Title

Development of the Natural Environment Scoring Tool (NEST)

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Citation:

Gidlow C, van Kempen E, Smith G, Triguero-Mas M, Kruize H, Gražulevičienė R, Ellis N, Hurst G, Masterson D, Cirach M, van den Berg M, Smart W, Dėdelė A, Maas J, Nieuwenhuijsen M. Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, 2018, 29, p.322-333

Abstract

Natural environments (green and blue space) are associated with a range of health benefits, but their use is likely to be influenced by the presence of features, facilities and amenities and the condition/maintenance, or the natural environment ‘quality’. Most ‘quality’ assessment tools have focused on green spaces and their support for physical activity. This limits their utility for assessment of other natural environment typologies and uses (e.g., social, relaxation). We aimed to develop a tool for feasible, in situ assessment of diverse natural environments that might support a variety of uses, and to explore associations between natural environment quality and objectively measured amount of natural environment and neighbourhood-level socio-economic status (SES).

This work was conducted as part of the PHENOTYPE project. Data were collected in 124 neighbourhoods in four European cities (Barcelona, Doetinchem, Kaunas, Stoke-on-Trent). The Natural Environment Scoring Tool (NEST) was developed using existing tools, expert input and field-testing. The final tool comprised 47-items across eight domains: *Accessibility*, *Recreation facilities*, *Amenities*, *Aesthetics – natural*, *Aesthetics – non-natural*, *Significant natural features*, *Incivilities* and *Usability*; typology-specific *Overall Scores* were derived.

In total, 174 natural environments, covering a range of typologies, were audited. Mean time to complete NEST was 16±28 minutes. Inter-rater agreement appeared good. Mean domain scores showed some expected patterns by typology (e.g., higher *Recreation Facilities* scores in urban parks and formal recreation areas; lower *Amenities* scores in natural/semi-natural areas). Highest mean *Overall Scores* were observed for areas of blue space and woodland, the types of area that often lack the recreational facilities or amenities that can be dominant in physical activity-focused audit tools. There was a trend towards lower natural environment quality in neighbourhoods of lower SES, with some inter-city variation. Correlations between NEST scores and amount of natural environment indicated higher natural environment in areas with worse access. We recommend further testing of NEST in other locations in relation to use and health outcomes.

Highlights

- NEST offers a feasible means of quality assessing a range of natural environments
- Expected variation was seen in domain scores across natural environment typologies
- Higher quality was associated with lower GIS-measured amount of natural environment
- Trend towards lower natural environment quality in lower SES neighbourhoods

Key words

Audit, Green space, Environment, Landscape assessment, Natural environment, Quality, Health

1. Introduction

1.1 Defining the research area

This paper reports the development of a tool to measure the *quality* of *natural environments* and its testing in different European cities. As potentially ambiguous concepts, it is important to define *quality* and *natural environments* in the context of this study. As Hartig et al. [1] described, *nature* refers to physical features and processes of nonhuman origin, whereby *natural environment* suggests an environment with little or no evidence of human presence or intervention. Yet, in this study and most research in the natural environment/health arena, the nature of interest is often situated in urban areas (e.g., urban parks, canals). Whilst acknowledging the potential for different interpretations across related disciplines (e.g., ecology, landscape architecture, planning, physical activity), we use natural environment (also referred to as natural outdoor environments, NOE) as a catchall term for green and blue space, which is often located (and created by humans) in urban areas.

The interpretation of natural environment *quality* might also vary between contexts and disciplines. There is growing recognition that living in areas with more natural environments can benefit health [1] and some indications from epidemiological and experimental studies that visiting/using natural environments is beneficial, particularly for mental health [2–6]. We were, therefore, interested in attributes that encourage or discourage people from visiting natural environments for any reason or type of use (e.g., social, relaxation, family activities). As such, quality was considered, in terms of the presence/absence of features (natural and non-natural), facilities and amenities, and the maintenance or condition of the environment, which determine fitness for purpose [7]. Central to this work was the need to accommodate a diverse range of natural environments across different European cities. This required development of a tool that allowed quality judgements appropriate to the type of natural environment and that would not favour certain types of natural environment (e.g., a tool focused on physical activity facilities would not be appropriate to assess a conservation area or woodland).

1.2 Measuring natural environment quality

There is a growing literature linking natural environment exposure and health [1], yet, natural environment quality is not always measured [8–10]. More commonly, Geographical Information Systems (GIS) or resident surveys are used to measure amount of, or access to natural environments, sometimes taking into account the typology and purpose [11,12]. Where quality has been measured, associations with health have been mixed, as have the approaches to quality assessment [13–15]. Methods have included using secondary land survey data in GIS to estimate green space qualities posited as important for use [15]. Remote quality assessment using Google Earth has also been applied in physical activity research [16,17]. Others have relied on surveys with local residents or users of the natural environment to capture perceived quality [13,18,19].

The present study used in situ audits to provide an objective measure of quality. This approach has some advantages [20,21]. GIS natural environment exposure indicators usually offer limited insight into the presence/absence/quantity of features or facilities, or condition of the environment because such data are rarely collected routinely. Remote audit methods can miss important context and transient detail, such as the presence of litter and the condition of facilities and amenities. Perceptions of local residents or users of natural environments can be useful for identifying features that will influence use, but these perceptions are specific to the individual and, if collected from users of a natural environment, are unlikely to be representative. Qualitative data have highlighted that perceptions of natural environments can vary between groups and individuals [22,23]. For example, older people might perceive a park as unsafe due to the presence of young people, who, in turn, have very different views of the same space [22]. Collectively, these points highlight a role for in situ assessment of natural environments objectively capture features, facilities/amenities and environmental condition, that can indicate fitness for purpose and, in turn, the likelihood of use by local residents.

1.2 A review of in situ quality assessment of natural environments

In situ assessment (or audit) involves one or more individuals scoring the natural environments against various criteria. This usually takes the form of a list of items grouped into domains, which can include accessibility (and surrounding area), recreation facilities, amenities, aesthetics, signage, incivilities (e.g., litter, noise, graffiti), maintenance and safety [24–27]. Building on an earlier review [20], we summarise existing in situ quality audit tools in terms of their purpose and composition (Table 1).

Physical activity-specific audit tools

Many natural environment audit tools have come from physical activity research, often with a focus on parks and the extent to which they support physical activity (e.g., [24–31]). Focusing on one natural environment typology (parks) and one type of use (physical activity) is conducive to standardising the features, facilities and amenities to be considered (e.g., children's play equipment, sports pitches, footpaths). This specificity perhaps affords greater reliability and validity in measurement. However, as noted elsewhere [20,32], instruments that primarily consider facilities in the context of physical activity support, might overlook natural and man-made features that support other types of activity (or use).

When considering a wider range of attributes that might encourage people to use different types of natural environment for a range of activities, we required a tool that would not give undue credence to facilities and amenities that support physical activity. Doing so would discriminate against natural environment typologies with different, but important attributes that attract users (e.g., country parks, beaches, forests).

Audit tools for other types of natural environment

Some in situ audit tools were relevant to our aims, in terms of their ability to accommodate different natural environment typologies or uses (i.e., not physical activity-focused). Van Dillen et al. [14] used a 10-item tool to capture urban green space quality on the basis that aesthetics were necessary for restorative benefit and to attract visitors. Using just one item for each of 10 relatively broad constructs had the advantage of low burden and rapid completion. Some items were common to those mentioned above (e.g., accessibility and maintenance). Others, such as *variation*, *clear*, *general impression* were perhaps open to interpretation, which could be problematic in studies with multiple assessors, languages and cultures.

The Public Open Space Tool (POST) was developed in Australia [33] and adapted for use in New Zealand [34]. Despite having a physical activity focus, the range of items, such as location on a beach/river foreshore, presence and coverage of trees, and presence/type and coverage water features, make POST amenable to assessment of natural environments other than parks or formal recreation areas. An overall score is not derived from POST data; rather, domain sum scores are generated.

