Acta Zoologica Academiae Scientiarum Hungaricae 54 (Suppl. 1), pp. 145–155, 2008

WAGTAILS (AVES: MOTACILLIDAE) AS INSECT INDICATORS ON PLASTIC SHEETS ATTRACTING POLAROTACTIC AQUATIC INSECTS

BERNÁTH, B.[1], KRISKA, GY.[2]*, SUHAI, B.[3] and HORVÁTH, G.[3]

[1]*Department of Zoology, Plant Protection Institute of the Hungarian Academy of Sciences, H-1525 Budapest, P. O. B. 102, Hungary*
[2]*Group for Methodology in Biology Teaching, Loránd Eötvös University, H-1117 Budapest, Pázmány Péter sétány 1, Hungary, E-mail: kriska@ludens.elte.hu*
[3]*Biooptics Laboratory, Department of Biological Physics, Institute of Physics Loránd Eötvös University, H-1117 Budapest, Pázmány Péter sétány 1, Hungary*

The polarization-based water detection of aquatic insects has evolved in a natural environment with scarce misleading polarization cues. In the last century man produced innumerable highly and horizontally polarizing surfaces acting as supernormal visual stimuli for water-seeking polarotactic insects. Typical examples are the black plastic sheets used in agriculture. To investigate the effects of horizontal plastic sheets on insects and birds, dual-choice field experiments were carried out from 1995 to 1997 with a pair of huge black and white plastic sheets laid on the ground in Hungary. The number of wagtails (*Motacilla alba*, *M. flava*) feeding in flocks on the plastic sheets and their feeding rate were counted to estimate the number of insects lured to the plastic sheets. According to our estimation, a raised-bed strawberry plantation of 10 hectares covered by shiny black plastic sheets can kill about 1 ton of aquatic insects day by day. Thus, the possible detrimental effects of such agricultural technologies may be serious and should be investigated thoroughly in the future.

Key words: plastic sheets, polarotaxis, visual deception, insectivorous birds, insect indicator, *Motacilla alba*, *M. flava*

INTRODUCTION

Polarization-based water detection of aquatic insects evolved in a man-free, natural environment with scarce misleading polarization cues. However, in the last century man-made industry produced numerous different shiny surfaces, which also reflect highly and horizontally polarized light (Fig. 1). As economy develops, more and more asphalt roads and polished cars run through wetlands. Nowadays black plastic sheets are commonly used in agriculture against weeds, and/or to keep the soil warm in order to speed up the sprouting, or simply to cover produce to protect it against rain and sunshine. In many countries plenty of temporary inland oil spills exist as a by-product of the oil industry or due to accidents or wars (HORVÁTH & ZEIL 1996, BERNÁTH *et al*. 2001*a,b*). All such surfaces lure and kill aquatic insects *en masse* (SCHWIND 1991, CSABAI *et al*. 2006). Thus, estimating the possible detrimental effects of artificial, highly and horizontally polarizing surfaces on polarotactic aquatic insects became an important task. To investigate the effects of horizontal plastic sheets on insects and birds, dual-choice field experiments were carried out from 1995 to 1997 with a pair of huge black and white plastic sheets laid on the ground in Hungary. The number of wagtails feeding in flocks on the plastic sheets and their feeding rate were counted to estimate the number of insects lured to the plastic sheets.

