Supplementary Material

Title: Clean and green urban waterbodies benefit nocturnal flying insects and their predators, insectivorous bats

Authors: Tanja M. Straka, Pia E. Lentini, Linda F. Lumsden, Sascha Buchholz, Brendan A. Wintle, Rodney van der Ree

Table S1: Invertebrate orders in the diet of bats known to occur in Melbourne, Australia (list based on data from the Victorian Biodiversity Atlas, Department of Environment, Land, Water and Planning, Victoria).
Literature used for this table: Burgar et al., 2014 [84] [a]; Churchill, 2009 [97] [b]; Gonsalves et al., 2013 [83] [c]; Law and Urquhart, 2000 [98] [d]; Lumsden and Bennett, 2005 [43] [e]; O'Neill & Taylor, 1989 [99] [f]; Reside and Lumsden, 2011 [100] [g], Kolkert et al. 2019 [101] [h], Straka et al. [102] [i]. Note: *Scotorepens orion* has also been found in Melbourne, but nothing is known of its diet (Churchill 2009) and therefore it was not included in this table.

	Diptera	Coleoptera	Lepidoptera	Trichoptera	Hymenoptera	Hemiptera	Blattodea	Plecoptera	Orthoptera	Isoptera	Neuroptera	Araneae	Mantodea
Austronomus australis		x [b]	x [b, e]		x [b]	x [e]			x [b]				
Chalinolobus gouldii	x [b, f, h, i]	x [b , c, f, h, i]	x [a, b, c, e, f, i]	x [i]	x [b]	x [a, e, f, h]	x [b, c]	x [b]	x [h]		x [a, h]		x [a]
Chalinolobus morio	x [b, f]	x [b, f]	x [b, e, f]		x [b]	x [b, f]				x [b]	x [b]		
Falsistrellus tasmaniensis	x [b]	x [b]	x [b]		x [b]								
Myotis macropus	x [b, d, i]	x [b, d]	x [i]	x [d, i]	x [b, d]	x [b]	x [b]			x [b]		x [b]	

Miniopterus orianae oceanensis	x [b]	x [b]	x [b]				x [b]						
Ozimops ridei	x [b, g]	x [b, g]	x [b, g]		x [b, e]	x [b, e, g]							x [b, g]
Ozimops planiceps	x [b, g]	x [b, e, g]	x [b, g]		x [b]	x [b, e]				x [b, g]			
Nyctophilus geoffroyi	x [b. f, h]	x [b, e, f, h]	x [b, e, f, h]		x [b]	x [b, f, h]	x [b]		x [b, e, h]		x [b]	x [b]	
Nyctophilus gouldi	x [a, b, c]	x [b, e]	x [a, b, c, e]		x [b]	x [b, c]	x [b, c]		x [b]		x [a]	x [b]	
Scotorepens balstoni	x [b]	x [e]	x [b]		x [b, e]	x [e]	x [b]		x [b]	x [b]			
Vespadelus darlingtoni	x [b, e]	x [b, e]	x [b]		x [e]	x [b, e]				x [b]	x [b]		
Vespadelus regulus	x [a, b, e, f]	x [b, e, f]	x [a, b, e, f]	x [f]	x [b]	x [b, f]				x [b]	x [a, f]		
Vespadelus vulturnus	x [b, c, e, f, h, i]	x [b, e, f, h]	x [b, c, f, h, i]	x [i]	x [b, e, i]	x [b, e, f, h, i]	x [b]		x [b, h]	x [b]	x [b, i]	x [b]	

Table S2. Landscape-scale measures of urbanisation.

Layer name	Data type	Source	Description	Resolution
NDVI	Raster (binary)	Data at red and near infrared portions of the light spectrum and index of vegetation greeness. NDVI values range between -1 and +1 (higher values = denser and/or greener vegetation, values close to 0 = areas without greenery, i.e. bare earth and impervious surfaces, values close to -1 = water bodies)	A. Hahs, The University of Melbourne (unpublished data)	30 m pixel size
Light	Raster (continuous)	NOAA (2012) Earth observation group: Version 4 dmsp-ols night-time lights time series. Accessed 29 July, 2014, URL http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html	Visible-near infrared (VNIR) radiance (quantity of radiation that passes through or is emitted from a surface). Relative measurement.	1 km pixel size

Table S3: Nocturnal flying invertebrates captured at water body and non-water body sites.