Voigt et al. [32] developed an approach to assess urban parks in Berlin and Salzburg. Despite the focus on parks, the premise of including three dimensions that could affect visitors' perceptions and activities (biotic, abiotic, infrastructure facilities) was consistent with our aims.

It could not inform this study as it was published after NEST development and combined data from in situ assessments, user surveys and GIS.

The Neighbourhood Green Space Tool (NGST) [20], a feasible, standalone in situ audit tool, was developed to capture factors that would influence use of green space by local residents; this was consistent with our aims. It was developed using a combination of qualitative and quantitative methods and has shown inter-rater reliability that compared well with other tools. However, it was originally was developed for green space assessment and was, therefore, not ready for application across a range of natural environment typologies.

Considerations for NEST development

Based on tools available for in situ natural environment assessment, there were some important considerations for NEST development. First, physical activity-focused tools would disadvantage other types of natural environment that might be fit for purpose, but lack traditional sport/recreation facilities (e.g., woodlands, rivers, canals or conservation areas). Second, some more comprehensive tools that allow a broader focus often comprised many items and, for large areas, could require splitting in to zones (e.g., [28]), reducing feasibility. Third, the importance of the natural (or biotic) features is recognised, but so too are the difficulties around species identification and other aspects of ecology assessment [35]. To develop a tool that was feasible and did not require assessors with specific skills/knowledge, similar to Voigt et al. [32], we considered natural features on a more structural level.

Finally, among the domains common in existing audit tools (Table 1), some are conducive to objective measurement as they require assessment of the presence/absence, adequacy or condition of specific features (e.g., accessibility, recreation facilities, signage and incivilities).

Others, such as aesthetics, maintenance, safety and overall impression involve a greater degree of subjectivity and risk double counting if used within a composite quality score (i.e., including specific indicators and global assessor rating of a given construct). We aimed to score overall quality through a composite of items (grouped in to domains) that might influence use and that are conducive to reliable and objective assessment. By assessing the adequacy and/or condition within each domain, we could negate the need for separate domains, such as condition, maintenance and overall impression, which can be more subjective.

1.3 Inequalities in natural environment accessibility and quality

Understanding potential socio-economic inequalities in natural environment provision is important given their health-promoting potential. Higher levels (or accessibility) of neighbourhood green space has been linked with lower socio-economic inequalities in mortality [36] and mental well-being [37], and beneficial green space-health associations are often strongest in the most deprived groups (e.g., [8,38,39]).

Evidence of socio-economic differences in access to natural environment is somewhat mixed. Data from England have indicated that, nationally, the amount of green space is lower in more deprived areas [40,41]. Similar patterns have been reported in studies from North America [42], New Zealand [43] and for park access in North American research [44–46]. However, others have observed that such associations are in the opposite direction [47] or absent [48,49].

As noted above, quality is less studied, and often limited to assessment of how well parks support physical activity. Here, socio-economic patterning in park quality is inconsistent. There is evidence of lower quality in more deprived areas (in Melbourne, Australia [50]; Missouri, North America [51]); that income and park quality are not associated [52]; and that the presence and direction of such associations differ by region [53,54]. There is a relative dearth of evidence of such patterns beyond the park context and from Europe.

1.4 Natural Environment Scoring Tool

The aim of the Natural Environment Scoring Tool (NEST) was to provide a feasible means of in situ quality assessment of a range of types of natural environments in different European cities. Using the definitions in 1.1, this can be considered as an audit of green and blue spaces based on the presence/amount and condition of various features, amenities and facilities, which inform judgements about fitness for purpose.

This work was conducted as part of the European 7th Framework-funded Positive Health Effects of the Natural Outdoor environment in TYpical Populations in different regions in Europe (PHENOTYPE) project [55]. PHENOTYPE's overarching aim was to explore mechanisms behind the natural environment-health association in different regions of Europe; specifically in four diverse European cities Spain (Barcelona), Netherlands (Doetinchem), Lithuania (Kaunas) and United Kingdom (Stoke-on-Trent/Newcastle-under-Lyme). As reported elsewhere, within each city, detailed individual-level data on health, health behaviour, socio-demographics, use and perceptions of natural environments were collected for residents of approximately 30 neighbourhoods [55,56]. As part of a comprehensive approach to characterising natural environment exposure within those neighbourhoods, we developed the NEST.

The aims of this paper were: (1) to describe the development and utility of NEST for assessing diverse natural environments in different European cities; (2) to investigate the association between quality of natural environments and the amount of, and access to, natural environments; (3) to investigate the relationship between neighbourhood socio-economic status and natural environment quality.

2. Materials and Methods

2.1 NEST development

Our review did not identify a natural environment audit tool that could accommodate the diversity of green and blue spaces, within and between different European cities, without adaptation. We, therefore, chose to adapt the Neighbourhood Green Space Tool (NGST) [20] for several reasons: it was designed for simple, feasible in situ assessment; its development involved qualitative and quantitative methods to identify factors that would influence use of natural environments by local residents; inter-rater reliability compared well with other tools; domain scores are used to derive an overall quality score. As NGST was developed for green space assessment, it was necessary to adapt the composition and structure for use in a range of green and blue spaces.

The development and testing process is summarised in Figure 1. Using NGST as a basis and with expert input from PHENOTYPE consortium members (CG/GS/NE, Stoke-on-Trent; EvK/JM/MvdB, Doetinchem; MTM/MC, Barcelona; AD/RG, Kaunas), items were amended and added to accommodate a greater range of natural environments. Where possible new items were adapted from existing tools [24,28,33]. The 36-item, 6-domain NGST was augmented to create a 59-item, 8-domain provisional NEST. This was used to audit natural environments (see 2.2-2.3). Through the process below (2.3), it was reduced to 47 items grouped into eight amended domains (see Supplemental file S1 and S2): Access (AC); Recreational Facilities (R);

Amenities (AM); Aesthetics - Natural (NA); Aesthetics - Non-natural (NN); Incivilities (IN); Significant Natural Features (NAsig); Usability (US).

2.2 Neighbourhood and natural environment sampling

Sampling for the main PHENOTYPE project is reported in more detail elsewhere [56]. Briefly, 30 spatial units/neighbourhoods that varied in accessibility to green space and social economic status (SES) were selected in each city (34 in Doetinchem; total 124). To ensure variability in available green space, neighbourhoods were categorised into quintiles based on the average distance between all residential addresses in the neighbourhood to the nearest green space (≥1 hectare) using Urban Atlas, which includes green urban areas, agricultural and semi-natural areas , wetlands and forests. To ensure neighbourhood variability in SES, city-specific data were used to define tertiles of SES based on within-city ranking of neighbourhood SES. Neighbourhoods were then allocated to one of 15 (5x3) categories according to natural environment and SES. Two non-adjacent neighbourhoods were then selected from each category.

Within each selected neighbourhood, one to three natural environments that met two were selected: at least 0.5 hectares; located within or adjacent to the neighbourhood (and therefore easily accessible to residents). There was a degree of pragmatism when selecting natural environments for audit using local knowledge to ensure that those chosen were representative of neighbourhoods. A maximum of three natural environments per neighbourhood was feasible; some neighbourhoods had access to only one and for most, two were accessible and considered to represent accessible natural environment within the neighbourhood. Additional audits were conducted in Stoke-on-Trent to improve the coverage of natural environment typologies for the purposes of tool development.

2.3 Data collection

In each city, assessors (n=19 in total) were provided with a guide and instructions, and received brief training prior to starting data collection. In Barcelona and Stoke-on-Trent, two assessors first completed a small number of audits together to ensure consistency in interpretation. Subsequent audits were undertaken independently (i.e., two assessors completing simultaneously, but independently). The latter was included to enable estimates of inter-rater reliability. In Doetinchem, following training, pairs of assessors independently assessed all sites, whereas in Kaunas, two assessors scored each natural environment by consensus (1 completed audit per space). Table 2 shows the number of audits completed overall, by consensus, independently by two assessors, or by a single auditor. CG performed data quality assurance and followed up errors or anomalies with leads for each city (EvK, Doetinchem; MTM/MC, Barcelona; AD/RG, Kaunas).

