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DEVELOPMENT OF GLOBAL SCALE LCIA METHOD

Ecosystem damage assessment of land transformation using species loss

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Abstract
Purpose The objectives of this study are to develop life cycle impact assessment (LCIA) methods that enable an assessment of the impact on the biodiversity by land use categorized in general land use types and to obtain the implications for an assessment of global land use impact, using the methods in the Life Cycle Impact Assessment Method based on Endpoint Modeling (LIME).
Methods Expected Increase in Number of Extinct Species (EINES), which was calculated by summing the increments in extinction risks of each threatened vascular plant species due to land transformation, was used as an indicator of damage to biodiversity. EINES per land use category was calculated using data from the "Threatened Wildlife of Japan, Red Data Book 2nd ed. Volume 8, Vascular Plants" (hereinafter referred to as "RDB").
Results and discussion The EINES of wetlands and grassland was relatively high. The number of species that were assumed to exist in forestland was large; however, the EINES of forestland was relatively low. It was considered to be influenced by the huge area of forestland in Japan. EINES of other land was also relatively high, and it was considered to be the reflection of the existence of species whose habitat is peculiar, such as limestone areas or high mountains.
Conclusions Damage factors developed for Japan in this study have broad potential application, as they have more general land use categories than those in LIME 1 and 2; however, it will be necessary to develop damage factors in other countries, taking into account threatened species categories and regional differences in the importance of various land use categories. It is also necessary to accumulate detailed data on threatened species across the planet to develop worldwide damage factors.

Keywords Biodiversity · Ecosystem · Extinction risk · Land use · LCIA · Threatened species

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1 Introduction

Over the past 50 years, ecosystems have been changing rapidly and extensively. Many ecosystem services are degraded, with significant implications for human well-being. Among the main direct drivers of change in biodiversity and ecosystems, habitat change has had a high impact on biodiversity over the last century, and these impacts are currently increasing in many ecosystems (Millennium Ecosystem Assessment 2005).

To conserve ecosystems and ensure ecosystem services, assessing the impacts on biodiversity and ecosystems of land use is a necessary first step. However, it is difficult to assess the impacts comprehensively and quantitatively because the concept of biodiversity is complicated and biodiversity varies among regions. Furthermore, the availability of data related to biodiversity limits the development of such methods.

Research on life cycle impact assessment (LCIA) has proposed various methods for making a quantitative assessment of impacts on biodiversity (Curran et al. 2011). The potentially disappeared fraction (PDF) is one of the typical damage indicators derived from species-area relationship (SAR). It has been pointed out that this concept lacks well-defined spatial scales in estimating species extinctions (Curran et al. 2011) and does not reflect the relative scarcity of species (Milà i Canals et al. 2007). Some methods have been applied to assess land use impacts (Goedkoop and Spriensma 2001; Goedkoop et al. 2009; Humbert et al. 2012; Steen 1999; Frischknecht et al. 2009; de Baan et al. 2013a, b). Many indicators used in these methods are based on species density in each land use category (Goedkoop and Spriensma 2001; Goedkoop et al. 2009; Humbert et al. 2012; Frischknecht et al. 2009; de Baan et al. 2013a, b; Verones et al. 2015; Chaudhary et al. 2015). Among the various levels of diversity, including genes, species, and ecosystems, the diversity in species is regarded as important because species are the bases of ecosystems and influence the properties of genes. To conserve diversity, many efforts are being made to prevent the extinction of species. Therefore, the extinction of species should be addressed in LCIA methods.

Changes in extinction risk of threatened vascular plant species are used as an indicator of damage to biodiversity in the Life Cycle Impact Assessment Method based on Endpoint Modeling (LIME), which has been developed as part of the LCA national project in Japan (Itsubo and Inaba 2012). The Expected Increase in Number of Extinct Species (EINES) is used as an indicator of damage to biodiversity, which is the increment of the reciprocal of the average elapsed years from the present to the extinction of threatened vascular plant species calculated based on data of the "Threatened Wildlife of Japan, Red Data Book 2nd ed. Volume 8, Vascular Plants" (Environment Agency of Japan edt. 2000). In this method using EINES, the increments of extinction risk are calculated based on population decrease of each species due to land use, whereas the differences in number of species between a given land use and reference status are calculated as species extinction due to land use in the existing methods based on SAR (such as de Baan et al. (2013b)), or such differences multiplied by the vulnerability score, which is based on International Union for Conservation of Nature and Natural Resources (IUCN) threat level and geographical range, are calculated as the characterization factors in the recent studies (Verones et al. 2015; Chaudhary et al. 2015). The availability of the data necessary for calculating EINES is limited compared to that for the methods based on SAR; however, the method using EINES assesses more directly the cause-effect relationship between land use and extinction of species. In LIME 1 and 2, damage factors for land use impact on biodiversity were calculated based on data from environmental impact assessment statements in Japan. The damage factors were developed for land use project activities such as road construction, mining of soil and stone, and construction of final disposal sites. This method mainly addresses the extinction of species, and the assessment of land use types is limited. Also, the method is mainly for land use in Japan, given the limited availability of data to calculate damage factors.

2 Objective

In LIME 3, the target area of the impact assessment is being expanded to a global scale.

