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Biological indicators to monitor responses against climate change in Korea

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ABSTRACT: The most useful criteria and selection procedures of biological indicators have been developed in Korea because they have taken into account local and national concerns on biological responses against climate change. On the basis of these criteria and selection procedures, 100 climate-sensitive biological indicator species were selected to predict biodiversity distribution shift by climate change and manage biological resources integratedly at the national level. It is expected that selection and monitoring of biological indicators by climate change will provide significant information to prepare protective strategies of vulnerable species against climate change and adaptive policies under the changing environment in Korea. In this paper, we have reviewed what kinds of criteria were considered in selecting bioindicators to assess responses of biological organisms against climate change. Definition and selection steps of bioindicators were proposed, and the 100 species of climate- sensitive biological indicators were selected out of 33,253 taxa reported in Korea.

Keywords: Bioindicator, Climate change, Global warming, GEO BON

Introduction

The average temperature of the globe increased by 0.6±0.2°C for last 100 years (Houghton et al., 2001), but a recent trend of temperature climbing is so remarkable that the temperature will rise up by 1.4~5.8°C (IPCC, 2001). The Korean peninsular is also getting warmer. The average temperature of the peninsular has climbed up by 1.3°C during 60 years from 1941 to 2000 due to recent global warming (Lee et al., 2009). According to weather information from Korea Meteorological Administration (2009), thirty-year-average temperature of Incheon increases by 0.9°C as compared with temperature of the 1910th, Mokpo by 0.7°C, Gangneung and Busan by 1.0°C, respectively. The temperatures of Jeonju and Daegu located at inland areas increase by 1.0°C and 1.3°C, respectively (Fig. 1).

Because climate warming has influenced directly habitat distribution of biological organisms, phenological responses of leafing in vascular plants, migration of migratory birds, and egg-laying periods of amphibians and reptiles might be changed. For example, climate change over the past 60 years might produce vegetation shifts of temperate evergreen broad-leaved trees in Korea. Examination in distribution of these 48 species revealed that they have migrated nearly 14 to 74 km up North. The research showed that the expansion of the temperate evergreen broad-leaved trees is the most vigorous and expeditious in Gwangju, throughout Jeonnam and along the western coastal areas of Chungnam. From these results derived from changed distribution shift, a northern distribution line of subtropical evergreen broad-leaved trees was adjusted to reflect the new research findings linking Baegryeong-do-Cheongyang-Jeongeup-Pohang (Lee et al., 2010). Information related to ecosystems and biodiversity changes were obtained by observation results over long time periods, and thus acquisition of results are different from the place to place. In eastern asian regions, some observation results were referred in writing up the Intergovernmental Panel on Climate Change (IPCC) special report (Rosenweig and Casassa, 2007). Although there are ample evidences accumulated on biological responses by recent climatic changes in Korea, there was no any reference related to Korea found in the report. Furthermore, the methods to collect biological information against climate change have been recently changing from professional to community participation. In order to make biodiversity observation information be more readily accessible to managers, policy-makers, and professionals, the Group on Earth Observations Biodiversity Observation Network (GEO BON) was established under the arm of the Global Earth Observation System of Systems (GEOSS). The activities of GEO BON were recognized by an editorial of the journal Nature (2010). The editorial has recognized