2.4 NEST data processing

When all natural environments had been audited using the 59-item provisional NEST, data were processed to refine the tool and derive quality scores. First, domain reliability was assessed using the Cronbach's alpha coefficient and inter-item correlations to determine whether items in each domain 'hung together' as coherent constructs (Table 3; Supplemental file S2 shows original and revised NEST items and scoring protocol). We assessed changes after eliminating items with the aim of achieving a Cronbach's alpha of >.7 (or a Standardised Cronbach's alpha of .5 if fewer than 10 items per domain), and a mean inter-item correlation of .2 to .4 [57]. All changes and associated reasons are detailed in Supplemental file S1. The most notable changes related to the *Safety* and *Aesthetics - Natural Features* domains. The three items for the Safety domain were omitted as they were not congruent or deemed to provide a reliable indicator of safety. Moreover, previous qualitative research [20] has highlighted that safety can be inferred from certain incivilities that act as markers of misuse or antisocial behaviour (i.e., evidence of alcohol use or drug taking, graffiti, broken glass, vandalism). Six items from the original *Aesthetics - Natural Features* domain that related to the presence of water bodies, viewpoints and tree coverage were removed to improve domain internal reliability. However, it was important to recognise that some natural environments attract users specifically because of significant natural features (e.g., beaches, lakes, vistas). We, therefore, used these items to create a separate *Significant Natural Features* domain that comprised three dichotomous items: >50% water coverage (to indicate presence of significant water body); >50% tree cover (to indicate presence of forest/woodland area); presence of good view/vista points. These items did not achieve a high Cronbach's alpha as such features are unlikely to co-exist within an area.

Second, the revised items were used to calculate domain scores out of 100 were calculated using the remaining items [(∑ item scores / max. domain score)*100].

Third, we aimed to generate an *Overall Score* in which composite domain scores were weighted appropriately for each natural environment typology. We used 11 typologies from the classification system that was created using GIS methods and locally held data from the relevant authority/similar in each city [11] for the wider PHENOTYPE study. The following steps were used to estimate the relative domains scores for each typology within our sample of natural environments, which were used to derive typology-specific domain weights (Supplemental file 2 for detail).

i) For each typology, we determined the mean domain score (out of 100) across the audited natural environments (∑items / maximum score *100).

ii) Relative mean domain scores for each typology were compared (mean domain score for a typology / ∑mean domain scores for all typologies).

iii) Using these figures, the relative contribution (or domain weighting) for each typology was determined (relative domain score / ∑ mean relative domain score for all typologies).

iv) *Overall Score* was derived by summing domain scores, with the typology-specific weighting applied to each; e.g., Urban Park *Overall Score* = (AC *.12)+(R *.22)+(AM *.13)+(NA *.12)+(NN *.20)+(IN *.11)+(NAsig *.09).

The *Usability* domain that was included to reflect multi-functionality of natural environments was excluded from the *Overall Score.* It was kept separate so that the *Overall Scores* were generated from items/domains that were conducive to objective assessment and could be weighted (as above) by typology. *Usability* involved assessor's global judgement regarding the extent to which a natural environment supported different activities (or uses). Figure 2 illustrates the relative contributions of each domain to the *Overall Scores* for each natural environment typology. This illiustrates how each natural environment typology should be rated on the basis of relevant attributes. For example, *Recreational facilities* accounted for the largest proportion of the *Overall Scores* for Urban Parks (22%), but the smallest proportion for Woodlands, Lakes, Rivers (0-7%)).

v) Sense checking of *Overall Scores* was performed by each partner. Local knowledge was used to confirm that the approximate scores and relative rankings of different natural environments were plausible, and to identify anomalies.

The final step was to generate all domain scores and *Overall Scores* for each of the 124 neighbourhoods included in the wider PHENOTYPE study [55]. Where two assessors had independently scored a natural environment, the average was taken. Natural environment scores were then averaged for the neighbourhood. The final tool composition with data processing instructions is shown in Supplemental file S2.

2.5 Additional neighborhood data

To explore patterns by neighbourhood SES and objectively measured amount of natural environment, we also report:

- *GIS-derived natural environment indicators*. Two indicators if amount of natural environment were used: Normalised Difference Vegetation Index (NDVI), which uses a -1 to +1 scale to reflect surrounding greenness, where higher values indicate more higher levels of greenness [58,59]; Distance to the nearest (m) green space, blue space and natural environment (green and blue spaces) derived from Urban Atlas [60]. For both indicators, values for each neighbourhood were the mean of values calculated for areas around residential address locations of participants of a survey undertaken as part of the wider PHENOTYPE project [55,56] (using 100m, 300m and 500m buffers for NDVI).
- *Neighbourhood-level SES*: Local data were used to create tertiles based on within-city ranking of neighbourhood SES (where 1=most deprived). This allowed comparable categorisation based on relative SES within-cities in the absence of consistent neighbourhood-level socio-economic data across the four cities (deprivation index in Barcelona and Stoke-on-Trent; household income in Doetinchem; education in Kaunas).

2.6 Analysis

In addition to the aforementioned analysis of for domain reliability (Cronbach’s alpha), we explored inter-rater agreement using scatterplots and Pearson correlations for domains where the scores provided continuous data. Strength of agreement was assessed using the correlation coefficient, r (where r = .10 to .29 is weak; r = .30 to .49 is medium; and r ≥ .5 is strong) and the coefficient of determination, R^2, which is a measure of the proportion of variance shared by the two raters (e.g., if R^2=.67, the raters shared 67% of the variance). For two domains, *Aesthetics - non-natural* and *Significant natural features*, which had a limited number of possible domain scores (4 and 3, respectively), percentage agreement was explored descriptively using cross-tabulations. Between-city and -SES comparisons were also descriptive as the primary aim was to develop an audit tool that could assess quality across typologies of natural environments, neighbourhoods and cities. Associations with GIS-derived natural environment indicators were explored with Spearman's rank correlations (where ρ < .10 to .29 is weak; ρ = .30 to .49 is medium; and $\rho \geq .5$ is strong). Analysis for the tool development (i.e., domain coherence, inter-rater agreement) included data from all audits (n=290 audits, 174 natural environment; Supplemental file S3). Analysis of patterns by SES and objective GIS-derived natural environment indicators included only audits completed in the PHENOTYPE neighbourhoods (n=254 audits, 151 different natural environments).

3. Results

Results are summarised according to our three man aims of developing and testing the utility of the NEST, exploring associations between NEST scores and objective natural environment indicators, and between NEST scores and neighbourhood SES.

3.1 Development and utility

Completed audits

Table 2 summarises the number of completed audits and individual natural environments audited by city. In total, 174 natural environments were audited (with 290 individual audits overall). The mean recorded time to complete an audit was 16±28 minutes, which suggested feasibility. The relatively large variation in time reflected different sizes of natural environments audited. The most common typologies were urban parks, civic spaces, green corridors and formal recreation areas (Supplemental file S3). The distribution of natural environment typologies across cities was varied, which is somewhat reflective of differences in city composition; e.g., highest number of green corridors in Doetinchem; highest number of civic spaces and marine/coastal areas in Barcelona.

Inter-rater reliability

Inter-rater agreement for the NEST domains and *Overall Score* was good overall, with r-values ranging from .78 to .96 and percentage agreement of 80 to 83% (Supplemental file S4). Strongest inter-rater agreement was observed for domains that involved judgements about the presence, absence or quantity of specific facilities (*Recreational facilities*; *Amenities*). Agreement for the *Overall Score* was strong (R^2=.76, r=.87).

Natural environment scores by typology

Mean domain scores showed some expected patterns by typology (Figure 3). For example: higher *Recreation Facilities* scores in urban parks and formal recreation areas; lower *Amenities* scores in natural/semi-natural areas, woodland/forest, and river/canals; highest *Significant Natural Features* scores for marine/coastal, country parks, and woodland/forest areas.

The highest mean *Overall Scores* were observed for areas of blue space (especially coastal) and woodland, the types of area that often lack the recreational facilities or amenities that would result in lower quality scores using more physical activity-focused quality assessment tools. This indicated a degree of success of the typology-specific domain weights that did not systematically underscore certain types of natural environment.

