The enterprising evaluation for the Korean National Long-Term Ecological Research (KNLTER) Project for six years (Review)

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Abstract

The Korean National Long-Term Ecological Research (KNLTER) project seeks to predict the effects on Korean ecosystems caused by stress derived from environmental changes from a national perspective. The objective of this article about the KNLTER program, continuously supported by the Ministry of Environment (MOE) since 2004, was to inspect the general plans and to evaluate the project for the KNLTER program objectively, and to make suggestions about the developmental direction of the project. As a result of evaluation on the research site, the numbers of research sites in 2010 correspond to 50% of those presented in the basic plan of the KNLTER project. As a result of evaluation on the research contents in the terrestrial ecosystem section of the KNLTER project, monitoring of climatic and atmospheric changes using eco-towers should be conducted over a long-term period. Additionally, the soil respiration part of the study needs to be expanded further in order to better understand soil systems. In the freshwater ecosystem section, we need to establish common standard investigation items, which can be used as indicators of the actual freshwater environment, considering that freshwater ecosystem management is closely related to human life. In the coastal ecosystem section, we should intensively analyze the correlation between the collected data accumulated thus far, as well as environmental changes including climate change, pollution, etc. For very sensible cases such as topographic changes due to rises in sea level, we should generate data applicable to prediction and confrontation for future changes through the continuous addition of variables and applications of a variety of simulation methods. In the animal ecology section, we should evaluate ecosystem changes based on animal phenology by selecting indicator animal species, which can be applied to each relevant ecosystem: namely, terrestrial, freshwater, and coastal ecosystems. As a result of synthetic evaluation conducted under the auspices of KNLTER, the stability of study areas is frequently implicated as the most common problem. If private lands are designated as study sites, it is very difficult to maintain them as study sites for a prolonged period. Therefore, it is necessary to designate national and public lands, such as national or provincial parks, as study sites. Efforts thus far conducted toward the construction of an appropriate database and modeling studies remain insufficient. After investigating the phenology of the specific species growing in all research sites, it is necessary to assess and report the overall changes in Korean ecosystems by applying that knowledge. The collection, analysis, and systematization of recent domestic and foreign research data related to natural ecosystem changes owing to environmental changes such as climate change and environmental pollution have been insufficient. Therefore, studies performed to obtain this information should be continuously pursued in the third stage.

Key words: climate change, ecosystem change, evaluation, KNLTER, Long-Term Ecological Research, Ministry of Environment

INTRODUCTION

Problems associated with the disturbance of natural ecosystems as the result of global warming are attracting great interest, and constitute an important question on an international scale (Kong 2005). The mean temperature of the earth has increased by approximately 0.6°C over the past century. The global atmospheric concentration of carbon have increased by approximately 30% from a pre-industrial value of about 280 ppm to about 370 ppm in 2000. Otherwise, the mean temperature of the earth in 2100 would have been expected to increase by approximately 1.4-5.8°C compared to 1990 (Solomon et al. 2007). Greenhouse gases have been implicated in this global warming, and global ecosystems change continually (Appenzeller et al. 2004).

Since the inception of this theory, changes in the steppe ecosystem of southern Tunisia from 1975 to 2000 (Hanafi and Jauffret 2008), changes in the insect appearance period or the insect population including moths in the United Kingdom (Kwon 2005), decreases in the nematode population (Simmons et al. 2009), and changes in bird and mammal communities (Stempniewicz et al. 2007) in arctic regions have all been reported as examples of this phenomenon.

Additionally, there have been many reports chronicling the effects of climate change on the ecosystem: endangered pygmy rabbits in North America (Larrucea and Brussard 2008), the effects of the circulatory system on the metastasis and survival power of the avian influenza virus (Gilbert et al. 2008), increases in the differences in phenological responses (Primack et al. 2009), changes in the ecological properties of sub-alpine coniferous forest (*Abies fabri*) in the Southwesten, China (Lu and Cheng 2009) are just a few examples.

Although we could assume that some ecosystem disturbances must have been caused by global warming in Korea, there is a dearth of scientific data to support this assumption.

Therefore, Ministry of Environment (MOE) prepared "the KNLTER basic plan" to monitor ecosystem changes induced by climate change and environmental pollution over a prolonged period, and launched a pilot project addressing the forest ecosystem (Mt. Jeombong), the freshwater ecosystem (Nakdong River and Junam Reservoir), the coastal ecosystem (Hampyeong Bay), and animal ecology (Magpie) (Ministry of Environment 2004a, 2004b). As the result of the pilot research project, MOE prepared a guidebook for Korean National Long-Term Ecological Research (KNLTER) research and launched the KNLTER project in 2004.

