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Polarized ecological traps at a mountain creek

A good practice in experiential environmental education

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Abstract

It is well-documented that highly and horizontally polarized light reflected from shiny dark artificial surfaces has adverse effects on positively polarotactic aquatic insects, including all insects, the larvae of which live in water. Such man-made surfaces may act as 'polarized ecological traps' for polarotactic insects, because they are inappropriate for the development of eggs laid by the deceived and attracted aquatic insects. We performed a field experiment on 27 May 2019 at a mountain creek and its anthropogenic environment to study this phenomenon. Our studies were carried out by Hungarian university students in a senior level biology teacher class. The methods and results can also be used in high and secondary schools. Our aim was to introduce students to the visual ecology of water insects, and help them to apply their knowledge the practice of environmental education.

Keywords: Asphalt road; Car paint work; Environmental education; Field experiment; Mayfly; Polarotaxis

1. Introduction

Totally linearly polarized light is composed of electromagnetic waves vibrating in a single plane. The light in which the waves with the same amplitude at a given wavelength vibrate in many planes is referred to as unpolarized (e. g., sun light). Unpolarized light can become partially polarized by reflection, refraction, and scattering. The photoreceptors in the human eye are not sensitive to polarization. Polarized filters are made of special materials, which are capable of blocking one of the two planes of vibration of the electromagnetic waves. When unpolarized light is incident to such a filter, it emerges as totally linearly polarized. Light reflected by shiny non-metallic surfaces such as asphalt road and water is partially or totally linearly polarized, except when the light is incident perpendicular to the surface. A linearly polarizing filter can be used to observe this effect (as an analyzer) by rotating it while looking through. At certain directions, the reflected polarized light will be filtered, thus some parts of the image will be darker. Linearly polarizing filters block all light polarized at 90° to the filters' transmission axis. A polarizing filter with a proper direction of its transmission axis can attenuate most of the polarized light reflected from different surfaces (e.g. water surface, asphalt road, shiny black plastic sheet used in agriculture, bodywork of dark-coloured cars) (Fig. 1).

Fig. 1. Pictures on the left side (A, C, E) were taken through a linear polarizer with horizontal transmission axis, while pictures on the right side (B, D, F) were taken through a polarizer with vertical transmission axis. (A-B) Water surface. (C-D) Shiny dry black circular plastic sheets on a dry asphalt surface. (E-F) Red car (Suzuki Swift). Photographs taken by György Kriska (A-D) and Gábor Horváth (E-F)

It has been reported that various man-made shiny dark horizontal surfaces, such as oil lakes (Horváth et al. 1998), asphalt roads, black plastic sheets (Kriska et al. 1998, Egri et al. 2017, Egri et al. 2019), bodywork of black, red and dark-coloured cars (Kriska et al., 2006) and black gravestones (Horváth et al., 2007) can attract different aquatic insects (Coleoptera: water beetles, Heteroptera: aquatic bugs, Plecoptera: stoneflies, Trichoptera: caddis flies, Ephemeroptera: mayflies, Odonata: dragonflies). These visually deceived insects often swarm above, land on and oviposit onto these surfaces, because they are attracted by the high and horizontal polarization of reflected light. Since these insects detect water surfaces by the horizontal polarization of water-reflected light (Schwind, 1985; Horváth and Varjú, 2004; Horváth, 2014), they are lured to every source of horizontally polarized light. This behaviour is called positive polarotaxis.

Horváth et al. (2009) introduced the term "polarized light pollution" as a new kind of ecological photopollution. Under polarized light pollution they mean strongly (i.e. with high degrees of linear polarization) and horizontally polarized light reflected from smooth (shiny) artificial surfaces having adverse effects on polarotactic aquatic insects, including all insects, the larvae of which live in water (e.g., aquatic beetles and bugs, dragonflies, mayflies, caddis flies, stoneflies and tabanid flies).

