Changes in bird life, surface fauna and ground vegetation following afforestation by black cottonwood (*Populus trichocarpa* Torr. & Gray)

Jón Ágúst Jónsson[1]
Bjarni D. Sigurðsson[1,2]
and
Guðmundur Halldórsson[1]

[1] *Icelandic Forest Research, Mógilsá, IS-116 Reykjavik, Iceland*
E-mail: jonj@skogur.is
E-mail: gudmundur@skogur.is

[2] *Agricultural University of Iceland, IS-311 Borgarnes, Iceland*
E-mail: bjarni@lbhi.is (corresponding author)

ABSTRACT
Black cottonwood (*Populus trichocarpa*) is a much planted tree species in Iceland, especially for establishing recreational areas and urban forests. Quantitative information about its effects on biodiversity is therefore of great interest. Afforestation of a former pasture in southern Iceland greatly affected species composition and density of birds and beetles. As the tree layer started to develop during the first 13 years following afforestation, new bird and beetle species quickly became dominant and other formerly common species abandoned the area. Less change was evident in the composition of ground vegetation than in bird and beetle populations. Species diversity (biodiversity) of ground vegetation and beetles increased significantly as the forest matured. The changes indicated that, although some species abandoned the afforested area, the forest offered more diverse habitats to accommodate new species.

Keywords: afforestation, biodiversity, Iceland, beetles, *Populus trichocarpa*

YFIRLIT
Áhrif asparræktar á fuglalíf, smádýralíf og gróðurfar
Alaskaösp (*Populus trichocarpa*) er mikilvæg trjátegund í borgar- og útivistarskógrækt á Íslandi. Tölulegar upplýsingar um áhrif gróðursetningar asparskóga á lífríkið eru því mikilvægar öllum þeim sem slíka skógrækt stunda. Niðurstöður þessarar vöktunar sýndu að skógrækt með alaskaösp hafði fljótt áhrif á tegundasamsetningu og þéttleika bjallna og fugla, en áhrifin á gróðurfarið voru lengur að koma í ljós. Þéttleiki bjallna og fugla jókst til muna í kjölfar skógræktar. Þá urðu þær tegundir dýra sem best voru aðlagaðar þessu nýja búsvæði ríkjandi, en aðrar færðu sig um set. Breytingar á tegundasamsetningu botngróðurs voru hægari og virtist skuggþol plantna ráða mestu um hvaða tegundir urðu ríkjandi. Tegundafjölbreytni bjallna og botngróðurs jókst er skógurinn þroskaðist. Það bendir til þess að þrátt fyrir að sumar tegundir yfirgefi skógarbotninn í kjölfar skógræktar aukist fjölbreytni búsvæða á skógarbotni þegar skógurinn vex upp, sem nýjar tegundir nýta sér.

INTRODUCTION

Forest and woodland in Iceland cover around 1.4% of the total surface area (Snorrason & Kjartansson 2004) and the official policy is to increase forest cover to ca. 3% of the total area by 2040 (Government Offices of Iceland 1999). Black cottonwood (*Populus trichocarpa* Torr. & Gray) is an exotic tree species in Iceland. It is the fifth most planted tree species, around 8% of the annual planting (Gunnarsson 2004). It has mainly been used to establish recreational areas and urban forests. Even though black cottonwood is one of the fastest growing tree species in Iceland (Snorrason & Einarsson 2002), planting aiming at wood production just started in recent years (Sigurgeirsson & Ásgeirsson 1998). Studies in other countries have shown that surface fauna and flora are highly affected by environmental changes brought about by afforestation (e.g. Ings & Hartley 2000, Peterken 2001). In Iceland, research on the effects of poplar plantations on birds and surface fauna has been scarce, although short-term effects on ground vegetation, beetles and spiders have been documented (Sigurdsson et al. 1998, Sigurjónsson 1998).

