

Supplementary Information

Citizen science reveals temporally structured insect attraction and mitigation efficacy under artificial light at night

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Table S1: Insect monitoring Neuglobsow UV ground traps 2022-204 (Overview). Number of attracted Taxa per light trap trap in Neuglobsow (Brandenburg, Germany). n=4, 19 nights, (x 5 intervals) from 2022-2024 (June to August).

Tra p ID	Aucheno rrhyncha	Brach ycera	Coleo ptera	Epheme roptera	Hemi ptera	Heter optera	Hymen optera	Lepid optera	Megal optera	Nema tocera	Psoco ptera	Sternorr hyncha	Thysan optera	Trich optera	abun dance
1	96	128	571	78	82	52	107	1575	12	1143	17	15	43	471	4390
2	77	244	587	19	56	31	97	952	9	605	34	26	75	290	3102
3	30	77	503	42	49	48	103	552	10	521	7	6	14	232	2194
4	107	85	327	20	7	106	61	1343	9	685	17	10	10	355	3142
TO TA L	310	534	1988	159	194	237	368	4422	40	2954	75	57	142	1348	12828

Table S2: Insect monitoring Neuglobsow road lights 2023-204 (Overview). Number of attracted Taxa per treatment and trap in Neuglobsow (Brandenburg, Germany). Conventional HPS/ Shielded LED road lights, n=3 traps per treatment, 13 nights (x 5 intervals) from 2023-2024 (June to August).

Trap ID	treatment	Aucheno rrhyncha	Brac hyce ra	Cole opter a	Ephem eropter a	Hem ipter a	Heter optera	Hyme nopter a	Lepid opter a	Nema tocera	Psoc opter a	Sternor rhynch a	Thysa nopter a	Trich opter a	abun danc e
1	Shielded LED	0	14	43	28	27	1	6	3	57	2	0	19	4	204
2	Shielded LED	0	6	25	56	13	0	6	2	42	3	1	4	4	162
3	Shielded LED	1	12	25	11	13	0	11	3	61	3	0	3	2	145
4	Convention al HPS	2	24	44	12	27	14	20	16	279	1	0	8	21	468
5	Convention al HPS	0	12	46	75	20	3	16	6	172	2	0	8	9	369
6	Convention al HPS	1	16	27	114	31	8	18	8	126	1	0	5	6	361
	Total	4	84	210	296	131	26	77	38	737	12	1	47	46	1709

Table S3: Effects of time intervals on insect abundance at UV ground traps (generalized linear model). n=4 traps, 19 nights (x 5 intervals) from 2022-2024 (June to August). P-values are based on a two-sided Wald z-test. P-values lower than $p=0.05$ are printed in bold.

	Estimate	Std. Error	Z-value	P-value	
Interval 1 (Intercept)	2,39528899	0,20758899	11,5386128	8,43e-31	***
Interval 2	1,5592635	0,27944835	5,57979132	2,41e-08	***
Interval 3	1,27184756	0,27821697	4,57142335	4,84e-06	***
Interval 4	0,77836051	0,2789674	2,79014866	0,00526838	**
Interval 5	0,01572583	0,28304253	0,05555995	0,95569237	
Nightly mean temperature	0,11194315	0,02535	4,41590314	1,01e-05	***
Sunset timing (h)	-0,8103919	0,20106242	-4,0305489	5,56e-05	***

Table S4: Effects of light treatments and time intervals on insect abundance at road lights

(generalized linear model). n=3 traps per treatment (Conventional HPS, Tailored and Shielded LED, 13 nights (x 5 intervals) from 2023-2024 (June to August). P-values are based on a two-sided Wald z-test. P-values lower than $p=0.05$ are printed in bold.