The objectives of the research project were to predict long-term changes in the Korean ecosystem induced by climate change and environmental pollution, and to prepare the plan for biodiversity conservation.

In other words, the aim of this study was to predict the effects on our Korean ecosystem of stress derived from environmental change from a national perspective. The core topics of the KNLTER project include the following: 1) to monitor ecosystem changes as the result of environmental changes, such as climate change and environmental pollution, 2) to clarify the correlation between changes in the environment changes and changes in the ecosystem, and 3) to study the ecosystem properties of the study areas.

The objectives of this article addressing the KNLTER, continuously supported by the Ministry of Environment since 2004, are to inspect the general plans and to objectively evaluate the program of the KNLTER project, and to make some suggestions about the developmental direction of the project.

STUDY AREAS

We assigned our study areas into three types of ecosystems: namely terrestrial, freshwater, and coastal ecosystems (Table 1). The terrestrial ecosystem is subdivided into forest, agricultural land, and island types. The forest has 12 study areas, which include six natural forest areas (two sites each from the northern, central, and southern parts of South Korea respectively), one site from the pine and deciduous forests which represent Korea, and one industrial and one urban forest, respectively, to observe the effects of pollutants. The study area of agricultural land was selected in one site each from the central and the southern areas of South Korea, respectively. The warm temperate regions of Jeju and Ulleung, both of which are highly unique, were selected as the island study areas. For the study of the freshwater ecosystem, we selected the Nakdong, Han, and Sumjin rivers, the Daecheong, Paldang, and Jeju lake, and the Upo, demilitarized zone (DMZ) and Jeju Island (Mulyeongari) wetlands as the river, lake, and wetland studies, respectively. Two areas of the western coast and one area of the eastern, southern, Jeju, and Ullung coasts, respectively, were selected as study areas for coastal ecosystems. For the animal ecology study, we selected several animal taxa, including birds,

mammals, insects, fishes, amphibians, and reptiles.

Our research fields

Terrestrial ecosystems

First, we construct a monitoring system for ecosystem changes due to climate change, environmental pollution, and habitat changes in four forests in Korea. Ecological

monitoring study was accomplished at three more points per site.

Second, we measured the changes due to climate change and environmental pollution. The concentrations of pollutants were measured at specific regular intervals in air, organisms, soils, and streams.

Third, we evaluated the changes in specific characteristics of the forest ecosystem. In other words, ecological

Table 1. Fields of research, the study sites and the detailed study area

Fields of Research	Study sites		Region	Detailed study area
Terrestrial ecosystem	Forest	Natural forest	Northern	Mt. Seorak National Park Mt.Jeombong*
			Central	Mt. Worak National Park* Mt. Manisan in Ganghwa Island
			Southern	Mt. Deokyu National Park Mt. Jiri National Park*
			Damaged area	Samcheok forest fires damaged area*
		Urban forest	Northern	Seoul Namsan Park*
			Middle	Daegu Mt. Palgong
		Industrial forest	Middle	Near industrial area in Ulsan
			Southern	Mt. Halla*
		Broadleaf forest	Northern	Gwangneung broad leaved deciduous forest
		Coniferous forest	Southern	Sogwangri Seomyun Uljin Kyungpook
	Agriculture		Middle	Suwon Rural Development Administration (RDA) crop cultivation test area
			Southern	Crop cultivation test area (Wanjoo agriculture)*
	Island		Middle	Ullung Island
			Southern	Mt. Hanra*
Freshwater ecosystem	River		Middle	Han River* (Geum River)
			Southern	Nakdong River*, Sumjin River (Yeongsan River)
	Lake		Middle	Deachung Lake*, Paldang Lake, Saemangeum*
			Southern	Lake of Jeju Island
	Wetland		Northern	Demilitarized Zone (DMZ) Wetland
			Southern	Upo wetland*, Wetland of Jeju Island (Mulyeongari)
Coastal ecosystem	East coast		Coast	East Sea (Goraebul sand dune)*
			Island	Ullung Coast
	West coast		Coast	Hampyeong Bay*
			Island	Ganghwa Island Coast
	South coast		Coast	South Coast (Suncheon Bay)*
			Island	Jeju Island Coast
Animal ecology	Birds*			Magpie, Sparrow, Turtle dove, Crow
	Mammals*			Wild boar, Roe deer, Korean water deer, Bats
	Insects*			*Aporia crataegi, Callipogon relictus, Metopodontus blanchardi*, Hemiptera spp.
	Fishes, Amphibians, Reptiles			*Lepomis macrochirus, Micropterus salmoide Trachemys scripta elegans, Rana catesbeiana*