Natural environment scores by city

There were no clear, consistent patterns of mean neighbourhood NEST scores by city (Figure 4). There was some evidence that natural environments in Barcelona and Kaunas were rated better terms of *Accessibility*, *Aesthetics - non-natural* and *Significant natural features*, but differences between cities in *Overall Score* were not marked.

3.2 Natural environment scores and GIS-measured amount of natural environment

Correlations between NEST scores and objective natural environment indicators were inconsistent, but indicated a trend towards higher quality in areas with worse access. Medium-to-strong negative correlations (rho >.3) were observed between NDVI and *Amenities* (all buffer sizes), and *Accessibility* and *Aesthetics – natural* (for some buffer sizes; Table 4). For distance to the nearest natural environment, most correlations were positive (i.e., higher quality with worse access), reaching moderate strength for *Accessibility*, *Amenities*, *Usability* and *Overall score*.

3.3 Natural environment scores by neighbourhood SES

When looking at NEST scores by SES for all cities, some expected patterns were observed. For most domains (except *Significant natural features*), there was a trend towards lower quality scores in lower SES neighbourhoods; for *Accessibility*, *Incivilities*, *Usability*, and *Overall Score* (Figure 5). When patterns were explored by city, there was some variation. The same overall pattern of lower quality in lower SES neighbourhoods was observed for most domains in Barcelona, Stoke-on-Trent and Kaunas, but not Doetinchem (see Supplemental file S5).

4. Discussion

The NEST tool was developed for feasible, reliable, in-situ assessment of different types of natural environment, from formal parks and civic spaces, to rivers and coastal areas in different European cities. Our findings are considered in relation to our three overall aims.

4.1 Development and utility of NEST for assessing diverse natural environments in different European cities

We judged the potential utility of NEST based on its reliability (internal and inter-rater), feasibility for rapid assessment of natural environments, and through exploration of some patterns in scoring, in particular, between typologies. The final 47-item, 8-domain tool had acceptable internal reliability (based on Cronbach's alpha and inter-item correlations) such that domains comprised a coherent set of items to represent different natural environment attributes that might influence use.

Inter-rater agreement was generally strong. Similar to other, often more physical activity-focused green space quality scoring tools, highest agreement was observed for domains that involved recording the presence/number and quality of amenities and recreational facilities [20,26,28,33]. However, agreement between assessors was acceptable for domains of *Aesthetics*, *Incivilities* and *Usability*, which involve greater subjectivity. This is important as both incivilities (e.g., litter, broken features, dog mess) and aesthetics are considered important influences on use [10,14,22,23] and are easier to determine through in situ assessment (compared with remote methods).

Feasibility was high with a mean time to audit a natural environment of 16±28 minutes. This was understandably longer than the original 36-item NGST that focused on smaller green spaces (11.1±3.8 minutes), but in keeping with other tools where time to complete has been reported (e.g., 10 minutes for 49-item PARA tool [25]; 20 minutes for 61-item RFET tool [29]; 67 minutes for 646-item EAPRS [26]).

There was no indication that the NEST was biased towards any one city (i.e., one city did not score consistently higher for all domains). This was encouraging as it was derived from a tool developed in the UK and supports the potential application of NEST in different European countries. We are not aware of any other natural environment assessment tool that has been developed and tested in such a range of different European cities and environments.

Patterns of domain scores and *Overall Score* across different natural environment typologies indicated that, first, certain typologies had higher scores in expected domains (e.g., higher *Recreational Facilities* in formal recreation areas and urban parks; higher *Aesthetics – natural* in Woodlands, country parks, Lakes and Rivers). Second, the distribution of *Overall Score* by typology suggested the absence of systematic bias towards certain typologies, which might have resulted from use of a physical activity-focus audit tool. This latter point was central to the purpose of NEST. We cannot say that validation is complete until scores have been explored in relation to use. However, our data indicate that the tool allows comparison of a diverse range of natural environments from different typologies, and across different European cities.

4.2 Associations between quality of natural environments and the amount of, and access to, natural environments

The trend towards higher quality scores being associated with lower neighbourhood surrounding greenness (NDVI) and worse access to natural environment (higher distance to nearest) conflicts with earlier findings. Van Dillen et al. [14] explored correlations between quality of green space and GIS-measured area of green space per residence (5 categories: <37.5, 37.5-75, 75-112.5, 112.5-150, >150 m^2). Quality was assessed using 10 items on a 5-point scale that involved assessors making judgements on aspects such as accessibility, maintenance, variation, naturalness, colourfulness, litter and safety. Quantity and quality of green areas were positively correlated (r=.36), with a stronger correlation between auditor assessed quantity and quality of streetscape greenery (r=.76). Our contrary, negative association was observed for two different objective natural environment indicators. This suggests that, although GIS-derived objective measures of amount of, or access to, natural environments have been linked with health outcomes, they do not necessarily reflect quality of local natural environments that could encourage use by local residents. The relative associations between NEST scores, health and use, and GIS-derived natural environment exposure, warrant further exploration.

4.3 Associations between neighbourhood socio-economic status and natural environment quality

Socio-economic patterning of natural environment quality showed trends towards lower quality in lower SES neighbourhoods for *Accessibility*, *Incivilities*, *Usability*, and *Overall Score*, in three cities (not Doetinchem). This overall trend is consistent with some previous work. For example, a 2010 report by CABE Space highlighted that provision of parks in deprived areas of England was worse than in less deprived areas [40]. Some studies of SES and park quality (in terms of environmental supports for physical activity) from Australia and North America reported the same pattern of higher quality in higher socio-economic areas [50,51]; whereas others have found that this relationship varies by region [53,54]. The notion of regional variation in the SES-quality relationship accords with the lack of association in Doetinchem. One explanation for this particular finding is that Doetinchem it is a very green city and was the smallest of our four cities. It is, therefore, possible that nearby neighbourhoods of different SES, shared access to the same natural environments making it more difficult to identify socio-economic patterns in quality scores.

Epidemiological evidence has shown that beneficial health-natural environment associations are often strongest in the most deprived groups [8] (e.g., for self-reported health [61], mortality [36,41,62,63]). Moreover, analysis of data from England have indicated that natural environments might have a role to play in addressing health inequalities [36,37]. Our data strengthen the case for considering quality, not just quantity, as those most in need of the health-promoting effects of natural environment exposure might have access to poorer quality spaces that discourage use.

Given the relative sparsity of quality assessment outside the park-physical activity context, and as the majority of such research has been in North America, NEST could be used to explore SES patterns in natural environment provision in other European locations. Next steps should involve exploration of NEST-measured natural environment quality in relation to local residents' level of use of those environments, another far less studied 'exposure' measure (than residential proximity).

4.4 Strengths and limitations

This work has some strengths. First, it builds on a tool that had several development steps (involving qualitative and quantitative data collection from public), with additions from other relevant tools, and refinement using expert input and extensive field-testing. Second, we tested the tool in a large number of natural environments across a range typologies in four different

European cities. This provided a good test of utility in diverse environmental and cultural contexts. Third, the patterning of domain scores by typology, and of *Overall Score* by city, indicate that NEST can be used to assess a range of natural environments based on typology-relevant attributes.

We acknowledged a number of limitations, which mostly resulted from the practical challenges of data collection in each city. First, there were differences in coverage of typologies in each city. Some typologies were absent, but across the whole sample, there was sufficient natural environment diversity to give confidence that the tool has applicability in a range of natural environments. Second, inter-rater reliability was explored in three of the four cities, but not in Kaunas because of resource limitations. Third, we were not able to determine the intraclass correlation coefficients (ICC) to test inter-rater agreement as only one city (Stoke-on-Trent) used the same two assessors for all audits, and the other cities did not randomly allocate natural environments to assessor pairs (prerequisites for ICC calculation). Fourth, our approach to developing the domain weights to determine typology-specific *Overall Scores* was based our specific sample of natural environments. As above, there was good coverage of natural environment overall, but it was not possible to include all typologies in all cities. We, therefore, recommend that those wishing to apply the NEST in other cities use the domains scores in the first instance and test the utility of the *Overall Score* using the domain weights presented (Supplemental file 2), and sense check scores.