MATERIALS AND METHODS

The test surfaces used in our dual-choice field experiments were black or white polyethylene sheets measuring 12 m × 33 m. They were laid on the ground in a large alkaline field (bed of a former large lake) at about 500 m from a smaller alkaline lake in the Hungarian Great Plain near Kunfehértó (BERNÁTH & HORVÁTH 1999, BERNÁTH *et al*. 2001*a,b*). The vegetation beneath the plastic sheets was mown. Sheets were stretched out horizontally as tightly as possible and were pinned down by bricks at the edges. The distance between the two plastic sheets was 30 m. In all experiments involving two sheets the white plastic sheet was closer to the lake in the first half of the experiment, and the two sheets were transposed with each other in the second half. The behaviour of birds was observed from a hide at a distance of 25 m from the plastic sheets. Insects were observed from close range and their carcasses were collected 3 times a day, when the plastic sheets were re-stretched. The carcasses of insects larger than 5 mm were collected from the plastic sheets through 10 days in the first year. To estimate the numbers of insects lured by plastic sheets, sticky insect traps were also deployed in the same locality where our dual-choice experiment using dry test surfaces was performed in August 1999. Four sticky traps consisted of 1 m^2 black, white, light grey and dark grey shiny plastic sheets fixed onto horizontal wooden underplates and covered with non-drying Oecotak10 insect monitoring glue were used. These traps were placed in a square area at a distance of 5 meters from each other and left there for 10 days. These sticky traps captured all smaller insects touching them, but large-bodied dragonflies, for example, were observed to leave their surfaces. The reflection-polarization characteristics of the black sticky trap were practically the same as those of the shiny black plastic sheet, while the white sticky trap acted as the analogue of the shiny white plastic sheet. The four sticky traps formed a gradient of both the degree of linear polarization and the intensity of reflected light: the lower the intensity, the higher the degree of polarization. The number of insects stuck in the glue of the sticky traps was estimated by averaging the number of trapped insect items within 10 samples of 100 cm^2 areas on each trap surface. One-way ANOVA was used to compare the numbers of insects caught by the four sticky traps (Fig. 2). In all years from the very first days of our field experiments using the white and black plastic sheets insectivorous wagtails (*Motacilla alba* and *M. flava*) appeared in flocks on the sheets both in the morning and the evening, and fed on the small insects attracted by the plastic sheets (BERNÁTH *et al*. 2001*a,b*). From 1997 to 1999 the number of wagtails and their feeding rate were counted on the plastic sheets and on water banks in the vicinity. It was assumed that these numbers are proportional to the number of insects attracted to the plastic sheets (Figs 3 and 4). Between 23 and 31 July 1997 the feeding rate of wagtails was compared on the white and the black plastic sheets (each with an area of 400 m^2) and natural water banks. The numbers of wagtails gathering on the plastic sheets were recorded between 1 and 3 August 1997. Since on the water banks single individuals fed in the coastal zone that was no wider than 1 m, only feeding rate was recorded at this locality. Two-way ANOVA was used to compare the feeding rate and the number of wagtails feeding at the mentioned localities in the hours after sunrise and before sunset (Figs 3A,B and 4A,B). In 1998, from 17 July to 1 August the role of the area of the plastic sheet was studied by comparing the feeding rates and number of wagtails on the black plastic sheet, the area of which was 400 m^2 at the beginning, then it was halved by folding in every two days. The last (smallest) size of the plastic sheet was only 6 m^2. In 1999, from 4 to 20 August the same experiment was repeated, but then the area of the black plastic sheet laid onto the ground was 6 m^2 at the beginning, and it was doubled by unfolding in every two days. However, in 1999 the experiment was hindered by the humid weather conditions: all depressions and pits in the surrounding bed of the former lake were filled with water acting as competitors of the plastic sheet. The replenishment of the former lake prevented us to perform further experiment in the same area.

Fig. 1. Industry-produced, horizontally polarizing, shiny surfaces. (A) The use of black plastic sheets on several hectares became widespread in agriculture, especially in the modern raised-bed technology of strawberry production. (B) Waste oil lake in Budapest. (C) New asphalt roads are built in narrow walleyes on the very edge of creeks

