Capturing residents' values for urban green space: Mapping, analysis and guidance for practice.

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Abstract

Planning for green space is guided by standards and guidelines but there is currently little understanding of the variety of values people assign to green spaces or their determinants. Land use planners need to know what values are associated with different landscape characteristics and how value elicitation techniques can inform decisions. We designed a Public Participation GIS (PPGIS) study and surveyed residents of four urbanising suburbs in the Lower Hunter region of NSW, Australia. Participants assigned dots on maps to indicate places they associated with a typology of values (specific attributes or functions considered important) and negative qualities related to green spaces. The marker points were digitised and aggregated according to discrete park polygons for statistical analysis. People assigned a variety of values to green spaces (such as aesthetic value or social interaction value), which were related to landscape characteristics. Some variables (e.g. distance to water) were statistically associated with multiple open space values. Distance from place of residence however did not strongly influence value assignment after landscape configuration was accounted for. Value compatibility analysis revealed that some values co-occurred in park polygons more than others (e.g. nature value and health/therapeutic value). Results highlight the potential for PPGIS techniques to inform green space planning through the spatial representation of complex human-nature relationships. However, a number of potential pitfalls and challenges should be addressed. These include the non-random spatial arrangement of landscape features that can skew interpretation of results and the need to communicate clearly about theory that underpins results.

1. Introduction

Green spaces in urban environments are vital green infrastructure for a raft of environmental, social and economic benefits (Hunter & Luck, 2015; Jorgensen & Gobster, 2010; Swanwick, Dunnett, & Woolley, 2003). In the past few years, scholars have sought to understand the specific characteristics of green spaces that promote visitation (Grahn, Stigsdotter, & Berggren-Bärring, 2005), health benefits (McCormack, Rock, Toohey, & Hignell, 2010) and mental restoration (Nordh, Hartig, Hagerhall, & Fry, 2009). Recent reviews of the literature have shown that green spaces are indeed important for human health and well-being and environmental sustainability, although the specific mechanisms or pathways for these benefits are often complex (Kabisch, Qureshi, & Haase, 2015; Konijnendijk, Annerstedt, Nielsen, & Maruthaveeran, 2013). Social benefits of green spaces in particular have been shown to be influenced by a complex set of factors such as access, maintenance, amenities and perceptions of aesthetic attractiveness and safety (Konijnendijk et al., 2013; McCormack et al., 2010).

In contrast to the study of the health and environmental benefits of green space, social values and attitudes towards green spaces and the cultural services they offer have received less attention (Hitchings, 2013). In their review of empirical research on urban ecosystem services, Luederitz et al. (2015) found that cultural services were the least represented group. The values people assign to landscapes can be understood as an expression of these cultural services (Plieninger, Dijks, Oteros-Rozas, & Bieling, 2013). On a theoretical level, these values exist in the "relational realm", where value "emerges from the interaction between a subject and an object" (Brown, 1984). Assessing the values people assign to natural areas is a critical component in sustainable landscape management (Kenter et al., 2015; Plieninger et al., 2015), yet the importance of places

24   to urban residents will not necessarily be evident from their use patterns alone (Ives & Kendal,

25   2014; Swanwick, 2009). Indeed, Tyrväinen et al. (2007) in their study of green space values in

26   Helsinki found open spaces that were identified by local residents to be their favourite were not

27   the most frequently used green spaces.

28

29   Applying assessments of green space values and benefits to planning and management has been

30   identified as an area in need of further research (Luederitz et al., 2015; Tratalos, Haines-Young,

31   Potschin, Fish, & Church, 2015). Historically, a variety of approaches have been used to plan

32   and manage green space networks (Maruani & Amit-Cohen, 2007), yet there is a need for greater

33   knowledge of how specific landscape variables influence green space values and how these

34   insights can be applied to planning practice. A challenge of urban landscape planning is

35   reconciling knowledge on how landscapes function (i.e. what *is*) with normative assertions about

36   desired future states and actions towards them (i.e. what *ought to be*) (Campbell, 2012).

37   Lindholst *et al.* (2015) identify three scales at which reconciliation between research and

38   planning practice can take place: (i) the conceptual level, where scholarly ideas influence

39   planning frameworks and paradigms, (ii) the policy level, where knowledge can inform planning

40   policies, and (iii) the applied level, where insights on human interactions with ecosystems can

41   provide guidelines and practical advice on planning and management actions. When relating

42   evidence on landscape values to practice, it is therefore important to consider the level at which

43   this integration should occur.

44

45   If intangible values for green spaces are to be understood and integrated into planning practice,

46   there is a need for methods to capture these values in ways that can be readily applied. Public

47   Participation Geographic Information System (PPGIS) methods are growing in popularity in

48   applied landscape research because of their ability to engage stakeholders and capture spatially-

49   explicit information on intangible landscape values that can be integrated with existing planning

50   approaches (Brown, 2012; Van Herzele & van Woerkum, 2011). PPGIS is a field of geographic

51   information science that focuses on the use of geospatial technologies by the public (such as

52   mapping) to participate in public processes (Tulloch, 2008). Mapping activities have been

53   commonplace in community planning for some time, such as the use of maps as stimuli for

54   group dialogue or allowing community members to draw significant landscape features on maps

55   themselves in a deliberative setting (Wates, 2014). While these methods promote deep

56   engagement with the planning process and elicit nuanced local knowledge of an area, the PPGIS

57   method explored in this study is oriented towards greater quantification of this knowledge and

58   broader community representation. Such GIS-based approaches are able to spatially represent

59   community landscape perceptions within a form of data commonly used in decision-making.

60   Kabisch et al. (2015) therefore called for greater use of these techniques in urban environment

61   research because of their ability to connect research with practice.

62

63   However, while the number of scientific studies using PPGIS has increased over time, there

64   remains some resistance to the use of participatory approaches by planning professionals because

65   expert opinion is seen as superior or more reliable than 'crowd-sourced' information (Brown,

66   2015). Future empirical research that uses PPGIS techniques should therefore consider not only

67   scientific or theoretical issues, but also how PPGIS can be applied in landscape practice.

68

69   A number of studies have applied PPGIS techniques to urban systems in recent years with some

70   key insights beginning to emerge. First, a diversity of values have been shown to be assigned by

71   residents to green spaces (Brown, 2008; Tyrväinen et al., 2007), lending empirical support to the

72   notion of landscape value plurality (see Zube, 1987) within urban landscapes. Yet not all mapped

73   values for green space are of equal significance. For example, Kyttä et al. (2013) found the most

74   positive values were associated with attractiveness, ease of walking/cycling and presence of

75   nature, while Tyrväinen *et al.* (2007) found 'opportunities for activity' and 'beautiful landscape' to

76   be the most frequently assigned social values in green spaces. Second, geographic factors

77   influence the strength and diversity of mapped values. This led Brown (Brown, 2008) to develop

78   a 'theory of urban park geography' using data from a public survey where residents of

79   Anchorage, Alaska identified places on a map of their local area that they valued. Brown (2008)

80   found strong support for the theory that the diversity of park values is positively related to green

81   space size (area), and weak support for a negative relationship between value diversity and the

82   distance of a green space from concentrated human habitation. Similar results were found by

83   Brown et al. (2014) who found that larger green spaces contained more mapped benefits and

84   activities from an online survey in Adelaide, Australia. The influence of geographic proximity as

85   a variable lends support to the theory of spatial discounting of place values (Norton & Hannon,

86   1997). Finally, other PPGIS studies have shown that specific biophysical and management

87   characteristics of green spaces influence assignment of values. For example, green space

88   classification has been related to the values assigned to the spaces and the activities undertaken

89   within them (Brown et al., 2014; Brown, 2008), and green spaces located in close proximity to a

90   shoreline being found to also be assigned more positive values (Balram & Dragićević, 2005;

91 Kyttä et al., 2013). Given PPGIS remains a relatively new technique for assessing relationships

92 between people and green spaces, there is a need for further empirical research on these issues.

