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Artificial light at night reduces earthworm activity but increases growth of invasive ragweed

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Abstract

Background Artificial light at night, also referred to as light pollution (LP), has been shown to affect many organisms. However, little is known about the extent to which ecological interactions between earthworms and plants are altered by LP. We investigated the effects of LP on anecic earthworms (*Lumbricus terrestris*) that come to the surface at night to forage and mate, and on the germination and growth of the invasive and allergenic ragweed (*Ambrosia artemisiifolia).* In a full factorial pot experiment in the greenhouse, we tested four factors and their interactions: LP (5 lux vs. 0 lux at night), earthworms (two individuals vs. none), plant species (seeding of ragweed only vs. mixed with *Phacelia* seeds) and sowing depth (seed placed at the surface vs. in 5 cm depth). Data were analysed using Generalized Linear (Mixed) Models and multifactorial ANOVAs with soil parameters as covariates.

Results Light pollution reduced earthworm surface activity by 76% as measured by casting activity and toothpick index; 85% of mating earthworms were observed in the absence of LP. Light pollution in interaction with earthworms reduced ragweed germination by 33%. However, LP increased ragweed height growth by 104%. Earthworms reduced ragweed germination especially when seeds were placed on the soil surface, suggesting seed consumption by earthworms.

Conclusions Our data suggest that anecic earthworms are negatively affected by LP because reduced surface activity limits their ability to forage and mate. The extent to which earthworm-induced ecosystem services or community interactions are also affected by LP remains to be investigated. If the increased height growth of ragweed leads to increased pollen and seed production, it is likely that the competition of ragweed with field crops and the risks to human health will also increase under LP.

Keywords Light pollution, Earthworms, *Lumbricus terrestris*, Ragweed, *Ambrosia artemisiifolia*, Agroecology, Plant-animal interactions, Artificial light at night, ALAN

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Background

Lotus pedunculatus

Lumbricus terrestris

L. terrestris

Ambrosia trifida

Ambrosia artemisiifolia

L. terrestris)

A. artemisiifolia)

L. terrestris

Phacelia tanacetifolia)

