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Relationship between insect herbivory and environmental variables in forests of northern Iran

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Abstract. *Hajizadeh G, Jalilvand H, Kavosi MR, Varandi HB. 2016. Relationship between insect herbivory and environmental variables in forests of northern Iran. Nusantara Bioscience 8: 155-160.* This research aimed to recognize the relationship between the intensity of insect herbivory and environmental variables (stand structure, and physical and chemical properties of soil and litter) in Hyrcanian forests, northern Iran. Three forest types (*Pinus brutia*, *Parrotia persica-Carpinus betulus*, and *Fagus orientalis*), which covered the elevational gradient of the study region, were selected. In each forest type, three random plots (20×20m) at 100m intervals were sampled. The dominant polyphagous species, *Ennomos quercinaria* (Hufnagel, 1767), belonging to Geometridae family was identified. The forest types experiencing the lowest and highest defoliation intensity were *P. brutia* (12±2.08) and *F. orientalis* (57.67±5.36), respectively. The intensity of insect herbivory was significantly correlated with various structural parameters [forest type, elevation, diameter at breast height (DBH), tree density, tree cutting and canopy opening (%)], physical and chemical properties of the soil [clay, pH, and potassium (K)], and litter properties [depth and total nitrogen (N)]. The study illustrates a way to monitor geometrid population dynamics across environmental gradients in terms of their population density, degree of polyphagy and distribution; such results could be useful for developing appropriate management plans for these economically important insects.

Keywords: Environmental gradient, forest type, Geometridae, outbreak, population dynamics

INTRODUCTION

The environmental condition is important to survival and abundance of insects. Environmental variables that affect population densities can be classified into three broad categories: (i) biotic; (ii) physical; and (iii) disturbances (Ciesla 2011). Biotic factors include host abundance and quality, levels of competition and natural enemies. Physical factors include climate, soil, and landscape features such as elevation, slope, and aspect. Disturbances include wildfire, severe storms, and anthropogenic activities that can have a profound effect on the quality and quantity of food and breeding sites (Ciesla 2011).

In recent years, many studies have been conducted on the ecological and economic effects of insect defoliation on forest ecosystems. Outbreaks of defoliating insects are usually followed by a sudden reduction in tree growth and forest productivity (short-term effects), increased tree mortality or decline of tree health, changes in species composition and increased leaching of nutrients (long-term effects) (Swank et al. 1981; Webb et al. 1995; Eshleman et al. 1998; Reynolds et al. 2000). Herbivory levels can stimulate physiological responses in a range of host plants (Pataki et al. 1998; Chen et al. 2001; Ozaki et al. 2004a; Quentin et al. 2011). Allocation of carbon to various parts of the tree can be reduced (Schultz and Baldwin 1982) because of restricted carbon storage above ground and increasing of soil microbial activity in below ground (Le Mellec et al. 2011). These effects on allocation and growth have economic importance. For example, in boreal forests in Canada, depletions caused by insect herbivory between 1977 and 1987 at an average rate of 106 m^3/year had a substantial impact on timber in growth (Fleming 2000). In the USA, more than 20 million ha of forested land are annually affected by insect outbreaks, resulting in drastic economic losses of approximately US$20 million per annum (Ayres and Lombardero 2000). In northeastern Germany, defoliation by the black arches moth (*Lymantria monacha*) estimated levels of defoliation of up to 500 000 ha, with economic losses of approximately €16 million (Kato 1993).

Several invasive insect species have caused extensive tree mortality in Hyrcanian forests, including *Lymantria dispar* (Hajizadeh et al. 2010), *Hyphantria cunea* (Kavosi and Gninenko 2007), *Altica viridula* (Kavosi 2007), and, more recently, species of Geometridae (*Ennomos quercinaria*, *Erannis defoliaria* and *Operophtera brumata*) (Barimani Varandi et al. 2006; Kiadaliri 2005, 2007; Rajaei et al. 2010; Babaei 2013). Most studies conducted in Hyrcanian forests have focused on identifying the insect pests and studying their biology and natural enemies. Therefore, the present study investigated whether there is a relationship between herbivory intensity and environmental variables of stand structure, and the physical and chemical properties of soil and litter in Hyrcanian forests, northern Iran.

