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VISUAL ECOLOGICAL IMPACT OF "SHINY BLACK ANTHROPOGENIC PRODUCTS" ON AQUATIC INSECTS: OIL RESERVOIRS AND PLASTIC SHEETS AS POLARIZED TRAPS FOR INSECTS ASSOCIATED WITH WATER

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The waste oil lake in Budapest (Hungary) deceived, attracted and killed insects in large numbers and acted as a huge insect trap for 50 years from 1951. From August, 1997 to September, 1998 we observed and collected certain typical insects trapped by the oil. An estimate was made of numbers of insects associated with water of different groups identified in the 3000 m^3 of the waste oil lake.

Many insects associated with water (*e.g.*, aquatic insects, insects living on moist substrata, dragonflies and mayflies) find their aquatic habitat by means of polarotaxis, that is, on the basis of the horizontally polarized light reflected from the water surface. We measured the reflection-polarization characteristics of the surface of the waste oil lake through time. In warm weather the surface of the oil was flat, shiny and acted as an efficient reflector and polarizer, like a water surface. Then the shiny oil surface occurred as an exaggerated, attractive water surface offering a supernormal optical stimulus to flying, polarotactic water-seeking insects. In cool or cold weather, however, the surface became dull, matt, or even wrinkled and lost its polarization and attractiveness to polarotactic insects.

To investigate how dragonflies behave at the waste oil lake, and how they are entrapped by the oil, and what is their behaviour like prior to the moment of entrapping, we observed the typical water-specific behaviour of dragonflies at the oil surface.

To study the visual ecological impact of the huge shiny black or white plastic sheets used in agriculture, we performed dual-choice field experiments with certain insects associated with water. We laid a shiny black and a shiny white plastic sheet onto the ground and observed

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the attracted insects and their behaviour. The measured and calculated reflection- polarization characteristics of these plastic sheets are also presented.

Finally, some environmental protective and animal welfare arrangements are suggested that should be taken urgently in the vicinity of the habitats and biotopes of insects associated with water in order to eliminate the dangerous visual attractiveness of any open-air oil reservoirs and tar, asphalt or plastic surfaces to these insects.

Keywords: Insect fauna; Insect trap; Waste oil lake; Plastic sheets; Asphalt roads; Environmental impacts; Visual deception; Water detection; Polarization vision; Polarotaxis; Reflection polarization; Polarimetry

INTRODUCTION

Since 1951 has existed an open-air oil reservoir, the so-called "waste oil lake" in a suburb of Budapest (Horváth *et al.*, 1998). Bernáth *et al.* (2001) reported on the impact of this oil lake on the avifauna. We observed that this oil lake deceives, attracts and traps also insects in large numbers (Fig. 1). We could observe the behaviour of larger dragonflies. Several dragonfly species are on a list of protected insects in many countries. Unfortunately, in practice they receive no protection from several environmental damages; they are entrapped in large numbers by the natural tar seeps or artificial open-air oil reservoirs, for instance. Studying their reaction to the water-imitating black oil surfaces could help in suggesting necessary arrangements to be taken

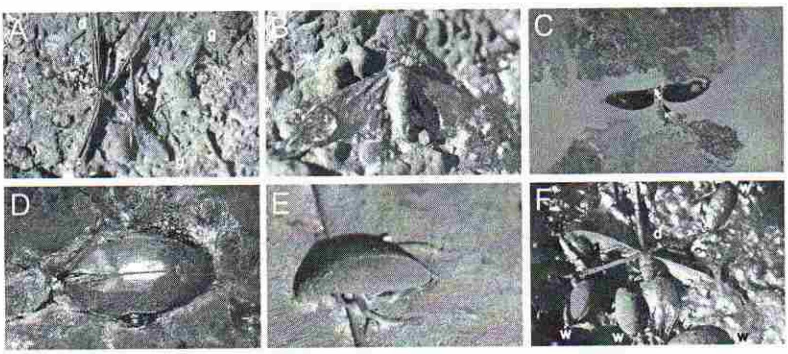

FIGURE 1 Some typical representatives of the insects collected from the waste oil lake in Budapest and photographed on the oily shore (A, B, E, F) and the oil surface (C, D). (A) A dragonfly (d, *Anax imperator*), a long-bodied water scorpion (b, *Ranatra linearis*) and two waterstriders (g, *Gerris lacustris*). (B) A moth (Lepidoptera sp.). (C) A mayfly (*Cloeon dipterum*). (D) A water beetle (Dytiscus sp.). (E) A great silver diving beetle (*Hydrous piceus*). (F) A dragonfly (d, *Sympetrum vulgatum*), and scavenger beetles (w, Hydrophiliidae sp.). (See Colour Plate I at the end of the issue).

for the prevention of their mass trapping by these oil surfaces. Prior to the removal of the waste oil lake in Budapest, from August, 1997 to June, 1998 we could observe and document insects trapped by the oil. To estimate the number of trapped water insects, we sampled their carcasses in one of the seven oil reservoirs. The first aim of this work is to report on the results of this observation.

Insects associated with water can be deceived not only by oil or tar surfaces but also by every shiny and darker surface if it is more or less horizontal. Fernando (1958) and Popham (1964), for example, have observed water insects deceived by glass panes, car roofs and wet asphalt streets. Horváth *et al.* (1998) and Kriska *et al.* (1998) showed that dragonflies and mayflies are deceived by and attracted *en masse* to dry asphalt surfaces and shiny black plastic sheets. We observed, too that many other insects associated with water are attracted to dry windscreens, car roofs, asphalt roads and black plastic sheets (Figs. 2 and 3).

