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Comparing densities of spider mites (Tetranychidae) and predatory mites (Phytoseiidae) on the common oak (*Quercus robur* L.) in forests of natural and industrial areas

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Abstract. This paper presents results of studies conducted in the forest areas of the Polesie National Park and in the surroundings of the chemical producer Zakłady Azotowe in the town of Puławy on the abundance of mites from the families Tetranychidae and Phytoseiidae. These studies were conducted on eight different sites in the years 2002–2004 and aimed at answering the question of whether mite abundance is related to factors such as area, site and year. In total, 8894 specimen of the spider mite family and 1835 specimen of the predatory mite family were collected. Spider mites were more abundant in Puławy than in the Polesie National Park, whilst the abundances of predatory mites were similar in both study areas. For spider mites, statistically significant differences were found in terms of study area and site, but also in terms of the study area in relation to the year of investigation. In the case of predatory mites, statistically significant differences were also found in terms of the study area in relation to the year of investigation.

Key words: herbivorous mites, natural enemies, environmental impact, pollution

1. Introduction

The study of arthropods inhabiting the pedunculate oak was carried out in both forest and urban areas. The most important forest pests of oaks include numerous species of butterflies and beetles, eg. *Euproctis chrysorrhoea* (Linnaeus 1758), *Lymantria dispar* (Linnaeus 1758), *Operophtera brumata* (Linnaeus 1758), *Altica quercetorum* (Foudras 1860), or *Scolytus intricatus* (Ratzeburg 1837) (Michalski et Mazur 2006). However, also important are arthropods with piercing-sucking mouthparts, predominantly aphids (Aphididae) and spider mites (Tetranychidae), especially in urban landscapes (Rychlik 1979; Kropczyńska-Linkiewicz et al. 1990; Cichocka et al. 1990ab; Cichocka et Goszczyński 1991). Many studies discussing the effects of environmental pollution have been focusing on soil mites, especially on moss mites (Oribatida) (Gulvik 2007; Gergócs et Hufnagel 2009). It has been observed that the abundance of mites usually decreases due to strong pollution caused by various industrial plants (Kaczmarek et Seniczak 1996; Klimek 2000). A particularly adverse effect on moss mites was observed in the case of heavy metals (Seniczak et al. 1997ab; Klimek 2000). Pollution with sulphur compounds also resulted in a significant drop in the abundance of the Oribatida (Dąbrowski et al. 1996). Another important factor that negatively affected moss mites was pollution with nitrogen compounds, whose high concentrations caused a decrease in moss mites abundance. On the other hand, an average level of pollution with nitrogen compounds resulted in an increase in moss mite density (Seniczak et al. 1998).

Mites from the spider mite family (Tetranychidae) constitute the most significant group of herbivorous mites. They inhabit many species of trees, but most commonly linden trees, oaks, and maples (Kielkiewicz et Van de Vrie 1990; Kropczyńska 1999). Many studies have noted that those mites are more abundant in polluted areas, e.g. beside the streets, than in the areas that have retained a more natural character, such as city parks or forests (Ehler et Frankie 1979; Kropczyńska-Linkiewicz et al. 1990, Kropczyńska et al. 2002, Mackoś 2010). These mites easily adapt to new environmental conditions, as well as

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quite quickly become immune to chemical substances that are supposed to eradicate them (Boczek 1999; Kropczyńska 1999 Attia et al. 2013). What is more, according to Kropczyńska et al. (1988), female individuals of *Eotetranychus tiliarium* living in trees beside the streets lay significantly more eggs than their counterparts living in natural habitats. According to Kropczyńska (1999), oaks can be populated by species representing the following genera: *Eotetranychus*, *Oligonychus, Schizotetranychys*, and *Tetranychus*.