Results

Earthworm activity

Ragweed germination and growth

Phacelia

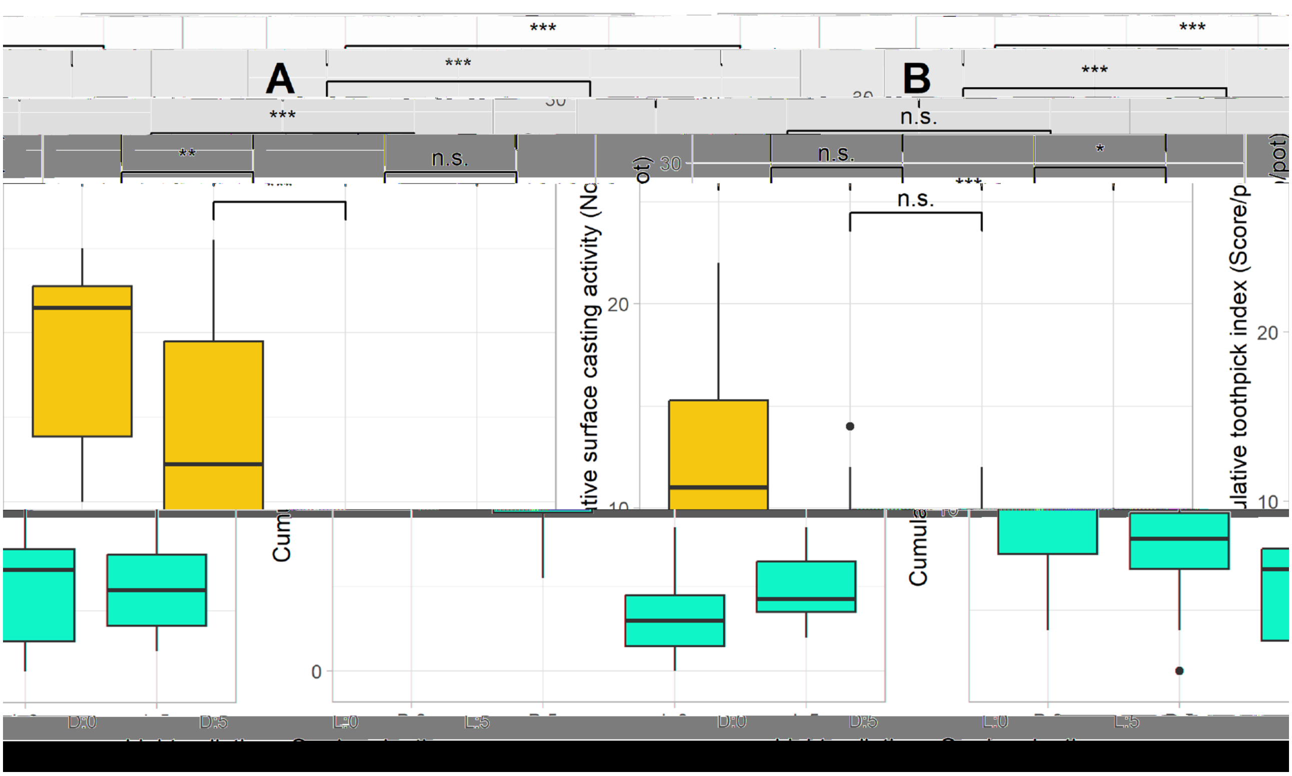

Fig. 1 Earthworm surface activity assessed with the toothpick index (**A**) and the surface casting activity (**B**) throughout all 12 samplings, considering eects of light pollution (D…dark, L…light) and sowing depth (0…surface sown, 5…sown in 5 cm depth). *N* = 6. Each box represents the 1st and 3rd quartiles, the median as the horizontal line and the whiskers as minimum and maximum values

Table 1 Earthworm activity (measured by toothpick index and surface casting activity) in response to light pollution (LP), plant species (PS), sowing depth (SD), their interactions, and the covariates initial worm weight, soil moisture, and humidity. Significance code for Pr (> ChiSq): *** <0.001, ** <0.01, * <0.05

Earthworm surface activity				
	Toothpick index		**Surface casting activity**	
Parameters	**Df**	**Pr (> ChiSq)**	**Df**	**Pr (> ChiSq)**
Light pollution (LP)	1	< $2.200e^{-16}$***	1	$1.410e^{-05}$***
Plant species (PS)	1	0.604	1	0.990
Sowing depth (SD)	1	0.919	1	0.060
LP x PS	1	0.037*	1	0.090
LP × SD	1	$4.139e^{-04}$***	1	0.007**
PS × SD	1	0.227	1	0.318
LP × SD × PS	1	0.001**	1	0.755
Initial worm weight (g)	1	0.901	1	0.567
Soil moisture (%)	1	0.503	1	0.591
Air humidity (%)	1	0.009**	1	$5.223e^{-05}$***
Air temperature (°C)	1	$1.350e^{-11}$***	1	$3.201e^{-08}$***

Table 2 Change in earthworm numbers and biomass from start to end of the experiment in response to light pollution (LP), plant species (PS), sowing depth (SD), their interactions, and the covariates initial worm weight and soil moisture. ChiSq = Likelihood ratio Chi squared, df = degrees of freedom, Significance code for Pr(> ChiSq) and Pr(> F): *** <0.001, ** <0.01, * <0.05

	Earthworm number change		**Earthworm biomass change**	
Parameters	**Df**	**Pr (> ChiSq)**	**Df**	**Pr (> F)**
Light pollution (LP)	1	0.015*	1	0.169
Plant species (PS)	1	0.573	1	0.097
Sowing depth (SD)	1	0.220	1	0.305
LP x PS	1	0.474	1	0.371
LP × SD	1	0.891	1	0.429
PS × SD	1	0.198	1	0.069
LP × SD × PS	1	0.054	1	0.437
Initial worm weight (g)	1	0.118	1	0.011*
Soil moisture (%)	1	0.056	1	0.547
Residuals			33	

Discussion

Earthworm activity

Fig. 2 Two *L. terrestris* individuals during mating. Also seen are toothpicks used to determine surface activity and germinated seedlings of ragweed (top right and bottom centre) and *Phacelia* (top centre)