Since, environmental education methods for studying this phenomenon were lacking, we developed in-door class work and a field experiment for students to fill this gap. Our regular training programme for biology teacher students at the university class focuses on three principal areas of skill development: ability of demonstration, organizing lessons and arrangement of laboratory and field experiments. In the scope of the first one of these skills teacher trainees get the mastery of the object-teaching elements (drawing on black-board, applying audio-visual aids). Organizing lessons means the ability to elaborate a detailed plan for a class and testing it in practice. To acquire this task, the students are asked to give a practice teaching for their own group members. This teaching practice are always discussed by the students and the lecturer. Within the framework of the third training programme area students get acquainted with the master strokes of biological experiments. Methodology of simple laboratory and field experiments (e. g., osmosis, examinations with a microscope or in a test-tube, biological qualification of freshwater etc.) is included in this programme. The subject of the present work was also included in the itinerary of this programme.

2. Methodology

A preliminary class work was performed at Eötvös University (Biological Institute, Budapest) on 6 May 2019 and to teach the theoretical bases of polarotaxis and to practice the use of linearly polarizing filters, and to identify freshwater invertebrates. Students looked for reflecting surfaces in the seminar room, and analyzed the reflected light by linearly polarizing filters. Living and preserved freshwater macroinvertebrates, especially insect larvae, were identified by a field guide (Kriska, 2013). The field guide contains detailed material on freshwater invertebrates in general, and on mayfly larvae in particular. Identification keys can be seen in vector diagrams on the odd pages of the book and invertebrate photographs appear on the even pages. The graphics of invertebrates are subtitled, in this way it is easier to identify the animals from the creek.

For the next class on 13 May 2019 the teacher trainees were requested to collect and study scientific papers dealing with visual ecology of insects. They were also asked to plan a research method suitable for revealing the effects of artificial shiny surfaces on the behaviour of insects. In order to facilitate this planning work, the students were informed about the scene of the field experiment: the study site is the bank of a typical reach of a mountain creek in Hungary, called Bükkös, from which mayflies emerge in large numbers. In the immediate vicinity (at a distance of 1–5 m) of the creek, an asphalt road ran among trees and bushes almost parallel to the water and in some places it crossed the stream over small bridges. The creek itself ran in a valley under trees and bushes, and it was usually completely shadowed by riparian vegetation, except where it was crossed by the road. The road ran in several metres higher than the creek, and above it the sky was open.

In the course of the next seminar in-door activity on 20 May 2019 a brain storming method was applied: students shared their ideas with each other under our guidance. This method was very useful to get to know more thoroughly our students’ way of thinking. The processes of the field experiment were based on the proposals of the students.

The experiments were carried out on 27 May 2019 near the village of Dömörkapu located approximately 30 km away from Budapest, Hungary. Altogether twelve students were equally subdivided into three groups. The members of the first team collected insect larvae from the water and imagos in mid air by capturing them with hand-nets. The captured insect larvae were identified on the spot using an original field guide (Kriska, 2013), and imagos were referred later in the lab (Bauernfield and Humpesch, 2001). Our original field guide was evaluated previously by students in different wetlands and in the lab of the university. The students of the first group have studied the mayfly swarming along the creek in natural conditions too.

The second team made experiments at the asphalt road. In the multiple-choice experiments, students laid different types of rectangular materials as test surfaces onto the asphalt road at different reaches of the creek where mayflies swarmed. The 1 m × 2 m test surfaces were placed 0.5 m apart. The test surfaces used were composed of shiny black plastic (polyethylene) sheet and matt black cloth. Due to depolarization by diffuse reflection a matt black cloth reflects light with much lower degrees of polarization than a shiny black plastic sheet. Occasionally, students counted the number of mayflies landing on and swarming immediately above (height no more than 0.1 m) a 0.1m × 0.1m region of the test surface during the mass-swarming for 30 s (Table 1).