In order to contribute to the development of LIME 3, this study focused on revising methods to assess the impacts of land use on biodiversity that were utilized in LIME 2, so as to enable the assessment of the impacts on biodiversity due to more general and various land use types as well as to obtain the implications for an assessment of global land use impact.

Biodiversity and net primary production are defined as objects of protection related to ecosystems in LIME. This paper reports the development of an impact assessment method for biodiversity.

3 Methods

3.1 Indicator

We adopted Expected Increase in Number of Extinct Species (EINES) as the damage indicator for biodiversity in LIME 3, as in the case of LIME 1 and LIME 2. EINES is derived from the expected value of the increased risk of the extinction of species due to the environmental burden. EINES is calculated by the following formula (1), which sums the changes in the extinction time of each species due to the environmental burden (Itsubo and Inaba 2012).

$$\mathrm{EINES} = \sum_{s} (\Delta R_s) = \sum_{s} \left(\frac{1}{T_{\mathrm{after},s}} - \frac{1}{T_{\mathrm{before},s}} \right) \quad (1)$$

where

EINES Expected Increase in Number of Extinct Species
ΔR_s Change in the risk of extinction of a species s
$T_{\mathrm{after},s}$ Extinction time of a species s after occurrence of environmental burden (year)
$T_{\mathrm{before},s}$ Extinction time of a species s before occurrence of environmental burden (year)

Biodiversity includes diversity within species, between species, and of ecosystems as stated in the Convention on Biological Diversity; however, LIME focuses on diversity between species taking into consideration difficulties in making a comprehensive assessment for all levels of biodiversity, trends in biological conservation, the importance of species recognized in ecology, data availability for quantitative assessment, and other LCIA studies that assess biodiversity. It further focuses on the risk of species extinction as it directly expresses the damage to biodiversity, and its decrease is aimed at activities for protecting species, including the Red Lists (Itsubo and Inaba 2012).

The reciprocal of the extinction time is used as the extinction risk, and the extinction time is defined in LIME as the average elapsed years from the present to species extinction. The population of a species fluctuates within the maximum permissible level and may become zero, which is the extinction of the species, due to various limitation factors. The methods to calculate the extinction time in LIME are explained in the Electronic Supplementary Material of this paper.

To assess the impact on biodiversity due to land use, threatened vascular plant species that are subject to an impact from land transformation are assessed in LIME taking into consideration the importance of plant species in biodiversity, the inevitability of influence due to their immobility, data availability of plant species, and the great impact of land transformation on the population of species compared to those of land occupation. If a place where individuals of a vascular plant species exist is altered, the national population of the species decreases and the average elapsed years before extinction will be shortened compared to that before transformation (Itsubo and Inaba 2012).

This assessment method is based on past studies, which include one carried out for a liquefied natural gas (LNG) supply base (Oka et al. 2001) and another for the main venue of the Aichi Exposition (Matsuda et al. 2003). The model used to calculate the extinction time in LIME is based on the work of Matsuda et al. (2003). Some of the conditions of the simulation model were modified (such as limiting the number of species used to those threatened species listed in the Threatened Wildlife of Japan, Red Data Book 2nd ed. Volume 8, Vascular Plants (hereinafter referred to as "RDB") (Environment Agency of Japan edt. 2000) along with the necessary information for calculation purposes). The simulated average rate of decrease over 10 years and the national population were calculated for 1146 taxa. These results were used in regression analysis to obtain representative values (regression coefficients) and standard errors for the parameters of the average rate of decrease over 10 years and the national population used in the calculation formulas.

The basic idea of the extinction risk is used as quantitative criteria for determining species in the Red List category. IUCN, which compiles the Red List at a global level, adopted new categories based on quantitative assessment criteria in 1994 which use extinction probability. The quantitative criteria stipulated in the Red Data Book Category (Environment Agency of Japan 1997) are based on the criteria of IUCN. For example, the E criterion for "Critically Endangered (CR)" species is defined as the extinction probability within 10 years equal or over 50 %. The simulation

Table 1 Land use categories and their area in Japan

Category	Contents	Area data	Area in Japan as of 2000 (kha)
Rice fields	Rice fields	"Rice field" subcategory data in "cropland" in NIR (allocated by the data of agricultural land as of 2000)	2,620.6
Other agricultural land	Upland fields and orchard	"Upland fields" and "orchard" subcategories data in "cropland" in NIR	1,532.0
Forest land	Forests under Forest Law of Japan Article 5 and 7.2	"Forest land" data in NIR	24,876.0
Grassland	Pasture land, grazed meadowland, and grassland other than pasture land and grazed meadowland (mainly wild grassland)	"Grassland" data in NIR	1,004.6
Wetlands	Land covered with water (such as dams), rivers, waterways, and coast (Assuming that this category includes lake, pond, and wetland)	"Wetlands" data in NIR and "coast" subcategory data in "other land" in NIR	1,396.0
Other land	Cultivation abandonment area and other (Assuming that this category includes rock and cliff)	"Cultivation abandonment area" and "other" subcategories data in "other land" in NIR	1,866.4

The six land use categories are determined taking into consideration the characteristics of the habitats of plants and availability of land data. Areas of each land use category are cited from NIR (Ministry of the Environment, Japan and Greenhouse Gas Inventory Office of Japan (GIO), CGER, NIES 2012) or calculated based on NIR and other statistics

Table 2 Example of information included in the RDB (for *Primula sieboldii*)

Number of grids in each population size category						
n_1 10 or less	n_2 100 or less		n_3 1000 or less	n_4 beyond 1000	Unknown	Extinct
12	60		17	6	13	23
Number of grids in each population decline rate category						
f_1 1/100 or less	f_2 1/10 or less	f_3 1/2 or less	f_4 1 or less	f_5 1 or more	Unknown	Extinct
8	25	24	10	6	45	13

This table is cited from "Threatened Wildlife of Japan, Red Data Book 2nd ed. Volume 8, Vascular Plants" (Environment Agency of Japan edt. 2000) and translated by the authors

model to calculate extinction probability of the RDB species is based on the above simulation model described in Matsuda et al. (2003).