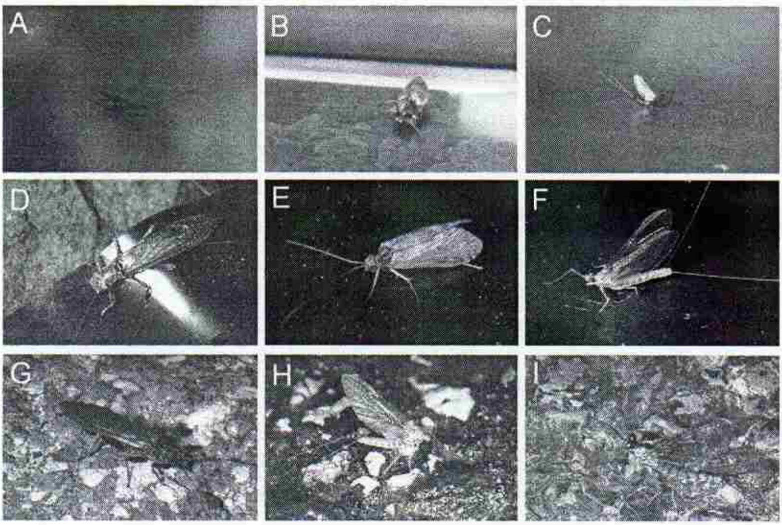

FIGURE 2 Some examples how water-loving insects can be deceived by and attracted to different artificial shiny dry surfaces such as windscreens (A), car roofs (B, C), black plastic sheets used in agriculture (D–F) and asphalt roads (G–I). (A) A male mayfly (*Rhithrogena semicolorata*). (B) A scavenger beetle (Hydrochara sp.). (C) A male mayfly (*Baetis rhodani*). (D) A female large stonefly (*Perla burmeisteriana*). (E) A female caddish fly (Trichoptera sp.). (F) A female mayfly (*Rhithrogena semicolorata*). (G) A female large stonefly (*Perla burmeisteriana*). (H) A female mayfly (*Rhithrogena semicolorata*). (I) A male mayfly (*Epeorus silvicola*). (See Colour Plate II at the end of the issue).

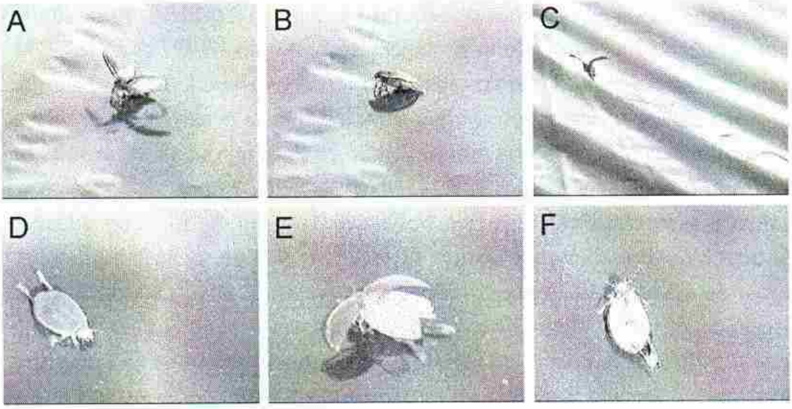

FIGURE 3 Behaviour of a great diving beetle (*Dytiscus marginalis*) on a shiny dry black plastic sheet at sunset. (A) Landing on the plastic sheet, the temperature of which was about 20°C. (B) Touching, trying and probing the sheet. (C) Flying up from the plastic sheet and looking for another place. (D) After landing again, the beetle tries to swim, crawl, or creep on the smooth plastic sheet. (E) After half an hour the beetle gets entirely exhausted, it cannot fly away, although it tries to fly up several times. (F) After an hour the beetle perishes. (See Colour Plate III at the end of the issue).

Certain insects swarming in large numbers are frequently attracted towards shiny car-bodies and lay often their eggs onto the coach-work. Recently, Stevani *et al.* (2000a,b) demonstrated that the eggs laid by some Brasilian dragonflies onto car-bodies produce strong sulfonic acids above 70°C that destroy the clearcoat. These acids originate from proteins of the egg-shell (chorion) as products of chemical reactions that can proceed in the eggs of most insects. The temperature of car-bodies can often rise above 70°C in sunshine. Then eggs laid onto the car surface can damage the resin like acid rain. According to our measurements, the hood and the top of car-bodies can reflect strongly and horizontally polarized light, that attracts many polarotactic insects. They land or oviposite onto the glittering horizontal parts of the coach-work, because they mistake them for water.

The above natural or artificial shiny surfaces deceive and attract polarotactic insects by the horizontally polarized reflected light, because many aquatic insects and insects living on moist substrata find their aquatic habitat by means of polarotaxis, that is, on the basis of the horizontally polarized light reflected from the water surface (Schwind, 1991, 1995). The same was shown for dragonflies and mayflies (Horváth *et al.*, 1998; Kriska *et al.*, 1998; Wildermuth, 1998). Horváth and Zeil (1996); Horváth *et al.* (1998) and Kriska *et al.* (1998) demonstrated that black oil, asphalt or shiny plastic sheets are efficient reflectors, the direction of polarization of the light reflected from their surface is always horizontal and in the visible range of the spectrum its degree of polarization is higher than that of light reflected from natural bodies of water. Thus, these shiny surfaces act as an exaggerated water surface offering a supernormal optical stimulus to flying, polarotactic insects associated with water. These authors showed too, that olfaction and thermoreception are not relevant for detection of water by polarotactic insects.

In warm weather the surface of the oil lakes, tar pits or asphalt seeps is flat, shiny and acts as an efficient reflector and polarizer, like a water surface. In cool or cold weather, however, the surface becomes dull, matt, or even wrinkled and loses its polarization. To demonstrate this effect we measured the reflection-polarization characteristics of the surface of the waste oil lake in Budapest *versus* time. The second aim of this work is to present the results of our polarometric measurements.