5. Conclusions

The NEST appears to provide a feasible means of assessing of a diverse range of natural environment in different European cities in terms of their features, facilities and amenities, maintenance/condition and, in turn, fitness for purpose. The tool appears to function well by not systematically under- or over-scoring certain natural environment typologies. The apparent trend of poorer quality natural environment in lower SES neighbourhoods is intuitive, but should be further explored. The negative association with GIS-measured amount of natural environment warrants further investigation, perhaps through exploring their respective associations with use and health.

Acknowledgements: This study was conducted as part of PHENOTYPE project (Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe) (www.phenotype.eu) funded by the European Commission Seventh Framework Programme (Grant No. 282996).

Competing Interests Declaration: Authors declare that they have no conflicts of interests to disclose.

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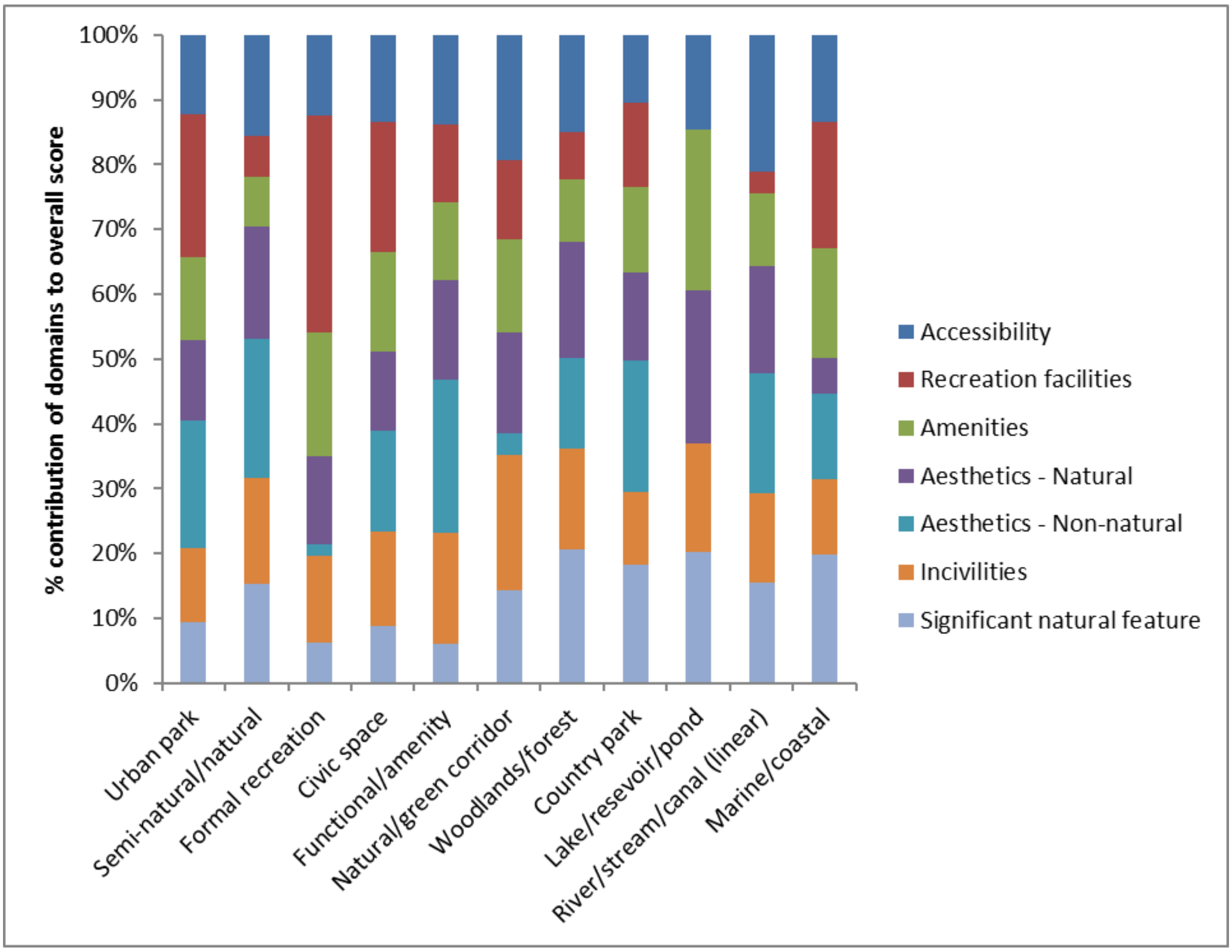
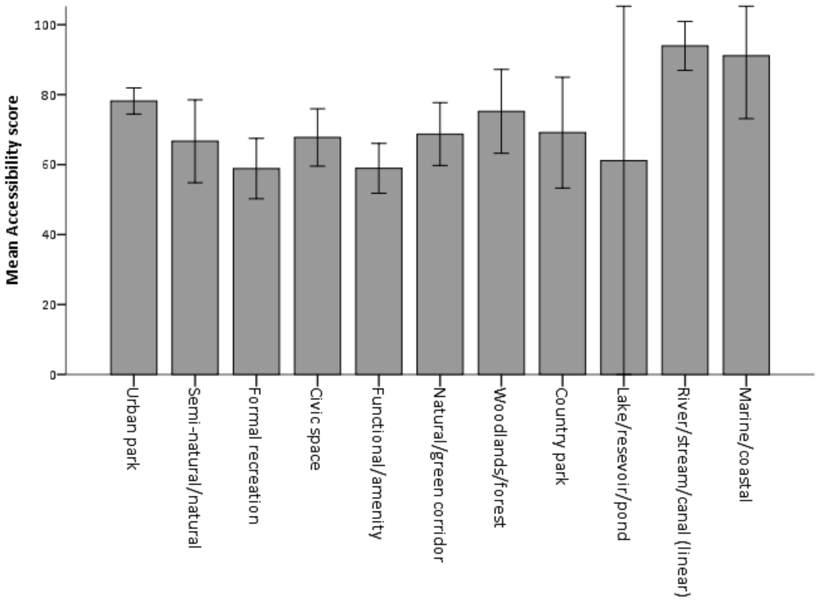
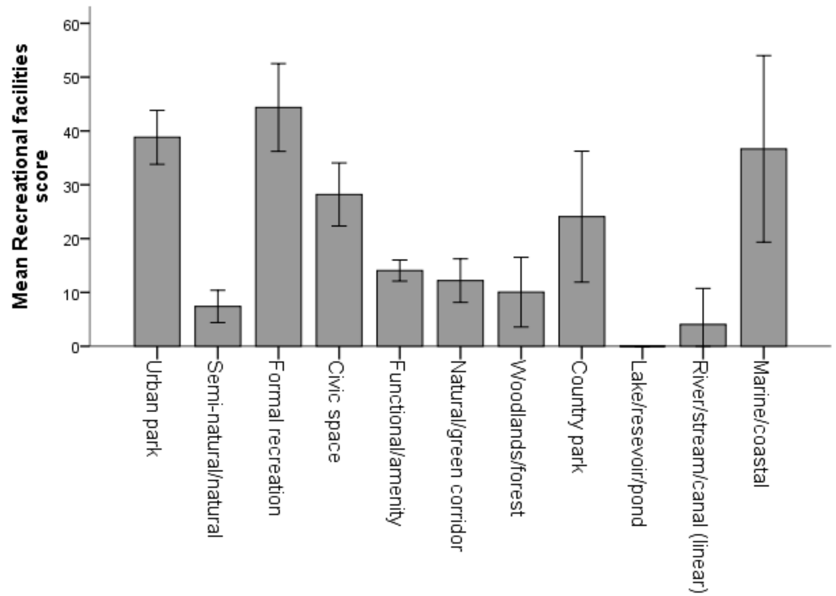