This paper reports species composition of ground vegetation, vegetation cover and biodiversity of plants in a 13-year-old poplar plantation established in 1990. Results are compared to those obtained in 1993 at the same site using the same methodology. The gap fraction of black cottonwood overstorey in 2003 was measured and compared to values recorded in 1993, 1996 and 2001. Surface fauna samples were gathered in 2003 and ground beetles (Carabidae) identified as to species. Ground beetles have been found to be good indicators of environmental changes as they show clear associations with environmental parameters such as soil type and vegetative cover (Gardner 1991). Their terrestrial habits also make sampling relatively easy by use of pitfall traps (Luff 1975). The ground-beetle sampling results were compared to those obtained in 1993 by the same method over the same time period. Finally, to estimate the effects of afforestation on species composition and breeding density of birds, nests were counted and identified in the plantation and in a similar non-afforested area.

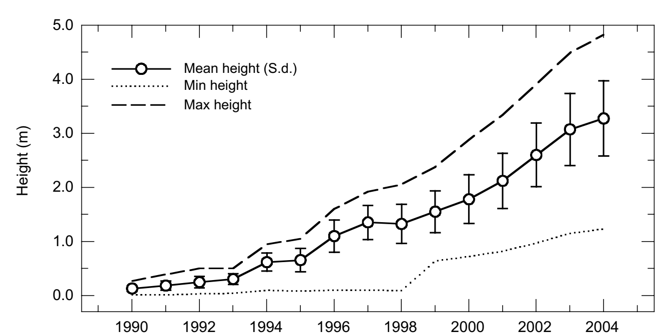

Figure 1. Height increment in the black cottonwood plantation since establishment in 1990.

MATERIALS AND METHODS

Experimental site

The experimental site is located in Gunnarsholt in southern Iceland (63° 51´ N and 20° 13´ W, elevation 78 m). In 1990 cuttings of a single clone of black cottonwood were planted in an abandoned hayfield from which the sod had been removed in 1989. A total of 145,000 propagated cuttings were planted in 14.5 ha with 1 m spacing (stand density of 10,000 trees ha^{-1}). The stand development was slow in the beginning and the saplings only reached a height of 30 cm in 1993 (Figure 1). After the saplings had overgrown the competing vegetation and the most active frost layer in 1997, the average annual height increment has been 33 cm. The average tree height in 2003 was 3.1 m (Figure 1). More information about the climate, soil and other physical conditions at the site can be found in Strachan et al. (1998) and Sigurdsson (2001).

Plant colonisation and vegetation cover

In August 2003, measurements of species composition and vegetation cover were repeated by the method used in 1993 (Sigurdsson et al. 1998). Measurements were carried out at the same locations in eight 10x10 m plots that were randomly established in 1993. All vascular plant species found within each plot were recorded. Vegetation cover was determined by recording all hits by 100 pins within a 50x50 cm frame that was randomly laid out on 10 different locations within each plot (point quadrant frame method; Greig-Smith 1983). In some instances it was impossible to place the frame in exactly the same spot as in 1993 because the trees had grown taller and thicker. In such cases the frame was put as close to the original location as possible. Since the recently established black cottonwood saplings were included in the cover estimates in 1993, all the original data from Sigurdsson et al. (1998) were recalculated, excluding the tree saplings. This made the data comparable between 1993 and 2003.

To estimate the changes in the biodiversity of the ground vegetation between 1993 and 2003 the Shannon-Wiener diversity index (H) was used (Fowler et al. 1998):

$$H = -\sum p_i \ln p_i \qquad (1)$$

where p_i is the proportion of a particular species in a sample which is multiplied by the natural logarithm of itself. Such an estimate was generated for each of the eight plots, both in 1993 and 2003. A t-test was then used to test whether the average biodiversity was significantly changed between the two years ($P<0.10$; Sokal & Rohlf 1995).

Measurements of gap fraction

Gap fraction of the black cottonwood overstorey was measured by an LI-2000 Plant Canopy Analyzer (LI-COR, Inc. Lincoln, Nebraska). This instrument measures the above- and below-canopy diffuse sky radiation at five zenith angles simultaneously (Welles & Norman 1991).