It is of particular importance to establish how insects, especially certain protected species (*e.g.*, some dragonfly species), behave at the oil lakes, and how they are entrapped by the oil, and how they behave prior to the moment of entrapping. It is important to know what the deceived insects do at shiny black plastic sheets, which cannot trap them. These plastic sheets are often used in agriculture against weeds, and/or to keep the soil warm in order to speed up the sprouting, or simply cover produce and protect it against rain. Do the attracted insects leave such a shiny black horizontal surface having recognized that it is not water? If not, such a surface can also be dangerous for polarotactic insects, because they can dry out easily and perish hopelessly. Till now little attention has been paid to the visual ecological impact of these huge shiny black plastic sheets to the insect fauna.

Apart from the plunge reaction of the water bug *Notonecta glauca* (Schwind, 1984) and the reproductive behaviour of certain mayflies (Kriska *et al.*, 1998) and dragonflies (Horváth *et al.*, 1998; Wildermuth, 1998) above dry asphalt roads and different shiny plastic sheets, the behaviour of aquatic insects above such artificial shiny surfaces has not been investigated till now. The third aim of this work is to report briefly on the behaviour of certain aquatic insects deceived by and attracted to shiny white and black plastic sheets and black oil surfaces, and to present measured and calculated reflection-polarization characteristics of these plastic sheets.

MATERIALS AND METHODS

Collection of Insect Carcasses and Observation of the Behaviour of Dragonflies at the Waste Oil Lake in Budapest

The waste oil lake is positioned (47°27′ North, 19°17′ East) in the 18th district of Budapest (Hungary) and consists of 7 reservoirs situated within an approximately 220 m × 110 m rectangular area. From April, 1998 the oil lake is being removed. From August, 1997 to June, 1998 we surveyed the waste oil lake weekly to collect the carcasses of typical representatives of the insects trapped by the oil. The larger insect carcasses were collected simply by hand and photographed on the shore of the oil lake (Fig. 1).

In September, 1998 the liquid waste oil was removed from the reservoirs and transported. During removal the entire mass of the oil was mixed frequently in the lake to ease pumping. This allowed us to sample on the shore the insect carcasses floating and submerged in the oil. These insect carcasses may be representative for all the 3000 m^3 of oil in the lake. Large volume samples were taken to collect carcasses of insects trapped in small numbers too. Using large strainers and scoops, we filtered 145 litres of waste oil in three equal portions on the shore of the oil lake. The diameter of the holes of the strainer was 1 mm, thus insect carcasses larger than about 1 mm were filtered from the oil. The collected and filtered insect carcasses were cleaned using petrol and conserved in methanol in the laboratory for later identification. Special care was taken to save every fragment of carcasses during separation, cleaning and identification.

Dual-choice Field Experiments with Insects Associated with Water

In every May, June and August from 1996 to 1999 we performed simple dual-choice field experiments with certain aquatic insects at two different places in Hungary:

1. In a large alkaline field at about 500 m from a smaller alkaline lake near Kunfehértó, a village in the southern part of the Hungarian Great Plain. Two plastic (polyethylene) sheets of 600 m^2 were laid on the ground 30 m apart. The vegetation beneath the sheets was mown, and the sheets were

stretched out horizontally as tightly as possible. Such plastic sheets are commonly used in agriculture. One of the sheets was black and the other milky translucent.

In sunshine, the lower surface of the latter dimmed in some minutes following unfolding and the plastic sheet became brilliant white because the billions of tiny condensed water drops scattered the incident light diffusely. The black plastic sheet was used to imitate the shiny dark surface of oil or tar surfaces, and the white plastic sheet mimicked the surface of brighter bodies of water. We observed the insects attracted to the sheets. From 2 to 14 August, 1996 we collected the carcasses of aquatic insects larger than 5 mm at every noon for later identification.

2. Near the village of Dömörkapu located approximately 30 km from Budapest. Our study site was the bank of a typical reach of a mountain creek called "Bükkös patak". Two polyethylene sheets of 20 m^2 were laid on the ground 5 m apart on the bank, and the insects attracted to them were observed. The arrangement and orientation of the sheets were changed randomly during an experiment.

Measurement and Calculation of the Reflection-polarization Characteristics of the Waste Oil Surface and the Plastic Sheets

Using videopolarimetry, we measured the reflection-polarization characteristics of the surface of the waste oil lake in spring, summer and autumn. In winter such measurements were not performed because the surface of the oil lake was usually covered by snow and in winter flying insects were generally absent. The method of videopolarimetry is described in detail by Horváth and Varjú (1997). The measurements were performed always under clear skies for a solar zenith angle of 60°. The viewing direction of the camera was 60° relative to the vertical and perpendicular to the solar meridian. We obtained the data of the daily maximal air temperature in Budapest from the Hungarian Meteorological Service. The reflection-polarization characteristics of the white and the black plastic sheet used in the dual-choice experiments were also measured under a clear sky for a solar zenith angle of 60°. The viewing direction of the camera was 60° relative to the vertical and perpendicular to the solar meridian.

We could measure the polarization of reflected light through the three colour channels of the video camera: red (650 nm), green (550 nm) and blue (450 nm). Because the recorded waste oil surface and the plastic sheets were colourless, their reflection-polarization characteristics were practically independent of the wavelength of light. These surfaces have the common spectral feature that they reflect the entire visible spectrum of the incident light approximately equally, as do all neutral grey objects. Thus, we present only the reflection-polarization patterns measured in the blue range of the spectrum and omit the similar patterns measured in the green and red spectral ranges.

The degree of polarization of light reflected from a white and a black plastic sheet as a function of the angle of incidence was calculated on the basis of the mathematical method of Horváth and Pomozi (1997). The calculations were performed for different values of the albedo of the white plastic sheet.