Mean abundance of insects captured over two consecutive nights at 35 water body and 35 non-water body sites. Sorted from highest to least abundant. Insect orders that may be included in the diet of Australian bats are marked with [a]; the others are not commonly recorded in the diet of bats. Significant differences between abundance at water body and non-water body sites are indicated with *, using a t-test and a $p < 0.05$ significance level.

Insect order	Water body Mean numbers (±SE) Range (number of individuals)	Non-water body Mean numbers (±SE) Range (number of individuals)
Lepidoptera [a]	65.7 (± 12.6) 0–593	68.4 (± 14.7) 0–839
Coleoptera [a]	48.5 (± 11.5) 0–581	41.9 (± 10.5) 0–560
Diptera [a]	47.0 (± 10.9)* 0–452	11.2 (± 2.6)* 0–112
Trichoptera	45.0 (± 17.1)* 0–1068	8.2 (± 4.6)* 0–328
Hymenoptera [a]	23.4 (± 7.9) 0–445	12.7 (± 3.0) 0–157
Hemiptera [a]	15.3 (± 4.2) 0–194	16.1 (± 6.13) 0–406
Ephemeroptera	1.5 (± 0.80) 0–48	0.01 (± 0.01) 0–1
Psocoptera	1.0 (± 0.31)* 0–16	0.29 (± 0.07)* 0–2
Neuroptera [a]	0.73 (± 0.35) 0–23	0.28 (± 0.7) 0–3
Isoptera	0.37 (± 0.22) 0–15	0.08 (± 0.03) 0–1
Dermaptera	0.29 (± .11) 0–6	0.32 (± .2) 0–11
Orthoptera [a]	0.21 (± .07) 0–2	0.11 (± .05) 0–2
Mantodea	0.09 (± .05) 0–3	-
Odonata	0.07 (± .03) 0–1	0.01 (± .014) 0–1

Insect order	Water body Mean numbers (±SE) Range (number of individuals)	Non-water body Mean numbers (±SE) Range (number of individuals)
Plecoptera	0.06 (± .06) 0–4	0.01 (± .01) 0–1
Blattodea	0.06 (± .04) 0–2	0.14 (± .08) 0–5
Total numbers	**249.3 (± 49.2)** **0–2687**	**159.8 (± 29.6)** **0–1372**
Total orders	**12** **0–12**	**11** **0–11**

Table S4: Correlation for explanatory variables in landscape, water body and bat-insect models

Landscape insect model (correlation among landscape and moon variables)

	NDVI500m (Spearman's rho)	Moon (Polyserial correlation coeff)
VNIR500	-0.41	-0.06

Water body insect model (correlation among water body variables)

	Tree cover (Spearman's rho)	Understorey (Spearman's rho)	Aquaveg (Spearman's rho)	Size (Spearman's rho)	SQQ (Spearman's rho)
Tree cover	-	0.10	-0.13	0.14	0.01
Understorey	-	-	0.38	0.10	-0.26
Aquaveg	-	-	-	-0.46	-0.15
Size	-	-	-	-	0.15

Bat-insect model (correlations among insect abundance, order richness and abundance of insect orders)

	Coleoptera (Spearman's rho)	Diptera (Spearman's rho)	Lepidoptera (Spearman's rho)	Trichoptera (Spearman's rho)	Insect abundance (Spearman's rho)
Insect abundance	0.84	0.80	0.90	0.70	-
Order richness	0.79	0.66	0.79	0.61	0.80

Table S5: Model selection results for landscape, water body and bats and insects models.

Model selection results for generalised linear mixed effects models (GLMMs) with Poisson error distributions and a log link. Reverse stepwise variable reduction based on AICc (corrected for sample size). Δ AICc = AICc – minimum (AICc). Models shown within Δ AICc < 4.