The advantages of using EINES are that the meaning of the result and the form of expression are easy to understand and that it is possible to compare and integrate different channels, such as the exposure of a toxic substance and land rearrangement (Itsubo and Inaba 2012).

3.2 Land use/cover category

In LIME 1 and LIME 2, the damage factors were calculated for each cause of land use, i.e., road construction, mining of soil and stones, construction of final disposal sites, and others. The damage factors in LIME 1 and LIME 2 were calculated based on data from environmental impact assessment statements, and land use/cover before transformation is not considered nor expressed in the damage factors. As it is considered that extinction risks of threatened species depend more on land use/cover that is altered by human activity than on the cause of land use, the former is adopted in this study.

Taking into consideration characteristics of the habitats of plants and availability of land data, land before transformation is categorized into six land use/cover categories (hereinafter referred to as "land use category"), which include rice fields, other agricultural land, forest land, grassland, wetlands, and other land, based on the land data in the National Greenhouse Gas Inventory Report of Japan (Ministry of the Environment, Japan and Greenhouse Gas Inventory Office of Japan (GIO), CGER, NIES 2012) (hereinafter referred to as "NIR") which was submitted to the United Nations Framework Convention on Climate Change. The area of each land use category as of 2000 (Table 1) was used in this study to calculate damage factors because the species data was published in 2000.

3.3 Data used

The extinction time, i.e., average elapsed years from the present to the extinction of each threatened species, was calculated using data from the RDB.

In RDB, threatened species are catalogued by classifying each species into one of the several Red Data Book Categories depending on the extinction risk along with other quantitative/qualitative methods. Data in the RDB was originally collected from research collaborators for all plants that could be extinct and then organized. Data on the numbers of grids (approximately 10 km^2) in each population size category and in each population decline rate category in the RDB, which had been used to estimate the extinction risk in order to determine the Red Data Book Category of each species, were used to calculate extinction time in this study. Table 2 shows an example of information included in the RDB.

The RDB also provides qualitative information, such as in what kind of habitat each species exists (Table 3).

3.4 Methods for calculating damage factors in Japan

The process of calculating damage factors in Japan is summarized in Fig. 1.

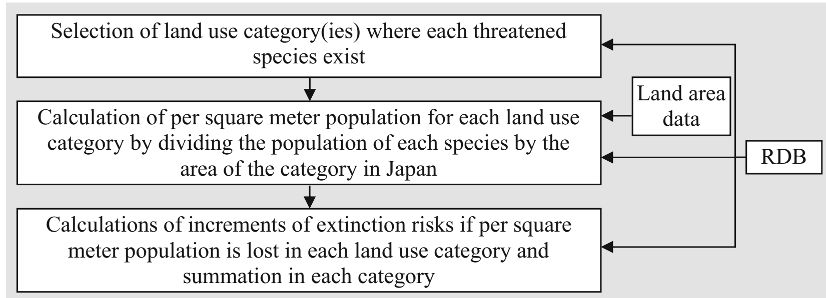
Vascular plant species in the Red Data Book Categories Critically Endangered (CR) (threatened species class IA), "Endangered (EN)" (threatened species class IB), and "Vulnerable (VU)" (threatened species class II) were subject to the calculation in this study. One or more land use category where each threatened

Table 3 Example of qualitative information included in the RDB

Species	Qualitative information related to habitat
Polemonium kiushianum	Herbaceous perennial which grows in upland grassland
Salvia isensis	Herbaceous perennial which grows in sunlit open forest or grassland of serpentine areas

Information in this table is cited from "Threatened Wildlife of Japan, Red Data Book 2nd ed. Volume 8, Vascular Plants" (Environment Agency of Japan edt. 2000) and translated by the authors

Fig. 1 Process of calculation. The process of calculating damage factors in Japan in this study is summarized in this figure



species exists was selected based on qualitative information on the habitat of each species in the RDB and other information sources. The results of selecting land use category for each species habitat are summarized in Fig. 2. Around 450 species are expected to exist in forest land; however, small numbers of species are expected in other agricultural land and rice fields. The ratio of the number of species in each Red Data Book Category does not differ significantly among land use categories.