MATERIALS AND METHODS

Site study

The study area was located in the Darabkola forest, Sari, Northern Iran. The boundary of this area is located at 36°28´-36°33´ N and 53°16´-53°20´ W. The study region has an average annual temperature of 31°C, a total annual rainfall of 700-750 mm, and an altitudinal range of 140-880 m (asl.) (Figure 1). The Darabkola forest covers an area of approximately 2600 ha, comprising natural temperate and uneven-aged stands. The main tree species are *Quercus castaneifolia*, *Carpinus betulus*, *Acer velutinum*, *Alnus subcordata*, *Tilia begonifolia*, *Parrotia persica*, *Ulmus glabra*, *Acer platanoides*, *Diospyros lotus*, *Zelkova carpinifolia*, *Fagus orientalis*, and *Acer cappadocicum*.

Study design

A field survey carried out at Darabkola forest, Sari, northern Iran during the growing season, 2014 showed clear signs of herbivory and tree canopies that were almost devoid of leaves. To understand the relationship between herbivory intensity and environmental variables, three distinct forest types [*Pinus brutia* (150-400 m asl.), *Parrotia persica*-*Carpinus betulus* (450-600 m asl.), and *Fagus orientalis* (650-900 m asl.)] were selected. In each forest type, three random plots (20×20m) were selected at 100m intervals and all trees within each plot were sampled. In addition, within each plot, environmental variables (stand structure, and physical and chemical soil and litter properties) were measured. Herbivory intensity based on Shariati Najafabadi et al. (2014) defined as follows: no defoliation (0), <10% (1), 11-25% (2), 26-40% (3), 41-60% (4), 61-80% (5) and >80% (6). For each tree, the diameter at breast height (DBH), tree height, density (number of stems), and tree cutting (to represent disturbance effects), were recorded. In the center of each plot, canopy opening cover (%) was measured. In each plot, three soil samples were taken from the depth of 0-10 cm and, after mixing, composed one soil sample (Maranon et al. 1999). Soil samples were air-dried and passed through a 2mm mesh. The following soil characteristics were determined (methods given in parentheses): (i) soil texture [hydrometric method (Bouyoucos 1962)]; (ii) soil pH (of a soil-water solution of 1:2.5); (iii) soil bulk density (BD) [clod method (Ghazanshahi 1999)]; (iv) total nitrogen (N) [semi-micro-Kjeldahl method (Bremner 1996)]; and (v) soil organic carbon (C) [Walkey and Black method (Walkley and Black 1934)]. In addition, available phosphorus (P) was analyzed according to standard methods (Olsen et al. 1954), and exchangeable potassium (K) was determined by ammonium acetate at pH 7.0 using a flame-photometer.