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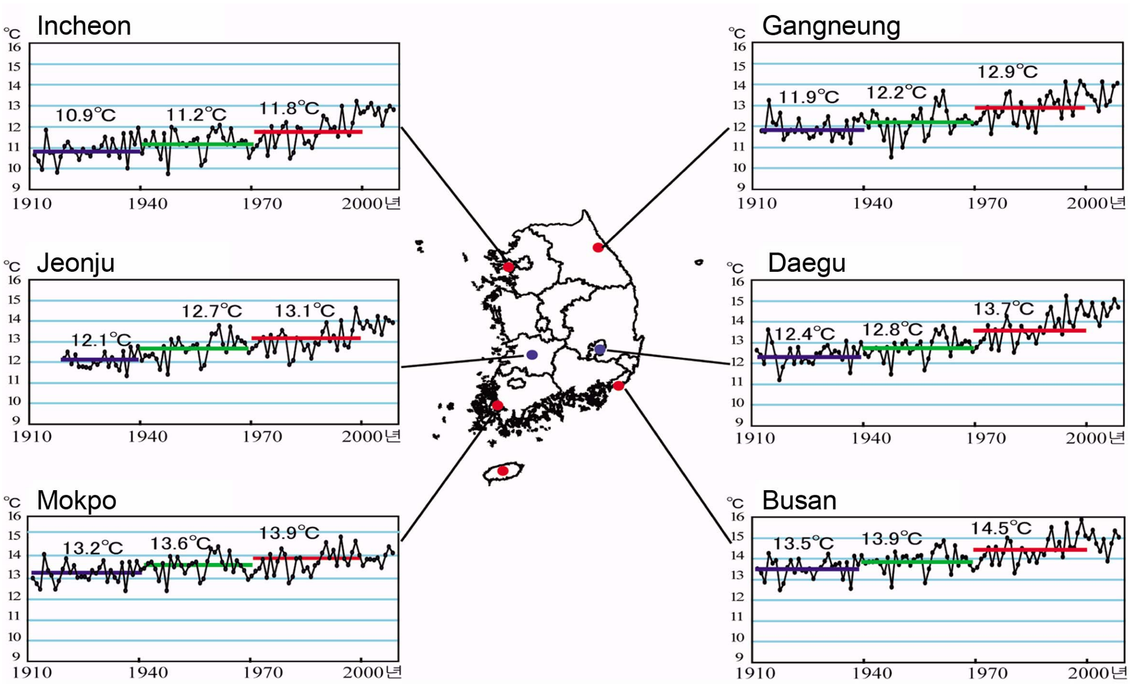

Fig. 1. Temperature change over 90 years in Korea. The average temperature was calculated on the basis of thirty-year-long temperature.

observation of GEO BON as important activities for collecting biodiversity information and for supporting the proposed Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Although the GEO BON observed and collected biodiversity information in a collaboration of more than 100 governmental and non-governmental organizations, there is no any standard network system for community participation established to assess climatic impacts on biodiversity in Korea.

Selection and criteria of bioindicators

In order to prepare adaptive strategies of biological organisms against climate change, it might be the best way to assess climatic affect to all the 33,253 biological taxa known to live in Korea (National Institute of Biological Resources, 2008). Instead of applying this impossible method to assess climatic affects to all the biodiversity, some of biological organisms were selected as biological indicators and used to provide general information about complexity between climate and biodiversity changes. For more than 50 years, certain biological organisms have been used as bioindicators because they are sensitive to environmental factors such as climate change, ozone, or water pollution (Middleton et al., 1950; Manning, 1998). Environmental bioindicators have also proved to be tools in understanding the effects of the presence of contaminants or in detecting biological changes in the environment. However, there are still no unanimous definition or criteria for selection of bioindicators despite the long history of use of them (Rainio and Niemelä, 2003). According to McGeoch (1998), bioindicators can be defined as a species group that reflects the abiotic or biotic state of the environment, represents the impact of environmental change on a habitat, community or ecosystems, or indicates the diversity of other species (Colwell and Coddington, 1994; Rainio and Niemelä, 2003). There are some problems in using bioindicators because of representatives of bioindicators selected. Rainio and Niemelä (2003) have questioned how well one species or a species group represent the remaining taxa. Another problem is a standardization of bioindicator data observed and analyzed. Considering the importance of community participation in accumulating the biodiversity information, standardized methods should be required prior to field examination of bioindicators. From the technical series of the Convention on Biological Diversity, Watson et al. (2003) suggested that indicators must be practical and meaningful at both the national and site levels as well as consistent with the main objectives of the project or policy intervention. In order for indicators to be most useful and effective, they also suggested that the suite of indicators should be relevant to the project as much detailed as follows. Biological indicators should be cost-effective to monitor; well-established in order to reveal meaningful trends; be precise so that they can be clearly defined and understood the same way by different stakeholders; be chosen that allow the identification and separation of the effects of climate change;

