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Distribution of Damaged Oaks and Annual Oak Biomass Removal by Oak Nut Weevil (*Mechoris ursulus*) in Korea

You, Young-Han[1]*, Young Jin Chun[2], Hee-Sun Lee[3], Chang-Seok Lee[1] and Joon-Ho Kim[2]

[1]*Faculty of Environment and Life Science, Seoul Women's University, Seoul 139-774, Korea*
[2]*School of Biological Sciences, Seoul National University, Seoul 151-742, Korea*
[3]*Department of Science Education, Seowon University, Cheonju 362-742, Korea*

ABSTRACT : Herbivory is an important selective forces on plants by reducing the ability of the plant to compete with its neighbors and to produce offspring. Oak nut weevil (*Mechoris ursulus* Roelofs) females lay eggs in unmatured acorns and cut off the branch of oviposited acorns. To investigate the influences of branch-cutting behavior of oak nut weevils on oak production, we surveyed the horizontal and vertical distribution ranges of damaged oaks and depth of sites of overwintering larvae and quantified the amounts of biomass and acorn removed by the weevils on deciduous oak species. All of the endemic oak species in Korea were damaged by oak nut weevils in all of the study sites including Mt. Halla and Mt. Seorak. The upper limit of vertical distribution of damaged oaks by the weevils raried from 700 m to 900 m. Mostly their larvae were found in soil from 8.1 cm to 10.0 cm depth in winter. Percentage of annual net primary productivity (720 g $\cdot m^{-2} \cdot yr^{-1}$) of oak species removed by the weevils was about 7%, which is higher than the percentage removed by all the herbivores in typical temperate forest (5%) and equivalent to that by all the herbivores in tropical forest. The predation percentage of annual acorn production by oak nut weevil was 27% in *Q. mongolica* and 33% in *Q. acutissima*. This results indicate that the branch-cutting behavior of oak nut weevil may be the most important factor regulating oak population and affecting other predators dependent on acorns.

***Key words*:** Acorn removal, Distribution limit, Herbivory, Net primary productivity, Oak nut weevil, *Quercus*.

INTRODUCTION

Insects and plants have inhabited the earth together and they exhibit every kind of relationship from mutualism to antagonistic interaction (Bernays 1992). Among them, herbivory is an important selective forces on plants (Ehrlich and Raven 1967). Also, plant-animal interaction is an important issue among many interactions in natural ecosystem (Janzen 1970, 1980).

Oaks are a kind of endemic and dominant tree species of forest communities in Korea. The biomass production of oaks takes up about 27% of the total tree biomass production in Korea (Forestry Research Institute 1989). Moreover, their distribution range will be wider with time because some oaks such as *Q. mongolica* are late successional species (You *et al.* 1995).

There are many herbivores feeding on oak leaves and acorns (Feeny 1970). Among them, oak nut weevil (*Mechoris ursulus* Roelofs) outbroke in the mid 1980's in Korea and is a major herbivore of oak species nowadays (Choi *et al.* 1993). From the literatures on taxonomy, oak nut weevils (*Mechoris ursulus* Roelofs) are classified to tribe Rhynchitini - subfamily Rhynchitinae - family Attelabidae - superfamily Curculionoidea - order Coleoptera (Sawada 1993). There are 13 species of tribe Rhynchitini in Korea, but oak nut weevils are the only species that has unique behaviors of ovipositing in acorns and cutting branches with oviposited acorns. They are distributed in Korea and Japan (Sawada 1993) and in Korea, they were first reported in 1935 (Bae 1993).

Their females lay eggs in unmatured acorns and cut off the branch of oviposited acorns from late summer to late fall (You and Kim 1994). After a female of *M. ursulus* nicks the branch that she determines to cut off, she drills the acorns on the branch through cupule and pericarp using her proboscis making a hole that reaches the inner cotyledon (Fujii 1993). After she lays one or two eggs per hole, she buries the hole with chips of cupule. Finally, she cuts off the branch with an oviposited acorn to let the branch with unmatured acorns and leaves fall to forest floor. After hatching, the larvae grow in the acorn and escapes into soil in autumn. They overwinter at the states of larvae in self-made caves by next spring and continue their life cycle.