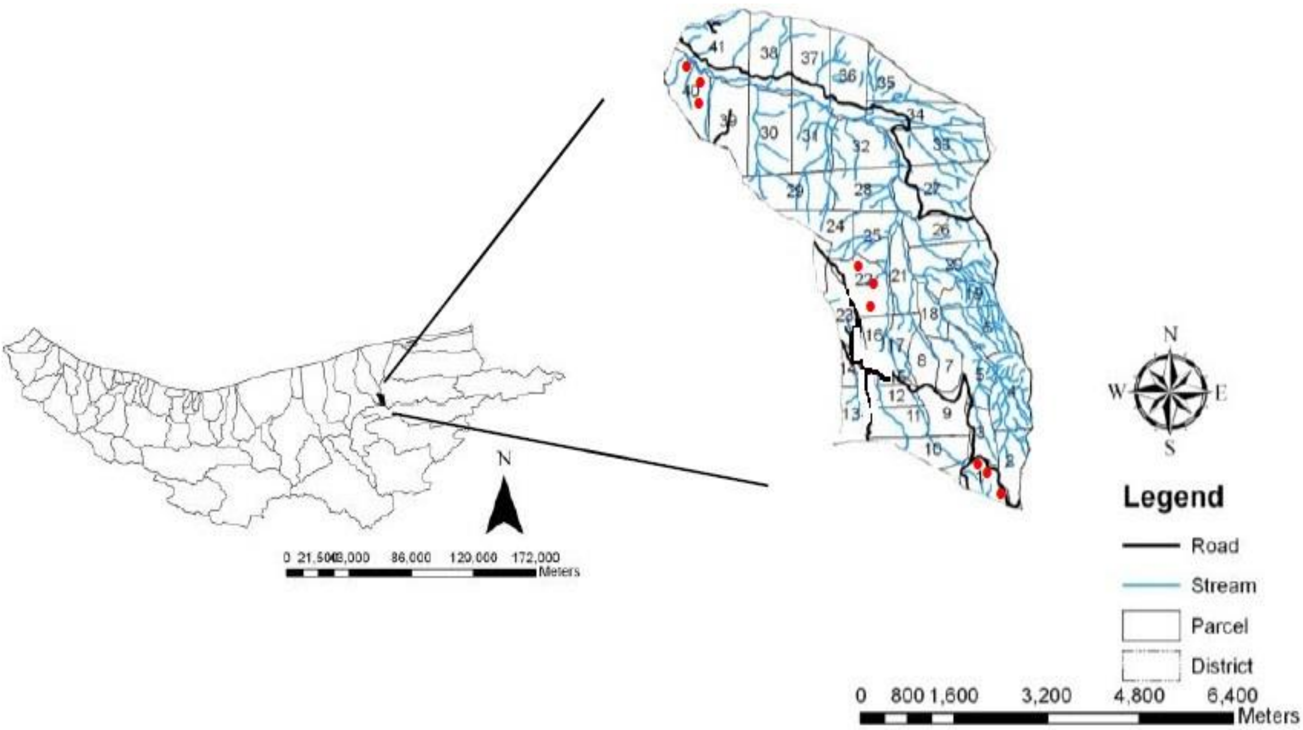

Figure 1. Study site in Mazandaran province, northern Iran. Sample plots in Darabkola forest are identified by red circles (Akbarimehr et al. 2016).

Data analysis

Normality of variables was checked using the Kolmogorov-Smirnov test, and Levene's test was used to examine the equality of variances. One-way analysis of variance (ANOVA) with a Tukey post-hoc test was used to examine differences in environmental variables between forest types. Correlations between insect herbivory and environmental variables were determined by Pearson's correlation coefficient. All statistical analyses were carried out in SPSS 19.0 (SPSS. Inc.) was used.

RESULTS AND DISCUSSION

Results

The dominant polyphagous species, *Ennomos quercinaria* (Hufnagel, 1767), belonging to Geometridae family was identified. In a comparison of stand structure characteristics, there was a significant difference in DBH and tree cutting (p= 0.05) and density of trees (p=0.01) among the forest types. The lowest and highest of DBH were observed in *Pinus brutia* and *Parrotia persica-Carpinus betulus* forest types respectively. But, the maximum and minimum of tree cutting and tree density occurred in *Pinus brutia* and *Fagus orientalis* types respectively. Total N and depth of litter showed a significant difference in forest types (p= 0.01) (Table 1). The lowest and highest defoliation intensity were observed in *Pinus brutia* (12±2.08) and *Fagus orientalis* (57.67±5.36) types, respectively (F=35.03, p= 0.01) (Table 2). No relation was found between herbivory intensity and height of trees, whereas significant correlations were found for other stand characteristics. Open stands (p =0.05) and moderate DBH classes (p =0.01) were attacked more by herbivores. In terms of the level of disturbance (represented by tree cutting), herbivorous populations were more abundant on trees with average levels of disturbance (p =0.05). Insect herbivory was increased with elevation (Figure 2). A significant correlation was found between herbivory intensity, clay soil, K (p= 0.01), and pH (p =0.05). A significant relation was also found between litter depth and herbivory intensity (p=0.01) (Table 3).

Table 2. Comparison of defoliation intensity between three forest types

Forest types (Elevation)	Mean ± SE
Pinus brutia (150-400 m asl.)	12±2.08c
Parrotia persica-Carpinus betulus (400-650 m asl.)	39.33±3.48b
Fagus orientalis (650-900 m asl.)	57.67±5.36a

Table 1. Comparison (mean ± SE) of stand structure, physical and chemical soil and litter characteristics across forest types