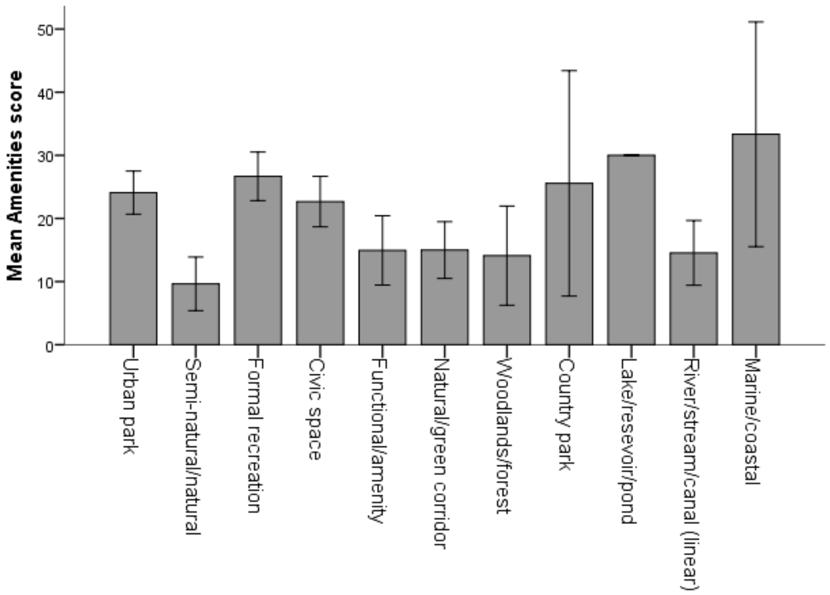
Figure 1. Domain contributions to overall NEST score by natural environment typology

