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Title

Simulation of Natural Capital and Ecosystem Services in a Watershed in Northern Japan Focusing on the Future Underuse of Nature
-By Linking Forest Landscape Model and Social Scenarios-

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Abstract

A quantitative scenario approach to compare the future state of natural capital and ecosystem services (ESs) plays a key role in facilitating decision making for the sustainable management of landscapes. In Japan, the shrinking and aging population will likely lead to a situation of underuse of natural resources, resulting in rewilding of terrestrial ecosystems. This study conducted a quantitative scenario analysis of natural capital and ESs by linking model and social scenarios on a local scale. The case study area was the Bekanbeushi River Watershed in northern Japan. LANDIS-II model (a forest landscape model) was used to simulate the vegetation dynamics in species composition, age structure and biomass considering impacts of forest and pasture land management. Four "population distribution" and "capital preference" scenarios were translated into forest and pasture land management. The population distribution and capital preference assumptions resulted in different consequences for natural capital and ESs. The population distribution affected the spatial allocation of abandoned pasture land and level of isolation of managed pasture land. The capital preference assumptions largely affected the consequences for ESs. Finally, these simulation results demonstrated the capacity to feed quantitative information to the narrative scenarios. Our process-based approach provides insight into the relationships among social drivers, ecological processes and the consequences that will affect natural capital and ESs, which can contribute to decision making and sustainability design of regions, which may face issues associated with underuse in the future.

Keywords: LANDIS-II model, terrestrial ecosystem, depopulation, forestry practice, farmland abandonment

Introduction

Natural capital is defined as ecosystems that provide ecosystem services, analogizing the general definition of capital as stock that yields a flow of services over time (Costanza and Daly 1992; Costanza et al. 2017). Therefore to sustain ecosystem services, it is necessary to carefully consider the maintenance and management of natural capital. Quantitative scenario analysis facilitates the comparison of diverged plausible futures, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) suggested that scenarios and models of indirect drivers, direct drivers, nature, nature’s benefits to people, and good quality of life need to be better linked to improve the understanding and explanation of the important relationships and feedback between these components of coupled social–ecological systems (IPBES 2016).

Underuse of natural resources is one of the critical social drivers which alters natural conditions worldwide. Some regions, such as Europe, East-Asia, North America, and Oceania, are facing a situation of underuse due to the shrinking and aging population of farmers and foresters, as well as the changes in policies and economic conditions (Mauerhofer et al. 2018). The underuse problems were mainly researched in Europe and East-Asia in terms of biodiversity conservation. It was suggested that the effectiveness of conservation strategies is generally unclear, and shedding light on the mechanisms and consequences of underuse is important.

Japan is a representative country of an aging and shrinking population (Cabinet Office Japan 2016), and this situation results in the underuse of natural resources, especially in rural regions (Japan Biodiversity Outlook Science Committee 2015). The underuse of natural resources is one of the major driving forces likely to change Japanese terrestrial ecosystems and cause farmland abandonment and vegetation transition which will affect the biodiversity and ESs in the future (Japan Biodiversity Outlook Science Committee 2015). Although scenario analyses have been conducted in Japan to assess the impact of underuse of natural resources, these studies were somewhat limited. The Japan *Satoyama Satoumi* Assessment (JSSA) conducted a scenario analysis in *Satoyama* and *Satoumi* landscapes, which are traditional socio-ecological production landscapes and seascapes in Japan (JSSA 2010). In the JSSA report, a variety of assessment sites were selected and grouped into five major clusters across Japan. Four future scenarios were then generated by following two scenario axes according to the framework of the Millennium Ecosystem Assessment (MA 2005): Local or Global, and Nature-Oriented or Technology-Oriented. However, the output of the JSSA report was limited to the qualitative scenario assessment of ESs based on subjective expert judgment.

To overcome this limitation, the Predicting and Assessing Natural Capital and Ecosystem Services (PANCES) project was launched to develop the integrated model of social–ecological systems which consist of population, land use and natural capital sub-models (PANCES 2016; Takeuchi et al. 2017). Future scenarios provided by the PANCES project adequately represent the way of utilizing natural capital under the future shrinking society in Japan (Saito et al. 2018). This PANCES project also provides social drivers such as population distribution and capital preference under each plausible scenarios, which will contribute to predicting impacts of underuse of natural resources and making domestic and international biodiversity assessment frameworks.

The consideration of processes and feedbacks among social drivers and ecological systems is essential for integrated analysis of social-ecological systems (Carpenter et al. 2009). The demographic conditions have been used to translate scenarios into land use and land cover change using land change models to evaluate ecosystem services (e.g., Estoque and Murayama 2012; Syoyama and Yamagata 2014). For example, Shoyama and Yamagata (2014) quantitatively projected land-use transitions for each scenario using the empirical model Dyna-CLUE (Verburg and Overmars 2009) and evaluated the future ESs based on the InVEST model (Tallis et al. 2011) in the Kushiro watershed in Japan. In the scenario where farmland abandonment progresses due to underuse, the supporting and provisioning services are projected to decline as local communities disappear. However, the Dyna-CLUE model projects future changes based on empirical trends. Also, the InVEST model converts land use (ha) to ESs multiplying predetermined conversion factor (e.g., Mg-C ha^{-1}). These models did not take ecological dynamics and status into consideration, while the ecological dynamics such as farmland abandonment and following forest succession will affect the property of natural capital and ESs (Japan Biodiversity Outlook Science Committee 2015). Thus, scenario analysis of natural capital and ESs in Japan need to be quantitatively conducted, and ecological processes of natural change and its effect on natural capital and ESs must be taken into consideration in terms of planning effective human intervention as the next logical step in this field of study.

Forest Landscape Models (FLMs) have advantages in simulating landscape-scale processes, including forest succession, seed dispersal, natural disturbances (e.g., fire, wind, insect, and browsing), and forest management activities (Xi et al. 2009; Shifley et al. 2017). Among the FLMs, LANDIS-II can simulate the cyclic accumulation of biomass, carbon, and nitrogen, and it has been widely used (Dai et al. 2015) and embedded in a climate change assessment model (MOSAICC model) (FAO 2015). FLMs are widely used for scenario analysis of forest management at a local scale, while the tighter coupling of socio-economic drivers is still challenging (Shifley et al. 2017). Forest succession under each narrative scenario simulated using the FLMs, and outputs were evaluated in terms of biodiversity and ecosystem services, such as the resilience of biomass and species composition and multiple ESs (Swearingen et al. 2015; Price et al. 2016; Thompson et al. 2016a; Lucash et al. 2017), whereas management rules under scenarios was determined by expert judgment.

The purpose of our study is to conduct a quantitative scenario analysis of natural capital and ESs by linking LANDIS-II model and the PANCES scenarios. The study offers some important insights into 1) the effects of ecological dynamics on natural capital and ESs in the context of future underuse trends in Japan, and 2) the coupling of FLMs and social drivers under each scenario at a local scale. Therefore, the specific objectives include: 1) the translation of narrative scenarios into practical management options that can be input to the model directly, 2) the simulation of vegetation succession under different scenarios, and 3) the visualization of consequences for natural capital and ESs, with a discussion of its impacts on local communities. The effectiveness of this study is also discussed by comparing the results with previous scenario analyses studies.

Materials and methods

Description of LANDIS-II model

The LANdscape DIsturbance and Succession model (LANDIS-II), which is one of the prominent FLMs, was designed to simulate the biomass and material cycle for each species cohort and the various disturbance events on grid cells at large landscape scales (Scheller et al. 2007). LANDIS-II represents landscapes as grid cells, and each cell consists of the cohorts defined by tree species name and age information. The surrounding species composition of forests and environmental factors affect vegetation transition pathways. Therefore, forest landscape dynamics such as seed dispersal is modeled explicitly from a spatial perspective.

LANDIS-II NECN succession v4.2 (Scheller et al. 2011) was selected from the model's various functions in this study. The NECN succession is suitable to evaluate the impact of climate change and carbon and nitrogen cycling for future assessment efforts. In NECN succession, biomass growth and seedling establishment are designated as functions of environmental conditions. Biomass growth is calculated by the difference between monthly net primary production (NPP) and monthly mortality. NPP is calculated by multiplying the monthly maximum aboveground NPP (maxANPP) by environmental limiting factors corresponding to the monthly mean of daily maximum and minimum temperatures, nitrogen availability, soil moisture, shading, and density effect. The monthly mortality is a function of the aboveground biomass and its age. In relation to seed dispersal and seedling establishment, the NECN succession uses a simplified algorithm. First, the NECN succession calculates the arrival probability of seeds from other cells. In the process, the effective and maximum seed dispersal distance for each species decides a probability distribution for seed dispersal. The establishment probability is then calculated stochastically, depending on the shade tolerance by tree type, temperature and soil-water conditions. The species-specific parameters for the NECN succession can be found in S1, and the calibration and validation processes are shown in S2 of the electronic supplementary materials.