The national population of each species was estimated using the numbers of grids in population size category in RDB. Assuming that each species exists in the selected land use category, the national population was distributed among each land use category. If multiple land use categories were selected for one species, the population was divided on the basis of the ratio of areas of categories selected.

$$N_{s,b} = N_s \times A_{s,b} \div \sum_b A_{s,b} \quad (2)$$

where

$N_{s,b}$ National population of a threatened species s in a land use category b

N_s National population of a threatened species s

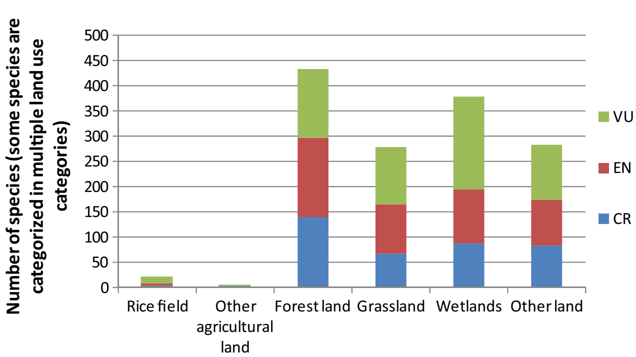


Fig. 2 Land use category selected for threatened species. The land use category is selected as habitat for each threatened species based on the RDB and other information sources. Some species are categorized in multiple categories. This figure shows the number of species in each land use category

$A_{s,b}$ Area throughout the country of land use category b, which was selected as the habitat of a threatened species s (m^2)

The population of each threatened species in each land use category calculated in formula (2) was divided by the national area of the category to calculate the population of threatened species to be lost if 1-m^2 land of that category is transformed.

$$\Delta N_{s,b} = N_{s,b} \div A_{s,b} \quad (3)$$

where

$\Delta N_{s,b}$ Lost population of a threatened species s when 1-m^2 land of a land category b is transformed

$N_{s,b}$ National population of a threatened species s in a land use category b

$A_{s,b}$ National area of land use category b, which was selected as habitat of a threatened species s (m^2)

The population of unit land use calculated in the Eq. (3) was subtracted from the national population, and this value and the rate of decrease of the species were used to calculate extinction time if land transformation occurs.

$$T_{\text{after},s,b} = A - B \times \ln(N_s - \Delta N_{s,b}) \div \ln(1 - R_{\text{reg},s}) + C \times \ln(L_s) \quad (4)$$

where

$T_{\text{after},s,b}$ Extinction time of a threatened species s after 1-m^2 land of land use b is altered (year)

N_s National population of a threatened species s

$\Delta N_{s,b}$ Lost population of a threatened species s if 1-m^2 land of land use b is altered

$R_{\text{reg},s}$ Regular rate of decrease of a threatened species s

L_s Number of grids where a threatened species s exists

A 1.891, B 5.806, C 7.572

The difference between reciprocal numbers of extinction time for the regular case and land transformation case was calculated.

$$\Delta(1/T_{s,b}) = (1/T_{\text{after},s,b}) - (1/T_{\text{before},s}) \quad (5)$$

Table 4 Examples of calculation results of extinction risk

Species	Category	N_s	$T_{\text{before},s}$	Land use category	$\Delta N_{s,b}$	$T_{\text{after},s,b}$	$\Delta\ (1/T_{s,b})$
Polemonium kiushianum	CR	443	30.9660187332	Grassland	4.4E−08	30.9660187329	2.64E−13
Salvia isensis	VU	4420	78.0635416019	Forest land	1.7E−08	78.0635416018	4.24E−15
				Grassland	1.7E−08	78.0635416018	4.24E−15

This table shows an example of the calculation results for extinction risk in this study. Multiple land use categories, i.e., forest land and grassland, are selected for *Salvia isensis* as the habitat, and the extinction risks of the species are calculated for both land use categories

where

$\Delta(1/T_{s,b})$ Increment of extinction risk of a threatened species s if 1 m^2 of land use b is altered

$T_{\text{after},s,b}$ Extinction time of a threatened species s after 1-m^2 land of land use b is altered (year)

$T_{\text{before},s}$ Extinction time of a threatened species s before occurrence of environmental burden (year)

The calculation results in Eq. (5) for each species are summed for each land use category, and these are the damage factors in Japan.

$$\text{EINES}_b = \sum_s \left(\Delta\left(1/T_{s,b}\right)\right) \tag{6}$$

where

EINES_b Damage factor of land use for land use b to biodiversity

$\Delta(1/T_{s,b})$ Increment of extinction risk of a threatened species s if 1-m^2 land of land use b is altered

4 Results

4.1 Calculation result of extinction risk for each species

Among 1665 threatened vascular plant species (CR, EN, and VU), the extinction risk of 1147 species could be calculated because the populations of about 520 species were zero calculated from data on the number of grids in population size categories. Examples of the results of calculation of extinction risk are shown in Table 4.

In Fig. 3, the regular extinction time ($T_{\text{before,s}}$) was categorized by 20 years and the numbers of species of each land use category in each $T_{\text{before,s}}$ category were plotted. The regular extinction times of many threatened species were between 20 to 80 years. The ratios of the numbers of species for each land use category did not vary for each $T_{\text{before,s}}$ category.

In Fig. 4, the increment of extinction risk of each threatened species due to 1-m^2 land transformation ($\Delta(1/T_{s,b})$) was categorized by one digit and the numbers of species of each land use category in each $\Delta(1/T_{s,b})$ category were plotted. Increments of extinction risk of the most threatened species with the use of 1-m^2 land vary from 1E−15 to 1E−12. $\Delta(1/T_{s,b})$ for many species in forestland was 1E−15 to 1E−14; however, those for many species in grassland, wetlands, and other land were 1E−14 to 1E−12. The increment of extinction risk of species categorized to forestland is comparatively lower than those of other categories.