be evaluated by minimum number of individuals and agencies in their evaluation. The United States Environmental Protection Agency (2009) identified an evaluation system of species' vulnerabilities to climate change. In order to evaluate the likely responses of species to climate change, the Agency proposed several categories such as physiological information, demographic or life history information, habitat information, phenological information, and stressor information. Several authors have also defined the requirements of bioindicator selection. In short, a good bioindicator should be well-known taxonomically, be distributed over a broad geographic area, be easy and cost-effective to survey, be relatively independent of sample size, and should be of potential economic importance (Noss, 1990; Groot et al., 1995; Niemelä, 2000; Rainio and Niemelä, 2003).

Definition and selection criteria of CBIS in Korea

The most important factor in defining bioindicators sensitive to climate change is how sensitive biological organisms are to climatic elements such as temperature, precipitation, and humidity rather than other environmental factors including acidification, land use change, habitat constraints, and etc. Therefore, the climate-sensitive biological indicator species in Korea were defined as species which need to be consistently investigated and managed in a type of indicators because they are showing or expected to show clear change in activity, distribution or size of population owing to climate change. Criteria to select CBIS in Korea were classified into two; basic and general ones. When selecting a biological indicator, a couple of basic criteria should be considered as requirements. The first criterion is that bioindicators should be more sensitive to climate change than other environmental factors. Another basic criterion is that a species can be identified and observed easily for their habitat conditions. We have selected ten criteria in order to select CBIS in a general concern. The ten criteria can be classified into two fields; the academic field, and the business and handling field. In order to meet the first criterion of the academic field, a species should be well-known for its taxonomy and ecology. The second criterion is how regular species are distributed. Bioindicators should be distributed over a broad geographical area in a regular pattern because the proper spatial scales should be considered for investigating suitable bioindicators (Rainio and Niemelä, 2003). Other criteria are related to a taxon's southern or northern distribution limits, or multiple populations. Scientific knoweldge of biological organisms by climate change is also considered as a selection criterion. Other five criteria were selected considering issues related to the business and handling field. The first criterion is the easiness of observation of the bioindicators. This is consistent with the criterion proposed in the CBD technical series; bioindicators should be amenable to sampling by non-specialists, including user or local communities (Watson et al., 2003). Species with long appearance or with multiple individuals can be bioindicators because they can be recognized easily for a relatively long duration. There are several survey methods for bioindicators depending upon what kinds of collection tools were used for sampling. To be most useful and effective, bioindicators might be cost-effective to monitor. Species important for society, business, and culture would be considered as a good candidate for bioindicators.

Procedural steps to select CBIS

Four procedural steps were developed in selecting CBIS of Korea. This is a step-by-step procedure beginning with applying two basic criteria to biological organisms. Out of approximately 33,253 species, 1,003 species were selected when we applied two basic criteria; sensitivity to climate change, easy observation and identification (Table 2). All 122 species of mammals reported in Korea were excluded from the CBIS because their habitat change can not be detected against climate change in a small size of Korean peninsula. Other biological organisms of Chaetognatha, Millipodes, Diatoms, Cibtes, Myxomycetes, and etc. were also excluded from the indicators because of difficult identification and observation. The second selection step of CBIS was to calculate how many general criteria were shown in each of 1,003 species passed through the first step. The 290 of biological organisms having more than five general criteria were selected from the candidates in the second selection process. The third selection step is to assess 290 selected species in detail on the basis of each

Table 1. Two basic and ten general criteria for selecting Climate-sensitive Biological Indicator Species (CBIS) in Korea.