Site description

ESs evaluation worldwide has been performed at various spatial scales depending on the research question (Englund et al. 2017), and finer scale analyses is essential for understanding both win-win and trade off relationship of biodiversity and ESs and for targeting specific conservation actions (Naidoo et al. 2008). The case study area was the Bekanbeushi River Watershed (between 42°59'48" N and 43°21'15" N in latitude and 144°36'17" E and 145°00'26" E in longitude) in the eastern Hokkaido prefecture (Figure 1). In this watershed, the population of workers in the primary industry have continuously decreased since 1960 (Akkeshi town 2017; Shibecha town 2017). The major industries include fishery, forestry, and pasture grass production for dairy farming (Akkeshi town 2017). Population is projected to decline to 52% of 2015 levels by 2045 (NIPSSR 2018). Therefore, the abandonment of forestry and agriculture due to the shortage of workers and its impact on the local ecosystems are key concerns in the region and considered to be suitable for a case study of underuse problems.

The area of this watershed is approximately 700 km^2 and consists of various ecosystems such as forests (c.a. 70%), pasture land (c.a. 20%), and wetlands (c.a. 4%) registered in the Ramsar Convention in 1993. In national forests in the northern part of the watershed, the main vegetation consists of Japanese larch (*Larix kaempferi* (Lamb.) Carrière) plantations. The species composition in prefectural forests in the southern area is Todo fir (*Abies sachalinensis* (F.Schmidt) Mast.) plantations and mixed forests of Todo fir–Japanese oak (*Quercus crispula* Blume).

Future scenarios

Social scenarios developed on a national scale by Saito et al. (2018) were used as the base context. This national scenario consists of two bidirectional aspects specifying four different future visions (Figure 2). Four scenarios are represented by the following two scenario axes in the future: “population distribution” and “capital preference.” The former assumption decides the two types of population distribution: dispersed population (Dsp) and urban compactification (Cmp). The Dsp scenario assumed that rural communities will be maintained by a decentralized approach, while in the Cmp scenario, people will move from rural to urban areas, which will result in the accelerated disappearance of rural communities. The latter assumption characterizes people's capital preferences. The natural capital basis (Ntr) utilizes more local natural capital (e.g., domestic timber use), and the produced capital basis (Prd) utilizes more goods produced and imported from elsewhere, thereby relying on foreign natural capital.

In this study, scenarios in the watershed were set by localizing the national scenarios in terms of the social context of the region. First, a business as usual (BaU) scenario was defined by assuming that past trends of forestry and agriculture will continue in the future. Four future scenarios were set by referring the BaU scenario as follows. In relation to the assumption of capital preference, the primary industries were assumed to actively manage the local forest and farmland in the Ntr scenarios, while the local natural capital was assumed to be gradually abandoned in the Prd scenarios. In terms of population distribution, it was assumed that people will remain in the watershed and continue to manage local natural capitals in the Dsp scenarios, whereas the management of remote farmlands far from residential grid cells will gradually become more challenging to manage because of population out-migration in the Cmp scenarios.

Forest management setting

Biomass Harvest Extension v3.2 (Scheller and Domingo 2018) of LANDIS-II model was used to simulate forest management activities under each scenario. The Biomass Harvest Extension enables the setting of the target species, the proportion of the biomass to be removed, and the proportion of target cells which are managed each year (management intensity). In the watershed, Todo fir and Japanese larch is the target species of forestry (Hokkaido 2017a), thus, clear-cutting and thinning rules for the two species were designed based on a regional forest management plan (Hokkaido 2017a). These forestry practices were applied to the stands (forest management unit) containing mature Todo fir and Japanese larch in descending order of mean cohort age until the total harvested area reaches the annual management intensity.

The management intensity in 2050 was set by the capital preference assumption (Table 1). The initial management intensities of "clear cut and plantation," "clear cut and natural regeneration," and "thinning" in 2015 were determined so that the mean harvest areas during 35-year simulation in the BaU scenario become as same as the actual value by regional forestry statistics. (row one on Table 1) (Hokkaido 2017b); the rotation period of clear cutting ranged from 133 years (0.075% per year) to 400 years (0.025% per year), and that of thinning was approximately 75 years (1.3% per year). These rotation periods were much longer than the standard rotation periods in the region (Hokkaido 2017a). In the BaU scenario, forestry practices were assumed to continue the present management intensities from 2016 to 2050 (row two on Table 1). In the Ntr scenarios, people utilize local timber products and actively manage the forest in the watershed, so the management intensities of Todo fir and Japanese larch clear cutting were assumed to linearly increase to 1.7 and 2.0% in 2050, respectively (row three on Table 1). These management intensities were decided by the standard rotation periods of Todo fir (60 years) and Japanese larch (50 years). According to the regional standard, the management intensity of Todo fir and Japanese larch thinning was set to 4 times per 60 years (15% per year) and 4 times per 50 years (12.5% per year), respectively. The proportion of the removed biomass by thinning was set as 26.5% according to the regional forest management plan (Hokkaido 2017a) and 100% by clear-cutting. In the Prd scenarios, forestry was assumed to be abandoned, and therefore, management intensity of clear cutting and thinning was set to decrease linearly to 0% by 2050 (row four on Table 1). The manageability of forestry practice was assumed to be the same, while the manageability of pasture land was considered somewhat different, as described in the next section. This is because the frequency of forestry practices is lower than pasture land management practices, in general.

Pasture land management setting

Pasture land management and abandonment was represented by LANDIS-II Biomass Harvest Extension v3.2 (Scheller and Domingo 2018) according to Middendorp et al. (2016). In this region, pasture management is conducted from April to October, including approximately 2 harvesting events (758 kg 10a^{-1})

(Nemuro Agriculture Improvement Promotion Center 2016) and 3 fertilizing events (10 gN m^{-2}y^{-1} nitrogen) (Hokkaido 2015). According to the agricultural census, the farmland abandonment ratio was 0.89% in 2005 and 1.37% in 2015, which is an annual increase of 0.048 % yr^{-1} (2005 to 2016 in Figure 3) (Ministry of Agriculture, Forestry and Fisheries 2018). The Biomass Harvest Extension assumed to remove both pasture grass and other species established in each cell every year until the pasture land in the cell became abandoned.

In the BaU scenario, the abandonment ratio was set to increase 0.048 % annually until 2050 (solid line in Fig. 3). In the Ntr scenarios, abandoned pasture land in 2015 was assumed to be gradually re-cultivated, and the abandoned farmland ratio became 0% in 2050 (dashed line in Fig. 3). On the other hand, the dependence on imported foods was assumed higher in the Prd scenarios. Therefore, the annual increment in the farmland abandonment rate was set to 1.35%, and the abandonment rate was projected to be 48.8% in 2050 (dotted line in Fig. 3). This increment rate is equal to the highest 95% of the increase rate of farmland abandonment ratio among all municipalities in Japan from 2005 to 2015 (S3 of the electric supplemental materials) (Ministry of Agriculture, Forestry and Fisheries 2018).

Population distribution was assumed to affect the manageability of pasture land, and pasture land that has a lower manageability value assumed to be abandoned earlier. The gridded population distribution under each scenario was derived from the PANCES project at 1 km resolution (Figure 4) (Matsui et al. 2018). In the PANCES project, BaU follows the population distribution in 2050 estimated by the National Spatial Planning and Regional Policy Bureau (Ministry of land, Infrastructure, Transport and Tourism 2018). The spatial allocation of population reflects the population distribution rule for each scenario. In the BaU scenario, population in the watershed decreased from 8,604 to 4,148, and the population was concentrated in the center of the town of Akkeshi in the coastal area. In the urban compactification (Cmp) scenarios, it was assumed that people moved to neighboring Kushiro and Naka-Shibetsu, and the population in the watershed eventually decreased to zero. In the dispersed population (Dsp) scenarios, although it was assumed that some people would remain in the watershed in 2050, the population decreased from 8,604 to 4,940.