Abundance ~	Estimate	Std. Error	Z value	P value	
(Intercept)	0,97955533	0,16843691	5,81556215	6,04e-09	***
interval2	1,33568026	0,20787697	6,42534013	1,32e-10	***
interval3	1,41470452	0,20964845	6,74798452	1,50e-11	***
interval4	0,67011165	0,2158464	3,10457639	0,00190552	**
interval5	0,29653393	0,22979814	1,29041051	0,19690817	
Treatment Shielded-roadlight	0,32535017	0,23412765	1,38962727	0,16464209	
Nightly mean temperature	-0,1500821	0,02017628	-7,4385433	1,02e-13	***
Sunset timing (h)	-0,2383144	0,0961941	-2,4774329	0,01323313	*
Interval 2:treatment Shielded-roadlight	-1,3374652	0,30934138	-4,3235898	1,54e-05	***
Interval 3:treatment3 hielded-roadlight	-1,2805958	0,29883978	-4,2852254	1,83e-05	***
Interval 4:treatment Shielded-roadlight	-0,9694695	0,32362445	-2,995662	0,0027385	**
Interval 5:treatment Shielded-roadlight	-0,7267354	0,3448668	-2,107293	0,03509219	*

Table S5: Principal component analysis Neuglobsow UV traps 2022-204. Values depict loadings of individual insect taxa on Principal components 1-4. Loadings higher than 0.27 were considered important (bold numbers). Data based on. n=4 traps, 19 nights (x 5 intervals) from 2022-2024 (June to August).

	PC1	PC2	PC3	PC4
Auchenorrhyncha	0,41064586	-0,0601737	-0,146254	0,11529111
Brachycera	0,25998928	0,35222684	0,09124681	0,09453573
Coleoptera.	-0,41037	-0,0663656	0,01511125	0,0526143
Ephemeroptera	-0,2264375	-0,3307149	0,08827769	-0,0539356
Hemiptera	-0,1299624	0,34907193	-0,0099091	-0,569515
Heteroptera	0,24301177	-0,2524082	-0,3041482	0,10911751
Hymenoptera	0,06880887	0,41835011	0,06088311	-0,2606779
Lepidoptera	0,32368853	-0,220972	0,20551081	-0,2319473
Megaloptera	-0,2252182	-0,0791145	-0,5784699	-0,0614776
Nematocera	0,38846094	-0,1384482	0,00037418	-0,1724447
Psocoptera	0,13690447	0,26009187	0,2582187	0,58147032
Sternorrhyncha	-0,0423626	0,27194866	-0,5495991	0,29692826
Thysanoptera	-0,3678339	-0,0189714	0,34340165	0,23104217
Trichoptera	0,03434914	-0,4263113	0,04927862	0,03026333

Table S6: Principal component analysis Neuglobsow road lights 2023-204. Values depict loadings of individual insect taxa on Principal components 1-4. Loadings higher than 0.26 were considered important (bold numbers). Data based on n=3 traps per treatment (Conventional HPS, Tailored and Shielded LED, 13 nights (x 5 intervals) from 2023-2024 (June to August).

	PC1	PC2	PC3	PC4
Brachycera	0,11304651	0,06857456	-0,5213458	0,58698972
Coleoptera.	-0,4337374	0,25063453	0,13462442	-0,0720277
Ephemeroptera	0,22281594	0,5434759	0,21545844	0,0331361
Hemiptera	0,12406375	0,14134783	-0,3379886	-0,7528805
Hymenoptera	-0,0614251	-0,1386771	0,65597314	0,10296003
Lepidoptera	0,2712641	-0,43706	0,14238681	0,08058213
Nematocera	0,50093833	-0,1495495	-0,0590714	0,01250161
Psocoptera	-0,4100819	-0,3656864	-0,0219397	-0,1227159
Thysanoptera	-0,4818669	-0,0700191	-0,2920127	0,1481583
Trichoptera	0,07344568	-0,4958705	-0,097976	-0,1675333

Table S7: PERMANOVA results road lights. Differences in insect community composition between light treatments and time intervals. The results of this two-way PERMANOVA with interaction term (999 permutations, Bray-Curtis dissimilarity, stratified by luminaire ID) indicate significant variation among groups. Data based on n=3 traps per treatment (Conventional HPS, Tailored and Shielded LED, 13 nights (x 5 intervals) from 2023-2024 (June to August)).

