Conflicts among ecosystem services may depend on environmental awareness: a multi-municipality analysis

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Abstract

Timber and non-timber ecosystem services (ESs) of forests can have trade-offs. These trade-offs are often influenced by local characteristics, and a higher awareness of local ESs among the location population could support forest management to supply ESs sustainably. This study examines trade-offs among timber and non-timber ESs in three adjacent municipalities in Japan where social contexts differ and discusses them in relation to the environmental awareness of each community. First, we explored the local awareness of the population of ESs in interviews. Then we produced maps of landslide prevention, sediment retention, and forest recreation ESs in plantations at 30-m resolution and classified forests according to evaluations of each ES. We overlaid the ES maps with a map of logging locations from the previous 5 years to calculate the logged ratio for each ES class. In a region with a long history of forestry, where awareness of ESs seems to be high, forests providing a wider range of ESs had a lower logged ratio than forests with lower ESs. In contrast, in a region in which contracted foresters from outside of that region were coordinating logging activities, even forests providing numerous ES had a high logged ratio. Thus, increasing awareness of ESs amongst the local population may lead to a more balanced use of ESs. Our results indicate that local governments would be best placed to raise awareness by educating forest enterprises or providing science-based information on ESs to foresters. We conclude that analyses of local ES trade-offs under consideration of the social context as presented here, is the first step towards developing and maintaining sustainable forest management principles.

1. Introduction

Since our daily lives benefit from ecosystem services (ESs) both directly and indirectly, the continuous maintenance and improvement of ESs is an important goal (Millenium Ecosystem Assessment, 2005). ESs vary by region, influenced by diverse landscapes shaped by local weather and topography (Frizzle et al., 2022; Katila et al., 2020). Simultaneously, their use by local people also varies (Karjala et al., 2004; Sherry et al., 2005). In some regions, ecosystem-based disaster risk reduction is vital (Dalimunthe, 2018); in others, local people make a living from the commercial use of natural products (Santika et al., 2019). People who rely on local ESs evolve their lifestyles to benefit from them more efficiently (Asah et al., 2014; Orenstein and Groner, 2014). Such local use can affect ES supply (Barlow et al., 2016; Gardner et al., 2010). Thus, the local supply and use of ESs have woven unique cultures and settings where natural dynamics and human activities interact (Martin et al., 2020).

In recent decades, globalization and new technologies have brought about rapid changes in forest usage, threatening ESs in some cases (e.g. Athukorala et al., 2021). To avoid such events, it is essential to understand the possible conflicts among local ES uses.

ESs from forests, which are major sources of ESs (Aznar-Sánchez et al., 2018), are diverse and can be classified into timber and non-timber ESs. Generally, timber ESs contributes to local economies and non-timber ESs secure local livelihoods (TEEB, 2010). Both types are important to a local community's infrastructure and need to be continuously supplied. In addition, logging for the use of timber ESs changes forest structure and may affect non-timber ES supply. Thus, timber and non-timber ESs often have trade-off relationships with each other (Howe et al., 2014; Nalle et al., 2004).

These relationships can vary spatially across regions. For instance, among three distinct patterns of timber and non-timber relationships at the forest stand scale (as depicted in Fig. 1a), foresters may choose to avoid harvesting stands that have high non-timber ES values (pattern C), but relationships may not always be clear (pattern B). In some cases a stand with higher non-timber ES values may also supply more timber ESs (pattern A). Pattern A is likely to be the case for example for old growth forests near roads which may serve as recreational areas but are also profitable for timber production. These relationships give rise to regional trade-offs (as depicted in Fig. 1b) that can be viewed as potential productivity frontiers and that form the basis for sustainable planning (King et al., 2015b).

Fig. 1 Trade-off relationships at the forest stand scale produce different regional trade-off relationships. Pattern A: forest stands with higher non-timber ES value are more likely to be logged; Pattern B: there are no clear relationships between the use of timber ES and non-timber ES values; Pattern C: foresters may avoid cutting forest stands with high non-timber ES values.

We predict that the relationship between timber and non-timber ESs can be greatly influenced by environmental conditions and social context, which can differ regionally. For example, at locations where rapid changes in social conditions occurred and the population is no longer aware of the importance of non-timber ES, the use of the timber ESs may undermine the sustainability of non-timber ESs. On the other hand, where traditional use continues or environmental awareness is high, conflict among ESs may be minimized by local stakeholders. Exploring and understanding such relationships in various social and environmental contexts is highly relevant for sustainable forest management.