Comparing these results, $T_{\text{before,s}}$ did not vary largely among land use category, but $\Delta(1/T_{s,b})$ did, so it is considered that the area of each land use category that was used to calculate $\Delta N_{s,b}$ has an effect on the result.

4.2 Result of calculating damage factors in Japan

Calculated damage factors for each land use category are shown in Table 5.

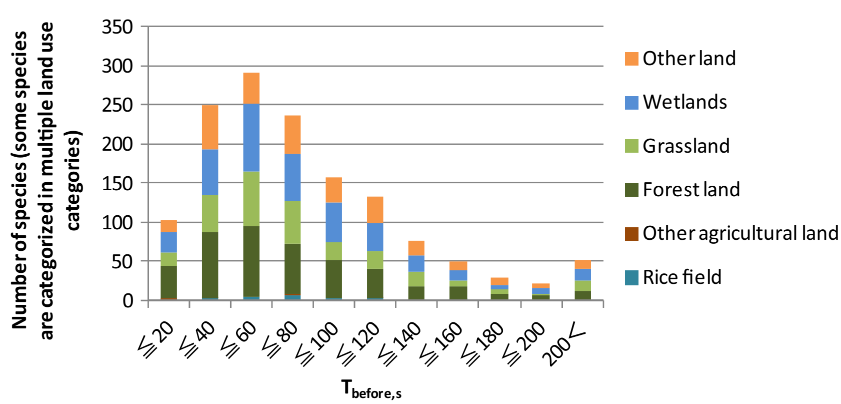


Fig. 3 Species in each category and their extinction time ($T_{\text{before,s}}$). This figure shows the numbers of species in each category and their extinction time ($T_{\text{before,s}}$). The rate of the number of species per land use category does not vary among $T_{\text{before,s}}$ categories

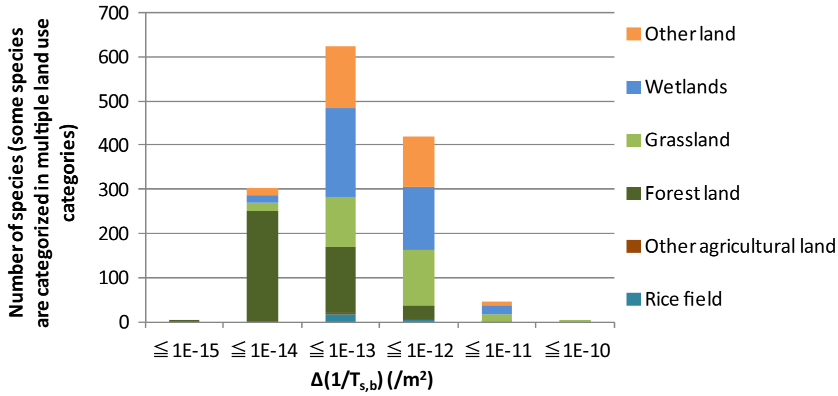


Fig. 4 Species in each category and their extinction risk increments ($\Delta(1/T_{s,b})$). This figure shows increments of extinction risk for each species due to 1 m^2 of each land use transformation. $\Delta(1/T_{s,b})$ of many species in forest land was 1E−15 to 1E−14; however, those of many species in grassland, wetlands, and other land were 1E−14 to 1E−12

The summation of extinction risks in wetlands and grassland was relatively high. Species with small populations have a large extinction risk increment, and it is considered that this contributes the EINES. The number of species that was assumed to exist in forestland was large; however, the summation of extinction risks was relatively low. This is considered to be influenced by the huge area of forestland in the country as well as by the forestland composition that consists of not only natural forest but also planted forest. The summation of extinction risks in other land was also relatively high, and it is considered to be reflected by the existence of species whose habitat is peculiar, such as limestone areas or high mountains.

The EINES in this study and the EINES in LIME 1 and 2 have very similar digits, i.e., 1E−10 or 1E−11.

$\Delta N_{s,b}$ is linear to transformation area, but $T_{\text{after,s,b}}$ and $\Delta(1/T_{s,b})$ are not linear to the transformation area as shown in formulas (4) and (5). Meanwhile, as damage due to per-unit activity is defined as a damage factor in LIME, it is necessary that the damage is linear to activity. Therefore, changes of $\sum\Delta(1/T_{s,b})$ were calculated if the transformation area was changed 1 m^2, 1 ha, and 1 km^2 (Fig. 5). As a result, it was confirmed that $\sum\Delta(1/T_{s,b})$ within 1 m^2 and 1 km^2 was almost linear to the area of transformation.