93

94 There are some key outstanding research gaps in the application of PPGIS information on urban

95 green spaces to urban planning. Relevant questions include (i) how applicable are the findings

96 from the few existing PPGIS studies on social values for green space to other regions? (ii) how

97 can statistical techniques be refined to better accommodate the type of data collected in PPGIS

98 studies and what might these tell us about the nature of relationships between mapped values and

99 biophysical green space characteristics? and (iii) what challenges might need to be overcome in

100 order to better apply spatially-mapped social values for green spaces to landscape planning

101 practice? This article addresses these gaps by pursuing the following objectives: (1) assess the

102 spatial representation of positive and negative social values for green space in an urbanising

103 region, (2) analyse their statistical relationships to key environmental values and one another,

104 and (3) consider how PPGIS techniques and these results might be applied to green space

105 planning. We pursue these objectives through undertaking a PPGIS survey of residents' values

106 for green spaces (defined here as open spaces with grass or other vegetation but excluding

107 private gardens and street trees) in an urbanising region of eastern Australia.

108

109 **2. Methods**

110 *2.1 Study area*

111 Four suburbs within two Local Government Areas (LGAs) in the Lower Hunter Valley, New

112 South Wales, Australia were selected for the study. The Lower Hunter Valley was experiencing

113 significant land use change, and at the time of the survey was the subject of an extensive regional

114   planning process that would consider priorities for economic activities, urban growth and

115   conservation (see Raymond & Curtis, 2013 for details). The four suburbs selected were

116   Charlestown and Toronto (within the Lake Macquarie LGA), and Nelson Bay and Raymond

117   Terrace (within the Port Stephens LGA) (Fig. 1). These suburbs were chosen because they are

118   areas of current and future urban growth and contain a variety of green spaces. Population

119   statistics for the four suburbs were as follows (suburb initials used for brevity): (i) Population –

120   C 12411, T 5433, NB 5396, RT 12725; (ii) Median age - C 39, T 44, NB 47, RT 35; (iii) Number

121   of private dwellings - C 5326, T 2472 NB 4083, RT 5082; (iv) Median weekly household income

122   (AUD) - C \$1244, T \$816, NB \$930, RT \$1003 (Australian Bureau of Statistics, 2011). The total

123   number of formal green spaces delineated in our study area was 323.

124

125   *2.2 Survey administration*

126   Survey instruments were developed to ascertain the values that residents in the Lower Hunter

127   Valley assigned to the green spaces in their local area. Survey packets were mailed to a total of

128   1,000 residents from the four suburbs in July 2013. Survey recipients had expressed willingness

129   to participate via initial screening telephone calls from a larger database of residents phone

130   numbers. Recipients were asked to indicate their age to ensure that >20 % were 18-35 and >20 %

131   35-55 as a way of minimising the bias towards an older demographic which is typical in survey

132   respondents. 418 surveys were returned from a possible 972 (43%) (28 of the 1000 survey

133   packets were returned to sender). The percentage of responses differed slightly between suburbs

134   as follows: Raymond Terrace 18.4 %; Nelson Bay 28.9 %; Charlestown 27.8 %; and Toronto

135   24.9 %. Of the respondents, 50.6 % were male and 43.3 % were female (7.1% did not specify

136   their sex). 93 % of respondents nominated the contact address as their principle place of

137   residence. The median respondent ages for the four suburbs were as follows (with the census

138   median age given in parentheses): Raymond Terrace 57 (census = 35); Nelson Bay 60.5 (census

139   = 47); Charlestown 62 (census = 39); Toronto 61 (census = 44). We observed an older

140   respondent profile despite efforts to recruit younger participants (see supplementary material S1),

141   however, the difference may not be as pronounced as it appears since the Australian census data

142   includes those under 18 years old.

143

144   The survey instrument contained the following components: (i) a paper map of the resident's

145   suburb displaying official municipal green spaces, significant roads and walkways and extant

146   tree cover (scale = 1:13,500); (ii) an interactive map legend with descriptions of green space

147   values and negative qualities corresponding to numbered marker dots for participants to stick to

148   the map (red, 6 mm diameter, six per value attribute); and (iii) a series of socio-demographic

149   questions including gender, age, education, occupation, income and housing status. For the

150   interactive mapping component, participants were instructed to stick the marker dots denoting

151   specific values to green spaces on the map. Participants could assign as many or as few marker

152   dots as they wished (up to the maximum of six per value type), and were not restricted to placing

153   dots in formally identified green spaces.

154

155   The 'values for green spaces' associated with the stickers on the map legend were adapted from

156   existing typologies developed for PPGIS studies in the context of urban green spaces (see

157   Brown, 2008; Tyrväinen et al., 2007). The specific value classes and definitions were further

158   refined to ensure content validity and contextual relevance after interviewing key stakeholders

159   such as government, industry and Non-Governmental Organisation representatives from the

160   Hunter Valley area, meeting with local government staff, and undertaking focus groups with

161   community members from both municipalities. The final typology of values and negative

162   qualities was as follows:

163

164   • Aesthetic / Scenic (e.g. places that are visually attractive)

165   • Activity / Physical Exercise (e.g. places you value because they provide opportunities for

166   physical activity)

167   • Native Plants and Animals (e.g. places you value for the protection of native plants and

168   animals)

169   • Nature (e.g. places to experience the natural world)

170   • Cultural Significance (e.g. opportunities to express and appreciate culture or cultural

171   practices such as art, music, history or indigenous traditions)

172   • Health/Therapeutic (e.g. places you value for mental or physical restoration)

173   • Social Interaction (e.g. opportunities for you to interact with other people)

174

175   The 'negative qualities of green spaces' were:

176   • Unappealing (e.g. neglected, damaged, unaesthetic, ugly)

177   • Scary/Unsafe (e.g. dangerous or threatening)

178   • Noisy (i.e. disturbingly loud or noisy)

179   • Unpleasant (unpleasant or exposed to the elements, i.e. too hot, too windy, no shade or

180   shelter etc.)

