Risk-benefit analysis in ecological risks

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Abstract Red list of Japanese vascular plants was determined by extinction risks assessment. We calculated extinction risk of 1500 taxa within the next 10 years, 20 years and 1 century. The mean time to extinction of a threatened species is strongly related with the estimated number of individuals and the population decline rate of that species. We considered increment in the inverse of the mean time to extinction of threatened species as a measure of human impact on biodiversity. The weighted sum of these increments is called "expected loss of biodiversity" (ELB). We applied these extinction risk assessment to the World Exposition 2005 and a liquefied natural gas (LNG) plant.

1. Introduction

Risk assessment becomes popular in conservation ecology (Matsuda et al. 2000). The list of threatened species (Red List, IUCN 1994) is partly determined by extinction risk assessment. Local extinction is mainly caused by habitat loss, overexploitation, environmental pollution and invasion of exotic species (Matsuda 2000). The extinction risk of a population or a species depends on the mean rate of population decline, the magnitude of environmental stochasticity and the demographic stochasticity.

In addition, risk assessment and risk communication become popular in wildlife management and fisheries management. The deer population management program in Hokkaido Island, Japan, is based on the risk management to avoid both overabundance and local extinction (Matsuda et al. 1999). The risk control in deer management is a model case for Japan's wildlife management law, revised in 1999. Japan's environmental impact assessment law is also based on risk assessment. In environmental impact statement, uncertainty in prediction of environmental impact must be investigated. In particular, impact assessment of habitat loss of threatened species is based on the increment in extinction risk of these species.

Table 1. Data used in extinction risk assessment of the red list for *Primula sieboldii* (Yahara et al. 1997). (a) Frequency of the population sizes in grids.

Population size class	<10	<100	<1000	>1000	Extinct	Unknown
Number of grids	12	60	15	8	13	23

(b) Frequency of the decline rates within the past 10 years in grids.

Class of decline rates	<0.01	<0.1	<0.5	<1	>1	Extinct	Unknown
Number of grids	8	23	24	12	6	13	45

development of quantitative methods in estimating the extinction risks of threatened species (Lande 1993; Mace & Lande 1990). Among these, criterion E is based on the extinction risk. A taxon is critically endangered (CR), endangered (EN) or vulnerable (VU) when the extinction probability is at least 50% within 10 years or 3 generations, whichever is the longer, at least 20% within 20 years or 5 generations, whichever is the longer, or at least 10% within 100 years, respectively. Criterion E can be applied for any organism if appropriate demographic data are available. However, demographic data are rarely available in most threatened taxa. There are 4 other criteria A-D, which are based on the population decline rate (criterion A), the area of distribution (B), combination of the absolute population size and decline rate or subpopulation fragmentation (C), and the absolute number of mature individuals (D).

In 1997, Japan Environment Agency (JEA) made the red list of Japanese vascular plants collaborated by the Threatened Species Committee, the Japanese Society of Plant Taxonomists (TSC-JSPT, see Yahara et al. 1998). About 400 experts in plant taxonomy, including university professors, staffs of museums or botanical gardens, or high school teachers, surveyed the numbers, decline rates and risk factors of each species within each grid (approximately 10km x 10km). There are about 4400 grids (map sheets of 1/25000) in Japan. There are about 7000 taxa of native vascular plants in Japan.

Using these data, TSC-JSPT compiled the number of extant grids, the approximate number of individuals and factors of decline in each grid, in each species (see Table 1 for the case of *Primula sieboldii*). These data were published in the Red Data Book of Japanese plants, published by JEA (2000). A source program for these evaluations is uploaded in a web site, http://www2.ori.u-tokyo.ac.jp/~matsuda/redlist.html. TSC-JSPT evaluated the population decline rate within 10 years (denoted by R), the extinction risk within the next 10, 20 and 100 years (P_{10}, P_{20}, P_{100}, respectively), the mean time to extinction (T), and the expected number of individuals in 10, 20 and 100 years after the present (N_{10}, N_{20}, N_{100}, respectively), averaged over 1000 trials, throughout Japan for each species (see Fig. 1). They assumed that trends in population decline within the past 10 years in each species will continue in the future and no heterogeneity exists in future decline rates.