ESs have been modeled and mapped to identify forests that need to be conserved (Maes et al., 2012; Stritih et al., 2021). Relationships such as trade-off/synergy among ES supplies have been analysed by locating supply (Dai et al., 2017; Frizzle et al., 2022), demand (Adams et al., 2011; Soto et al., 2018) or both (Caglayan et al., 2021; Khosravi Mashizi and Sharafatmandrad, 2021). Scenario analyses have also been conducted for analysing relationships among ESs chronologically (Yamaura et al., 2021). However, little research so far relates ES trade-offs to local awareness. The objectives of this study were to analyse local spatial trade-off relationships between timber and non-timber ES supplies in forests in Japan.

The use of the timber supply ES, which through logging can change forest landscapes drastically, also significantly affects other ESs (Ager et al., 2017). For a sustainable supply of both timber and non-timber ESs, logging locations must be selected in a manner to avoid conflicts between both types of ESs. Thus, we here examine local logging tendencies in relation to the distribution of non-timber ESs. We compared logging locations and ES distributions in three adjacent municipal regions in Southwestern Japan with different timber harvesting practices: Saiki, Bungo-Ono, and Taketa. Because distributions of non-timber ESs and logging locations differ among them, each region has unique trade-off relationships. We discuss these trade-offs among ESs in relation to the environmental awareness of each community as revealed in interviews with local stakeholders. This study examined the hypothesis that the capability to produce timber while avoiding competition with non-timber ESs is high in a region with high ES-awareness.

To reach our objectives, we first investigated local awareness of ESs in interviews. Then, we created forest ES distribution maps from topographic and land-use maps. We evaluated three ESs which are generally diminished by logging: landslide prevention, sediment retention, and forest recreation. Next, we overlaid these maps with forest logging locations identified from satellite imagery. Finally, we examined the observed trade-offs among ESs in relation to local attitudes to ESs.

2. Materials and methods

Our study area covers three adjacent municipalities, each with different geographic and social conditions (see 2.1). We interviewed staff of local government and forestry enterprises in the study area (see 2.2). Combining the social conditions identified in the interviews with spatial analysis of ESs and logging locations, we examined the trade-offs between timber and non-timber ESs and the social factors that led to them. In the spatial analysis, we divided the study area into 30-m × 30-m cells, and derived non-timber ES values of each cell (see 2.3) using topography, land-use, forest type, and stand age information based on the models proposed in Yamaura et al. (2021). This resulted in maps indicating the value for landslide prevention, sediment retention, and forest recreation for each cell. Each cell was assigned into one of four categories for each non-timber ES. These maps were overlaid with logging locations identified from satellite imagery (see 2.4). In each non-timber ES class, the ratios of logging area were calculated. Finally, the ratios were compared among forests with different ES values to represent the local relationships among timber and non-timber ESs.

2.1. Study area

We studied privately owned forestry plantations in three adjacent municipal regions—Saiki, Bungo-Ono, and Taketa—on Kyushu, southwestern Japan (Fig. 2), most of which are owned by individual smallholders. Japanese cedar (*Cryptomeria japonica*) and hinoki cypress plantations (*Chamaecyparis obtusa*) dominate the forested area.

Fig. 2 Study area in Kyushu, southwestern Japan.

Most of the plantation forests lie within 100 m of roads (Fig. 3). In Saiki, 13% of the area lies more than 300 m from roads. Harvesting in such distant areas needs the construction of temporary roads, which are excluded from the calculations used to create Figure 3, and are generally avoided due to the high associated cost. If we consider only the slope and distance from the road, Taketa is the most profitable and Saiki is the least profitable region with respect to harvesting costs.

Almost all forest plantations in the study area are even-aged, with unimodal age distributions (Fig. 4). Clear-cutting followed by replantation is the predominant cultivation system. The relative distributions of age are not significantly affected by slope or distance from roads. The median forest age is >40 years, which means that there are sufficient resources to harvest forest plantations in all environmental conditions in the study area. We focused on privately owned forests, where owners manage their forests at their own discretion. Private forests are not subject to strong regulations on logging. Local governments designate forest areas that should be preserved for disaster prevention purposes, but areas can be logged if such designation is lifted. Local governments in the three regions recommend clear-cutting in planted forests 40 years or older for continued timber production, and in general, all timber is produced in a manner consistent with the recommendations. More than 90% of the forest owners in Taketa and Bungo-Ono and about 65% in Saiki are residents within the region, according to government statistics, and are therefore beneficiaries of non-timber ESs as well.