RESULTS

Only the black plastic sheet attracted insects associated with water, while the white plastic sheet was unattractive to them. The following insect species were attracted to the horizontal shiny black plastic sheet used in the dual-choice field experiment of BERNÁTH *et al*. (2001*b*): Ephemeroptera: *Baetis rhodani, Cloeon dipterum, Ecdyonurus venosus, Epeorus silvicola, Ephemera danica, Haproleptoides confusa, Rhitrogena semicolorata;* Plecoptera: *Perla burmeisteriana;* Coleoptera: *Acilius sulcatus, Anacaena limbata, Besorus luridus, Copelatus ruficollis, Cybister laterimarginalis, Cymbiodita marginella, Dytiscus dimidatus, Hydaticus transversalis, Hydrobius fusipes, Hydrochara caraboides, H. flavipes, Hydrophilus piceus, Hyphydrus ovatus, Laccophilus obscurus, Phylidrus bicolor, Rhanatus punctatus, Spercheus emarginatus;* Heteroptera: *Sigara assimilis, Corixa affinis, Cymatia rogenhoferi, Hesperocorixa linnei, Notonecta glauca, Sigara falleni, S. lateralis, S. striata.* Although both plastic sheets were checked every day, water insect carcasses were found exclusively on the black plastic sheet. The carcasses of insects larger than 5 mm collected during 10 days included 86 Hydrophiliidae, 42 Dytiscidae, 23 Corixidae and 21 Notonectidae. All these aquatic insects showed similar behavioural elements on and above the black plastic sheet: landing, flying up, touching and crawling on the surface, egg-laying. Finally, all of them dried out and perished within some hours. Butterflies, flies, bees, wasps and dragonflies were

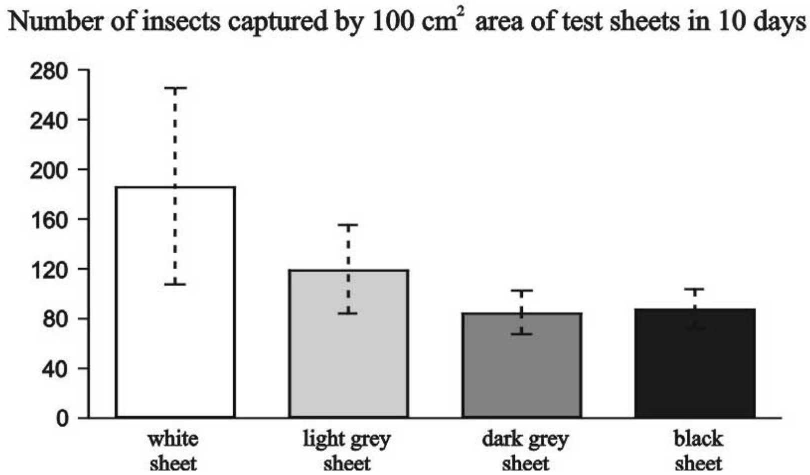

Fig. 2. The number of insects trapped by 1 dm^2 sampling areas of the sticky plastic sheets. Columns represent the average, vertical bars show the standard deviation of the number of insects in 12 sample areas on each sticky plastic sheet

also attracted to both plastic sheets, but they did not perish on them. Thus, black plastic sheets (like oil surfaces) can be dangerous mostly for aquatic insects. No aquatic insects crashing on the white plastic sheet were observed (BERNÁTH *et al.* 2001*b*). Almost at every sunset the black plastic sheet rattled sounding like the pattering of raindrops. The reason for this was thousands of Corixidae bugs landing on and crashing into the black plastic, then jumping repeatedly up and down. They did not leave this optical trap, and did not fly away from the visually attractive black