Predatory mites (Phytoseiidae) are very lively and constantly look for food, which constitutes of mites from: Tetranychidae, Eriophyoidea, Tarsonemidae, Tydeidae and Acaridae groups, as well as eggs and young insect larvae, pollen and plant nectar, as well as mycelium (Kropczyńska-Linkiewicz 2001). Also observed in Phytoseiidae is intraspecies and interspecies predation (Boczek 1999; Walzer et al. 1999; Boczek et Błaszak 2005; Kropczyńska-Linkiewicz 2001). The Phytoseiidae is a very important group of predatory spider mites (Fiedler 2012). Predatory mites are more resistant to high temperature and low humidity than spider mites (Boczek 1999; Kropczyńska-Linkiewicz 2001). These mites are observed on nearly all plant species, but prefer to inhabit the plants with trichomes on their leaves – a perfect hiding place (Kropczyńska-Linkiewicz 2001; Norton et al. 2001). The pedunculate oak, on the underside of its leaves – especially in vein angles – has numerous domatia, in which, during the present study, hidden moving stages of predatory mites were observed. Predatory mites can occur in both natural and anthropogenic habitats (Kropczyńska et al. 1988, Mackoś 2010, Puchalska 2014; Puchalska et al. 2014). It was noted that in areas affected by pollution (e.g. beside city streets, in the proximity of industrial plants) the abundance of mites was similar to their abundance in areas having a more natural character, such as city parks or green spaces in housing estates (Kropczyńska-Linkiewicz et al. 1990, Sahajdak et al. 1995; Kropczyńska et al. 2002; Mackoś 2010). Furthermore, it was noted that the Phytoseiidae were capable of developing im-munity to some chemical substances used for plant protection (Niemczyk et al. 1980; Vidal et Kreiter 1995; Bonafos et al. 2007). Species representing the following genera may occur on oaks: *Amblyseius, Anthoseius, Euseius, Neoseiulus, Phytoseius, Paraseiulus,* and *Thypholdromus* (Kropczyńska-Linkiewicz 2001). According to Cichocka et al. (1990b), *Euseius inlan-dicus* (Oudemans 1915) was a dominant species on maples, lindens and oaks in Warsaw.

The goal of this research was to compare the average densities of mites from the Tetranychidae family and their predators from the Phytoseiidae family, inhabiting the pedunculate oak (*Quercus robur* L.) in relation to the environment where the studied trees grow. It was also checked whether the study area, year of study, and study site can be a factor determining the differences in the abundance of the studied mite families.

2. Material and methods

2.1. Study sites

Research was carried out in two areas: in the forest communities of the Polesie National Park, and in woodlots in the protective zone of the Zakłady Azotowe in Puławy (Lubelskie province, South-Eastern Poland). The area of the Polesie National Park (PPN) is characterised by a natural quality of plant communities. For the purpose of this research, four sites representing different types of forest communities were selected:

1. Site PPN 1 (N 51°25’24” E 23°11’48”) is situated in the *Tilio-Carpinetum* community at the border between the forest and wastelands.

2. Site PPN 2 (N 51°25’31” E 23°11’30”) is situated between what used to be two drainage ditches. Oaks grow in a small grouping. Behind one of the ditches is *Potentillo albae -Quercetum*, dominated by the sessile oak (*Quercus petraea* (Matt.) Liebl.).

3. Site PPN 3 (N 51°25’46” E 23°11’24”) is situated in the *Ribeso nigri-Alnetum* community, in the direct vicinity of the pedunculate oak (*Quercus robur* L.).

4. Site PPN 4 (N 51°26’28” E 23°14’41”) is situated at the edge of *Ribeso nigri-Alnetum*, and the oaks grow surrounded by the silver birch (*Betula pendula* Roth).

The surroundings of the Zakłady Azotowe in Puławy is an area exposed to air pollution, especially NO_2 and particles (Table 1). Plant communities in Puławy have been, and still are, subjected to strong human impact, their species composition is significantly changed, and the trees growing there were planted in coniferous habitats. As in the Polesie National Park, four study sites were chosen in Puławy:

1. Site Puławy 1 (N 51°28’1” E 21°56’5”) is situated at the road from Puławy to Dęblin. Oaks grow surrounded by the Scots pine (*Pinus sylvestris* L.), black locust (*Robinia pseudoacaccia* L.), and silver birch (*Betula pendula* Roth).

2. Site Puławy 2 (N 51°27’26” E 21°57’42”) is situated 200 m from the Zakłady Azotowe. Oaks in this site grow in an open area, surrounded by herbaceous plants.

