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Relationships between Invertebrate Availability and the Abundance of Three Species of Shrews and the Shrew-mole in Managed Forests

Lee, Sang Don*

Wildlife Science Group, Division of Ecosystem Sciences and Conservation, College of Forest Resources, AR-10, University of Washington, Seattle, WA 98195, USA

산림 내에서 곤충의 현존도와 식충목 4종의 풍부도간의 상관 관계

이 상 돈*

미국 워싱턴대학교 산림자원대학 생태과학 및 보존부

ABSTRACT

The abundance of coarse woody debris (CWD) has been hypothesized to increase niche for forest dwelling insectivores, concentration of nutrients, and the diversity of invertebrates. However, no objective assessment based on replication in the field has yet been done. This study was carried out to test the relationships between invertebrate availability and the abundance of four insectivores (*Sorex trowbridgii*, *S. vagrans*, *S. monticolus* and *Neurotrichus gibbsii*) in western Washington, USA. Pitfall traps were used to determine abundance and diversity of invertebrates. Abundance of insectivores was not different between habitats except for *S. vagrans* which was more abundant in habitats with low amounts of CWD than in habitats with high amounts of CWD. Simpson's diversity index computed for invertebrates did not differ between habitats. There were no significant relationships between the diversity indices of invertebrates and the abundance of shrews. Shrew abundance and the Coleopteran beetles also did not show any significant relationship. The results suggested insectivores might select a wide range of prey items in addition to surface-active invertebrates.

Key words: Coarse woody debris, Diversity index, Insectivores, Invertebrates, Managed forests, Pacific Northwest, USA

INTRODUCTION

The utilization of coarse woody debris (CWD)-primarily in the form of stumps, downed

* Present Address : NICEM (National Instrumentation Center for Environmental Management), College of Agriculture and Life Sciences, Seoul National University, Suwon 441-744, Korea

logs, and boles and large branches - can be an important component in wildlife management after timber harvest (Thomas 1979). In various stages of decay dead and fallen woody materials serve many important functions. The sponge-like decaying wood allows it to retain significant quantities of water and nutrients, benefiting the plant community surrounding it. Fungi colonize the moist wood and nutrients accumulate due to the presence of fungi hyphae, rhizomorphs, and sporocarps (Harmon *et al.* 1986). The fungi and other nutrients aid in the process of nitrogen concentration as well as become an important source of food for both invertebrates and vertebrates. Downed woods attract a wide range of foraging and cover-seeking animals from terrestrial invertebrates (Lloyd 1963, McComb and Noble 1982) to vertebrates (Harmon *et al.* 1986). Coarse woody debris in old-growth forests is complex in its structure and often present in large amount (Spies *et al.* 1988). Considering benefits of CWD (moisture availability and cover) to wildlife negative correlations between small mammal abundance of *Clethrionomys gapperi* and this habitat element were observed (West 1991). Amount of CWD in old-growth forests may exceed minimum threshold levels. Identification of critical elements of forest habitats is essential in the management of forest ecosystems because the managed forests compromise 80% of Pacific Northwest forest lands (West 1991, Spies *et al.* 1988). Coarse woody debris is the primary component of old-growth habitat that is eliminated by current forestry practices (Harris *et al.* 1982, Carey and Johnson 1995). Abundance of many animal species from shrews to black bears are positively correlated with CWD (Hunter 1990).

Forest-dwelling shrews are not favoured by management practices (e.g., clear-cutting or burning). The loss of woody debris, resulting in a decrease of both cover and invertebrate prey, can lead to decline in shrew populations. However, *Sorex trowbridgii* have been reported to increase in numbers following timber harvest if woody debris is remained (Sullivan and Sullivan 1982). The authors explained that the increase of population might be the result of response to abundant invertebrate populations associated with remaining woody debris. The presence of a hospitable microenvironment associated with CWD helps to create a quality environment for shrews.

Aitchison (1984) stated that shrew diets were closely correlated with invertebrates captured in pitfall traps. Since the number of invertebrates caught in pitfall traps depends on their level of activity, results of pitfall trapping are sometimes called "activity density" or "activity abundance" (Thiele 1977). Although the number of invertebrates captured are influenced by their activity, it is certainly not independent of the local abundance. Shrews inhabiting in areas where the invertebrates are highly active and abundant might have greater chance to prey upon them than in areas where the invertebrates are less active and sparse in numbers. Under these context, I assumed that invertebrates caught in pitfall traps would give a crude approximation of prey availability for shrews. The objectives of this study were 1) to compare the diversity of invertebrate communities between habitats differing in the amount of CWD and 2) to determine the relationships between invertebrate diversity and the abundance of three species of shrews and the shrew-mole in habitats with high and low amount of CWD.