Fig. 3 Distributions of forest plantations in the study area. Values are proportions of forest plantations in the whole area of the region.

Fig. 4 Relative frequency distributions of forest plantation ages in each category of slope degree (upper row) or distance from roads (lower row). The dashed lines are median values. Data were drown from the Oita Prefecture forest register.

We obtained locations and age distributions of the plantation forests from the forest register managed by Oita Prefecture. Terrain covariates of slope angle, aspect, and curvature were calculated from a digital elevation model (DEM) provided by the GeoSpatial Information Authority of Japan (GSI). The original DEM, which has a spatial resolution of 10 m, was generated through field measurements and the analysis of aerial photographs. Road proximity was also calculated from the DEM on a 1:25 000 digital road map provided by GSI. We obtained geology and soil type from a seamless 1:200 000 digital geological map provided by the Geological Survey of Japan and a 1:50 000 soil map provided by GSI. All spatial data were resampled to 30-m resolution in UTM projection, and slope degree and angle were calculated in SAGA v. 7.6.2 GIS software. Calculations for evaluating

ESs and analyzing overlays were conducted in the gdal 3.1.4, geopandas 0.9.0, pandas 1.1.5, and numpy 1.16.0 packages in python v. 3.6. Model scripts used in this study are provided in the supplementary material.

2.2. Interviews

We conducted semi-structured interviews about the current forestry situation in the study area with representatives of the prefectural government, three municipal governments, and one forestry enterprise in each municipality from July 2017 to December 2022. Each agency was interviewed at least twice. We asked five questions: (1) who conducts the clear-cuts in the plantations in each municipality, (2) attitudes towards non-timber ESs, (3) any criteria for selecting logging sites, (4) legal regimes related to logging, and (5) relationships between forestry enterprises and local residents.

2.3. Ecosystem service maps

2.3.1. Landslide prevention

Landslides, which occur mostly in steep areas, are restrained by tree root networks that stabilize the surface soil (Stumpf and Kerle, 2011). Within and around the study area, landslides caused by heavy rainfall are becoming more frequent under climate change, threatening livelihoods. The landslide protection ES is therefore important in the study area, and harvesting in forests with high potential risk of landslides is ideally avoided (Saito et al., 2017). Clear-cutting in susceptible forests results in immature root systems and impairs the non-timber ES that prevents landslides.

We evaluated spatial landslide risk by using a conversion table provided by the Japan Forestry Agency (JFA) to evaluate landslide hazards (MAFF, 2016). The conversion table is based on expert knowledge and the Hayashi’s Quantification Method-II (HQM-II), a discriminant analysis method that allows qualitative variables to be used as explanatory variables (Hayashi, 1951). HQM-II categorized the cells in the study area into four categories including very unstable, unstable, stable, or very stable. The conversion table was created by combining expert judgement with geological factors as explanatory variables and susceptibility as the objective variable. Each 30-m × 30-m forest cell was scored according to geology, topography, soil depth, and forest age (Table S1) and rated as very unstable, unstable, stable, or very stable on the basis of these scores (Table S2). Two kinds of geology underlie most of the study area (Fig. S1): Neogene sedimentary rocks, which are generally stable, and can be found in Saiki and the southern part of Bungo-Ono; and volcanic rocks, which are relatively unstable, and are the most common parent material in the northern part of Bungo-Ono and Taketa. Differences are also evident in the topography: the southern part of the study area has steeper and more complex terrain than the northern part (Fig. S2). We estimated soil depth distributions over the whole study area from soil depth and profile curvature (Table S3) according to the JFA (2011). When applying the conversion table, we assumed young forests, 15 years old, to cover the entire study area. These young forests are the most susceptible to landslide owing to their immature roots, In this way, we excluded the influence of the current forest composition and structure and focused on the theoretical landslide risk of each pixel.