3. Site Puławy 3 (N 51°27’29” E 21°57’34”) is situated 400 m from the Zakłady Azotow. Oaks grow alongside black locust (*Robinia pseudoacaccia* L.), hackberry (*Prunus padus* L.), apple trees (*Malus domesticus* Borkh.), and silver birch (*Betula pendula* Roth).

4. Site Puławy 4 (N 51°27’59” E 21°56’3”) is situated at the road from Puławy to Dęblin. It is located at a oxbow lake of Vistula River, on the opposite side of the road from Site 1. Oaks grow surrounded by the Scots pine (*Pinus sylvestris* L.), black locust (*Robinia pseudoacaccia* L.), and silver birch (*Betula pendula* Roth).

2.2. Methods of sample collection

In each of the eight study sites from 3 to 5 trees at the age of 20–50 (years old) were chosen. In each site 10 green shoots and woody shoots, approximately 30–40 cm long, were collected including the leaves (100 specimens). Samples were collected in approximately 14-day intervals from May to October in the years 2002–2004. Samples were collected in 28 series in four sites in Puławy and in 34 series in four sites in the Polesie National Park. In laboratory leaves were inspected using a stereo microscope, and the mites were identified to family and counted.

2.3. Statistical analyses

This study included performing statistical analyses of mean population densities of the studied mites on the pedunculate oak with use of nonparametric statistics. The two-sample Kolmogorov-Smirnov test was used to determine whether mite densities differed depending on a research area at the significance level of $p = 0.05$. Furthermore, the Kruskal-Wallis H test for many independent samples was applied, as well as multiple comparisons. It was tested whether mite densities differed depending on the year of the study, the study site, the research area and the year of the study at the significance level of $p = 0.05$. It was also determined whether the densities of the studied mites differed depending on the study site and the year of the study assuming the significance level at $p = 0.01$.

3. Results

As a result of the present research, the pedunculate oak yielded a total number of 8894 representatives of the spider mite family, 5621 (63.2%) of which were collected in Puławy, and 3273 (36.8%) in the Polesie National Park. The mean density of the spider mite population, measured as the number of specimens per 100 leaves equalled 54.05 in Puławy, and 27.28 in Polesie National Park (Table 2). It was determined that this difference was statistically significant at the level of $p < 0.001$ according to the Kolmogorov-Smirnov test. The first specimens of Tetranychidae appeared in Puławy in the middle of May, inhabiting the bottom side of laminas, and covering them with web, whereas the last specimens were noted in the first decade of October. In the first year of study (2002) spider mites were the most numerous, and their mean density equalled 45.89 specimens/100 leaves (Table 3). In the following years the density of these mites kept decreasing, however no statistically significant differences were found (Table 3).

Study areas differed significantly in the number of Tetranychidae in the following years of study at the level of $p = 0.034$. In Puławy, the density of spider mites changed from 81.50 in 2002 to 40.35 specimens/100 leaves in 2004. In Polesie National Park the highest density was noted in 2003 (32.15 specimens/100 leaves), and the lowest in the first year of study (20.98 specimens/100 leaves). It was determined that the lowest density noted in the Polesie National Park in 2002 significantly differed from the two averages noted in Puławy in 2002 and 2003 (Table 4).

Table 1. The average annual concentration ($\mu g \cdot m^{-3}$) of the main air pollutants in research areas in 2002–2004

Pollutants	Puławy			PPN		
	2002	2003	2004	2002	2003	2004
NO_2	21.2	22.5	28.8	6.6	7.9	6.9
SO_2	3.5	3.4	1.8	4.9	5.3	5.1
Particulate matter	13.2	20.6	16.9	2.9	2.0	3.8

Source: Reports of The Regional Inspectorate for Environmental Protection in Lublin stating the condition of natural environment in Lublin Province in 2002. 2003. 2004

Table 2. Average density of mites (specimens/100 leaves) depending on the study area

Study area	Tetranychidae		Phytoseiidae	
	Average ±SE		Average ±SE	
PPN	27.28 ±1.95	a	8.13 ±0.63	a
Puławy	54.05 ±7.02	b	8.27 ±0.80	a

Mean values in columns marked with different letters differ significantly

Table 3. Average density of mites (specimens/100 leaves) depending on the year of the study

