Special Feature
J. Ecol. Field Biol. 34(1): 87-93, 2011

JEFB Journal of Ecology and Field Biology

Vegetation change and emerging research feedback for Korean National Long Term Ecological Research (KNLTER)

Yong Chan Cho[1], Chang Seok Lee[2,6,*], Hyun Je Cho[3], Kyu Song Lee[4] and Pil Sun Park[5]

[1]Division of Forest Biodiversity, Korea National Arboretum, Pocheon 487-821, Korea
[2]Faculty of Environment and Life Sciences, Seoul Women's University, Seoul 139-774, Korea
[3]Korea Green Promotion Agency, Daejeon 302-831, Korea
[4]Department of Biology, Gangneung-Wongju National University, Gangneung 210-702, Korea
[5]Department of Forest Sciences, Seoul National University, Seoul 151-742, Korea
[6]Present address: Planning Office of National Ecological Institute, Ministry of Environment, Korea

Abstract

Various responses of forest ecosystems to climate change underscore the need to improve our understanding of the environmentally-driven changes in forests, most effectively by long-term monitoring protocols. We have explored vegetation dynamics based on changes in community structure, species composition, diversity and demographics in four Korean National Long Term Ecological Research (KNLTER) sites--Mt. Nam, Mt. Jeombong, Mt. Worak, and Mt. Jiri--between 2004 and 2009. Most of the sites and forests studied exhibited increments in total basal area, but this was not observed in *Quercus mongolica* forests in Mt. Nam and Mt. Worak. Stem density exhibited various changes. Altitude gradient was the representative factor in differences in species composition. Two patterns of compositional change--convergence and divergence--were detected. The vegetation of Mt. Nam and *Q. mongolica* community of Mt. Work showed relatively larger changes in composition. However, in the other sites, few changes were observed. Changes of species richness were not notable except for Mt. Nam, where three species were added in the pine forest, whereas one species disappeared in the oak forest. In the oak forests, mortality rate was as follows (in descending order): Mt. Nam (25.5%), Mt. Jeombong (24.3%), Mt. Worak (16.4%) and Mt. Jiri (0.8%). In the pine forest, the recruitment rate was as follows (in descending order): Mt. Nam (63.7%), Mt. Worak (12.9%), Mt. Jeombong (7.6%) and Mt. Jiri (7.3%). The mortality rate and change rate of basal area were strongly negatively correlated (r = -0.9, P = 0.002), and the recruitment rate and change rate of density were positively correlated (r = 0.77, P = 0.026). In the KNLTER sites, larger vegetation changes were attributed to anthropogenic activities such as salvage logging. Suppression or competition for resources would also affect these changes. Research suggestions such as monitoring to clarify the causes of species mortality were discussed.

Key words: Korea, LTER, mortality, *Pinus densiflora*, *Quercus mongolica*, recruitment, vegetation

INTRODUCTION

As gradual phenomena progressed in large spatial scale, the spans of research into climate and its changes can include the climatology, geography, and evolutionary biology. Ongoing climate change is regarded as a driving factor for ecosystem changes in the 21st century (Intergovernmental Panel on Climate Change 2001). Effects on the dynamics of biotic communities have been frequently associated with extreme weather events on

Open Access DOI: 10.5141/JEFB.2011.011

pISSN: 1975-020X eISSN: 2093-4521

Received 20 December 2010, Accepted 04 January 2011

*Corresponding Author
E-mail: leecs@swu.ac.kr
Tel: +82-2-509-7942

ecological time scales (Easterling et al. 2000), and with climatic extremes at evolutionary time scales (Gutschick and VassiriRad 2003). Since the middle of the 20th century, average global forest net primary production has apparently increased, largely because of various combinations of increasing temperature, precipitation, cloudless days, atmospheric CO_2, and nutrient deposition (Boisvenue and Running 2006). Regional exceptions also exist, because compensatory increases of precipitation have not been homogeneous (Jump et al. 2006). Such observations underscore the necessity for long-term monitoring programs to improve our understanding of environmentally-driven changes in ecosystems.