Therefore, manageability of each pasture land was calculated from Equation (1).

$$Y_i = \frac{pop_i}{distToResi_i} \times \frac{1}{distToRoad_i} \times \frac{1}{meaSlope_i} \times \frac{1}{meaElev_i}, \tag{1}$$

where *Yi* is the manageability of cell *i*, and pop_i and $distToResi_i$ denote the population in the nearest residential grid cell and the distance to the nearest residential grid cell from cell *i*, respectively. $distToRoad_i$ is the distance to the nearest road from cell *i* (Conservation GIS-consortium Japan 2017), and $meaSlope_i$ and $meaElev_i$ represent the mean slope and the elevation of cell *i* (National Land Numerical Information download service 2017). These variables were standardized from 1 to 2.

Model simulation

Landscape initialization

The total simulated area within the watershed was 50,415 ha. LANDIS-II represents the landscape as grid cells, and the cell size was set at 100 m referring the mean size of each forest management unit in this area. Wetland areas were excluded from the simulation because the scope of this study was to assess the impact of underuse of manageable ecosystems, which does not apply to wetlands.

LANDIS-II estimates initial aboveground biomass of each cohort through spin up simulation based on the species name and its age information in each cell (Scheller et al. 2018). In this study, the distributions of tree species were obtained from a vegetation map (Biodiversity Center of Japan 2017). In the vegetation map, the vegetation distribution at the community level was recorded, therefore, we decided the representative species for each community from the community's name (S4 of the electronic supplemental materials). The age information was added by the forest register of national, prefectural, and private forests (Ministry of Agriculture, Forestry and Fisheries 2017a; Hokkaido 2017c). To reduce the complexity of the simulation, the most dominant communities in the watershed were selected, which represent 94% of the total coverage (S4), and as the result, 10 species were taken into account in this study (Table 2).

Environmental variable setting

Environmental conditions were set by ecoregion in LANDIS-II. In the NECN succession, users can input the soil and climatic conditions. The initial soil conditions were individually set for the pasture land and the forest ecoregion. The allocation parameters of soil organic matter (SOM) pools were set by the parameterization workbook of the CENTURY soil organic matter model (CENTURY4 2000). The decay rate of each SOM pool was obtained from the user guide of the NECN succession (Scheller et al. 2018). Soil-water condition was calculated to estimate the plant available water using a simple bucket model with the soil's physical parameters, such as soil depth and the percent of clay and sand, which were determined from available literature (Hokkaido National Agricultural Experiment Station 1983).

With respect to the climatic setting, the ecological processes, such as the growth of aboveground biomass and the decomposition of dead wood and soil organic matters, respond to climatic conditions, thus, monthly maximum and minimum temperatures and monthly precipitation were required. In Japan, climate change is regarded as the "fourth crisis" of biodiversity (Japan Biodiversity Outlook Science Committee 2015). Recent studies suggest that the potential habitat of some broad-leaved tree species will expand to cool temperature zones (Nakao et al. 2014), and the vegetation succession process will also be affected by climate change (Laflower et al. 2016). These climate change effects cannot be ignored in the mid- and long-term future forecasts of tens to hundreds of years targeted by the scenario approach. In this study, climate change is assumed to be the baseline trend, and climatic conditions under the IPCC RCP8.5 scenario calculated by the MRI-CGCM3 were thus selected from the CMIP-5 project database (ESGF-CoG 2017). The grid size was approximately 1 degree in latitude and longitude, and the grid covers the entire study area. Therefore, the distribution of climatic conditions was assumed to be uniform. To correct the bias between climatic values from MRI-CGCM3 and observation, monthly temperature and precipitation offsets were determined by comparing data from the model and the Ota Meteorological Observatory, which is located within the watershed (Japan Meteorological Agency 2018), and the offset values were applied to future climate data. Annual rainfall is estimated to increase by 115 mm, and the annual means of monthly maximum and minimum temperatures to increase by 1.5 °C and 2.1 °C in the 2040s, respectively (S5 of the electronic supplementary materials).

Simulation conditions

By combining the assumptions of capital preference (Ntr and Prd) and population distribution (Cmp and Dsp), four future scenarios (PrdCmp, PrdDsp, NtrCmp, and NtrDsp) and a BaU scenario were simulated under the RCP8.5 climate scenario obtained from the MRI-CGCM3. The duration was 35 years, from 2016 to 2050. The time step for vegetation succession was set at 1 year, and the biomass growth and cohort mortality were calculated in monthly time steps.

Evaluation of natural capitals and ESs

Natural capital was evaluated by considering the composition and diversity of the land cover and aboveground biomass at the watershed scale. In this study, land cover was defined as a tree species with the largest biomass in each cell. It should be noted that, if the cell contains multiple species, non-dominant species were ignored for land cover types.

The diversity of land cover and biomass was calculated using Simpson's diversity index (SD), as expressed by Equation (2),

$$SD_t = 1 - \sum_{i=1}^{S} \left(\frac{N_{t,i}}{Ntotal_t} \right)^2, \qquad (2)$$

where SD_t is Simpson's diversity index at the watershed scale for year t. For land cover, S is the total number of land cover types, $N_{t,i}$ is the number of cells for land cover i in year t, and $Ntotal_t$ is the total number of active cells. For aboveground biomass, S is the total number of tree species, $N_{t,i}$ is the biomass of species i in year t, and $Ntotal_t$ is the total biomass at the watershed scale.

To analyze the impact of pasture land abandonment on landscape patterns, the perimeter and area of each pasture land patch were calculated using FRAGSTATS software (version 4.2).

Regarding ESs, the timber and pasture grass provisioning and carbon sequestration services were evaluated by the harvested timber and pasture and net ecosystem exchange (NEE), respectively. In this study, the carbon sequestration service is evaluated by the net ecosystem exchange and is calculated using Equation (3),

$$ES_{carbon\ sequestration} = \sum_{t=2016}^{2050} \sum_{i=1}^{L} \sum_{j=1}^{N} (-NEE_{t,i,j} \times 10^4), \qquad (3)$$

where $ES_{carbon\ sequestration}$ is the cumulative amount of sequestrated carbon at the watershed scale, and $NEE_{t,i,j}$ (gC m^{-2}) is the simulated annual total net ecosystem exchange (NEE) on cell j of land cover type i in year t. NEE represents the net carbon balance of plant and soil layer and is calculated by the heterotrophic respiration minus NPP. L denotes the total number of land cover type and N is the total number of cells in land cover type i in year t.

Results

Natural capital: Changes in land cover

The assumptions related to capital preference and population distribution affected the total area and the distribution of abandoned pasture land (Figure 5). In terms of capital preference, pasture land decreased by 45% in the Prd scenarios and decreased by 3% in the BaU scenario over the simulation periods (S6 in the Electronic Supplemental Materials). After the pasture land was abandoned, mainly Japanese white birch established and grew because Japanese white birch is a pioneer species in the region having the lowest shade tolerance and the longest seed dispersal distance among the 10 species considered (S1(a)).

In the two Prd scenarios, the population distribution affected the spatial arrangement of abandoned pasture land because the accessibility components associated with each pasture land are different, as indicated in Eq. 1. In the PrdCmp scenario, people migrated to the cities outside the watershed such as Kushiro (47 km west from the watershed) and Naka-Shibetsu (77 km north from the watershed) by 2050 (Fig. 4(c)). Table 3 shows the mean score of the components in Eq. 1 among the abandoned pasture land in 2050 when the ratio of abandonment reached 48.8% for Prd scenarios. In both Prd scenarios, elevation (meaElev$_i^{-1}$) had a significant impact. In the PrdCmp scenario, the distance to the nearest residential grid cell affected the distribution of the abandoned pasture land. Therefore, the southeastern and northwestern pasture lands far from these cities were largely abandoned (Fig. 4(c) and Fig. 5). In the PrdDsp scenario, people remained in the watershed in 2050 (Fig. 4(d)), and thus, geographical conditions such as elevation and slope were the major driving forces affecting pasture land abandonment (Table 3).

The assumptions related to capital preference and population distribution also affected the patch metrics of pasture land (S7 of the Electronic Supplemental Materials). The number of patches of pasture land increased in all scenarios, while the mean area and the mean perimeter decreased in all scenarios. In particular, the PrdCmp and PrdDsp scenarios showed significant changes, and the number of patches increased from 141 to 206 and 193, mean area decreased from 108 ha to 41 and 43 ha, and mean perimeter decreased from 10.8 km to 4.3 and 4.7 km, respectively.