Oak nut weevils profoundly alter vegetative growth, sexual reproduction, regeneration, and nutrient circulation of oak communities and thereby affect the vegetation structure. In aldition, they

* Author for correspondence; Phone: 82-2-970-5822, Fax: 82-2-970-5822, e-mail: you84327@hosanna.net

influence competition between seed predators. However, there is few quantitative research on the vegetative growth and sexual reproduction of oaks affected by their activity (Fujii 1993).

In this study, to investigate the influences of branch-cutting behavior of oak nut weevils on oak production, we surveyed horizontal and vertical distribution ranges of damaged oaks in nine mountains including seven National Parks and depth of overwintering sites of larvae and quantified biomass of vegetative growth and sexual reproduction of six deciduous oak species removed by the weevils in Kwangnung Experimental Forest Station, Korea.

MATERIALS AND METHODS

Horizontal and vertical distribution of *M. ursulus*

From the year from 1993 to 2001, we checked the oak species damaged by oak nut weevils along the trails of aeven National Parks including Mt. Hallasan in the South and two urban natural parks, Mts. Kwanaksan and Tohamsan (Table 1). We determined the upper limit of distribution range by observing damaged oak branches of six deciduous oak species.

To investigate the depth of overwintering site of larvae, we digged out soil with hand shovel and measured soil depth of caves of larva or pupae in oak stands of Kwangnung Experimental Forest in Feb. 1994.

Oak biomass removal by *M. ursulus*

The damaged oak branches with acorns and leaves by oak nut weevils and primary oak production per unit area($1m^2$) were collected in oak stands of Mt. Soribong (536 m) of Kwangnung Forestry Experimental Station using six litter traps installed 0.5m high above ground level. We sampled every ten days from June to Nov. 1993. The characteristics of the study site are described in previous study in the area (You *et al.* 1995). Oak branches with acorns and leaves were weighed after dried in drying oven (80℃) to constant weight. Annual net primary productivity of oak trees was estimated using allometry equation with the data of oak dbh(diameter at breast height) increment from 1993 to 1994 (Park 1985). The percent of annual primary productivity (g/m^2) removed by oak nut weevils was calculated by subtraction the falling phytomass from annual primary productivity. To assess the influence of oak nut weevil on the reproduction of major oaks, we counted the number of intact branches and cut ones of six trees of *Q. mongolica* and *Q. acutissima*.

RESULTS

All of the endemic oak species were damaged by oak nut weevils in all of the study sites in Korea (Table 1). Damaged oaks were *Q. mongolica, Q. serrata, Q. aliena, Q. dentata, Q. variables* and *Q. acutissima*. The upper limit of vertical distribution of damaged oaks by the weevils ranged from 700 m to 900 m.

Their larvae were found in soil from 2.1 cm to 14.0 cm depth in Kwangnung Experimental Forestry Station (Fig. 1). The most preferred depth was from 8.1 cm to 10.0 cm. The two ranges of 6.1 - 8.0 cm and 8.1 - 10.0 cm took up about 63% of total frequency distribution. This high occured depth of soil is neraly coincide with that(7 - 11 cm) of previous report(Choi *et al.* 1993) in field observation in Seoul.

The weevils attacked oak branches from July 30 to Sep. 30 with a mean of 7.3 g $\cdot$ m^{-2} ten $days^{-1}$ (Fig. 2). Removed biomass was the greatest ($19.7 g/m^2$) around Aug. 30. This peak period is rather later than the adult peak period(early-August: Choi *et al.* 1993). Annual mean biomass removal was 51.3 g $\cdot$ m^2 yr^{-1} with a maximum of 118.0 g $\cdot$ m^2 yr^{-1}. Percentage of annual acorn production removal was 27 $\pm$12% of *Q. mongolica* and 33 $\pm$16% of *Q. acutissimia* (Fig. 3).

