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Quantifying the polarised light pollution of an asphalt road: an ecological trap for the stonefly, *Perla abdominalis* (Guérin-Méneville, 1838) (Plecoptera: Perlidae)

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Abstract

A unique form of optical ecological traps is polarised light pollution. Typical sources of this phenomenon are asphalt roads that attract a variety of polarotactic aquatic adult insects seeking horizontally polarised sources recognized as water surfaces. Several harmful effects of polarised light pollution have been previously demonstrated but no quantitative data is available in regard to the loss of a given adult population under these conditions. Our objective was to study the impact of an asphalt road parallel to a creek on the stonefly *Perla abdominalis* (Guérin-Méneville, 1838). Throughout a three-year study, by comparing the number of exuviae along a stream and the number of adult individuals attracted by the road, we established that 19.6% of the females were trapped by the nearby road. By measuring the reflection-polarisation characteristics of the stream and asphalt surface, we demonstrated that the road may act as attractive, supernormal stimulus for adult females.

KEYWORDS: Plecoptera; *Perla abdominalis*; polarised light pollution; ecological trap; Hungary

Introduction

Schwind (1983, 1989, 1991) discovered that several aquatic bug and beetle species detect water by means of the polarisation of water-reflected light (Schwind and Horváth 1993; Gál, Horváth, and Meyer-Rochow 2001) instead of using reflected intensity or colour or other non-visual cues (reviewed in Horváth and Varjú 2004). The term ‘polarised light pollution’ has been defined as the ‘altered, disturbed behaviour of polarisation-sensitive aquatic insects caused by the horizontally polarised, water-imitating light reflected from artificial surfaces’ (Horváth, Kriska, Malik, and Robertson 2009).

Polarised light pollution typically occurs at black asphalt roads (Kriska, Horváth, and Andrikovics 1998), black agricultural plastic mulch (Bernáth, Kriska, Suhai, and Horváth 2008), open-air oil reservoirs (Horváth, Bernáth, and Molnár 1998; Bernáth, Szedenics, Molnár, Kriska, and Horváth 2001), glass surfaces of buildings and greenhouses (Kriska, Malik, Szivák, and Horváth 2008; Malik, Hegedüs, Kriska, and Horváth 2008), metal surfaces with dielectric coating (e.g., car bodies) (Wildermuth and Horváth 2005; Kriska, Csabai, Boda, Malik, and Horváth 2006) and solar panels (Horváth et al. 2010). Water-seeking aquatic insects are preferentially attracted to such artificial surfaces instead of water when the degree of polarisation of the reflected, horizontally polarised light is high enough (Bernáth et al. 2001; Kriska et al. 2008). Observing mass mortality of aquatic insects at such man-made surfaces (Kriska et al. 1998, 2006, 2008; Bernáth et al. 2001, 2008; Malik et al. 2008; Horváth et al. 2009, 2010; Robertson, Kriska, Horváth, and Horváth 2010) has provided the best evidence for the ecological trap phenomenon (Kokko and Sutherland 2001; Schlaepfer, Runge, and Sherman 2002; Robertson and Hutto 2006). Ecological traps are phenomena when rapid changes in the environment caused by man result in individuals of a population choosing inappropriate habitats for themselves and their offspring even though they follow earlier adaptive behavioural patterns (Delibes, Ferreras, and Gaona 2008; Kokko and Sutherland 2001; Robertson, Rehage, and Sih 2013). This may lead to a dangerous decrease in or the extinction of the local population even if there remains sufficient number of appropriate habitat patches in the vicinity. This phenomenon is a current issue in environment protection and nature conservation.

Quantifying the risk of polarised light pollution that may lead to the decrease or extinction of aquatic insect populations is an important information for ecologists and conservation biologists for a given site. However, as this phenomenon was recognized (Horváth et al. 2009), no attempt has been made to quantitatively measure the harmful effect of polarised light pollution on aquatic insect communities.

The impact of polarised light pollution on the population can be assessed by estimating the numbers of trapped and dead polarotactic insects but the efficacy of ecological traps cannot be determined without data on the abundance of the exposed aquatic insect populations. Collecting such quantitative data is very complicated. As horizontally polarising objects can attract polarotactic insects from great distances (Bernáth et al. 2001; Kriska et al. 2008), it is difficult to identify the sections of a river, for example, where the emerging individuals may be affected by a given ecological trap. The only species that can be used for quantification of capture rate are those that lay eggs within the locality where they emerged.