In the two Ntr scenarios, all pasture lands were conserved, and some parts of the Japanese larch forest in the middle north were shifted to Japanese white birch through natural regeneration after clear-cutting (Fig. 5).

In all scenarios, the abandoned pasture lands (pasture grass in 2016) were mainly dominated by Japanese white birch by 2050 (S6). Todo fir and Japanese larch shifted to Japanese white birch and Japanese alder after natural regeneration. The Japanese white birch dominated in the mixed forest of Japanese white birch and Japanese oak and was distributed mainly in the northern region (Fig. 5) in 2016. After 35 years, the mixed forest was dominated by Japanese oak because of the difference in the longevity of the two species, where the longevity of Japanese white birch and the longevity of Japanese oak were 100 and 400 years, respectively. In the mixed community of Japanese oak and Todo fir in the southeast of the study area, the dominant species shifted from Japanese oak to Todo fir because the maximum biomass of Todo fir is higher than that of Japanese oak (S2).

These vegetation transitions altered the composition of land cover (Figure 6). Capital preference affected the total amount of the abandoned pasture land and the clear-cutting area. In the Prd scenarios, pasture land decreased with progress in pasture land abandonment, and Japanese white birch increased in these cells compared to the BaU scenario (S6). In the Ntr scenarios, Japanese white birch established and grew following natural regeneration after clear-cutting of the Japanese larch (S6). Consequently, Japanese white birch increased in both scenarios compared with the BaU scenario. The landscape diversity value at the watershed scale was 0.83 in the Prd scenarios and was slightly higher than that of the BaU and Ntr scenarios in the year 2050 (0.80).

Natural capitals: Changes in biomass

The composition and total amount of the AGB at the watershed scale were substantially affected by capital preference (Figure 7). In the BaU scenario, the AGB of Japanese white birch decreased because of age-related mortality. The

AGB of Japanese larch increased by 405 Gg-biomass due to the increase in mature cohorts which were not clear cut. In the PrdCmp and PrdDsp scenarios, the total amount of AGB was 964 and 931 Gg-biomass, respectively, which were both higher than BaU. Japanese white birch forest expanded in the abandoned pasture land, and the AGB of the species in the PrdCmp and PrdDsp scenarios increased by 434 and 421 Gg-biomass compared with the BaU scenario, even though that of Japanese white birch decreased in forest cells because of age-related mortality. In the forest ecosystems in the PrdCmp and PrdDsp scenarios, the AGBs of Japanese larch slightly increased by 38 and 45 Gg-biomass, and that of Todo fir increased by 40 and 62 Gg-biomass over that in the BaU scenario, respectively. In the NtrCmp and NtrDsp scenarios, the total AGB was 1499 and 1511 Gg-biomass below the BaU scenario. This is because the AGB of Japanese larch decreased 887 and 888 Gg-biomass and that of Todo fir decreased 311 and 305 Gg-biomass than the BaU scenario, respectively, due to the promotion of timber harvesting activities. In both the Ntr and Prd scenarios, the species diversity based on the AGB of each species at the watershed scale was 0.80 among the Prd and Ntr scenarios and only slightly higher than that of the BaU scenario (0.79).

Provisioning services: Timber and pasture provisioning

The capital preference affected both timber and pasture yields (Figure 8). In the Ntr scenarios, the total timber yield was approximately 2.8 times higher than the yield in the BaU scenario because of active forestry. Japanese larch and Todo fir were harvested at levels that were 7.3 and 2.2 times higher than harvesting levels in the BaU scenario, respectively. The total amount of pasture grass production in the BaU and Ntr scenarios were virtually identical, but was 20% less in the Prd scenarios.

Regulating service: Carbon sequestration

The carbon sequestration service of the Ntr and Prd scenarios was 1.2 and 1.1 times higher than that in the BaU scenario, respectively (Table 4), while the major carbon sinks differ among the scenarios. The land cover, which was dominated by Japanese larch, Japanese white birch, and pasture grass, was net carbon sink in all scenarios. In the Ntr scenarios, Japanese larch sequestrated 2.3 times more carbon than the amount sequestered in the BaU scenario because the mean age of the species became younger over time by activate forestry practice. By contrast, the amount of sequestered carbon by the Todo fir decreased compared with the BaU scenario due to the lower growth rate as compared to the Japanese larch (S2) and the decrease in coverage area (S6). Japanese white birch forest was established after the "clear cutting and natural regeneration" resulting in the increase of the service. In the Prd scenarios, Todo fir and Japanese larch became mature and the carbon sequestration service decreased because of the low management intensities. The major sink of the Prd scenarios was Japanese white birch which established and grew following pasture land abandonment, while the carbon sequestration by pasture grass decreased.

Comprehensive comparison among future scenarios

The assumption of population distribution and capital preference led the different consequences among the scenarios. The population distribution affected both the spatial allocation of abandoned pasture land (two Prd scenarios in Fig. 5) and the patch metrics of managed pasture land (S7) in the PrdCmp and PrdDsp scenarios. The patch number of managed pasture land in the PrdCmp scenario was larger and the perimeter and area were smaller than those in the PrdDsp scenario. This suggested that the managed pasture land was more isolated in the PrdCmp scenario.

The assumption of capital preference largely affected the consequences for ESs in the watershed. The Ntr scenarios had an advantage in terms of species diversity based on the AGB, the timber and pasture yields (Fig. 8), and total carbon sequestration (Table 4), while active management negatively impacted the changes in the amount of biomass (Fig. 7). In the Prd scenarios, changes in the amount of biomass (Fig. 7) and landscape diversity were maximized. The BaU scenario ranked between the Prd scenarios and the Ntr scenarios from the perspective of biomass change and timber and pasture yields, while landscape and species diversity was the lowest among the scenarios.

The effect of forestry practices on carbon sequestration differed among species due to the difference in growth rates. Both Japanese larch and Todo fir, which are the target species of forestry in this region, experienced higher rates of clear cutting and thinning in the Ntr scenarios. As the result, Japanese larch increased both the timber provisioning and carbon sequestration services, while the carbon sequestration of Todo fir decreased compared with the BaU scenario. However, Todo fir has a potential to increase carbon sequestration in the future as long as it is managed continuously. These results suggested that the model simulation enables us to understand complex effects of landscape management practices on carbon sequestration.

Discussion

Scenario improvement by feeding back simulation results

The results of this study can feed quantitative information to the narrative scenarios provided by the PANCES project (Saito et al. 2018), which were localized by the future vision for the town of Akkeshi (Akkeshi town 2016) (Table 5). The row titles in Table 5 were consistent with the main framework of the PANCES scenario (Saito et al. 2018), and the column titles represent the scenario names.

First, "Industrial structure and economy" complemented by the concrete management intensity and the expected timber and pasture grass yields. In produced-capital-based societies (Prd), the spatial distribution of abandoned pasture land was characterized by the manageability under each scenario (PrdDsp or PrdCmp) using Eq. 1.

The "Infrastructure and policy" was localized, referring to population distribution in 2050 (Matsui et al. 2018) and the local future vision of Akkeshi town (Akkeshi town 2016). In natural-capital-based societies (Ntr), people are assumed to utilize the local natural capital and ESs. The difference between NtrCmp and NtrDsp is where the forestry and agricultural workers live and engage in the utilization of them. To vitalize agriculture and forestry, collaboration and job creation will be promoted. In contrast to this, under the Prd scenarios, landscape managements will be gradually abandoned.

Finally, local community conditions and contact with nature in "Culture and Value" were discussed. In the Dsp scenarios, local communities were vitalized through job creation, while people moved out of the watershed, leaving no residents by the year 2050 in the Cmp scenarios. In the Ntr scenarios, people was assumed to conserve the local ecosystems, and local residents continued traditional contact with nature and wildlife in the NtrCmp scenario, while people outside the watershed managed them in the NtrDsp scenario. In low management intensity societies (Prd), the area of forest increased because of pasture land abandonment, and pasture lands become isolated, especially in the PrdCmp scenario. This can cause a habitat change for wildlife such as the Hokkaido sika deer and Brown bear, and inefficiency of pasture land management. From a perspective of living with nature, a potential for conflict between human and wildlife still remains in two Prd scenarios because people continue to live in the watershed in the PrdDsp scenario and pasture workers from outside watershed visit to manage the pasture land in the PrdCmp scenario.