Table 1. Number of mayflies landed on horizontal shiny black plastic sheet and a matt black cloth in the double-choice field experiment versus time. Data belonging to the shiny black plastic sheet (marked by *) are significantly larger than the corresponding data belonging to the matt black cloth (χ^2-test, $p < 0.001$). Time = local summer time = UTC + 2h.

		Number of mayflies landed	
Time (h)	Air temperature (°C)	Shiny black plastic	Matt black cloth
19:00	26	3	0
19:10	25.5	5	0
19:20	25	8	1
19:30	24	12	0
19:40	24	20	2
19:50	23	14	0
20:00	22.5	16	1
20:10	22	24	1
20:20	21	67	1
20:30	20	153	0
20:40	19	97	2
20:50	18	32	0
21:00	17	7	0
sum		$458^{(*)}$	8

The position of the two test surfaces with respect to each other was changed randomly in order to avoid the possible influence of their position on the number of mayflies attracted. At the same time the persons of the third team worked at a parking lot near to the creek. They counted mayflies on the cars of different colours occasionally (Table 2).

Table 2. Number of mayflies landed on car roofs of different colours versus time. Samples were taken as described in the text. Time = local summer time = UTC + 2h.

	Number of mayflies		
Time (h)	Red car	Dark sienna car	White car
19:00	1	2	0
19:20	0	1	0
19:40	2	1	0
20:00	1	3	0
20:20	1	3	0
20:40	3	4	0
21:00	3	2	1
sum	11	16	1

The experiments were always carried out under clear skies. At the beginning of an experiment, the landscape was illuminated by direct light from the setting sun, and after sunset by skylight from above. During the experiments a person of the first team measured the water temperature, the air temperature immediately above the creek and the asphalt road. To compare the data pairs in Table 1, χ^2-test was performed by the computer program Statistica 6.1.

The experiences of the outdoor practice were also evaluated from a pedagogical point of view. Using the „buzz group” seminar technique we asked each student to write down any ideas they have how this method could be applied in their environmental teaching practice. Then they were asked to share their thoughts with a teammate for a couple of minutes. They were given some time to discuss and then we asked the question again – asking them for their suggestions.

3. Results

After the field experiment a class work was performed to share the experiences of our observations and to evaluate the collected data. Larvae of mayflies, caddis flies, stoneflies and beetles were collected by the students from the creek. The mayfly larvae belonged to three families: Baetidae, Ephemeridae and Heptageniidae (Fig. 2A, B, C). The captured adult mayflies were identified as *Baetis rhodani*, *Rhithrogena semicolorata*, *Epeorus silvicola*, and *Ephemera danica*.

The swarming of mayflies began at around sunset on 26 May 2019 at the creek. After the emergence of the mayflies from the mountain creek, the males gathered in several diffuse swarms in the air at a distance of approximately 4–5 m from the ground. First diffuse swarms appeared everywhere above the streamlet, asphalt road, and clearings in the vicinity of the emergence sites. Generally, these swarms developed in places where the sky was visible. Later, the swarms became nearer gradually to the ground, and more females flew through them in order to copulate with the males. After mating, the females returned to the streamlet or began the egg-laying flight on the asphalt road, horizontal shiny black plastic sheet or roofs of dark-coloured cars.