Surface fauna

Surface fauna was sampled in 1993 with Barber traps adjacent to four of the permanent vegetation plots (Sigurjónsson 1998). This sampling was repeated in 2003 during exactly the same time period and with the same catching method. Each trap consisted of a pair of 200 ml plastic cups with a 38.5 cm^2 opening, placed within one another to minimize trap disturbance during servicing (Luff 1975). The top of the outer cup was level with the soil surface. Flooding and vertebrate predation were minimized by placing a plastic lid, 20 cm in diameter, ca 2 cm above each trap. The lids were supported with two 18-cm long nails which were pushed through the lids and fitted into the ground. About 50 ml of water was poured into each cup and a drop of detergent added to reduce surface tension. Two traps were placed at opposite edges of each of the four vegetation plots. The traps were inserted into the ground on 10 June and emptied weekly until 18 August. After emptying, the samples were put in an isopropyl solution. Beetles in the samples were identified as to species under a stereoscope, except for those of the genera *Oxypoda* and *Atheta*, which could not be distinguished. Changes in biodiversity of beetles between 1993 and 2003 were estimated by Equation 1 and statistically tested in the same way as was done for ground vegetation.

Breeding density of birds

Bird nests were counted in late May and the beginning of June 2003. The experimental site was divided into eight plots. Within each plot, a 30x350 m section was randomly chosen for bird nest counting. A researcher walked 10 lines in each section at three meter intervals and recorded all bird nests that were discovered. To estimate the effect of afforestation on breeding density of birds the same procedure was carried out in a similar treeless area located two km west of the experimental site. The comparison site was also an abandoned hayfield, but which had not been afforested. It had also been protected from sheep grazing for a number of years and its vegetation had changed from grassland to more dwarf bush and willow dominated vegetation. Because zeros occurred in some observations, the Kruskal-Wallis test was used to compare the nesting density at the two sites.

RESULTS

Plant colonisation and vegetation cover

In 1993, three years after planting, less than 1% of the surface was bare ground, 3% was covered by forbs, 39% by grass, 36% by moss and 22% by litter (Table 1). Ten years later (2003) bare ground cover was still under 1% of nants (Sigurdsson et al. 1998) that was a common surface type in 1993, with 11 hits per frame, was not present in 2003 (Table 1). Two new surface types (habitats) were recorded in 2003, dead wood with 0.3 hits per frame and leaf litter with 26 hits per frame (Table 1).

The grass *Agrostis capillaris* L. was by far the most common species in both years, with 60 hits per frame in 1993 and 52 hits per frame in 2003 (Table 1). During the same period the cover of two other grass species, *Festuca*

Table 1. Vegetation cover estimation for 6-12 August 1993 (Sigurdsson et al. 1998) and 22-29 August 2003 by point quadrant frame method. Cover values indicate mean number of hits per frame from 80 frames on 8 plots, where each frame has 100 pins. x = the species was recorded in a plot but not in a frame.

Species	Mean		Species	Mean	
	1993	2003		1993	2003
Lichens	1	1	*Agrostis vinealis*	0.1	
Mosses	61	69	*Festuca richardsonii*	2	0.0
Mushroms		0.1	*Festuca vivipara*	0.1	8
Cerastium fontanum	1	0.1	*Poa pratensis*	4	20
Polygonum aviculare	x		*Deschampsia caespitosa*		x
Leontodon autumnalis	1	3	*Alopecurus geniculatus*	0.1	
Taraxacum sp.	0.0	0.1	*Equisetum arvense*	x	0.1
Rumex acetocella	3		*Luzula multiflora*	0.2	1
Achillea millefolium	x	0.0	*Luzula spicata*	x	
Spergula arvensis	0.0		*Matricaria maritima*	x	
Chamomilla suaveolens	0.0		*Salix callicarpaea*	x	
Alchemilla alpina	x		*Salix phylicifolia*	x	0.1
Alchemilla vulgaris	x	x	*Salix lanata*	x	x
Epilobium sp.	x		*Populus trichocarpa*	0.2	0.0
Coeloglossum viride		x	Dead wood		0.3
Platanthera hyperborea		x	Bare ground	0.3	0.1
Empetrum nigrum		x	Leaf litter		26
Carum carvi		0.0	Crust	11	
Agrostis capillaris	60	52	Ground vegetation litter	26	20

total surface cover, 2% of the surface was covered by forbs, 40% by grass, 34% by moss and 23% by litter.