Forest (or community) development, maturity, and monograph are complex processes which occur in spans of decades to hundreds of years. Even ecologists have yet to clarify the precise processes and patterns relevant to the establishment and development of forests. In temperate regions, the vegetation responses to gradual climate change and extreme weather events have been observed in mature and old growth forests (e.g., van Mantgem and Stephenson 2007, van Mantgem et al. 2009). In young forests, during the maturational process, the majority of changes in structure, composition, and demographics are attributed not so profoundly to exogenous processes such as climate change and pathogen, but rather largely to endogenous processes such as competition and disturbance exclusion (e.g., fire).

In Korea, forest land, as emerging landscape, is in a developmental stage after severe disturbances, the Korean War, heavy utilization, and fire; thus, most Korean forest land is less than 60 years old. Therefore, long-term ecological research involving the installation of permanent plots and meteorological stations can be employed not only to evaluate climate-related responses, but also to clarify the processes and patterns inherent to community development. Based on such long term observations and acquired information, sustainable and adaptive natural resource management can be achieved.

We analyzed changes in community structure (breast height area and stem density), composition, diversity (richness), and demographics (mortality and recruitment rates) in four Korea National Long Term Ecological Research (KNLTER) sites: Mt. Nam (Mt. N), Mt. Jeombong (Mt. Je), Mt. Worak (Mt. W), and Mt. Jiri (Mt. Ji). Herein, we have focused on the changes in vegetation attributes, because meteorological sensors are not installed at all LTER sites. We concluded by discussing emerging research challenges (feedbacks) for KNLTER.

MATERIALS AND METHODS

Four KNLTER sites-Mt. N, Mt. Je, Mt. W, and Mt. Ji-were analyzed in this study. The geographical location and physical environments of each site are shown in Table 1. Four mountains and three forest types (*Quercus mongolica*, *Pinus densiflora*, and regional representative forests such as *Abies koreana, A. holoplylla, Q. variabilis,* and *Robinia pseudoacacia* forests in Mt. Ji, Mt. Je, Mt. W and Mt. N, respectively) were selected for monitoring purposes. In 2004, we installed three permanent plots of 400 m^2 (20 × 20 m) for each vegetation type; thus, total 36 plots were established. Vegetation sampling was conducted based on KNLTER field protocols (unpublished). All woody species with diameters in excess of 2.5

Table 1. Geographical locations and physical descriptions of KNLTER sites

	Mt. Nam		Mt. Jeombong		Mt. Worak		Mt. Jiri	
Parameter	Oak forest	Pine forest	Oak forest	Pine forest	Oak forest	Pine forest	Oak forest	Pine forest
Geographic location	N 37°33'00"	N 37°32'46"	N 38°02'10"	N 38°04'12"	N 36°51'30"	N 36°51'28"	N 35°17'49"	N 35°16'27"
	E 126°59'34"	E 126°59'42"	E 128°26'11"	E 128°23'01"	E 128°12'13"	E 128°04'49"	E 127°33'18"	E 127°29'17"
Altitude (m)	200	230	1,066	611	820	260	1,350	390
Angle of slope (°)	18-23	15-20	14-38	8-9	23-30	25-27	5-11	6-11
Azimuth	NE	SW	SN	W	SW	S	N	W
Topograph	Middle slope -ridge	Middle slope-ridge	Low slope-ridge	Low slope	Mddle slope	Upper slope -ridge	Middle- high slope	Upper slope-ridge
Ratio of rock (%)	5<	5<	4	0	30	25	40	60

KNLTER, Korean National Long Term Ecological Research; N, north; E, east; S, south; W, west.

cm appearing in the plots were tagged (by aluminum label) with numbers, and diameters for breast height were measured. Plots installed in 2004 were re-measured in 2009. We showed only the results of common forests (*Q. mongolica* and *P. densiflora* communities) in this paper because of the efficiency in generalization of results.

