**Supplemental Material**

**Doses of Neighborhood Nature: Benefits for Mental Health of Living with Nature**.

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**Contents**

**Appendix S1.** Ethical clearance **2**

**Appendix S2.** Calculation of Index of Multiple Deprivation and neighborhood population density  **3**

**Appendix S3.** Characterization of the urban form for each tile  **4**

**Appendix S4.** Estimation of neighborhood actual bird abundance and species richness, and the abundance and richness of birds that people are likely to experience **5**

**Table S1.** Socio-demographic variables used in the analysis  **8**

**Table S2.** Depression, Anxiety and Stress Scale 21 (DASS 21) included in the urban lifestyle questionnaire **9**

**Table S3.** Distribution of the subset of respondents for which we calculated metrics of neighborhood nature, across socio-demographic variables **10**

**Table S4.** a) variation in five metrics of neighborhood nature, and b) a count of respondents for the severity for each mental health disorder **11**

**Table S5.** Pearson’s correlations between five metrics of neighborhood nature **12**

**Table S6.** Binary risk factors for each covariate that was significant in the first analysis **13**

**Table S7.** Pooled detection functions for species with similar morphology and behavior **14**

**Figure S1.** Remote sensing image showing how neighborhood bird abundances and richness were estimated **15**

**References 16**

**Appendix S1. Ethical clearance**

This research was conducted with approval from the Bioscience ethics committee of the University of Exeter (project number 2013/319). Participants provided written consent at the beginning of the online survey by checking a box stating their agreement to participate.

**Appendix S2. Calculation of Index of Multiple Deprivation and neighborhood population density.**

*Index of multiple deprivation:* We used the Indices of Multiple Deprivation (IMD, *Sharegeo.ac.uk*, data sourced from *Data.gov.uk*) produced by communities and local government to derive a socio-economic deprivation score for each tile. The IMD contained separate indices for separate domains of deprivation (e.g. ward level income, employment, health deprivation and disability), which were simply averaged. This IMD is provided at the postcode scale.

*Neighborhood population density:* We used the UK gridded population based on the Census 2011 and Land cover map 2007 (Reis et al. 2016). This dataset contains a gridded population density with a spatial resolution of 1 km x 1 km. For each 250 m buffer around the centroid of a respondent’s postcode we scaled the estimated population relative to the area of the gridded population square that the buffer covered. Where the buffer covered more than one tile we weighted our estimate by the proportion of each tile that was covered.

**Appendix S3. Characterization of the urban form for each tile.** The urban form for each tile was characterised using airborne hyperspectral (Eagle imaging spectrometer; 12 bit, pushbroom, hyperspectral sensor with a 1000 pixel swath width, covering the visible and near infra-red spectrum 400 - 970nm) and LiDAR (Light Detection and Radar) (Leica ALS50-II) data collected by the Natural Environment Research Council (NERC) Airborne Research and Survey Facility (ARSF) aircraft in July and September 2012. The normalized difference vegetation index (NDVI; Tucker 1979) was calculated from the hyperspectral data using a red band centered on 570nm and a near infra-red band centered on 860 nm with a spatial resolution of 2m. Histograms of NDVI were examined and a threshold of 0.2 identified as being suitable to separate vegetated (NDVI>=0.2) from non-vegetated (NDVI<0.2) pixels (Liang 2004). The LiDAR data were used in discrete return mode, with up to four returns per laser pulse. The laser point density was between one point per 25cm2 and one point per 2m2, depending on flight line overlap. The lastools ‘lasground’ function (Isenburg 2011) was used to find ground returns within the LiDAR point cloud. Pixels (2m resolution) with an NDVI greater than 0.2 and a mean height of first return more than 0.7 m above the ground were marked as trees (figure S1). Heights from discrete return LiDAR are well-known to produce biased results over vegetation (Hancock et al. 2011) and so this 0.7 m threshold may have represented a more variable vegetation threshold height, and since that bias is most usually an underestimation, it could correspond to taller vegetation (up to 1.7 m tall). We then measured neighborhood tree cover as vegetation ≥0.7 m in height, within a 250 m buffer around the centroid of each respondent’s postcode. We estimated that the average area of the respondents’ postcodes was 12,436 m2, (14,257SD), and so fell within the neighborhood buffer.