Landscape insect model (Full model: Habitat, NDVI500m, Light500m, Moon, Temp)

Insect order richness	**AICc**	**Δ AICc**	**Akaike weight**
Full model	725.91	0.00	1

Insect abundance	**AICc**	**Δ AICc**	**Akaike weight**
Full model	15812.08	0.00	1

Coleoptera	**AICc**	**Δ AICc**	**Akaike weight**
Full model	3629.84	0.00	1

Lepidoptera	**AICc**	**Δ AICc**	**Akaike weight**
Full model	5792.43	0.00	1

Diptera	**AICc**	**Δ AICc**	**Akaike weight**
Full model	3769.58	0.00	1

Trichoptera	**AICc**	**Δ AICc**	**Akaike weight**
Model 1 (Habitat, VNIR, Temp, Moon)	3090.69	0.00	0.71
Full model	3092.52	1.83	0.28

Waterbody insect models (Full model: SQQ, Tree cover, Size, AquaVeg, Understorey, Temp and Moon)

Insect order richness	**AICc**	**Δ AICc**	**Akaike weight**
Model 2 (TreeCover, SQQ, Temp, Moon)	553.58	0.00	0.41
Model 3 (SQQ, Temp, Moon)	553.69	0.11	0.39
Model 1 (TreeCover, SQQ, Understorey, Size, Temp, Moon)	555.73	2.15	0.14

Insect abundance	**AICc**	**Δ AICc**	**Akaike weight**
Model 3 (SQQ, Temp, Moon)	13688.26	0.00	0.45
Model 2 (SQQ, Understorey, Temp, Moon)	13689.09	0.81	0.30
Model 1 (Size, SQQ, Understorey, Temp, Moon)	13690.33	2.07	0.16

Coleoptera	**AICc**	**Δ AICc**	**Akaike weight**
Model 1 (TreeCover, Understorey, SQQ, Temp, Moon)	2965.68	0.00	0.51
Model 2 (TreeCover, SQQ, Temp, Moon)	2967.15	1.47	0.25
Full model	2967.79	2.12	0.18

Lepidoptera	**AICc**	**Δ AICc**	**Akaike weight**
Model 2 (TreeCover, Temp, Moon)	4202.08	0.00	0.63
Model 1 (TreeCover, SQQ, Temp, Moon)	4203.97	1.89	0.25
Full model	4205.96	3.88	0.09

Diptera	**AICc**	**Δ AICc**	**Akaike weight**
Model 3 (SQQ, Temp, Moon)	3862.35	0.00	0.57
Model 2 (SQQ, AquaVeg, Temp, Moon)	3863.67	1.32	0.30

Model 1 (SQQ, AquaVeg, Understorey, Temp, Moon)	3865.94	3.58	0.10

Trichoptera	**AICc**	**Δ AICc**	**Akaike weight**
Model 2 (Size, SQQ, Temp, Moon)	3202.06	0.00	0.42
Model 1 (Size, SQQ, AquaVeg, Temp, Moon)	3202.38	0.33	0.35
Full model	3204.56	2.50	0.12
Model 3 (Size, Temp, Moon)	3205.56	3.50	0.07

Bats and insects model (Full model: Coleoptera abundance, Diptera abundance,Trichoptera abundance, Lepipoptera abundance, total insect order + habitat + NDVI 500m + Light 500m)

Bat species richness	**AICc**	**Δ AICc**	**Akaike weight**
Model 1 (Dip, Lep, Tri, InsectOrder, Habitat, NDVI, VNIR)	745.60	0.00	0.76
Full model	747.89	2.30	0.24

Bat activity	**AICc**	**Δ AICc**	**Akaike weight**
Full model	6031.94	0.00	0.74
Model 1 (Drop Coleoptera)	6034.04	2.10	0.26

C. gouldii	**AICc**	**Δ AICc**	**Akaike weight**
Full model	3922.36	0.00	0.76

C. morio	**AICc**	**Δ AICc**	**Akaike weight**
Full model	1230.60	0.00	0.78
Model 1 (Col, Lep, Tri, InsectOrder, Habitat, NDVI, VNIR	1233.46	2.89	0.18

A. australis	**AICc**	**Δ AICc**	**Akaike weight**
Full model	950.01	0.00	1

V. darlingtoni	**AICc**	**Δ AICc**	**Akaike weight**
Model 1 (Dip, Lep, Tri, InsectOrder, Habitat, NDVI, VNIR)	1349.10	0.00	0.65
Full model	1350.35	1.26	0.35

V. regulus	**AICc**	**Δ AICc**	**Akaike weight**
Model 2 (Col, Tri, InsectOrder, Habitat, NDVI, VNIR)	491.70	0.00	0.62

Model 1 (Lep, Col, Tri, InsectOrder, Habitat, NDVI, VNIR)	493.10	0.00	0.62

V. vulturnus	**AICc**	**Δ AICc**	**Akaike weight**
Full model	1710.62	0.00	0.65

Table S6: Parameter effect sizes (± SE) for fixed factors (Diptera, Coleoptera, Lepidoptera, Trichoptera, Insect order richness, Habitat, NDVI and VNIR) and site as random effect derived from Poisson GLMMs.