181
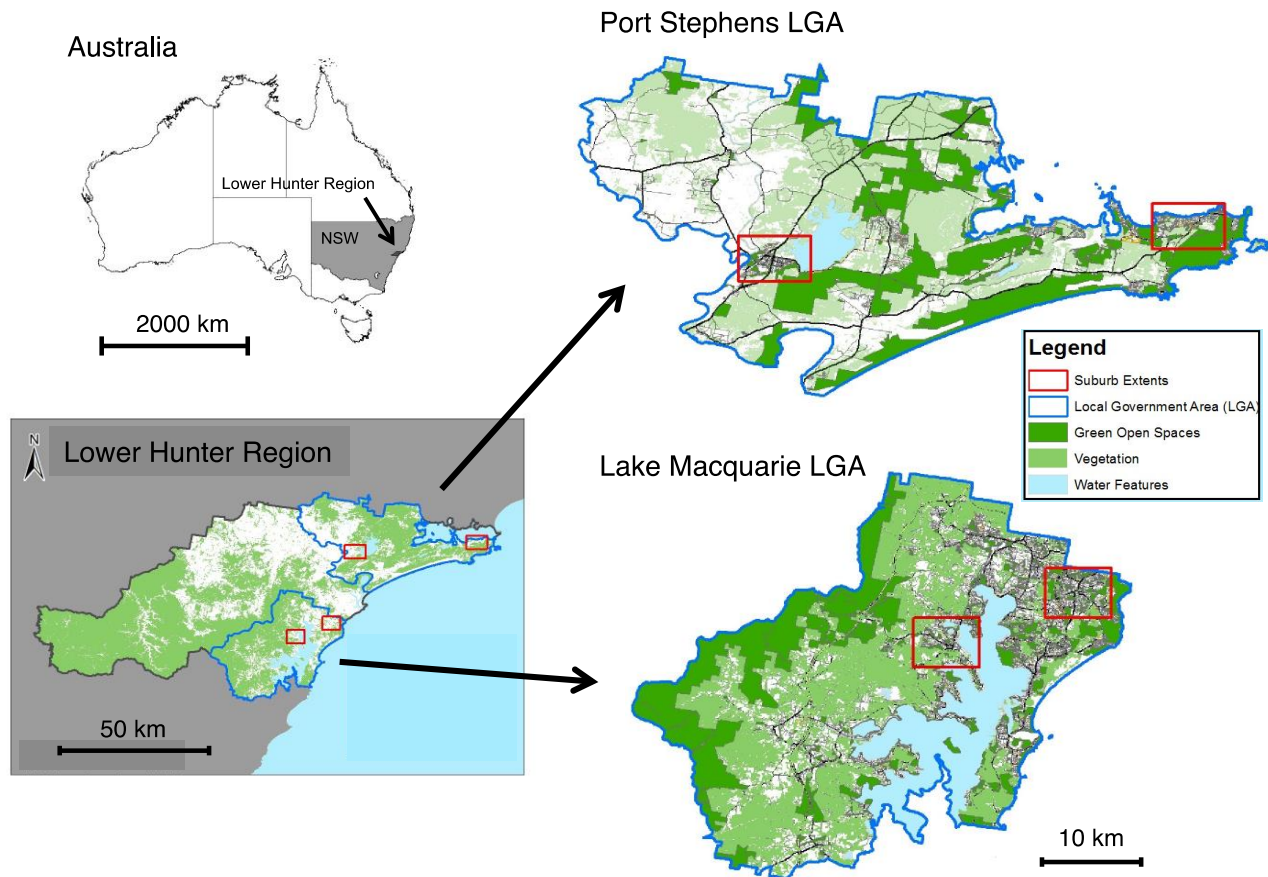
Figure 1. Maps of the location of the four study suburbs within the two Local Government Areas in NSW, Australia.

To maximise response rates, a series of incentives and reminders were employed according to

the Dillman (2007) tailored design method. This included a gift of six packaged postal stamps,

an opportunity to win a $100 AUD shopping voucher, and two reminder postcards and an

additional complete survey packet for non respondents distributed at two week intervals where

necessary. The survey design and administration procedure was reviewed and approved by

[*identity hidden for peer review*] University's ethics board (project 06/13).

2.3 Data processing and spatial mapping

194   Returned paper maps were scanned at a resolution of 400 dpi and the location of mapped sticker

195   dots digitised to enable spatial analysis in ArcGIS. Spatial data layers were obtained from local

196   councils and the Australian and New South Wales Governments including maps of public open

197   space lands, extant vegetation cover, roads and housing lots and aerial photographs. Google

198   maps, Google street view imagery, and Gregory's Newcastle Street Directory (2012) was used to

199   validate and edit council open space layers. Green space values (as indicated by marker dots)

200   were assigned to green spaces they intersected with, with a spatial tolerance of 80 m (the width

201   of the marker once assigned to the map). Address locations of survey respondents were manually

202   digitised from volunteered addresses, or in cases where this was information was withheld, the

203   nearest street corner.

204

205   For each suburb, 'heat' maps of the spatial concentration of assigned marker dots were generated

206   by creating an Inverse Distance Weighted surface to indicate locations of high value for each

207   variable of interest, using Spatial Analyst in ArcGIS. Inverse Distance Weighting determines the

208   value of a cell by interpolating values from nearby cells, with those nearer to the focal cell being

209   given greater weight than those further away. Geometric attributes of green space polygons (e.g.

210   area, width etc.) were calculated using standard Spatial Analyst tools in ArcGIS. The 'near' tool

211   was used to calculate the distance of green spaces from water bodies (sea, lakes, rivers and

212   creeks) and resident's home addresses according to the closest point of approach between these

213   features. Finally, the management categories that green spaces were classified as were assessed.

214   Because the Local Environment Plans of the two LGAs contained different green space

215   management classes, consistency between the LGAs was maintained by assigning green space

216 polygons to one of three management categories based upon the original plans (see Table 1 for

217 details of this reclassification).

218

219 **Table 1.** Management categories assigned to green spaces in the two LGAs studied.

Lake Macquarie Local Government Area	
Original Council Classes	*Classification for Analysis*
General Community	General
Natural Areas	Natural
Public Parks	General
Sportsfield	Sportsfield
Port Stephens Local Government Area	
Original Council Classes	*Classification for Analysis*
Cultural Significance	General
Foreshore	General
General Community	General
Natural Area	Natural
Sportsfield	Sportsfield
Urban Park	General

220

221 *2.4 Statistical analysis*

222 A range of statistical techniques were used to explain why green spaces varied in the number and

223 type of value marker dots. Relationships between green space characteristics and mapped value

224 markers were explored by treating the abundance of value markers within individual green space

225 polygons as the response variable, and the green space characteristics as explanatory variables.

226 The data has excessive zeros, with 100 green spaces (31%) containing no markers. Green spaces

227 that did not receive markers were on average smaller (mean = 5.26 ha, s.d. = 10.06 ha) compared

228 to those without markers (mean = 0.62 ha, s.d. = 1.48 ha), and had a smaller perimeter to area

229 ratio (without markers: mean = 11.68, s.d. = 9.93; with markers: mean = 29.98, s.d. = 24.75),

230 suggesting that smaller green spaces were less salient to respondents. The observed variance to

231 mean ratios in the number of markers also demonstrated a clear over-dispersion, ranging from

232   10.57 to 43.25 across all types of positive value makers for green spaces. A *hurdle* model was

233   deemed appropriate to deal with both these issues. Hurdle models analyse the zero and positive

234   counts separately (Zeileis, Kleiber, & Jackman, 2008) by using a binomial process to model the

235   likelihood that an observation will have a count of zero and a zero truncated distribution to

236   model the positive counts. We chose a zero truncated negative binomial regression model to

237   handle the over-dispersion. The analyses were conducted using the "pscl" package (Jackman,

238   2015; Zeileis et al., 2008) in R (R Development Core Team, 2015).

239

240   Environmental characteristics of green spaces were used as either continuous or categorical

241   independent variables in our negative binomial regression model to predict value marker dot

242   abundances. Multicollinearity was reduced by selecting environmental predictor variables to

243   include in the model using a stepwise variance inflation factor (VIF) selection process. This

244   operates in four iterative stages: (1) calculation of a VIF for each variable using the full set of

245   explanatory variables; (2) removal of the variable with the highest VIF value and recalculation

246   all VIF values with the new set of variables; (3) removal of the variable with the next highest

247   VIF value; and (4) replication of the process until all VIF values are below the threshold (5 was

248   selected as a reasonable trade-off between explained variance and model parsimony) (Beckmw,

249   2013). The set of variables selected for further modelling were: percentage of vegetation cover,

250   distance from a significant water body, area, width, perimeter:area ratio, length:width ratio, and

251   the presence/absence of a walking path.

252

253   Quadratic terms of continuous predictor variables were also included to test for non-linear

254   relationships. Suburb was included and retained as a predictive factor in all the models to

255   systematically account for any differences between the four study areas. The best models of

256   different green space values were determined through the following process: (1) a negative

257   binomial model was calculated using all predictors, (2) the variable with the highest P-value was

258   removed and the model recalculated, (3) the two models were compared using the "vuong"

259   function within the "pscl" R package, with the model with the lower AICc index retained, (4)

260   variables were sequentially dropped using this process until no further improvement in AICc was

261   found. We present only the model results for the positive counts because we are interested in

262   identifying the factors that influence the strength and type of values of green spaces that receive

263   marker dots, not the factors that determine whether or not green spaces receive marker dots at all.