We analyzed the changes in community structure (basal area and stem density), species composition (by detrended correspondence analysis [DCA]), richness, and mortality and recruitment rates. For ordination analysis, the matrix of importance values for each species was established by the sum of relative basal area (BA) and density, and fed to the DCA ordination using PC-ORD ver. 4.0 (McCune and Mefford 1999). Mortality rate (for 5 years) was calculated by dividing the number of dead trees for 5 years by the number of living trees in the previous measurement. The recruitment rates (for 5 years) were obtained by determining the ratio of the number of trees added at the current measurement to the number of living trees in the previous measurement. Notably, our results were not expressed on an annual basis demograph. Finally, we conducted regression analyses between mortality and recruitment rate and between the rate of change in basal area and stem density. SPSS ver. 15.0 (SPSS Inc., Chicago, IL, USA) was applied for analyses.

RESULTS

Changes of basal area and stem density

Most of the sites and forests studied exhibited increments in total BA, but *Q. mongolica* in Mt. N (from 23.2 m^2/ha to 23.2 m^2/ha) and Mt. W (from 34.2 m^2/ha to 34.6 m^2/ha) evidenced only minimal changes (Table 2). The largest growth in BA was in the oak (11.7%) and pine (10.4%) forests of Mt. Ji.

Changes in stem density showed severe variation (Table 2). Abrupt changes in density occurred in the pine forest of Mt. N, evidencing the largest increase (33.3% as from 848 stems/ha to 1,270 stems/ha), and the oak forest exhibited the largest decrease (-31.8% as from 1,237 stems/ha to 938 stems/ha). Increases of density were in the pine (9.6%) forest of Mt. W and in the oak (4.9%) and pine (7.3%) forests of Mt. Ji. Stem density was reduced in the oak (-17.6%) stand of Mt. W and in the oak (-23.2%) and pine (-1.3%) forests of Mt. Je.

Table 2. Comparison of breast height area (DBA) and stem density between 2004 and 2009 in KNLTER sites

		DBA (m^2/ha)		Density (No. of stems/ha)	
Site	Forest	2004	2009	2004	2009
Mt. Nam	*Quercus mongolica*	23.2	23.2	1,237	938
	Pinus densiflora	30.4	32.3	847	1,270
Mt. Jeombong	*Q. mongolica*	37.6	38.2	2,140	1,737
	P. densiflora	37.5	41.2	1,888	1,864
Mt. Worak	*Q. mongolica*	34.2	34.6	1,162	988
	P. densiflora	24.3	26.0	1,096	1,212
Mt. Jiri	*Q. mongolica*	24.1	27.4	1,945	2,045
	P. densiflora	39.0	43.5	820	885

KNLTER, Korean National Long Term Ecological Research.

Changes in species composition

Compositional change in woody vegetation in the KNLTER sites was analyzed by applying DCA ordination method (Fig. 1). Altitude gradient was the representative factor for the differences in species composition, as sites in higher areas occupy the left side and those in lower areas were distributed on the right side, forest types (deciduous broadleaved and evergreen coniferous forests) also affected the results; the oak stands were clearly divided from the pines in the left and right sides, respectively.

Two patterns of compositional change--vegetation convergence and divergence--were noted (Fig. 1). Most of

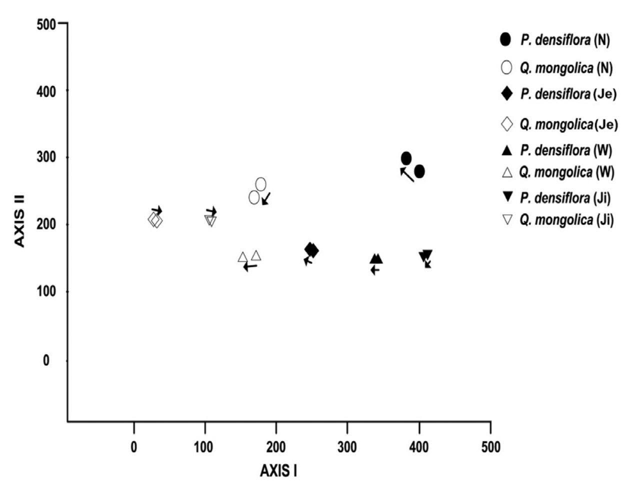

Fig. 1. The change in the vegetation composition of each forest type in KNLTER sites assessed via DCA ordination. The beginning of the arrows in diagram indicate the 2004 data. KNLTER, Korean National Long Term Ecological Research; DCA, detrended correspondence analysis; N, Mt. Nam; Ju, Mt. Jeombong; W, Mt. Worak; Ji, Mt. Jiri; *P. densiflora*, *Pinus densiflora*; *Q. mongolica*, *Quercus mongolica*.

the samples of oak and pine forests moved to the central part of the AXIS Ⅰ. The change in *P. densiflora* stands in Mt. N revealed a different direction from those observed at other sites. The vegetation of the Mt. N and *Q. mongolica* stands in Mt. W showed larger changes in species composition, as indicated by the arrow length in Fig. 1.