	Diptera (Effect size ± SE)	Coleoptera (Effect size ± SE)	Lepidoptera (Effect size ± SE)	Trichoptera (Effect size ± SE)	Insect order richness (Effect size ± SE)	Habitat (Effect size ± SE)	NDVI(500m) (Effect size ± SE)	VNIR(500m) (Effect size ± SE)	Deviance reduction (%)
Austronomus australis	**0.41*** ±0.06**	**-0.62*** ±0.09**	**0.51*** ±0.07**	**0.25*** ±0.07**	**-0.35*** ±0.07**	0.26 ±0.36	**0.92*** ±0.19**	-0.09 ±0.17	44.0
Chalinolobus gouldii	**0.31*** ± 0.02**	**-0.27*** ±0.03**	**0.24*** ±0.03**	**-0.17*** ±0.02**	**0.25*** ± 0.03**	-0.34 ± 0.35	0.30 ± 0.18	0.01 ± 0.18	29.4
Chalinolobus morio	**-0.08* ± 0.04**	**0.55*** ±0.06**	**0.09* ±0.03**	**-0.29*** ±0.07**	**-0.67*** ±0.07**	-0.81 ±0.49	**0.99*** ±0.26**	-0.28 ±0.23	36.0
Vespadelus darlingtoni	**-0.42*** ± 0.08**	NA	**-0.60*** ±0.09**	**2.38*** ±0.22**	**0.45*** ±0.06**	-1.68 ±1.61	**2.75** ±0.95**	-1.29 ±0.88	40.6
Vespadelus regulus	NA	**-0.46* ± 0.23**	NA	**0.67* ± 0.26**	**0.38*** ±0.10**	-0.49 ± 1.07	**1.63** ± 0.61**	-0.38 ± 0.55	33.3
Vespadelus vulturnus	**-0.14*** ±0.03**	**0.39*** ±0.05**	**0.19*** ±0.03**	**-0.18*** ±0.04**	**-0.33* ±0.06**	-0.79 ±0.42	**0.85*** ±0.22**	-0.04 ±0.21	32.6
Total bat activity	**0.15*** ± 0.01**	**-0.04* ± 0.02**	**0.09*** ± 0.02**	**-0.06*** ± 0.02**	**0.13*** ± 0.02**	**-0.62* ± 0.29**	**0.46** ± 0.15**	-0.13 ± 0.14	26.1
Bat species richness	0.01 ± 0.04	NA	0.05 ± 0.04	-0.02 ± 0.04	0.07 ± 0.05	-0.08 ± 0.09	**0.25*** ± 0.05**	0.01 ± 0.04	25.1

Results are shown for bats species activity of the most recorded bat species at the surveyed wetlands (Straka et al. 2016). NA indicates that variables were not included in the final model after the model selection process, based on AICc (see Suppl. Material Table S3). Significant results are indicated in bold and by * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$.

[97] Churchill, S. *Australian Bats*; New Holland: Sydney, Australia, 1998.

[98] Law, B.; Urquhart, C.A. Diet of the large-footed myotis *Myotis macropus* at a forest stream roost in northern New South Wales. *Aust. Mammal.* **2000**, *22*, 121–124.

[99] O'Neill, M.G.; Taylor, R.J. Feeding ecology of Tasmanian bat assemblages. *Aust. J. Ecol.* **1989**, *14*, 19–31.

[100] Reside, A.E.; Lumsden, L.F. Resource partitioning by two closely-related sympatric freetail bats, *Mormopterus* spp. In *Biology and Conservation of Australian Bats*; Law, B., Eby, P., Lunney, D. and Lumsden, L, Eds.; Royal Zoological Society of NSW: Mosman, NSW, Australia, 2011; pp. 155–166.

[101] Kolkert, H.; Andrew, R.; Smith, R.; Rader, R.; Reid, N. Insectivorous bats selectively source moths and eat mostly pest insects on dryland and irrigated cotton farms. *Ecol. Evol.* **2020**, *10*, 371–388.

[102] Straka, T. M. The shared habitat: Understanding and linking the needs of insectivorous bats and people at urban wetlands. Doctoral dissertation. The University of Melbourne, Melbourne, Australia. **2015.**