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Faculty of Science

ENVIRONMENTAL PHYSICS METHODS LABORATORY PRACTICES

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MAGYARORSZÁG MEGÚJUL

A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg.

KEYWORDS:
Environmental physics, environmental radiation, noise, acustics, infra sound, natural radioactivity, solar energy, polarized light, dosimetry, ionizing radiation, radon, gamma-spectroscopy, positron emission tomography.

SUMMARY:

In this book we overviewed 17 laboratory practices in the subject of environmental physics. Our measurements mainly covered the area of environmental radiations starting from the acoustic waves, electromagnetic radiation hazard, visible light and going into the area of radioactivity: X-rays, gamma-spectroscopy, annihilation radiation, Cherenkov-radiation, alpha- and beta-spectroscopy. These exercises are good examples for those students who intend to work in laboratories using these spectroscopic or other environmental physics methods.

There are of course lots of areas in environmental physics that were not covered here, but these exercises are adjusted to the technical possibilities of the Environmental Center at Eötvös Loránd University, Budapest.

Preface

This work is based on three laboratory practices that environmental major students have been studying for about 10 years at Eötvös Loránd University (ELTE). We describe 17 lab practices and give 4 more chapters as an introduction to the fields. Several laboratory practices have a Hungarian description in a book edited by Prof. Dr. Ádám Kiss with coauthorship of our colleauges: Panni Bornemisza, Gyula Pávó, Ottó Csorba, Ferenc Deák, Botond Papp, András Illényi and the authors of this book. However, a few new measurement were added to the list and this book covers already the actual material for the laboratory measurement of three lab teaching units: Environmental Physics, Environmental Physics Methods and Radiation Physics. The introductory chapters of this book are also helpful for the students of the master course: „Environmental radiation”.

New measurement of electromagnetic radiation hazards, microwave radiation, infrasound, Cherenkov-radiation, radon exhalation, solar heat collector and polarized light pollution widened our topics in the broad field of environmental physics.

Especially, the English description of the „Infrasound wave detection” laboratory practice is well established on a work of Gábor Szeifert, Gábor Gelencsér and Gyula P. Szokoly at the Department of Atomic Physics of ELTE. The chapter about the „Solar heat collector” is based on the Hungarian description and undergraduate research thesis (TDK) of Edina Juhász and Veronika Pongó.

This English text is for those student who study at ELTE e.g. as Erasmus students in environmental sciences or in physics or by any reason they prefer English language description.

Budapest, March 2012.

The authors

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9. Polarized light pollution (POL)

The aim of the laboratory practice is to inform the students about (i) the term of ***polarized light pollution*** (PLP) and its physical and biological bases, (ii) the natural and artificial (anthropogenic) reflection-polarization characteristics, and (iii) the method of imaging polarimetry that is able to measure polarization patterns. Students have to measure and analyze the reflection-polarization patterns of some typical sources of polarized light pollution in the immediate vicinity of the physical and biological buildings of the Eötvös University.

9.1 Introduction

In this chapter we introduce the term 'polarized light pollution' (PLP), meaning all adverse effects on polarotactic aquatic insects attracted by exactly or nearly horizontally polarized light reflected from smooth and dark artificial surfaces. PLP is a new kind of ecological photopollution, it is global and novel in an evolutionary sense. We review the experimental evidences of PLP, such as (i) trapping of aquatic insects by dark oil surfaces; (ii) dehydration of polarotactic insects attracted to black plastic sheets used in agriculture; (iii) egg-laying of polarotactic mayflies onto dry asphalt roads; (iv) attraction of aquatic insects to black, red or dark-coloured car paintwork; (v) deception of polarotactic dragonflies by shiny black gravestones; (vi) attraction of mass-swarming polarotactic caddis flies to glass surfaces; (vii) attraction of aquatic insects to photovoltaic solar cells and sun collectors. All such highly and horizontally polarizing artificial surfaces may act as 'polarized ecological traps' for polarotactic insects, because these surfaces are inappropriate for the development of eggs laid by the deceived aquatic insects. We discuss possible benefits and/or disadvantages of predators (spiders, birds, bats) feeding on the polarotactic insects attracted to different sources of PLP. Finally, some remedies of PLP are suggested. Conservation planners should pay much more attention to aquatic insects because of their positive polarotaxis and their demonstrated vulnerability due to PLP.

9.2 Polarized Light Pollution and Polarized Ecological Trap: Definitions

It is a well-known fact that the degradation of human views of the night sky in and near cities makes practically all astronomical observations impossible. The stars and other celestial bodies are washed out by artificial citylights that are either directed or reflected upward. This phenomenon is called the 'astronomical light pollution' (Rich and Longcore, 2006, p. 3). On the other hand, the term 'ecological light pollution' (ELP) is used to describe all kinds of 'photopollution' (a synonym of 'light pollution') which disrupts ecosystems (Rich and Longcore, 2006). ELP has been defined as the "degradation of the photic habitat by artificial light". ELP includes direct glare, chronically increased illumination, and temporary, unexpected fluctuations in lighting. Sources of ELP include sky glow, lighted structures (e.g., buildings, towers, bridges), street lights, security lights, lights of vehicles and fishing boats, flares on offshore hydrocarbon platforms, and lights on undersea research vessels (Rich and Longcore, 2006, pp. 3-4). Both the documented and possible ecological consequences of all these artificial night lighting were comprehensively summarized in the monograph edited by Rich and Longcore (2006).

The first step of all these effects of artificial night lights is the attraction, or repulsion of animals by the spatiotemporally enhanced intensity of light relative to the dark environment. This phenomenon, called positive or negative phototaxis (Nowinszky, 2003), is elicited by the intensity and/or colour of artificial light. Until now only this phototaxis has been considered as the major visual phenomenon underlying the ELP. Here we introduce the term 'polarized light pollution' (PLP) as a new kind of ecological photopollution (Horváth *et al*., 2009). Under PLP we mean highly and horizontally polarized light reflected from smooth (shiny) artificial surfaces (see Figures 9.1 and 9.2) having adverse effects on polarotactic aquatic insects (see Figure 9.3), including all insects, whose larvae live in water (e.g., aquatic beetles and bugs, dragonflies, mayflies, caddis flies and tabanid flies).

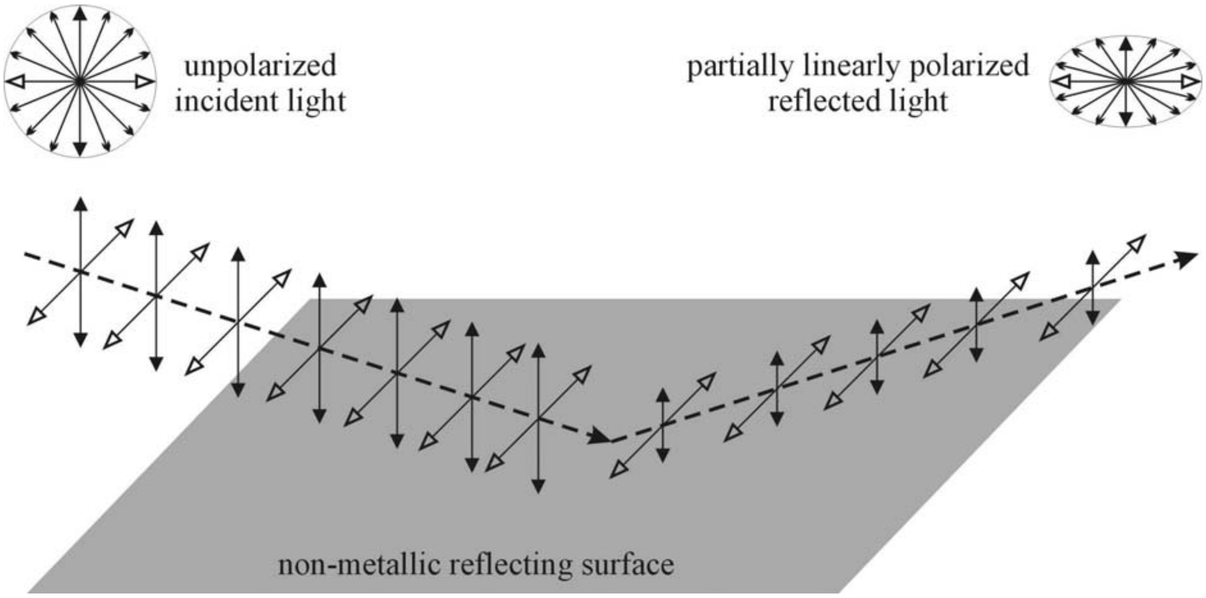

Figure 9.1. After reflection from a non-metallic surface unpolarized light becomes partially linearly polarized, whose electric field vector is smaller in the plane of reflection (double-headed arrows with black head) than that perpendicular to this plane (double-headed arrows with empty head).

In 1985 Rudolf Schwind has discovered that the backswimmer, *Notonecta glauca* detects water by means of the horizontally polarized light reflected from the water surface, rather than by the intensity or colour of water-reflected light, or by the glittering, or mirroring of the water surface. In the ventral eye region of *Notonecta* there are ultraviolet-sensitive photoreceptors with horizontal and vertical microvilli being highly sensitive to horizontally and vertically polarized light. These orthogonally polarization-sensitive photoreceptors are able to determine whether the direction of polarization of light from the optical environment is horizontal or not. In *Notonecta* an exactly or nearly horizontally polarized light stimulus elicits a typical plunge reaction. This attraction of *Notonecta* to horizontally polarized light is called 'positive polarotaxis'.

Most of the females of aquatic insects (e.g., Ephemeroptera, Odonata, Plecoptera, Trichoptera) must return to water to lay their eggs. Water bodies also often serve as rendezvous for both sexes of aquatic insects. As orientation in aquatic insects is predominantly visual, we may ask for the optical cues by which specific water bodies are recognized. The eye in many aquatic insects is sensitive to the polarization of light in the visible or ultraviolet spectral ranges (Schwind, 1991). These insects find their habitat on the basis of the horizontally polarized light reflected from the water surface. Aquatic insects detect polarization in that region of the spectrum, which is characteristic of their preferred habitat (Schwind, 1991). Depth, turbidity, transparency, colour, surface roughness of the water and substratum composition as well as the illumination strongly influence the reflection-polarization characteristics of water bodies (Horváth and Varjú, 2004). Polarized light reflected by water provides important information on the quality of freshwater habitats for polarotactic insects and can aid the orientation of these insects from a distance when other cues (e.g., atmospheric humidity, dimension and shape of the water body, undulation of the water surface, water plants on the surface and the shore, temperature and odour) are still ineffective (see Figure 9.2A).