*The current study areas (2010) (total 19 areas: eight terrestrial ecosystems, five freshwater ecosystems, three coastal ecosystems and three animal ecology. One of the animal fields is equally treated to the other study areas).

studies were conducted to measure changes in the forest ecosystem, including measurements of flowering and leafing time, nutrient cycling, the production and decomposition of organic matter, the mechanisms underlying forest successions, and the study of animal changes according to vegetative succession, etc.

Fourth, we attempted to clarify the relationship between environmental changes and biodiversity changes.

Freshwater ecosystems

First, we conducted research into changes in the freshwater ecosystem and monitoring system according to climate change, environmental pollution, and habitat changes in 2 river sites and in 1 wetland area. We conducted the ecological research at more than 3 study points per 1 study area.

Second, we measured the changes in climatic and environmental (water quality) conditions at regular intervals, along with measurements of the concentration of pollutants in water, organisms, and benthic lands.

Third, we studied the specific changes in the freshwater ecosystem, such as research into the flowering and leafing time periods of main freshwater plants, changes in population size among primary freshwater organisms, changes in production (measuring the productivity) and decomposition of organic matter, annual changes in limnologicalphenomena, changes in the population sizes of invasive species (can be limited to certain invasive species), the changeable characteristics of freshwater ecosystems, etc.

Fourth, we carried out research into the correlationships between environmental changes and freshwater ecosystems, including research into changes in biological diversity.

Coast ecosystems

First, we conducted research into changes in coast ecosystem and monitoring systems attributable to climate change, environmental pollution, and habitat changes. We conducted ecological research at more than 3 study points per study area.

Second, we measured the changes in climatic and environmental (water quality) conditions at regular intervals, with measurements of the concentrations of pollutants in water, organisms, and benthic lands located in coast ecosystems.

Third, we studied specific changes in coast ecosystems, including measurements of the flowering and leafing time periods of main coastal plants, changes in population size on main coastal organisms, changes in the

production (measuring the productivity) and decomposition of organic matter, annual changes in limnological phenomena, changes in the population sizes of invasive species (may be limited to certain invasive species), the changeable characteristics of coast ecosystems, etc.

Fourth, we carried out research into the correlationships between changes in the environment and in coast ecosystems, including biological diversity change research.

Animal ecology section

In the animal ecology section, we attempted to collect ecological data for animals based on the following content. First, in the bird study, we needed to analyze voice signals; for the bird and mammal studies, we analyzed feeding behavior and measured dispersion distance and the reproductive success rates. For the insect study, we evaluated community dynamics, the relationship between temperature change and insects' developmental time, and the number of larvae on the eating leaves of their host plants. Additionally, for the study of fishes, reptiles, and amphibians, we needed to analyze the selected habitats for their egg laying and feeding behavior, their natural enemies, and their competitive species. The investigative items in common included the setup for the devices used to measure natural environmental factors, the operations to test the equipment, the investigations and choice of animal populations, the development and standardization of the research method, and the completion of the animal ecology study protocols.

DIRECTIONS FOR RESEARCH PROJECT

To push ahead with this research project in the most effective direction, we need 1) to carry out research designed to characterize climate change-associated ecosystem changes in the context of our national lands; 2) to carry out a basic period of ecological research for 10 years but separated into 3 stages (3 years + 3 years + 4 years) with research results evaluated every year, reflecting the evaluation results in each phased evaluation; 3) to push ahead for 31 areas including forests, rivers, wetlands, islands, and coastal regions, but specifically to push ahead with 1 step in 8 areas (4 lands, 2 rivers, 1 wetland, 1 coast) and gradually expand study of each area; 4) to launch a research effort according to research guidebook compiled in accordance with a pilot research plan; 5) to accumulate the research results into a database system every year along with the establishment of a scientific

maintenance system and a KNLTER home page that provides measured data in each area of study for immediate GIS-DB integration, and to construct a system that can be readily accessed to everyone over the internet; 6) to organize the "KNLTER research body" for consistency and efficiency of research, under the responsibility of supervising research institutions; and 7) to build up management systems that can manage combination, land, coast/wetland, and animal research centers, ensuring consistent and coherent cooperative research.