RESULTS

Insects Trapped by the Waste Oil Lake

Figure 1 shows some typical representatives of the insects collected from the waste oil lake in Budapest and photographed on the oily shore and the oil surface. Table I summarizes the names of all insect species, the carcasses of which were collected from the waste oil lake in Budapest and could be identified. We observed that dragonflies, mayflies, water bugs, water beetles and butterflies were trapped *en masse* by the oil in spring, summer and autumn at the time of their swarming and migration. Usually, the insects landed or plunged directly on the sticky oil surface and became immediately entrapped. We often observed copulating pairs of insects – *e.g.*, dragonflies, and mayflies – to be trapped by the oil during copulation and/or egg-laying. Depending on the viscosity of the oil the trapped insects sank within more or less time. The greater the oil temperature, the lower the oil viscosity, and the shorter the time interval (ranging from 5–10 seconds to 1–3 months) between landing and submergence of an insect.

Most of the insect carcasses filtered from the oil were in very bad condition, so that it was not possible to identify them. Insects with softer bodies decayed almost completely; in most cases only their wings remained, and carcasses of Coleopterans were preserved in the best condition. We assume that the insects found in the oil may have been trapped during the last year before our sampling. To estimate the number of insect carcasses in the oil lake,

TABLE I Insect species, the carcasses of which were collected from the waste oil lake in Budapest and could be identified

Odonata	*Aeshna mixta, Anax imperator, Sympetrum vulgatum*
Heteroptera	*Notonecta glauca, Ranatra linearis, Gerris lacustris, Gerris pallidus, Callicorixa concinna, Corixa punctata, Hesperocorixa linnei, Sigara falleni, Sigara lateralis, Sigara striata*
Coleoptera	*Hydrophilus piceus, Hydrophilus atterinus, Dytiscus marginalis, Acilius sulcatus, Coelambus impressopunctatus, Colimbetes fuscus, Copelatus ruficollis, Cybister laterimarginalis, Dytiscus circumflexus, Hydaticus transversalis, Hyphydrus ovatus, Ilybius subaenus, Rhanatus punctatus, Elaphrus riparius, Oryctes nasicornis, Longitasrus tabidus*
Mantodea	*Mantis religiosa*

fragments of the bodies were counted separately. The minimum number of insects allowed by the number of body parts was calculated, although they could have belonged to more individuals. Six separated wings of damselflies were counted as two animals, for example.

Filtrates contained insects associated with water in large numbers (Tab. I). Ephemeropterans and trichopterans could be identified only on the basis of their wing remains. Species of Corixidae were abundant (although in most cases only their wings remained). Nematocerans were found most frequently; 44% of them could be classified as Chironomids. Hymenopterans were found in large numbers, many of them were swarming ants. An estimate was made of numbers of different aquatic insect groups identified in the waste oil lake (Tab. II). Although these numbers should be considered as a gross approximation, it is clear that the waste oil lake in Budapest trapped a huge number of insects during its existence of half a century.

Certain insects – *e.g.*, *Mantis religiosa* and *Oryctes nasicornis holdhausi* – probably became entrapped by the oil during their walk when they reached the shore of the oil lake, where the soil and the pebbles were covered by the sticky oil.

TABLE II Numbers of different groups of insects associated with water identified in the 3000 m^3 of the waste oil lake in Budapest and estimated for 1 year and 50 years

	Odonata	*Trichoptera*	*Ephemeroptera*	*Nematocera*	*Corixidae*	*Dytiscidae*
1 year	$150 \cdot 10^3$	$100 \cdot 10^3$	$50 \cdot 10^3$	$17.9 \cdot 10^6$	$1.4 \cdot 10^6$	$600 \cdot 10^3$
50 years	$7.5 \cdot 10^6$	$5 \cdot 10^6$	$2.5 \cdot 10^6$	$895 \cdot 10^6$	$70 \cdot 10^6$	$30 \cdot 10^6$

Although some of the larger insects, like great silver diving beetles (*Hydrophilus piceus*), were able to crawl out from the oil to the shore or to a pebble (Fig. 1E), they soon perished because their trachea openings became filled by oil. This is one of the reasons why so many carcasses of large insects could be found on the shore of the waste oil lake. The other reason is that the level of the oil lake gradually decreased from year to year due to evaporation and percolation of the oil into the soil, so that many insect carcasses became exposed on the shore (Figs. 1A, B, F).

Behaviour of Dragonflies Above the Waste Oil Surface

Male dragonflies frequently patrolled above the flat oil surface and protected their territory against all intruders. They tried to attack all flying objects (*e.g.*, other dragonflies and larger insects, birds, and even helicopters and airplanes). Male dragonflies often sat guard on the tip of perches at the shore. We frequently observed copulating pairs of dragonflies flying above the oil surface or trying to lay their eggs into the oil. They became trapped during water-touching manoeuvres or egg-laying. In the latter case sometimes only the female became entrapped when the tip of her abdomen was dipped into the oil. In many cases, however, the male was also carried along with the female into the oil. Touching the surface by dragonflies observed often by us at the waste oil lake is a reaction which is typical only above water surfaces when dragonflies inspect the surface to select the ideal habitat or oviposition site (Wildermuth, 1993; Corbet, 1999). The most frequently observed behaviour types of dragonflies above the waste oil surface were the air fight, hovering and protection, which again are typical only above water surfaces (Wildermuth, 1998; Corbet, 1999).

After rain, pools of water formed on the shore of the waste oil lake. The surface of these pools was covered by a thin iridescent oil layer. We observed that dragonflies or other insects that touched the surface of a water pool with a thin oil layer frequently became entrapped and drowned because the thin oil layer reduces the surface tension of the water surface, which wets the wings. (That is why a thin layer of oil has been used for many decades for mosquito control, for example.) Even if the insect could crawl out from the water, its trachea openings were blocked by the oil. The same was observed by Horváth and Zeil (1996) at the crude oil lakes in the desert of Kuwait. In the case of unpolluted water bodies dragonflies and larger water beetles can fly out easily from the water if they are dropped into water (Corbet, 1999).