METHODS

Study area

This study was conducted in the Fort Lewis Military Reservation, located at east of the southern tip of the Puget Trough Province in Pierce County, Washington, USA during June 1991~June 1993. There were six different sites: three controls (sites with high amount of CWD) and three treatments (sites with low amount of CWD). The treatments were chosen from those sites where CWD, especially downed logs, were removed as a part of forest management practices to prevent forest fire, but there was no additional removal of CWD in those sites during the study period. In the controls, CWD was not removed by such management practice rather they were reserved to maintain natural resources. In each site a 1-ha study plot was established. To reduce the site variability each control and treatment was formed as a pair within the distance of 5 km. The volume of downed logs, standing snags, and stumps was measured in length, and diameter of both ends. The volume of CWD was significantly higher (paired t-test, $P<0.05$) in controls than in treatments (Lee 1995).

Pitfall and live trapping

Twenty-five pitfall traps were placed in a 5×5 grid, 10m apart during June 1991~June 1993. Pitfall traps were designed to capture non-jumping rodents and insectivores, and were partially filled with water so that small mammals die quickly. Drowning is a general method recommended by the American Society of Mammalogists when animals caught in pitfall traps are needed to be killed. The pitfall trap was No. 10 tin can (15 cm in diameter) sunk flush with the soil surface and covered with a piece of wood cover that was propped one to several cm over the can lip with twigs or a nearby log. About one third of the trap was filled with water. For insectivores, species, sex, and weight were recorded. Reproductive condition was determined in the autopsy. Length and width of testes, presence of uterine scars, and length, width and number of embryos (pregn at females) were recorded. Initially pitfall traps were opened for two consecutive nights every two weeks. In the beginning of July 1992 pitfall trapping periods were extended to 10 consecutive days per month.

Invertebrates were collected by pitfall traps twice in July and September 1992 and preserved in Kahle's solution (Borror *et al.* 1981). The invertebrates were later counted, and identified by taxonomical family and order. The wet biomass of invertebrates was measured up to 0.5 g.

Live trapping was carried out for two consecutive days twice a month, from June 1991 to June 1993. Traps were opened on day one and checked on days two and three. During the winter months (November through February), animals were trapped only once a month except for January and February of 1993 during which no trapping was made. A Sherman collapsible trap was placed in a 10×10 array of each trapping station with 10-m spacing per grid. In each trap synthethic bedding and rolled oats were used.

Vegetation sampling

Vegetation at each site was sampled during June and August 1992. Thirty randomly chosen stations were selected in each site out of 100 live trapping stations. In each station a nested design of 2.0 m^2 plot for shrubs and 1.0 m^2 plot for herbs was used. Understory vegetation was assessed by measuring percent cover by species (more than one percent in each plot). Percent cover was estimated by projecting imaginary polygons along with the natural spread of the species' foliage (Daubenmire 1968). Percent cover of each species was measured independently, so total percent cover could exceed 100% due to overlapping foliage. Categories of shrubs and herbs were taken from Halverson (1986).

To assess the amount of light penetration to the understory, canopy coverage was estimated in each site surveyed. Five slides of the canopy were taken at each site (four corners and one center) through a Nikon 8mm fish eye lens. These were then analysed using a computer program, 'OPTIMAS', which calculates percent of light present on each slide.

Data analysis

Simpson's Diversity Index (Pielou 1975) was applied to estimate diversity of vegetation. A paired t-test was used to compare the Diversity Index as resolution of sites of vegetation between treatment and control sites. For each plant species, total percent cover of 30 sampling plots in each site was estimated. The proportion of each plant species to the total percent cover was calculated to estimate Diversity Index. For an abundant species (e.g, salal, *Gautheria shallon*, sword fern, *Polystichum munitum*, Oregon grape, *Berberis nervosa*) I used Hotelling-Lawley's T^2 test to compare differences between control sites and treatment sites (Zar 1984). Percent total live cover, % of moss, and % of bare ground also were compared with Hotelling-Lawley's T^2 test. Percent light penetration was analysed using a paired t-test to compare differences between control and treatment sites.