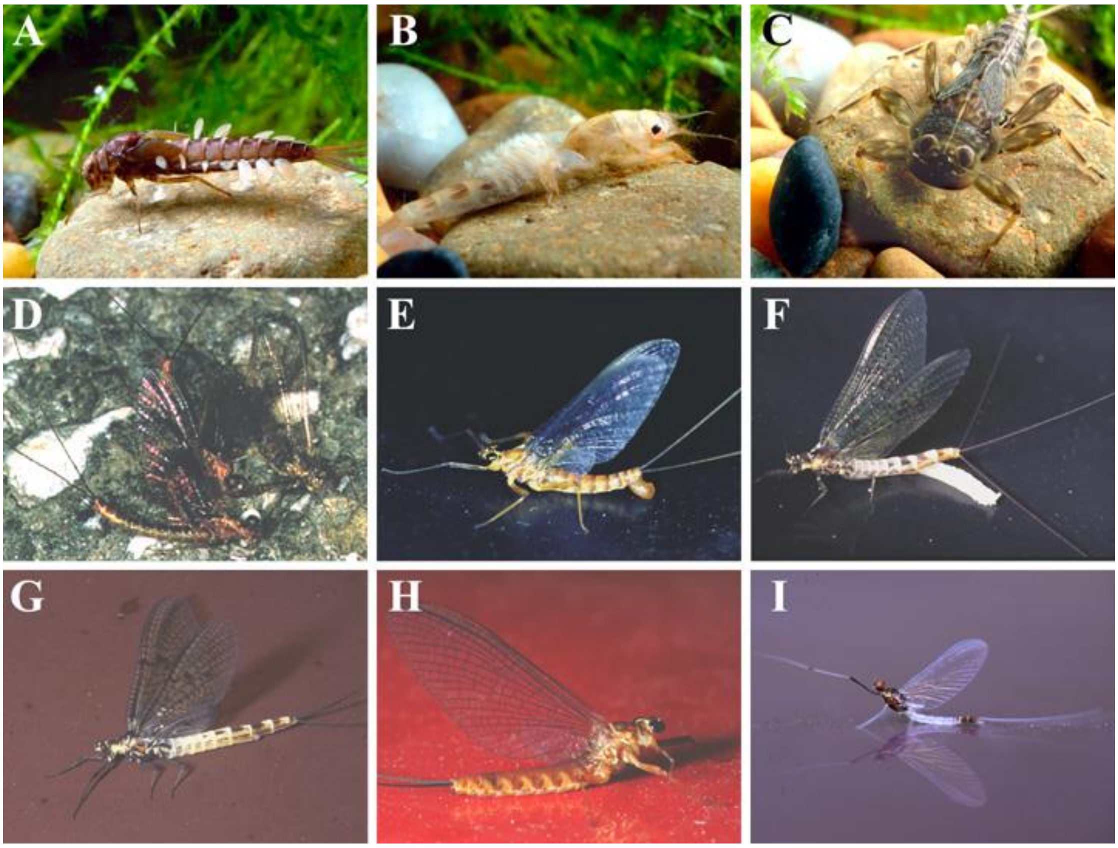

Fig. 2. (A-C) Mayfly larvae from the Bükkös creek. (A) Baetidae larva. (B) *Ephemera danica* larva. (C) *Ecdyonurus* sp. larva. (D-I) Mayfly imagoes on dry horizontal anthropogenic surfaces. (D) Copulating *Epeorus silvicola* mayflies on an asphalt road. (E-F) Egg-laying *Rhithrogena semicolorata* and *Ephemera danica* females on a shiny black plastic sheet. (G-I) Adult mayflies on cars. (G) Female *Ephemera danica* on the roof of a dark sienna car. (H) Heptageniidae imago on the roof of a red car. (I) Male *Baetis rhodani* on the windscreen of a red car (photographs taken by György Kriska).

During the egg-laying flight the females showed a typical flight pattern, which is similar to the nuptial dance of the swarming males. At the end of this flight the females landed on the highly and horizontally polarizing surfaces and laid their egg-batches (Fig. 2E-F). Only a few mayflies landed on the black plastic sheet at the beginning of swarming above the asphalt road (at approximately 19:00 h), but their number increased rapidly over time. At 20:30 h the reproductive activity reached its maximum on the plastic sheet (Table 1). The matt black cloth was not attractive to mayflies similarly to the light-coloured car roofs. Only a few mayflies landed on these surfaces (Table 1). The diffuse reflection from the rough surface of matt black cloth in all possible directions results in depolarization (reducing p), because the reflected electromagnetic waves vibrate at many planes. Thus, matt black cloth does not attract flying imagos. The bodywork of cars reflects linearly polarized light, the direction and degree of polarization of which depend on the orientation and colour of the car surface. According to the rule of Umow (1905), the darker a reflector, the higher the degree of linear polarization p of reflected light. This is the reason for why light-coloured car roof did not attract polarotactic mayflies. Later, as the air temperature and intensity of ambient light decreased, the swarms were observed exclusively above the asphalt road where the air temperature was higher. In these swarms, both the males and females flew periodically up and down, displaying the species-specific nuptial dances, or flew parallel to the asphalt surface. They frequently touched the asphalt and car surfaces, or dropped onto them for a few seconds. When the air temperature decreased below 14–15 °C and the light intensity was low, mayfly swarming suddenly ceased, and the insects disappeared from asphalt and car surfaces. Then they landed on the leaves of neighbouring trees, bushes and grass in order to roost.