	Variable	*Pinus brutia*	*Parrotia persica-Carpinus betulus*	*Fagus orientalis*	F-value	P-value
Stand structure	Canopy opening (%)	25±2.89	23.33±4.41	15+2.89	2.385^{ns}	0.173
	DBH (cm)	13.15±0.7^{b}	40.82±3.28^{a}	39.29±7.71^{a}	10.258*	0.012
	Tree height (m)	16.47±0.84	25.67±1.76	22.33±4.58	2.619^{ns}	0.152
	Density (tree/ha)	1216.67±87.002^{a}	316.67±58.33^{b}	275±76.38^{b}	50.533**	0.000
	Tree cutting (ha)	125±38.19±22.05	33.33±22.05	8.33±8.33	5.621*	0.042
Soil	BD (g/cm^3)	1.55±0.08	1.26±0.03	1.56±0.13	3.502^{ns}	0.098
	Clay (%)	14.24±1.13	18.3±3.04	20.22±2.0003	1.9222^{ns}	0.226
	Silt (%)	37.31±5.82	36.56±3.31	37.94±2.08	0.192^{ns}	0.83
	Sand (%)	48.44±6.96	45.13±5.2	39.84±2.98	0.646^{ns}	0.557
	RH (%)	24.51±0.79	29.15±6.78	25.34±2.61	0.243^{ns}	0.792
	pH (1:2.5)	6.46±0.14	6.04±0.52	5.59±0.27	1.523^{ns}	0.292
	EC	0.4±0.03	0.3±0.03	0.34±0.04	1.948^{ns}	0.223
	OC (%)	5.97±1.15	5.94±0.64	4.29±0.39	1.461^{ns}	0.304
	N (%)	0.1±0.8	0.03±0.01	0.04±0.01	1.59^{ns}	0.279
	OM	10.28±1.98	10.24±1.11	7.39±0.67	1.461^{ns}	0.304
	C:N	61.47±19.29	200.22±55.07	135.63±49.38	2.473^{ns}	0.165
	P (mg/kg)	7.56±0.96	9.52±2.2	6.44±1.45	0.924^{ns}	0.447
	K (mg/kg)	204.72	144.52±33.57	124.86±26.48	2.67^{ns}	0.148
Litter	RH (%)	32±2.08	40.04±8.4	44.77±7.04	0.958^{ns}	0.435
	Depth (cm)	0.97±0.15^{b}	1.93±0.04^{a}	2.63±0.32^{a}	20.174**	0.002
	OC (%)	35.46±4.32	32.11±3.83	38.58±8.69	0.289^{ns}	0.759
	N (%)	0.73±0.008^{a}	0.48±0.008^{c}	0.62±0.01^{b}	104**	0.000
	OM (%)	61.13±7.45	55.35±6.61	66.51±14.99	0.289^{ns}	0.759
	C:N	48.27±5.59	66.02±8.13	61.59±12.56	1.003^{ns}	0.441
	P (mg/kg)	0.08±0.007	0.66±0.0006	0.06±0.009	3.414^{ns}	0.102
	K (mg/kg)	0.2	0.01±0.005	0.01±0.005	2^{ns}	0.216

Note: n.s. = not significant. *p<0.05, **p<0.01. (ANOVA). BD (Bulk density), RH (Relative humidity), OC (Organic carbon), OM (Organic matter) and EC (Electrical conductivity)

Table 3. Pearson correlation coefficients between insect herbivory and stand structure, physical and chemical soil and litter characteristics across forest types

	Characteristic	Pearson correlation	P value
Stand structure	Forest type	0.954	0.000**
	Elevation (asl.)	0.934	0.000**
	Canopy opening (%)	-0.686	0.041*
	DBH (cm)	0.798	0.01**
	Height (m)	0.64	0.063ns
	Density (tree/ha)	-0.886	0.001**
	Cutting tree (ha)	-0.705	0.034*
	Slope (%)	-0.392	0.296ns
Soil properties	BD (g/ cm^3)	-0.163	0.676ns
	Clay (%)	0.817	0.007ns
	Silt (%)	0.116	0.766ns
	Sand (%)	-0.375	0.319ns
	WHC (%)	0.037	0.924ns
	pH (1:2.5)	-0.683	0.042*
	EC	-0.422	0.256ns
	C	-0.555	0.121ns
	N (%)	-0.469	0.203ns
	OM (%)	-0.555	0.121ns
	C:N	0.355	0.348ns
	P (mg/kg)	-0.261	0.497ns
	K (mg/kg)	0.822	0.007**
Litter properties	Depth (cm)	0.914	0.007**
	WHC	0.328	0.398ns
	C	0.078	0.824ns
	N (%)	-0.551	0.124ns
	OM (%)	-0.078	0.842ns
	C:N	0.394	0.295ns
	P (mg/kg)	-0.505	0.166ns
	K (mg/kg)	-0.66	0.53ns

Note: ns not significant, *significant at $\alpha = 0.05$, **significant at $\alpha = 0.01$. BD (Bulk density), RH (Relative humidity), OC (Organic carbon), OM (Organic matter) and EC (Electrical conductivity)