Limitation and Challenge

This study defined future management intensity of forestry and pasture considering assumptions of population distribution and capital preference provided by the PANCES scenarios, while previous studies visualized the consequences of each scenario by setting plausible management case by expert judge (Swearingen et al. 2015; Price et al. 2016; Thompson et al. 2016a; Lucash et al. 2017). This approach successfully demonstrated the effect of those assumptions on future state of natural capital and ESs and will make an important contribution to the development of an integrated model of socio-ecological systems.

Our study is capable of covering the provisioning services of materials (timber and pasture grass) and climate regulation service. The results of timber and pasture grass yield can be used to evaluate the energy supply potential (De Jong et al. 2007; Oba et al. 2016) and food provisioning by integrating our results and other models (FAO 2015). The JSSA report evaluated four scenarios using 13 types of ESs indices (six provisioning services, three regulating services, and four cultural services) even though they were qualitative, so still we have many challenges in the quantitative evaluation of the other ESs.

The previous spatially explicit scenario analysis at the local scale (Shoyama and Yamagata 2014) projected future land use change using machine learning approaches and past land use data. This approach projects the future land use change by extrapolation with the past trends assuming stationarity (Brown et al. 2013; Shoyama et al. in press). However, this approach can bring biased results if the past trends will not continue in the future due to inexperienced social transition such as rapid population decline and aging. Our process-based approach can simulate future land cover in underuse situation by calibrating management intensities, which enabled us to better understand the relationships between the changes in ecological processes and the consequences of natural capital and ESs; farmland abandonment and changes in landscape metrics and climate regulation service, and forestry practices and timber provisioning services and carbon sequestration service. As a future direction, the land use change projection can be used for input data of ecological process models. Recently, challenges coupling with land change modeling and ecological process models are emerging (Thompson et al. 2016b; Shoyama et al. 2017). However, important limitations and challenges still remain as below.

Scenario translation

In this study, the assumption of population distribution and capital preference were considered to be independent of one another. Further studies are needed to introduce the interactions and systematic changes of those indirect drivers such as capital, demographics, and infrastructure to design much more plausible management strategies for forestry and farmland abandonment in different scenarios. For example, the usage of the system dynamics model in the scenario translation process (Mallampalli et al. 2016) can help explain the interaction between social-economic drivers, indirect drivers such as the demand, and direct drivers such as management intensity.

To evaluate impacts on vegetation succession under social and climate change, a longer-term simulation is expected. Administrative management plans are set from several years to several decades, while ecological changes in the forest ecosystems are extended for much longer durations. This gap in the time horizon may cause the over or under estimation of some ESs. For example, in this study, the simulation period was 35 years, from 2016 to 2050, referring to relevant administrative plans, and the result showed the early successional stage with the expansion of pioneer species such as Japanese white birch and Japanese larch.

Improvement of model reliability

LANDIS-II NECN succession was localized in Japanese ecosystems by collecting the species-specific parameters and calibrating empirical data, as shown in S1 and S2. To validate the output of LANDIS-II, the forest register in the region was used. However, the forest register mainly recorded commercial species, such as

Japanese larch and Todo fir, and the data for natural forests was limited. Furthermore, there was not enough data for verifying the long-term vegetation transition. Therefore, long-term field observations are necessary to improve the reliability of the model using new techniques, such as remote sensing technology and cross comparison with other models (Wang et al. 2014; Shifley et al. 2017).

Cross-benefit evaluation

Our results made it possible to compare scenarios using multiple indicators of natural capital and ESs. Toward 2050, the results of this study suggested that the intensity of forest and pasture land management had large impacts on natural capital and ESs. Meanwhile, local stakeholders have multiple interests and concerns not only sustainable ecosystem management but also social well-being such as promoting decent works and establishing resilient cities announced in the Sustainable Development Goals (United Nations 2015). To form a consensus on ecological management, the output of the LANDIS–II model and other FLMs should be linked with multiple benefits in terms of both social and ecological systems.

In relation to the social system, the output of LANDIS-II can serve as an input to ecosystem service models such as the InVEST model (Thompson et al. 2016a), and it can facilitate a holistic evaluation of ESs. In Japan, the interaction between terrestrial and marine ecosystems has received national attention in the form of the "Connect and Support Forests, Satoyama, Rivers and Sea" campaign (Ministry of the Environment 2018). A coupling of the LANDIS-II and hydrological models will also help explain the linkage between different types of ecosystems.

In terms of evaluation of ecological systems, biodiversity should be evaluated from multiple perspectives. To evaluate floral change, we calculated the diversity of land cover and the AGB in the watershed scale to evaluate the landscape diversity and species diversity, respectively. The landscape diversity probably impacts the quality of habitat for wildlife. The output of the LANDIS-II model can be used to calculate the habitat suitability index (HSI) of various species (e.g., De Jager et al. 2017). On the other hand, species diversity probably reflects the diversity of ESs. The following are examples of species and their characteristic ESs: Todo fir and Japanese larch provide both a timber provisioning service (Fig. 8) and a carbon sequestration service (Table 4), Japanese white birch provides a carbon sequestration service (Table 4). Therefore, it is expected that the use of landscape and species diversity as comprehensive indicators of regional-scale biodiversity and ESs diversity would be confirmed.

To evaluate the cross benefit, the effects of natural disturbances that impact entire socio-ecological systems should also be taken into consideration. In this study, the interactions among only human activities and flora was modeled to simplify the ecological process in the region, while disturbance events such as browsing by Hokkaido sika deer, forest fire, and wind throw are important disturbances. For example, the growth of the Hokkaido sika deer population and the damage caused by their browsing is one of the major problems facing agriculture and forestry in the region (3.2 hundred-million-yen loss in 2014 which means 4.5 % of GDP in Akkeshi town: 1 USD = 110 yen (Akkeshi town 2015; Ministry of Agriculture, Forestry and Fisheries 2017b)). Local population decline will also decrease the resilience in the face of those disturbances and the magnitude of their impact may vary by scenario. The LANDIS-II modeling community has developed extensions to simulate the effects of fire (He and Mladenoff 1999), wind throw (Mladenoff and He 1999), and outbreaks of insects and disease (Sturtevant et al. 2004), and extensions that consider the effect of browsing ungulates are now in development (De Jager et al. 2017). The simulation of impacts of those disturbances considering human intervention will contribute to local decision making and sustainable design of landscape management.

Conclusions

Our study conducted scenario analysis of natural capital and ESs focusing on underuse using LANDIS-II in the Bekanbeushi River Watershed, northern Japan. The assumptions of population distribution and capital preference which characterized the four future scenarios led to different consequences for natural capital and ESs. Population distribution affected the spatial allocation of abandoned pasture land and promoted the isolation of managed pasture land. The assumptions of capital preference largely affected the quantity of ESs, and the provisioning service and climate regulation service were both increased in the Ntr scenarios comparing with underuse situations expressed by the BaU and Prd scenarios.

These simulation results were usable to add quantitative information to the narrative scenarios provided by Saito et al. (2018) in terms of "Industrial structure and economy," "Infrastructure and policy" and "Culture and Value." This information concretized how future scenarios may affect not only ecological aspects but also lifestyles of local people and local industrial structure. Our process-based approach provided a better understanding of the relationships among social drivers, ecological processes and the consequences of natural capital and ESs, which will advance the quantitative scenario analysis in the regions in the context of future underuse trends.