264   Results of the final model were displayed by plotting predictor variable effects to allow visual

265   comparison of model differences. The influence of the green space management classification by

266   local councils (general, natural, sportsfield) on green space values was analysed in separate

267   models because it was not a physically observable variable associated with a green space.

268   Results of models with green space management classification were also displayed graphically,

269   with predicted means of value reported.

270

271   To analyse the effect of distance from home residence on the assignment of value dots, it was

272   necessary to account for the configuration of green spaces in each suburb relative to the locations

273   of the respondents. For example, if most green spaces occurred close to respondents' home

274   addresses, the distance to green spaces for each respondent would tend to be small, potentially

275   indicating a strong effect of green space distance. But this may be spurious as even if their true

276   preference had no relationship to distance (or indeed their selection of value dots was completely

277   random), respondents would likely select more green spaces close by if these were the majority

278   of green spaces to choose from. To this end, a null model of green space values was generated

279   for each suburb by randomly assigning 6 'dots' per respondent to green spaces in their suburb.

280   The distribution of the distances between these dots and their home addresses was then

281   calculated. The resulting output represented a distribution of green space distances that resulted

282   solely from the spatial locations of the respondents relative to the green spaces rather than any

283   sort of preference. This could then be compared to the real distribution from the mapped data,

284   with any difference representing the effect respondent's preferences as opposed the effect of the

285   geometry. To understand the difference between these two distributions, they were both plotted

286   as histograms. One histogram was then subtracted from the other resulting in a histogram where

287   the value of each bin represented the difference in the values for each bin of the histogram. The

288   statistical differences between the two distributions were calculated via Chi-squared tests for

289   given probabilities of histogram bins, using simulated p-value (based on 2000 replicates).

290

291   Finally, the compatibility between different green space values (defined here as the degree of co-

292   occurrence of different value marker dots in individual polygons) was explored through

293   Spearman rank correlations of the abundances of value marker dots, and by factor analysis.

294   Factor analysis of mapped value markers was performed using the 'factanal' package in R (with

295   varimax rotation), with the number of factors determined by viewing eigenvalues on a scree plot.

296

297   3. Results

298   *3.1 Mapping marker dot abundance.*

299   The four suburbs contained a total of 318 distinct green spaces, and 9,186 points were assigned

300   to them by respondents out of a total of 9,691 points assigned to the maps. The most commonly

301   assigned value marker type was "activity/physical exercise" (n = 1131) while "noisy" received

302   the fewest dots (n = 131) (see Fig. 2)
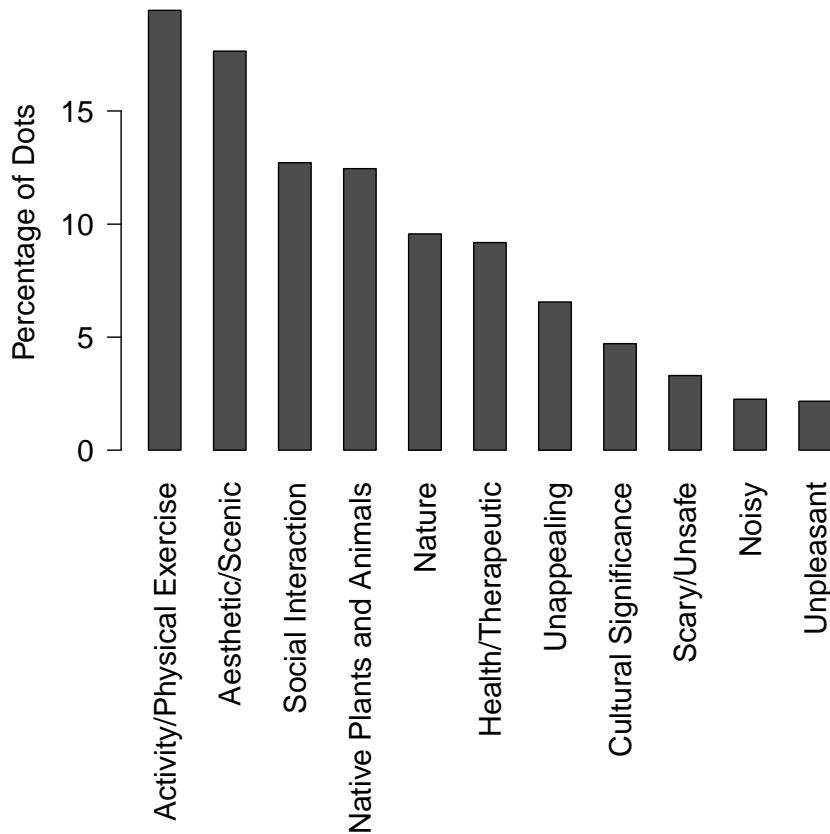
303

304   **Figure 2.** Proportion of mapped value marker dots across all suburbs.

305

306   Displaying the spatial location of value markers through the Inverse Distance Weighted surface

307   reveals substantial variability in the location of the bulk of value markers. This technique is

308   particularly useful for communicating results with landscape managers and for displaying

309   visually the differences between various value markers. Examples of this mapping can be seen in

310   Fig. 3, with a complete set of Inverse Distance Weighted maps for the 4 suburbs available as

311   supplementary material S2.

312
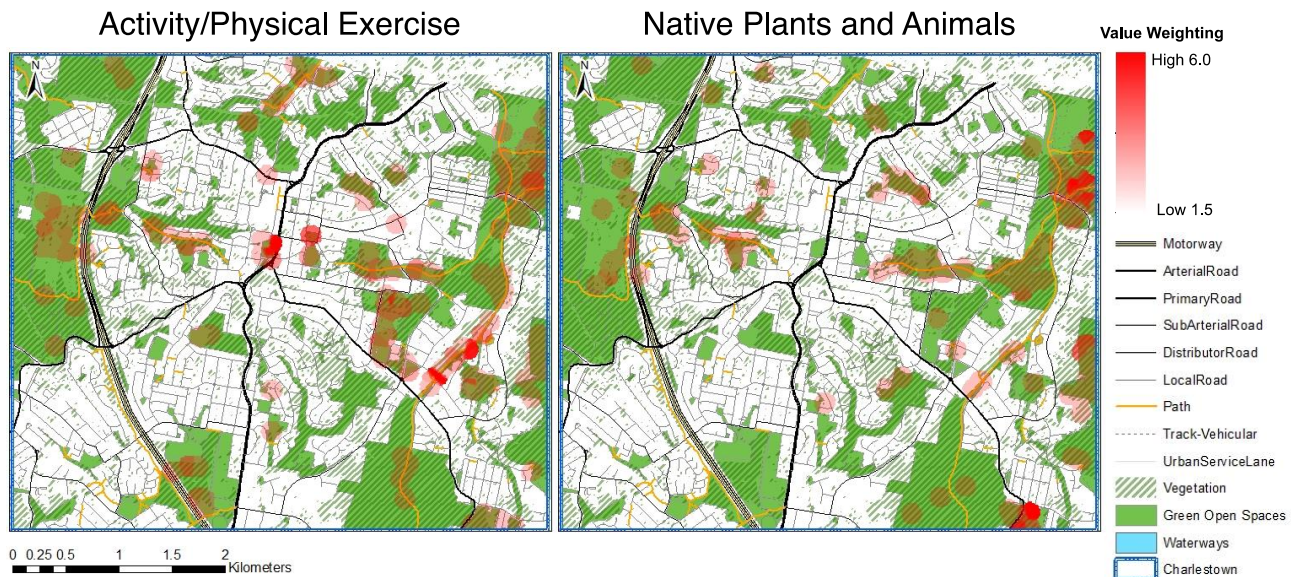
Figure 3. Inverse Distance Weighted maps of the spatial locations of mapped points, aggregated for all respondents within Charlestown. The two panels demonstrate the differences between the two value attributes. The numerical 'value weighting' score is proportional to the density of marker dots at a location.