	Df	SumOfSqs	R2	F value	P value	
Interval	4	0,98820162	0,3759373	5,08360576	0,001	***
Treatment	1	0,32794074	0,12475709	6,74810232	0,001	***
Interval:Treatment	4	0,34054226	0,12955103	1,75185158	0,019	*
Residual	20	0,97194951	0,36975458			
Total	29	2,62863412	1			

Table S8: PERMANOVA results UV traps. Differences in insect community composition between light treatments and time intervals. The results of this two-way PERMANOVA (999 permutations, Bray-Curtis dissimilarity, stratified by luminaire ID) indicate significant variation among groups. Data based on. n=4 traps, 19 nights (x 5 intervals) from 2022-2024 (June to August).

	Df	SumOfSqs	R2	F value	P value	
Interval	4	0,89200959	0,76125225	11,9569543	0,001	***
Residual	15	0,27975652	0,23874775			
Total	19	1,17176611	1			

Table S9: Characteristics of light treatments. Photometric measurements of the light situations (mobiLux USB lux meter, Czibula & Grundmann GmbH Berlin, Jeti specbos 1201-UV spectrometer, Jeti Technische Instrumente GmbH Jena). Illuminance measurements were taken at four fixed vertical distances (0.75m, 2.25m, 3.75m, and 5.25m) across a range of increasing horizontal distance values (0.38m to 4.13m).

	UV traps	Conventional HPS	Tailored & Shielded LED
Coordinates	49.021079689. 08.377794075	49.411850863. 08.519436153	48.36368351 08.48160923
Habitat	grassland in resident gardens	riparian vegetation	riparian vegetation
Traffic usage	No traffic	Residential street <30km/h. Motorized vehicles + sidewalk	Residential street <30km/h. Motorized vehicles + sidewalk
Light regime	rural	rural	rural
Luminaire Height (m)	0.1	3.3	3.3
No. luminaires per treatment	4	3	3
Sample events	19 nights (2022-2024)	13 nights (2023-2024)	13 nights (2023-2024)
Period	June – August	June - August	June - August
Illuminant	50-cm-long 2835 SMD-LED-strip	HPS	LED
Mean road Illuminance (lux)	-	4.0	4.1
Min road Illuminance (lux)	-	0.9	0.3
Spectral characteristics	peak emission: around 400 nm	CCT (K): 2000	CCT (K): 2200

Table S10: List of Sampling dates in Neuglobsow. Mean nightly temperatures were derived from hourly data (09.pm-06.00am) from the closest nearby station of the German Weather Forecast DWD (Station ID. 03509).

Roadlights	UV ground traps	Date	Date2	Nightly mean Temperature C	SUNSET	SUNRISE
	220624	220624	24.06.22	19,03	(21:40:04)	(04:42:42)
	220625	220625	25.06.22	19,38	(21:40:06)	(04:43:05)
	220719	220719	19.07.22	21,82	(21:24:27)	(05:05:52)
	220720	220720	20.07.22	22,85	(21:23:12)	(05:07:16)
	220819	220819	19.08.22	18,52	(20:29:40)	(05:56:12)
	220820	220820	20.08.22	15,51	(20:27:30)	(05:57:56)
230706	230706	230706	06.07.23	12,33	(21:36:49)	(04:50:17)
230707	230707	230707	07.07.23	14,98	(21:36:12)	(04:51:14)
230708	230708	230708	08.07.23	16,08	(21:35:31)	(04:52:13)
230709	230709	230709	09.07.23	18,12	(21:34:47)	(04:53:15)
240601	240601	240601	01.06.24	16,61	(21:25:32)	(04:48:43)
240602	240602	240602	02.06.24	13,66	(21:26:41)	(04:47:52)
240603	240603	240603	03.06.24	11,83	(21:27:47)	(04:47:05)
240714	240714	240714	14.07.24	15,1	(21:29:37)	(04:59:53)
240715	240715	240715	15.07.24	17,35	(21:28:33)	(05:01:09)
240716	240716	240716	16.07.24	14,56	(21:27:27)	(05:02:27)
240825	240825	240825	25.08.24	9,27	(20:15:18)	(06:07:22)
240826	240826	240826	26.08.24	11,07	(20:13:01)	(06:09:06)
240827	240827	240827	27.08.24	16,16	(20:10:44)	(06:10:49)