Change of diversity

The changes in woody species richness for 5 years between 2004 and 2009 are shown in Table 3. In the *P. densiflora* forests of Mt. N and Mt. Ji, three and one species (e.g., *Q. mongolica* and *Acer* spp.) were added, respectively and one species disappeared in the *Q. mongolica* stands of Mt. N and Mt. W. Other KNLTER sites revealed no changes in species richness.

Mortality and recruitment rate

We calculated 5-year mortality and recruitment rates at the KNLTER sites (Table 4). With the exception of Mt. Ji, the *Q. mongolica* stands exhibited higher mortality rates than were observed in the *P. densiflora* stands, and the opposite was true for recruitment rate. In oak forests, mortalities were as follows (in descending order): Mt. N (25.5%), Mt. Je (24.3%), Mt. W (16.4%) and Mt. Ji (0.8%). In the pine forest, recruitment rates were as follows (in descending order): Mt. N (63.7%), Mt. W (12.9%), Mt. Je (7.6%), and Mt. Ji (7.3%).

Overall correlation analyses between community demographs and rates of change in DBA and stem density were shown in Fig. 2. Mortality rate and rate of DBA change were strongly negatively correlated (r = -0.9, P = 0.002), and the recruitment rate and change rate of density were positively correlated (r = 0.77, P = 0.026).

Table 3. The change of mean species richness of plots in KNLTER sites

Site	Forest	Richness 2004	Richness 2009
Mt. Nam	*Quercus mongolica*	7	6
	Pinus densiflora	5	8
Mt. Jeombong	*Q. mongolica*	10	10
	P. densiflora	12	12
Mt. Worak	*Q. mongolica*	10	9
	P. densiflora	9	9
Mt. Jiri	*Q. mongolica*	9	9
	P. densiflora	9	10

KNLTER, Korean National Long Term Ecological Research.

Table 4. Comparison of community mortality and recruitment rate on a 5-year basis

Site	Forest	Mortality (%)	Recruitment rate (%)
Mt. Nam	*Quercus mongolica*	25.5	1.3
	Pinus densiflora	13.7	63.7
Mt. Jeombong	*Q. mongolica*	24.3	5.7
	P. densiflora	8.8	7.6
Mt. Worak	*Q. mongolica*	16.4	4.4
	P. densiflora	2.3	12.9
Mt. Jiri	*Q. mongolica*	0.8	5.6
	P. densiflora	3.7	7.3

DISCUSSION

Climate change, which includes gradual pattern and extreme events, can affect the attributes (dynamics, composition, structure, productivity, diversity, etc.) of the biological community in various and complex ways. Ecosystem responses to climate change, which are the target of the KNLTER program, can be interpreted only by long-term observations with comprehensively and precisely designed systems. We presented only the results of the first re-measurement (5-year interval) on woody vegetation. Thus, our focus in discussion is on short-term findings and research feedbacks rather than the vegetation responses to climate change and regional weather.

Vegetation changes in KNLTER sites

Variations in structural changes were detected in this study, and such variations can be interpreted as the results of forest developmental processes and environmental differences among sites and vegetation types. *Q. mongolica* stands in Mt. W and both forest types in the Mt. Ji site exhibited positive changes in both BA and stem density. Such patterns can be interpreted as reflective of differences in the environmental conditions of those sites, as well as forest developmental stages (Franklin et al. 2002). In general, active stem exclusion can be observed in the stages of canopy formation and understory development. As dead woody species were small diameter classes (data not shown), sites that revealed density increments are likely in their later stages. Various levels of forest seral stages were reported; however, in Korea, an insufficient number of studies have been conducted to determine forest succession in relation to natural and