Ragweed germination and growth

Ambrosia artemisifolia … *Ambrosia trifida* …

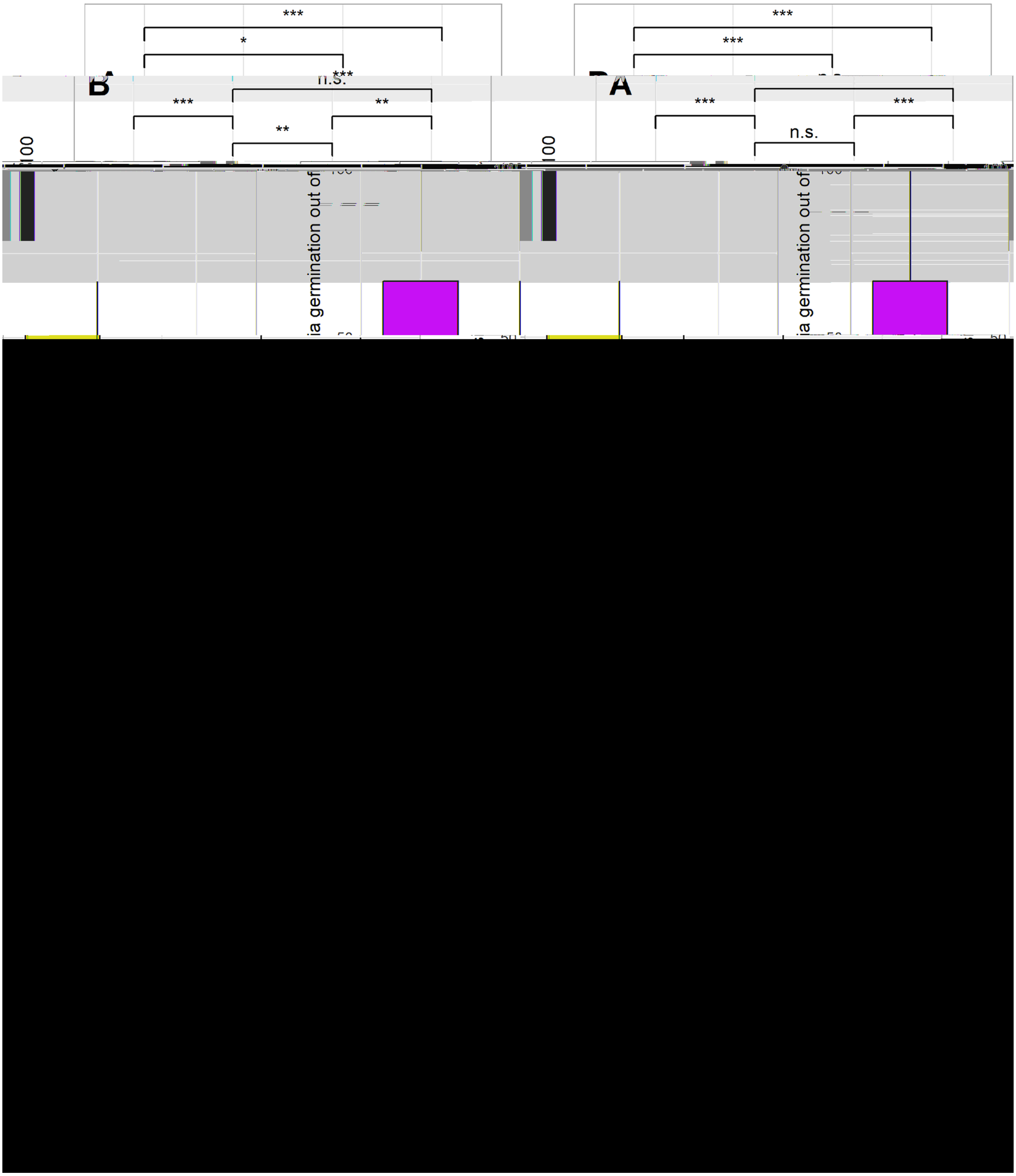

Fig. 3 Ragweed germination of 100 in response to experimental factors light pollution (**A**, **C**), earthworms (**A**, **B**), sowing depth (**B, C, D**), and plant species (**D**). Abbreviations: Light pollution: D…dark, L…light; Earthworms: EW+…present, EW-…absent; Sowing depth: 0…sown at sown, 5…sown in 5 cm depth; Plant species: A…only Ragweed sown, M…Ragweed seeds and *Phacelia* seeds sown. $N = 6$

Table 3 Ragweed germination, mean plant biomass, and mean plant height in response to light pollution (LP), earthworms (EW), plant species (PS), sowing depth (SD) and their interactions. Mean plant height and biomass analyses only considering the 56 pots containing ragweed plants at the end. Pr (> ChiSq) and Pr (> F) significance codes: *** <0.001, ** <0.01, * <0.05