TSC-JSPT listed a taxon in CR, EN and VU if the extinction risks within the next 10 years, 20 years and 1 century are respectively larger than 50%, 20% and 10%. They also listed a taxon in CR, EN and VU if the expected number is less than 50 in 10 years after, 250 in 25 years

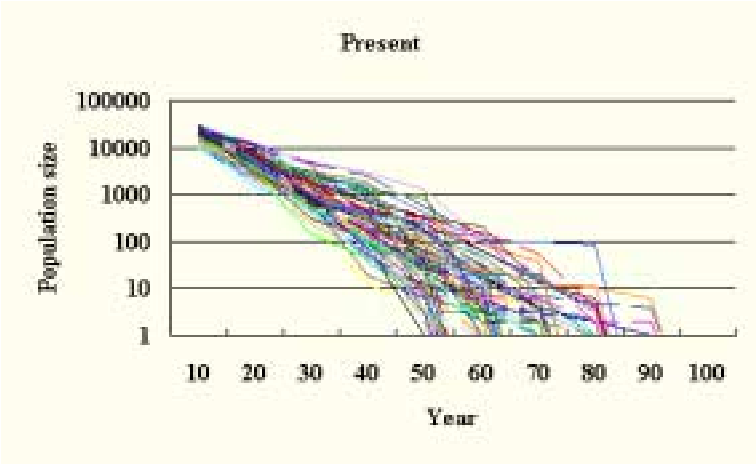

Fig. 1. Projection of population decline of Primura

after and 1000 in 1 century after the present, respectively.

Surprisingly, about 20% of native vascular plants, ca.1400 taxa, are listed in threatened. This list is based on combination of population size and population declining rate. Among these, population sizes of ca.400 taxa (6% of native plants) are over 1000 individuals. Major reason of population decline in these plants may be habitat destruction and illegal collection. Japanese bellflower (*Platycodon grandiflorum*) is listed as vulnerable. Why are so many abundant species listed as threatened? These are because population decline rate is so large that the extinction risk within the next one-century is very high, if the past decline trends continue in the future.

3. Extinction Risk Assessment in the 2005 World Exposition, Japan

The database in red data book of Japanese vascular plants (JEA 2000) is definitely useful for environmental impact assessment (EIA). In 1999, EIA law was enforced in Japan. In accordance with the guideline of EIA law in 1997, loss of individuals or habitat of threatened species must be quantitatively investigated or estimated in environmental impact statements. We can evaluate an impact assessment of habitat loss by increment of extinction risk of threatened species. We apply impact assessment on extinction risk to the World Exposition 2005 (EXPO2005), held in Seto City and its vicinity, Aichi Prefecture, Japan, during March 25 to September 25, 2005. Kaisho Forest is a secondary forest, but a hotspot of threatened species. There are 27 national and 22 regional threatened taxa of vascular plants in Kaisho Forest (Table 2 for list of species). Japan Association for the 2005 World Exposition (hereafter abbreviated by JAE) plans that the anticipated attendance was ca. 25 million (see JAE's web site, http://www.expo2005.or.jp/english/s3/gaiyo1.html). Japan Government and JAE addresses that "the entire site might well be termed an experimental eco-museum park exploring the interaction between human society and the surrounding ecosystem". EIA for EXPO2005 collected the numbers of individuals and locations for each threatened plants that distributes in the Kaisho Forest are counted and loss of the number due to habitat loss for each threatened taxa are estimated by JAE, as shown in Table 3.

Table 3. Increment of extinction risk caused by habitat loss for Expo 2005. N_1: the number of individuals in the planned site of EXPO2005, N_2: the number of lost individuals caused by EXPO2005, N_p: The observed number of individuals throughout Japan compiled by JEA, N_g: The number of extant grids (ca.10×10 km^2) throughout Japan, T_0: The mean time to extinction. The species is ranked by $\Delta(1/T)$.