The total number of plant species recorded within the point quadrat frames was 14 and 13 in 1993 and 2003, respectively (Table 1). Other plant species recorded within the permanent plots were 11 in 1993 (Sigurdsson et al. 1998) and 6 in 2003. Crust, defined as a thin organic layer formed by mosses, lichens and litter rem-

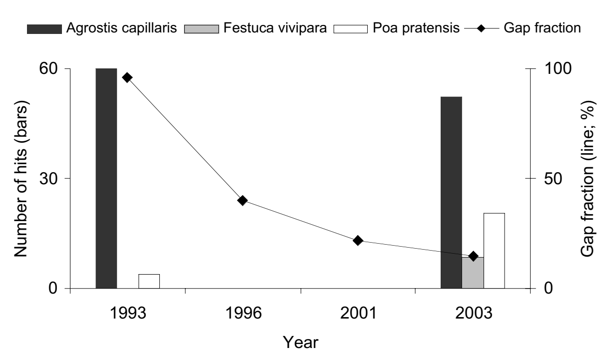

Figure 2. Changes in the relative amount of three key grass species between 1993 and 2003 in the field layer of the experimental forest in Gunnarsholt (number of hits by 100 pin frame) compared to the decrease in gap fraction of the tree canopy.

vivipara (L.) and *Poa pratensis* L., increased from 0.1 to 8 hits per frame and from 4 to 20 hits per frame between 1993 and 2003, respectively (Figure 2).

The mean value of the Shannon-Wiener index for ground vegetation cover changed from 1.38 to 1.63 between 1993 and 2003, respectively (Figure 3). This was a significant increase in vascular plant biodiversity (P=0.001).

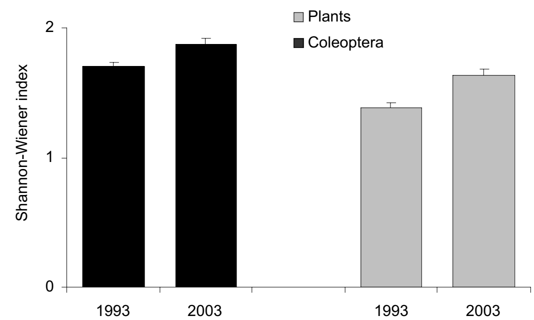

Figure 3. Shannon-Wiener diversity index for plants and coleoptera (beetles) in the black cottonwood plantation in 1993 (Sigurdsson et al. 1998, Sigurjónsson 1998) and 2003.

Gap fraction measurements

The gap fraction was ca. 96% in 1993 (Figure 2), when the tree saplings were only a little higher than the ground vegetation (Sigurdsson et al. 1998). In 1996, 2001 and 2003 the gap fraction decreased to 40%, 22% and 15%, respectively, as the tree layer was established (Figure 2).

Surface fauna

The total number of beetles caught in eight traps was 203 and 1230 in 1993 and 2003, respectively (Table 2). Beetles caught in 1993 included 12 species in addition to the genera of *Oxypoda* and *Atheta*. Beetles caught in 2003 also included some unidentified species of the genera *Oxypoda* and *Atheta* and 17 other verified species.

Considerable changes were noted in the species composition of beetles between 1993 and 2003. Besides *Oxypoda* and *Atheta*, only six species were caught both years (Table 2). Those species were *Acidota crenata* (Fabricius), *Calathus melanocephalus* (L.), *Hypolithus riparius fabricius, Notiophilus biguttatus* (Fabricius), *Parocyusa rubicunda* (Erichson) and *Quedius boops* (Gravenhorst). Furthermore, a large shift was noted in the relative abundance of the species within the total catch. The most noticeable shift was the increase of *P. rubicunda*, which increased from 1% to 25% of the total catch between 1993 and 2003 (Table 2). Out of the three species that made up 66% of the total catch in 1993 (*Amara quenseli* (Scönherr), *Bembidion bipunctatum* (L.) and *Nebria gyllenhali* (Schönherr)), none was caught in 2003.

Table 2. Total number of caught Coleoptera in eight Barber traps for the periods of 10 June to 19 August 1993 (Sigurjónsson 1998) and 10 June to 18 August 2003.