4.3 Case study on office building

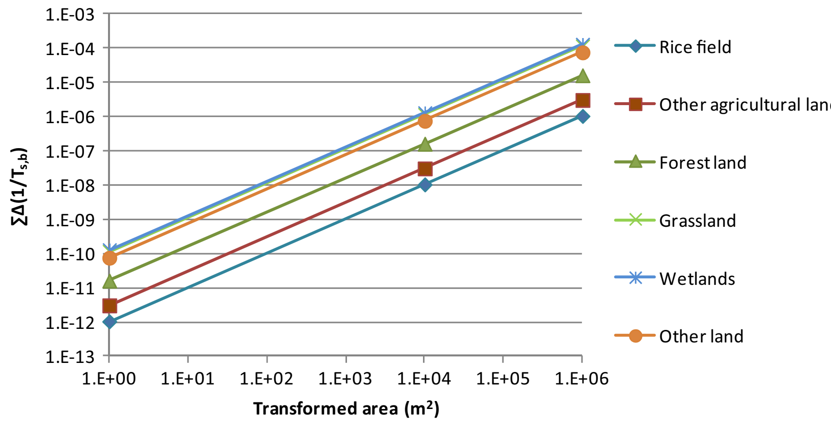
We applied the calculated damage factors to the model office building (RC, 8 F+B1F+PH1F, 7583 m^2 of total

Table 5 Damage factor for land use/cover category for Japan (EINES)

Land use category (to be transformed)	Damage factor: $EINES_b = \Sigma(\Delta(1/T_{s,b}))$ (unit: EINES/m^2)	Average of $\Delta(1/T_{s,b})$	Number of species
Rice fields	1.05E−12	4.99E−14	21
Other agricultural land	3.07E−12	7.68E−13	4
Forest land	1.62E−11	3.73E−14	433
Grassland	1.16E−10	4.16E−13	279
Wetlands	1.30E−10	3.44E−13	377
Other land	7.57E−11	2.68E−13	282
Damage factors in LIME 2 (for reference)			
Project type		Damage factor: $EINES_a = \Sigma(\Delta(1/T_{s,a}))$ (unit: EINES/m^2) mean value/median value	
Road construction		2.77E−08/3.49E−10	
Mining of soil and stone		4.86E−09/8.28E−11	
Construction of final disposal sites		9.97E−10/4.44E−10	
Others		1.07E−08/2.22E−10	

The upper part of the table shows damage factors (EINES per m^2) calculated in this study, and the lower part of the table shows those in LIME2 (Itsubo and Inaba 2012) for reference

Fig. 5 Summation of extinction risk for different transformation areas. This figure shows a summation of extinction risk ($\sum\Delta(1/T_{s,b})$) for 1 m^2, 1 ha, and 1 km^2 of land transformation. It is confirmed that the damage was almost linear to the area of transformation in this range



floor size). This building has been studied for life cycle CO_2 emission ($LCCO_2$) and other environmental loads in other existing LCA studies in Japan, and Ii et al. (2002) compiled the land use inventory of the building as shown in Table 6. As Ii et al. (2002) did not identify the category of previous land use where these land use activities in the land use inventory occur, we assumed them taking into consideration of the situation in Japan.

The result of the case study is shown in Table 6. The damage in the construction stage was the worst and that in the scrap stage is the smallest among three stages.

5 Discussion

5.1 Damage factor values in Japan

The summation of extinction risks in wetlands and grassland was relatively high. The number of species which are assumed to exist in forestland is large; however, the summation of extinction risks was relatively low. This is considered to be influenced by the huge forestland area in the country. Figure 6 shows a box plot of the increment of the extinction risk of species due to 1-m^2 transformation of each land use category.

Table 6 Case study: damage on biodiversity caused from life cycle of the model office building

	Inventory[a]	Damage assessment		
	Land use (m^2)	Assumed previous land use	Applied damage factor (EINES/m^2)	Damage (EINES)
Construction	*2,094*			*2.55E−08*
Raw materials				
Limestone	41	Other land	7.57E−11	3.10E−09
Aggregates	226	Forest land	1.62E−11	3.66E−09
Iron ore	17	Forest land	1.62E−11	2.75E−10
Coal	141	Forest land	1.62E−11	2.28E−09
Excess soil and mud	838	Forest land	1.62E−11	1.36E−08
Building site	831	Other agricultural land	3.07E−12	2.55E−09
30 years operation	*1,112*			*4.55E−09*
Electricity consumption (coal)	217	Forest land	1.62E−11	3.52E−09
MSW (total)	64	Forest land	1.62E−11	1.04E−09
Building site	831	–	–	–
Scrap	*59*			*9.56E−10*
Wastes (concrete)	59	Forest land	1.62E−11	9.56E−10
Total	*3,265*			*3.10E−08*

The upper part of the table shows the result of the case study on the model office building. The land use inventory of the building was compiled in Ii et al. (2002). Damage of the building on biodiversity was calculated using the damage factors developed in this study

[a] Ii et al. (2002)

