1. Needs and problems of conservation of rare riparian trees

Riparian forests maintain diverse vegetation structure through the influence of various types, intensities, and frequencies of disturbance promoted by fluvial and geomorphic processes (Nilsson et al. 1989; Baker 1990; Ito and Nakamura 1994; Sakio 1997; Suzuki et al. 2002). At the same time, riparian forests provide habitats for rare or infrequent plant species (Sakio and Yamamoto 2002) including several endangered trees (Ito et al. 2003; 2004; Ito & Nogami 2005). Thus, riparian forests have a high conservation value in terms of the maintenance or restoration of the habitats for the rare riparian trees (Ito et al. 2003; Ito and Nogami 2005).

However, the mountainous riparian forest in Japan, particularly in the warm-temperate region, has been totally exploited or converted to plantations of evergreen conifers such as sugi (Cryptomeria japonica) or hinoki (Chamaecyparis obtusa) because of the high site productivity (Ito et al. 2003). This resulted in the severe decline of habitats for the rare riparian trees (Ito et al. 2004; Ito & Nogami 2005). Most of the rare riparian trees cannot complete their life history beneath the dense canopy of planted conifers because their reproduction usually requires bright crown conditions. Thus, it is a quite important strategy for conserving these rare riparian trees to restore the habitat by re-converting the conifer plantations to semi-natural forests, as well as maintaining the remnant populations in the natural riparian forest patches (Ito et al. 2004).

In the timber production area, it is a problem to be solved to combine the timber production and biodiversity conservation including maintenance of rare species. For managing both, the reallocation strategy of new semi-natural riparian forests should cover the potential habitats of the target species population taking into account the conservation efficiency. As the riparian species often depend on specific soil conditions and/or disturbance regimes (Nakamura and Inahara 2006), the expected potential tree density based on the site conditions with respect to the soil and disturbance regimes is a criterion to select the candidate for reallocating semi-natural patches.

The remnant patches of natural riparian forests would also have significance for site selection of potential habitats. Generally, the connectivity of habitats is principle for biodiversity conservation in the managed landscapes (Kirby et al. 1999). For the riparian forests, ecological functioning as a corridor has been often emphasized and considered in the conservation practices in the managed landscapes. Moreover, the remnant patches consisting of mother trees of the rare species has an important role as the seed source for restoration of the population utilizing natural regeneration processes. These imply that spatial arrangement regarding the remnant patches of natural forests is also the key factor in reallocating the semi-natural forests into the plantation-dominated landscapes.

In this chapter, we describe a systematic idea of reallocating strategy of the semi-natural forests into the managed landscape through the case studies carried out for estimation of potential habitat and examination of conservation efficiency of two rare riparian tree species in the warm-temperate region in southern Japan.

2. Case study 1: Estimation of potential habitat for an endangered riparian species

Riparian trees often have strong dependence on specific topography. In the estimation of potential habitats for these species at a coarse scale, GIS-based analysis of tree distribution using digital elevation model is quite useful (Næsset 1997; Quine et al. 2002). In these analyses, the target points (pixels in the raster analysis) are usually treated as dispersed points, and their topographic
attributes such as slope inclination are generally used without the relationship to the other points (Franklin 1995, 1998; Guisan & Zimmermann 2000; Wimberly & Spies 2001a, 2001b). However for the riparian trees, which is dependent on fluvial and geomorphic processes, the attributes not only of the target point but of the river characteristics which affect to the target point is also important to explain the habitat condition for the species. Similarly, spatial relationships of the target point to the river such as horizontal and vertical distances from the channel would also provide useful information.

In the recent study, the authors compared the usefulness of these different levels of topographic information in estimating the potential habitats of *Lagerstroemia subcostata* var. **fauriei** (LSF) (Ito et al. unpublished). LSF is an endangered riparian species native to mountainous riparian area in Yakushima Island in southern Japan (Environmental Agency Japan, 2000). This species can be found on debris flow deposits along the stream channel or on taluses in small catchments (less than ca. 1000 ha). We measured the actual tree distribution of LSF in a sample area (ca. 15ha) within two catchments (60 ha in total) located in western part of Yakushima Island.

Based on this data, we modeled distribution of the tree density for 4320 pixels sized 12.5 x 12.5m of the whole area of the two catchments by using the Poisson Loglinear Model with GIS-derived topographic factors. The modeling was performed by adding the four different levels of topographic factors: Level-1) topographic attributes of the target cell such as elevation or slope inclination, Level-2) cell position relative to the adjacent channel, Level-3) attributes of the adjacent channel, and Level-4) difference of the catchments.