Insects Attracted to the Shiny Black Plastic Sheets and their Behaviour

Figure 2 shows some examples how water-loving insects can be deceived by and attracted to different artificial shiny dry surfaces such as windscreens, car roofs, black plastic sheets used in agriculture and asphalt roads. Figure 3 shows examples for the behaviour of a great diving beetle (*Dytiscus marginalis*) on a shiny dry black plastic sheet at sunset: The water beetle landed on the relatively cool (20°C) plastic sheet, touched and probed the surface. Then flew up from the plastic sheet and looked for another place. After landing again, the beetle tried to swim, crawl, or creep on the smooth plastic sheet. After half an hour the beetle got entirely exhausted, it could not fly away, although it tried to fly up several times. Within an hour the beetle perished.

We found that only the black plastic sheet laid onto the ground next to bodies of standing or running water attracted insects associated with water (Tab. III), and the white plastic sheet was totally unattractive to them. Though we checked both plastic sheets every day we were able to collect water insect carcasses exclusively from 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. There was no any carcass on the white plastic. All these aquatic insects showed similar behavioural elements on and above the black plastic sheet: landing, flying up, touching, crawling, egg-laying, copulating, reproductive activity. Finally, all of them dried out and perished within some hours. Butterflies, flies, bees, wasps, dragonflies and waterstriders (living on land and/or on the water surface)

TABLE III Insect species lured to the shiny black plastic sheet used in the dual-choice field experiments

Ephemeroptera	*Epeorus silvicola, Rhitrogena semicolorata, Baetis rhodani, Ephemera danica, Ecdyonurus venosus, Haproleptoides confusa, Cloeon dipterum*
Plecoptera	*Perla burmeisteriana*
Coleoptera	*Cybister laterimargnalis, Dytiscus dimidatus, Acilius sulcatus, Hydaticus transversalis, Rhanatus punctatus, Copelatus ruficollis, Hyphydrus ovatus, Laccophilus obscurus, Hydrochara flavipes, Hydrochara caraboides, Hydrophilus piceus, Hydrobius fusipes, Spercheus emarginatus, Besorus luridus, Cymbiodita marginella, Anacaena limbata, Phylidrus bicolor*
Heteroptera	*Cymatia rogenhofferi, Sigara lateralis, Sigara striata, Sigara falleni, Aigara, assimilis, Hesperocorixa linnei, Corixa affinis, Notonecta glauca*

were also attracted to both plastic sheets, but they did not perish on them. Sometimes we searched the plastic sheets by eye and using binoculars for 3–4 hours and checked the insects that landed on them. We found no aquatic insects crashing on the white plastic sheet. At sunset the black plastic sheet was as cool as the white one. Thus we must conclude that the higher temperature of the black plastic sheet was not the reason why only the black plastic sheet trapped aquatic insects. Apparently, the black plastic sheet was visually more attractive to water-seeking insects than the white one.

When our plastic sheets were laid onto the ground in the vicinity of an alkaline lake near Kunfehértó, almost at every sunset we heard the black plastic sheet rattle sounding like the pattering of raindrops. The reason for this was thousands of Corixidae landing on and crashing into the black plastic sheet, then jumping repeatedly up and down. They did not leave the optical trap, and did not fly away from the visually so attractive black plastic sheet; they remained on it throughout the night and perished. At the white plastic sheet we did not witness such an effect so we conclude that it did not deceive and lure Corixidae.

Reflection-polarization Characteristics of the Surface of the Waste Oil Lake and the Plastic Sheets

Figures 4A–C shows the patterns of the brightness I, degree of polarization δ and angle (or direction) of polarization (or E-vector alignment) α of light reflected from the surface of the waste oil lake in Budapest *versus* time. In Figure 4D the daily maximal air temperature T in Budapest and the average degree of polarization of the light reflected from the oil surface are shown as a function of time. The average of δ is calculated for the entire oil surface visible in the pictures. Due to the relatively wide field of view of the camera ($50^\circ \times 40^\circ$), the angle of reflection changes vertically on a picture, thus the value of δ changes too. On the other hand, δ changes from point to point in the picture if the oil surface is not smooth and homogeneous. This is the case in the cooler and colder months when the oil surface is dull, matt or even wrinkled sometimes with rain-water pools. The horizontal bars in Figure 4D represent the standard deviation of δ.

It is clear from Figure 4 that the reflection-polarization characteristics of the surface of the waste oil lake has a characteristic seasonal cycle. In summer (from June to August) the oil surface is flat and shiny, the reflected light is