Table S11: Model selection UV ground traps.

Comparison of generalized linear mixed models with negative binomial error distribution for abundance data. Data based on. n=4 traps, 19 nights (x 5 intervals) from 2022-2024 (June to August). Models were compared using likelihood ratio test (χ^2 test), and model fit improved with increasing complexity, as indicated by decreasing AIC values. Model 1 showed the best fit. Fixed effects included time interval, nightly mean temperature and sunset time. Year and trap ID were included as random intercepts. P-values are based on a two-sided Wald z-test.

	D f	AIC	BIC	logLik	deviance	Chisq	Chi Df	P value
Mod 6	6	2911,397 26	2934,317 75	- 1449,698 6	2899,397 26			
Mod 5	7	2904,561 11	2931,301 69	- 1445,280 6	2890,561 11	8,836147 17	1	0,0030
Mod 4	8	2903,605 1	2934,165 76	- 1443,802 5	2887,605 1	2,956011 57	1	0,0856
Mod 3	9	2897,582 87	2931,963 62	- 1439,791 4	2879,582 87	8,022225 27	1	0,0046
Mod 2	1 0	2892,609 17	2930,81	- 1436,304 6	2872,609 17	6,973698 94	1	0,0083
Mod 1	1 1	2877,648 55	2919,669 46	- 1427,824 3	2855,648 55	16,96062 29	1	3,82e- 05

Table S12: Model selection Road lights.

Comparison of generalized linear mixed models with negative binomial error distribution for abundance data. Data based on n=3 traps per treatment (Conventional HPS, Tailored and Shielded LED, 13 nights (x 5 intervals) from 2023-2024 (June to August). Models were compared using likelihood ratio tests, and model fit improved with increasing complexity, as indicated by decreasing AIC values. Model 1 showed the best fit. Fixed effects included time interval, treatment, their interaction, nightly mean temperature and sunset time Year and trap ID were included as random intercepts. P-values are based on a two-sided Wald z-test.

	D f	AIC	BIC	logLik	deviance	Chisq	Chi Df	P value
Mod 7	6	1638,726 63	1660,807 67	- 813,3633 2	1626,726 63			
Mod 6	7	1630,292 11	1656,053 31	- 808,1460 5	1616,292 11	10,43452 87	1	0,0012
Mod 5	8	1611,749 77	1641,191 15	- 797,8748 8	1595,749 77	20,54233 61	1	5,83e- 06
Mod 4	9	1601,636 2	1634,757 75	- 791,8181	1583,636 2	12,11356 95	1	0,0005
Mod 3	1 3	1591,596 99	1639,439 23	- 782,7984 9	1565,596 99	18,03921 28	4	0,0012
Mod 2	1 4	1516,794 22	1568,316 64	- 744,3971 1	1488,794 22	76,80276 26	1	1,89e- 18
Mod 1	1 5	1513,216 88	1568,419 47	- 741,6084 4	1483,216 88	5,577345 33	1	0,012