The stonefly, *Perla abdominalis* (Guérin-Méneville, 1838), is an example of such species. To quantify the loss of this stonefly due to a horizontally polarising asphalt road, we investigated a local population of this species at a stream immediately next to an asphalt road located in northeastern Hungary. By counting the larval skins (exuviae) along the stream, we determined the number and the sex ratio of adults emerged from a selected stream section. We then counted the individual adults perished on the section of the nearby asphalt road during the adult activity period of this species. This allowed us to assess the proportion of individuals that perished due to the polarised light pollution at the asphalt road. In this study, we primarily associate the term 'adult activity' with the flight of adult female stoneflies related to egg laying.

Material and methods

Collection of the material was performed in May 2013, 2015, and 2016 in the vicinity of the village of Dömörkapu, Hungary at a relatively undisturbed section of the Bükkös Creek. An asphalt road runs parallel to the creek through several kilometers; however, a preliminary study indicated that there is only a 110-m-long road section (47°41'46"N, 18°59'49"E) where *P. abdominalis* adults can be found consistently during the adult activity period (Figure 1a). The site of our trials was located at this road section.

In the adult activity period, we assessed the number of emerged *P. abdominalis* adults by regularly collecting and counting the exuviae along the selected stream section (Figure 1d–e) on the days shown in Table 1. Our previous observations showed that the larvae do not crawl out farther than 2 m from the water for moulting to the adult. After moulting, the larval exuviae remained fixed on the exposed stones, and the stream water level was constant during the sampling period preventing loss of exuviae. Four persons, one after the other, surveyed the dry pebbles and stones in the water-course and on the entire bank of the investigated creek section. We surveyed the water-course and the proximate 2-m-wide zone of the shore. The visually well-discernible exuviae were firmly attached to the stone surfaces; in this way, we could ensure that during the four consecutive surveys, only few exuviae may have been overlooked. We collected the exuviae and transported them to the laboratory in dry condition. Species and sex of all collected exuviae were identified later in the laboratory.

On the investigated asphalt road, cars pass by every 30 minutes on average during the day. Bicyclists and pedestrians also use this road. Thus, stonefly adults landing on the asphalt surface are crushed with high probability. During the adult activity period, we surveyed the 110 m road section, collected and then identified all dead and living *P. abdominalis* individuals (Figures 1f–i). Whenever living stoneflies were found on the asphalt road, we observed their behaviour for 15–20 minutes. Simultaneously, we searched for exuviae on the water-course. After *in situ* identification, living individuals were released 1 km downstream where dense riparian vegetation obscured the polarising asphalt surface. This way we could minimize the risk of recollecting them. Our surveys on the road were performed between 18:00 and 19:00 (GMT + 2 h) on the days indicated in Table 1.

Microclimate measurements

To characterize the local microclimate, we measured the temperature (with an accuracy of ±0.1 °C) and relative air humidity (with an accuracy of ±5%) 5 cm above the asphalt surface and at the water-course using a digital microclimate station (Weather Station, Conrad Electronic, Item No:

672861). These measurements were performed on two different days, (14 May 2013 at 19:00 h and 18 May 2013 at 12:00 h), when there was no precipitation.

Imaging polarimetry

The reflection-polarisation characteristics of the collection sites were measured by imaging polarimetry in the red (650 ± 40 nm wavelength of maximal sensitivity ± half bandwidth of the CCD detectors of the polarimeter), green (550 ± 40 nm) and blue (450 ± 40 nm) part of the spectrum with the method described by Horváth and Varjú (1997, 2004). In the case of the stream, we performed two imaging polarimetric measurements, whereas the asphalt road was measured from a single position (Figure 2).

Statistics

For statistical analyses, we applied χ^2-tests using StatSoft Statistica 7.0 software. We tested if the ecological trap has different impact on either sex by comparing the numbers of female and male exuviae found at the creek with the number of female and male stonefly adults found on the road.