	Germination		Mean plant biomass		Mean plant height	
Parameters	**Df**	**Pr (> ChiSq)**	**Df**	**Pr (> F)**	**Df**	**Pr (> F)**
Light pollution (LP)	1	< 2.200e^{-16}***	1	0.054	1	3.490e^{-07}***
Earthworms (EW)	1	< 2.200e^{-16}***	1	0.068	1	0.208
Plant species (PS)	1	0.044*	1	0.662	1	0.618
Sowing depth (SD)	1	< 2.200e^{-16}***	1	0.857	1	0.140
LP x EW	1	1.508e^{-09}***	1	0.970	1	0.699
LP × SD	1	5.730e^{-14}***	1	0.288	1	0.479
LP x PS	1	0.236	1	0.686	1	0.443
EW × SD	1	< 2.200e^{-16}***	1	0.578	1	0.983
EW x PS	1	0.102	1	0.740	1	0.540
SD × PS	1	2.999e^{-05}***	1	0.808	1	0.393
LP x EW × SD	1	4.575e^{-06}***	1	0.990	1	0.862
LP × SD × PS	1	0.002**	1	0.253	1	0.600
EW × SD × PS	1	0.010*	1	0.717	1	0.934
LP x EW x PS	1	0.063	1	0.751	1	0.802
Residuals			41		41	

[illegible]

Conclusion

[illegible]

Methods

Experimental setup

[illegible]

- Factor light pollution (LP): complete darkness (D) vs. artificial light pollution (L).
- Factor earthworms (EW): *L. terrestris* present (EW+) vs. absent (EW-).
- Factor plant species (PS): seeding *A. artemisiifolia* alone (A) vs. in combination with *Phacelia tanacetifolia* (M).
- Factor sowing depth (SD): surface sown seeds (0) vs. sowing depth of 5 cm (5).