EVALUATIONS ON KNLTER PROJECT

Evaluation on the research site

The basic plan for the KNLTER project was established in 2003 and the project was implemented in four terrestrial, three aquatic, and one coastal ecosystem in 2004. In 2005, burned areas in the terrestrial ecosystem and animal ecology components were added, thus expanding the number of study sites to 10. In 2006, the project progressed without any change in study sites. In 2007, the number of research sites was increased to 11 with the addition of the Saemangeum area to the aquatic ecosystem sector. In 2008, the study objects expanded to 17 with the addition of the Yeocheon industrial region as an industrial ecosystem, an island forest on Mt. Halla as a terrestrial ecosystem, Daecheong Lake as an aquatic ecosystem, and the Goraebul sand dunes as a coast ecosystem etc. In 2009, the same research objects as in 2008 were studied. In 2010, the Suncheon Bay was added to the coastal ecosystem sector, and the animal ecology component of the project was reconfigured into bird, mammal, and insect groups thereby, a total of 19 objects were selected for the KNLTER project (Table 1). Those research objects selected in 2010 corresponded to 50% of those (the 38 objects) shown in the basic plan of the KNLTER project.

Evaluation on the research contents

Terrestrial ecosystem section

Terrestrial ecosystem studies were conducted at eight sites: Mt. Nam, Mt Worak, Mt. Jeombong, Mt. Jiri, Mt Halla, the Samchuk burned area, the Yeocheon industrial complex area, and the Wanju agricultural area. The terrestrial ecosystem components constitute an important axis of the KNLTER studies, specifically regarding the responses of forest ecosystems as environmental indicators for climate change studies. In an effort to clarify the vari-

ous responses and changes of ecosystem components, the structures and functions of ecosystems and changes in ecological phenomena of specific populations must be studied over a prolong period within a given area. Therefore, vegetation dynamics, biogeochemical cycles, and the phenology and ecology of specific animal species are studied in the terrestrial ecosystem sector.

As KNLTER is a research project tasked with assessing changes in ecosystems due to climate change and environmental pollution over the long-term, the basic research contents should be controlled for consistency in all study sites through the application of standardized and unified methods. However, studies of vegetation dynamics, primary productivity, phenology, etc. related to plants will be conducted in all sites, whereas research focusing on animals such as insects, amphibians, reptiles, birds and mammals will be executed only at selected sites.

The site most sensitive to global warming due to climate change is expected to be the alpine regions. Therefore, the fluctuation of species, which occurs only in susceptible species and those whose habitats change, should also be assessed in relation to climate change. Monitoring for climatic and atmospheric environmental changes using eco-towers should be carried out over a long-term period. At present, eco-towers have been installed in only three areas such as Mts. Nam, Jeombong, and Jiri, and the data collected thus far is insufficient for any definitive conclusions. Additionally, the soil respiration component of the project will have to be expanded in order to gain insight into the soil systems, which stores vast quantities of CO_2. In regard to phenology studies, objectivity should be enhanced by prescribing standardized common items among researchers. Further, worn out, broken, damaged, and inaccurate, monitoring instruments installed in the field must be regularly inspected and improved in order to reduce measurement errors.

Freshwater ecosystem section

With societal development, dependence on freshwater resources increases inexorably, and thus the management of water systems, such as rivers and lakes, is increasingly crucial. However, we currently lack the fundamental scientific data necessary for effective freshwater ecosystem management. Thus, through the aforementioned long-term ecological monitoring protocols, the project seeks to construct a fundamental database for the prediction and solution for future environmental problems centering around freshwater ecosystems. Currently, the study areas in the freshwater ecosystem component of KNLTER

consist of the Nakdong River, the Han River, the Upo Wetlands, Saemangeum, and Daechung Lake, and we have studied the changes in freshwater ecosystems attributable to climate change and environmental pollution.

Measurements of water quality, fish surveys, etc. are conducted at all sites. Because certain ecological research items (biological phenology, avifauna, insect fauna, primary productivity, food-web, etc.) have been studied through varying protocols at the different study areas, we need to implement common investigation items for those areas.