3.2 Environmental predictors of green space values.

Multivariate modelling revealed that different mapped values were related to different green space characteristics. The final suite of variables retained in the best models according to AICc indices is shown in Figure 4 (for full model statistics, see supplementary material S3). Distance from water was the most regularly selected variable, having an important negative effect on the abundance of marker dots in a green space (higher abundances in green spaces closer to water). Many variables were found to have a non-linear effect on mapped values, as indicated by the significant quadratic terms. Suburb was found to have a significant influence on half of the measured value types, with green spaces in Charlestown found to have more mapped value dots than the others in these cases. Regarding native plants and animals and nature values, the width of a green space was positively related to the abundance of mapped dots.

Effect Size of Variables Included in Best Model (Hurdle Negative Binomial Modelling)
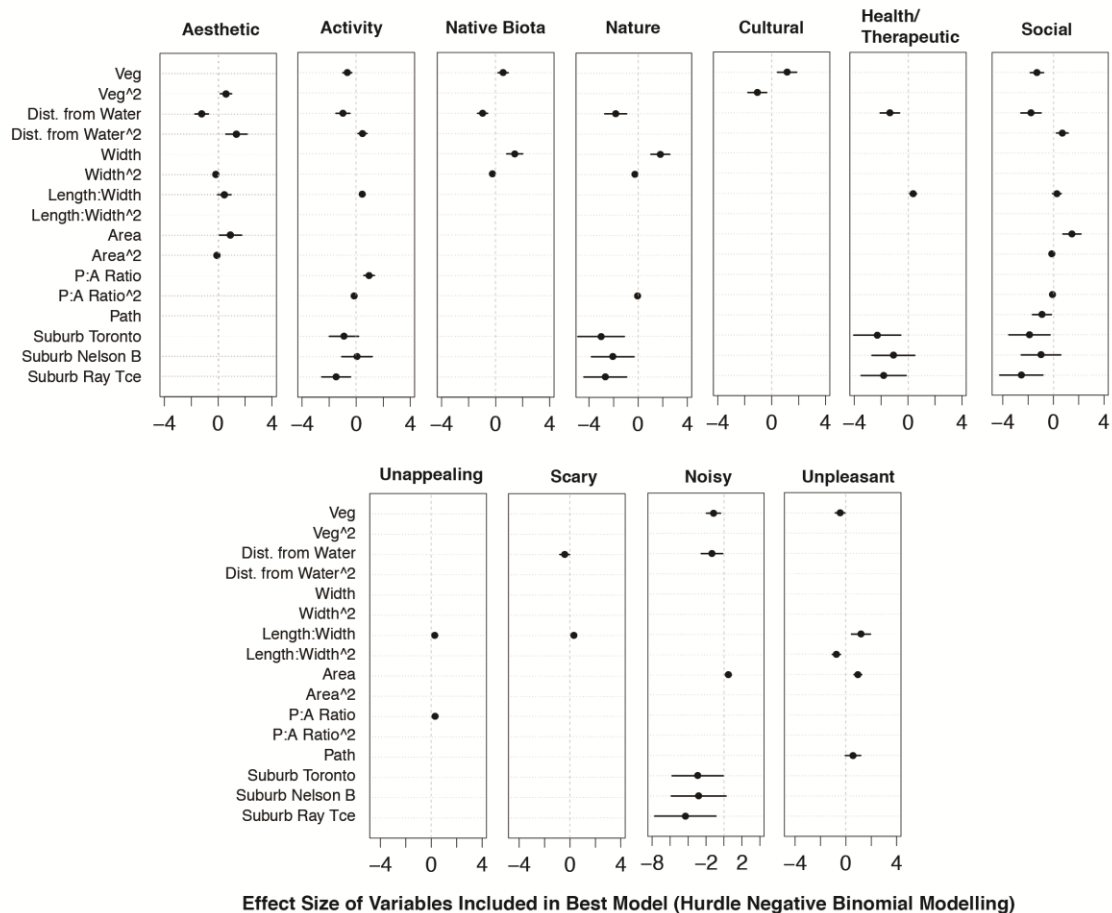
330

331 **Figure 4.** Models of the green space values (the response variable), with the effect sizes of

332 different predictor variables (shown in each row). For variables retained in the final model, the

333 mean effect size is indicated by a black dot, along with its 95% credible interval as indicated by

334 the line. Quadratic terms are denoted by ^2.

335

336 *3.3 Effect of green space type (management classification)*

337 Despite its significance for green space management, municipal planning classification was not

338 strongly related to the abundance of mapped marker dots for most values. Fig. 5 shows the

339 expected mean abundance of all values according to planning category. This analysis used the

340 same hurdle model as for other green space variables but included planning classification as the

341 only covariate (for full model statistics, see supplementary material S4). Of particular interest is

342 that green spaces designated as 'natural' areas did not have significantly more 'native plants and

343   animals' or 'nature' values assigned to them than areas designated for 'general' use, when

344   considering the mean number of value markers at individual green space level
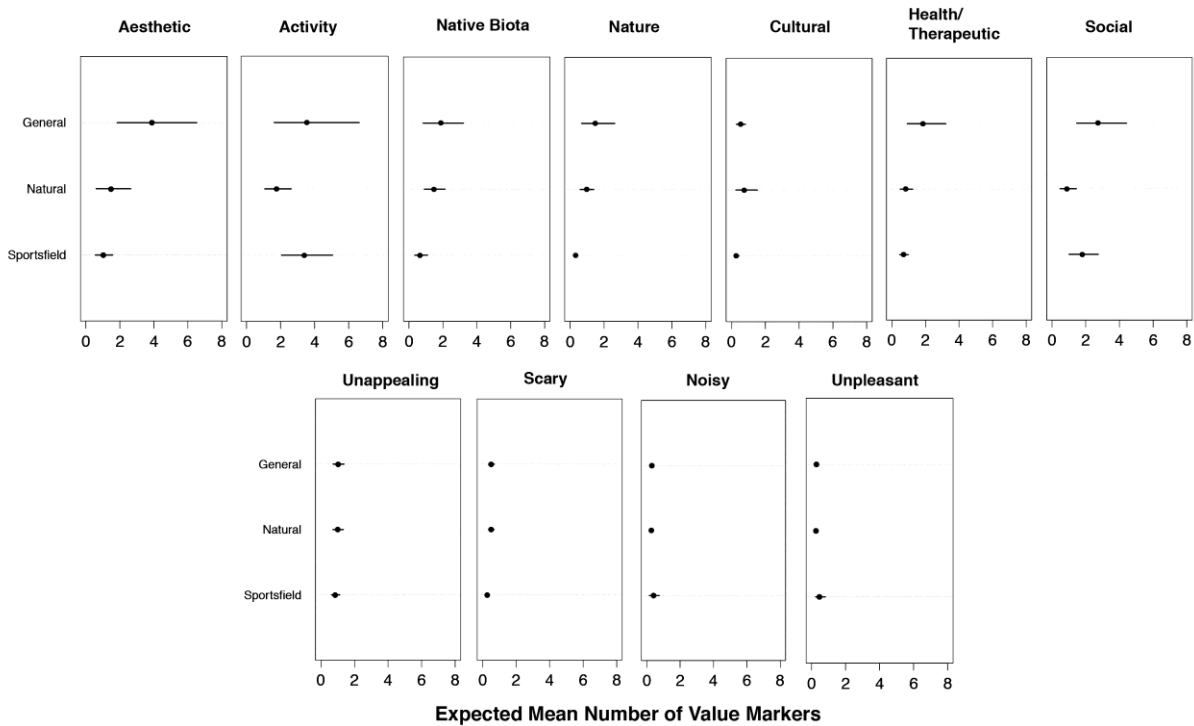

345

346   **Figure 5.** Expected mean abundance of value marker dots per green space polygon according to

347   green space management category. The black dots indicate the mean value and the lines indicate

348   the 95% credible interval.