DISCUSSION

Oak nut weevils attack all of the deciduous oak species in the entire range of South Korea, including Mt. Hallasan in Cheju island from the south to Mt. Seoraksan in Kangwon-do to the

Table 1. Distribution and upper limit of damaged deciduous oak species in nine National Mountain Parks and Mt. Kwanak of Korea

Study site (Elevation)	Locality (Province)	Damaged oak species	Upper limit (m)	Year of study
Mt. Hallasan(1,950 m)	Cheju-do	Qm, Qs, Qa, Qd, Qv, Qac	700	1997-2001
Mt. Chirisan(1,915 m)	Chollabuk-do	Qm, Qs, Qa, Qd, Qv, Qac	800	1998
Mt. Tohamsan(745 m)	Kyongsangbuk-do	Qm, Qs, Qa, Qd, Qv, Qac	700	1995
Mt. Kyeryongsan(845 m)	Chungchonnam-do	Qm, Qs, Qa, Qd, Qv, Qac	800	1995
Mt. Seoraksan(1,708 m)	Kangwon-do	Qm, Qs, Qa, Qd, Qv, Qac	800	1996
Mt. Songnisan(1,057 m)	Chunchongbuk-do	Qm, Qs, Qa, Qd, Qv, Qac	900	1995
Mt. Odasan(1,563 m)	Kangwon-do	Qm, Qs, Qa, Qd, Qv, Qac	800	1999
Mt. Bukhansan(836 m)	Seoul	Qm, Qs, Qa, Qd, Qv, Qac	800	2001
Mt. Kwanaksan(829 m)	Seoul	Qm, Qs, Qa, Qd, Qv, Qac	800	1993-2001

Abbreviations; Qm: *Quercus mongolica*, Qs: *Q. serrata*, Qa: *Q. aliena*, Qd: *Q. dentata*, Qv: *Q. variabilis*, Qac: *Q. acutissima*

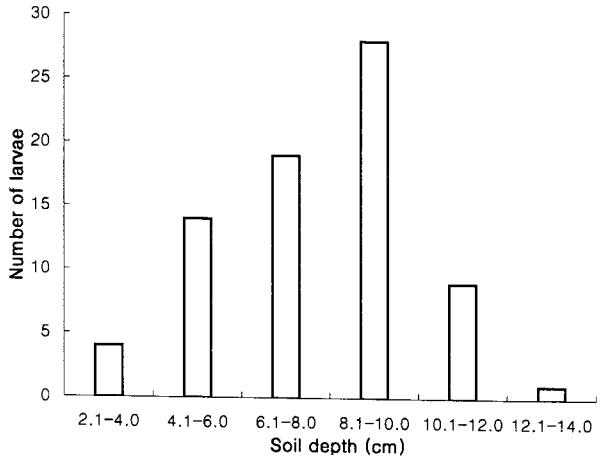

Fig. 1. Vertical distribution of *M. ursulus* larvae in oak stands of Kwangnung Experimental Forest Station surveyed during Feb., 1994.

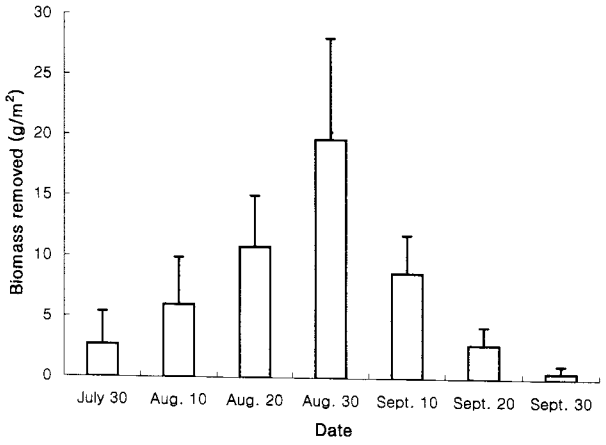

Fig. 2. Temporal changes of oak biomass removed by *M. ursulus* in Kwangnung Experimental Forest Station from July to Sep., 1993 (n=6). Bars indicate means ±1S.E.