The freshwater ecosystem management part of the project is, in the aggregate, progressing smoothly. When we consider the direct relationship between human life and freshwater ecosystems, the need for common standard investigation items becomes clear; only with such study protocols will pragmatic indicators of the actual freshwater environment be reliably discovered. In particular, ecosystem food-web research has been conducted only at the Nakdong River site, and the research items thus far implemented at Daechung Lake are somewhat scanty relative to the other study areas. We also see a need for comparative analyses among similar study areas using specific characteristics of other study sites.

Coastal ecosystem component

When we consider the unique characteristics of Korea, which is surrounded on three sides by sea, we can anticipate that coast ecosystem conservation will continue to be an issue for the country. The coast ecosystems are also the areas expected to be most seriously affected by changes in topography caused by rises in the sea level and the effects of global warming.

Thus, the coastal ecosystems, as the ecotone areas between terrestrial ecosystems and marine ecosystems, require continuous monitoring with regard to environmental changes including water quality, water temperature, topographical changes, etc.

Currently, we have accomplished long-term ecological research at three areas: Hampyeong Bay, the Goraebul sand dunes, and Suncheon Bay. Although the climate and environmental factor assessments and plant studies were conducted in all three areas, the birds, fishes, and sea algae inhabiting each site differ to some degree, and have been studied through different designs. Therefore, it is important to derive some common investigation items for the three sites.

We have intensively analyzed the correlations between the collected data accumulated until now, and have also done some research into environmental changes such as climate change and pollution in these areas. It is clearly important that simulation research also be done through the introduction of continuous variables and other various methods to assess the most sensitive issues, such as topographical changes caused by sea level rise; via these efforts, we should be able to generate applicable and relevant data for predictions and possible mitigation of future changes.

Animal ecology component

Climate change and pollution may alter the physiology and ecology of animals. Thus, in an effort to characterize environmental change, we can monitor the ecology of specific animal species that can be applied as indicator species over the long-term. Long-term research into animal ecology in Korea has involved the study of actual condition of wild animals since 1967, the study of birds' migratory behaviors and habitats since 1993, and a census of birds taken at the same time each winter since 1999. A nationwide study of the natural environment that began in 1997 has involved a survey of the animal fauna inhabiting local areas in Korea. However, the KNLTER is the only ecological study assessing ecological changes in specific animals over a long-term period in Korea.

Currently, this project is in the process of accomplishing a study of ecological changes in selected animals (bird: magpie, mammals: elk, bat, insects: *Paromius exiguus*, *Scotinophara lurida*). Although standard and common investigation items have not been established for each animal species, the interpretation of survey results from the rise of annual mean temperature and the environmental pollutions can clearly be enhanced by our information regarding animal species. This project undertook, first, a selection of indicator animal species according to each ecosystem type (terrestrial ecosystem, freshwater ecosystem, and coast ecosystem); the next step in this process entails a study of ecosystem change in terms of animal phenology. The animal ecology component is expected to prove very important in identifying the relevant negative impacts, such as climate change, environmental pollution, and disturbances caused by human interference; unfortunately, these studies have yet to yield relevant analysis results.

Common issues in the KNLTER fields and the overall evaluation

The problem common to all KNLTER study areas involves stability: in short, it is very difficult to continuously sustain these areas as research areas. Possible KNL-

TER study areas that are inhabited by humans may prove unstable for long-term ecological research. Therefore, whenever possible, public lands, such as national parks, provincial parks, national forests, etc., should be selected as long-term ecological research areas.

When sites inhabited by people must be selected as KNLTER areas, clear agreements should be made between the land owners and the KNLTER investigators in order to ensure the viability of long-term research.

Thus far, a variety of papers derived from this project have been published, results from the project have been presented at various conferences, and many KNLTER workshops have been successfully convened; the database construction and modeling study components of the project remain insufficient, however. Thus, the next third step (2010-2013) in the KNLTER program select appropriate insurance policies and to select the proper consumable goods for the researchers' safety, and to carefully assess the KNLTER researchers' needs regarding vehicles and equipment when estimating the research expenses for the next few years.

After the biological phenological studies are carried out by selecting the most relevant animal species at all research sites, it will be necessary to interpret the data with an eye toward elucidating overall ecosystem changes in Korea. The third step for the KNLTER project may require the most ambition and focus, because the collections, analyses, and arrangements of the latest international and national research data in relation to changes of natural ecosystems caused by climate changes and environmental pollutions have thus far proven insufficient.