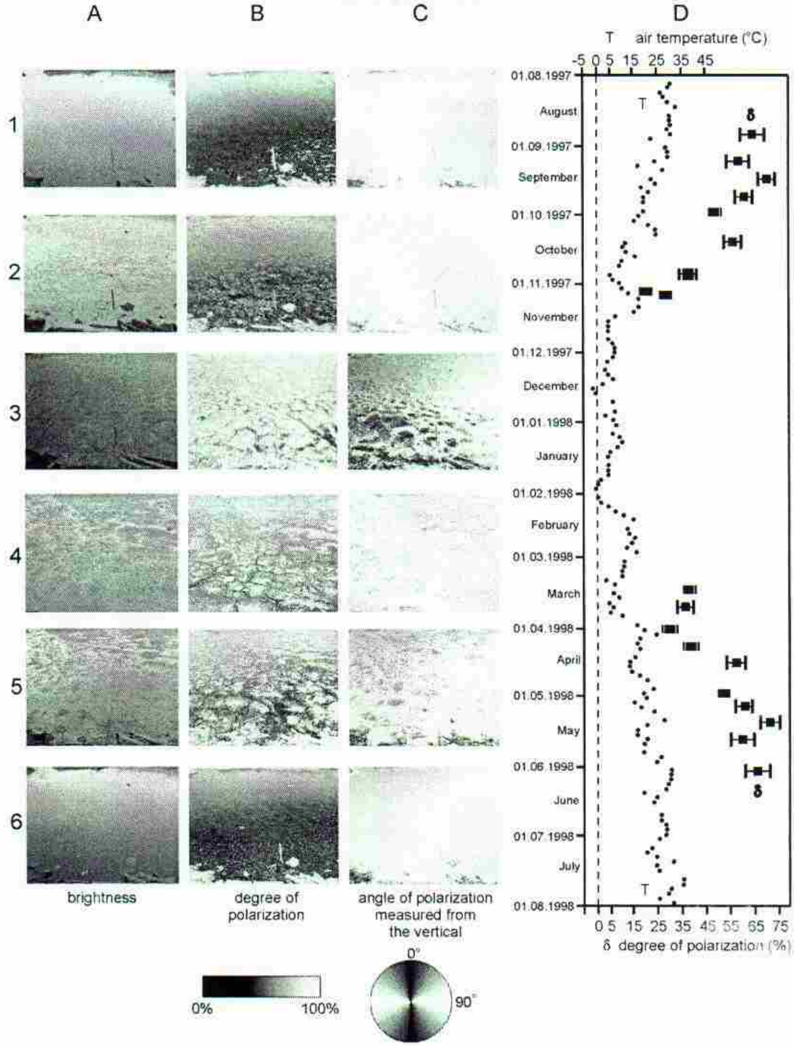

FIGURE 4 Reflection-polarization characteristics of the surface of the waste oil lake in Budapest *versus* time measured by videopolarimetry in the blue range of the spectrum ($\lambda = 450$ nm) under clear skies for a solar zenith angle of 60°. See insets below for the grey-level codes for the values of the degree and the angle of polarization. (A) Brightness (or intensity) I of light reflected from the oil surface. (B) Degree of polarization δ of reflected light (white: $\delta = 0\%$, black: $\delta = 100\%$). (C) Angle of polarization α of reflected light measured from the vertical (black: $\alpha = 0°$, white: $\alpha = 90°$). (D) The daily maximal air temperature T in Budapest (by courtesy of the Hungarian Meteorological Service) and the average (calculated for the entire picture) degree of polarization of the light reflected from the oil surface as a function of time. The horizontal bars represent the standard deviation of δ; sample size = number of pixels in the pattern of $\delta = 560 \times 736 = 412160$. Viewing direction of the camera was 60° relative to the vertical and perpendicular to the solar meridian. (See Colour Plate IV at the end of the issue).

highly and horizontally polarized (rows 1 and 6 in Fig. 4). This is disturbed neither by rainfall nor by cool weather. The viscosity of the oil remains low due to the great thermal inertia of the oil mass. The oil keeps its fluidity also in cool periods, consequently, the denser rain-water sinks down in the lighter oil. Thus the shiny, mirror flat and highly polarized appearance of the black oil surface remains a characteristic feature throughout the summer.

In autumn (from September to November) the oil surface becomes dull, and the average degree of polarization of reflected light gradually decreases as the air temperature decreases and the oil becomes more viscous (row 2 in Fig. 4). The direction of polarization of reflected light differs considerably from the horizontal in the dull regions of the gradually stiffening oil surface. In winter (from December to February) the oil surface becomes matt and wrinkled, and rain-water or snow accumulates on it (row 3 in Fig. 4). Then the oil surface looks like gluey asphalt if it is not covered by snow. The average degree of polarization of reflected light is very low, and the direction of polarization is not horizontal and changes from point to point. In spring (from March to May) as the temperature gradually increases, the oil surface becomes gradually smooth and shiny, its average degree of polarization increases, and its direction of polarization approximates the horizontal (rows 4 and 5 in Fig. 4).

Figures 5A–D show the reflection-polarization characteristics of the white and the black plastic sheet (used in the field experiments). In Figure 5E the degree of polarization of light reflected from a white and a black plastic sheet calculated for different values of the albedo A of the white plastic sheet is shown as a function of the angle of incidence Θ with respect to the vertical. The light reflected from the black plastic sheet has much higher degrees of polarization than the light reflected from the white plastic sheet (Figs. 5B, E). On the other hand, the white plastic sheet reflects a much greater amount of light (Fig. 5A). The direction of polarization of the black plastic sheet is always parallel to the surface, that is, more or less horizontal (Figs. 5C, E). On the other hand, the white plastic sheet reflects more or less vertically or obliquely polarized light (Figs. 5C, E).

As the incident angle Θ increases from zero to 90°, the degree of polarization δ of the black plastic sheet increases from zero to 100% up to the Brewster angle ($\Theta_B = 57°$), then δ decreases to zero, but it remains always positive. This is the typical change of polarization of light reflected from the surface of a non-transparent, black insulator. The light component penetrating into