349

350   *3.4 Distance from home*

351   Histograms of the proportion of marker dots assigned at different intervals from respondents'

352   place of residence showed peaks at between 1 km and 2 km for all suburbs (see Fig. 6, solid grey

353   bars). However, similar patterns were also observed for the randomised, null models (Fig. 6,

354   dashed bars). Chi-squared tests comparing the histogram bars of the two distributions revealed

355   that the two distributions were significantly different (Charlestown χ^2 = 398.98, d.f. = 24, P =

356   <0.001; Nelson Bay χ^2 = 2243.80, d.f. = 29, P = <0.001; Raymond Terrace χ^2 = 700.41, d.f. = 23,

357   P = <0.001; Toronto χ^2 = 1017.6, d.f. = 22, P = <0.001). Plots of the differences between

358   histogram bars for real and null distributions showed a disproportional abundance of value

359   markers nearer to place of residence for all values (particularly for distances <2 km), but this

360   pattern was relatively weak and more pronounced in some suburbs more than others (e.g.

361   Toronto) (see Fig. 6). Although some value attributes showed the strongest densities within 1 km

362   of respondents' place of residence (e.g. social interaction value), others (especially negative

363   qualities) displayed no relationship with distance from home (see supplementary material S5).

Charlestown, All Values

Toronto, All Values

Raymond Terrace, All Values

Nelson Bay, All Values
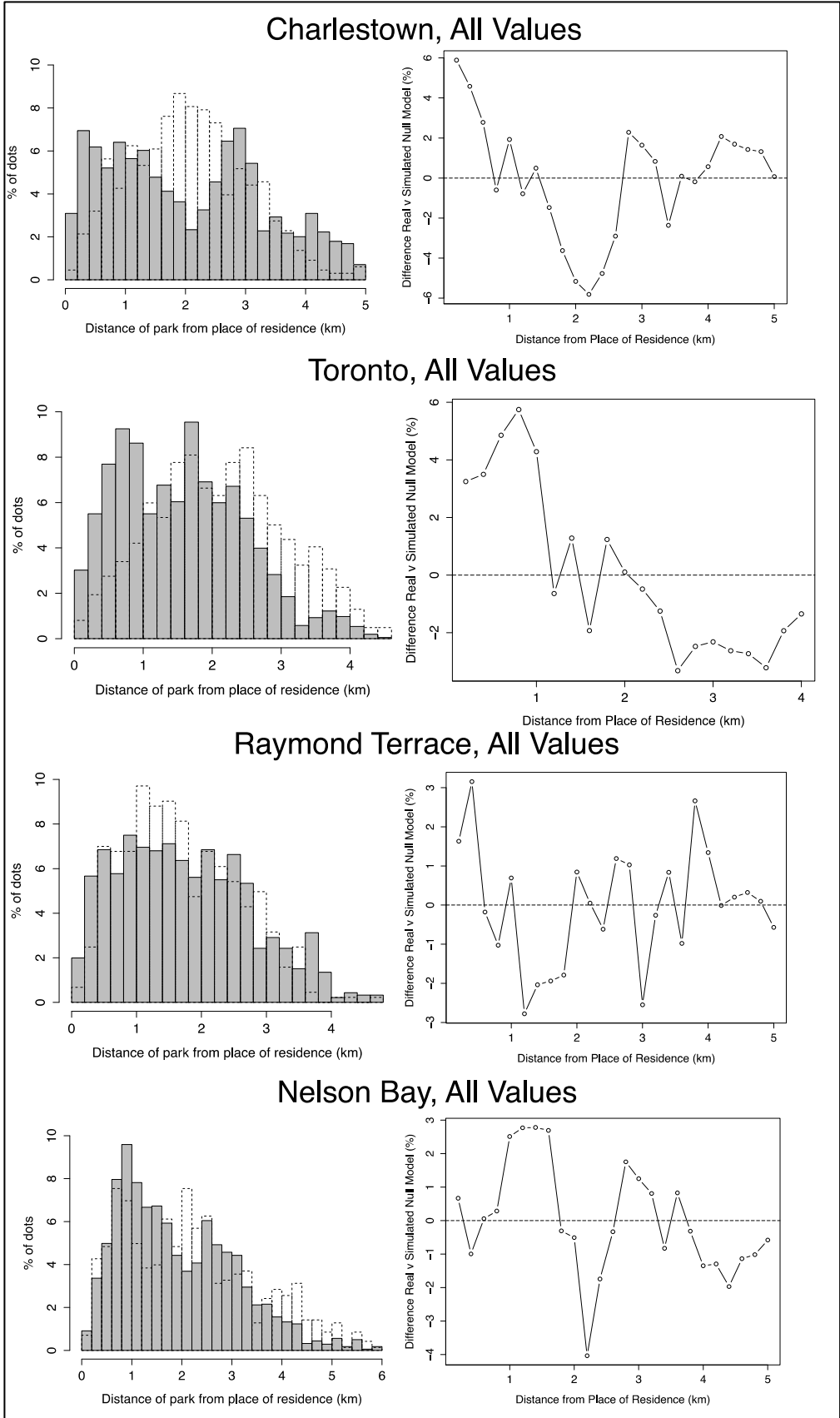
365 **Figure 6.** Plots of the association between assigned values (all marker dots) and distance from

366 place of residence. Histograms on the left-hand side show the proportion of marker dots at

367 different distances from respondents' place of residence. Differences between real and null

368 models (see methods) can be seen by comparing the solid grey bars (real data) with the dashed

369 bars (null models). Plots on the right-hand side show the difference between real and null-models

370 for the proportion of marker dots.

371

372 *3.5 Values compatibility.*

373 Some pairs of values were found to be more compatible (tended to co-occur in green spaces)

374 more than others. Some of the highest compatibility scores from the Spearman rank correlation

375 analysis were between Aesthetic & Health/Therapeutic Value (Spearman's $\rho = 0.714$; $P <$

376 0.001), Native Plants/Animals & Nature Value ($\rho = 0.745$; $P < 0.001$), Activity/Physical

377 Exercise & Social Interaction Value ($\rho = 0.674$; $P < 0.001$), Activity/Physical Exercise &

378 Health/Therapeutic Value ($\rho = 0.681$; $P < 0.001$), and Native Plants/Animals &

379 Health/Therapeutic Value ($\rho = 0.572$; $P < 0.001$). Factor analysis of mapped values identified

380 three factors with eigenvalues >1 (see Table 2). These correlations are confirmed, with the first

381 factor receiving highest loadings of nature and culture values, the second health and activity

382 values, and the third negative values. Interestingly, the fact that some green spaces are

383 considered noisy does not seem to compromise their activity, social interaction or health values

384 (see factor 2). In contrast, the other negative qualities all loaded on a single factor, suggesting

385 that these rarely are found alongside other values in green spaces.

386

387

388 **Table 2.** Exploratory factor analysis of mapped values, with loadings >0.4 reported. Although
389 there is some overlap of values between factors, the factors help identify values that tend to co-
390 occur in green spaces.