Species	1993	2003	Species	1993	2003
Acidota crenata	1	1	*Otiorhynchus nodosus*		9
Amara quenseli	49		Oxypoda	12	173
Atheta	12	31	*Parocyusa rubicunda*	2	307
Bembidion bipunctatum	65		*Patrobus septentrionis*		151
Bembidion grapei		1	*Pterostichus adstrictus*		10
Byrrhus fasciatus		2	*Quedius boops*	1	1
Calathus melanocephalus	34	9	*Quedius fulvicollis*		340
Gabrius trossulus		23	*Quedius umbrinus*		2
Hydroporus nigrita	1		*Stenus canaliculatus*		1
Hypolithus riparius	1	1	*Stenus carbonarius*	1	
Lathrobium fulvipenne		50	*Tachinus corticinus*		117
Nebria gyllenhali	20		*Trichocellus cognatus*	2	
Notiophilus biguttatus	2	1	Total of caught coleoptera	203	1230

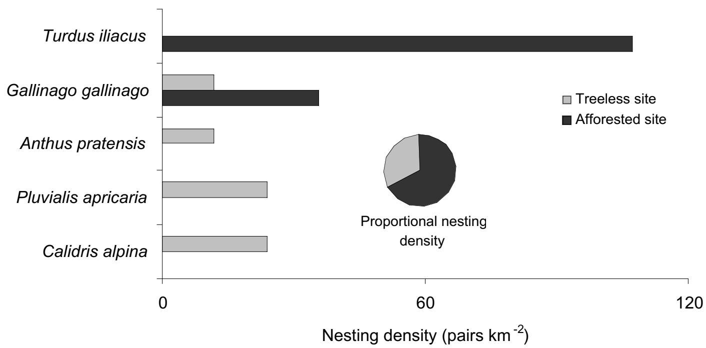

Figure 4. Bird species composition and density as pairs km^{-2} (bars) and proportional nesting density in the afforested site and a nearby treeless site (pie).

The mean value of the Shannon Wiener index for beetles increased from 1.71 to 1.87 between 1993 and 2003 (Figure 3). A t-test showed a significant increase (P=0.08) in beetle biodiversity between 1993 and 2003.

Breeding density of birds

Bird nesting density was twice as much in the black cottonwood plantation compared to the treeless site (Figure 4). Average nesting density was 143 nests km^{-2} and 71 nests km^{-2} in the plantation and the treeless site, respectively. A Kruskal-Wallis test confirmed that the higher breeding density in the forest site was statistically significant (P=0.04). A considerable difference was also found in species composition between the two sites. Redwing (*Turdus iliacus* L.) was the most common bird species in the black cottonwood plantation, but it was not present at the comparison site (Figure 4). The common snipe (*Gallinago gallinago* (L.)) was also three times more common in the plantation than at the comparison site. However, three bird species that laid eggs at the treeless site were not found in the plantation (Figure 4). These were meadow pipit (*Anthus pratensis* (L.)), golden plover (*Pluvialis apricaria* (L.)) and dunlin (*Calidris alpina* (L.)).

DISCUSSION

Plant colonisation and vegetation cover

In 2003 the dominant trees in the forest were approaching a height of 5 m (Figure 1) and its canopy was becoming dense, with only a 15% gap fraction. This can be compared to a 0.3 m height and ca. 96% gap fraction in 1993 (Figure 1 and 2). In spite of these radical changes in shading, relatively small changes occurred in vegetation cover, but some shifts were observed in ground vegetation composition (Table 1). In total, 30 plant species and groups were found in 1993 (Sigurdsson et al. 1998) compared to 26 on the same plots in 2003, of which 17 were found both years (Table 1). The changes in species composition of the ground vegetation that occurred in the plantation after 1993 led to a significant increase in biodiversity, quantified by the Shannon-Wiener index (Figure 3). Although total vegetation cover had not changed much, there were some interesting shifts in the key grass species (Figure 2). The most interesting change was that the dominant *A. capillaris* was to some extent replaced by other grass species, namely *P. pratensis* and *F. vivipara*. This may indicate that the heath species, *A. capillaris*, was loosing in competition to other species better adapted to changes in environmental conditions at the site, such as the decreased light availability shown in Figure 2. An alternative explanation could be that an increase in available nutrients was benefiting the *P. pratensis* more than the two other grass species. *P. pratensis* has been found to have a strong positive response after introduction of nitrogen-fixing Nootka lupin (*Lupinus nootkatensis* Sims) into treeless areas in Iceland (Magnússon et al. 2003).