2.3.2. Sediment retention

Soil loss not only reduces plant growth and water retention, but also causes water pollution in rivers (Pimentel and Kounang, 1998). This is why sediment retention is a fundamental ES. Forest vegetation moderately but surely alleviates soil loss. Tree crowns and leaf litter weaken raindrop impact, and the understory vegetation holds the surface soil together (Hartanto et al., 2003). Bare soil caused by logging can lead to significant soil loss. Soil can easily run off in young plantation forests where understorey vegetation is sparse owing to the dense crown cover (El Kateb et al., 2013). Thus, appropriate selection of logging locations is vital for conserving the sediment retention ES.

We estimated annual soil loss in the study area by using the Revised Universal Soil Loss Equation (RUSLE: Renard et al., 1997). RUSLE estimates annual soil loss (*A*, t ha^{-1} year^{-1}) from erosion risk factors, namely rainfall-runoff erosivity (*R*), soil erodibility (*K*), slope length and steepness (*LS*), cover and management (*C*), and support practice (*P*) (Schmidt et al., 2019), as:

$$A = R \times K \times L \times S \times C \times P$$

C represents forest functions that hold the surface soil; immature forests growing in logged and reforested areas are at high risk of soil erosion owing to their high *C* value. *C* can be estimated from the percentage of forest floor cover (C_F, %) Miura et al. (2015) as:

$$C = \exp(-0.051C_F).$$

As we did for the landslide prevention ES, we used the C_F value of a 15-year-old forest to identify forests where logging should be avoided. C_F was set at 0.008 for forests with slopes less than 32 degrees and 0.015 for other forests based on the mean values obtained from Japanese National Forest Inventory. Descriptions on the other factors are provided in the supplementary material.

Annual soil loss was categorized as: slight (<1 t ha^{-1} year^{-1}), moderate (1–5 t ha^{-1} year^{-1}), high (5–10 t ha^{-1} year^{-1}) or significant (>10 t ha^{-1} year^{-1}). The thresholds were established with reference to previous research (e.g. Fartas et al., 2022; Hagras, 2023; Masullo, 2017).

2.3.3. *Forest recreation*

The JFA has been encouraging commercialization of the forest recreation ES for recreational uses such as forest bathing (a.k.a. *shinrin-yoku*: entering forests to breathe in the clean air and to bathe in its fragrance for physical and mental health) since 2019. There are high expectations of the forest recreation ES as a source of tourism income to revitalize regions (Cordell et al., 2018; Starbuck et al., 2006). Generally, older and larger forests are preferred for their landscape aesthetics, as an important component of forest recreation (Gundersen and Frivold, 2008). This ES is higher near roads with good accessibility (Abildtrup et al., 2013; Termansen et al., 2013), creating a clear trade-off with timber production.

We evaluated the forest recreation ES on the basis of forest stand area and adjacency to roads. Forest stand area is identified from the forest register, and a map of adjacency to roads is created by the Accumulated Cost tool in SAGA with a slope–distance map as a cost layer created from the DEM and a road distribution map provided by GSI as a source layer. Forest stand area and adjacency to roads are scored according to the results of the analytical hierarchy method of Kagawa (1991, 1990) which models the preferential uses of the forest for recreation. Scores were calculated as:

$$S_{area} = 0.0106\text{^}exp(-3.21 \times a)$$

$$S_{road} = 1 - \mathrm{d}/100,$$

where S_{area} and S_{road} depend on forest stand area (a, ha) and distance from roads (d, m). We multiplied these scores of each cell to calculate an index of forest recreation. Although the forest recreation ES should be higher in older forests, we did not consider forest age, and instead assumed that every forest in the study area is mature enough and scores depend only on forest area and road proximity, because our objective was not to identify current distributions of evaluation values but to estimate effects of logging on potential recreational value.

The values of the forest recreation ES were categorized into four classes for convenience of comparison with the other two non-timber ESs: very low (< 0), low (0–0.2), high (0.2–0.35) and very high (>0.35). These thresholds were determined so that the evaluated cell areas categorized as low, high and very high were approximately the same.

2.4. Logging locations

Logging locations were identified from satellite imagery. We used a forest disturbance dataset for all of Japan (Shimizu and Saito, 2021). This dataset was generated by using a pixel-level Landsat time-series analysis and a random forest classification approach to map annual forest disturbance types (i.e. logging, conversion, thinning and natural disturbances) at a 30-m spatial resolution from 1985 to 2019. For the logging class, the dataset has a producer accuracy of 80.1% and a user accuracy of 93.8%. We clipped the dataset to the study area and used logging locations detected from 2015 to 2019 for this study.