Year of the study	Tetranychidae		Phytoseiidae	
	Average ±SE		Average ±SE	
2002	45.89 ±9.37	a	7.97 ±1.04	ab
2003	39.62 ±4.39	a	9.86 ±0.89	a
2004	34.53 ±4.14	a	6.80 ±0.66	b

Mean values in columns marked with different letters differ significantly

Table 4. Average density of mites (specimens/100 leaves) depending on the study area and the year of the study

Study area and year of the study		Tetranychidae		Phytoseiidae	
		Average ±SE		Average ±SE	
PPN	2002	20.98 ±3.26	a	6.20 ±0.96	a
	2003	32.15 ±3.41	ab	11.58 ±1.39	b
	2004	28.70 ±3.32	ab	6.60 ±0.60	ab
Puławy	2002	81.50 ±20.67	b	10.50 ±2.05	ab
	2003	47.92 ±8.32	b	7.94 ±1.00	ab
	2004	40.35 ±7.35	ab	7.00 ±1.17	a

Mean values in columns marked with different letters differ significantly

The comparison of densities of Tetranychidae population in all of the eight sites allowed to determine significant differences among them at the level of $p = 0.018$ (Table 5). The highest density of 75.88 specimens/100 leaves was found in the Puławy 2 site, which is the nearest to the Zakłady Azotowe. It significantly differed statistically from the lowest density in the PPN 4 site (17.27 specimens/100 leaves). Furthermore, a density level significantly higher from the density level at the above site was also observed in the Puławy 3 site (Table 5).

No statistically significant differences with reference to densities of the Tetranychidae were noted in the following years of the study in any of the study sites (Table 6). In the area of the Polesie National Park the lowest density was noted in the study site 1 in 2002 (8.7 specimens/100 leaves), whereas the highest density – in the study site 2 in 2004 (45.9 specimens/100 leaves). In the vicinity of the Zakłady Azotowe in Puławy these mites reached higher densities in three sites: Puławy 1, 2 and 3. The densities recorded in the Puławy 4 site were similar to the sites in the Polesie National Park (Table 6).

Predatory mites appeared on the studied oaks in the middle of May and most often were in the vicinity of a colony of spider mites. The last specimens of Phytoseiidae in the Polesie National Park were noted in similar numbers to the spider mites in the first half of October, whereas in Puławy a little longer. During the 3 years of study 1835 representatives of this family were collected. In Puławy 860 specimens were noted, and in the Polesie National Park – 975. The mean density of Phytoseiidae population measured as the number of specimens per 100 leaves was similar in both areas, as the Kolmogorov-Smirnov test did not show a statistically significant difference. In Puławy it equalled 8.27, and in the Polesie National Park – 8.13 (Table 2). In the following years of study the mean density of predatory mites changed. It was the highest in 2003 (9.86 specimens/100 leaves), and the lowest in 2004 (6.80 specimens/100 leaves) and this difference was statistically significant at the level of $p = 0.014$ (Table 3).

Study areas did differ significantly in terms of the collected specimens of Phytoseiidae in subsequent years of study at the level of $p = 0.013$. Maximum density was noted in 2003 in the Polesie National Park, equalling 11.58 specimens/100 leaves. It differed statistically from the two densities: in the Polesie National Park in 2002 and in Puławy in 2004 (Table 4).

Densities of the Phytoseiidae in all eight study sites did not significantly differ from one another (Table 5). While analysing the densities of predatory mites in relation to the study site and year of study it was found that in Puławy they reached between 3.10 and 12.86 specimens/100 leaves, whereas in the Polesie National Park – from 4.60 to 14.50

Table 5. Average density of mites (specimens/100 leaves) depending on the study site

Study site	Tetranychidae		Phytoseiidae	
	Average ±SE		Average ±SE	
PPN 1	21.30 ±3.12	ab	8.50 ±1.14	a
PPN 2	36.23 ±5.11	ab	8.17 ±1.50	a
PPN 3	34.30 ±3.72	ab	8.50 ±1.12	a
PPN 4	17.27 ±1.98	a	7.33 ±1.04	a
Puławy 1	47.65 ±10.72	ab	7.35 ±1.87	a
Puławy 2	75.88 ±21.63	b	9.42 ±1.60	a
Puławy 3	61.50 ±12.50	b	6.96 ±1.09	a
Puławy 4	31.15 ±5.48	ab	9.35 ±1.75	a

Mean values in columns marked with different letters differ significantly

specimens/100 leaves. However these differences were not statistically significant (Table 6).