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Figure

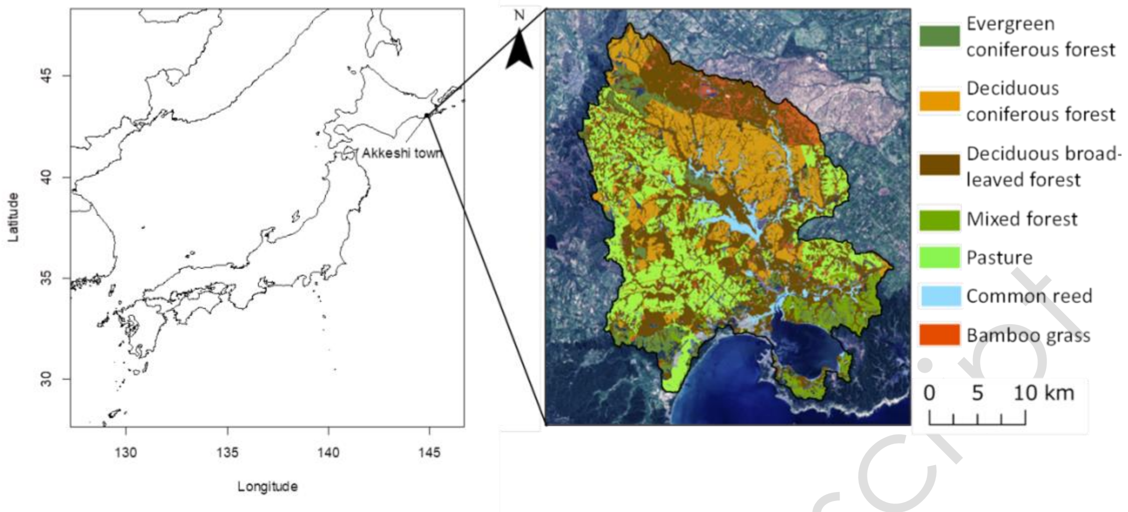


Fig. 1 Location of the study site and its vegetation and land cover.

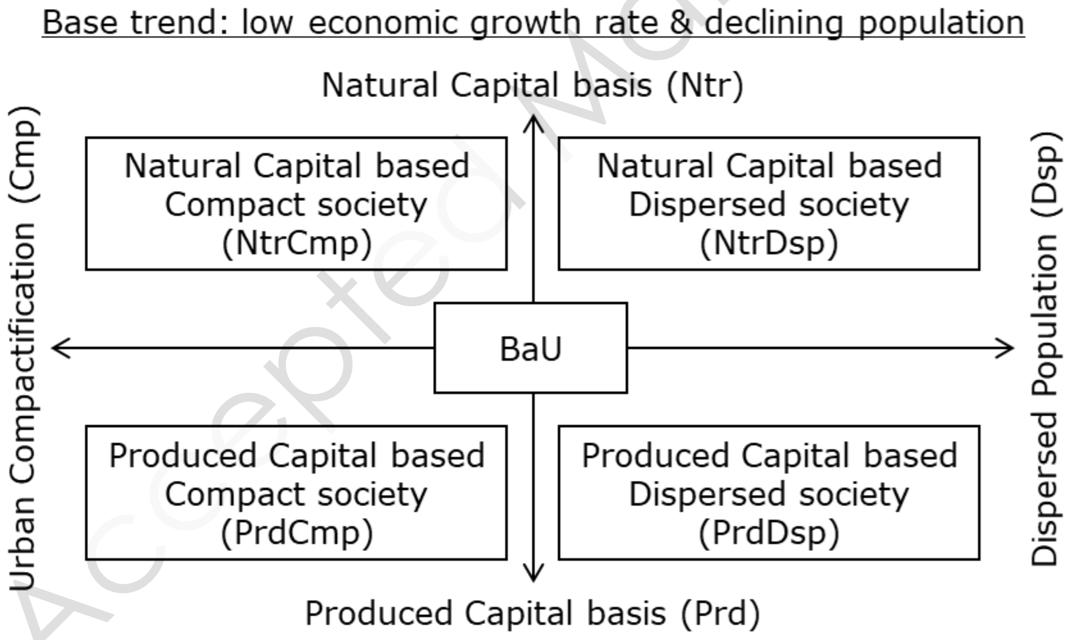


Fig. 2 Four future scenarios on a national scale. The abbreviation of each scenario is shown in the bracket. For more details, see Saito et al. (2018).

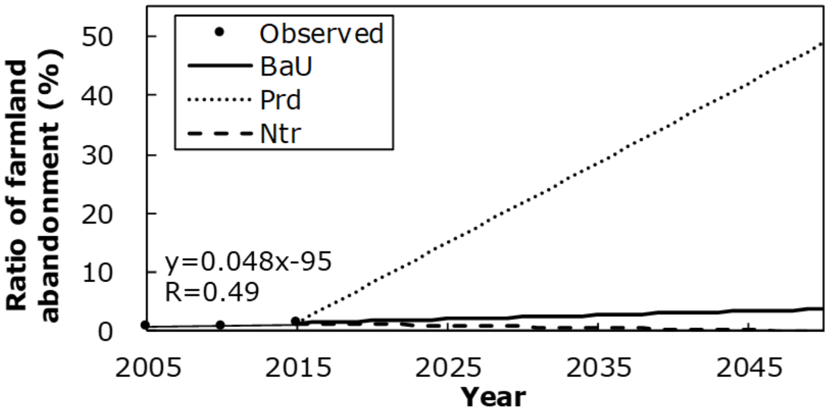
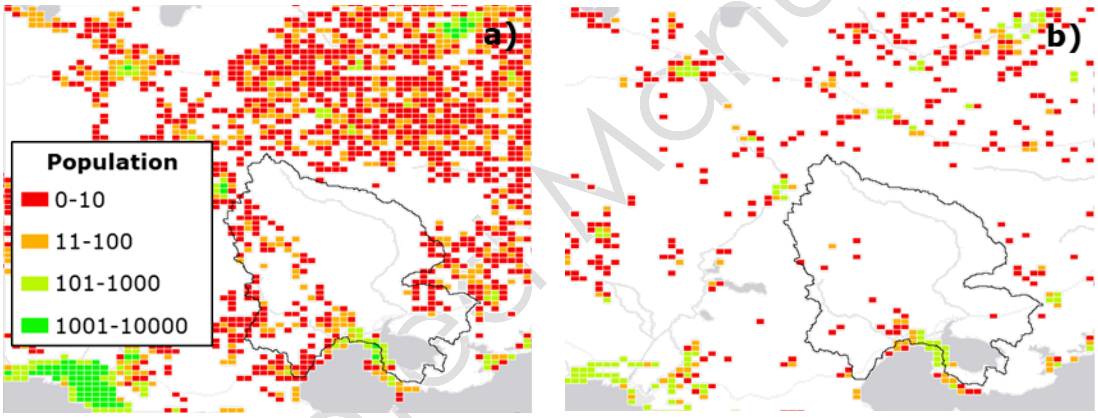


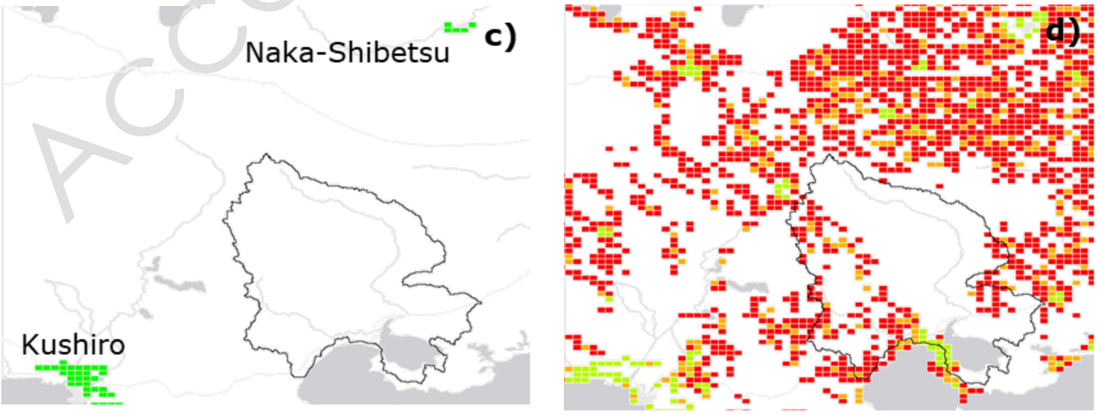
Fig. 3 The trend and assumptions of the farmland abandonment ratio for each year.



Population in the watershed:

8,604

4,118



Population in the watershed:

0

4,940

Fig. 4 Distribution of residential population by scenarios. The black line shows the boundary of the watershed, where (a) is the population distribution in 2010, and (b)-(d) indicate the population distribution under the BaU, Cmp, and Dsp scenarios in 2050, respectively.