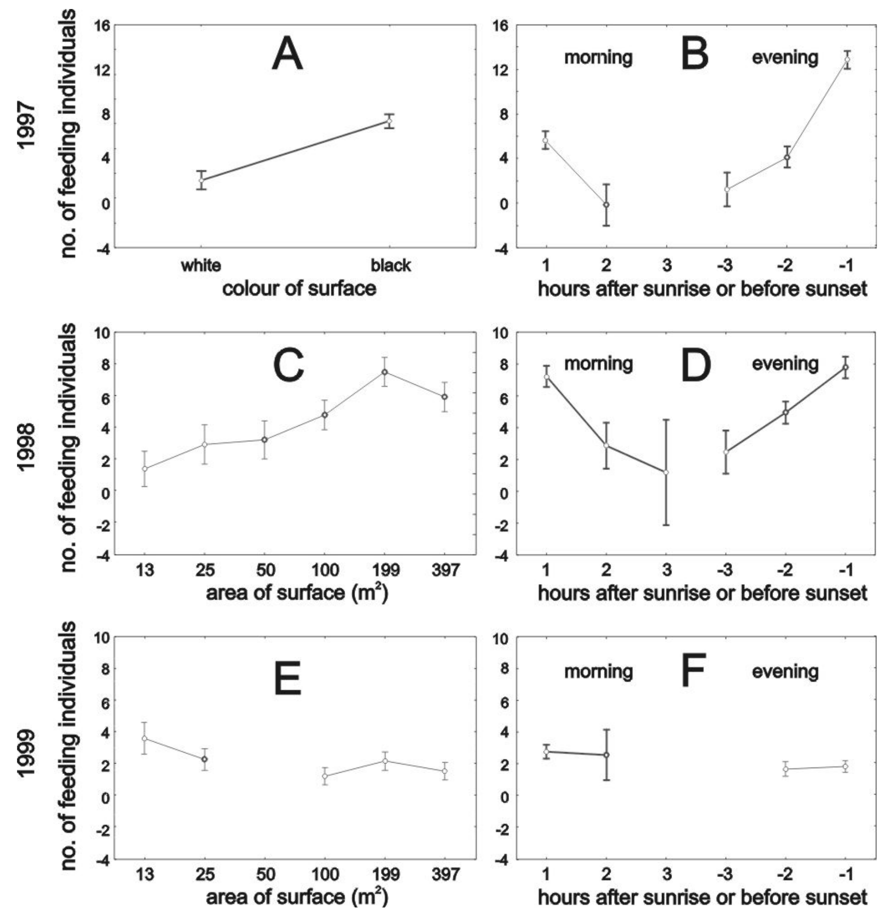

Fig. 3. Average number of wagtails (*Motacilla alba* and *M. flava*) feeding on natural water banks and the (black and white) plastic sheets used in our field experiments (A, C, E) in the hours after sunrise and before sunset (B, D, F) in 1997 (A, B), 1998 (C, D) and 1999 (E, F) near Kunfehértó, C Hungary. Vertical bars show 0.95 confidence intervals. In 1997 the wagtails were studied on both the black and white plastic sheets as well as on the shore of alkaline lakes. In 1998 and 1999 the wagtails were investigated on a single black plastic sheet with gradually decreasing and increasing area, respectively