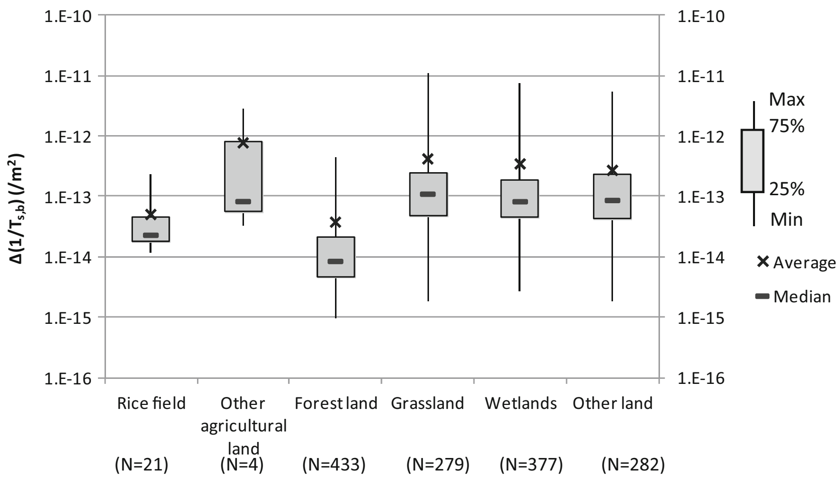


Fig. 6 Increment of extinction risk of each species due to 1 m^2 of land transformation ($\Delta(1/T_{s,b})(/\mathrm{m}^2)$). This figure shows *box plots* of the calculated increment of extinction risk of each species due to 1-m^2 land transformation ($\Delta(1/T_{s\,b})(/\mathrm{m}^2)$). The value shown under each land use category indicates the number of species whose habitat is classified under the corresponding land use category. The values do not include those species whose extinction risk could not be calculated

Similar to EINES, which sums the increments of extinction risk with each 1-m^2 transformation, increments of the extinction risks of species in grassland and wetlands were large, while those in forest land are small. On the other hand, the increment of the extinction risk of species due to the loss of one individual was not notably different among species in forest land, grassland, and wetlands (Fig. 7), so the extinction risk of the species itself is on the same level in those land use categories. Therefore, the damage factor of forestland was calculated to be comparatively small because the area of forestland in Japan is significantly larger than those of grassland and wetlands, but if a threatened species exists in a transformation place in forestland, damage of the transformation is large. We considered that the damage of land transformation in forestland differed depending on the specific site where the threatened species existed and did not exist.

The location information of the grid where 408 RDB species (hereinafter referred to as published species) exist is published on the Japan Integrated Biodiversity Information System website (Ministry of the Environment, Japan 2013). Assuming that the population of each published species is evenly distributed in the land area of the grids where the species exists, the increment of extinction risk of each published species due to 1-m^2 land transformation in each grid was calculated and the result for each grid was summed up (Fig. 8). This figure shows that the values of some specific grids are

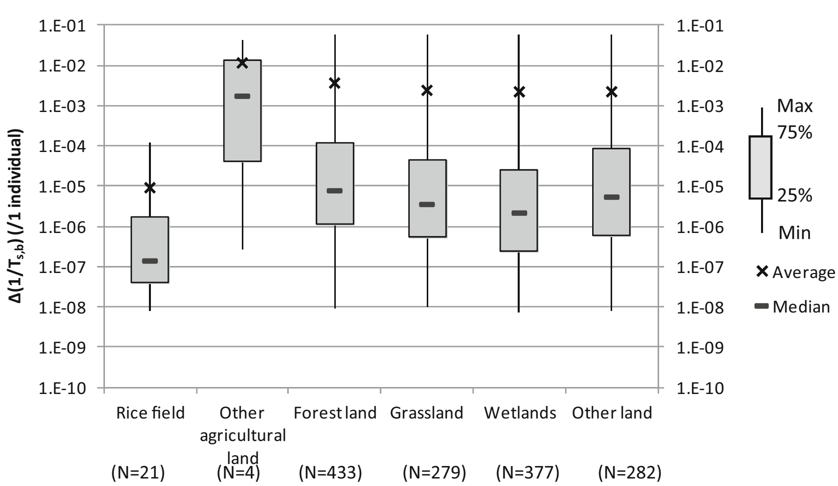


Fig. 7 Increment of extinction risk of each species due to loss of one individual ($\Delta(1/T_{s,b})(/1$ individual)). This figure shows *box plots* of the calculated increment of extinction risk of each species due to the loss of one individual ($\Delta(1/T_{s,b})(/1$ individual)). The value shown under each land use category indicates the number of species whose habitat is classified under the corresponding land use category. The values do not include those species whose extinction risk could not be calculated