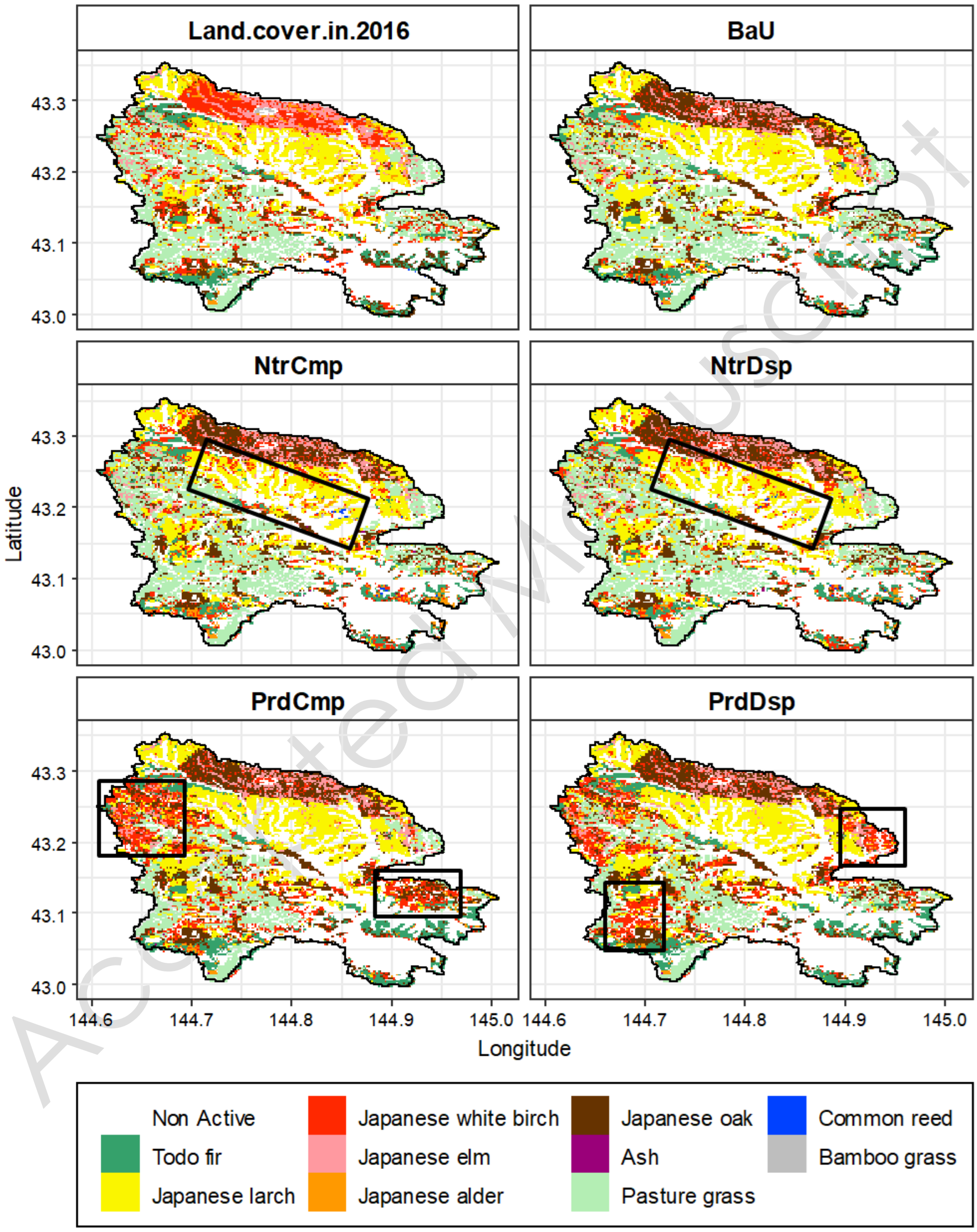


Fig. 5 The land cover maps in 2016 and 2050 of each scenario.

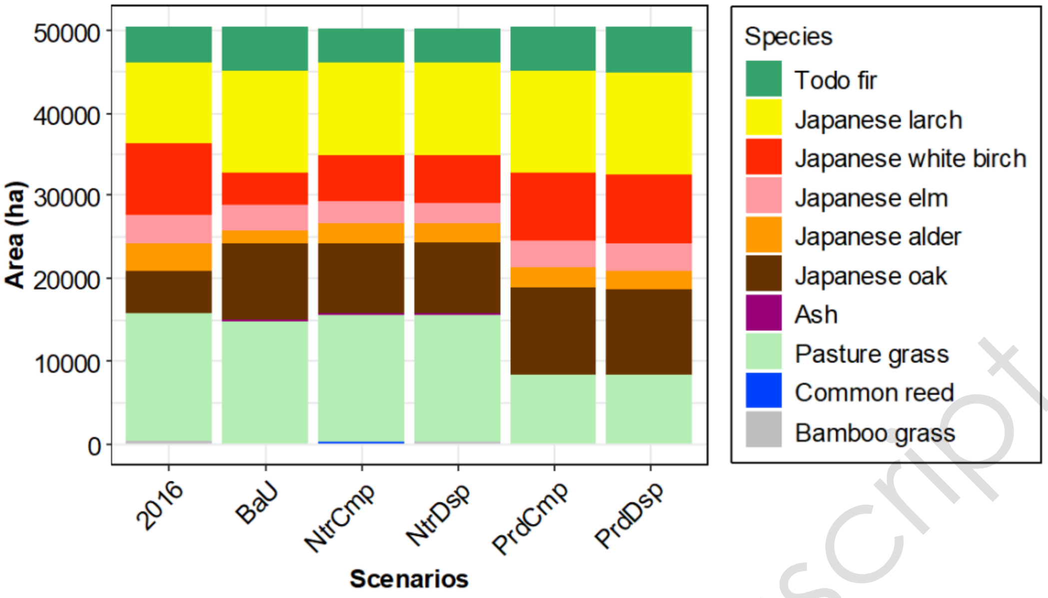


Fig. 6 The composition of land cover in 2016 and 2050 for each of the five scenarios.

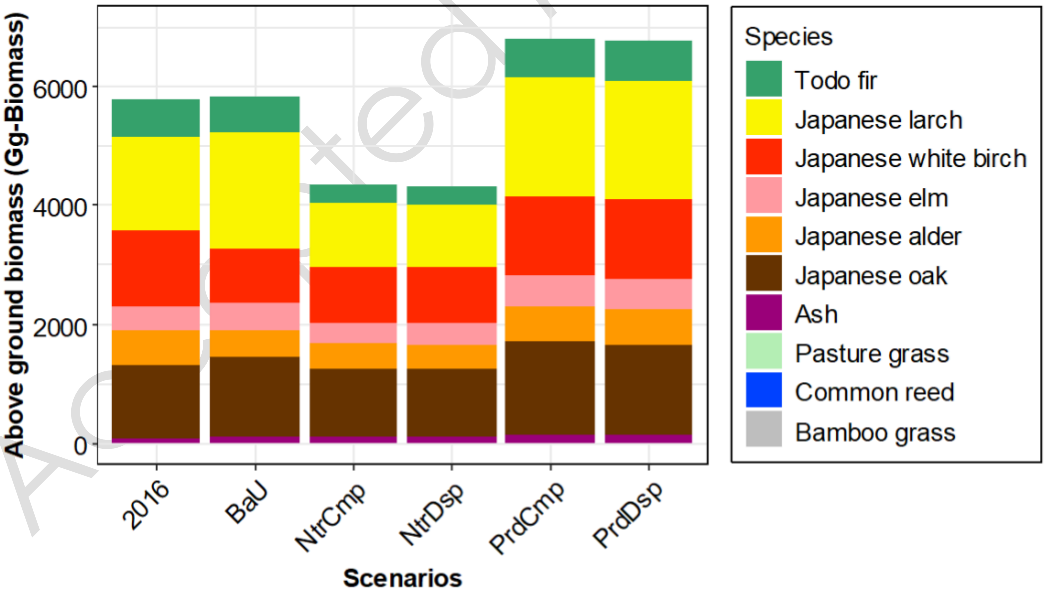


Fig. 7 The composition of aboveground biomass in 2016 and 2050 for each of the five scenarios.