plastic sheet; they remained on it throughout the night and perished do to dehydration. At the white plastic sheet similar effect was not observed (BERNÁTH *et al.* 2001*b*). At sunset the black plastic sheet was as cool as the white one. Thus, we conclude that the (same) temperature of the plastic sheets was surely not the reason for the attractiveness of the black plastic to aquatic insects. The numbers of insects trapped in 10 days by the sticky traps was proportional. Interestingly, the number of trapped insects was proportional to the surface brightness (intensity). The white sticky trap caught the most insects. There was no significant difference between the black and the dark grey traps, and both traps captured significantly less insects than the light grey trap. The species compositions of trapped insects were, however, quite different: The white trap captured mainly small dipterans, while small aquatic insects and Corixidae water bugs, for example, were found exclusively on the dark grey and black traps. On the other hand, dipterans were never observed to be detained and perish on the shiny white dry (non-sticky) plastic sheet. This suggests that the number of insects occurring throughout the day in the immediate vicinity of the plastic sheets is an unsuitable measure of their potential detrimental effect, since many insects visit bright/dark (in warm/cool weather) surfaces as part of their thermoregulation, for example. Wagtails obviously were attracted to the plastic sheets as to rich food sources due to the lured insects. They started to gather on the plastic sheets in the afternoon at about 3 hour before sunset, but most of them arrived only in the last hour prior to sunset. All wagtails left the plastic sheets about 10 minutes after sunset at the latest. In this period they collected the most insects lured to the plastic sheets. The active feeding of wagtails on both the black and white plastic sheets proved that the plastic surfaces lured many insects. However, the black plastic was more effective insect attractor in the evening: aquatic insects arrived to the black plastic *en masse* in the dusk period and possibly also at night. Wagtails returning early in the cool morning hours fed on the carcasses of insects perished on the plastic sheets during the night. They arrived shortly before sunrise and left the plastic sheets within about 3 hours. Since the feeding activity of wagtails was well observable through binoculars, these birds served as excellent indicators of the insects attracted to the plastic sheets. Both the black and white plastic sheets acted as a significantly much richer food source than the water banks (Fig. 4A, $F(2, 199) = 26.613$, $p < 0.001$). The feeding rate of wagtails was not significantly higher on the black plastic sheet than that on the white one ($F(2, 146) = 0.257$, $p = 0.613$). In the hour before sunset the feeding rate was significantly higher both on the (black and white) plastic sheets and the water banks (Fig. 6B, $F(5, 199) = 2.196$, $p = 0.056$). On the white plastic sheet never were observed more than 14 birds to feed together. This maximal bird density was much lower than that on the black plastic, where up to 35 individuals were counted in some occasions in 1997.

Significantly more birds fed on the black plastic, especially in the hour before sunset (Fig. 3B, $F(4, 385) = 90.703$, $p < 0.001$). Obviously, wagtails kept so high feeding rate on both plastic sheets, which was unreachable on the water banks (Fig. 4B). Although confrontations and conflicts among the wagtails feeding on the plastic sheets were observed sparsely, no characteristic elements of territorial behaviour (DAVIES 1977, HOUSTON *et al.* 1985) were observed. Since the birds may move to the richest food sources, their distribution on the plastic sheets indicated the density of insects lured to the plastic sheets. Although numerous insects were available also on the white plastic, the black plastic provided a much richer insect supply, where the wagtails could consume as much as maximum 700 insects per minute prior to the sunset. Considering the number of wagtails and their feeding