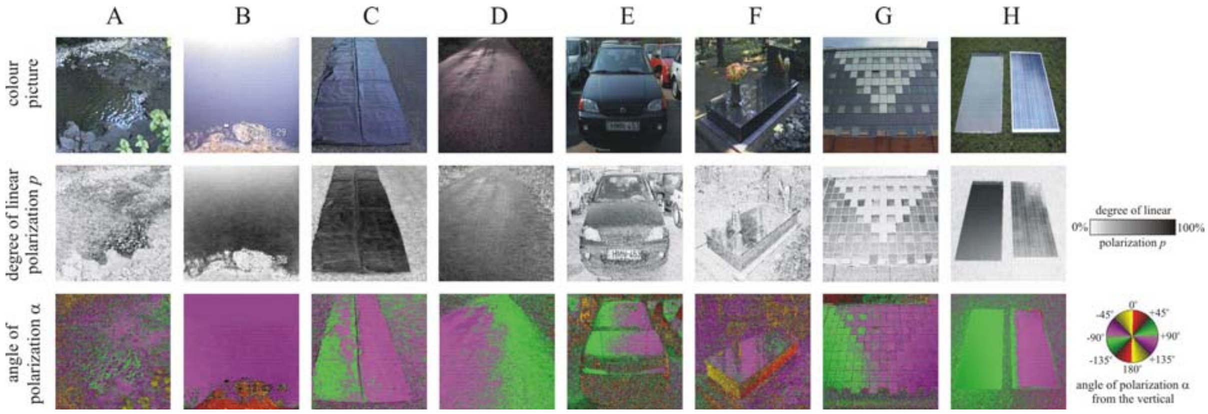

Figure 9.2. Colour pictures (row 1) and patterns of the degree of linear polarization p (row 2) and angle of polarization α from the vertical (row 3) of light reflected from a dark water surface (A) and different artificial surfaces (B-H) causing polarized light pollution. The p- and α-patterns were measured by imaging polarimetry in the blue (450 nm) part of the spectrum. A: A dark water body illuminated by the light from a clear sky after sunset. B: A sunlit crude oil lake in the desert of Kuwait (on the bottom of the picture the sandy shore can be seen). C: A dry shiny black plastic sheet laid on a dry asphalt road after sunset under a clear sky. D: A dry asphalt road lit be the setting sun. E: A sunlit black car under a clear sky. F: A shady polished black gravestone under a clear sky. G: Vertical wall of a building under a clear sky after sunset. The wall between the windows is covered by light grey and black glass surfaces as ornamentations. H: Two horizontal photovoltaic solar panels. Left: homogeneous black solar panel. Right: heterogeneous polycrystallic solar panel.

In a series of observations Schwind (1991) showed that several species of aquatic bugs and beetles are polarotactic. Later studies (Kriska *et al.*, 1998, Csabai *et al.*, 2006) found that beside aquatic bugs and beetles, also many other aquatic insects like dragonflies, mayflies, tabanid flies, stone flies and caddis flies exhibit positive polarotaxis when searching for water. Until now more than 300 polarotactic aquatic insect species are known that recognize their aquatic habitat by positive polarotaxis.

Figure 9.3. Polarotactic aquatic insects and insects associated with water deceived by and attracted to different sources of polarized light pollution (photographs taken by G. Kriska). Row 1: Some typical representatives of insects trapped by a crude oil lake in the desert of Kuwait (A), and a waste oil lake in Budapest, Hungary (B-D). A: An Aeschnid dragonfly (courtesy of Dr. Jochen Zeil). B: A dragonfly (Sympetrum vulgatum) and scavenger beetles (Hydrophilidae sp.). C: A mayfly (Cloeon dipterum). D: A great silver diving beetle (Hydrophilus piceus). Row 2: Water insects landed on horizontal shiny black dry plastic sheets used in agriculture. E: Copulating mayflies (Rhithrogena semicolorata). F: A female mayfly (Ephemera danica) laying her eggs on the black plastic sheet. G: A female large stonfly (Perla burmeisteriana). H: A tabanid fly (Tabanidae). Row 3: Aquatic insects landed on dry asphalt roads. I: A male mayfly (Epeorus silvicola). J: Copulating mayflies (Rhithrogena semicolorata). K: Oviposition by a female large stonefly (Perla burmeisteriana), whose black egg-batch at the tip of her abdomen is shown by the tip of the white arrow. L: A great silver diving beetle (Hydrophilus piceus). Row 4: Insects associated with water on the dry roof of a red car. M: A mayfly (Ecdyonuridae sp.). N: A water bug (Sigara striata). O: A water beetle (Hydrochara caraboides). P: A tabanid fly (Tabanidae). Row 5: Q: A male dragonfly (Sympetrum sp.) perching near a polished black tombstone. R: Mass swarming of Hydropsyche pellucidula caddis flies (white spots) in front of the vertical glass surfaces of a building on the bank of the river Danube in Budapest. S: A H. pellucidula landed on a pane of glass.
T: A copulating pair of H. pellucidula on a glass pane.

Thus, it is quite understandable that polarotactic insects can be deceived by and attracted to every artificial surface that reflects highly and horizontally polarized light: such a man-made surface mimicks an exaggerated water surface to water-seeking aquatic insects by the highly and horizontally polarized reflected light functioning as a supernormal stimulus (see Figures 9.1 and 9.2). This visual ecological phenomenon is the major reason for the PLP. The physical (1), behavioural (2) and ecological (3) bases of PLP are the following (Horváth *et al*., 2009):

According to the so-called Umow rule, the darker a surface in a given part of the spectrum, the higher the degree of linear polarization p of light reflected from it. Since diffuse reflection from raugh (matt) surfaces results in depolarization, the smoother (the shinier) a surface, the higher the p of reflected light. Since the direction of polarization of light reflected from smooth dielectric materials is always perpendicular to the plane of reflection, if this plane is exactly or nearly vertical, the reflected light is exactly or approximately horizontally polarized. From these it follows:

(1) Smooth and black artificial surfaces with exactly/nearly vertical plane of reflection mirror highly and exactly/nearly horizontally polarized light.

The higher the p of light and the less deviates its direction of polarization from the horizontal, the larger its attractivity to polarotactic aquatic insects (Horváth and Varjú, 2004). Consequently:

(2) Smooth and black artificial surfaces with exactly/nearly vertical plane of reflection are strongly attractive to polarotactic insects.

Aquatic insects attracted to highly and horizontally polarizing dry artificial surfaces may perish due to dehydration, or may oviposit onto these surfaces, the consequence of which is that the eggs perish inevitably. From this we can conclude that:

(3) Highly and horizontally polarizing artificial surfaces may act as 'polarized ecological traps' for ovipositing polarotactic aquatic insects (Schlaepfer *et al*., 2002), because such surfaces are completely inappropriate for the development of eggs laid by the deceived and attracted aquatic insects.

On the basis of the above we can formulate the following visual ecological thesis: Smooth and dark artificial surfaces with exactly/nearly vertical plane of reflection are strongly attractive to polarotactic aquatic insects, and thus constitute polarized ecological traps for these animals, consequently induce PLP. In the next section we review the experimental evidences supporting this thesis. Using theoretical calculations and imaging polarimetry (Horváth and Varjú, 2004), the reflection-polarization characteristics of water surfaces and artificial reflectors can be compared. Imaging polarimetry is a useful technique to establish and monitor the sources of PLP. Excluding the astronomical photopollution, Table 9.1 summarizes the major characteristics of the conventional ecological photopollution and the PLP.

characteristics	conventional ecological photopollution	polarized light pollution
source of photopollution	artificial night lights: sky glow, lighted structures, streetlamps, security lights, vehicle headlights, fishing boats, flares on hydrocarbon platforms, lights on undersea research vessels	highly and horizontally polarized light reflected from artificial surfaces: oil lakes; asphalt roads; black plastic sheets in agriculture; glass surfaces; black, red, dark-coloured car paintwork; black gravestones; photovoltatics panels
extent of photopollution	global	global
cue(s) eliciting the photoreaction of animals	intensity and colour of light	horizontal polarization of light
time of day of photopollution	between dusk and dawn	both day and night
directly or indirectly concerned animals	night-active animals	polarotactic aquatic insects and their predators (spiders, birds, bats)
effects of photopollution	- attraction/repulsion by lights - disturbances in biorhythm - disruption of physiological processes (reproductive condition, preparing to migrate or hibernate, egg laying, molt, hormone production) - increased deaths in collisions - disruption of seasonal changes in behaviour - disturbances in orientation and migration (dis/misorientation) - disruption of foraging - disturbances in intra/interspecific visual communication - disturbance in nest site choice - desynchronization of mating - disturbance of community interactions (e.g., increased competition and predation)	- attraction of polarotactic aquatic insects to horizontally polarized light - perishment of attracted aquatic insects due to dehydration - perishment of the eggs laid onto the polarized-light-polluting surfaces due to dehydration - disruption of water-associated behaviour elicited by horizontally polarized light - disturbances in orientation to water and migration between waters - disturbances in oviposition site selection - attraction of predators (spiders, birds, bats) by the polarotactic insects lured to the sources of horizontally polarized light

Table 9.1. Major characteristics of conventional ecological photopollution and polarized light pollution (Horváth and Zeil, 1996; Horváth *et al*., 2009; Kriska *et al*., 1998; Horváth and Varjú, 2004; Csabai *et al*., 2006; Malik *et al*., 2008).

Modern human development has resulted in the introduction of different sources of PLP to natural habitats. In the natural optical environment only the flat water surface reflects horizontally polarized light, whose p is high if light is reflected from dark water bodies at the Brewster angle (Horváth and Varjú, 2004). PLP is mainly a byproduct of the human architectural, building, industrial and agricultural technology, and it may allow to function feeding webs composed of polarotactic insects and their predators, such as spiders, birds and bats, for example (see Figure 9.4).

Figure 9.4. Predators feeding on the polarotactic insects attracted to two different sources of polarized light pollution (photographs taken by G. Kriska). Rows 1-2: Urban birds feeding on the mass-swarming caddis flies, Hydropsyche pellucidula attracted to vertical glass surfaces. A-B: A male house sparrow, Passer domesticus hunting caddis flies at a window. C: A great tit, Parus major standing on a window-frame. D: A P. major following caddis flies with attention. E: A European magpie, Pica pica on an edge of a building. F: A P. pica on wing capturing caddis flies from a glass pane. G: A white wagtail, Motacilla alba perching on a protrusion of a building. H: A hovering wagtail gathering caddis flies from a glass pane. Row 3: Spiders on the wall of a building where caddis flies (H. pellucidula) swarmed. I: An Araneus umbraticus feeding on a caddis fly captured by its cobweb. J: A Tetragnathidae sp. on a reddish brick. K: A Thomisidae sp. between two reddish bricks. L: A Salticus zebraneus on a reddish brick. Row 4: Carcasses of insectivorous vertebrates lured by polarotactic insects and trapped by the waste oil lake in Budapest. The insects were attracted to the polarized-light-polluting oil surface. M: A black redstart, Phoenicurus ochruros. N: A European goldfinch, Carduelis carduelis. O: A yellowhammer, Emberiza citrinella. P: Flock of European greenfinches. Q: European magpie. R: A bat (Chiroptera). S: An owl. T: A kestrel, Falco tinnunculus.

PLP is a well-documented cause of egg mortality among aquatic beetles and bugs, mayflies and caddis flies. The phenomenon of PLP is global and new in an evolutionary sense, having increased rapidly only over the last decades, following the spread of highly and horizontally polarizing artificial surfaces such as oil lakes and open-air oil reservoires, asphalt roads, plastic sheets, glass surfaces, cars and solar panels, for example. The mortality associated with PLP may threaten populations of endangered aquatic insect species.