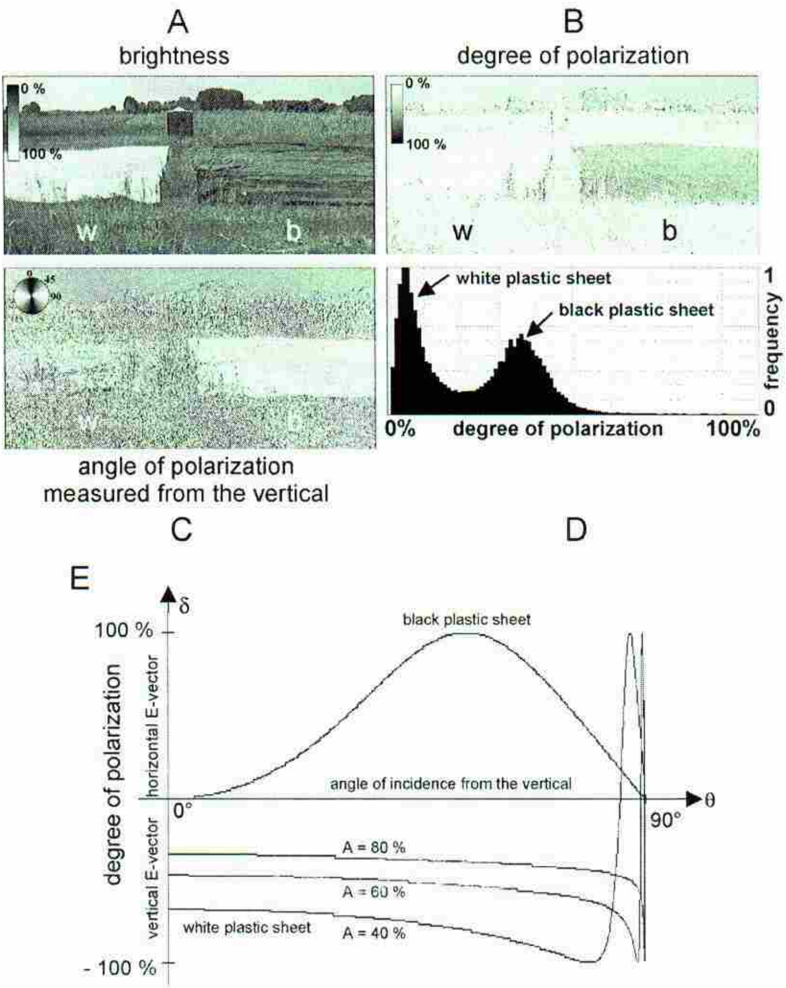

FIGURE 5 (A–D) The reflection-polarization patterns of the white (w) and the black (b) plastic sheets used in the field experiments and measured by videopolarimetry in the blue range of the spectrum ($\lambda = 450\,\text{nm}$) under a clear sky for a solar zenith angle of 60°. Scale: the height of the hide (seen behind the sheet) is 1.8 m, from which the observations were done. The viewing direction of the camera was 60° relative to the vertical and perpendicular to the solar meridian. (E) The degree of polarization of light reflected from a black and a white plastic sheet calculated for different values of the albedo A of the white plastic sheet as a function of the angle of incidence Θ with respect to the vertical. Positive and negative δ values mean horizontally and vertically polarized reflected light, respectively.

the black plastic sheet is absorbed by the dark pigments, thus makes no contribution to the reflection polarization.

The situation is quite different in the case of the white plastic sheet. Here a considerable part of the incident light penetrates into the translucent plastic sheet, then it is diffusely scattered backwards by the white condensation layer, finally it is refracted at the upper surface of the plastic sheet. The light emanating from the sheet is always vertically polarized due to the refraction at the plastic sheet-air interface (Horváth and Pomozi, 1997). This vertically polarized condensation-reflected light is superimposed with the horizontally polarized light reflected specularly from the upper surface of the plastic sheet. If the former component dominates, then the net direction of polarization is vertical, otherwise it is horizontal. When the albedo of the condensation layer is great enough, the condensation-returned, vertically polarized refracted light dominates for smaller incident angles, but for quite grazing angles (for large Θ's) the horizontally polarized, specularly (mirror-) reflected light controls the net degree of polarization, as we can see in Figure 5E. The theoretical change of the degree of polarization of the white and black plastic sheets in Figure 5E is in accordance with the measured reflection-polarization patterns in Figures 5A–D.

The dry soil and the vegetation in the surroundings of the plastic sheets have a very low degree of polarization (Fig. 5B) and their direction of polarization changes randomly in space (Fig. 5C) due to the diffuse reflection and scattering of light. Although the reflection-polarization characteristics of the plastic sheets depend on the angle of view, on the solar zenith distance and on the meteorological conditions, Figure 5 demonstrates well the fact that the shiny black plastic sheet is a more effective polarizing reflector than the white plastic sheet, even relatively far away from the Brewster angle. Thus, the shiny black plastic sheet may be a supernormally polarized stimulus for polarotactic water-seeking insects.

Comparing the reflection-polarization characteristics of the plastic sheets (Fig. 5; Horváth *et al.*, 1998; Horváth and Pomozi, 1997; Kriska *et al.*, 1998) with those of crude and waste oil (Horváth and Zeil, 1996; Horváth *et al.*, 1998), asphalt (Kriska *et al.*, 1998) and natural water bodies (Horváth *et al.*, 1998; Horváth and Varjú, 1997; Horváth and Zeil, 1996; Kriska *et al.*, 1998) we can establish the following: (1) the optical cues of the shiny black plastic sheet are practically the same as those of wet, marshy soil; dark, deep water bodies; and black crude/waste oil or asphalt surfaces. (2) The reflection-polarization characteristics of the shiny white plastic sheet are very similar to those of bright-bottomed shallow clear water bodies; and turbid white (*e.g.*, alkaline) water bodies. Hence, the white plastic sheet used in the choice experiments mimicked a body of water with bright bottom and clear water, or white and turbid water, while the black plastic sheet imitated some kind of black and wet mud, or black crude/waste oil or dark asphalt surfaces.