As the result, the AIC of the obtained models decreased according to the addition of the data from Level-1 to Level-4 (Fig. 1). This indicated that the topographic attributes of the target cell (Level-1) itself can not sufficiently explain the potential habitat for LSF. Adding the factors of channel characteristics (Level-2) and spatial relationship to the channel (Level-3) obviously improved the accuracy of prediction (i.e., lower AIC) of the LSF’s habitats, because these factors can presumably explain the occurrence of sedimentation along the channels. Moreover, the models adopting Level-4 factors showed a best performance (Fig. 1 and 2). The difference of catchments characteristics which were not accounted for by the other geomorphic...

Fig. 1. Relationship of measured and estimated tree densities of *Lagerstroemia subcostata* var. **fauriei** calculated by the Poisson Loglinear Models using four different sets of explanation variables.
factors (Level-1 to Level-3) could be the presence of the sediment source and the seed sources. The sediment sources such as small landslides in the upstream are closely related to the formation of debris flow terraces in the downstream of the catchment as the suitable habitat for LSF (Miyawaki 1980; Ito and Nogami 2005). The effective seed source is also critical for the establishment of the target species on the physically suitable habitat (Ito et al. 2004). Thus, we suggest that the information of catchment characteristics such as the existence of the sediment source or the seed source, if available, can improve the model to explain the actual distribution of LSF.

We can assume that the geomorphic factors of Level-1 to Level-3 are less changeable (or difficult to detect the change on the bases of map information) in the natural process of population dynamics. In contrast, the catchment characteristics such as the sediment and the seed sources could vary drastically by the natural and human disturbances or artificial modification of the forest landscape. Therefore, the third model derived from the less changeable factors (Level-1 to Level-3) is the most appropriate for the prediction of the “potential” habitat for LSF at the long time scale. However, in the actual situation where we have to establish the conservation strategy, or to evaluate the effectiveness of possible countermeasure for conservation, the model 4 which take into account the changing catchment characteristics would be more useful to predict the habitat under the specific circumstances.

As well as the selection of factors, selection of the statistical model is also important. As the rare riparian species occurs infrequently, this kind of analysis faces to the problem of the a lot of the “zero cell” where the observed tree density is zero. This often results in the inappropriate estimation of model parameters because of the overdispersion due to excess zeros. For these case, the zero-inflated poisson model or the zero-inflated negative-binomial model (Martin et al., 2005) would be helpful to avoid the problem of zero inflation.

3. Case study 2: Reallocation of semi-natural forests based on expected tree density

Once the potential habitat for the rare riparian species was estimated in terms of the suitable physical environment (i.e., suitable micro-topography), the success of tree regeneration by reallocating semi-natural woodland would strongly depend on the biological factors such as seed dispersal. The authors simulated the consequence of reallocating semi-natural woodland in conifer plantation-dominated landscape for the conservation of a riparian rare species, *Quercus hondae* Makino, taking into account the quality of the potential habitat and the seed sources in the remnants of natural forest patches (Ito et al. 2004).

In this section, we introduce the summary of our simulation results and discuss the importance of strategic reallocation of semi-natural woodland.

*Quercus hondae* is an evergreen oak found only in southeastern Kyushu and southern Shikoku (Mashiba 1973; Ito et al. 2004). The natural distribution of *Q. hondae* is limited on lower slope along mountainous streams (Miyawaki 1981; Ito et al. 2000). This species has been designated as one of the endangered species (Environmental Agency of Japan, 2000) owing to their limited distribution and decreasing population due to the loss of natural habitats by establishment of conifer plantation.

We estimated the expected tree density of *Q. hondae* of
the given site when the conifer plantation is converted to semi-natural woodland by the following equation:

\[ De \times D_{\text{max}} \times f_1 \times f_2 \]

where, \( De \) and \( D_{\text{max}} \) are the expected tree density and its maximum value, respectively. \( f_1 \) and \( f_2 \) are the constraint functions (varying form 0 to 1) of physical habitat quality (represented by micro-landforms) and seed dispersal (depending on the distance from the natural forest patch), respectively. Based on the field survey of a natural forest (5.3ha in total), we determined \( D_{\text{max}} \) to be 45.1 per ha, which was the reproductive tree density observed on the lower slope. \( f_1 \) was determined as the discrete variant for each of the three micro-landforms, according to the observed ratio of tree density in natural forest to that of the lower slope: 1.000 for the lower slope, 0.358 for upper the slope and 0.040 for the slope crest, respectively. \( f_2 \) consists of two factors which are the constraint functions of relative amount of seed fall and quality of seed source patch. The constraint function of relative amount of seed fall was basically given to be an exponential function
reducing from 1.0 at the edge of seed source patch (distance = 0 m) to 0.01 at 100 m distant from the seed source. Then, we weighed this constraint score by the quality of seed source patches according to their micro-landform same as in $f_j$ (Fig. 3). Simulation was performed to reallocate semi-natural forest patches to the site selected in the order of higher expected tree density with different assumptions (Case-1 to -3).