To calculate the logged area ratio in each ES category, numbers of logged/not logged raster cells were counted and summarized for each ES category. The logged/not logged area (ha) was calculated by multiplying the number of raster cells by 0.09, the area of each raster cell, and the logged area ratio was calculated by dividing the number of logged records by that of all raster cells in each category. These calculated logged area ratios were then subjected to comparative analysis, and the statistical significance was elucidated through a two-tailed test ($P < 0.1$) for each municipality.

3. Results

3.1. Interviews

Across all regions, logging locations were predominantly selected by forest owners' associations or forestry enterprises, who then approached forest owners about the potential for logging. Typically, forest owners have limited interest in the management of their forests and rely on the suggestions of the forestry enterprises. Although forestry enterprises are obligated to inform local government where they are logging, local government lacks the authority to control logging.

Saiki produces more timber than the other two regions. The forest owners' association plays a central role in timber supply there (Table 1). Most forests in Saiki cover steep slopes, and local people recognize the need for protecting mountainous lands. In addition, since Saiki faces the sea and has a thriving fishing industry, they want to avoid water pollution caused by soil loss. Thus, awareness of non-timber ESs is high in this region. The forest owners' association in Saiki sets criteria for selecting logging sites based on their experience to avoid harvestings in forests where landslides and soil loss occur easily.

A biomass power plant in Bungo-Ono commenced operations in 2016, but local forest owners had been amassing timber for energetic use already several years before. Although statistical data are lacking, local governments have observed a significant surge in logging activities by non-regional forestry companies, corresponding with rapidly increasing demand for timber. The municipal government stated that these enterprises have limited engagement with local residents, leading to possible concerns of limited corporate responsibility towards the local ESs.

In Taketa, several local companies conduct small-scale logging operations and are responsible for most of the logging in the region. The companies are fond of maintaining a good reputation in the local community and hence try to avoid ES degradation caused by their logging. However, they have not established any specific criteria to conserve ESs in the selection of logging sites.

Table. 1 Comparison of logging practices and environmental awareness in the three regions.

Thus, landslide prevention and soil retention are critical concerns in Saiki and Taketa. Contrarily, the forest recreation ES is of no interest in any region. There was only provisional awareness of this ES, which is a new concept among residents, and little attention was paid to it.

3.2. Ecosystem service maps

The distribution of forests with a high risk for landslides is similar to that of steep slopes (Figs. 5a, S2), with lower risks in forested areas underlain by Neogene sedimentary rocks (Fig. S1). Taketa has the largest area of high-risk forests, and Saiki the lowest. Although Saiki has a wide distribution of steep terrain, the risk of landslide is lower because of the sedimentary geology (Fig. S1). Soil loss shows the opposite results to landslide, with Saiki having the highest risk and Taketa the lowest (Fig. 5b). In Saiki, Brown Forest soils, which are easily eroded, cover steep slopes, posing high risk and the need for careful consideration in the selection of logging sites (Fig. S3). On the other hand, Taketa was evaluated as having less risk because it is covered with Black soil, which is relatively stable on moderate slopes. The forest recreation ES map shows that Saiki has the largest low-value area (Fig. 5c), most likely caused by the low road network density due to the steepness of the terrain. Bungo-Ono and Taketa have similar distributions of this ES.

Fig. 5 Distributions of ecosystem service values of (a) landslide susceptibility, (b) sediment retention and (c) forest recreation.

3.3. Logging locations

The logged area ratio in Saiki is about twice of that observed in the other two regions (Table 2). Logging is evenly distributed throughout most of Saiki, although it is sparse along the eastern coast (Fig. 6). The area ratios of logged forests were higher on gentle slopes, where both logging cost and hazard risk are low (Fig. 7). On the other hand, forests near roads, where the forest recreation ES is high, are logged more frequently. In Bungo-Ono, logging is relatively common in the southern part. Forests on steep slopes were also logged frequently there (Fig. 7). In Taketa, logged forests were distributed mainly in the northern and southern parts, and to a minor extent in the central part.

Fig. 6 Locations of forests logged in 2015–2019.

Fig. 7 Logged area ratio in each category. Each value shows the ratio of logged area to forest plantations in each category (sum = 1.0).

Table. 2 Logged area ratio in each region in 2015–2019.