Simpson's Diversity Index was computed to estimate diversity of invertebrates. Biomass of invertebrates was used to compare invertebrate availability between treatments and controls. Linear regression analysis between shrew abundance and invertebrate diversity in each site was performed. Linear regression was applied to determine the relationship between biomass of beetles and shrew abundance (Churchfield 1982).

RESULTS

Small mammal abundance

A total of 591 insectivores was caught by pitfall and live traps and *S. trowbridgii* was the

Table 1. List and biomass (g) of invertebrates collected by pitfall traps in each site in July and September 1992. Biomass was combined in July and September samples. No captures are indicated by blanks

		SITE A		SITE B		SITE C		Total
		Control	Treatment	Control	Treatment	Control	Treatment	
Beetles	Carabidae	19.23	132.30	28.87	90.80	79.45	75.10	425.75
	Carcilionidae						0.50	0.50
	Staphylinidae	0.08	0.10	0.66	1.37	0.14	0.41	2.76
	Silphidae	26.10	1.40	6.70	11.50	25.60	12.80	84.10
	Other			6.00	4.15	0.01	3.20	13.36
Mites	Acari	0.10	0.10	0.10	0.10	0.30	0.29	0.99
Spiders	Araneae	9.59	10.50	1.71	1.44	13.40	12.40	49.04
Millipedes	Chilopoda	0.11	0.01	1.75	0.78	0.10	0.86	3.61
	Diplopoda	0.15	1.80	1.10		3.55	7.33	13.93
Flies	Diptera	0.20	1.10		0.20	0.10	0.20	1.80
	Diptera larvae	0.52	0.30	0.30	1.24	0.01		2.37
Ants	Formicidae	181.00	39.00	0.70	1.50	14.20	79.40	315.80
	Other Hymenoptera		1.10		0.10			1.20
Springtails	Collembola	1.65	1.37	0.07	0.04	0.04	0.02	3.19
Grasshoppers	Orthoptera	0.40				0.70	0.40	1.50
Earthworms	Lumbricidae		0.02	0.45	0.36			0.83
Total		239.13	189.10	48.41	113.58	137.60	192.91	920.73

predominant species (n=330) (Lee 1995). Results of paired t-test were not significant for all insectivores except for *S. vagrans*. Abundance of *S. vagrans* was significantly higher in sites with low amount of CWD than in sites with high amount of CWD ($P<0.05$). *S. vagrans* was not captured in two control sites (B and C).

Vegetation and invertebrates

The three species (salal, Oregon grape, and sword fern) showed no difference between sites with low amount of CWD and sites with high amount of CWD in Hotelling-Lawley's T^2 test. There was no difference in percent total live cover, percent moss or percent bare ground between control and treatment. Simpson's Diversity Index for vegetation was not significantly different between control and treatment sites. Light penetration was significantly different between control and treatment sites ($P<0.001$). Biomass of invertebrates in each site was listed in Table 1. Simpson's Diversity Index for invertebrates was not different between treatment and control. Linear regression of abundance of shrews in each site and Diversity Index was not significant ($P>0.05$, $n=6$, $r^2=0.481$). Linear regression of Coleopteran beetles and shrew abundance also was not significant ($P>0.05$, $n=150$, $r^2=0.016$).

DISCUSSION

Hooven and Black (1976) reported that *S. trowbridgii* densities were related primarily to ground cover and they were abundant in Oregon old-growth forest only when there was sufficient cover of decaying matter which contained reliable food sources. Increase of *S. trowbridgii* population after clearcuts was attributed to increased cover by shrub vegetation and, in turn, increased invertebrate abundance in slash residues (Gashwiler 1970). The abundance of *S. trowbridgii* between treatment and control sites was not different, but proportion of adult population was higher on control sites than treatment sites (Lee 1995). Higher proportion of adult population was one of the characteristics of quality habitat (Ostfeld and Klosterman 1986).