**Appendix S4**. **Estimation of neighborhood actual bird abundance and species richness, and the abundance and richness of birds that people are likely to experience.** We divided the landscape within the urban limits of the three towns into 500×500 m square ‘tiles’ (250,000 m2), where tiles within the urban limit were defined as those within the administrative boundary that had greater than 25% urban built form, as assessed by eye (Gaston et al. 2005). As a measure of urban form within each tile we calculated the tree cover (Appendix S3), as well as the number of building polygons shown in the Ordnance Survey MasterMap (2013). We then selected a subset of 116 tiles using random sampling stratified to provide consistent variation in urban form between 0% and 50% tree cover and between 0 and 20% built cover, reflecting the range of values found in the study towns. Within each tile, up to four point locations were identified (mean per tile, 3.89 ± 0.37 SD), in order to represent the diversity of urban forms present as fully as possible, subject to access restrictions. Survey points were selected to be ≥200 m apart and ≥100 m from tile edges, such that surveys from each point sampled different birds, with fewer than four points being chosen if sufficiently separated points could not be accessed.

To measure bird abundance, we used point counts and a distance sampling procedure to account for differences in detectability among species (Buckland et al. 2001). All point counts were conducted by one of two trained researchers. To estimate actual bird abundance, two early-morning surveys (06:00 – 10:00 hours) were conducted at each point in all tiles during the breeding season, one in May and one in June; these were timed to maximize the detectability of the component species of the local breeding bird community. The abundance that people are likely to experience was estimated using two later-day surveys (10:00 – 18:00 hours) that were conducted in each tile from May – July using the same protocols as the early-morning surveys. Point counts were conducted for ten-minute periods, divided into two-minute intervals. Within each two-minute interval, the number of birds and the radial distance from the observer at which they were seen was recorded in bands of 0-20 m, 20-40 m, 40-60 m and 60-100 m. Birds were recorded independently in each two-minute period. Individuals that moved during a two-minute period were recorded in the distance band in which they were first detected.

For each individual ten-minute point count, we selected the maximum count of each species per distance band from the multiple two-minute intervals. For each band we then selected the maximum total count across visits. We used these data and the ‘unmarked’ package (Fiske and Chandler 2011) to calculate bird abundance corrected for detection probability, whilst adjusting for percentage tree cover >0.7 m and percentage built cover within the survey radius. We calculated a pooled detection function for species with similar morphology and behavior, assuming that these species had similar detection characteristics (table S7). This is because a number of species had small sample sizes (<40 records), which precluded appropriate distance analysis on these individual species. Species with small sample sizes that were morphologically and/or behaviorally distinct were excluded from analysis (Northern lapwing *Vanellus vanellus*; pheasant *Phasianus colchicus*; European cuckoo *Cuculus canorus*; European kingfisher *Alcedo atthis;* Grey wagtail *Motacilla cinerea*). Models failed to converge for a further five groups of species and the original abundances were used (table S7). Because detection of species might vary with time of day (Alldredge et al. 2007) we calculated detection probabilities for each species, or group of species, for both early morning and afternoon surveys. We calculated an adjusted measure of abundance in each survey tile by dividing raw abundance counts for each species by its detection probability, before summing adjusted counts across species (or unadjusted counts for those species or groups of species where models failed to converge) within each survey point to get the total abundance by survey tile.

To estimate actual species richness within each survey tile we calculated the total number of species seen across all early morning surveys. We repeated this for afternoon surveys to obtain an estimate of the species richness that people are likely to experience.

**Table S1.** **Socio-demographic variables used in the analysis.** Variables used to examine the relationship between three negative mental states (depression, anxiety and stress) and a participant’s exposure to five metrics of nature intensity.

