most critical technical problems cannot be resolved without two aspects: what is the influence threshold value of the passing effect of rural road network on forest landscape degradation? How to use the passing effect of rural road network to restore degraded forest landscape?

Conflict of Interests

The authors have not declared any conflict of interests.

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