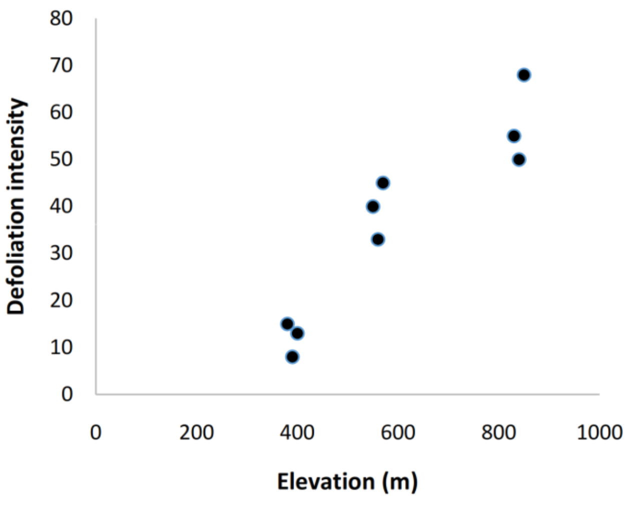

Figure 2. The relationship between elevation and defoliation intensity

Discussion

The main purpose of this research was to elucidate the relationship between the intensity of phytophagus insect species and multiple biotic and abiotic variables in Hyrcanian forest. Our field survey showed the most of the herbivorous larvae collected belonged to the Geometridae moth's family.

In this study, between stand structures variables (DBH, elevation, trees density and height) and defoliation intensities, the significant correlation was observed. Defoliation intensity was increased with elevation. This pattern probably related to microclimate, region conditions, disturbances, natural enemy, pure stand and especially host tree species. The primary host tree species of Geometridae family in the forest selected area was *Fagus orientalis* which covered the elevation of 650-900m (asl.). This result consistent with the other studies in northern Iran (Kavosi 2012). Insect population is known to reach a peak at mid-altitude gradients (Janzen et al. 1976; Holloway 1987; Olson 1994; Chey 2000). In addition, factors determining the insect herbivores at higher elevations are thought to include a reduction in host plant, reduced structural complexity of vegetation, climate conditions, and physiological adaptations. The possibility of lower predation at higher elevations might also be important in the abundances of the Geometridae in such regions. However, other studies have reported a reduction of insect at higher elevations. A significant relationship was also found between DBH and herbivory intensity, such that most of the defoliated trees were observed in moderate diameter classes. Karamiyan Omrani et al. (2014), reported that the relationship between environmental variables (diameter at breast height, trees height, and elevation) and insect herbivory of Geometridae family in northern Iran, Gorgan province. Their results show that the highest defoliation occurred in *F. orientalis*, *C. betulus*, and *P. persica* tree species. Also in this study, the most attacked trees were observed in moderate through high diameter classes. Positive relationship between defoliation intensity and environmental variables selected was observed. Moderate disturbance, unlike intensive disturbance, was followed by increasing of diversity and herbivory was consistent with the results of other studies (Sargeev 1998; Humphrey et al. 1999; Joshi et al. 1999; Kitahara and Sey 2001).

There are many mechanisms in which the activity of insect herbivores can cause changes in nutrient availability in soils: (i) insect herbivores can deposit significant quantities of grass into litter and soil (Fogal and Slansky 1985; Grace 1986). In the present study, N in litter and soil in *Fagus orientalis* plots was higher than in the other forest types. The relationship between insect herbivory and clay, pH, and K were also significantly correlated; (ii) insect herbivory can affect the nutrient content of rain that passes through the plant canopy (Tukey and Morgan 1963); (iii) insect herbivores may change the quantity and quality of litter fall from the canopy through defoliation, increase phenol content, root mortality, and changes in the relative abundance of plant species or genotypes with different litter quality (Faeth et al. 1981); (iv) herbivory may influence plant populations not only by enhancing litter quality, but also through improving soil nutrient levels (Kielland et al. 1997); (v) herbivory affects relationship between plants and their symbionts (Bardgett et al. 1998; Hunter 2001); and (vi) herbivory affects tree canopy structure and ground covered as a result of changes in access to light and soil moisture. Changes in soil microclimate resulting from herbivory can affect the nutrient cycle. Similarly, by changing light availability, herbivory also affects the quality of litter by affecting plant chemistry (Hunter and Forkner 1999; Strand et al. 1999) and/or plant diversity and productivity (Van Der Wal et al. 2000). This hypothesis is more consistent with the results of the present study based on the significant correlation between herbivory intensity and canopy openness. In addition, our data do not show strongly that changes in insect herbivory cause changes in nutrient cycling in soils. Which although a number of other published studies do support that conclusion.

In conclusion, elevation and tree density (stand structure), clay, K, pH (soil variables), and litter properties (C:N, depth, P, and K) are responsible for the observed defoliation in selected forest types. The study illustrates a way to monitor geometrid moth population dynamics across environmental gradients in terms of their population density, degree of polyphagy and distribution; such results could be useful for developing appropriate management plans for these economically important insects. In finally, variables that are correlated with insect herbivory can be measured to assess the relative risk of a forest for increased insect herbivory.

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