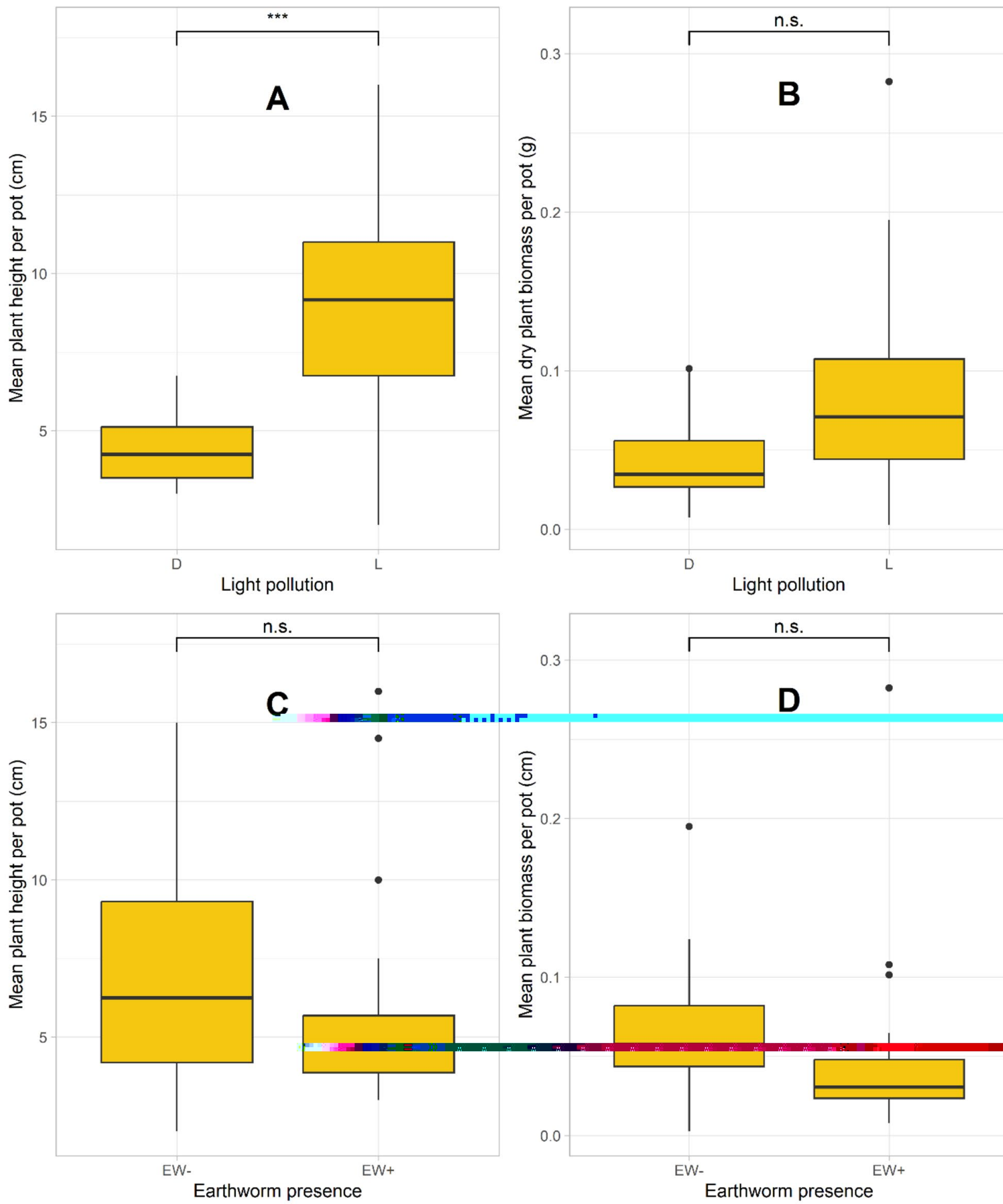

Fig. 4 Mean ragweed plant height and plant biomass in response to light pollution (**A, B**) and earthworm presence (**C, D**). Abbreviations: D…dark, L…light, EW-…Earthworms absent, EW+…Earthworms present, n.s.…not significant, *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05. $N = 6$

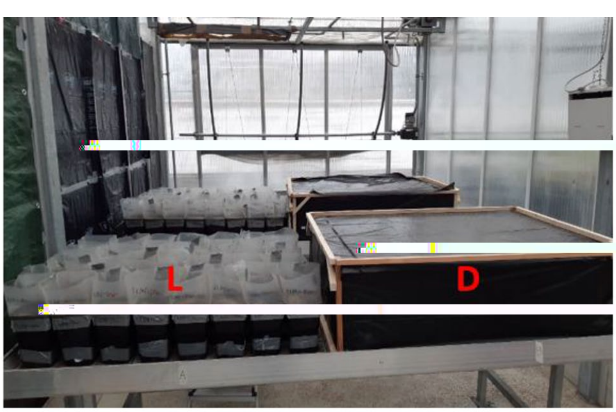

Fig. 5 Experimental setup in the greenhouse. Light pollution (L) was achieved by covered ceiling lights, and the dark (D) treatment by covering pots with opaque plastic sheets

Measurements

Statistical analysis

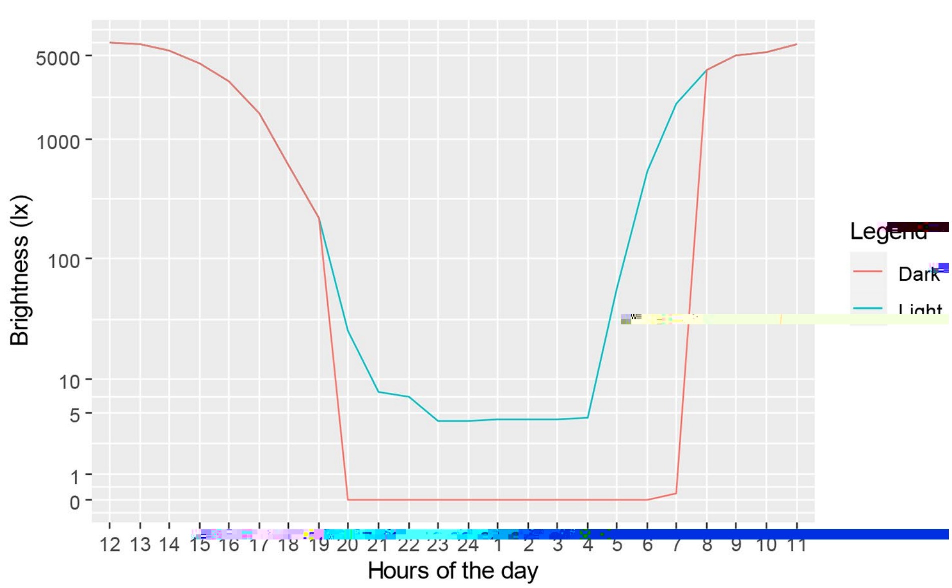

Fig. 6 Mean brightness measured throughout all experimental days comparing the dark (D) and light (L) treatments

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