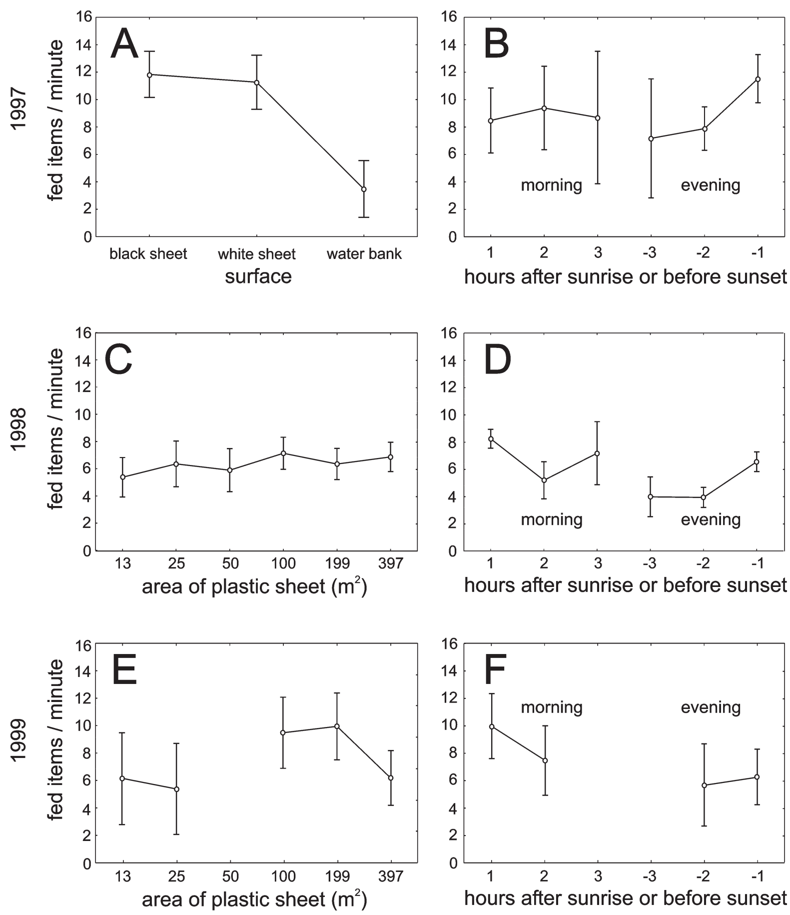

Fig. 4. As Fig. 3 for the average feeding rate of wagtails

rate, 400 m^2 black plastic sheet may attract and trap (due to dehydration) at least 50 000 small aquatic insects evening by evening. Thus, a raised bed strawberry plantation of 10 hectares covered with shiny black plastic sheets, for example, can kill about 1 ton of aquatic insects every day. In 1998 no wagtails were observed on the black plastic sheet, if its surface was smaller than 12 m^2. This suggests that wagtails feed in the evening and morning only on marshy water banks with a surface larger than about 12 m^2. The maximum number of wagtails on the black plastic sheet with an area of 400 m^2 was 30. The feeding rate of wagtails did not change significantly during the 1998 season (Fig. 4C, $F(5, 710) = 1.121$, $p = 0.35$) in spite of the fact that the area of the black plastic sheet was gradually reduced from 100% (400 m^2) to 3% (12 m^2). As it has also been observed earlier, wagtails fed much more intensely in the hour before sunset (Fig. 4D, $F(5, 710) = 17.275$, $p < 0.001$) and left the black plastic only when the sun descended below the horizon. Most wagtails gathered on the black plastic sheet prior to sunset and immediately after sunrise (Fig. 3D, $F(5, 637) = 20.671$, $p < 0.001$). However, the number of birds became lower and lower as the size of the black plastic sheet was reduced; the number of birds was proportional to the plastic area (Fig. 3C, $F(5, 637) = 23.603$, $p < 0.001$). An anomalous effect was found at the beginning of the experiment: on the second day more wagtails gathered on the black plastic sheet than on the first day, although the plastic area was reduced by 50%. The reason for this anomaly might be the spreading of information among birds: in the first days more and more individuals followed the experienced members of the flock to the plastic sheet. Similar effect was observed also during our experiments in 1995 and 1996. In 1999 wagtails appeared first when the area of the black plastic sheet reached 12 m^2. Unlike in earlier seasons, only exceptionally gathered more than 5 wagtails on the black plastic, and their number never exceeded 7. However, in contrast to our earlier results, the feeding rate (Fig. 4E, $F(4, 68) = 5.648$, $p < 0.01$) and the number (Fig. 3E, $F(4, 68) = 4.555$, $p < 0.01$) of wagtails on the black plastic differed significantly when the plastic area gradually increased. Since generally only 1 or 2 birds fed on the black plastic, the results of the statistical analysis were not interpretable. Although in this season many small water bodies existed in the vicinity of the plastic sheet, wagtails were only seldom observed on their shore. Consequently, only a few wagtails were in the habitat. Although the food supply on the black plastic sheet was again much richer than on the banks of water, the food need of the few wagtails occurring in the habitat could be easily satisfied on the shore of the numerous neighbouring ponds. Thus, in 1999 the number of wagtails was not an appropriate measure of the amount of aquatic insects lured by the black plastic sheet.