Sp.	RDB	R	N_1	N_2	N_p	N_g	T_0	$\Delta(1/T)$	$\Delta\log T$
12	VU	0.59	4370	447	1000	10	84	5×10^{-5}	0.004
13	VU	0.46	137	31	1000	40	128	2×10^{-6}	3×10^{-4}
19	VU	0.68	1721	108	7000	20	77	2×10^{-6}	2×10^{-4}
4	EN	0.84	31	18	2000	20	38	3×10^{-6}	1×10^{-4}
7	VU	0.29	1554	140	10000	20	302	3×10^{-7}	9×10^{-5}
25	nt	0.35	1888	681	100000	60	274	2×10^{-7}	4×10^{-5}
3	EN	0.85	13	9	4000	10	40	7×10^{-7}	3×10^{-5}
26	nt	0.48	64	41	10000	50	156	1×10^{-7}	2×10^{-5}
23	nt	0.38	711	88	30000	60	229	9×10^{-8}	2×10^{-5}
5	EN	0.74	2	1	2000	20	56	9×10^{-8}	5×10^{-6}
20	VU	0.62	2	1	3000	100	88	3×10^{-8}	3×10^{-6}
24	nt	0.31	127	33	60000	50	316	1×10^{-8}	4×10^{-6}
1	CR	0.74	—	—	30	1	27	0	0
2	EN	0.72	1	0	600	10	51	0	0
6	VU	0.59	—	—	20000	100	116	0	0
8	VU	0.59	503	0	3000	90	96	0	0
9	VU	0.72	58	0	8000	50	69	0	0
10	VU	0.31	1	0	500	20	195	0	0
11	VU	0.45	—	—	2000	20	142	0	0
14	VU	0.58	13	0	40000	100	123	0	0
15	VU	0.70	15	0	10000	200	79	0	0
16	VU	0.64	—	—	20000	80	101	0	0
17	VU	0.70	3	0	8000	10	74	0	0
18	VU	0.68	78	0	7000	8	77	0	0
21	VU	0.73	2143	0	10000	100	73	0	0
22	nt	0.64	340	0	10000	100	93	0	0
27	nt	0.45	226	0	9000	3	163	0	0

The main site of the EXPO2005 was Kaisho Forest. Kaisho Forest is a secondary forest that includes 27 threatened or near threatened species of vascular plants. We calculate the population decline rate (R) of species s, compiled by TSC-JSPT as background level. By using the database, we obtain the mean time to extinction of species s (T). We quantify the increment of extinction risk through a single habitat loss of threatened taxa.

From a multivariable regression analysis, I assume that T as a function of N and R:

$$T = -10.1 - 8.9\log(N)/\log(1-R)$$

where their correlation coefficient is 0.964. An unrepeatable development decreases the

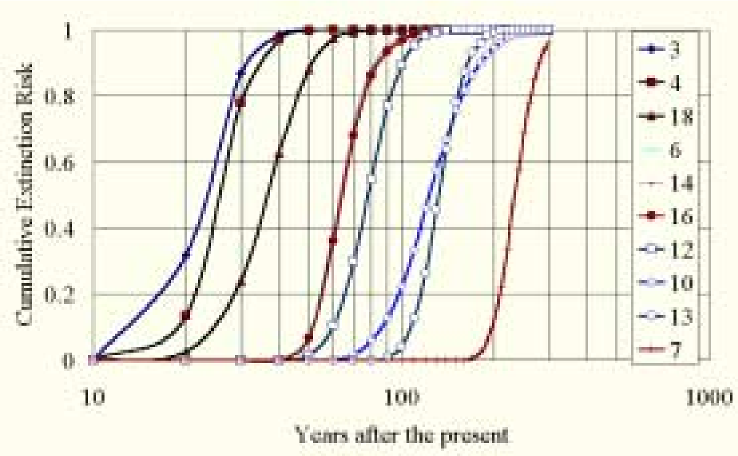

Fig. 2. Cumulative extinction risk of threatened plants inhabiting in Kaisho Forest. Species number is shown in Table 1

population size at the present or in the near future, but unlikely increase the population decline rate in the future. In contrast, impact of a repeatable development increases the population decline rate in the future. Some factors affect both loss of the current size and increase of future decline rate.