4. Discussion

During the present study a dependence between the number of mites from the Tetranychidae family and the area of study was observed. The densities of spider mites on oaks subjected to air pollution near the Zakłady Azotowe in Puławy were significantly higher than on the trees growing in the Polesie National Park. This finding confirms numerous results of studies which showed that the condition of the natural environment influences the numbers of herbivorous arthropods. Usually in a polluted environment the number of herbivorous arthropods with piercing-sucking mouthparts increases (Chudzicka 1979; Czechowska et al. 1979; Kropczyńska-Linkiewicz et al. 1990; Cichocka et Goszczyński 1991; Cichocka et al. 1998; Tykarska, 2001; Jaśkiewicz, 2006; Mackoś 2010; Lubiarz et al. 2011; Lubiarz et Solski 2012; Mackoś-Iwaszko 2012; Lubiarz 2013). As proven by Kropczyńska et al. (1988), a higher level of environmental pollution in urban areas had a positive impact on demographic parameters of *Eotetranychus tiliarium* (Hermann 1804). Cichocka et al. (1990a) observed more abundant spider mite populations in trees lining the streets than in city parks and forests. According to the above mentioned authors, environmental pollution may endanger oaks and lindens by providing favourable conditions for abundant occurrence of spider mites. The authors suggest some methods of eradicating these pests but only in the trees growing beside the streets (Cichocka et al. 1990a).

Previous works (Lubiarz et Cichocka 2005; Lubiarz 2013) have shown an increase in nitrogen content in the leaves of the studied oaks growing in the vicinity of the Zakłady Azotowe in comparison to the Polesie National Park. It was the most probable cause of an increased number of spider mites in Puławy. A similar phenomenon was observed by Kropczyńska-Linkiewicz (1984) on linden trees in Warsaw. Also Sahajdak et al. (1995) noted the effect of industrial pollution on aphids and mites (Tetranychidae, Eriophyoidea) on the apple tree (*Malus* sp.), raspberry (*Rubus* sp.), tansy (*Tanacetum vulgare* L.) and the wormwood (*Artemisia campestris* L.). In the proximity of industrial plants (Huta Warszawa, Cementowania Warszawa, Elektrociepłownia Żerań, Zakłady Azotowe in Puławy, Petrochemia in Płock), considerably higher numbers of aphids, Eriophyoidea and spider mites were noted than in the control site (Sahajdak et al. 1995). Also Kiełkiewicz et al. (1997) noted the effect of pollution on the occurrence of Eriophyoidea on the tansy and the wormwood in the proximity of such industrial plants as Rafineria Płock, Zakłady Azotowe in Puławy, Elektrociepłownia Żerań and Huta Warszawa. In sites located close to those plants the abundance of Eriophyoidea was several times higher than in the control site. It was also noted that the highest densities of Eriophyoidea occurred in the proximity of Elektrociepłownia Żerań, where the highest soluble protein and carbohydrate contents were discovered in wormwood leaves (Kiełkiewicz et al. 1997).

The research by Kropczyńska-Linkiewicz (1984) indicates that the number of predatory mites between 0.1–1.0 specimen/leaf was sufficient to maintain the spider mites population on linden trees in urban conditions at a low level. The obtained results allow a conclusion that despite the fact that on the

Table 6. Average density of mites (specimens/100 leaves) depending on the study site and the year of the study