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Variable | Description | Supporting reference for inclusion |
| Age  (ordinal) | Age | Respondents selected from 11 brackets: 18-20 years, then increasing increments of five years until >60 years. Responses were then banded as: 18-30 years; 31-45 years; 46-60 years; >60 years | (Astell-Burt et al. 2014a, Mroczek and Kolarz 1998, Wu et al. 2015) |
| Gender (categorical) | Gender | Female or Male | (Rosenfield and Mouzon 2013, Ross and Mirowsky 2006) |
| Language (categorical) | Primary language spoken at home | Respondents speak a language other than English at home (No or Yes) | (Bratter and Eschbach 2005, Wu et al. 2003) |
| Income (categorical) | Personal annual income | Respondents selected from eight brackets: No income; £1-£199 a week (£1-£10,399 per year); £200-£299 a week (£10,400-£10,599 per year); £300-£399 (£15,600-£20,799 per year); £400-£599 a week (£20,800-£31,199 per year); £600-£799 a week (£32,200-£41,599 per year); £800-£9,999 a week (£41,600-£51,999 per year); >$1,000 a week (>£52,000) | (Astell-Burt et al. 2014b, de Vries et al. 2003, Weich et al. 2001) |
| Physical activity (numeric) | Physical activity | Self-reported number of days in previous week that the respondent exercised for more than 30 minutes | (Barton and Pretty 2010, Cohen-Cline et al. 2015, Deslandes et al. 2009, Mitchell 2013, Richardson et al. 2013) |
| Physical health (ordinal) | Self-assessment of health | Respondents selected from: Very poor; poor; average; good; very good | (Maas et al. 2006, van Dillen et al. 2012) |
| Education (categorical) | Highest formal education | Highest qualification (selected from four categories equivalent to: General Certificate of Secondary Education (GCSE); A-levels; Bachelor’s degree; Postgraduate degree) | (Fryers et al. 2003, Miech and Shanahan 2000) |
| Recent nature experience  (factor) | Relative time spent in nature in previous week | Respondents selected from: less time; about the same time; more time. |  |
| IMD  (numeric) | Index of Multiple Deprivation | Indices of Multiple Deprivation weighted for the 250m buffer of the centroid of the respondents postcode (see appendix S2). | IMD, *Sharegeo.ac.uk*, data sourced from *Data.gov.uk* |
| Population density (numeric) | Population density | UK gridded population based on the census 2011 and Land cover map 2007, weighted for the 250m buffer of the centroid of the respondents postcode (see appendix S2). | (Reis et al. 2016) |

**Table S2. Depression, Anxiety and Stress Scale 21 (DASS 21) included in the urban lifestyle questionnaire** (taken from (Lovibond and Lovibond 1995) and reproduced here for ease of reference). Seven statements rated each mental health state. a) Answers to each statement were given on a four-point scale from: did not apply to me at all; applied to me to some degree, or some of the time; applied to me to a considerable degree, or a good part of the time; applied to me very much, or most of the time. b) The severity of each mental health state was then rated by summing the relevant scores.

|  |  |
| --- | --- |
| **a) Statement** | **Mental state** |
| I found it hard to wind down | Stress |
| I was aware of dryness of my mouth | Anxiety |
| I couldn't seem to experience any positive feeling at all | Depression |
| I experienced breathing difficulty (e.g. excessively rapid breathing, breathlessness in the absence of physical exertion) | Anxiety |
| I found it difficult to work up the initiative to do things | Depression |
| I tended to over-react to situations | Stress |
| I experienced trembling (e.g. in the hands) | Anxiety |
| I felt that I was using a lot of nervous energy | Stress |
| I was worried about situations in which I might panic and make a fool of myself | Anxiety |
| I felt that I had nothing to look forward to | Depression |
| I found myself getting agitated | Stress |
| I found it difficult to relax | Stress |
| I felt down-hearted and blue | Depression |
| I was intolerant of anything that kept me from getting on with what I was doing | Stress |
| I felt I was close to panic | Anxiety |
| I was unable to become enthusiastic about anything | Depression |
| I felt I wasn't worth much as a person | Depression |
| I felt that I was rather touchy | Stress |
| I was aware of the action of my heart in the absence of physical exertion (e.g. sense of heart rate increase, heart missing a beat) | Anxiety |
| I felt scared for no good reason | Anxiety |
| I felt life was meaningless | Depression |

|  |  |  |  |
| --- | --- | --- | --- |
| **b)** | **Depression** | **Anxiety** | **Stress** |
| Normal | 0 – 4 | 0 – 3 | 0 - 7 |
| Mild | 5- 6 | 4- 5 | 8 – 9 |
| Moderate | 7 – 10 | 6 – 7 | 10 – 12 |
| Severe | 11 – 13 | 8 – 9 | 13 – 16 |
| Extremely severe | 14 + | 10 + | 17 + |