Results

The examination of exuviae showed that in 2013 adult activity of *P. abdominalis* was initiated with the emergence of males during the first week of May and culminated a few days later when female adults emerged *en masse* (Table 1). Along the investigated creek section, emergence of 263 males and 463 females was indicated by the collected exuviae (Figure 1d–e, Table 1). Although larvae transformed to adults in great numbers, only a few adults were seen during our surveys along the water-course. These adults stayed motionless on top of rocks (Figure 1g) or on the leaves of the nearby vegetation. On the asphalt road, adults were seen in the morning, early afternoon, and during counting between 18:00 and 19:00 h.

In 2015 and 2016, the emergence period was of short duration and we did not find as many exuviae as in 2013; the males and females began to emerge simultaneously (Table 1). Precipitation occurred on almost all the days of the adult activity period.

Flying individuals were several times observed taking a direct course from the creek towards the asphalt road and landing on its surface (Figure 1f). We observed a striking difference between the behaviour of male and female *P. abdominalis* individuals on the asphalt surface: males ran actively on the asphalt, where they remained only for a few minutes, and then they flew back to the bushes along the creek shore. Females were also active immediately after landing on the asphalt, but then their activity gradually decreased, and in approximately 5 min, they became inactive (Figure 1f) and did not escape even from direct mechanical stimuli. Females that landed on the asphalt surface remained there until they perished. Black egg-batches were found on every living and perished female that was collected from the road (Figure 1h–i). This striking difference in their behaviour is represented by Table 1. The total number of females and males found on the asphalt road were 109 and 15, respectively.

Figure 3 indicates the time course of the total (female + male) number of larval exuviae (dashed line) found at the creek in 2013 and the time course of the total (female + male and dead + alive) number of imagoes (solid line) collected on the road surface. Each catch number was normalized with the number of days between the last and the actual collection time, thus the surface area under each horizontal section of the graph represents the number of larvae/adults. The number of larval exuviae peaked on 10 May, whereas the number of collected dead and/or alive adults peaked ~4 days later.

Microclimate measurements

The microclimate over the asphalt road and the stream differed from each other, although the sites are only a few meters apart. We registered 23.4^{o}C and 51% relative air humidity (RH) on the road on 14 May 2013 at 19:00 h, whereas 20.9^{o}C air temperature and 55% RH was measured at the stream. The difference was greater on 18 May 2013 at 12:00 h, when we measured 32.2^{o}C and 35% RH on the road, and 25^{o}C and 51% RH at the stream.

Imaging polarimetry

Figure 2 shows the patterns of degree and angle of polarisation of the stream and the asphalt road in the blue spectral range. The red and green channels were qualitatively similar. To characterize the polarisation of light reflected from the water-course and the road, we calculated the mean angle and degree of polarisation in the areas enclosed by dashed lines on Figure 2. The first and second rows of Figure 2 show the measurements at the creek and the third row displays the reflection-polarisation characteristics of the asphalt road. In the case of Figures 2a–c, light reflected by the creek-surface had a mean angle of polarisation $\alpha_{\text{creek},1} = -31.8^{o} \pm 57.6^{o}$ (mean ± standard deviation) and mean degree of polarisation $d_{\text{creek},1} = 25.1\% \pm 21.4\%$, while for Figures 2d–f, the same quantities were $\alpha_{\text{creek},2} = -95.9^{o} \pm 20.5^{o}$ and $d_{\text{creek},2} = 37.5\% \pm 13.8\%$. For the light reflected from the asphalt road, the related values were $\alpha_{\text{road}} = 97.92^{o} \pm 31.9^{o}$ and $d_{\text{road}} = 13.6\% \pm 8.4\%$ (Figure 2g–i). Note that the angle of polarisation values were measured from vertical, thus $\alpha = 90^{o}$ means horizontal polarisation. Thus, the investigated section of the dry asphalt road had a more homogeneous, expansive reflection-polarisation pattern than the stream.

Statistics

The sex ratio between the larval exuviae found at the stream and the imagoes trapped by the asphalt road indicated that females were significantly more affected than males (χ^2=36.66, df = 1, $p < 0.00001$).