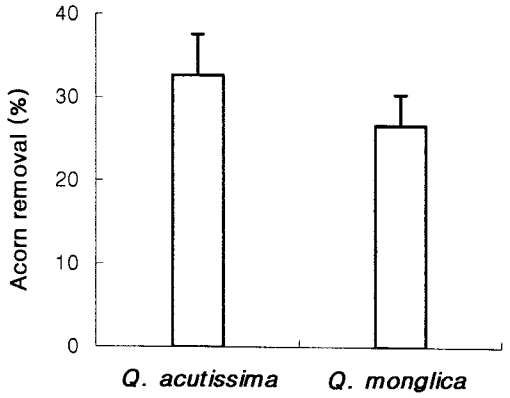

Fig. 3. Percentage of annual removal of acorn production by *M. urusulus* at of *Q. acutissima* and *Q. mongolica* stands in Kwangnung Experimental Forest Station in 1993 (n=6). Bars indicate means±1S.E.

north (Table 1). In addition to the endemic species, we observed several hybrid oak species including *Q. x grosseserrata, Q. x urticaefolia* and *Q. x maccormickii* were damaged by oak nut weevils. Therefore, it was assumed that the weevils either coadapted with, or tracked the adaption of, the oaks as the plant chemistry diversified, since chemistry is critically important in the host selection behavior (Bernays 1992).

The upper limit of vertical distribution of damaged oaks by the weevils ranged from 700 m to 900 m. Oak nut weevils are distributed up to the top in the relatively lower mountains such as Mt. Kwanak and Mt. Bukhansan with rock areas on their summits.

Our results on the upper distribution limit and preferred soil depth by larvae indicate that the vertical distributions of oak nut weevils in mountains are limited by the factors such as low temperature, shallow soil depth and low water contents. The result reesembles that of Stevens and Fox(1991) that both soil depth and winter soil temperature decrease with increasing altitude and soil depth is reversely correlated with soil water content.

Percent of annual net primary productivity (720g · m^{-2} · yr^{-1}) of oak species removed by the weevils was about 7% with the range from 16% to 1%. It is higher than the percentage removed by all the herbivores in typical temperate forest (5%) and equivalent to that of by all the herbivores in tropical forest (Table 2). Such greater biomass removal percentage by oak nut weevils comes from the fact that they cut down branches, leaves and acorns at the same time.

The intensive seed predation in plant communities may be the most important factor regulating tree populations (Janzen 1970). For example, the germination ability of acorns damaged by weevils was greatly lower than that of intact or fungal attacked acorns (Andersson 1992). Also, it can be countered by the mast seed-

Table 2. Comparisons of percentage of productivrity removed by oak nut weevil with that by the other herbivores in various ecosystems

Ecosystem type	Net primary production removed by herbivores (%)	Remark	Source
Temperate deciduous forest	5	All herbivores in all strata	Whittaker (1975)
Tropical rain forest	7	All herbivores in all strata	Whittaker (1975)
Grassland	10	All herbivores in herb layer	Whittaker (1975)
Oak forest	7	One species in tree and subtree layer	This study

ing, a defensive strategy which satiates seed predators in mast years and starves them in the intervening periods (Silvertown 1980).

On the other hand, the high ratio of predispersal seed predation may cause serious influences on the populations of postdispersal predators, such as mandarin duck (*Aix galericulata*), jay (*Garrulus glandarius*) and several rodents that feed on acorns, especially in winter(personal communication with Oh).

This is the first step to study the damage by oak nut weevils. This study provides some insights about their impacts on oak communities in Korea. However, to find out a measure to reduce the damage, it is necessary to investigate the ecological characteristics of the weevils in acorn. It could contriute to prepare an effective managing plan of the pests.

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