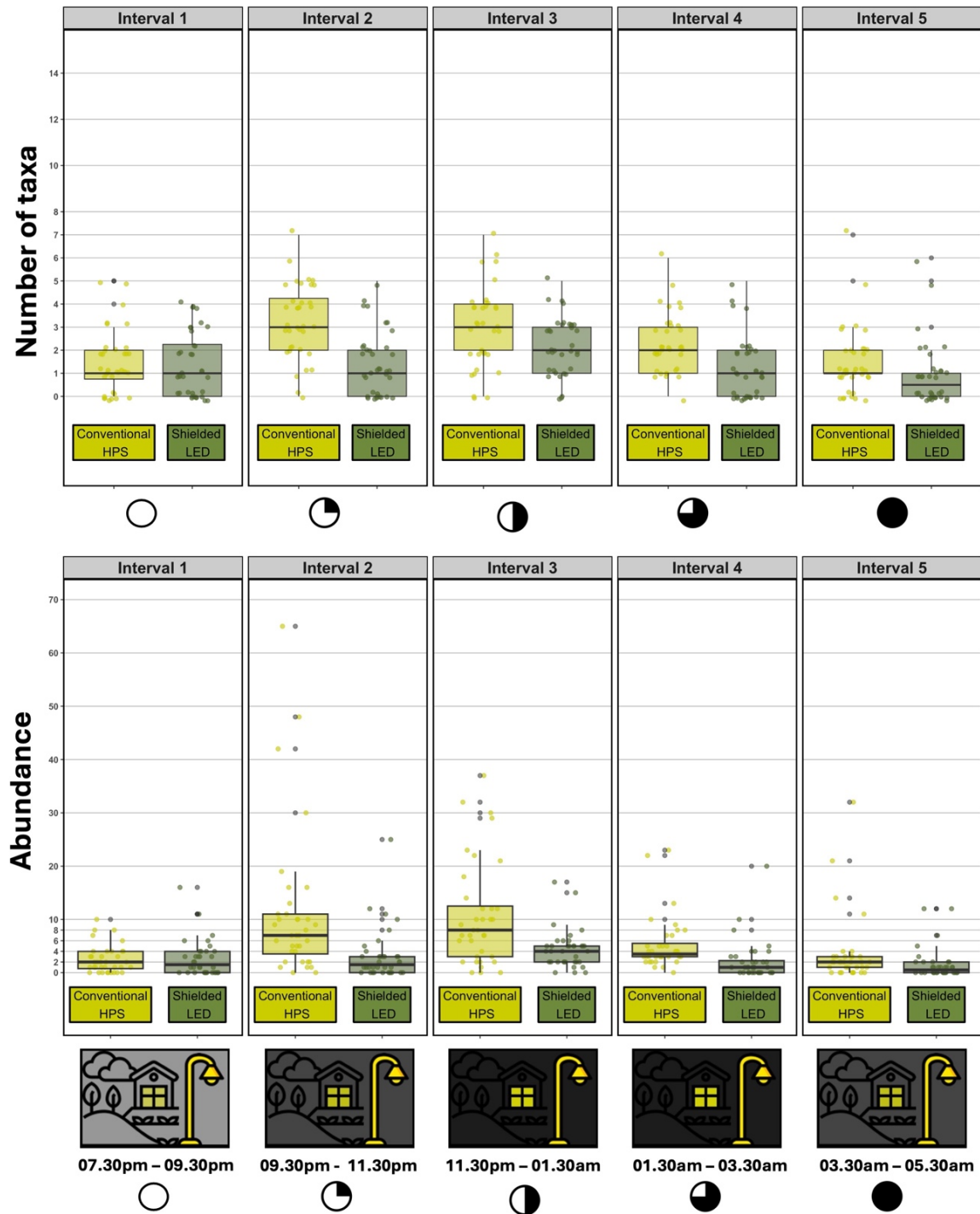


Figure S1: Number of taxa and abundance for time resolved road light samplings.

Number of attracted taxa (upper panel) and individuals (Lower panel) (points) per treatment (x-axis) and time interval (facets). Conventional HPS vs. tailored and shielded LED road lights, n=3 traps per treatment, 13 nights (x 5 intervals) from 2023-2024 (June to August). Box plots

show median (thick line), interquartile range (IQR) (box), outliers (black points), $1.5 \times \text{IQR}$ (whiskers). 667 sampling events in total (one trap in one night in one interval).