Criteria		Explanation of criteria
Basic criteria		• Species more sensitive to climatic change than other environmental factors • Species identified and observed easily for their habitat conditions
General criteria	Academic field (60 points)	• Species well known for their taxonomy and ecology • Species with regular distribution • Species with definite habitats (north. or south. limit) • Species with multiple population • Species reported for their response to climate change
	Business and handling field (40 points)	• Species observed easily • Species with long appearance • Species with multiple individuals • Species to be cost-effective • Species important for society, business, and culture

general criteria which was divided into three different degrees; high, middle, and low ones. In order to calculate how many scores each of 290 species obtained, three different degrees were assigned into 100, 70, and 50 percent of basic scores, respectively. Basic scores of criteria belonging to the academic field were assigned to 12 points while those belonging to the business and handling field were 8 points. The maximum score of general criteria were calculated into 100 scores. Several experts have involved in scoring the criteria to each candidate. Out of 290 candidate species, *Machillus thunbergii* of vascular plants has scored the highest point of 98.6 while *Uroctea lesserti* of spiders obtained the lowest point of 61.6. The last selection step is to finalize the list of CBIS considering species and ecosystem diversities by a group of experts.

The 100 CBIS in Korea

Korean CBIS are categorized into four different taxonomic fields; forty six species of animals (14 Aves, two Fish, two Amphibia, one Mollusca, 24 species of Arthropoda including 21 insects), 44 species of vascular plants, five species of fungi, and five species of macro-algae, respectively. Of fourteen avian species, distribution areas of three species such as *Grus vipio*, *Anser fabalis*, and *Cygnus cygnus* are expected to be reduced because numbers of individuals of the species decreased at the major wintering sites. Subtropical birds such as *Ardea cinerea*, *Ardeola bacchus*, *Egretta garzetta,* and *Pitta brachyura* visit Korea during the summer season, but individuals of the species increase staying in Korea over the winter. Subtropical bird species such as *Sturnus seriseus, Pycnonotus sinensis* were first observed recently at Ganghwa-do or Eocheong-do, but breeding populations of those species in Korea are expected to increase. It is recognized that the breeding season of the resident bird, *Parus major*, is getting earlier during the spring. Another resident bird, *Zosterops japonicus*, distributed to Jeju-do, Ulreung-do, and southern coastal areas, but the distribution of the bird is expected to be expanded toward the north or inland areas. Egg-laying periods of two amphibians such as *Kaloula beoralis* and *Rana dybowskii* are expected to be changed due to a drought or a torrential downpour. Two freshwater fish such as *Rhynchocypris kumgangensis* and *Phoxinus phoxinus* were restricted to the uppermost mountain streams of the Han river or the Geum river, but the distribution of these species are expected to be reduced. The seven subtropical invertebrate species belonging to Animalia excluding Insecta and Chordata were selected as Korean CBIS. The distribution of these seven species such as *Certonardoa semiregularis*, *Dendronephthya gigantea*, and *Stenopus hispidus* are expected to be migrated to the north from their original habitat's southern limits such as Jeju-do or southern coastal areas. Twenty one taxa belonging to Insecta were chosen as bioindicators. Of these, 10 taxa were butterflies or moths, four taxa danselflies or dragonflies. Three beetles, two bees and two flies were also selected. Distributed mainly in Jeju-do or southern coastal areas, twelve taxa of insects such as *Argyresus hyperbius*, *Lampides boeticus*, *Choaspes benjaminii*, *Eurema hecabe*, *Papilio helenus*, *Ceriagrion nipponicum*, and *Camponotus kiusuensis* are expected their distribution to be expanded toward middle parts of the Korean peninsula. Southern boundary limits of four insects such as *Ischnurae legans, Sympetrum striolatum, Chrysolina virgata,* and *Volucella pellucens tabanoides* are expected to be shrinked due to their migration to north by climate warming. Forty four taxa belonging to plants were chosen as bioindicators. Of these, two taxa were monocotyledones, thirty taxa of dicotyledones, five gymnosperms, and seven taxa were ferns. All the seven taxa of ferns such as *Lemmaphyllum microphyllum*, *Dicranopteris linearis*, *Cyrtomium falcatum*, and *Cyclosorus acuminatus* vegetated to dry forests, rock surface, or cliffs of Jeju-do and/or southern parts of the Korean peninsula. The distribution of these evergreen ferns are expected to be expanded toward the north or inland areas. Due to restricted distribution or small populations, 15 species of vasular plants including *Abies koreana, Taxus cuspidata, Pinus pumila, Rhododendron brachycarpum, Pedicularis mandshurica, Maianthemum dilatum*, and *Anemone narcissifolia* will be more threatened. Temperate evergreen broad-leaved trees including *Elaeagnus macrophllya, Aucuba japonica*, and *Ardisia japonica* have substantially expanded their range of distribution into North. For example, the original northernmost distribution line for *Elaeagnus macrophllya,* Jeonbug Eocheong-do, moved upward to Beagryeong-do. This northern invasion of temperate evergreen species is recognized as an adaptive consequence ensuing from global warming in Korea (Lee et al., 2000). Five fungal taxa including S*arcodon aspratus, Flammulina velutipes,* and *Boletopsis leucomelaena* were selected while five algal taxa such as *Caulerpa okamurae, Odonthalia corymbifera, Dictyopteris undulata* were selected as CBIS (Table 2).