3.4. Overlaying maps

Figure 8 shows the relationships between the ESs and logging locations in each municipality. The ratios of logged area show that the spatial relationships with ESs differ substantially. In Saiki, the ratio of logged area is significantly smaller in landslide susceptibility classes of very unstable and unstable forests than in stable and very stable. However, the overall logged area is large, resulting in a large logged area in the high-risk category. In Taketa, which has the greatest area susceptible to landslide (Fig. 5a), the ratios of logging area were lower in the two least stable classes than in the two most stable classes. In Bungo-Ono, the ratio was slightly but significantly lower in stable forests than in very stable, unstable, and very unstable forests, which did not differ. Foresters from outside of the municipality might have harvested timber even in forests at high risk owing to lack of knowledge or concern with regard to landslide risk.

Fig. 8 Logged area ratio of each category with (I) landslide susceptibility class (*x*-axis) a, very stable; b, stable; c, unstable; d, very unstable; (II) annual soil loss class (*x*-axis) a, slight (<1 t ha^{-1} year^{-1}); b, moderate (1–5); c, high (5–10); d, significant (>10); (III) forest recreation index class (*x*-axis): a, low (0); b, moderate (0–0.2); c, high (0.2–0.35); d, very high (>0.35). Letters on the red curves indicate other classes from which each class differed significantly ($P < 0.1$).

Saiki had the largest area in the category at the highest risk of soil loss, and Taketa had the smallest (Fig. 8II). In Saiki, the logged area ratio was significantly lower in the category at highest risk of soil loss than in the categories at lower risk. The category at lowest risk might have insufficient forested area to detect significance. In Taketa, the logged area ratio was significantly higher in the two lower risk categories than in the two higher risk categories. These spatial logging tendencies contribute to the maintenance of the sediment retention ES, especially in Saiki, where there is a generally high risk of soil loss. In Bungo-Ono, on the other hand, the logged area ratio was higher in unstable forests. As regards the landslide prevention ES, this spatial relationship could lead to ES degradation.

The relationships between logging locations and the forest recreation ES were obscure (Fig. 8III). In each municipality, the forested area in the lowest rated category was the largest. Distributions were similar among them, but the forest area ratio with the lowest values was largest in Saiki. There was no overall consistent tendency in logging ratios, although there were significant differences. In Taketa only, the logged ratio was highest in the category with the lowest forest recreation ES, even though these forests are disadvantageous for logging operations owing to long distances from roads.

According to the relative frequency distribution of forest ages in each ES category (Fig. 9), although there are slight differences in age distributions among categories, the median values in all categories exceed the recommended harvest age of 40 years. Figure 9 suggests that resources are sufficient and do not constrain wood production in any category.

Fig. 9 Relative frequency distribution of forest plantation ages in each category of landslide susceptibility class (upper row): a, very stable; b, stable; c, unstable; d, very unstable; annual soil loss class (middle row): a, slight (<0.1 t ha^{-1} year^{-1}); b, moderate (0.1–1); c, high (1–10); d, significant (>10); or forest recreation class (lower row) : a, <0.1; b, 0.1–0.25; c, 0.25–0.5; d, ≥0.5. The dashed lines are median values.

4. Discussion

We explored trade-off relationships between timber and non-timber ESs in three adjacent municipalities and found great variations among them. In regions where local timber production is closely tied to the local community, as in Saiki and Taketa, spatial conflicts between timber and non-timber ESs tended to be lower. According to the foresters in Saiki and Taketa, logging is usually avoided in areas with important non-timber ESs, as these benefit local residents and should be conserved. The foresters also expressed fear of damaging their reputation in the community. Thus, foresters seem to avoid logging areas with high local ES values (pattern C in Fig. 1a). In contrast, logging locations in Bungo-Ono, which were selected by external forestry enterprises, were not systematically related with non-timber ES distributions. These forest enterprises have a tenuous relationship with local residents. According to the municipal officer, foresters from outside the municipality have been crossing and logging along the southern boundary, and the fact that biomass power plants have started operating as a destination for timber consumption is likely to have fueled this trend. At the same time, a greater area of forests in the southern part is at high risk of landslide and soil loss (Fig. 5a). As a result, the logging ratio is not low even in forests at high risk (Fig. 8). This may lead to regional conflicts between timber and non-timber ESs, negatively affecting local sustainability (Fig. 1b).