Surface fauna

Substantial changes were noted in the beetle community between 1993 and 2003 (Table 2).

The number of caught beetles increased more than sixfold. The increased density was probably caused by the increased productivity of the forest. Takeda (1987) has shown that habitat biomass is the key determinant of the number of collembola present. As a result of increased productivity, more organic litter becomes available for decomposers, such as bacteria and fungi, which provide food for soil fauna, such as mites and collembola (Takeda 1987). A similar increase in soil fauna following an increase in habitat biomass was observed by Oddsdóttir (2002). Soil fauna is an important food source for beetles and many other ground-living species.

Beetle species composition also changed. Only 5 taxonomic groups were found in both years and the most common species in 2003, *Quedius fulvicollis* (Stephens), was totally missing in 1993 (Table 2). The species composition in 2003 was more similar to the species composition of birch stands at Gunnarsholt than it was to the species composition of the former hayfield in 1993 (Halldórsson, unpublished data). Such a rapid change in surface fauna communities following a change in vegetation cover and composition has been described by various authors (e.g. Oddsdóttir 2002). This change had already started in 1993, since Sigurjónsson (1998) then found very significant differences in beetle species composition between the black cottonwood plantation and an adjacent hayfield.

Beetle biodiversity, measured by the Shannon-Wiener index, showed a significant increase over the period (Figure 3). This is in accordance with the gradient hypothesis for biological communities (Whittaker 1970) which predicts that ecosystem gradients will vary in the abundance of successive trophic levels. Various other studies have also shown that an increase in plant diversity can cause an increase in arthropod herbivore diversity (e.g. Altieri 1984, Niemela et al. 1996, Siemann 1998).

Bird nest counting

Mean breeding density at the experimental site (143 nests km^{-2}) was twice that of the treeless comparison site (71 nests km^{-2}; Figure 4). These results are in good agreement with recent results from heathlands, planted larch forests and naturally regenerated birch forests in eastern Iceland (Nielsen 2003). There, breeding density was found to increase with afforestation and was found to be up to four times greater in forests than in treeless heathlands.

In the present study changes were also noted in species composition between the two habitats (Figure 4). Redwing was the most common species in the plantation forest but was not found in the treeless pasture. Common snipe was three times more common in the forest than outside. Common snipe is not listed as a woodland bird in neighbouring countries, but for some reason is one of the most common woodland birds in Iceland (Nielsen 2003, Gunnarsson et al. 2006). Three bird species, golden plover, dunlin and meadow pipit, were found breeding at the treeless comparison site but not in the plantation. In 1994 to 1996, when the trees were small and the forest was still very open, dunlin along with meadow pipit were the most common nesting birds in the plantation (Sigurdsson, unpublished records). The fact that dunlin abandoned the forest as it got denser was in accordance with results from birch woodlands and Siberian larch forests in eastern Iceland (Nielsen 2003). However, meadow pipit was one of the three most common bird species in the birch woodland and in the Siberian larch plantations (Nielsen 2003), but for some reason seems to avoid the black cottonwood plantation.

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REFERENCES

Altieri MA 1984. Patterns of insect diversity in monocultures and polycultures of Brussels sprouts. *Protection Ecol.* 6, 227-232.

Fowler J, Cohen L & Jarvis P 1998. *Practical statistics for field biology.* John Wiley & Sons, New York, 259 p.

Gardner SM 1991. Ground beetle (Coleoptera: Carabidae) communities on upland heath and their association with heathland flora. *J. Biogeog.* 18, 281-289.

Government Offices of Iceland 1999. Lög um landshlutabundin skógræktarverkefni (Laws on Regional Afforestation Programs). (In Icelandic).

Greig-Smith P 1983. Quantitative Plant Ecology. University of California Press, Berkeley, 359 p.

Gunnarsson E 2004. Skógræktarárið 2003. [The forest work in 2003]. Skógræktarritið 2004 (2), 118-122. (In Icelandic, English summary).