Recommendation for evolution

The ultimate goal of the LTER is to conserve biodiversity in Korea by monitoring the interrelationships among plants, animals, and the abiotic environment in terms of its constituent ecosystems, as well as alterations in these ecosystems attributable to environmental changes including climate change on the basis of long-term ecosystem observational studies. Most studies on ecosystem change thus far conducted in Korea have generally been concerned with environmental pollution and studies on the effects of factors which do not significantly impact the natural environment. However, in recent years, these types of studies have become increasingly popular (Ministry of Environment 2002). The biggest differences between KNLTER and these other environment-related studies consist in the research period and the concentrations of topics. In the case of KNLTER, the research pro-

gresses for at least 10 years at a given site and involves several to dozens of field surveys, including seasonal surveys, per year. This is important because our objectives can probably be achieved only through long-term study--10 years or more. Taking this long time requirement into consideration, the KNLTER Project is generally driven by the establishment of a center for ecological research in each region even in developed countries; this is not only because of the difficulty inherent not only to the actual carrying out of long-term and intensive field surveys, but also because of the difficulty in retaining governmental support on a continuous basis.

KNLTER also needs to establish and operate centers for basic ecological research on the bases of existing research sites throughout the entire country in the future, taking into account the environmental quality of national territory, the regional distribution of researchers, and the ecological characteristics specific to each local area. The system by which the national basic ecological research effort should be structured includes four research centers--for terrestrial ecosystems, fresh water and coastal ecosystems, animal population and specific species, and data management, as well as a system to manage the integration of those four centers' research. By implementing such a structure, we can ensure the viability of the basic ecological data and derive an application plan by establishing systems for monitoring changes in the natural environment, evaluating changes in the natural ecosystem, and furthermore, preparing a plan to ameliorate negative influences on the ecosystem.

LITERATURE CITED

Appenzeller T, Dimick DR, Essick P. 2004. The heat is on: introduction. Natl Geogr Mag 206: 2-11.

Gilbert M, Slingenbergh J, Xiao X. 2008. Climate change and avian influenza. Rev Sci Tech 27: 459-466.

Hanafi A, Jauffret S. 2008. Are long-term vegetation dynamics useful in monitoring and assessing desertification processes in the arid steppe, southern Tunisia. J Arid Environ 72: 557-572.

Kong WS. 2005. Selection of vulnerable indicator plants by global warming. Asia-Pacific J Atmos Sci 41: 263-273.

Kwon OS. 2005. Climatic change and its impact on insects. Clim Change Newsl 3: 4-97.

Larrucea ES, Brussard PF. 2008. Shift in location of pygmy rabbit (*Brachylagus idahoensis*) habitat in response to changing environments. J Arid Environ 72: 1636-1643.

Lu XY, Cheng GW. 2009. Climate change effects on soil car-

bon dynamics and greenhouse gas emissions in *Abies fabri* forest of subalpine, southwest China. Soil Biol Biochem 41: 1015-1021.

Ministry of Environment. 2002. Research on the Corresponding Strategies of the UNFCCC (United Nations Framework Convention on Climate Change). Ministry of Environment, Gwacheon.

Ministry of Environment. 2004a. A Study for Preparation of Basic Plan for the National Basic Ecological Research. Ministry of Environment, Gwacheon. (in Korean)

Ministry of Environment. 2004b. Report of Korean National Long-term Ecological Research with Standard Protocols. A Long-term Plan for Ecosystem Change Researches in Korea. Ministry of Environment, Gwacheon. (in Korean)

Primack RB, Ibanez I, Higuchi H, Lee SD, Miller-Rushing AJ, Wilson AM, Silander JA Jr. 2009. Spatial and interspecific variability in phenological responses to warming temperatures. Biol Conserv 142: 2569-2577.

Simmons BL, Wall DH, Adams BJ, Ayres E, Barrett JE, Virginia RA. 2009. Long-term experimental warming reduces soil nematode populations in the McMurdo Dry Valleys, Antarctica. Soil Biol Biochem 41: 2052-2060.

Solomon S, Quin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

Stempniewicz L, Blachowlak-Samolyk K, Weslawski JM. 2007. Impact of climate change on zooplankton communities, seabird populations and arctic terrestrial ecosystem: a scenario. Deep-Sea Res Part II 54: 2934-2945.