DISCUSSION AND CONCLUSIONS

In this work we identify a seldom addressed conservation and animal welfare issue, the possible large-scale hazard for aquatic insects of all the "shiny black anthropogenic products" including oil reservoirs as well as asphalt and plastic sheets used especially in agriculture. We start with the impact of a peculiar waste oil lake in Budapest and then shift to a more general problem, the deception and attraction of aquatic insects to plastic sheets and other black and shiny surfaces: We report on insects deceived by, attracted to and trapped by the waste oil lake in Budapest in large numbers. Similar observations are presented for insects lured to shiny black plastic sheets used in agriculture. These insects show the same behaviour at the oil and black plastic surfaces as at real water surfaces. These typical water-specific behavioural elements involve touching the water surface (*e.g.*, at egg-laying, or probing the oviposition site), or landing on the water surface, or plunging into the water. All of these reactions are fatal for insects in the case of oil surfaces, because the sticky oil traps the insects. We also observed that a thin oil layer on the water surface can hinder an insect from escaping, the consequence of which can be drowning. It is important to emphasis that water insects laid their eggs on the surface of plastic sheets, so these surfaces may endanger the renewal of their populations too (Kriska *et al.*, 1998).

We also demonstrated that, although the dry shiny black plastic sheets used frequently in agriculture cannot mechanically trap the attracted insects as does the sticky oil, they can be very dangerous to aquatic insects, because the optical cues of such smooth, shiny surfaces are so strong that insects associated with water are visually compelled to remain on the dry plastic sheets in spite of the fact that other senses signal that these surfaces are not water. The consequence of this reaction is drying out and perishing.

To our knowledge, this is the first instance to call the attention to the dangerous visual deceiving capability of the huge shiny black plastic sheets used in agriculture to insects and to demonstrate that the attracted insects can perish *en masse* on these plastic sheets. In our opinion the visual ecological impacts of these plastic sheets to the insect fauna must not be under-estimated in those habitats and biotopes, in the vicinity of which such huge shiny black plastic sheets are used in agricultural production. The impact of oil reservoirs on the fauna is well-known and more widely problems with oil spills have been well documented especially for marine fauna (*e.g.*, Pilcher and Sexton, 1993; Pearce, 1995). Much less attention has been paid to the possible global (worldwide) impact of oil wastes and other black and shiny products on the continental aquatic fauna.

We demonstrated that in the warmer months (from March to October) the surface of the waste oil lake in Budapest is smooth, shiny, highly and horizontally polarized, like all shiny dark surfaces (*e.g.*, glass panes, plastic sheets and car roofs). Thus, it is likely that the deceiving capability and attractiveness of the waste oil lake in Budapest to insects can be explained by the same phenomenon, at least in the case of polarotactic insects associated with water. These insects mistake the oil, tar, asphalt or plastic surfaces for water due to the strong and horizontal polarization of the reflected light mimicking an exaggerated water surface. On the other hand, the more or less vertically polarized white plastic sheets are not attractive at all to polarotactic insects associated with water, which are attracted only by horizontally polarized light.

On the basis of the above it is clear that if the degree of polarization of reflected light was somehow reduced and it was someway ensured that the direction of polarization of reflected light differs from the horizontal, then the dangerous visual attractiveness of artificial shiny surfaces to polarotactic insects associated with water could be reduced or even eliminated. A general rule is that the brighter and rougher a surface, the lower is the degree of polarization of the reflected light and the more it deviates the direction of polarization from the horizontal. Thus, we suggest the following environmental protective arrangements should be taken urgently in the vicinity of the habitats and biotopes of insects associated with water:

(i) In agriculture, the huge shiny black plastic sheets should be replaced by matt grey or white plastic sheets. (It has to be investigated still whether these sheets would perform their agricultural function as properly as black sheets, and therefore be acceptable to farmers.)

(ii) Asphalt roads should be covered by a thin bright and rough layer composed of sand or gravel.

(iii) Until their removal, the surfaces of open-air oil reservoirs, spills and seeps should be covered by a thin layer composed of finely granulated white polystirol spheres. This layer may require frequent renewal, because the spheres themselves can eventually become coated all over.

These measures would be relatively inexpensive and could save countless members of the insect fauna in the vicinity of asphalt roads, open-air oil reservoirs and areas where huge plastic sheets are used in agriculture.

The waste oil lake in Budapest acted as a huge insect trap for half a century and existed in an area where there was no water surface within 3 kilometres. Unfortunately, it is not the only artificial oil lake, which traps insects *en masse*. In the desert of Kuwait more than 900 similar crude oil lakes came into being at the end of the Gulf War in 1991 (Pilcher and Sexton, 1993; Pearce, 1995) and trapped countless insects, especially those associated with water (Horváth and Zeil, 1996). Also the Pleistocene natural asphalt seeps in Rancho La Brea (Akersten *et al.*, 1983) and the pleistocene tar pits in Starunia (Angus, 1973; Kowalski, 1999) acted as massive insect traps. In Rancho La Brea 95% of the entrapped animal species belong to insects. Other fossil insect deposits associated with natural oil reservoirs are the Talara tar seeps in Peru, and the tar pits in Binagadin near Baku in Azerbaidjan (Kowalski, 1999).

On the basis of our results presented in this work we propose that these ancient tar pits and asphalt seeps might have been acted as huge "polarized insect traps" like the waste oil lake in Budapest. Most of the insect fossil remains found in Starunia were water beetles belonging to the genus *Helophorus* (Angus, 1973). The carcasses of water beetles are better preserved than those of soft-bodied species. Thus one may assume that many other insects associated with water (*e.g.*, nematocerans, ephemeropterans, trichopterans, heteropterans and odonates) were also trapped by these Pleistocene tar seeps, but their carcasses decayed quickly.

Countless smaller or larger temporary inland oil spills come into being as a by-product of the oil industry. We observed that even a tiny and shallow oil spill with an area of about 4 dm^2 and a depth of 5–10 millimetres can attract, trap and kill smaller water insects. It would be important to investigate further the visual ecological impacts of oil surfaces to the insect fauna, because only on the basis of such studies can be explained the high and dangerous attractiveness of waste, crude, refused and spent oil reservoirs to insects. These studies are the prerequisite of the necessary environmental protective arrangements that should be taken urgently in order to eliminate any man-made oil spills and open-air oil reservoirs which are so dangerous to insects.

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