Discussion

Perla abdominalis adults are poor flyers and they rarely leave the vicinity of their natal stream (Fochetti and Tierno de Figueroa 2006), which is the habitat of the immature stages. Larvae of *P.*

abdominalis have a three-year life cycle (Tierno de Figueroa, Sánchez-Ortega, Membiela Iglesia, and Luzón-Ortega 2003; Kriska 2013). The 110-m-long section of the road is the only asphalt surface in the immediate vicinity of the studied stream. Other sections of the same road are more than 30 m away from the water and many are located several meters higher than the water level. At the stream, larvae and exuviae of *P. abdominalis* were found far upstream and downstream from the studied stream section. Since adults have limited flying abilities, we conclude that the greater vertical and horizontal distances between the road and the water prevented stoneflies from reaching the asphalt surface. As *P. abdominalis* adults do not fly long distances and normally move only a few meters from the point of emergence (Fochetti and Tierno de Figueroa, 2006), nearby asphalt surfaces may primarily affect adults that emerge from proximate creek sections. This makes it possible to assess the proportion of all emerged stonefly imagoes in the studied creek section and imagoes trapped and killed by the nearby asphalt road. The mortality rate is probably underestimated because birds and carabid beetles were observed to prey on the 3-cm-long stoneflies found on the asphalt surface. In the evenings, when the stonefly adult flights were the most intense above the asphalt surface, we observed on several occasions that birds pick up insects from the road. The occurrence and feeding of insectivorous birds near polarised light polluting objects are a well-documented behavioural phenomenon (Bernáth et al. 2008; Robertson et al. 2010, Pereszlényi, Horváth, and Kriska 2017).

In 2013, the peak number of stonefly adults attracted by the asphalt road was delayed by ~4 days relative to the peak of their emergence (Table 1, Figure 3). This time delay suggests that adults, similarly to other stonefly species (Tierno de Figueroa, Luzón-Ortega, and Sánchez-Ortega 2000; Yoshimura 2003) did not copulate and lay their eggs immediately after emergence. In 2015 and 2016, the adult flights, possibly because of the wet weather, did not last long and no such delay of adults was observed (Table 1). Examination of the dead adults collected from the asphalt surface indicated that the two major causes of mortality, not including unquantified predation by birds and beetles, were dehydration and being crushed by vehicles. Owing to their high activity, males escaped from the road more successfully than females (Table 1). Based on the data of the studied period of three years, 19.6% of the emerged gravid females were found dead or dying on the asphalt road. We found several dead females on the road that had no visible damage to their bodies. We hypothesize that they may have died due to the microclimate of the asphalt road which is characterized by higher surface and air temperature and lower relative air humidity. This hypothesis is supported by the characteristic changes in the displayed behaviour of females on the road: their initially intense, though decreasing activity during the first minutes, followed by a stunned state and the final death. This raises the possibility that asphalt roads may harm the environment by increasing traffic, as well as producing a unique microclimate.

The reflection-polarisation characteristics of a water surface depend on angle of observation, illumination, turbidity and brightness of the water, depth and the brightness/reflectivity of the bottom. In the case of dark waters, the horizontally polarised water-reflected component dominates the light returning from the water. When the water contains bright suspended particles and/or the bottom is visible, light also returns from the bottom and/or the suspended particles. This component becomes mainly vertically polarised at the water-air interface, thus the total light returning from the water will be the mixture of the surface-reflected partially horizontally polarised light and the backscattered, and then refracted partially vertically polarised components. This mixing of the two components results in the decrease of the degree of polarisation. In cases, when the vertically polarised component overwhelms the surface-reflected light (e.g., when direct sunlight illuminates the water), the total water-returned light can be vertically polarised (Farkas et al. 2016) as shown in Figures 2a–c. Thus, the angle of polarisation α of creek-reflected light depends on sunlight and shade conditions. In Figures 2d–f, another situation is shown where the water-reflected light is dominant so that the degree of polarisation becomes higher and the angle of polarisation is practically horizontal. Although d of light reflected from the turbulent creek surface was higher than that of the light reflected from the asphalt road (Figure 2), the much larger and uniformly horizontally polarising road surface represented a strong polarised stimulus, which possibly induced the preference of female stoneflies for the asphalt road versus the water surface as an ovipositon site. A similar phenomenon has been demonstrated for the mayfly *Ephemera danica* (Müller, 1764) (Egri et al. 2017). The larger and more homogeneous reflecting surface of the asphalt road provide a supernormal horizontally polarised stimulus for the polarotactic gravid females (Horváth et al. 2009). This raises the following question: why an ecological trap emitting a supernormal optical stimulus can catch only a small portion of the observed stonefly population? The main reason for this may be the dense vegetation along the stream which hides the asphalt surface from the majority of the flying females that fly above water. Thus, the only adults that are trapped are those that move several meters away from the shore. Should the vegetation along the water-course be less dense or removed, the asphalt surface would be visible from above the water, and it would ecologically trap more stoneflies. In an analogous situation, millions of caddisfly adults are trapped by the glass surfaces of buildings on the river bank that are well visible from the water surface (Kriska et al. 2008).