PLP can occur not only in daytime, but also at night, if moonlight or citylight (e.g., skyglow, streetlamps) is reflected from polarized-light-polluting surfaces. The vulnerability to PLP (based on positive polarotaxis) could be enhanced by the synergetic interaction with conventional photopollution (based on positive phototaxis) caused by artificial night lighting. PLP could also be influenced by lunar cycles, especially in rural environment, where artificial night lighting is rare or lacking. It is important to determine and monitor the sources of PLP in order to minimize and/or replace them by artificial surfaces which are "aquatic insect friendly". Since many human developments with numerous polarized-light-polluting artificial surfaces are near water bodies, the aquatic insects living in/at lakes, rivers, ponds and streams are all subject to PLP. Because aquatic insects are critically important as members of food webs in aquatic ecosystems, adverse effects of PLP on these animals could have serious ecological consequences.

Flight to horizontally polarized light reflected from artificial surfaces could disturb the ecology of aquatic insects, and often can lead to high mortality of the adults and/or the eggs laid onto these polarized-light-polluting surfaces. Polarotactic aquatic insects frequently are not able to escape from the source of PLP. This behaviour is called the "polarization captivity effect", which culminates in the death of insects due to dehydration and exhaustion. The migration, dispersal, mating and reproduction of aquatic insects can also be disturbed by sources of PLP encountered in their long-distance flight paths. This is called the "polarization crash barrier effect" because of the interruption of movement across the landscape. Aquatic insects are also vulnerable to normal (unpolarized) artificial lights: Streetlamps, for example, have a long-distance effect for light-susceptible mayflies and caddis flies emerging from a small mountain stream. The night-time attraction of these insects to lamps is so strong that if there were a row of streetlamps along a stream, a species could become locally extinct in a short time. This extinction can only be accelerated by PLP.

9.3 Evidences of Polarized Light Pollution

9.3.1 Aquatic Insects Trapped by Dark Oil Surfaces

Many individuals of the dragonfly *Anax junius* have been killed as a result of mistaking an open surface of crude oil for water, and other dragonflies have been attracted to pools of petroleum. Horváth and Zeil (1996) observed a similar phenomenon in the desert of Kuwait: During the Gulf War in early 1991, Iraqi occupation forces blasted oil wells and pipelines in the desert of Kuwait, forming more than 900 oil ponds. Several years later, the majority of these oil lakes still existed and continued to trap a variety of animals, mainly insects, especially aquatic insects (Horváth and Zeil, 1996). Reductions in the oil level due to evaporation and percolation into the ground created distinct bands of insect carcasses at their edges. Bands of dead dragonflies, damselflies and ground-beetles reflected arrivals of migrating insects in autumn and spring. Mass arrivals of aeschnid dragonflies were witnessed by Jochen Zeil in October 1994 and February 1995, many females being trapped while attempting to lay eggs in the oil (see Figure 9.3A). Different species of water beetles (Dytiscidae, Coleoptera), giant water scorpions (*Belostoma* sp., Nepidae, Heteroptera), mole crickets (Gryllotalpidae, Orthoptera) as well as sphingid moths, *Vanessa* butterflies, solifugid spiders, scorpions, reptiles, birds and mammals were found at the edge of the oil ponds.

Horváth and Zeil (1996) suggested that polarotactic water insects were attracted by the high and horizontal polarization of light reflected from the oil surface. This hypothesis has been tested and supported in multiple-choice field experiments with dragonflies in Hungary. The numbers of dragonflies caught by water, crude oil and salad-oil traps with different reflection-polarization characteristics have been compared. It has been demonstrated that positive polarotaxis is the most important mechanism which guides dragonflies during their habitat choice and oviposition site selection, and this is the reason why dragonflies can be deceived by and attracted to crude and waste oil, tar or asphalt. Using horizontally aligned test surfaces with different reflection-polarization characteristics in multiple-choice field experiments with dragonflies, it has been obtained the same result in Switzerland.

Horváth and Zeil (1996) also compared the reflection-polarization characteristics of crude oil and transparent/translucent water surfaces by imaging polarimetry. They showed that a dark oil surface reflects always horizontally polarized light, whose degree of linear polarization p is very high (near 100%) near the Brewster angle [$\theta_{\mathrm{Brewster}}$ = arc tan (n) ≈ 58° from the vertical for the refractive index n = 1.6 of oil] (see Figure 9.2B), while water bodies, especially the bright ones reflect light usually with lower p and not always with horizontal polarization. The larger the p and the smaller the deviation of the direction of polarization of reflected light from the horizontal, the greater is the attractiveness of a reflecting surface to polarotactic water insects (Horváth and Varjú, 2004). The consequence is that a dark oil pond can be even more attractive to polarotactic aquatic insects than a brighter water body. Thus, for polarotactic water insects oil lakes appear as an exaggerated water surface acting as a supernormal optical stimulus.

Unfortunately, in many countries plenty of temporary inland oil spills exist as a by-product of the oil industry (exploitation, transport, storage and refinery of the oil). At warm weather the surface of these oil lakes is flat, shiny and acts as an efficiently polarizing reflector of sunlight and skylight, like a water surface. Since 1951 there has existed an open-air waste oil reservoir in a suburb of Budapest, Hungary. It has been observed that this open-air oil reservoir deceived, attracted and trapped water insects in large numbers. They also measured the reflection-polarization characteristics of the waste oil surface versus time. This oil reservoir acted as a disastrous polarized insect trap for 50 years.

It has been observed that dragonflies, mayflies, caddis flies, water bugs and water beetles were trapped *en masse* by the waste oil in spring, summer and autumn at the time of their swarming and migration (see Figure 9.3B,C,D). Usually, the insects landed or plunged directly on the sticky oil surface and became immediately entrapped. Pairs of insects, e.g., dragonflies and mayflies, were trapped frequently by the oil during copulation and/or egg-laying.

Horváth and Zeil (1996) observed the behaviour of larger dragonflies above the crude oil lakes in Kuwait and the waste oil reservoir in Budapest. Male dragonflies frequently patrolled above the flat oil surface and protected their territory against all intruders. They tried to attack all flying insects. Male dragonflies often sat guard on the tip of perches at the shore. Copulating pairs of dragonflies were frequently observed flying above the oil surface or trying to lay 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 at oil lakes is a reaction, which is typical only above water surfaces when dragonflies inspect the surface to select the optimal habitat or oviposition site. The most frequently observed behaviour types of dragonflies above the oil surface were the air fight, hovering and protection, which again are typical only above water surfaces.

9.3.2 Polarotactic Insects Deceived by Black Plastic Sheets on the Ground

Kriska *et al*. (1998) and Csabai *et al*. (2006) performed choice experiments with polarotactic aquatic insects in the field using white and black plastic (polyethylene) sheets laid on the ground in different wetlands. Such 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 and to protect it against rain. A horizontal black plastic sheet reflects always horizontally polarized light with high degrees of linear polarization p near the Brestwer angle [$\theta_{\mathrm{Brewster}}$ = arc tan (n) ≈ 56.3° from the vertical for the refractive index $n = 1.5$ of plastic] (see Figure 9.2C), while a white plastic sheet reflects vertically or obliquely polarized light with very low p. Hence a shiny black plastic sheet is a more effective polarizer than a white plastic sheet. Thus, the light reflected from a horizontal shiny black plastic sheet acts as a supernormally polarized stimulus for polarotactic water-seeking insects.

Kriska *et al*. (1998) and Csabai *et al*. (2006) found that only the horizontal black plastic sheet attracted insects associated with water, while the white plastic sheet were unattractive to them. All these aquatic insects attracted showed similar behavioural elements on and above the black plastic sheet: landing (see Figure 9.3G,H), flying up, touching, crawling, egg-laying (see Figure 9.3F), copulating (see Figure 9.3E), reproductive activity. Finally, some of them (e.g., aquatic bugs and beetles) dried out and perished within some hours. During these field experiments almost at every sunset a rattling sound has been heard from the black plastic sheet like the pattering of raindrops. The reason for this was thousands of water insects (e.g., Corixidae water bugs or swarming mayflies) 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 attractive black plastic sheet; they remained on it. At the white plastic sheet similar effect was not observed. All these experiments and observations show that horizontal black shiny plastic sheets can deceive and attract polarotactic water insects due to the highly and horizontally polarized reflected light, while white plastic sheets are unattractive to these insects, because the reflected light is weakly and/or not horizontally polarized.

Kriska *et al*. (1998) showed that the mayfly species *Ephemera danica*, *Ecdyonurus venosus*, *Epeorus silvicola*, *Baetis rhodani*, *Rhithrogena semicolorata*, *Haproleptoides confusa* and *Palingenia longicauda* detect water by means of the horizontal polarization of light reflected from the water surface, and then move towards it, thus showing positive polarotaxis. This is the reason why these mayflies can be deceived by and attracted to horizontal shiny black plastic sheets, above which they swarm, copulate, and onto which they lay their eggs *en masse* (see Figure 9.3E,F).

It has been discovered the attraction to horizontally polarized light (positive polarotaxis) in both males and females of the tabanid fly species *Haematopota pluvialis*, *Heptatoma pellucens*, *Hybomitra ciureai*, *H. solstitialis*, *H. ucrainica*, *Tabanus bovinus*, *T. bromius*, *T. sudeticus*, *T. tergestinus*. All these tabanids are terrestrial, but lay their eggs onto the lower side of the leaves of marsh-plants leaning over the water surface, because after egg hatching the larvae must drop into the water where they develop. It has been proposed that in these tabanids the first step in the remote search for potential terrestrial rendezvous and egg-laying sites happens indirectly by means of the detection of horizontally polarized light reflected from the surface of waters, on the shore of which appropriate plants for oviposition may occur. Due to their positive polarotaxis all the mentioned tabanid fly species can be attracted to highly and horizontally polarizing shiny black plastic sheets laid on the ground as has been demonstrated in choice experiments (see Figure 9.3H).

9.3.3 Attraction of Polarotactic Aquatic Insects to Dry Asphalt Roads

It has been observed that during their swarming above the river Tisza in Hungary *Palingenia longicauda* mayflies were attracted to a wet asphalt road running on the bank parallel to the river. It has been reported that different dragonfly species patrolled along dry asphalt roads instead of rivers and showed a typical water-touching behaviour above the asphalt surface. Kriska *et al*. (1998) observed that near sunset the individuals of the mayfly species *Ephemera danica*, *Ecdyonurus venosus*, *Epeorus silvicola*, *Baetis rhodani*, *Rhithrogena semicolorata* and *Haproleptoides confusa* swarmed, mated above and landed on dry asphalt roads (see Figure 9.3I,J), shiny black plastic sheets and windscreens and roofs of cars in the immediate vicinity of their emergence sites (mountain streamlets). After copulation the female mayflies laid their eggs on the dry asphalt surface instead of laying them on the water surface. The mayflies showed the same behaviour above the asphalt road as at water surfaces. In spring near to the mountain creeks female stoneflies with their egg-batches could also often be seen on the asphalt roads (see Figure 9.3K). These observations, especially the egg-laying by females, show that the mayflies and stoneflies were apparently deceived by and attracted to the dry asphalt surface.