DISCUSSION

The strong attractiveness of horizontal shiny black plastic sheets to polarotactic insects makes them an efficient tool for entomologists to monitor aquatic insects (CSABAI *et al*. 2003, 2004, 2006). However, if laid out on great areas in the field, such plastic sheets may seriously harm the local population of water-loving insects. This visual ecological phenomenon may not be severe for water insect populations, but aquatic insects are not pests in conventional agriculture, thus their perishing is unnecessary and potentially tilts over the balance of nearby aquatic habitats. Huge horizontal plastic surfaces may also isolate the water insect populations of smaller lakes by trapping most aquatic insects migrating from one lake to the other. Thus, agricultural mulching technologies involving large, highly and horizontally polarizing plastic sheets may be the points of interest. Considering the number of wagtails feeding on plastic sheets, for example, the larger the plastic area, the more insects are lured and trapped (by dehydration). Wagtails are known to feed normally on small insects on marshy water banks in the evening (ZAHAVI 1971, DAVIES 1977, DAVIES & HOUSTON 1981). They were also regularly observed on the shores of the nearby small alkaline lakes during our choice experiments. Because of their rapid metabolism, wagtails aspire to reach the highest possible feeding rate (DAVIES 1977), especially prior to sunset (when insects are abundant on the shore of water bodies) and after sunrise (to compensate the overnight loss of energy). The feeding rate of wagtails is a good measure of the food supply only, if it is relatively poor, when the birds cannot reach the maximum number of consumable food items. In the case of richer food sources also the number of birds should be taken into consideration, although it might be strongly influenced by the territorial behaviour and several environmental factors (ZAHAVI 1971, DAVIES 1977, DAVIES & HOUSTON 1981). In contrast to insects, birds are able to learn the differences between water surfaces and artificial horizontal shiny surfaces. This makes ambiguous the interpretation of the results of our choice experiments. However, the primary reactions of birds should be based on their former experiences gained near water surfaces. That may be the reason for why the observed wagtails took the plastic sheets as water, and why have they been trapped in great numbers by oil lakes (*e.g.* BERNÁTH *et al*. 2001*b*). Thus, among the detrimental effects of inland oil surfaces, also optical cues misleading insects and birds should be specified. Although birds too are usually trapped in great numbers by open-air oil reservoirs, their reactions to the plastic sheets during our choice experiments did not lighten why are they lured to these surfaces. On the other hand, it is noteworthy that wagtails assembled on the plastic sheets in great numbers even in the first evening of the deployment of the plastics. Nevertheless, on the subsequent days of our choice experiment the knowledge of the black plastic sheet as a rich food source obviously played a more important role in the behaviour of wagtails. Although wagtails sleeping together are known to follow well-fed individuals to rich food sources – that means that the information about food sources spreads among birds (ZAHAVI 1971) – such reactions could be explained only by the familiarity of wagtails with reflecting surfaces having similar optical characteristics. During the day wagtails feed primarily on larger dipterans around dung spots protected and guarded by single individuals. However, in the morning and evening wagtails assemble on water banks to hunt for small aquatic insects flying in these periods in great numbers (DAVIES 1977, CSABAI *et al*. 2003, 2004, 2006). Wagtails are also known to take advantage of insect-attracting artificial surfaces like asphalt roads and wet moles (REZANOV 1981). The aggregation of wagtails on the plastic sheets must have been driven primarily by the optical cues of the plastics perceivable from great distances and being similar to those of marshy water banks or asphalt roads. This may be the cause why birds, too are usually killed in great numbers by open-air oil reservoirs. Environment damages induced by horizontal artificial dark shiny surfaces not killing instantly the animals touching them, should also be taken into consideration, since they polarize the reflected light highly and horizontally, consequently they are highly dangerous to polarotactic, water-seeking insects. On the other hand, these surfaces practically do not harm birds. Since the size, shape and optical characteristics of plastic sheets (*e.g.* black: highly polarizing, grey: moderately polarizing, white: depolarizing) can be manipulated and controlled easily, even in field experiments, such plastic sheets can be applied as a useful method in future behaviour-ecological researches, especially in dry habitats, where large natural water surfaces are rare or missing.