As *P. abdominalis* adults emerge, mate and oviposit within a single locality, the adults died on the asphalt most probably emerged from the nearby stream section. Thus, in this affected stream section, fewer females could lay their eggs and fewer larvae are produced. However, the decrease in the abundance of larvae could hardly be detected in the affected section, because the upstream-directed compensatory oviposition flight of the females can be a trade-off against the consequence of the harmful effects in the nearby stream sections (Zwick 1990). Stream discharge is low throughout the year, thus the downstream drift of larvae is negligible, but stonefly larvae generally move towards the flow, thus there is little opportunity of larval migration (Otto and Sjöström 1986).

Ecological traps decrease the survival rate of the next generation of the affected populations. This effect is the greatest when gravid females are killed before producing offspring, as occurred at our study site. The abdomen tips of every living or dead stonefly female that was collected from the road contained black egg-batches (Figures 1h, i). All egg-batches we have found were still attached to the abdomen of females, thus no detached egg-masses were observed. This indicates that the asphalt surface may prevent females from laying their eggs and leaving the site. The unsuccessful oviposition may be one of the reasons why females remained on the asphalt surface until they died.

Several stonefly species lay two egg-batches in succession (Dewalt and Stewart 1995; Tierno de Figueroa et al. 2000). Therefore, females carrying both egg-batches that were attracted to the asphalt road and became inactive before laying their first egg-mass, finally failed to lay both egg-masses. If the deceived females would lay one of their egg-batches on the inappropriate asphalt surface but would survive the trapping and would lay their other egg-batch in the water, the negative impact of the asphalt road on the next generation could be potentially lower.

Conclusions

Owing to the numerous exuviae, a relatively good estimation can be given for the number of active flying *P. abdominalis*. The number of individuals trapped by the horizontally polarising surface of the asphalt road can also be surveyed. In this way, a quantitative estimation of the harmful effect of polarised light pollution of the asphalt road on stonefly communities can be made. Due to the asphalt road being an ecological trap, the direct loss of female *P. abdominalis* developed in the surveyed stream section was ~20%. This may cause a decrease in the population density of the next generation of this species at a local scale. At a larger scale, the negative impact on the population may be smaller because only specific stream sections are affected, which are in the immediate vicinity of an asphalt road. As the population of *P. abdominalis* has been stable in the Bükkös Creek for several years, we suggest that the losses of production caused by the polarised light pollution may be replaced from other sections of the creek. However this could only be tested in a large-scale study. At creeks where the road runs parallel for a much longer distance, the polarised light pollution may have a negative effect on the persistence of stonefly populations, such as *P. abdominalis*. Since the description of the phenomenon of polarised light pollution (Horváth et al. 2009), no report has been previously published about the quantification of the detrimental effects of polarised light pollution at artificial surfaces. Our study is the first attempt to quantify the harmful effect of a horizontally polarising asphalt road on a polarotactic insect species. Further studies should examine the possible solutions to this kind of environmental problem.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Table

Table 1. Numbers of larval skins of *Perla abdominalis* (Guérin-Méneville, 1838) collected at the Bükkös Creek, near Dömörkapu, Hungary, and numbers of perished and alive adult specimens gathered on the asphalt road during the adult activity periods in 2013, 2015 and 2016.