Kriska *et al*. (1998) gave a convincing explanation of this behaviour of mayflies: Using imaging polarimetry, they showed that asphalt surfaces lit by skylight near sunset, when mayflies swarm, mimic a highly and horizontally polarizing water surface to water-seeking mayflies (see Figure 9.2D). The direction of polarization of sunlight reflected from sunlit asphalt roads is always perpendicular to the plane of reflection determined by the observer, the sun and the point observed. Thus, the direction of polarization of asphalt-reflected sunlight is usually tilted relative to the horizon, but it is always horizontal, if the observer views toward the solar or antisolar meridian, because in these cases the plane of reflection is vertical. If the asphalt road is diffusely illuminated by the downwelling skylight only, the reflected light is always horizontally polarized due to the extended sky, which illuminates the road from all possible directions. In multiple-choice experiments with swarming mayflies Kriska *et al*. (1998) showed that the above-mentioned six mayfly species detect water by means of the horizontal polarization of reflected light, and possess positive polarotaxis, because they are attracted to horizontally polarized light. Kriska *et al*. (1998) also showed that the darker and smoother the horizontal asphalt surface, the greater is its attractiveness to water-seeking polarotactic mayflies.

The highly and at sunset always horizontally polarized asphalt roads with a relatively homogeneous distribution of the degree p and angle α of linear polarization of reflected light can be much more attractive to polarotactic mayflies than the water surface. An asphalt road can reflect and polarize the incident light in such a way that the reflected light becomes a supernormal stimulus for water-seeking mayflies in comparison to the light reflected from water. This was also observed in the multiple-choice experiments of Kriska *et al*. (1998), when mayflies swarming above the asphalt road were attracted to the highly polarized shiny black plastic sheet after it was laid onto the road. A relatively small black plastic sheet (a few m^2) attracted all the mayflies swarming above the asphalt road within several tens metres.

Positive phototaxis (Nowinszky, 2003) and polarotaxis can synergetically govern the behaviour of water-seeking polarotactic aquatic insects: We observed (2007, unpublished data) that night-migrating scavenger beetles (*Hydrophilus piceus*) were attracted by phototaxis from large distances, and then trapped by polarotaxis by a lamplit dry asphalt surface. Hence, from a distance flying water seeking insects can be attracted to the street lamps above the littoral asphalt road by positive phototaxis. Then polarotaxis is not in action yet, because the lamps emit unpolarized light, and the horizontally polarized light reflected from the asphalt road is not visible yet. Approaching the lamplit asphalt road, the observed scavenger beetles could already perceive the horizontally polarized light reflected from the dry asphalt, thus they were attracted to the lamplit asphalt area by positive polarotaxis. Due to this strong polarization signal they remained temporarily in the circular light spot on the asphalt, because then there was no other horizontally polarized light signal in their optical environment (see Figure 9.3L).

9.3.4 Aquatic Insects Attracted by Black, Red or Dark-coloured Car Paintwork

Aquatic beetles (Coleoptera) and bugs (Heteroptera) have been frequently observed to land on the roofs, bonnets and boots of black or red cars (Kriska *et al*., 1998), and Ephemeroptera and Odonata females often lay their eggs on these car surfaces. To reveal the reasons for this phenomenon, the numbers of aquatic beetles and bugs attracted to horizontal shiny red, yellow, white and black plastic sheets have been monitored. It has been found that horizontal red and black reflectors are equally highly attractive to aquatic beetles and bugs, while yellow and white reflectors are unattractive. The reflection-polarization characteristics of red, yellow, white and black cars have also been measured in the red, green and blue parts of the spectrum. It has been found that in the blue and green parts of the spectrum p of light reflected from red and black cars is high, and the direction of polarization of light reflected from red and black car roofs, bonnets and boots is exactly or nearly horizontal (see Figure 9.2E). Thus, the horizontal surfaces of red and black cars are highly attractive to red-blind polarotactic aquatic insects. On the other hand, p of light reflected from the horizontal surfaces of yellow and white cars is low and its direction of polarization is usually not horizontal. The same was true for the reflection-polarization characteristics of black, white, red and yellow horizontal plastic sheets used in field experiments monitoring water insects. Hence, yellow and white cars and plastic sheets are unattractive to polarotactic aquatic insects. These results show that the visual deception of aquatic insects by red, black and dark-coloured cars can be explained solely by the reflection-polarization patterns of the car paintwork and the positive polarotaxis of these insects.

An egg-batch of a female mayfly, for example, contains 6000-9000 eggs (Kriska *et al*., 1998). All the eggs laid onto car surfaces perish. This also often occurs in the case of water insect imagoes due to dehydration on hot car surfaces. However, not only the highly and horizontally polarizing car paintworks can be dangerous to aquatic insects and/or their eggs, but the eggs laid onto car-bodies can also damage the resin of the clearcoat as does acid rain. It has been shown that the eggs of *Miathyria*, *Tauriphila* and *Erythemis* dragonflies at temperatures between 50 and 92°C produce sulfonic acids that destroy the clearcoat.

9.3.5 Polarotactic Dragonflies Deceived by Shiny Black Gravestones and Other Black Anthropogenic Products

It has been observed that the females of *Orthetrum* dragonflies laid their eggs on a shiny cement floor and *Copera marginipes* made repeated egg-laying movements in a dirty seam on a shiny black bench. Dragonflies have been attracted to shiny roofs of automobiles. It has been reported that *Libellula depressa* dragonflies laid their eggs onto a glass pane of a greenhouse. It has been experienced that mature individuals of *Pantala flavescens* performed sexual behaviour and oviposition movements over shiny roofs of tents. It has been found that the flight activity of dragonflies above shiny plastic sheets laid on *Sphagnum* bog was significantly higher than above control plots without plastic. Although these authors experienced that the dragonflies performed sexual behaviour and oviposition movements over the shiny surfaces mentioned, they did not recognize the important role of polarotaxis in the habitat choice of dragonflies and in their deceiving by different artificial shiny black surfaces.

It has been observed that the dragonfly species *Sympetrum flaveolum*, *S. striolatum*, *S. sanguineum*, *S. meridionale* and *S. danae* were attracted by polished black gravestones in a Hungarian cemetery without lacking any water body. The dragonflies showed the same behaviour as at water: (i) they perched persistently in the immediate vicinity of the chosen gravestones and defended their perch against other dragonflies (see Figure 9.3Q); (ii) flying individuals repeatedly touched the horizontal surface of the shiny black tombstones with the ventral side of their body; (iii) pairs in tandem position frequently circled above black gravestones. Tombstones preferred by the dragonflies had an area of at least 0.5 m^2 with an almost horizontal, polished, black surface, the sky was open above them, and there was at least one perch in their immediate vicinity.

Using imaging polarimetry, it has been found that the black gravestones, like smooth water surfaces, reflect highly and horizontally polarized light (see Figure 9.2F). In double-choice field experiments it has been showed that the dragonflies attracted to shiny black tombstones possess positive polarotaxis and therefore, under natural conditions, detect water by means of the horizontally polarized reflected light. Positive polarotaxis in several other dragonfly species has been demonstrated in other field experiments, in which it was also shown that these insects detect water by the horizontal polarization rather than by the intensity and/or colour of reflected light. The positive polarotaxis and the reflection-polarization characteristics of black gravestones explain why the observed *Sympetrum* dragonflies were attracted to black tombstones.

It has been observed that tandems of *Sympetrum* species oviposited onto nearly horizontal glass panes in a botanic garden. *S. striolatum* has been seen to oviposit on an old plastic windscreen thrown into a chalk pit and on glass panels of a tractor door that was left laid flat on grass. When the door was placed in an upright position the tandems lost their interest in it. It has been reported that a tandem of *S. vulgatum* laid 50 eggs on the metallic-green bonnet of a car. Black gravestones can also elicit oviposition in dragonflies. Actual and attempted egg-laying by dragonflies onto horizontal shiny dark surfaces such as car bodies, oil pools or asphalt roads has repeatedly been observed (Horváth and Varjú, 2004). All these man-made substrata can constitute ecological traps *sensu* Schlaepfer *et al.* (2002), thus reducing the dragonflies' individual fitness. The same is true for certain gravestones. The deception of *Sympetrum* species observed in a Hungarian cemetery could be a global phenomenon. In fact, in 2007 it has also been noticed in a graveyard near Lake Neusiedl, Austria.

9.3.6 Polarotactic Caddis Flies Lured to Glass Surfaces

The caddis flies *Hydropsyche pellucidula* emerge near sunset from the river Danube and swarm around trees and bushes on the river bank. It has been observed that these aquatic insects can also be attracted *en masse* to the vertical glass surfaces of buildings on the river bank in Budapest, Hungary (see Figure 9.3R). The mass-swarming *H. pellucidula* lured to dark vertical glass panes landed, copulated and remained on the glass for hours (see Figure 9.3S,T). Many of them became trapped by the partly open tiltable windows. In laboratory choice experiments it has been showed that ovipositing *H. pellucidula* are attracted to highly and horizontally polarized light stimulating their ventral eye region, and thus have positive polarotaxis, the function of which is to detect water, from which they emerge, and to which they must return to oviposit. In the field it has been documented that highly polarizing vertical black glass surfaces are significantly more attractive to both female and male *H. pellucidula* than weakly polarizing white ones.

Using imaging polarimetry, Malik *et al.* (2008) measured the reflection-polarization characteristics of shady and sunlit, black and white vertical glass surfaces of buildings (where caddis flies swarmed) from different directions of view under clear and overcast skies in the red, green and blue parts of the spectrum. Using these polarization patterns, they determined those areas of the investigated glass surfaces (see Figure 9.2G), which are sensed as water by polarotactic insects facing and flying toward, or landed on a vertical pane of glass. Malik *et al.* (2008) showed that the attraction of flying caddis flies to vertical glass surfaces and that these insects remain on vertical panes of glass after landing can be explained by the reflection-polarization characteristics of vertical glass surfaces and the polarotactic behaviour of these aquatic insects. They proposed that after its emergence from the river, *H. pellucidula* is attracted to buildings by their dark silhouettes and the glass-reflected horizontally polarized light. After sunset this attraction may be strengthened by positive phototaxis elicited by the buildings' lights. Since vertical glass panes of buildings are abundant in the man-made optical environment, and polarotactic aquatic insects are spread world-wide, these results are of general interest in the visual and behavioural ecology of aquatic insects.