	Factor 1	**Factor 2**	**Factor 3**
Aesthetic	0.618	0.697	
Activity	0.416	0.774	
Native plants and animals	0.928		
Nature	0.938		
Cultural significance	0.662		
Health	0.629	0.722	
Social interaction		0.895	
Unappealing			0.760
Scary or unsafe			0.777
Noisy		0.424	
Unpleasant			0.441
Loadings	3.286	2.858	1.813
Proportion variance	0.299	0.260	0.165
Cumulative variance	0.299	0.558	0.723

391

4. Discussion

393 In this study we sought to understand how people in a rapidly urbanising region assign value to

394 green spaces and assess the influence of environmental variables on these values. These insights

395 are important for building the evidence base from PPGIS research methods that are increasing in

396 popularity. In particular, our study can provide guidance on how statistical methods can be

397 appropriately applied to PPGIS data. Further, given some continuing resistance to the use of

398 PPGIS methods by planning practitioners (Brown, 2015) a key research question of this study

399 was to explore useful insights into how PPGIS assessment of green spaces can be applied in

400 practice. These issues are discussed in turn below.

401

402 *4.1 The impact of environmental variables on values for green spaces.*

403   The values people assigned to green space were very positive overall, with comparatively few

404   marker dots assigned that denoted negative qualities. This was true regardless of the type of

405   management applied to the green spaces (Fig. 5). Although ambivalent attitudes towards urban

406   green space have been observed (e.g. Bonnes, Passafaro, & Carrus, 2010), our result is consistent

407   with the bulk of research that has shown green environments are generally perceived positively

408   (Kellert & Wilson, 1995). For example, Kyttä *et al*. (2013) in their study of urban landscape

409   values in Finland found that 80% of value markers placed in green spaces denoted positive

410   attitudes.

411

412   The specific values assigned to green spaces were varied and responsive to a multiple

413   environmental variables. This suggests that people interact with landscapes in complex ways and

414   assign a plurality of values to them for different purposes, a result that has been found in other

415   landscapes (Ives & Kendal, 2013; see Purcell, Lamb, Mainardi Peron, & Falchero, 1994). We

416   encourage planners to consider the heterogeneity of green space values and stress that green

417   space networks for urban populations will require a 'portfolio of places' (Swanwick, 2009).

418

419   For many value attributes, green spaces closer to water bodies were valued more strongly than

420   those further away (see Fig. 4). This finding is consistent with most of the literature on public

421   preferences for landscapes (Swanwick, 2009), with people's affinity for water explained by the

422   theory that it enhances the perceived orderliness and naturalness of a scene (Kaplan & Kaplan,

423   1989), as well as adding to the coherence of a landscape (Litton, Tetlow, & Sorensen, 1974).

424   However, there is evidence that preferences for waterscapes can differ according to type and

425   context (Herzog, 1985). For example, a study in Victoria, Australia recently found that the public

426   distinguished between six categories of wetlands according to the amount of water visible,

427   presence of trees, water quality and habitat value (Dobbie & Green, 2012). Further, the literature

428   on 'ecological aesthetics' suggests that public preferences to landscapes is the result of a

429   combination of landscape features and individual factors like knowledge, values and attitudes

430   (Gobster, Nassauer, Daniel, & Fry, 2007). Given the high compatibility observed between

431   aesthetic values and other values (Table 2), it is likely that the visual preferences for green

432   spaces near water lead to the assignment of other values in these places. There is therefore

433   potential to include additional analysis of water body type and individual psychological factors

434   in future PPGIS studies.

435

436   The proportion of vegetation present in a green space was related to the abundance of marker

437   dots for many value types (Fig. 4), yet the nature of its influence varied. For native plants and

438   animals, the relationship was a positive one, for social interaction values a negative relationship

439   was observed, while a quadratic relationship was found for aesthetic values (Fig. 4). The factors

440   behind the effect of vegetation on mapped values are likely to be highly complex, but some

441   existing theories and recent empirical studies can provide insight. We suggest that the

442   relationship between vegetation cover and mapped values may reflect landscape preference,

443   environmental perception, mental restoration, and the suitability of spaces for certain activities.

444   Recent research elsewhere from Brisbane, Australia, found that visitation of green spaces peaked

445   at intermediate levels of vegetation cover (Shanahan, Lin, Gaston, Bush, & Fuller, 2015); a

446   pattern they attributed to theories that landscape preference is highest in savannah-type

447   landscapes (i.e. the information processing theory: Kaplan & Kaplan, 1989). The positive effect

448   of vegetation on mental restoration has also been shown in a number of studies. For example,

449   Nordh *et al.* (2009) showed greater likelihood of restoration in green spaces with increased cover

450   of trees and bushes, and Peschardt and Stigsdotter (2013) found that the 'natural' components of

451   urban green spaces (e.g. unstructured vegetation) were particularly important for increasing

452   perceived restorativeness in stressed individuals. The positive relationship between assigned

453   values for native plants and animals and vegetation cover is as would be expected, since people's

454   perception of biodiversity has been shown to relate strongly to vegetation cover (Dallimer et al.,

455   2012), even though this does not always align with scientific measurements of biodiversity such

456   as species richness. While there are many plausible theories that explain the results we have

457   observed, there is a need for greater exploration in future research of the specific mechanisms

458   that give rise to the observed mapped values.

459

460   Local governments in Australia regularly categorise green spaces according to their intended

461   purpose or use. Our study showed that in our case study areas, these categories had little to no

462   bearing on the abundance of value markers found in specific green spaces (Fig. 5). In particular,

463   we observed no statistical difference in the average abundance of marker dots for nature values

464   or native plants and animals values between green spaces designated as 'natural areas' and those

465   for 'general use' (Fig. 5). Our results suggest that formal categories may not have a strong

466   influence on the perceptions of local residents. This may either be because residents simply do

467   not strongly distinguish between these classes when valuing green spaces, or because residents

468   have little knowledge of the official designated purposes of the green spaces. Determining which

469   of these is the more accurate explanation is an area for future research. In terms of biodiversity

470   conservation, our findings present an opportunity for management agencies to maximise

471 biodiversity across the whole landscape rather than focussing exclusively on formal nature

472 protection areas since residents value nature on all different kinds of green spaces.

473

474 Distance from place of residence did not have a clear relationship to the assignment of values to

475 green spaces, after accounting for landscape configuration (Fig. 6). Although distance from

476 home has been found to be an important factor influencing green space visitation (Neuvonen,

477 Sievänen, Tönnes, & Koskela, 2007; Shanahan et al., 2015), it appears that landscape values, at

478 least in our case study, are quite different constructs and are less strongly influenced by spatial

479 proximity. The established theory of geographic or spatial discounting of values (Norton &

480 Hannon, 1997) supposes that PPGIS respondents will place disproportionately more markers

481 closer to their home than more distal locations, as has been empirically shown by Brown et al.

482 (2002). Although this pattern can be seen in the suburb of Toronto, it was not evident for the

483 other suburbs. Thus, our analysis highlights the importance of accounting for the spatial bias in

484 the locations of landscape features (for example via simulation) in order to further explore the

485 spatial discounting hypothesis in relation to PPGIS.

486

487 Finally, we found that the compatibility between different value types (based on their co-

488 occurrence in green space polygons) varied substantially between value types. The highest

489 compatibility observed was between 'native plants & animals' and 'nature' values, suggesting

490 that sampled residents do not distinguish substantially between these two concepts in the

491 Australian context. Further, high compatibility was also observed between 'native plants &

492 animals' and 'health/therapeutic' values. Interestingly, in their study of public perceptions of

493 urban biodiversity, Voigt and Wurster (2015) found that 'diversity' was used to express a sense

494   of well-being rather than an assessment of biological diversity or importance. This suggests that

495   there is a need for further research into what people are actually mapping when indicating

496   'nature' or 'biodiversity' values in PPGIS studies, but may also help to explain the compatibility

497   between nature and health values. Nevertheless, our results suggest that there is real potential for

498   green space planners and managers to improve both biodiversity conservation and public health

499   outcomes simultaneously (Lachowycz & Jones, 2012; Lee & Maheswaran, 2011).