DOI: 10.5141/JEFB.2011.011

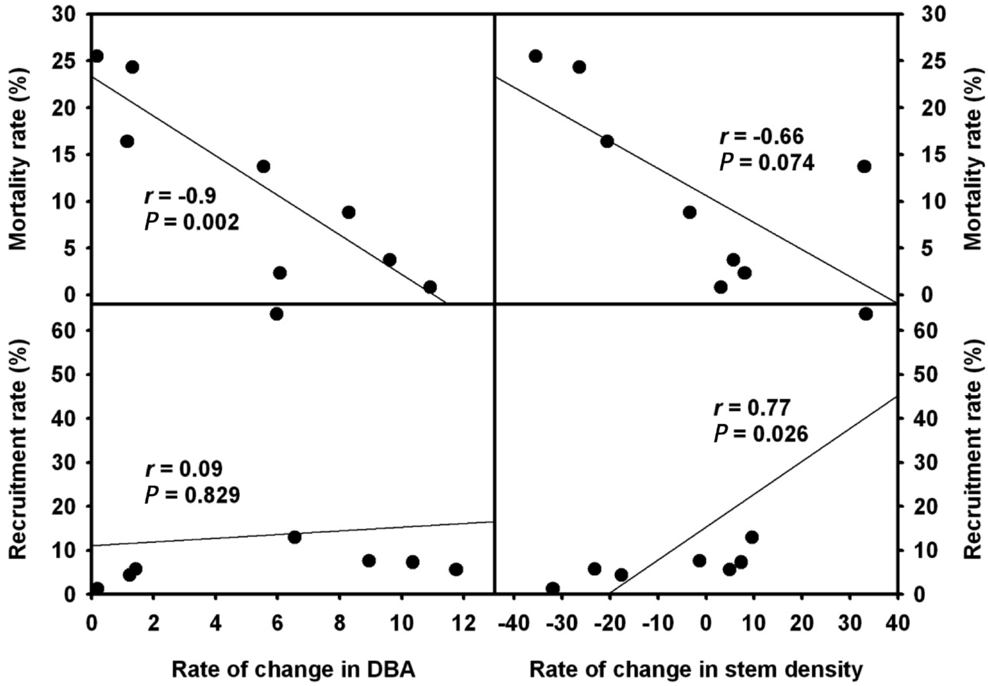

Fig. 2. Relationship between mortality and recruitment rate and change rates of basal area and density.

artificial disturbances (but see Lim et al. 2004). This also means a lack of background (or baseline) levels of variation in the structural attributes required to explain our results. Additionally, annual variations in BA and stem density depending on site condition may be involved in our results. In the *Q. mongolica* forest of Mt. N, salvage logging on damaged individuals by oak wilt disease had detectable effects on structural change.

Compositional convergence and divergence were illustrated in our ordination analysis. According to the results of DCA ordination, the direction of compositional changes in all the *P. densiflora* stands was toward the *Q. mongolica* sites (Fig. 1). All pine forests in the KNLTER sites have little number of its own seedlings. The increase in importance of deciduous broadleaved tree species, such as *Quercus*, *Styrax*, and *Fraxinus* spp. is likely responsible for this result. In Korea, the succession of the Korean red pine stand to broadleaved stands (oak forest) is commonly accepted but no empirical studies or evidence were not available so far. Through the KNLTER project, the seral trajectory of *P. densiflora* forest established in various environmental conditions can be clarified. In addition, species with strong habitat affinity (forest type) are also to be identified. Some differences in the compositional changes of pine forests in Mt. N are due to a large increment of *Styrax japonicus* and *Prunus serrulata* var. *pubescens* in the understory (Lee et al. 2006). These increases may be attributed to forest thinning and subsequent regeneration. Such forest operation also affects the magnitude of vegetation change, as was shown by the arrow length in Fig. 1 and the recruitment rate (63.7%) (Table 4).