4.1. Relationships between non-timber ecosystem services and logging locations

As the results indicate, local environmental awareness positively affects ES trade-offs. Sometimes, lack of awareness may reduce ESs, as in Bungo-Ono, where the social context has rapidly changed. In Saiki and Taketa, in contrast, the traditional use of ESs has had the opposite effect. Thus, our hypotheses that conflicts among ESs are moderate in regions with high ES-awareness are generally confirmed. Local awareness is shaped by local history and culture (Chen et al., 2019). However, in today's global society, numerous regions are experiencing major changes in the use of ESs (Brown, 2013; Jansson et al., 2015). In such regions, a different ES trade-off from before might emerge and cause conflict (King et al., 2015a). Research examining how changes in social conditions affect ESs and the consequences for our lives will become even more important (Carpenter et al., 2009; Chapin et al., 2010). An important research gap to be addressed is the relationship between environmental awareness and ES trade-offs. Quantifying environmental awareness by inquiry (Schuman and Presser, 1996) or by surveys on willingness to pay (Nelson et al., 2008) may enable such relationships to be statistically analysed.

We evaluated and mapped ESs in forest plantations that supply various ESs in addition to timber. Attention to such ESs has been rising, and earlier studies identified a great influence of terrain factors (e.g. Jackson et al., 2013; Yamaura et al., 2021). Our evaluation maps depended significantly on topography but also on geology, as shown clearly by the comparison among regions. For example, landslide susceptibility is lower in Saiki, despite its steep slopes, on account of the underlying geology. Thus, a comprehensive evaluation of geography forms an important basis in mapping the distribution of ESs. Although the topography in Saiki seems to be economically disadvantageous for forestry (Fig. 3), our results indicate that the municipality is well suited to logging owing to its high soil stability. In fact, timber production is more prevalent in this region than in other areas. While previous studies have reported that variables related to the profitability of a forestry operation, such as slope angle and distance from the road, affect the probability of harvesting (Beach et al., 2005; Polyakov et al., 2010; Prestemon and Wear, 2000), our study suggests that there may also be a relationship between ESs and harvesting. Identifying the factors involved in the selection of logging sites will contribute to the development of efficient policies for protecting ecosystem services from logging (Yamada, 2020).

In all municipalities, relationships between the forest recreation ES and logging locations were unclear (Fig. 8). Road proximity, a key factor in the forest recreation value, did not affect logged ratios in any region (Fig. 7). Even though forests with high forest recreation value are profitable for logging, there seem to be no critical conflicts. The forest recreation ES has not been realized by local residents as a benefit of forest ecosystems. The interviews revealed that the residents consider the forests to be the backdrop to their daily lives, and forest recreation to be irrelevant. Ninan and Inoue (2013) estimated forest recreation benefits at about USD 140 to 145 per hectare per year in other regions of Japan. Forest tourism also has a positive effect on local economic development in other countries (Archabald and Naughton-Treves, 2001; Mayer, 2014). However, spending related to forest recreation, including camping and guide fees, accounts for less than 1% of the tourism industry in the region (Oita Prefectural Government, 2013). Stimulating economic activities using the forest recreation ES can be expected to increase local awareness (Brandt and Buckley, 2018), and would therefore help to ease the competitive relationship with timber production as in other non-timber ESs observed in this research.

4.2. Efficient forest management methods for the study area

On the basis of our results, we suggest guidelines for avoiding conflicts among ESs that are appropriate for local logging practices. Public awareness of ESs is high in Saiki and Taketa. It would hence be beneficial to assist, but not regulate, foresters in selecting appropriate logging sites by offering ES information based on scientific analysis, e.g., ES evaluation maps (Maes et al., 2012; Schägner et al., 2013). In Bungo-Ono, where ESs seem to be of less concern, it would be beneficial to identify foresters responsible for logging operations in the region and focus on raising their awareness of ESs. Regulation of logging sites (Yamada and Yamaura, 2017) and direct payment schemes (Kemkes et al., 2010; Polasky et al., 2014) may also be effective tools.