*

Acknowledgement – This work was supported by an equipment donation received by G. HORVÁTH from the German Alexander von Humboldt Foundation. The grants OTKA T-020931, OTKA F-025826 and OTKA K-6846 received from the Hungarian Scientific Research Found are gratefully acknowledged.

REFERENCES

BERNÁTH, B. & HORVÁTH, G. (1999) Visual deception of a Great White Egret by shiny plastic sheets. *Ornis Hungarica* **8–9**: 1–2, 57–61.

BERNÁTH, B., SZEDENICS, G., MOLNÁR, G. & HORVÁTH, G. (2001*a*) Visual ecological impact of a peculiar oil lake on the avifauna: Dual choice field experiments with water-seeking birds using huge shiny black and white plastic sheets. *Archives of Nature Conservation and Landscape Research* **40**(1): 1–28.

BERNÁTH, B., SZEDENICS, G., KRISKA, G. & HORVÁTH, G. (2001*b*) Visual ecological impact of "shiny black anthropogenic products" on aquatic insects: oil reserviors and plastic sheets as polarized traps for insects associated with water. *Archives of Nature Conservation and Landscape Research* **40**(2): 87–107.

CSABAI, Z., BODA, P., BERNÁTH, B., KRISKA, GY. & HORVÁTH, G. (2006) A 'polarisation sun-dial' dictates the optimal time of day for dispersal by flying aquatic insects. *Freshwater Biology* **51**: 1341–1350.

CSABAI, Z., GIDÓ, ZS., MÓRA, A., BODA, P., DÉVAI, GY., KIRÁLY, A., SZILÁGYI, K. & VARJU, T. (2003) Migration activity patterns of aquatic beetles and aquatic bugs (Coleoptera, Heteroptera) I. Changing of the number of individuals and species richness. *Hidrológiai Közlöny* (*Journal of the Hungarian Hydrological Society*) **83**: 29–32. [in Hungarian]

CSABAI, Z., GIDÓ, ZS., BODA, P. & MÓRA, A. (2004) Migration activity patterns of aquatic beetles and aquatic bugs (Coleoptera, Heteroptera) III. Seasonal and daily migration of selected species. *Hidrológiai Közlöny* (*Journal of the Hungarian Hydrological Society*) **84**: 28–30. [in Hungarian]

DAVIES, N. B. (1977) Prey selection and social behaviour in wagtails (Aves: Motacillidae). *Journal of Animal Ecology* **46**: 37–57.

DAVIES, N. B. & HOUSTON, A. I. (1981) Owners and satellites: The economics of territory defence in the Pied Wagtail, Motacilla alba. *Journal of Animal Ecology* **50**: 157–180.

HOUSTON, A. I., MCCLEERY, R. H. & DAVIES, N. B. (1985) Territory size, prey renewal and feeding rates: interferation of observations on the Pied Wagtail (Motacilla alba) by simulation. *Journal of Animal Ecology* **54**: 227–239.

HORVÁTH, G. & ZEIL, J. (1996) Kuwait oil lakes as insect traps. *Nature* **379**: 303–304.

REZANOV, A. G. (1981) Feeding behaviour and modes of feeding in the Wagtail Motacilla alba (Passeriformes, Motacillidae). *Zoologichesky Zhurnal* **60**(4): 548–556. [in Russian]

SCHWIND, R. (1991) Polarization vision in water insects and insects living on a moist substrate. *Journal of Comparative Physiology A* **169**: 531–540.

ZAHAVI, A. (1971) The social behaviour of the White Wagtail (Motacilla alba alba) wintering in Israel. *Ibis* **113**: 203–211.

Revised version received April 8, 2007, accepted July 12, 2007, published December 30, 2008