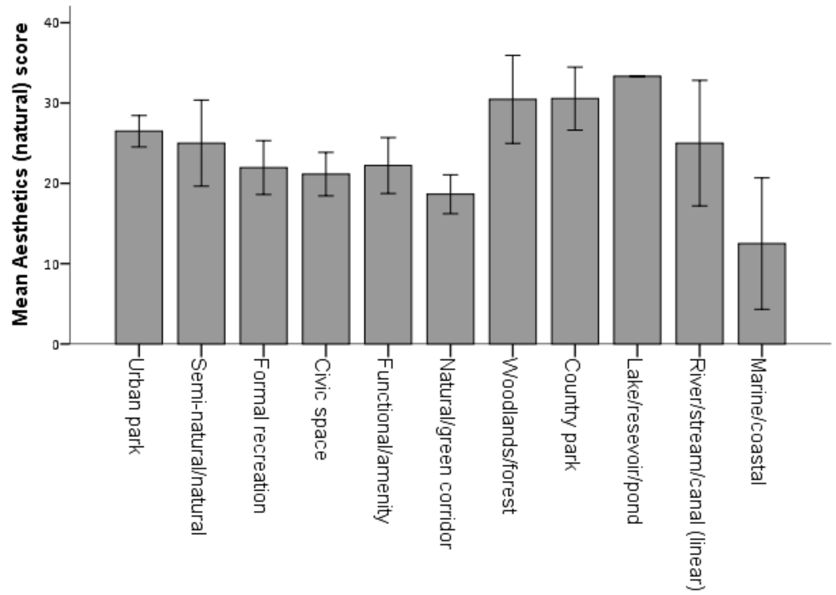


a. Accessibility



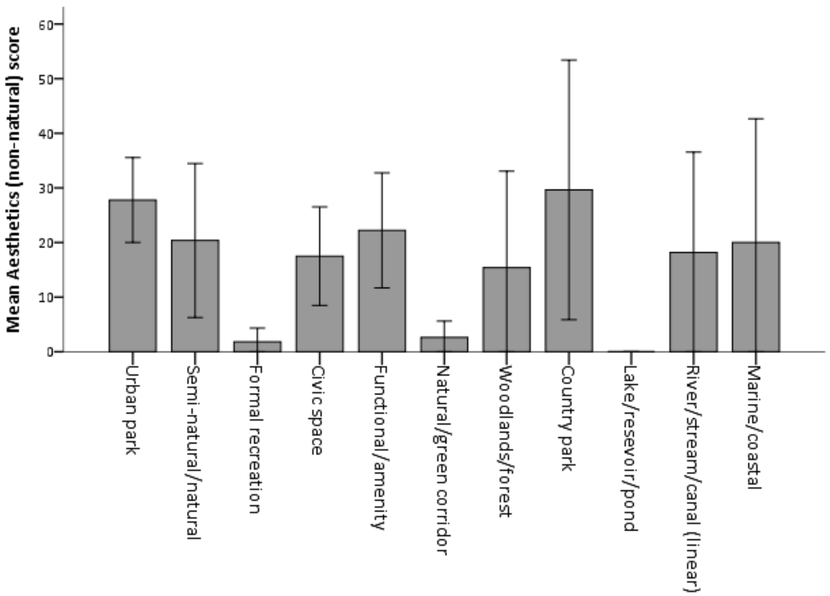
b. Recreational facilities

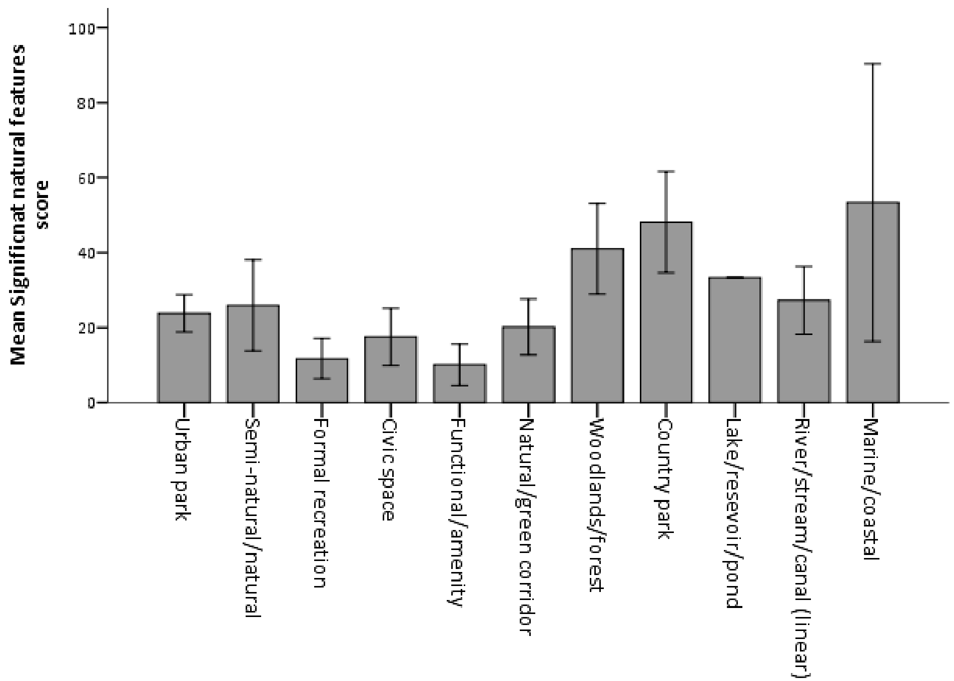




c. Amenities

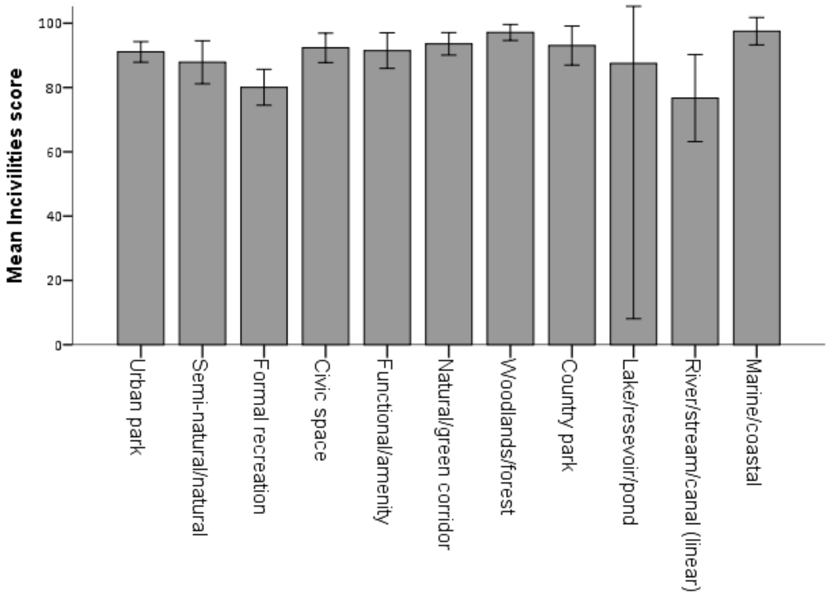
d. Aesthetics – natural



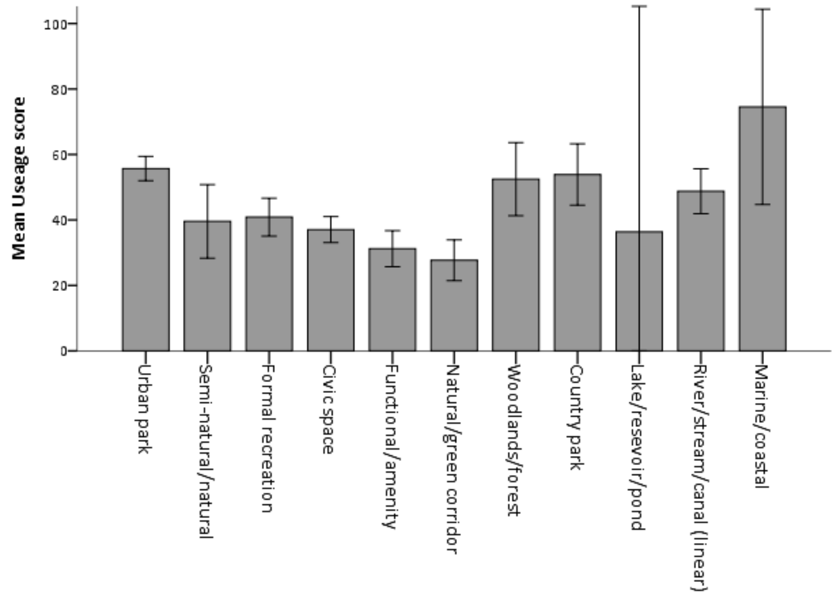


e. Aesthetics – non-natural

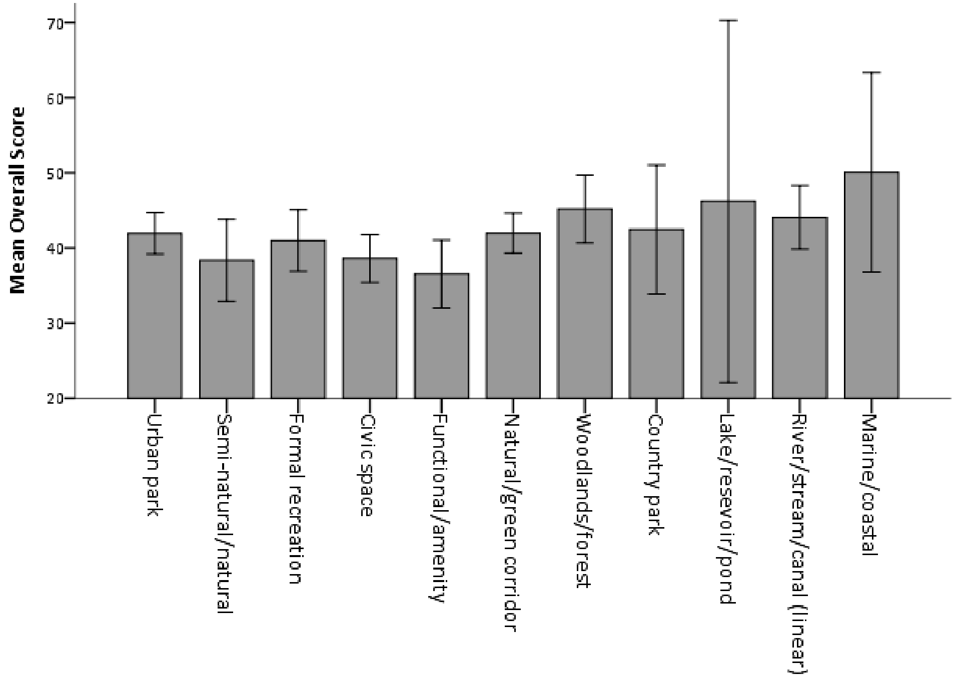
f. Significant natural features



g. Incivilities



h. Usability



i. Overall score

Figure 2. Mean NEST scores by natural environment typology (error bars show 95% CI)

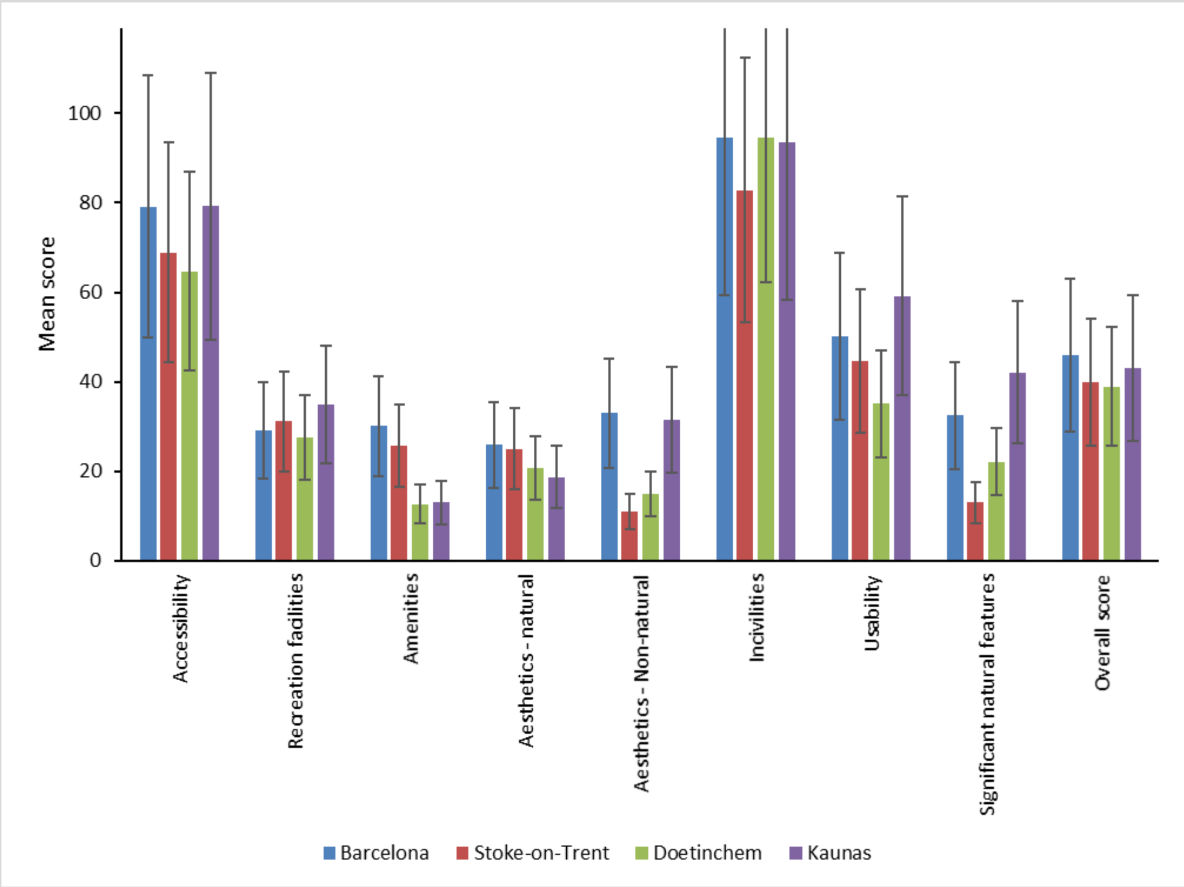


Figure 3. Mean NEST domain and overall scores by city (with 95% CI error bars)