Study site and year of the study		Tetranychidae		Phytoseiidae	
		Average ±SE		Average ±SE	
PPN 1	2002	8.70 ±2.46	a	4.70 ±1.66	a
	2003	32.50 ±5.70	a	14.50 ±3.08	a
	2004	22.70 ±4.85	a	6.30 ±0.94	a
PPN 2	2002	22.00 ±4.47	a	4.60 ±1.39	a
	2003	40.80 ±10.22	a	13.50 ±3.66	a
	2004	45.90 ±9.60	a	6.40 ±1.18	a
PPN 3	2002	39.60 ±9.20	a	7.80 ±2.66	a
	2003	34.90 ±5.03	a	10.20 ±1.62	a
	2004	28.40 ±4.07	a	7.50 ±1.37	a
PPN 4	2002	13.60 ±3.45	a	7.70 ±1.81	a
	2003	20.40 ±3.77	a	8.10 ±2.23	a
	2004	17.80 ±3.05	a	6.20 ±1.40	a
Puławy 1	2002	77.14 ±31.26	a	9.14 ±5.37	a
	2003	53.44 ±11.63	a	10.67 ±2.87	a
	2004	21.80 ±10.96	a	3.10 ±1.33	a
Puławy 2	2002	145.57 ±70.75	a	12.86 ±4.72	a
	2003	60.44 ±20.46	a	8.67 ±1.76	a
	2004	41.00 ±13.09	a	7.70 ±2.06	a
Puławy 3	2002	64.43 ±21.49	a	8.00 ±2.45	a
	2003	56.44 ±22.43	a	5.78 ±1.28	a
	2004	64.00 ±22.53	a	7.30 ±2.07	a
Puławy 4	2002	38.86 ±14.24	a	12.00 ±4.01	a
	2003	21.33 ±5.74	a	6.67 ±1.67	a
	2004	34.60 ±8.96	a	9.90 ±3.31	a

Mean values in columns marked with the same letter do not differ significantly

studied oaks Phytoseiidae reached the bottom level of abundance given by Kropczyńska-Linkiewicz (1984), they were not always capable of maintaining the spider mite population at a low level, especially in the sites situated in Puławy. The development of Phytoseiidae population is not as dependent on the level of environmental pollution and environmental conditions, as it is in the case of development of spider mites (Kropczyńska-Linkiewicz 1984). Similar data were given by Cichocka et al. (1990a), who noted that factors connected with urbanization, such as air pollution and the presence of dust particles did not negatively affect the occurrence of predators from the family Phytoseiidae. However, it was noted by Kropczyńska et al. (1988) that the Phytoseiidae were able to keep the population of *Eotetranychus tiliarium* under control only in trees growing in parks, and not in those growing beside the streets. Also Sahajdak et al. (1995) noted that predatory

mites from the family Phytoseiidae did not react to industrial emissions and achieved similar densities in the proximity of industrial plants (Huta Warszawa, Elektrociepłownia Żerań, Zakłady Azotowe in Puławy, Petrochemia Płock) and in the control site. Furthermore, in comparison with the control site, much higher numbers of Phytoseiidae were noted in the proximity of Cementownia Warszawa: mite densities in that site were higher, because of much higher density of spider mites (Sahajdak et al. 1995). The present research confirms that the level of environmental pollution does not influence negatively the abundance of predatory mites populations, since in both study areas the mean density of these mites was similar (approximately 8 specimens/100 leaves). In the individual years of study the density of these predators per one leaf was between 0.03 and 0.12 in the sites situated in Puławy, and between 0.04 and 0.14 in the Polesie National Park sites. In the present study, predatory mites from the family Phytoseiidae accompanied spider mites from spring until autumn. Similarly, Cichocka et al. (1990a) and Kropczyńska et al. (1988) observed the occurrence of those predatory mites throughout the whole sampling period. Sometimes they were collected in early spring, even before spider mites occurred (Cichocka et al. 1990ab).

5. Conclusion

As a result of the present study a high number of spider mites on the leaves of studied oaks was found. The highest densities of these mites were noted in the sites near the Zakłady Azotowe in Puławy, whereas in the Polesie National Park they were significantly lower, which might be due to a heightened nitrogen content in oak leaves in Puławy. The number of spider mites in the Polesie National Park was lower in each year of study in comparison to the Puławy area. However, no significant influence of years of study on the number of Tetranychidae was found. Predatory mites (Phytoseiidae) reached similar densities in both study areas and no statistically significant differences between the areas were found. Only the densities in the individual years of study differed significantly from each other.

Conflict of interest

The Author declares lack of potential conflicts.

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