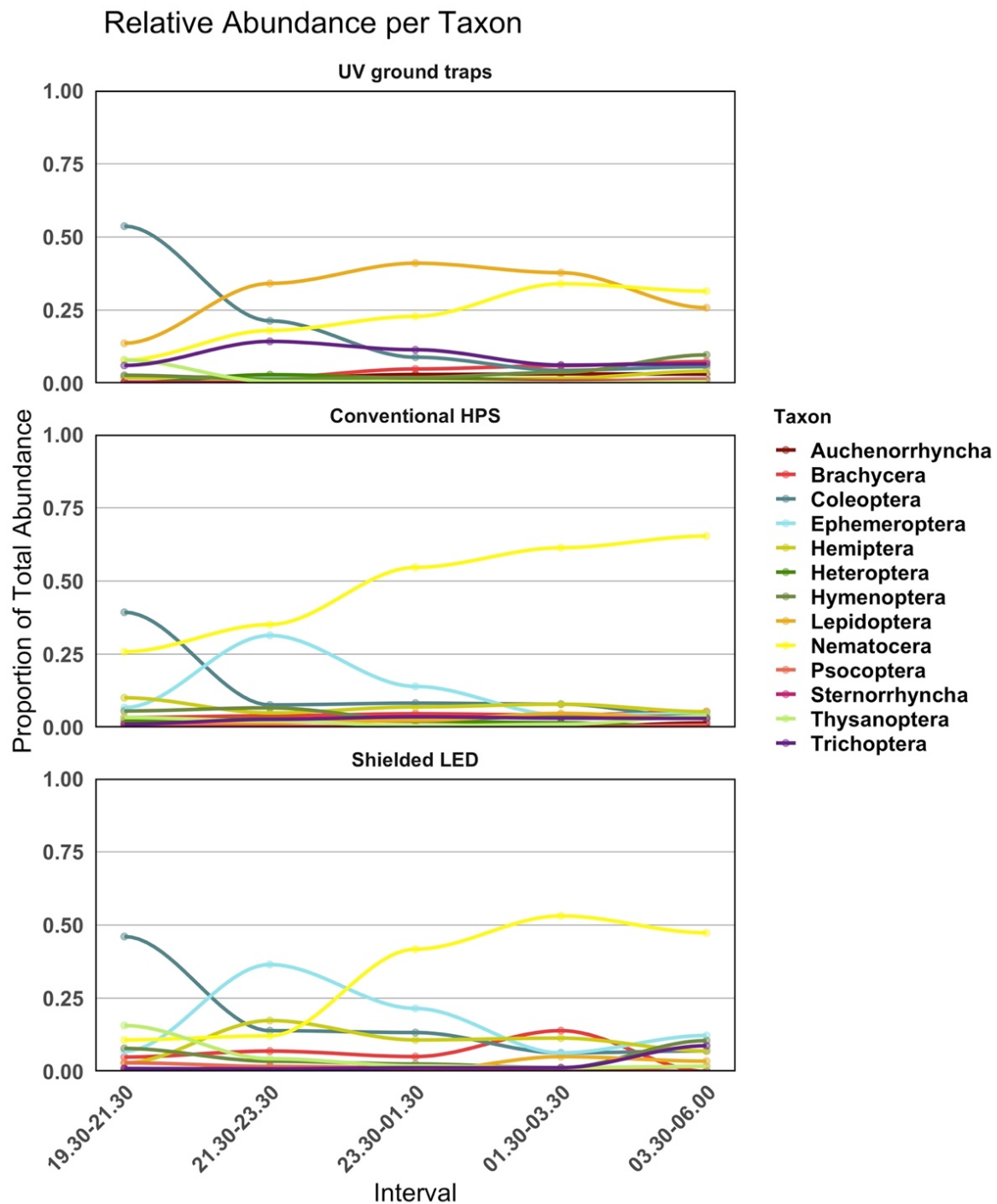


Figure S2: Proportion of Total abundances per road light treatment in different intervals.