**Table S3.** Distribution of the subset of respondents for which we calculated metrics of neighborhood nature, across socio-demographic variables within the study towns (263 respondents). For comparison we also show the distribution of the Buckinghamshire and Bedfordshire counties, 2011 Census population average.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Level | Subset of survey respondents | Local  population |
| Gender | Female | 56% | 51% |
|  | Male | 44% | 49% |
| Income | No income | 5% | 5% |
|  | £1-£10,399 per year | 12% | 12% |
|  | £10,400-£10,599 per year | 11% | 19% |
|  | £15,600-£20,799 per year | 14% | 11% |
|  | £20,800-£31,199 per year | 26% | 25% |
|  | £32,200-£41,599 per year | 16% | 18% |
|  | >£41,600 | 15% | 10% |
| Age | 18-30 years | 29% | 21% |
|  | 31-45 years | 35% | 25% |
|  | 46-60 years | 27% | 32% |
|  | >60 years | 9% | 21% |
| English is not the primary | No | 85% | 72% |
| language spoken at home | Yes | 15% | 28% |
| Self-assessment of health | Very poor | 1.5% | 0.8% |
|  | Poor | 5.7% | 2.7% |
|  | Average | 27.0% | 10.7% |
|  | Good | 40.3% | 33.8% |
|  | Very good | 24.7% | 52% |
| Highest level of education | 16+ (Secondary) | 18% | 28% |
| (or equivalent) | 18+ (A-level) | 40% | 12% |
|  | Undergraduate | 33% | 27% |
|  | Postgraduate | 9% | 8% |
| Physical activity | 0 days | 29% | - |
| (> 30 minutes exercise a | 1 day | 19.4% | - |
| week)\* | 2 days | 16% | - |
|  | 3 days | 14% | - |
|  | 4 days | 8% | - |
|  | 5 days | 9% | - |
|  | 6 days | 1% | - |
|  | 7 days | 4% | - |
| Relative time spent out of | Less time |  | - |
| doors in previous week\* | About the same |  | - |
|  | More time |  | - |

\* data is unavailable for county averages

**Table S4.** **We show** **a) variation in five metrics of neighborhood nature, and b) a count of respondents for the severity for each mental health disorder.**

|  |  |  |
| --- | --- | --- |
| a) Variable | Mean | Range |
| *Metrics of neighborhood nature* |  |  |
| Vegetation cover (%) | 23 (±10) | 6-50 |
| Bird actual abundance | 541 (±100) | 254-886 |
| Bird actual species richness | 22 (±4) | 14-33 |
| Bird afternoon abundance | 267 (±79) | 116-509 |
| Bird afternoon species richness | 15 (±3) | 10-23 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *b) Mental health* | Normal | Mild | Moderate | Severe | Ex. severe |
| Depression | 148 | 22 | 29 | 20 | 23 |
| Anxiety | 178 | 18 | 15 | 17 | 30 |
| Stress | 182 | 14 | 24 | 14 | 8 |

**Table S5. Pearson’s correlations between five metrics of neighborhood nature.** For comparisonwe also show correlations with vegetation cover within the bird survey tiles.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Nature metric** | **Vegetation cover** | **Actual abundance** | **Actual richness** | **Afternoon abundance** | **Afternoon**  **Richness** |
| **Vegetation cover** | - |  |  |  |  |
| **Actual abundance** | 0.08 | - |  |  |  |
| **Actual richness#** | 0.08 | 0.19 | - |  |  |
| **Afternoon abundance** | 0.11 | 0.29 | 0.05 | - |  |
| **Afternoon richness** | 0.14 | 0.23 | 0.72 | 0.27 | - |
| **Vegetation cover in bird survey tiles** | 0.57 | -0.07 | -0.08 | 0.11 | -0.00 |