If the present number of individuals is reduced by habitat loss in Kaisho Forest (N_2), the mean time to extinction decreases by

$$T_2=-10.1 - 8.9\log(N-N_2)/\log(1-R).$$

We use loss of the inverse of the mean time to extinction by a single habitat loss, $\Delta(1/T)$, as a measure of human impact on the extinction risk of threatened or nearly threatened taxa. We define $\Delta(1/T)$ as $1/T_2-1/T$.

By using the population size and decline rate over Japan and the lost number of individuals in the planned site of EXPO2005, we can calculate the impact on extinction risk of each threatened taxon. We should note difference in assessment effort between the JSPT survey over Japan and the EIA for EXPO2005 site. The latter is probably much stronger than the former. In fact, the number of *Salvia isensis* in the grids, ca.200km^2, including the EXPO2005 site compiled by JSPT is smaller than the number in the site (5.4km^2) counted by EIA for EXPO2005. We do not know the magnitude of difference in assessment effort between them. Therefore, we assume that the total number of individuals N is multiplied by a coefficient m. In Table 3, we assume that m=10. Whereas the magnitude of impact depends on m, the order of the magnitude among species did not change with m.

Japan Government and Aichi Prefecture changed their former plan of EXPO2005 in order to reduce extinction risk of the star magnolia, *Magnolia tomentosa*, which is listed as vulnerable and a symbol of Kaisho Forest. The star magnolia distributes in Aichi, Gifu and Mie prefectures, central Japan. To save a big habitat of the star magnolia, Aichi Prefecture divided the Expo 2005 site into 3 types of zoning. Zones A, B and C are respectively named "main facilities", "Natural zone", and "Forestry management". Habitats in zone B are expected to

Table 4. Increments in the inverse of extinction risk $\Delta(1/T)$, contribution of biodiversity (B) and expected loss of biodiversity (ELB) of vascular plants due to loss of Nakaikemi Wetland (Oka, Matsuda and Kadono, in review)

Species name	rank	ΔN	log$N$	N_g	1-R	T	log$\Delta(1/T)$	log$B$	ELB
Eusteralis yatabeana	VU	>100	3.7	17	76%	36	-3.45	6.5	1214
Najas japonica	EN	?	3.3	29	80%	38	-3.81	7.1	1782
Trapa i nci sa	VU	>1000	3.6	50	55%	85	-3.85	7.1	1755
Monochoria korsakowii	VU	>1000	3.9	52	68%	56	-4.18	7.1	802
Marsilea quadrifolia	VU	>100	4.3	51	87%	32	-4.19	7.3	1254
Prenanthes tanakae	VU	>100	4.1	98	49%	120	-4.29	6.3	108
Persicaria foliosa	VU	>10	3.8	33	62%	54	-4.37	6.9	303
Azolla japonica	VU	>1000	4.8	80	75%	53	-4.39	7.5	1267
Sparganium japoinica	NT	<10	4.4	114	34%	202	-4.96	7.1	139
Isoetes japonica	VU	>100	4.4	149	58%	90	-5.05	7.5	261
Iris laevigata	VU	>100	4.4	81	54%	102	-5.20	6.8	40
Salvinia natans	VU	>100	4.7	104	77%	55	-5.24	7.5	161
Sagittaria aginashi	NT	>100	4.8	128	40%	162	-5.36	7.0	49
Sparganium erectum	NT	>100	4.6	148	38%	185	-5.72	7.1	24
Habenaria sagittifera	VU	>100	4.1	121	61%	82	-5.83	6.3	3

survive. Therefore, the number of lost individuals, N_2 in Table 3 is smaller than the number of individuals in the site, N_1.

It should be noted that the impacts on species numbers 12, 13, 19 and 4 (*Salvia isensis*, *Siphonostegia laeta*, *Eularia speciosa* and *Najas japonica*), are larger than the impact on star magnolia, species No. 7, as shown in Table 3. The impact on *Salvia isensis* (No. 12) is still larger than the impact on star magnolia in the case of entire habitat loss in Kaisho forest. Because JAE changed a site plan in order to reduce the impact on star magnolia, we recommend JAE further conservation action for these species.