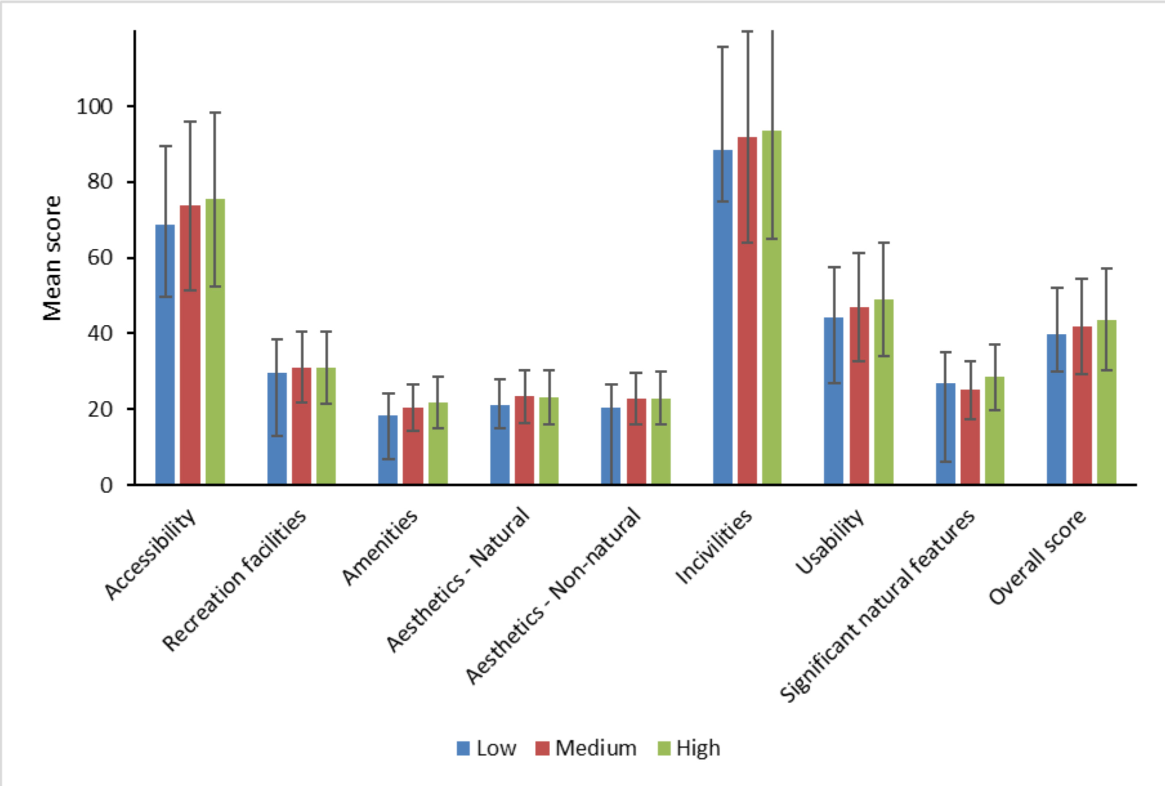


Figure 4. Mean NEST scores across neighbourhoods classified as low, medium and high socio-economic status (with 95% CI error bars)

Table 1. Summary of Natural Environment audits completed by country for tool development

	Count of audits	Count of spaces
Barcelona	**59**	**45**
Independent (2 auditors)	16	
Consensus (2 auditors)	12	
Single auditor	31	
Doetinchem	**84**	**42**
Independent (2 auditors)	84	
Stoke-on-Trent*	**130**	**70**
Independent (2 auditors)	84	
Consensus (2 auditors)	10	
Kaunas	**17**	**17**
Consensus (2 auditors)	17	
Grand Total	290	174

*For tool development additional sites were audited in the UK to boost numbers of natural environments per typology (18 natural environments audited independently by 2 assessors; 36 audits

Table 2. NEST items retained in the tool with Cronbach's Alpha and inter-item correlations for domains

Domains	Item	Items (summarised)	N items	Cronbachs Alpha	Std Cronbachs Alpha	Mean inter-item correlation
1. Access	AC1	Entrance points	3	**.57**	.55	.29
	AC5	Walking paths - amount				
	AC6	Walking paths – quality				
2. Recreational Facilities	R1	Playground equipment	7	**.74**	.77	.32
	R2	Grass pitches				
	R3	Courts				
	R4	Skateboard ramp(s)				
	R5	Other sports or fitness facilities				
	R6	Amount of open space (for informal games, play and walking)				
	R7	Quality of open space (for informal games, play and walking)				
3. Amenities	AM1	Seating/benches	8	**.71**	.71	.23
	AM2	Litter bins				
	AM3	Dog mess bins (or equivalent)				
	AM4	Public toilets				
	AM5	Cafe / kiosk				
	AM6	Shelter/shade - man-made				
	AM9	Picnic tables				
	AM10	Drinking fountains				
4a. Aesthetics (Natural features)	NA6	Primary surface quality	3	**.62**	.64	.37
	NA7	Flower beds / planters / wild flowers				
	NA8	Other planted trees / shrubs / plants				
4b. Aesthetics (Non-natural)	NN1	Water fountain (decorative)	3	**.66**	.68	.42
	NN2	Other public art				
	NN3	Historic/attractive buildings/structures;				
5. Incivilities	IN1	General litter	9	**.68**	.71	.22
	IN2	Evidence of alcohol use				
	IN3	Evidence of drug taking				
	IN4	Graffiti				
	IN5	Broken glass				

	IN6	Vandalism				
	IN7	Dog mess				
	IN8	Excessive noise				
	IN9	Unpleasant smells				
6. Significant natural feature	NA3	% area occupied by the water (≥50%)	3	.02	-.05	-.02
	NA4	Good view points, vistas, scenic views				
	NA5	% area occupied by trees (≥50%)				
7. Usability (suitability for…)	US1	Sport	11	**.80**	.80	.26
	US2	Informal games (football, frisby, etc.)				
	US3	Walking / running				
	US4	Children's play				
	US5	Conservation/biodiversity				
	US6	Enjoying the landscape / visual qualities				
	US7	Meeting, socialising with friends, neighbours, etc.				
	US8	Relaxing, unwinding				
	US9	Cycling				
	US10	Water sports				
	US11	Fishing				
		TOTAL	47			

Table 3. Correlations between NEST scores and GIS-derived indicators of surrounding greenness (NDVI) and access (distance to nearest) natural environment

	Mean NDVI						**Straight-line distance to nearest (m)**					
	100m		300m		500m		Natural space		Green space		Blue space	
	rho	p	rho	p	rho	p	rho	p	rho	p	rho	p
Accessibility	-.27	.004	**-.30**	**.001**	**-.33**	**<.001**	**.47**	**<.001**	**.48**	**<.001**	.14	.12
Recreation facilities	-.04	.677	-.10	.269	-.16	.094	.23	.012	.23	.012	.06	.525
Amenities	**-.53**	**<.001**	**-.52**	**<.001**	**-.53**	**<.001**	**.35**	**<.001**	**.36**	**<.001**	.20	.027
Aesthetics (natural)	**-.32**	**<.001**	-.25	.007	-.21	.021	.07	.474	.08	.398	.12	.216
Aesthetics (non-natural)	-.08	.373	-.12	.197	-.13	.151	.20	.034	.21	.026	.02	.837
Incivilities	.04	.637	-.02	.875	-.05	.597	.29	.002	.29	.002	.11	.232
Usability	-.10	.292	-.10	.284	-.14	.123	**.40**	**<.001**	**.40**	**<.001**	.19	.039

Significant natural features	.04	.67	.05	.621	.06	.506	.21	.023	.21	.022	.17	.066
Overall score	-.25	.006	-.30	.001	**-.31**	**.001**	.30	.001	**.32**	**<.001**	.05	.587

Correlations of at least moderate strength are emboldened