**Table S6. Binary risk factors for each covariate that was significant in the first analysis.**

|  |  |
| --- | --- |
| **Variable** | **Conversion to binary risk factor** |
| Age | The prevalence of mood disorders begin to decline in Australia at around 45 years (Statistics 2009). We therefore created a binary risk factor, at which above 45 years the risk of having poor mental health was zero and below was one. |
| Self-assessment of health | There is a higher prevalence of poor mental health in people with poor physical health (e.g. Osborn 2001). We created a binary risk factor at which the risk of having poor mental health was zero in people with average to very good health, and one in people with poor to very poor health. |
| Relative time spent out of doors in previous week | No information was available on time spent out of doors in the previous week and mental health. We thus considered that people had an increased risk if they spent less time out of doors in the previous week than usual. |
| Afternoon bird abundances | No information was available on bird abundances and mental health. We thus considered that people had an increased risk if they resided in a neighborhood with afternoon bird abundances below the median neighborhood bird abundance of this study (266 individual birds). |
| Neighborhood vegetation cover | We created multiple binary risk factors in increasing increments of 5%, for break points of neighborhood tree cover (10%, 15%, 20%, 25%, 30%, 35%). Where the levels of neighborhood vegetation cover were below this break point the risk of poor mental health was one, and above the risk was zero. |

**Table S7. Pooled detection functions for species with similar morphology and behavior.** We show whether models converged (there was no difference in convergence between morning and afternoon surveys).

|  |  |  |
| --- | --- | --- |
| **Species group** | **Species** | **Model converged?** |
| Duck | Great crested grebe (*Podiceps cristatus*);Cormorant (*Phalacrocorax carbo*)*;* Mute swan (*Cygnus olor*); Greylag goose (*Anser anser*); Canada goose (*Branta canadensis*); Mallard (*Anas platyrhynchos*); Moorhen (*Gallinula chloropus*); Coot (*Fulica atra*) | No |
| Raptor | Red kite (*Milvus milvus*); Buzzard (*Buteo buteo*); Sparrowhawk (*Accipiter nisus*);Kestrel (*Falco tinnunculus*); Hobby (*Falco subbuteo*); Peregrine (*Falco peregrinus*) | No |
| Wader | Little egret (*Egretta garzetta*); Grey heron (*Ardea cinerea*);Oyster catcher (*Haematopus ostralegus*); Common sandpiper (*Actitis hypoleucos*); Green sandpiper (*Tringa ochropus*) | No |
| Gull | Black-headed gull (*Chroicocephalus ridibundus*); Herring gull (*Larus argentatus*); Lesser black-backed gull (*Larus fuscus*); Common gull (*Larus canus*) | No |
| Woodpecker | Green woodpecker (*Picus viridis*); Great spotted woodpecker (*Dendrocopos major*) | Yes |
| Flier | Swift (*Apus apus*);Barn swallow (*Hirundo rustica*); House martin (*Delichon urbicum*) | No |
| Thrush | Song thrush (*Turdus philomelos*); Mistle thrush (*Turdus viscivorus*) | Yes |
| Warbler | Garden warbler (*Sylvia borin*); Blackcap (*Sylvia atricapilla);* Whitethroat (*Sylvia communis*); Lesser whitethroat (*Sylvia curruca*); Sedge warbler (*Acrocephalus schoenobaenus*); Reed warbler (*Acrocephalus scirpaceus*); Willow warbler (*Phylloscopus trochilus*); Meadow pipit (*Anthus pratensis*); Reed bunting (*Emberiza schoeniclus*) | Yes |
| Tit | Goldcrest (*Regulus regulus*); Coal tit (*Periparus ater*); Marsh tit (*Poecile palustris*); Long-tailed tit (*Aegithalos caudatus*); Nuthatch (*Sitta europaea*); Tree creeper (*Certhia familiaris*); Bullfinch (*Pyrrhula pyrrhula*) | Yes |
| Finch | Goldfinch (*Carduelis carduelis*); Greenfinch (*Chloris chloris*); Yellowhammer (*Emberiza citrinella*); Linnet (*Linaria cannabina*) | Yes |
| Corvid | Magpie (*Pica pica*)*;* Jay (*Garrulus glandarius*)*;* Jackdaw (*Corvus monedula*); Rook (*Corvus frugilegus*); Carrion crow (*Corvus corone*) | Yes |

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**Figure S1. Remote sensing image showing how neighborhood bird abundances and richness were estimated** for those respondents whose 250m-neighborhood buffer (purple) overlapped with at least one bird survey location (brown) within a survey tile (green). We show remote sensing land classifications within each urban area (dark grey, trees >0.7 m; medium grey, grass and shrubs <0.7 m; light grey, no vegetation >0.7 m; no vegetation ,0.7 m).

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