Q. mongolica sites revealed different directions of movement depending on site (Fig. 1). Differences with regard to changes in the importance value of *Q. mongolica* are likely attributable to this pattern, as the values were reduced in Mt. Ji (from 41.2 to 39.9) and Mt. Je (from 27.7 to 27.6) and increased in the Mt. N (from 35.8 to 38.1) and Mt. W (from 39.5 to 42.0) sites. Changes in the importance values of other species were stochastic in nature. Relatively large vegetational changes (see arrow in Fig. 1) occur as the result of vigorous understory growth, such as was seen with *Lindera obtusiloba* in oak forests in the Mt. W site. Savage logging in oak forests in Mt. N induced strong effects on compositional changes.

Mortality and recruitment rate at the community level are not available in the inland regions of Korea. In our results, negative correlations were detected between mortality and rates of BA and stem density changes (Fig. 2). The absence of reference demographic data at the community level makes us difficult to understand and interpret. The one year-based mortality rate of a *P. parviflora* forest located on Ulleung Island was 2.1%/y (Lim et al. 2004) and our 5-year results were higher in the oak forests (except for Mt. Ji) and lower in the *P. densiflora* forests (except for Mt. N) than mortality overall on Ulleung Island. The mortality of old growth was usually approximately 1% (Forrester and Runkle 2000). Community demographics and their consequences may vary depending on the landscape context, geographic location, forest age, spatial scale, and cause of death and supplement. Mortality and recruitment increases in regard to climate change were also noted in other regions (van Mantgem and Stephenson 2007, van Mantgem et al. 2009). Although community demographics, such as mortality, are often overlooked and rarely studied in Korea, they play pivotal roles in forest succession and development, as they facilitate turnover in species composition (Shugart et al. 1981, Runkle 2000) and affect changes in structure (Christensen and Peet 1981, Franklin and Hemstrom 1981, Hibbs 1983), and alter nutrient cycling and biomass accumulation rates (Marks and Bormann 1972, Marks 1974, Peet 1981, Bormann et al. 1995). KNLTER is in initial stage, and more data will need to be accumulated to interpret vegetation changes in response to exogenous processes, including climate change and weather events.

Feedback for comprehensive and effective vegetation monitoring

In our research design, four dead classes (standing, broken, leaning and fallen dead) are established for individual trees. These classes are just mortality patterns and thereby cannot be used to determine causes of death, such as competition (endogenous process) or natural disturbances (exogenous process). Causes of death of tree species vary among species with different life histories or canopy architectures (Acker et al. 1996, 2003, Canham et al. 2001), and, can change in importance, especially during succession (Bible 2001, Canham et al. 2001).Thus, according to the established protocols of this study, parameters for cause of death such as suppression, pathogens, and insect-induced death and physical processes (strong wind, landslide and snow loading) should be added and quantified.

KNLTER is currently constructing background variations in the forest ecosystem. Such research activities will constitute a fundamental tool for the interpretation and modeling of ecosystem responses to climate change; in this regard, dividing of responses to succession and climate change is particularly relevant. A static monitoring period of at least 10 years is recommended for the accumulation of ground data, because even in old growth sites, approximately 5-10 years are required for the accumulation of base data (e.g., Forrester and Runkle 2000). Without data regarding background dynamics, the effects of gradual increases in weather events (e.g., effect of Typhoon Kompasu on metropolitan area), such as heavy rainfall and drought on ecosystems, cannot be explained.

LITERATURE CITED

Acker SA, Gregory SV, Lienkaemper G, McKee WA, Swanson FJ, Miller SD. 2003. Composition, complexity, and tree mortality in riparian forests in the central western Cascades of Oregon. For Ecol Manag 173: 293-308.

Acker SA, Harmon ME, Spies TA, McKee WA. 1996. Spatial patterns of tree mortality in an old-growth *Abies–Pseudotsuga* stand. Northwest Sci 70: 132-138.

Bible KJ. 2001. Long-term patterns of Douglas-fir and western hemlock mortality in the western Cascade Mountains of Washington and Oregon. PhD Dissertation. University of Washington, Seattle, WA, USA.

Boisvenue C, Running SW. 2006. Impacts of climate change on natural forest productivity: evidence since the middle of the 20th century. Global Change Biol 12: 862-882.

Bormann BT, Spaltenstein H, McClellan MH, Ugolini FC, Cromack K Jr, Nay SM. 1995. Rapid soil development after windthrow disturbance in pristine forests. J Ecol 83: 747-757.