500

501   *4.2 PPGIS in practice*

502   In considering how the insights from this study should be applied to planning practice, it is

503   useful to recognise the different scales at which research and planning practice can be reconciled

504   as proposed by Lindholst *et al.* (2015). First we consider applying insights at the policy level (i.e.

505   deriving general principles for planning green space), and second at the applied level (by

506   providing guidance for practitioners considering using PPGIS in a local context).

507

508   *4.2.1 Green space planning principles*

509   According to the landscape character variables retained in our models of green space values (Fig.

510   4), our results suggest that when designing new green space networks, priority should be placed

511   locating green spaces near water bodies where possible and ensuring green spaces are

512   sufficiently large for meaningful social interaction. Managers of existing green spaces should

513   seek to promote multiple values simultaneously in individual green spaces regardless of their

514   management category (Fig. 5). Based on the value compatibility assessment (Table 2), some

515   values may be promoted alongside one another more easily than others (e.g. health and social

516   interaction, or nature conservation, aesthetics and culture). Practitioners should therefore

517 carefully plant and maintain vegetation in ways that are visually appealing and help to promote

518 biodiversity (Ives & Kelly, 2016). Of course, applying these general principles is only one

519 element of good planning practice; practitioners should also seek to engage the community and

520 encourage participation in the decision-making process, as difficult as this process can be

521 (Chiesura, 2004). Indeed, the effect of 'suburb' on some of our models of open space values

522 (namely activity value, nature value, health/therapeutic value, social interaction value, and noisy;

523 see Fig. 4) suggests that the valuation of green spaces may be influenced by unique demographic

524 and environmental characteristics of specific areas. It is imperative therefore that planners

525 supplement any general principles with knowledge of the needs specific to a region.

526

527 *4.2.2. Guidance for practitioners applying PPGIS*

528 Many methods exist for public communication, consultation and participation, each with

529 strengths and weaknesses depending on the decision-making context (Reed, 2008). We consider

530 PPGIS to be a useful complement to existing methods for engaging communities in urban green

531 space planning. PPGIS is more participatory than approaches that emphasise information

532 dissemination such as town hall meetings or leaflets, more representative than charettes or

533 community planning forums, more spatially nuanced than public surveys, and more quantitative

534 than focus groups. Yet the mass collection of quantitative data can also mask certain issues and

535 subtle complexities that emerge through more deliberative, qualitative methods. PPGIS is

536 therefore likely to be a useful tool that builds upon existing understandings of the social-

537 ecological landscape and feeds back into the planning process in order for a just and sustainable

538 outcome to be reached.

539

540   Our study identified a number of potential challenges and pitfalls that need to be considered by

541   urban landscape managers and planners seeking to apply PPGIS methods in a specific context. In

542   their study of participatory green space planning processes in Finland, Kahila-Tani *et al.* (2016)

543   noted that "though planners found the collected data and the analysis valuable, they still lacked

544   the skills and institutional motivation to use the data effectively" (p. 195). Below we provide

545   guidance along these lines that could assist urban planners in implementing PPGIS methods.

546

547   *4.2.2.1 Evaluation of PPGIS design and analysis choices*

548   If PPGIS data are used to inform decision-making, it is critical that they are accurate and reliable.

549   This study has identified a number of issues that need to be considered. First, it is important that

550   the sample frame is an accurate representation of the broader population's spatial, temporal and

551   socio-demographic variability. We strove to ensure a representative sample of participants, yet

552   even with appropriate survey design and administration measures taken we found some

553   demographic bias in our data. This has potential to overemphasise the importance of certain

554   values and places since different demographic groups interact with landscapes in different ways

555   (e.g. parents valuing safe areas for children to play). Any such bias should be recognised when

556   applying results to planning practice. Second, the spatial arrangement of respondents and

557   landscape features can impact results and their interpretation. By accounting for the relative

558   spatial distribution of green spaces to the respondents in our study areas, we found that the

559   distance of a green space from participants' place of residence did not have a strong effect on

560   marker abundance (Fig. 6). Failure to account for the relative locations of green spaces and

561   respondents could in many cases lead to inaccurate conclusions about how distance impacts

562   values, yet this kind of analysis is not a simple exercise for many management agencies. Finally,

563   PPGIS studies are normally conducted at a single point in time. They typically do not capture

564   how people's values for landscapes change temporally in response to seasonality, change in life

565   circumstances, or landscape modification. Although a recent study found an overall consistency

566   in the values for an Alaskan national forest indicated via PPGIS mapping over a 14 year time

567   period (Brown & Donovan, 2014), this is a topic that has received little attention in the literature

568   and is in need of further research, particularly in regards to individual responses and the

569   psychological antecedents of value assignment.

570

571   Another challenge in undertaking effective PPGIS research for green space planning is the

572   resources (time, money, expertise) it requires. Using physical paper maps is known to generate

573   higher response rates than online PPGIS methods (Pocewicz, Nielsen-Pincus, Brown, &

574   Schnitzer, 2012), yet printing and postal costs can be prohibitive for many small municipalities.

575   The substantial time taken to digitise markers and analyse responses may also be problematic if

576   it exceeds the personnel time allocated by management agencies for community engagement. A

577   related challenge is ensuring agencies have the appropriate expertise (particularly statistical)

578   required to appropriately analyse and interpret results. We encourage the continuing

579   development of new methods to engage citizens using new technologies (e.g. smartphone apps)

580   and assist practitioners in data analysis as a way of helping to meet these challenges.

581   Additionally, if limited analytical skills are available, it may be more appropriate to simply use

582   visualisations of mapped values to identify immediate management priorities or issues rather

583   than seeking to extrapolate results to more generalised principles.

584

585   *4.2.2.2 PPGIS in the context of different green space planning models*

586   Planning for green space is a complex process that brings together various social, environmental

587   and political considerations. Although the specifics of the planning process varies across

588   different places and times, Maruani and Amit-Cohen (2007) identified five general open space

589   planning models that have been applied in an urban context. In brief, these are (i) opportunistic

590   (random allocation of land for open space according to availability), (ii) space standards

591   (providing minimum area of open space for a given population), (iii) park systems (interrelated

592   parks and gardens), (iv) garden city (a comprehensive approach based on Ebenezer Howard's

593   principles), and (v) shape related models (such as green belts or green wedges). We suggest that

594   PPGIS can help transition urban green space planning from traditional standards-based or shape-

595   based planning models to a participatory, 'needs-based' planning approach: one that accounts for

596   a population's "socio-demographic composition, their leisure and recreation preferences and

597   those of various sub-groups" (Byrne & Sipe, 2010). Yet there is still some work needed to

598   mainstream new deliberative-analytic processes in green space planning (Kahila-Tani et al.,

599   2016). Combining PPGIS with other participatory tools for stakeholder engagement is likely to

600   help overcome some of the methodological challenges discussed above and aid the inclusion of

601   citizens' epistemological and ontological diversity (Kahila-Tani et al., 2016; Nahuelhual, Benra

602   Ochoa, Rojas, Díaz, & Carmona, 2016).

603

5. Conclusion

605   This study has demonstrated that public values for green space are varied and respond in

606   different ways to different suites of environmental variables. While some environmental

607   variables seemed to exert a consistently positive effect on all environmental variables (e.g.

608   distance from water), other variables (e.g. vegetation cover) were related only to a few value

609   types. Further, existing management categories were shown not to have a strong bearing on the

610   kinds of values people assign to green spaces. This research reveals a complex picture of how

611   different values are assigned to green spaces, and highlights the need for green space planners to

612   avoid the 'one size fits all' approach to the design of green space networks. We encourage

613   planners to pursue participatory techniques such as PPGIS as a means of ascertaining the values

614   and preferences of the urban public and planning for these accordingly. Yet we also emphasise

615   the need for careful consideration of the design and analysis of these methods to ensure that the

616   data used to inform decisions are accurate and reliable.

617

625

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