Gunnarsson TG, Gilla JA, Appleton GF, Gíslason H, Gardarsson AR, Watkinson A & Sutherland WJ 2006. Large-scale habitat associations of birds in lowland Iceland: Implications for conservation. *Biol. Conserv.* 128, 265-275.

Ings TC & Hartley SE 2000. The effect of habitat structure on carabid communities during the regeneration of a native Scottish forest. *For. Ecol. Managem.* 119, 123-136.

Luff ML 1975. Some features influencing the efficiency of pitfall traps. *Oecologia* 19, 345-357.

Magnússon B, Magnússon SH & Sigurðsson BD 2003. Áhrif alaskalúpínu á gróðurfar. [Effects of Nootka lupin on vegetation]. Náttúrufræðingurinn 71, 98-111 (In Icelandic, English summary).

Nielsen ÓK 2003. *SKÓGVIST: Mófuglar og skógarfuglar á Héraði 2002 [SKÓGVIST: Grassland and forest birds in Hérað in 2002].* Icelandic Institute of Natural History, Reykjavík. (In Icelandic, English summary).

Niemela J, Haila Y & Puntilla P 1996. The importance of small-scale heterogeneity in boreal forests: Variation in diversity in forest-floor invertebrates across the succession gradient. *Ecography* 19, 352-368.

Oddsdóttir ES 2002. *Áhrif skógræktar og landgræðslu á jarðvegslíf. [Effects of afforestation and land reclamation on soil fauna].* M.Sc. thesis, University of Iceland, Dept. of Biology, 50 p. (In Icelandic, English summary).

Peterken, GF 2001. Ecological effects of introduced tree species in Britain. *For. Ecol. Managem.* 141, 31-42.

Siemann E 1998. Experimental tests of effects of plant productivity and diversity on grassland arthropod diversity. *Ecol.* 79, 2057-2070.

Sigurdsson BD, Aradóttir ÁL & Strachan IB 1998. Cover and canopy development of a newly established poplar plantation in south Iceland. *Icel. Agric. Sci.* 12, 15-26.

Sigurdsson BD 2001. Environmental control of carbon uptake and growth in *Populus trichocarpa* plantation in Iceland. PhD. thesis. *Acta Universitatis Agriculturae Sueciae. Silvestria* 174, 64 p.

Sigurgeirsson A & Ásgeirsson S 1998. Aðferðir við ræktun alaskaaspar (Populus trichocarpa Torr. & Gray). I. Áhrif þakningaraðferða og plöntugerðar á lífslíkur og vöxt á jökuláraurum og framræstu mýrlendi. [Poplar cultivating methods I]. *Skógræktarritið* 1998, 50-65. (In Icelandic, English summary).

Sigurjónsson B 1998. The effects of afforestation of the species composition of spiders (Araneae) and beetles (Coleoptera). B.Sc. thesis. University of Iceland, Dept. of Biology, Reykjavík, 25 p. (In Icelandic).

Snorrason A & Einarsson SF 2002. Landsúttekt á skógræktarskilyrðum. Áfangaskýrsla 1997-2001 fyrir Suðurland og Suðvesturland. [Site indices for Iceland]. Rit Mógilsár 14, 68 p. (In Icelandic, English summary).

Snorrason A & Kjartansson BÞ 2004. Íslensk skógarúttekt. [The Icelandic National Forest Inventory]. *Skógræktarritið 2004* (2), 101-110. (In Icelandic, English summary).

Sokal RR & Rohlf FJ 1995. *Biometry*. 3rd ed. W. H. Freeman and Company, San Francisco. 887 p.

Strachan IB, Sigurdsson BD & McCaughey JH 1998. Soil hydrology at the Gunnarsholt experimental plantation: Measurement and results. *Icel. Agric. Sci.*12, 39-46.

Takeda H 1987. Dynamics and maintenance of collembolan community structure in a forest soil ecosystem. *Res. Popul. Ecol.* 29, 291-346.

Welles JM & Norman JM 1991. An instrument for indirect measurement of canopy architecture. *Agron. J.* 83, 818-825.

Whittaker RH 1970. *Communities and ecosystems*. MacMillan, New York. 162 p.

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