The results of selection of reallocation sites up to 30% of the total plantation area (Fig. 4) demonstrated that: for the Case-1 where $De$ was calculated only from the constraint function of relative amount of seed fall based on the distance from seed source (with no consideration of seed source quality nor habitat quality of the target point, i.e., constant $f_j$ to be 1.0 and the same $f_2$ starting from 1.0), a uniform width of buffers surrounding the remnant of natural forest patches were formed as the candidate of reallocation (Fig. 4b), while the different width of buffering zone was formed in the Case-2 (Fig. 4c) where seed source quality was taken into account for $De$ estimation (but $f_j$ is constant). For the Case-3 where $De$ was calculated considering quality of both the seed source and the regeneration sites (Fig. 4d), the reallocation candidates were distributed not only buffering the remnant of natural forest patches but connecting them. This reflected the continuing distribution of the lower slope, indicating the indirect effect of site selection base on the continuing micro-landform on the improvement of habitat connectivity. The continuity of the semi-natural forest patches has a significant role not only for plant species conservation but for the conservation of comprehensive biodiversity (Kirby et al. 1999). Thus, establishment of new semi-natural forest patches with taking into account the habitat quality based on micro-landform is expected to provide additional positive influences for the other living creatures beside the target tree species in the mountainous region.

Figure 5 compared these results from the view point of

![Figure 5](image_url)
conservation efficiency. When the reallocation site was selected randomly, the ratio of expected tree density to the total potential establishment achieved by conversion of whole plantations (the vertical axis of Fig. 5) would increase proportionally to the increase of the area ratio of reallocation site (the horizontal axis of Fig. 5). Compared to this random selection, the three cases of strategic reallocation concerning the seed source and/or habitat quality drastically improve the conservation efficiency, that is, a small area ratio required to obtain the same tree establishment. In particular, the Case-3 concerning both the seed source and habitat quality was shown to be very efficient than simple buffering. Furthermore, reallocation from the site of low productivity estimated for conifer plantation (c.f. Mitsuda et al. unpublished) showed the lower efficiency in requiring 10 times area of the Case-3 to achieve the same tree establishment.

These simulations indicated an effectiveness of strategic reallocation of semi-natural forest patches based on ecological factors for conservation planning of the target species. The random, non-strategic conservation planning would not be preferable because of its low efficiency, particularly when the other management objectives of forest landscape argue against the conservation of the target species. In addition, for the case of mountainous riparian species such as Q. hondae, which inhabits the better site for plantation with high site productivity, easy site selection for reallocation aiming to minimize the loss of productive area would result in unsuccessful conservation.

4. Conclusion

Quercus hondae, the species examined in our case study, would have relatively strong constraint of seed dispersal, while the habitat constraint might not be so severe because it can regenerate on slope or river sediment as far as located in lower part of slope. The other riparian species could have less constraint of seed dispersal, i.e., wind-dispersed seeds, but stronger habitat constraint limiting to more specific micro-landform such as the lower terrace along the active channel. Thus, the approach introduced in the case study 2 for Q. hondae should be examined for a wider range of species characteristics. We applied the same approach as the Q. hondae’s case to several hypothetical species characteristics with different levels of seed dispersal capacity (Fig. 6) and habitat specialization. As a consequence, we obtained the result showing that the species having stronger constraints of habitat quality and/or seed dispersal require smaller area of reallocation to achieve the same establishment ratio (Fig. 7). This suggests that strong constraints of seed sources or habitat quality would cause low total expected tree density in the landscape, and raise the importance of optimal reallocation strategy of semi-natural forests. The rare riparian species would be representative to have stronger constraints of habitat quality. For the species having higher seed dispersal capacity (e.g., wind-dispersal seeds), we can pay attention to the connectivity of their habitats in
reallocating semi-natural forests with less regarding the distribution of seed sources. In contrast, for the species of low seed dispersal capacity (e.g., gravity-dispersal seeds), precise estimation of the distribution of the seed-source trees will be the key for successful restoration.

We illustrated that the model explaining the spatial distribution of habitat suitability for the target species is quite helpful in planning the restoration strategy. It would not be so difficult to obtain the information for estimating the habitat constraint of the target species by short-term field survey. However, reproductive features of the target species would be less known, because they require long-term and intensive survey. Thus, further studies for reproductive features, including observation of masting traits or determination of dispersal capacity using molecular technique, for the rare riparian species are strongly expected as the basis of conservation.

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