Canham CD, Papaik MJ, Latty EF. 2001. Interspecific variation in susceptibility to windthrow as a function of tree size and storm severity of northern temperate tree species. Can J For Res 31: 1-10.

Christensen NL, Peet RK. 1981. Secondary forest succession on the North Carolina Piedmont. In: Forest Succession: Concepts and Application (West DC, Shugart HH, Botkin DB, eds). Springer-Verlag, New York, NY, pp 230-245.

Easterling DR, Meehl GA, Parmesan C, Changnon SA, Karl TR, Mearns LO. 2000. Climate extremes: Observations, modeling, and impacts. Science 289: 2068-2074.

Forrester JA, Runkle JR. 2000. Mortality and replacement patterns of an old-growth *Acer-Fagus* woods in the holden arboretum, northeastern Ohio. Am Midl Nat 144: 227-242.

Franklin JF, Hemstrom MA. 1981. Aspects of succession in the coniferous forests of the Pacific Northwest. In: Forest Succession: Concepts and Application (West DC, Shugart HH, Botkin DB, eds). Springer-Verlag, New York, NY, pp 212-229.

Franklin JF, Spies TA, Van Pelt R, Carey AB, Thornburgh DA, Berg DR, Lindenmayer DB, Harmon ME, Keeton WS, Shaw DC, Bible K, Chen JQ. 2002. Disturbances and

structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. For Ecol Manag 155: 399-423.
Gutschick VP, VassiriRad H. 2003. Extreme events as shaping physiology, ecology, and evolution of plants: toward a unified definition and evaluation of their consequences. New Phytol 160: 21-42.
Hibbs DE. 1983. Forty years of forest succession in central New England. Ecology 64: 1394-1401.
Intergovernmental Panel on Climate Change. 2001. Climate Ahange 1999: the Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergervonmental Panel on Climate Change. Cambridge University Press, Cambridge.
Jump AS, Hunt JM, Peñuelas J. 2006. Rapid climate change-related growth decline at the southern range edge of *Fagus sylvatica.* Global Change Biol 12: 2163-2174.
Lee CS, Cho YC, Shin HC, Lee CH, Lee SM, Seol ES, Oh WS, Park SA. 2006. Ecological characteristics of Korean red pine (*Pinus densiflora* S. et Z.) forest on Mt. Nam as a Long Term Ecological Research (LTER) site. J Ecol Field Biol 29: 593-602.
Lim JH, Jin GZ, Yun CW, Shin JH, Bae SW. 2004. Stand structure and dynamics of the *Pinus parviflora* forest in Ulleungdo Island. J Korean For Soc 93: 67-74.
Marks PL. 1974. The role of pin cherry (*Prunus pensylvanica* L.) in maintenance of stability in northern hardwood ecosystems. Ecol Monogr 44: 73-88.
Marks PL, Bormann FH. 1972. Revegetation following forest cutting: mechanisms for return to steady state nutrient cycling. Science 176: 914-915.
McCune B, Mefford MJ. 1999. PC-ORD. Version 4.0. Multivariate Analysis of Ecological Data. MjM Software Design, Gleneden Beach, OR.
Peet RK. 1981. Changes in biomass and production during secondary forest succession. In: Forest Succession: Concepts and Application (West DC, Shugart HH, Botkin DB, eds). Springer-Verlag, New York, NY, pp 324-338.
Runkle JR. 2000. Canopy tree turnover in old-growth mesic forests of eastern North America. Ecology 81: 554-567.
Shugart HH, West DC, Emanuel WR. 1981. Patterns and dynamics of forests: an application of simulation models. In: Forest Succession: Concepts and Application (West DC, Shugart HH, Botkin DB, eds). Springer-Verlag, New York, NY, pp 74-94.
van Mantgem PJ, Stephenson NL. 2007. Apparent climatically induced increase of tree mortality rates in a temperate forest. Ecol Lett 10: 909-916.
van Mantgem PJ, Stephenson NL, Byrne JC, Daniels LD, Franklin JF, Fulé PZ, Harmon ME, Larson AJ, Smith JM, Taylor AH, Veblen TT. 2009. Widespread increase of tree mortality rates in the western United States. Science 323: 521-524.