<table>
<tr><th colspan="2" rowspan="3">date</th><th colspan="2">number of Perla abdominalis larval skins at the creek</th><th colspan="4">number of Perla abdominalis imagoes on the asphalt road</th></tr>
<tr><th rowspan="2">female</th><th rowspan="2">male</th><th colspan="2">female</th><th colspan="2">male</th></tr>
<tr><th>perished</th><th>alive</th><th>perished</th><th>alive</th></tr>
<tr><td rowspan="17">2013</td><td>22 April</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>29 April</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>6 May</td><td>17</td><td>92</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>7 May</td><td>63</td><td>63</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>10 May</td><td>202</td><td>73</td><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>12 May</td><td>109</td><td>21</td><td>4</td><td>0</td><td>0</td><td>2</td></tr>
<tr><td>14 May</td><td>17</td><td>3</td><td>6</td><td>7</td><td>0</td><td>1</td></tr>
<tr><td>15 May</td><td>5</td><td>0</td><td>8</td><td>5</td><td>0</td><td>0</td></tr>
<tr><td>16 May</td><td>8</td><td>1</td><td>5</td><td>3</td><td>0</td><td>0</td></tr>
<tr><td>18 May</td><td>8</td><td>2</td><td>0</td><td>2</td><td>0</td><td>0</td></tr>
<tr><td>23 May</td><td>9</td><td>2</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>25 May</td><td>19</td><td>5</td><td>2</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>28 May</td><td>0</td><td>0</td><td>3</td><td>2</td><td>0</td><td>0</td></tr>
<tr><td>29 May</td><td>4</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>30 May</td><td>2</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">sum.</td><td rowspan="2">463</td><td rowspan="2">263</td><td>34</td><td>22</td><td>0</td><td>5</td></tr>
<tr><td colspan="2">56</td><td colspan="2">5</td></tr>
<tr><td rowspan="8">2015</td><td>4 May</td><td>0</td><td>5</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>6 May</td><td>2</td><td>7</td><td>3</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>11 May</td><td>13</td><td>10</td><td>9</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>12 May</td><td>17</td><td>14</td><td>10</td><td>0</td><td>0</td><td>2</td></tr>
<tr><td>16 May</td><td>6</td><td>4</td><td>14</td><td>0</td><td>1</td><td>3</td></tr>
<tr><td>18 May</td><td>4</td><td>3</td><td>4</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td rowspan="2">sum.</td><td rowspan="2">42</td><td rowspan="2">43</td><td>41</td><td>1</td><td>1</td><td>7</td></tr>
<tr><td colspan="2">42</td><td colspan="2">8</td></tr>
<tr><td rowspan="6">2016</td><td>3 May</td><td>48</td><td>43</td><td>1</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>5 May</td><td>2</td><td>0</td><td>3</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>8 May</td><td>0</td><td>0</td><td>3</td><td>3</td><td>0</td><td>0</td></tr>
<tr><td>11 May</td><td>1</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">sum.</td><td rowspan="2">51</td><td rowspan="2">43</td><td>8</td><td>3</td><td>0</td><td>2</td></tr>
<tr><td colspan="2">11</td><td colspan="2">2</td></tr>
<tr><td colspan="2">sum</td><td>556</td><td>349</td><td colspan="2">109 (19.6%)</td><td colspan="2">15 (4.3%)</td></tr>
</table>

Figure Captions

Figure 1. Collection sites and examined specimens of *Perla abdominalis* (Guérin-Méneville, 1838): (a) undisturbed section of the Bükkös Creek (Dömörkapu, Hungary); (b) nearby asphalt road; (c) larva (3 cm long); (d, e) exuviae on a stone in the immediate vicinity of the stream; (f) female *P. abdominalis* on the asphalt road; (g) male adult on a rock near the stream; (h, i) dead *P. abdominalis* females with their black egg-batches.

Figure 2. Photographs and polarisation patterns of the collection sites: (a, d) two studied sections of the Bükkös Creek (Dömörkapu, Hungary); (g) asphalt road; (b, e, h) patterns of degree of linear polarisation *d*; (c, f, i) patterns of angle of polarisation α. Presented polarisation patterns were measured in the blue (450 ± 40 nm) part of the spectrum, and the optical axis of the polarimeter enclosed an angle of -25° with the horizontal. Dashed lines mark the boundary of areas within angles and degrees of polarisation were averaged.

Figure 3. Temporal distribution of the numbers of female and male exuviae of *Perla abdominalis* (Guérin-Méneville, 1838) found at the stream (dashed line) and the numbers of dead and alive, female and male adults collected from the asphalt road (solid line) in 2013. Areas under the graphs represent the numbers of collected larvae and adults, respectively.