9.3.7 Polarized Light Pollution of Solar Panels and How it can be Reduced by White Grid-Patterns

Solar panels (including solar collectors and photovoltaic solar cells) are rapidly spreading in the world (see Figure 9.5). They usually have large, smooth, black surfaces maximizing the absorbed sunlight. Using imaging polarimetry, the reflection-polarization characteristics of solar panels have been measured (see Figures 9.2H and 9.6, 9.7). It has been showed that solar panels can reflect highly and horizontally polarized light, and thus are strong sources of polarized light pollution. Therefore they can be ecological traps for aquatic insects, which are attracted to horizontally polarized light, because they detect water by the horizontal polarization of light reflected from the surface of waters, where their larvae develop. In a Hungarian nature reserve park it has been observed that stoneflies (Trichoptera), mayflies (Ephemeroptera), dolichopodid dipterans and tabanid flies (Tabanidae) were attracted in a large number to photovoltaic solar cells, where they swarmed, displayed reproductive behaviour, and the females oviposited onto the shiny black solar cells (see Figure 9.8). Multiple-choice field experiments have been performed with these insects to study their attraction to solar panels. Solar panels polarized reflected light almost completely (degree of polarization $d \approx 100\%$) and substantially exceeded typical polarization values for water ($d \approx 30\text{-}70\%$).

Figure 9.5. Solar panels, including solar collectors (SCs) and photovoltaic solar cells (PVSCs), are increasingly spreading in the world. (A) A passive, closed-circuit water heating system using a multi-flow shiny black solar collector panel providing high-efficiency absorption of solar radiation. The heated-up water is stored in black cylindrical tanks (http://www.solahart.com). (B) A SC on the roof of a house (http://www.weishaupt.de). (C) A German solar electricity plant with thousands of PVSCs (http://www.phoenixsolar.com). (D) Horizontal PVSCs on a rooftop in Farmingdale, Long Island, NY, USA (http://www.power-technology.com/projects/long_island). (E) PVSCs on the rooftop of a building of the Szent István University in Gödöllő, Hungary (photo by G. Kriska). (F) PVSCs on the roofs of family houses in the Japanese solar town, Kiyomino (http://www.iea-pvps-task10.org).

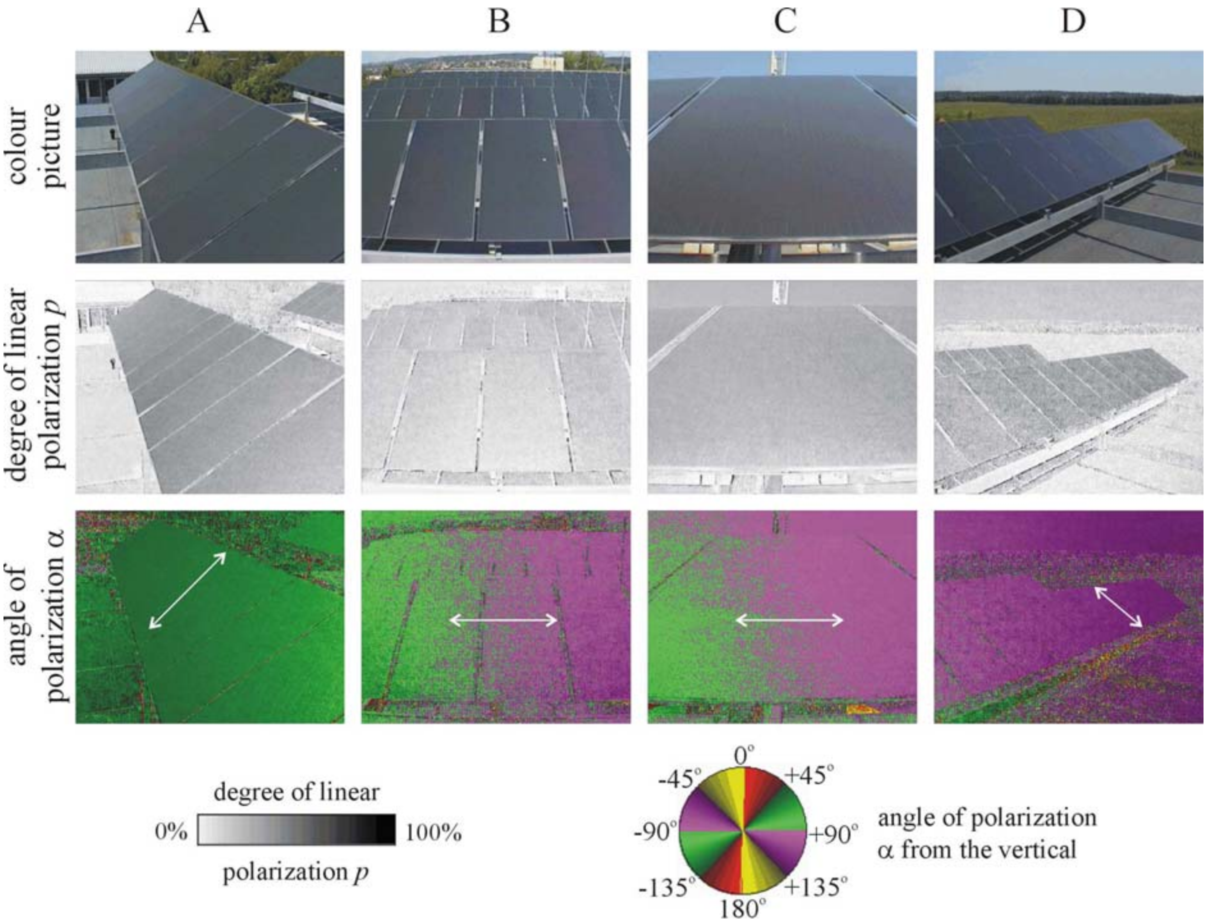

Figure 9.6. Colour pictures and patterns of the degree of linear polarization p and the angle of polarization α (clockwise from the vertical) of photovoltaic solar cells with homogeneous shiny black surface on the rooftop of the Szent István University in Gödöllő, Hungary measured in the green (550 nm) part of the spectrum from four different directions of view: from right (A), from front and above (B), from front and below (C), from left (D). In the α-patterns the double-headed arrows show the local direction of polarization of reflected light.

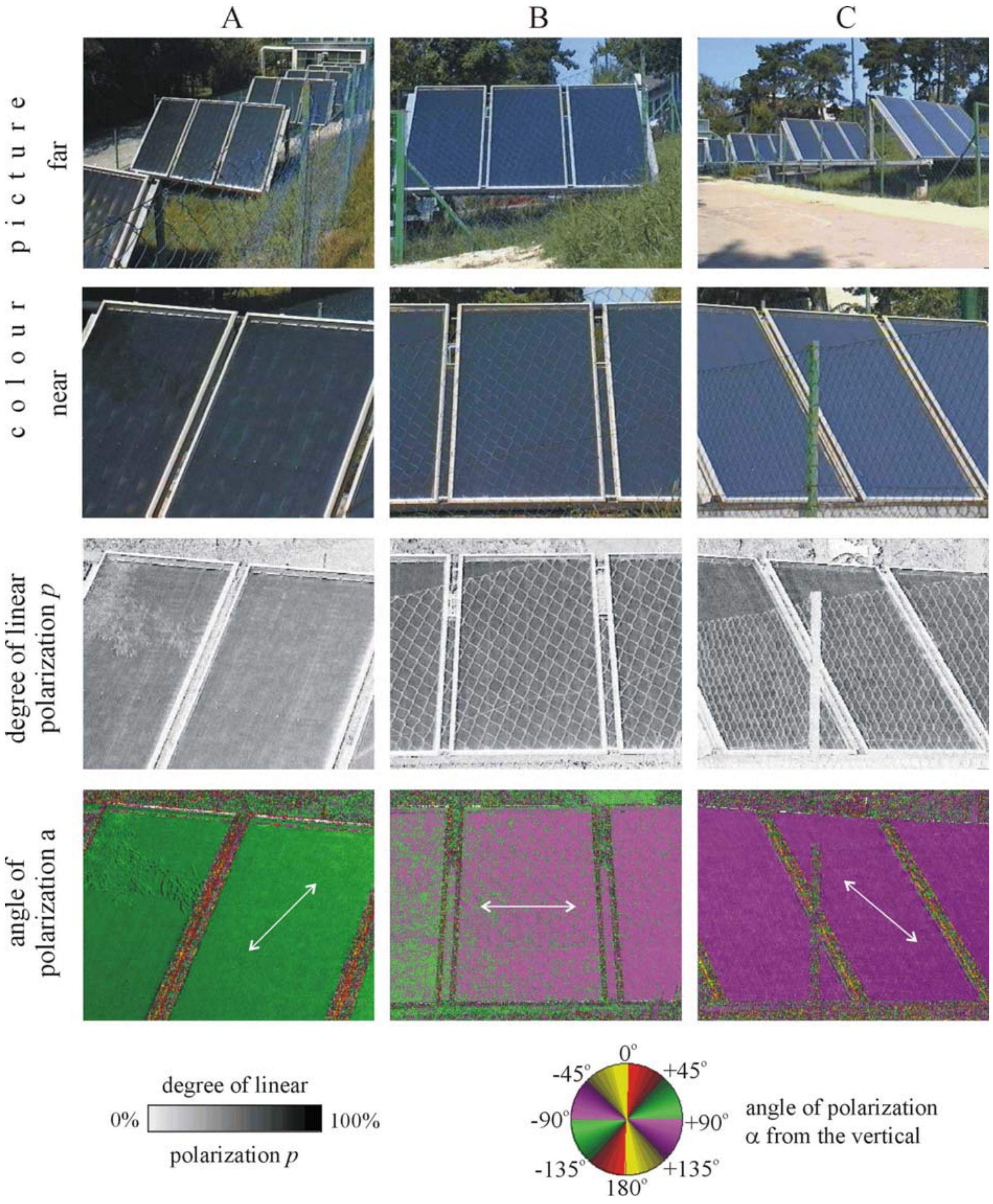

Figure 9.7. As Figure 9.6 for solar collectors in the garden of the Szent István University in Gödöllő, Hungary viewed from three different directions of view: from right (A), from front (B), from left (C). In the p-patterns of columns B and C it can be seen that the wire-grid of the fence reflects practically unpolarized light.