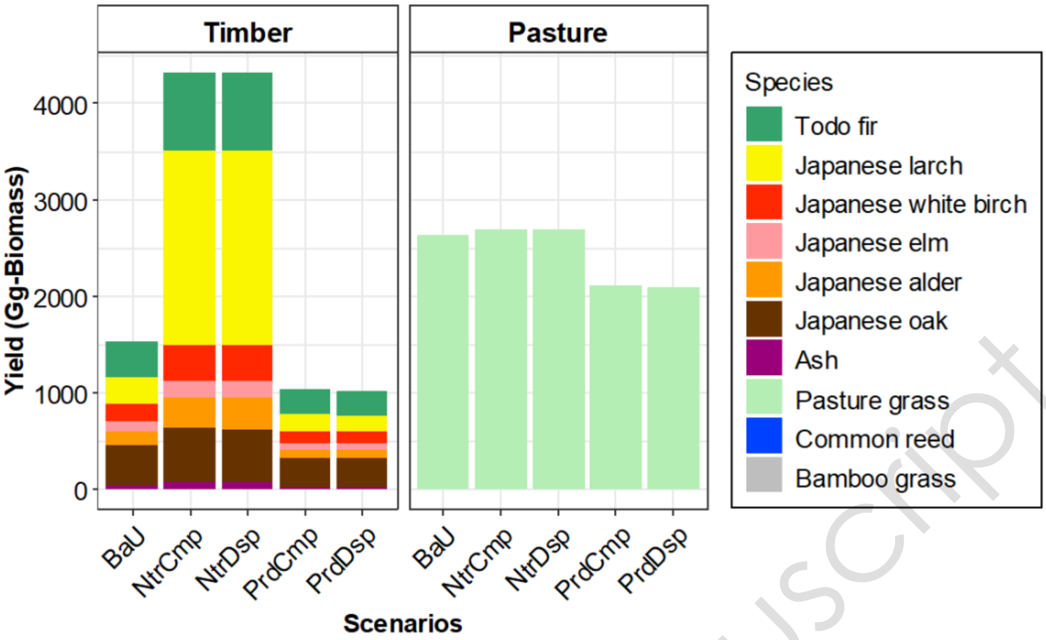


Fig. 8 The projected total timber and pasture grass yield over 35 years.

987

988

Tables

Table 1 Management intensity setting by scenario.

Scenario name	Target species	Clear cutting and plantation			Clear cutting and natural regeneration			Thinning		
		(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
2016	Todo fir:	0.025	0.045	0.075	0.025	0.030	0.050	1.30	1.40	1.30
	Larch:	0.025	0.045	0.075	0.030	0.025	0.050	1.30	1.40	1.30
BaU in 2050	Todo fir:	0.025	0.045	0.075	0.025	0.030	0.050	1.30	1.40	1.30
	Larch:	0.025	0.045	0.075	0.030	0.025	0.050	1.30	1.40	1.30
Ntr in 2050	Todo fir:	1.7	1.7	1.7	1.7	1.7	1.7	12.5	12.5	12.5
	Larch:	2.0	2.0	2.0	2.0	2.0	2.0	15.0	15.0	15.0
Prd in 2050	Todo fir:	0	0	0	0	0	0	0	0	0
	Larch:	0	0	0	0	0	0	0	0	0

NOTE 1: The numbers are the proportion of annual managed cell in percent unit.

NOTE 2: (a) National forest, (b) Prefectural forest, and (c) Private forest

Table 2 List of species used in the simulation.

Common names	Scientific Names
Japanese white birch	*Betula platyphylla* Sukaczev var. japonica (Miq.) H.Hara
Ash	*Fraxinus mandshurica* Rupr.
Japanese oak	*Quercus crispula* Blume
Japanese elm	*Ulmus davidiana* Planch. var. japonica (Rehder) Nakai
Japanese alder	*Alnus japonica* (Thunb.) Steud.
Japanese larch	*Larix kaempferi* (Lamb.) Carrière
Todo fir	*Abies sachalinensis* (F.Schmidt) Mast.
Pasture grass	-
Common reed	-
Bamboo grass	-

Table 3 The comparison of mean scores of all abandoned pasture lands during the simulation. Variable names are defined by Eq. 1.

	Population (pop_i)	Distance to the nearest residential grid cell ($distToResi_i^{-1}$)	Distance to the nearest road ($distToRoad_i^{-1}$)	Mean slope ($meaSlope_i^{-1}$)	Mean Elevation ($meaElev_i^{-1}$)
PrdCmp	1.04	0.67	0.83	0.76	0.68
PrdDsp	1.01	0.89	0.78	0.77	0.67

NOTE: Red to blue indicates the high and low impact to Y_i in Eq. 1, respectively.

Table 4 The composition of the amount of carbon sequestration from 2016 to 2050 by land cover type.

Land cover type	Carbon sequestration for 35 years (Gg-C)				
	NtrCmp	NtrDsp	BaU	PrdCmp	PrdDsp
Todo fir	99	100	154	138	141
Japanese larch	586	586	246	215	216
Japanese white birch	396	393	306	666	640
Japanese elm	87	86	90	92	94
Japanese alder	109	107	81	105	97
Japanese oak	100	99	110	118	116
Ash	3	2	2	3	3
Pasture grass	780	781	768	615	614
Common reed	−3	−2	0	0	0
Bamboo grass	−2	−3	0	1	1
Total	2155	2149	1757	1953	1922

NOTE: A negative value indicates the carbon source, and a positive value represents the carbon sink.

Table 5 Scenario improvements by combining local future plans and our scenario simulation results based on PANCES scenarios.

	NtrDsp	NtrCmp	PrdDsp	PrdCmp
Demographic structure	People live in the watershed, and the population in 2050 in the area is **1.19** times higher than the BaU scenario. Those local residents continue to manage the ecosystem actively.	People **move to the city center outside the watershed** by 2050. However, to manage the ecosystems in the watershed, agricultural and forestry workers come from nearby cities.	People live in the watershed, and the population in 2050 in the area is **1.19** times higher than the BaU scenario. The priority of ecosystem management is lower than NtrDsp because they rely on outside natural capital and ESs.	People **move to the city center outside the watershed** by 2050. Only the agricultural managers come to manage the pasture land for dairy farming, while the management is gradually abandoned.
Industrial structure and economy	Local residents or people who move to the nearest cities utilize the local food and timber products, and the self-sufficiency rate becomes higher. All pasture land is continuously managed for dairy farming and forestry. So the expected **pasture yield is the same level as the BaU scenario**. The forest management area (clear cutting) per year **increase to 1.7–2.0% yr^{-1}** and the **total timber yield is 2.8 times higher than the BaU scenario (Japanese larch and Todo fir are 7.3 and 2.2 times higher)**. The **species diversity is assumed to become 0.80, which is slightly higher than the BaU scenario**.		Local residents utilize imported food and timber production. In this situation, the self-sufficiency rate decreases. The pasture land abandonment progresses **due to the high elevation or steep-slope area**. **Pasture grass production has decreased to 80% compared to the BaU scenario**. **The timber yield decreases to 67%**, and people completely cease to manage the resources by 2050.	People who move to the nearest cities utilize imported food and timber production. In this situation, the self-sufficiency rate decreases. The pasture land abandonment progresses **in area far from settlements**. **Pasture grass production decreases to 80% compared to the BaU scenario**. **The timber yield is reduced to 67%**, and people completely cease to manage the resources by 2050.

Infrastructure and policy	Local managers or outside workers are promoted to activate the primary industry to utilize the local natural capital and ESs. For sustainable development of agriculture and forestry, the forest and pasture land is continuously managed through job creation.		There is no incentive to promote the primary industry.	
Culture and values	The local communities are vitalized by creation of jobs in the primary industry. The local natural capital will be conserved and **species diversity is higher than BaU scenario**. People will continue living in the watershed, and the contact with nature and wildlife will be maintained as traditional manners.	The local communities move to the city center, but the local natural capital will be conserved and **species diversity is higher than BaU scenario**.	The local communities are vitalized by the secondary or tertiary sector. **Japanese white birch forest increased** due to the farmland abandonment. This results in the **isolation of managed pasture land** and **slight increase in landscape diversity** than BaU and Ntr scenarios. This probably affect the habitat of wildlife such as Hokkaido sika deer and Brown bear. The risk of animal injury becomes higher than the NtrDsp.	There is no promotion to activate the local community. **Japanese white birch forest increased** due to the farmland abandonment. This results in the **isolation of managed pasture land** and **slight increase in landscape diversity** than BaU and Ntr scenarios. This probably affects the habitat of wildlife such as Hokkaido sika deer and Brown bear. People does not live in the region in 2050, while the risk of animal injury still exist for agricultural workers and it becomes higher than the NtrCmp.

NOTE: Improved points are highlighted in bold and underscore.