Figures

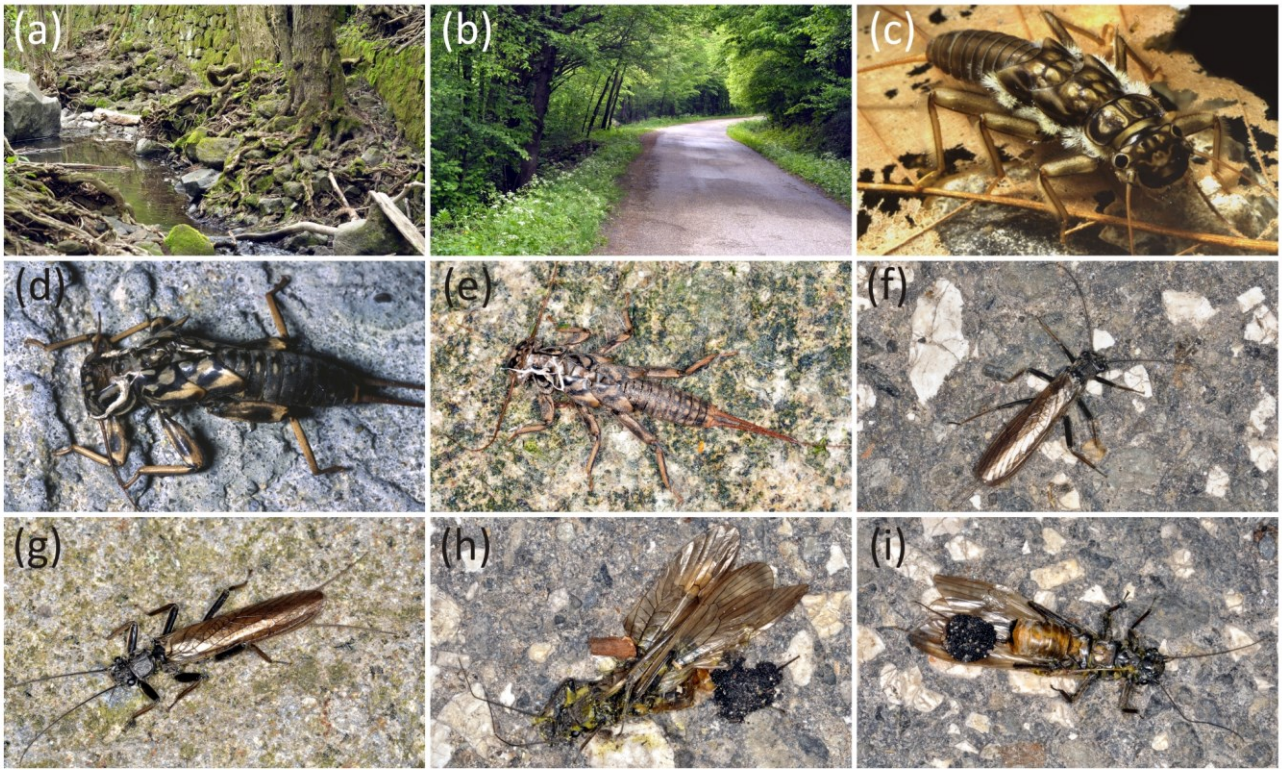


Figure 1

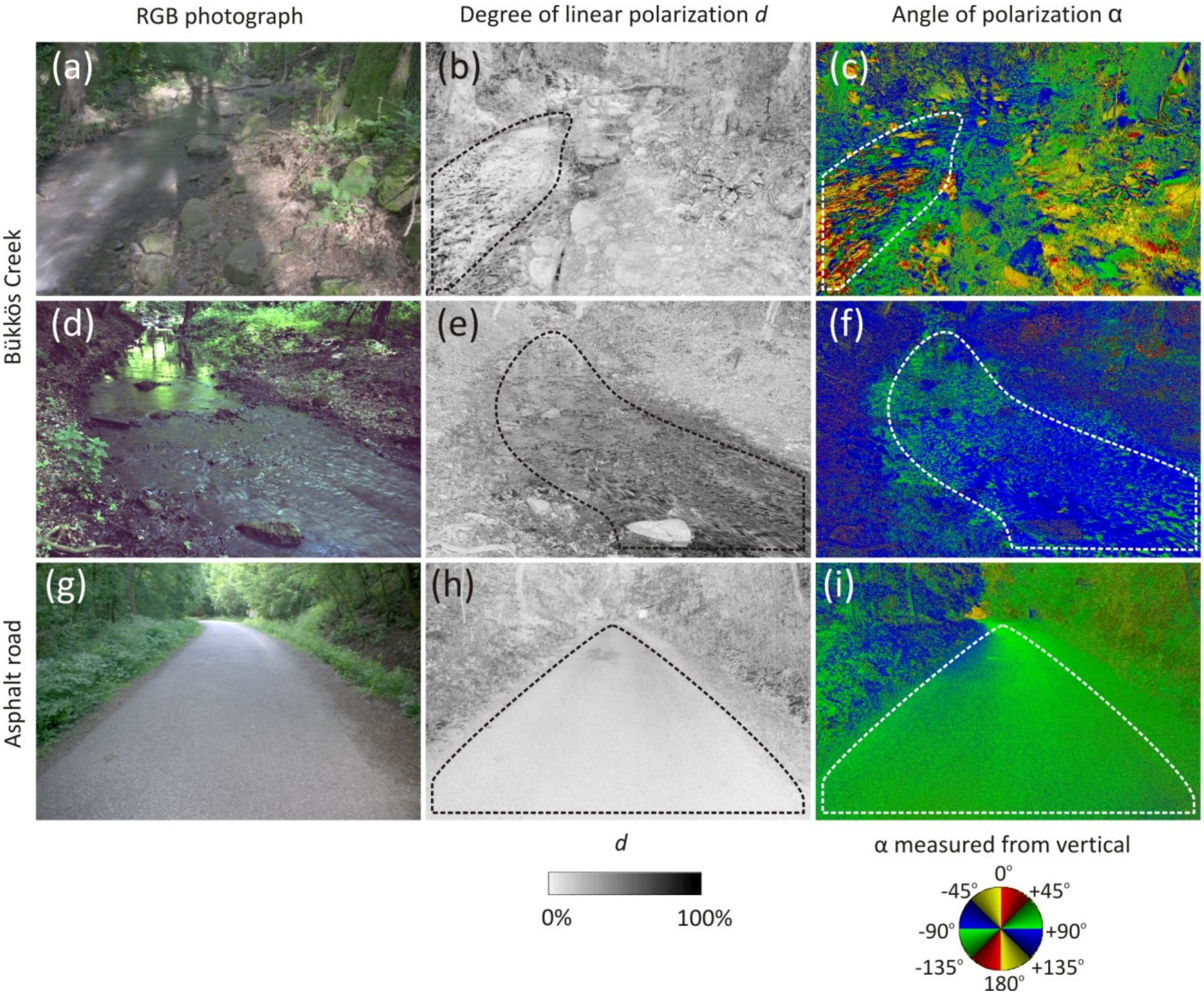
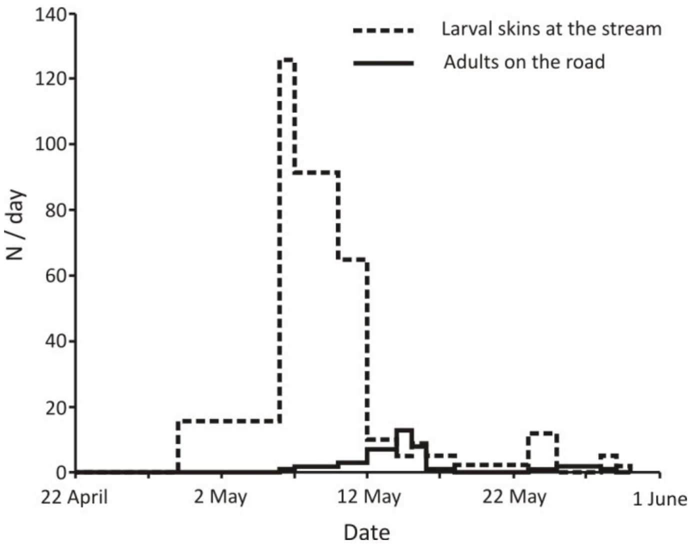

RGB photograph
Degree of linear polarization d
Angle of polarization α
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
Bükkös Creek
Asphalt road
d
0%
100%
α measured from vertical
0°
-45°
+45°
-90°
+90°
-135°
+135°
180°

Figure 2



140
120
100
80
60
40
20
0
N / day
Larval skins at the stream
Adults on the road
22 April
2 May
12 May
22 May
1 June
Date

Figure 3