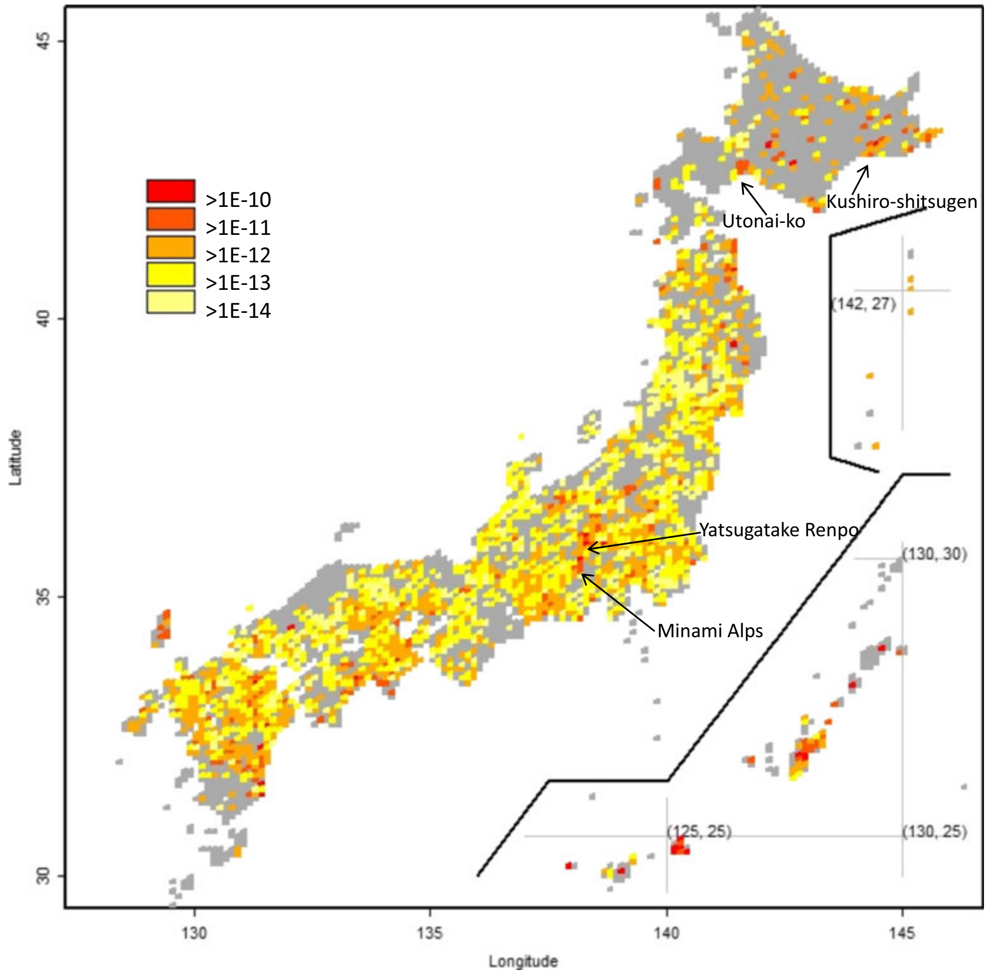


Fig. 8 Summation of the increment of extinction risk in each grid (published species only). Increment of extinction risk of each published species due to 1-m^2 land transformation in each grid is calculated. The summation of the increment in each grid is calculated and shown in this figure. The values of some specific grids are especially higher than other grid

especially higher than those of other grids. These grids include important areas in terms of biodiversity conservation, such as Kushiro-shitsugen and Utonai-ko which are the designated wetlands in the Ramsar List of Wetlands of International Importance and the Minami Alps which is in one of the national parks of Japan. Therefore, it is considered that the damage of land transformation in the same land use category differed depending on the specific site with or without the existence of the threatened species.

The damage factor for forestland is relatively low compared to the PDF in Eco-indicator 99 (Goedkoop and Spriensma 2001). This is considered to be due to the difference in indicators.

5.2 Land use after land transformation

Koellner et al. (2013) provided general principles for modeling land use impact on biodiversity, which assessed the impact of both land transformation and land occupation based on the difference in ecosystem quality between the land use situation and suitable reference. It is considered that even land use situation is regarded to have some ecosystem quality. Koellner et al. (2013) also mentioned that ecosystem quality is a result of the interaction between life with the abiotic environment, and life is, in the strict sense of the word, not reversible.

EINES in this study indicates how the risk of extinction increases due to land transformation and is calculated as the summation of the increments in the reciprocal of the extinction time for each threatened vascular plant species due to population decrease, based on the assumption that all population of the threatened vascular plants existing in the land which is to be transformed is to be lost unless otherwise selectively protected. Therefore, if forestland is transformed into agricultural land, for example, the degree of increase in extinction risk due to the population loss of the threatened vascular species which exist in forestland is evaluated, while the decrease in extinction risk due to the appearance of agricultural land is not evaluated. It seems that seeds of the threatened species, for which the land use after transformation is appropriate, are less likely to be in the soil of the land after transformation or to be carried by wind or birds naturally, whereby it seems that such threatened species less likely not to exist in the land after transformation. Therefore, it is considered that the evaluation of the effect due to the appearance of land use after transformation is not necessary in the method using EINES, which evaluates threatened species.

6 Conclusions

This study considered a method to assess damage to biodiversity by land use for use in LIME3.

This assessment method uses the extinction risk of vascular plant species as an indicator. As vascular plants are not movable, they are subject to direct influence due to land use. At the same time, the vascular plants consist only a part of the large amount of species in the world; however, more data is available than is the case for any other taxonomic group. Furthermore, other LCIA methods use plants as an indicator. As a result, methods to assess impacts due to land use on species of other taxonomic groups than vascular plants are expected for more holistic understanding of impacts on the ecosystem; however, it is still considered meaningful to use vascular plants as an indicator in LCIA.

The extinction time and the potentially decreased extinction time due to land use were calculated. The extinction time is the average elapsed years from the present to the extinction of each threatened vascular plant species. The damage factors were calculated for each land use category as the summation of increment of the reciprocal of the extinction time. This assessment method utilizes knowledge in conservation biology and is in line with its theoretical concept. As the method uses extinction risks as an indicator, it assesses increasing extinction risk due to decreasing population and also assesses the direct impact on the risk of species extinction and their causal relation.

EINES per 1-m^2 land use of each land use category in Japan ranges between 1E−10 and 1E−13. Further analysis indicates that EINES varies according to the location even in the same land use type. Land use categories are limited, and it is desirable to specifically assess differences among forest types.

Damage factors developed for Japan in this study have broad potential application, as they have more general land use categories than those in LIME 1 and 2. It will be necessary to develop damage factors in other countries which take into account threatened species categories and differences in importance among land use categories in other countries.

It will also be necessary to accumulate detailed data on threatened species across the planet in order to develop worldwide damage factors.

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