4. Expected Loss of Biodiversity for a Wetland Development

We applied the extinction risk assessment to the development of Nakaikemi Wetland, Tsuruga, Japan (Oka, Matsuda and Kadono, in review). The area of Nakaikemi wetland is about 25 ha and is characterized by its unique geomorphic feature of pouched valley aggraded with mud. Most of the area has been used as rice paddy for hundreds of years. However, abandoned these rice fields were abandoned because of low productivity.

We implicitly assumed equity in species conservation between species in the previous section. However, contribution of species conservation on a global biodiversity may depend on phylogeny of the species. We introduce a new risk measure, 'Expected Loss of Biodiversity (ELB)'. ELB is defined as the weighted sum of the increments in extinction risk of the species living in the wetland due to its development. With regard to the weighting for a particular species, this is calculated according to the length of the branch on the phylogenetic tree that will be lost if the species becomes extinct. The length of the branch on the phylogenetic tree is regarded as reflecting the extent of contribution of the species to the taxonomic diversity of the world of living things. Since the first diversion of vascular plants occurred 400 million years ago, we assume that the length of the branch on the phylogenetic tree of each species is estimated as $Y=4\times10^8B$ years, where the logarithm of biodiversity contribution (log B) is shown in Table 4

Many species of aquatic plants live in the Nakaikemi Wetland. These aquatic plants are regarded as declining nationwide, including 13 of the threatened and 2 of the near threatened plant species according to the Red List (JEA 2000). If Nakaikemi Wetland is lost, the number of individuals in each species decreases by ΔN, as shown in Table 4. There are also many species of fish including threatened cyprinodont and insects including more than 60 kinds of dragonflies and several kinds of declining diving beetles. These insects and plants are mutually indispensable due to pollination.

Osaka Gas Company made a plan for the construction of a liquefied natural gas (LNG) plant on this area in 1992. Environmental impact statements was published in 1996, whereby the plan was allowed on condition that habitat of threatened plant species be maintained in `protected conservation area' of 3.3ha and that a maintenance test be conducted for three years. The EIS also projected future succession process in Nakaikemi Wetland, in the case that neither the LNG plant nor “Protected Conservation Area” is made.

The increments in the extinction risk are calculated by a simulation used for making the Red List for vascular plants in Japan (JEA 2000). The expected loss of biodiversity for each species is defined as the product of increment of the inverse of extinction risk, $\Delta(1/T)$ and the contribution of biodiversity (B). The sum of ELB for all threatened or near threatened species of vascular plants, the resulting ELB for the loss of Nakaikemi wetland is 9,200 years.

This result is combined with the economic costs for conservation of the wetland to produce a value for the indicator of the 'cost per unit of biodiversity saved'. Depending on the scenario, the value is 13,000 yen/year-ELB or 110,000 to 420,000 yen/year-ELB.

5. Discussion

In this paper, I explained validity of extinction risk assessment in biodiversity conservation. Extinction risk assessment changed environment policy in Japan. A typical episode is change in site plan for the World Exposition 2005, Japan. However, it is still unclear that increment in extinction risk of threatened species caused by environmental chemicals. Effects of overexploitation and habitat loss on increments in extinction risk are relatively clear. Pollution including environmental chemicals rarely makes catastrophic extinction. However, environmental chemicals may affect irreversible impact on the future biodiversity, because there are many kinds of artificially environmental chemicals, effects of these chemicals on biodiversity are quantitatively unclear, these chemicals are rarely decomposed, these chemicals may decrease the fecundity rate of a wide range of taxa.

Habitat loss does not always increase the risk of global extinction. Red list of Japanese vascular plants assumed that the past decline rate will continue in the future and ignored regional heterogeneity in decline rate. The risk assessment based on these assumptions is definitely oversimplified. Because of such oversimplification, habitat loss or increment in local extinction will contribute increment in the risk of global extinction. We quantify increment in the risk of global extinction caused by a habitat loss.

In advance of conservation ecology, people tend to appreciate not only rare species but also ecosystem processes. Policy for environmental conservation must avoid local extinction of any species. In particular, the risk of local extinction of threatened species is usually high. Local extinction of threatened species is often irreversible. In contrast, the risk of local extinction of common species is often low, and reintroduction of common species is relatively easy. Methods of extinction risk assessment introduced here may be useful for risk management of local extinction.

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