Smoothed temporal dynamics of relative insect abundance across taxonomic groups in different road light treatments. Each panel represents one treatment type (UV ground traps, conventional HPS roadlights, and shielded LED roadlights). Points indicate normalized taxon-specific proportions within each time interval, and LOESS-smoothed lines depict continuous changes

in relative abundance throughout the night. The y-axis shows the proportion of total nightly catch contributed by each taxon, allowing comparison of diel activity patterns between light sources.



Figure S3: Study site situated in North-eastern Germany (A) in Neuglobsow near lake Dagow. Traps at road lights are presented as circle. Red circles indicate the location of modernized tailored and shielded luminaires, orange circles conventional HPS). Stars represent the location of UV traps. UV traps were not visible from the road lights and vice versa. Photo by Johanna E. Reinhard. Maps data: Google, © 2024 CNES / Airbus, Maxar Technologies.



Figure S4: Luminaire and trap types. Top: Map shows locations of individual road lights/ UV traps. Bottom: HPS column luminaire with flight interception trap (3.3m height) (A), tailored and shielded luminaire with flight interception trap (3.3m height) (B) and UV traps on

ground level (C). Images taken in the first row during daytime in the second row during nighttime. Interception traps were installed at road lights using a conventional carrier for Christmas lighting. UV traps were placed within a bucket for life insect collections at the ground. Maps data: Google, © 2024 CNES / Airbus, Maxar Technologies. Photos by Johanna E. Reinhard / Andreas Jechow.

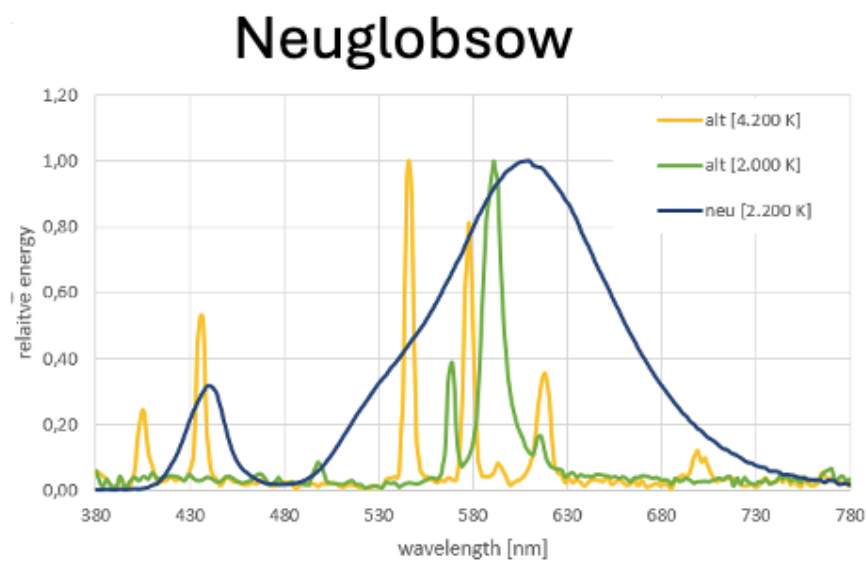


Figure S5: Individual spectra of road light treatments. The yellow curve shows the spectrum of luminaires installed before the experiment was conducted (MV luminaires, 0.98lx), not relevant. The green spectrum shows the conventional HPS control luminaires (4.0lx mean road illuminance), the blue line tailored and shielded LED luminaires (4.1lx). Photometric measurements of the light situations (mobiLux USB lux meter, Czibula & Grundmann GmbH Berlin, Jeti specbos 1201-UV spectrometer, Jeti Technische Instrumente GmbH Jena).