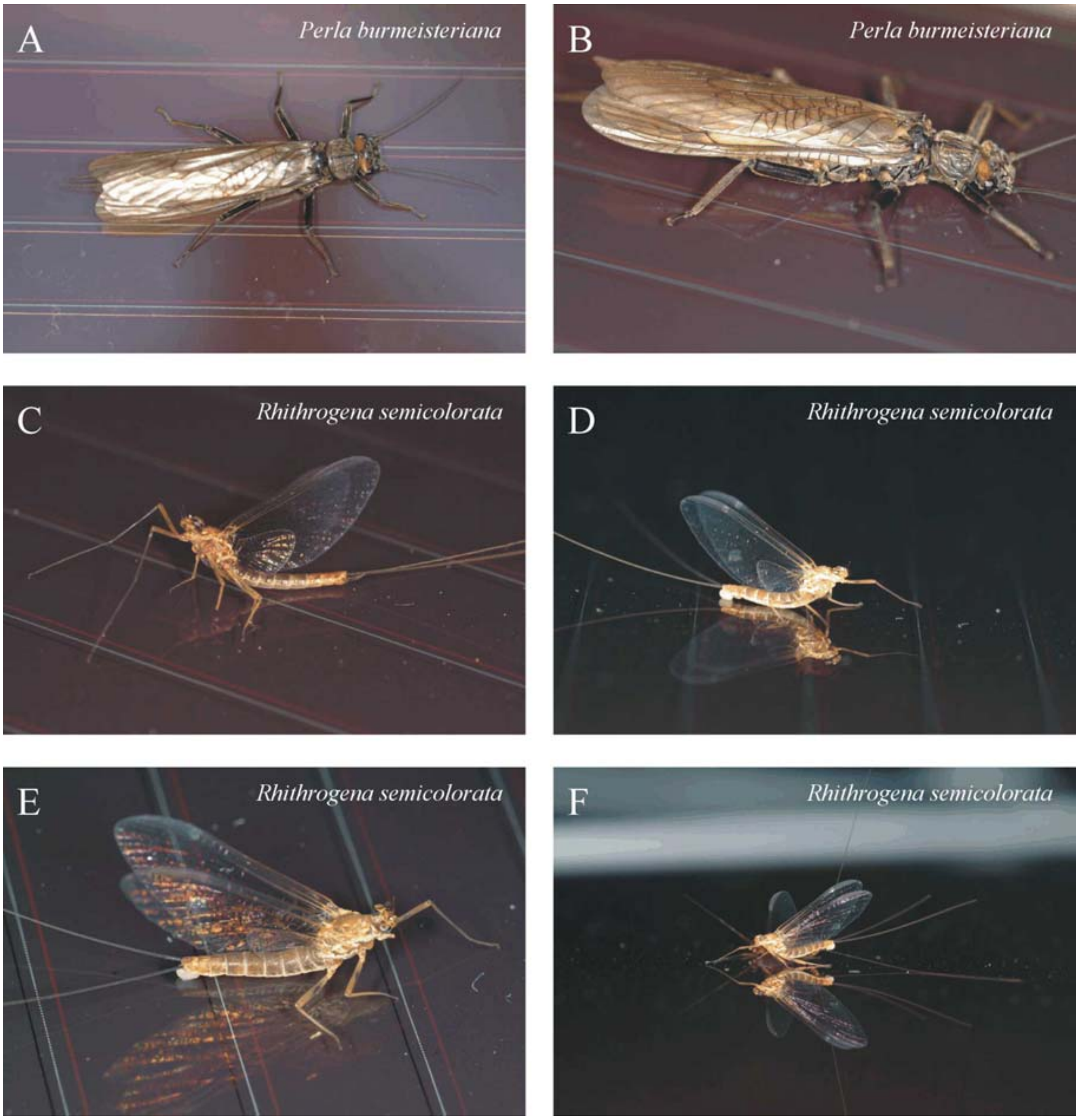

Figure 9.8. Polarotactic insects attracted to and landed on the shiny black surface of a shiny-black-framed photovoltaic solar cell on 23 May 2008 in the National Park at Dömörkapu, near Budapest, Hungary in our 3rd experiment. (A, B) Adult female stonefly (Perla burmeisteriana). (C) Male mayfly (Rhithrogena semicolorata). (D-F) Female R. semicolorata with a white egg batch on the end of her abdomen.

These insects were attracted to solar panels more often than to surfaces with lower degrees of polarization (including water), but in general they avoided solar panels with nonpolarizing white borders and white grates (see Figure 9.9). The highly and horizontally polarizing surfaces that had nonpolarizing, white cell borders were 10- to 26-fold less attractive to insects than the same panels without white partitions (see Figure 9.10). Although solar panels can act as ecological traps, fragmenting their solar-active area do lessen their attractiveness to polarotactic insects. This gave a new and reliable clue to reduce, or even eliminate the polarized light pollution of solar panels. These results are of general importance, because they are valid to all kinds of shiny black artificial surfaces reflecting highly and horizontally polarized light. It has been proposed that the strong polarized light pollution of such surfaces can be eliminated by an appropriate depolarizing (e.g., white) grid-pattern, which diminishes their attractivity to polarotactic aquatic insects, and thus makes them more environmentally-friendly.

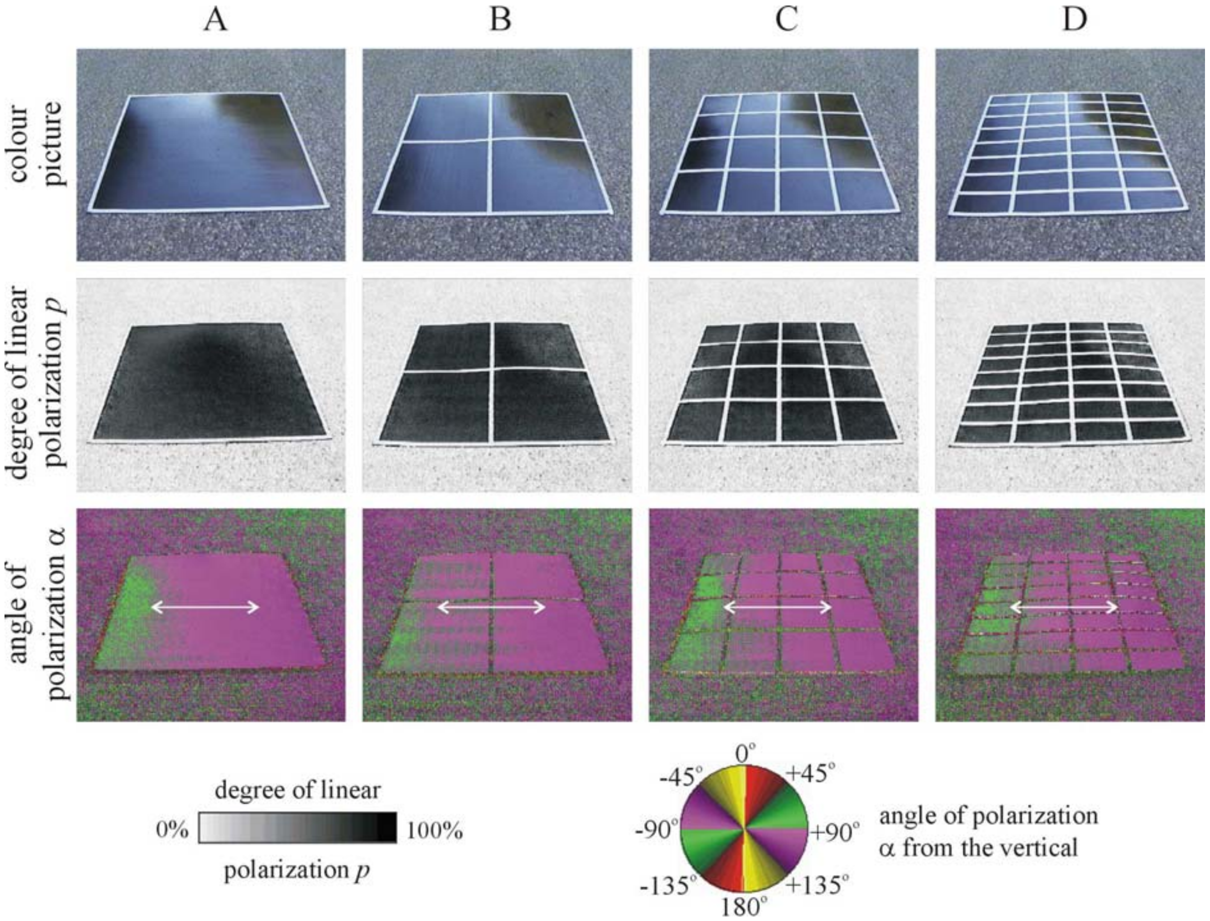

Figure 9.9. As Fig. 9.6 for four different sticky test surfaces laid on a dry asphalt road in a choice experiment.

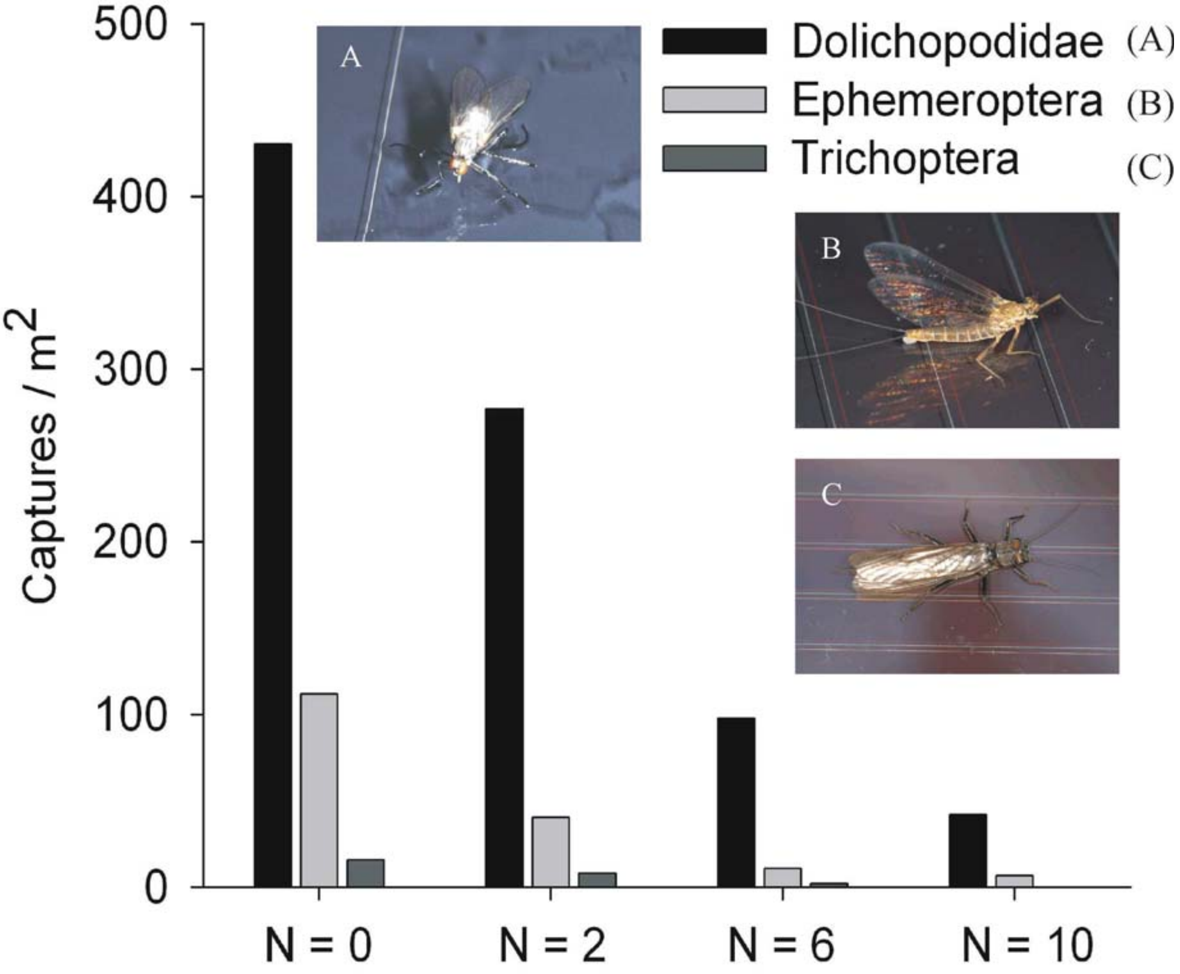

Figure. 9.10. The surface density of polarotactic dolichopodid (Diptera), mayfly (Ephemeroptera) and Philopotamus (Trichoptera) species trapped by sticky polarizing surfaces with N orthogonal white stripes in a choice experiment. Captures / m^2 are given calculated as $n(N) = m \cdot 1m^2 / A_{black}(N)$, where m is the total insect captures per test surface, $A_{black}(N)$ is the sum of the black polarizing area. Reduction in surface density associated with maximal partitioning were significant for all groups (binomial χ^2 test, N=0 / N=10; dolichopodids:, $\chi^2 = 320$, df = 1, $P < 0.0001$; Ephemeroptera: $\chi^2 = 93.3$, df = 1, $P < 0.0001$; Trichoptera: $\chi^2 = 14.2$, df = 1, $P = 0.0002$). Insets: Photographs of polarotactic aquatic insects attracted to the shiny black surface of a photovoltaic solar cell in the National Park at Dömörkapu near Budapest in Hungary. (A) Aquatic dolichopodid. (B) Female mayfly (Rhithrogena semicolorata) with a white egg batch
on the end of her abdomen. (C) Female stonefly (Perla burmeisteriana).