S. vagrans had an interesting pattern of abundance associated with forest succession. It showed a gradual increase in abundance during the early successional stages after timber harvest (Martell 1983). A litter layer may not develop until several years after cutting: the moss and shrub layer on clearcuts may not be fully developed. But, several years after clearcuts, thick herbs and shrubs as well as dense populations of invertebrates associated with woody debris were developed and became an important habitat for shrews and shrew-mole (Gunther *et al.* 1983). Gashwiler (1970) found that numbers of shrews on cutover areas increased to about the numbers on uncut areas as the herbaceous layer redeveloped after logging. Shrews in general apparently required well-developed litter layers for burrowing and foraging (e.g., Maser and Hooven 1974, Terry 1981). Such a litter layer often is present in undisturbed forested stands, but absent in harvested sites. Hennings and Hoffmann (1977) suggested that *S. vagrans* was more dependent on water than *S. monticolus* and had limited ability to survive on dry soil. Terry (1981) suggested that the non-burrowing *S. vagrans* was at a disadvantage in dry areas where the burrowing species *S. trowbridgii* and *N. gibbsii* were present. However in this study the higher abundance of *S. vagrans* on treatment sites did not correspond to Terry (1981)'s findings. *S. vagrans* might well adapt to dry sites where ground cover was lacking. A similar result was reported by Stinson (1987) who found that *S. vagrans* was the most common shrew in dry ponderosa pine habitat in eastern Washington.

A more diverse vegetation in the treatment site was expected due to a higher penetration of light in the underground. This was not the case. I excluded plant species with less than one percent cover in each plot. This might be the reason not finding a difference between treament and control.

A positive correlation between invertebrate diversity and shrew abundance was expected because shrews are insectivores. High abundance of shrews was expected to result from a greater light penetration in treatment sites, which in turn would promote a higher diversity of vegetation, which would promote more diverse invertebrate population. Simpson's Diversity Index did not detect a difference of invertebrate diversity between treatment and control sites. I identified invertebrates down to order and family. This could be one of the reasons for not finding a difference between control and treatment sites.

The relationship between diet and food availability in shrews has been the subject of several studies. Rudge (1968) and Churchfield (1982) found no close relationship between the abundance of certain prey items in the leaf litter and their occurrence in the diet of *S. araneus*. Pernetta (1976) was unable to find a positive correlation between the diet of *S. araneus* and the number of different prey types collected in pitfall traps. However, shrews were able to detect and find inactive prey like invertebrate larva in the surface litter (Buckner 1966) and probably hunted in cavities of stumps or logs. Shrews frequently prey on Homoptera, possibly climbing in vegetation (Stinson 1987). In his study he found significant correlations between availability indices (captured by pitfalls) and use by *S. cinereus* in grand fir habitat and *S. vagrans* in riparian areas. This was due to the shrews' use of surface active fauna which was the subset of the prey categories in the study area. In my study it seems that shrews may not be truely opportunistic predators because they do not show preference for the abundant prey in pitfalls.

A significant relationship between the Coleopteran beetles' occurrence in the diet and *S. araneus* abundance was noted (Churchfield 1982). An increase in the abundance of beetles might be accompanied by an increase in predation by shrews. This study failed to find correlations between Coleoptera and shrew abundance. Different foraging behaviour among shrew species may explain this. *S. araneus* is a burrower, so it is not limited to surface-active prey (Stinson 1987). In this study, the prey items were only monitored by pitfall traps. It is probable that the diet of shrews are not limited into certain taxa caught in pitfall traps. The high correlation between CWD and habitat use by insectivores in the microhabitat analysis makes a strong implication that shrews are selective predators on other prey in addition to surface-active invertebrates.

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요 약

벌채후의 잔목(殘木, coarse woody debris)은 산림내의 동물에게 서식지, 풍부한 영양, 그리고 다양한 곤충류를 제공한다는 가설이 제기되어 왔다. 그러나 제기된 가설에 대한 실험설계적 연구는 아직까지 이루어지지를 않았었다. 본 연구는 4종류의 식충종(*Sorex trowbridgii, S. monticolus, S. vagrans, Neurotrichus gibbsii*)과 곤충류의 다양성 관계를 알아보기 위하여 시행되

었다. *S. vagrans*의 서식밀도는 잔목밀도가 현저히 낮은 연구지에서 높게 나타났으며, 나머지 3종에서는 서식밀도와 잔목밀도간에 유의성이 없었다. Simpson의 곤충 다양성 지수는 잔목밀도의 높낮이 수준에 영향을 받지 않았다. 선형회귀에 의한 곤충류와 식충종의 관계는 유의성이 없었으며 딱정벌레 (Coleopterta)와 식충류의 관계도 유의하게 나타나지 않았다. 따라서 식충류는 본 연구에서 구명된 바와 같이 주로 지표에서 활발히 활동하는 곤충류 뿐만 아니라 보다 다양한 곤충류를 먹이로 선정하고 있음을 알 수 있었다.

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