Conclusion

Biological indicators have been discussed in diverse fields ranging from ecological investigation on species richness to the detection of ecological changes related to climate change, human land-use (Noss, 1990; McGeoch, 1998). From the present study, two basic and ten general criteria were chosen to select climate-sensitive biological indicator species (CBIS). All the criteria proposed in the investigation might reflect responses of biological organisms against climate change, and were selected to be suitable for developing user-friendly protocols to monitor the CBIS. Applying

Table 2. Selection steps of climate-sensitive biological indicator species (CBIS). Out of 33,253 taxa reported scientifically in Korea, 100 CBIS were chosen applying selection criteria.

Taxa			No. of species	No. of species after each selection step			
				1st step	2nd step	3rd step	4th step
Animalia	Chordata	Mammalia	122	0	0	0	0
		Aves	496	70	29	10	14
		Amphibia/Reptilia	52	4	2	1	2
		Actinopterygii and etc.	1,129	4	4	1	2
		Urochodata	99	0	0	0	0
	Echinodermata		128	7	3	1	1
	Porifera/Cnidaria		584	51	4	2	2
	Chaetognatha/Platyhelminthe		163				
	Rotifera/Acanthocephala/Entoprocta		167	0	0	0	0
	Bryozoa/Brachiopoda/Sipuncula		179				
	Mollusca		1,560	17	2	1	1
	Annelida		435	23	0	0	0
	Tardigrada		61				
	Nematoda/Echiura/Kinorhyncha/Phoronida		316	0	0	0	0
	Gastrotricha/Nematomorph/Nemertea		12				
	Arthropoda	Arachnida/Acari/Scorpionida	1,310	2	2	0	0
		Insecta	12,982	252	79	23	21
		Chilopoda /Diplopoda/Pycnogonida	116	0	0	0	0
		Crustacea	1,257	21	7	3	3
	subtotal		21,168	451	132	42	46
Plantae	Angiosperms (Monocotyledones)		856	76	13	2	2
	Angiosperms (Dicotyledones)		2,247	327	101	35	30
	Gymnosperms		52	17	7	4	5
	Ferns/Liverworts, Mosses		975	92	12	7	7
	subtotal		4,130	512	133	48	44
Fungi	Fungi		1,580	15	10	4	5
	Lichens		498	0	0	0	0
	subtotal		2,078	15	10	4	5
Protista	Algae		3,816	25	15	6	5
	Other protista		842	0	0	0	0
	subtotal		4,658	25	15	6	5
Bacteria	Blue-green algae/Bacteria		1,219	0	0	0	0
Total			33,253	1,003	290	100	100

these criteria, we have chosen 100 climate-sensitive biological indicator species covering animals, vascular plants, algae, and fungi. Habitat boundaries of these indicators might be expanded, retreated to the North, or shrinked toward the top of mountains. In order to observe the behavior, micro-habitat, and physiology of the wild 100 CBIS, a monitoring system is required to be established. As Anderson (1999) has commented, a comprehensive survey or analysis at species level is not necessary to detect a biological response against climate change. In short, monitoring protocols of the CBIS should be developed for efficient management of biological organisms, not for academic satisfaction of researcher's desire.

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