In certain cases the remedy of polarized light pollution, i.e. a depolarizing grid-pattern, is already embedded into the technology: The solar panel used in field experiments had a depolarizing white frame, and certain kinds of photovoltaic solar cells also possess such a white frame and a white grating (right panel in Figure 9.2H). These white gratings are the result of certain technical requirements, but fortunately as an unexpected byproduct, they also reduce the polarized light pollution. It is an important task of future research to determine the optimal pattern of these depolarizing gratings, which can maximally reduce the attractivity to polarotactic insects. It is probable that the optimal parameters (the width of depolarizing stripes and their distances from each other) of the depolarizing grid-pattern depends on the species. Solar panels provided with such an optimal depolarizing grid-pattern can surely appear in the market as environmentally-friendly new products.

What could be the reasons for the phenomenon that a simple depolarizing white frame/grid-pattern can reduce/eliminate the attractivity of horizontal shiny black surfaces to positively polarotactic insects? Figure 9.11 summarizes a possible explanation of this unexpected phenomenon.

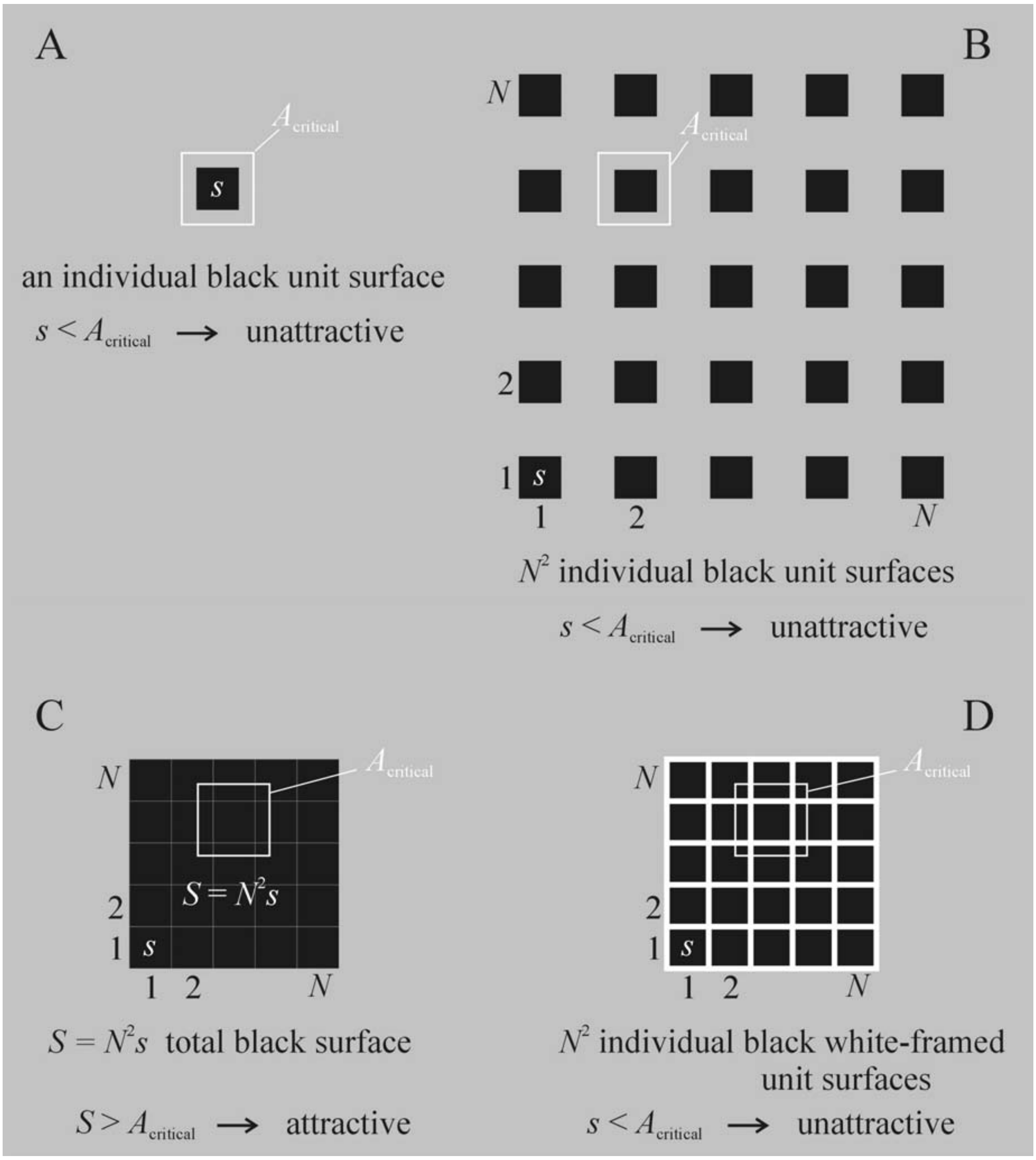

Figure 9.11. For explanation of the attractivity/unattractivity of horizontal shiny black surfaces without/with depolarizing white grid-patterns to positively polarotactic insects. A horizontal shiny black surface is attractive/unattractive to such insects, if its area is larger/smaller than a species-specific critical area A_{critical}.

A highly and horizontally polarizing shiny black surface is attractive/unattractive to polarotactic insects if its area s is larger/smaller than a critical area A_{critical}, that may be dependent on species. The biological reason for this is the following: At a given aquatic insect species there is a minimal and a maximal dimension of the bodies of water where the larvae can optimally develop. Thus the adult females of this species lay their eggs only in such water bodies, the surface of which is neither smaller, nor larger than these lower and upper limits.

- If there is only one black unit surface with $s < A_{\text{critical}}$ in a given optical environment, it is unattractive to water-seeking flying polarotactic insects (see Figure 9.11A).
- If there are $N \times N = N^2$ such black unit surfaces at large enough distances from each other, each of them functions further on as an individual unit surface s, thus remaining henceforward unattractive to polarotactic insects, because $s < A_{\text{critical}}$ (see Figure 9.11B).
- If, however, there are N^2 black unit surfaces contacting each other, their individual unit surfaces are summed up, functioning as a large surface with $S = N^2 s$ area, and if $S > A_{\text{critical}}$, they are attractive to polarotactic insects (see Figure 9.11C).
- If there are N^2 white-framed unit surfaces s contacting each other (see Figure 9.11D), they are separated from each other by a depolarizing white frame, and thus their individual unit surfaces s cannot be summed up in the visual system of the approaching polarotactic insect. Consequently each of them functions as an individual unit surface s, and if $s < A_{\text{critical}}$, they remain unattractive to polarotactic insects, in spite of the fact they contact each other (see Figure 9.11D). The prerequisites of this effect are that the depolarizing separations, i.e. the white stripes, should be wide enough, and their number has to be large enough.

9.4 Possible Benefits and Disadvantages of Insectivorous Predators from PLP

In the term PLP 'polarized light' refers to the fact that this phenomenon is elicited only by horizontally polarized light, and 'pollution' communicates the fact that the primary effects of PLP are adverse for the insects deceived by and attracted to light with horizontal polarization. Note, however, that the secondary effects of PLP could also be advantageous: If certain animals (e.g., insectivorous birds, spiders and bats) can feed on the polarotactic insects attracted to artificial horizontally polarized light, they can take advantage of PLP. The hunting of insects attracted to streetlamps at night by anuran amphibians, reptiles, birds, bats and spiders is a well known secondary effect of the conventional (non-polarized) ecological photopollution.

It has been reported that wagtails (*Motacilla alba* and *M. flava*) were lured by polarotactic insects attracted to highly and horizontally polarizing huge black dry plastic sheets laid on the ground. These wagtails systematically hunted and caught the insects above or on the plastic sheets which functioned like huge bird feeders. Kriska *et al.* (1998) observed that wagtails (*Motacilla alba*) frequently gathered the mayflies swarming and copulating above, and ovipositing on the dry asphalt roads running near creeks and rivers in suburban regions. It has also been observed that the caddis flies attracted to vertical glass surfaces of buildings on the bank of the river Danube in Budapest lured numerous different birds, such as european magpies, white wagtails, house sparrows and great tits. These birds systematically hunted and caught the caddis flies landed on the glass panes or swarming at the windows (see Figure 9.4A-H). Spiders also fed on these caddis flies on the bleak walls (see Figure 9.4I-L).

As a first approximation we can assume that the mentioned predators benefit from the abundance of caddis flies attracted to the glass surfaces as prey animals. An additional advantage of glass buildings from these predators' point of view, could be that they supply food (caddis flies) on a temporally and spatially more predictable basis than other habitats. This may be obvious for the attracted magpies, possessing no predators around the glass buildings. On the other hand, however, the numerous magpies lured by the caddis flies mean an enhanced predatory risk for the chicks of house sparrows, white wagtails and great tits, because magpies are dangerous nest predators of other smaller birds. This situation could be an ecological trap for sparrows, wagtails and tits: (i) The abundance of caddis flies lured to the glass surfaces attracts the mentioned bird species. (ii) These birds may lay their eggs in the vicinity of the glass buildings due to the insect prey abundancy. (iii) The chicks of wagtails, sparrows and tits could be predated by the magpies, which can destroy the local wagtail, sparrow and tit populations. On the other hand, due to the temporal food abundance more wagtails could grow up, but these birds might not find enough insects for survival after the caddis fly swarming. The birds attracted by the caddis flies swarming at glass surfaces feed also on the spiders lured (see Figure 9.4I-L). Thus, these spiders are not only predators, but also prey animals in this food web.

Similar, but a more complex food web has been observed at the open-air waist oil reservoir in Budapest: The highly and horizontally polarizing black oil surface attracted different polarotactic aquatic insect species in large numbers. These insects lured various insectivorous birds and bats, which were trapped by the sticky oil (see Figure 9.4M-P, 4R). The carcasses of these entrapped birds and bats attracted different carnivorous birds (e.g., owls and hawks), which have also been trapped by the oil (see Figure 9.4Q,S,T). Finally, all members of this food web based on the PLP of the waste oil surface were killed by the oil (see Figure 9.4M-T).