As a result of the pedagogical discussion the following teaching approaches were the most frequently mentioned: problem-based experiential learning and resource based tasks. A group of high school students work through a given problem gaining further information from the facilitator (practically from the biology teacher). The teacher provide the pupils with a range of resources (could be articles, quotations, tables of data, test results, photographs etc). Then the facilitator asks them to solve the problem or address a question using the provided resources. The outdoor trials will be held in small self-help group sessions run by students using the tutor as a resource.

4. Discussion

Our experiments demonstrate well that if mayflies can choose between a strongly and horizontally polarizing surface (e.g. asphalt road, horizontal shiny black plastic sheet or dark-coloured car roofs) and a weakly and not always horizontally polarizing one (e.g. matt black cloth, or brightly coloured car roof), they prefer the former. The smoother the surface, the higher the degree of linear polarization p of light reflected from it. Further, the darker a surface in a given spectral range, the higher the p of reflected light (Umow, 1905). Horizontal surfaces reflecting light with higher p-values are more attractive to polarotactic mayflies than less polarizing ones (Horváth et al., 1998). A similar phenomenon was observed for polarotactic aquatic beetles, water bugs and dragonflies (Horváth and Varjú, 2004; Horváth, 2014). Although the reflection-polarization characteristics of anthropogenic products depend on the illumination conditions, shiny black horizontal surfaces (sunlit or shaded) reflect always horizontally polarized light (Horváth and Varjú, 2004; Horváth, 2014). Therefore, such reflectors can attract mayflies. Asphalt roads, horizontal shiny black plastic sheets and dark car roofs in parking lots mimic well the optical characteristics of dark waterbodies. They were observed to attract mayflies emerged from a mountain creek and preferentially breeding in small bodies of slow flowing water. Therefore, horizontal dark shiny anthropogenic products may elicit mayfly oviposition. One of the prerequisites of mayfly mating is to swarm above places where the sky is visible, because the females are usually detected visually and captured by the males from below (Brodskiy, 1973). The sky is generally open above asphalt roads and parking lots; thus, in this respect, these artificial products near the emergence site of mayflies provide a good swarming place. After mating, the polarotactic female mayflies return to water to lay their eggs. Hence, asphalt roads and parking lots are visually attractive on several levels to mayflies: the sky above them is visible, the strong and horizontal polarization of reflected light mimics a water surface, and they have a slightly higher temperature than the surrounding areas. Mayflies are endangered all over the world. An egg-batch of a female mayfly, e.g. contains 6000–9000 eggs (Kriska et al. 1998, Egri et al. 2017, Egri et al. 2019), and all the eggs laid onto car or asphalt surfaces inevitably perish. All these man-made substrata may constitute ecological traps (Schlaepfer et al., 2002), thus reducing the insect’s individual fitness.

The naked human eye is practically not able to perceive the polarization of light. However, using a common liner polarizer, during our field experiments students could study the reflection-polarization characteristics of man-made objects and their adverse consequences for the survival of mayflies. The activities discussed in the present work improved considerably the environmental awareness of teacher trainees, and as they are easy to carry out, they can help students to extend their repertoire of methods applicable in the environmental education.

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