Although the three regions in our study are adjacent, ES relationships differ among them, highlighting the importance of considering local policy-making. A top-down approach, by which policies are formulated in a limited number of people, sometimes ignoring the local population, may not only provoke backlash from residents but also upset the existing equilibrium and impair ESs (Fraser et al., 2006). A bottom-up approach, in which local stakeholders participate in establishing policy, is required instead, since the policy will reflect each side's requirements for how the local ESs will be used (Ananda, 2007; Kangas et al., 1996). Moreover, this approach should raise participants' environmental awareness (Fraser et al., 2006). However, not all stakeholders are familiar enough with the current status and trade-offs of ESs in their local forests. Providing information based on analyses such as the distribution and usage tendencies of ESs in a region is essential in a bottom-up approach (Evans et al., 2018). As this study shows, we must first understand local harvesting practices, how ESs are used (and the effect of social context) and how their interactions have been shaped in a region. Presented with this information, local committees can establish local forest management policies to meet local demands for ESs (Maes et al., 2012).

5. Conclusion

To manage local forests sustainably, clear-cutting should be avoided in forests where a supply of high-value non-timber ESs is expected. Overlaying ES and logging location maps revealed the relationships between timber and non-timber ESs. Saiki where a forest owners' association manages the logging operations of the whole region, showed an ES-friendly spatial logging tendency. On the other hand, as shown in Bungo-Ono, non-timber ESs could be damaged if non-local foresters who are unaware of local conditions are responsible for logging. Thus, local awareness and the relationships between timber and non-timber ESs differ among regions. Sustainable provision of ESs, therefore, requires localized rather than uniform policymaking, and we conclude that exploring local awareness and relationships among ESs is the first step towards developing sustainable forest management strategies. For example, information based on scientific analysis would be helpful where local residents have a high awareness of ESs. On the other hand, education is required to make uninformed foresters aware of ESs in regions where forests with high non-timber ES values are being logged.

Data availability statement

The geospatial data underlying this article are available online at https://www.gsi.go.jp. Logging location data are published in Zenodo at https://doi.org/10.5281/zenodo.4654619.

Supplementary material

Supplementary data are available at *Forestry* online.

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Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

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Figures and legends

Fig. 1 Different trade-off relationships at forest stand scales produce different regional trade-off relationships. Pattern A: forest stands with higher non-timber ES value are more likely to be logged; Pattern B: In some cases, the relationships between the use of timber ES and non-timber ES values is unclear; Pattern C: foresters may avoid cutting forest stands with high non-timber ES values.

Fig. 2 Study area in Kyushu, southwestern Japan.

Fig. 3 Distributions of forest plantations in the study area. Values are proportions of forest plantations in the whole area of the region.

Fig. 4 Relative frequency distributions of forest plantation ages for in each category of slope degree (upper row) and distances from roads (lower row). The dashed lines indicate median values.

Fig. 5 Distributions of ecosystem service values of (a) landslide susceptibility, (b) sediment retention and (c) forest recreation.

Fig. 6 Locations of forests logged in 2015–2019.

Fig. 7 Logged area ratios in each category. Each value shows the ratio of logged area to forest plantations in each category (sum = 1.0).

Fig. 8 Logged area ratio of each category with (a) landslide susceptibility class (x-axis): a, very stable; b, stable; c, unstable; d, very unstable;, (b) annual soil loss class (x-axis): a, slight (<1 t ha−1 year−1); b, moderate (1–5); c, high (5–10); d, significant (>10);, and (c) forest recreation index class (x-axis): a, (0); b, (0–0.2); c, (0.2–0.35); d, (>0.35). Letters on the red curves indicate other classes from which each class differed significantly ($P < 0.1$).

Fig. 9 Relative frequency distribution of forest plantation ages in each category of landslide susceptibility class (upper row): a, very stable; b, stable; c, unstable; d, very unstable; sediment retention class (middle row): a, slight (<0.1 t ha−1 year−1); b, moderate (0.1–1); c, high (1–10); d, significant (>10); or forest recreation class (lower row): a, <0.1; b, 0.1–0.25; c, 0.25–0.5; d, ≥0.5. The dashed lines are median values.

Tables

Table 1 Comparison of logging practices and environmental awareness in the three regions.

	Saiki	Bungo-Ono	Taketa
Timber supplier	The forest owners' association	Non-regional forestry companies	Several local forestry companies
Awareness of landslide prevention and sediment retention ESs	High.	Low.	High.
Awareness of forest recreation ES	Low.	Low.	Low.
Logging criteria for conservation of ESs	Yes.	No.	No.

Table 2 Logged area ratio in each region in 2015-2019.

Saiki	Bungo-Ono	Taketa
7.24%	3.64%	3.75%