We have mentioned above that tabanid flies are also polarotactic, thus they can be attracted to all highly and horizontally polarizing surfaces. This PLP of shiny black surfaces can be used to develop new optically luring tabanid traps being more efficient than the existing ones based on the attraction by the brightness and/or colour of reflected light. This is disadvantageous for the local tabanid population, but is a benefit for humans and their domestic animals, because tabanids are spread world wide, and their females are usually haematophagous. Since female tabanids suck also the blood of domestic animals and humans, they are vectors of numerous dangerous animal and human diseases and/or parasites such as anthrax, tularemia, anaplasmosis, hog cholera, equine infectious anemia, filariasis and Lyme disease.

9.5 Suggested Remedies of PLP

Not every artificial horizontal surface reflecting light with high p induces PLP. Although they are horizontal and sometimes highly polarizing, certain surfaces do not attract polarotactic aquatic insects. Such surfaces are, for example, sunlit roads and plains. On sunny days mirages may appear on these hot surfaces, when there seems to be a pool of shiny water in the distance, which dissolves on approach. The sky, landmarks and objects are mirrored in this ”pool”. Using imaging polarimetry, it has been measured and compared the polarization characteristics of a mirage and a water surface. It turned out that the light from the sky and the sky's mirage has the same p and α. Since the direction of polarization of skylight is usually not horizontal, the non-horizontally polarized light from mirages is unattractive to polarotactic aquatic insects. On the other hand, there are large polarization differences between the skylight and the water-reflected light, the latter being usually horizontally polarized, and thus attractive to polarotactic aquatic insects. Mirages are not usual reflections, but are formed by gradual refraction and a total reflection of light. Such gradual refractions and total reflection do not change the state of polarization of light. Mirages can imitate water surfaces only for those animals, whose visual system is polarization-blind, but sensitive to brightness and colour differences. A polarization-sensitive water-seeking insect is able to detect the polarization characteristics of a mirage. Since these characteristics differ considerably from those of water surfaces, polarotactic insects cannot be deceived by and attracted to mirages, which thus cannot induce PLP.

Another example is a sunlit black burnt stubble-field. Due to the Umow effect (the darker a surface, the higher the degree of linear polarization of light reflected by it) p of light reflected from the black ash layer of burnt stubble-fields is very high. Numerous black burnt stubble-fields have been monitored, but aquatic insects or their carcasses have never been found in the ash, although flying polarotactic insects were abundant in the area, which was shown by attracting them to horizontal black plastic sheets in the vicinity of the investigated burnt stubble-fields. From this its was concluded that black burnt stubble-fields are unattractive to polarotactic aquatic insects. The reason for this is that the ash layer is a rough surface due to the random orientation of the charred stalks of straw. The consequences of this roughness are that the direction of polarization of light reflected from the black ash is nearly horizontal only towards the solar and antisolar meridians, and it is tilted in other directions of view, furthermore the standard deviation of both the degree p and angle α of linear polarization of reflected light is large.

On the basis of burnt stubble-fields, one of the possible remedies of PLP can be to make the reflecting surfaces inducing PLP as rough as possible: the rougher a surface, the lower the p of reflected light. If the surface roughness is so large that p of reflected light is lower than the threshold p^* of polarization sensitivity of a polarotactic insect, then the surface is unattractive to this insect, because it does not perceive the polarization of reflected light. On the other hand, the direction of polarization of light reflected from rough surfaces is usually not horizontal, thus rough surfaces are usually unattractive to polarotactic insects, which are lured only to exactly/nearly horizontally polarized light.

It has been proposed that visitors to wetland habitats should drive light-coloured (instead of black, red or dark-coloured) cars, to avoid egg loss by confused polarotactic aquatic insects. Due to depolarization by diffuse reflection, very dirty cars reflect light with much lower p than recently washed and/or waxed shiny cars. Thus, the most environmentally friendly car of all would be one that never gets washed. In other words, the "greenest" car is white and dirty. Such a car minimizes the PLP.

After the discovery of the causes of the reproductive behaviour of mayflies above dry asphalt roads (Kriska *et al*., 1998), the experts of protection of animals and environment could take the necessary measures to prevent the egg-laying by mayflies and to reduce the amount of eggs laid and perished on asphalt surfaces: One could, for example, treat the sections of the asphalt roads running near the emergence sites of Ephemeroptera in such a way that their surface becomes relatively bright and rough to reduce reflection polarization. This could be performed by rolling down of small-sized bright gravel on the asphalt surface. This treatment of asphalt reduces significantly the p of reflected light, which abolishes its attractiveness to polarotactic mayflies.

The huge shiny black plastic sheets used in the agriculture can also deceive, attract and kill *en masse* polarotactic aquatic insects, if they are laid on the ground near the emergence sites (wet-lands) of these insects. It would be advisable to forbid the farmers to use such black plastic sheets near wet-lands, where white or light grey plastic sheets (if appropriate) should be preferred. Another possible remedy could be to develop and use such a plastic material, which would reflect light efficiently in the ultraviolet (UV) and visible (VIS) parts of the spectrum, but absorb light strongly in the infrared (IR) spectral range. Such plastic sheets would reflect weakly polarized light in the UV and visible spectral ranges, and could keep the soil covered by them warm, which is one of the major functions of the black plastic sheets in agriculture. The UV/VIS-reflecting and IR-absorbing plastic sheets would not induce PLP in those spectral ranges (UV and VIS) where the polarization vision and positive polarotaxis of aquatic insects functions.

It has been showed that the polarotactic caddis flies *H. pellucidula* attracted to vertical glass surfaces can be trapped, if the tiltable windows are open, and thus such glass buildings can be ecological traps for mass-swarming caddis flies *sensu* Schlaepfer *et al*. (2002). On the basis of the results of Malik *et al*. (2008) we can establish the main optical characteristics of "green", that is environment-friendly buildings considering the protection of polarotactic aquatic insects. These "green" buildings possess such features that they attract only a minimum number of polarotactic aquatic insects when standing in the vicinity of fresh waters:

- Since a smooth glass surface polarizes strongly the reflected light, a "green" building must minimize the used glass material. All unnecessary panes of glass should be avoided that would have only a decorative, ornamental function. In a building practically the only necessary glass surfaces are the windows.
- Since all smooth surfaces polarize highly the reflected light, a "green" building has to avoid bricks with shiny appearing, that is, smooth surfaces. The optimal is the use of bricks with matt surfaces.
- Since according to the Umow rule, the darker a surface, the higher the p of reflected light, a "green" building must especially avoid the use of shiny dark (black, or dark grey, or dark-colored) surfaces. A building covered by dark decorative glass surfaces functions as a gigantic highly and from certain directions of view horizontally polarizing light trap for polarotactic aquatic insects. The windows of dark rooms can also attract polarotactic insects. If the bright curtains are drawn in, the degree of linear polarization of light reflected from the window is considerably reduced, and thus the window becomes unattractive to polarotactic insects.
- Since aquatic insects usually do not perceive red light (Horváth and Varjú, 2004), and thus a red shiny surface seems to them dark and highly polarizing, a "green" building has to avoid the use of shiny red surfaces.
- The surfaces of a "green" building must not be too bright either, because near and after sunset they reflect a large amount of citylight, which can also lure insects by phototaxis. The optimal compromise is the use of medium grey and matt surfaces, which reflect light only moderately with a weak and usually non-horizontal polarization.
- If a building possesses the above-mentioned optical features, it can attract only a minimum number of polarotactic and/or phototactic insects. A further important mechanical prerequisite of the environment-friendly character is that the glass windows of a "green" building must not be tiltable around a horizontal axis of rotation. If partly open, then such tiltable windows can easily trap the insects attracted to them and got in the room. The optimal solution would be the application of windows which can be opened by rotation around a vertical axis. If a building stands near fresh water and has the mentioned unfavourable tiltable windows, it can be made easily "greener" in such a way that its windows are kept closed (if possible) during the main swarming period of the polarotactic and/or phototactic insects swarming in the surroundings.

In sum, the two major remedies of PLP are to reduce the p of reflected light by replacing the highly and horizontally polarizing dark and smooth reflecting surfaces with (1) bright and (2) rough ones, because such surfaces reflect only weakly and not always horizontally polarized light, which is unattractive to polarotactic aquatic insects. This information should be communicated to professionals such as landscape planners, road and building designers, and policymakers, because their support is necessary to achieve these environmental measures.

The extent of PLP is global, because in the man-made environment highly and horizontally polarizing artificial surfaces (open-air oil surfaces, asphalt roads, black plastic sheets, car bodies, glass surfaces, black gravestones, etc.) are abundant and their world-wide distribution is progressive. Note that the ecologically disruptive highly and horizontally polarized reflected light can be itself the end product of anthropogenic processes that are themselves environmentally damaging: (i) the oil accumulated in oil spills and open-air waste oil reservoirs, for example, is a dangerous biological poison; or (ii) the black plastic sheets used in agriculture are usually composed of non-degradable materials, thus after their agricultural use they enhance only the plastic waste. We would like to emphasize that the measures against PLP are similarly necessary due to the protection of polarotactic aquatic insect populations as the measures against artificial night lighting to protect night-active animals (Rich and Longcore, 2006).

Populations of certain aquatic insect groups, e.g., mayflies and dragonflies are declining in countries with large human densities, which can be attributed to several different factors, including habitat change and destruction. By eliminating or controlling PLP we can reduce one of the factors responsible for this decline. If conservation of aquatic insects is a goal, we must develop and follow policies that minimize the polarized-light-polluting artificial surfaces with which insect mortality and behavioural disruption have been observed. In the urban environment with numerous water bodies or in the vicinity of wetlands an aquatic-insect-friendly building program could be developed, which is effective in reducing aquatic insect mortality by minimizing the sources of PLP.

9.6 Lab course tasks

1. Measure the reflection-polarization characteristics of some typical sources of PLPby imaging polarimetry in the Environmental Optics Laboratory and around the buildings of the Eötvös University.

2. Evaluate the measured polarization patterns by a computer program in the Environmental Optics Laboratory. Then the obtained reflection-polarization characteristics should be considering PLP.

3. Finally, answer the questions of a test about this practice.

9.7 References to this chapter

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Summary

In this book we overviewed 17 laboratory practices in the subject of environmental physics. Our measurements mainly covered the area of environmental radiations starting from the acoustic waves, electromagnetic radiation hazard, visible light and going into the area of radioactivity: X-rays, gamma-spectroscopy, annihilation radiation, Cherenkov-radiation, alpha- and beta-spectroscopy. These exercises are good examples for those students who intend to work in laboratories using these spectroscopic or other environmental physics methods.

There are of course lots of areas in environmental physics that were not covered here, but these exercises are adjusted to the technical possibilities of the Environmental Center at Eötvös Loránd University, Budapest.

This subject is more colorful, there are many interesting areas above these. The authors hope that these practices can help to understand the complex behaviour of the processes occurring in our environment.