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A sytematic review of the health and wellbeing benefits of biodiverse environments

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Running head:

Biodiversity and the promotion of good health

Key words

Systematic review; biodiversity; human health; human wellbeing; interdisciplinary; cultural ecosystem services

Abstract

Recent ecosystem service models have placed biodiversity as a central factor in the processes which link the natural environment to health. While it is recognized that disturbed ecosystems might negatively affect human wellbeing it is not clear whether biodiversity is related to or can promote 'good' human health and wellbeing. The aim of this study was to systematically identify, summarize and synthesize research which had examined whether biodiverse environments are health promoting. The objectives were twofold: 1) to map the interdisciplinary field of enquiry and, 2) assess whether current evidence enables us to characterize the relationship. Due to the heterogeneity of available evidence a narrative synthesis approach was used, which is textual rather than statistical. Extensive searches identified 17 papers which met the inclusion criteria: 15 quantitative and two qualitative. The evidence was varied in disciplinary origin with authors

approaching the question using different study designs and methods, and conceptualizations of - biodiversity, health and wellbeing. There is some evidence to suggest that biodiverse natural environments promote better health through exposure to pleasant environments or the encouragement of health-promoting behaviors. There was also evidence of inverse relationships, particularly at a larger scale (global analyses). However, overall the evidence is inconclusive and fails to identify a specific role for biodiversity in the promotion of better health. High quality interdisciplinary research is needed to produce a more reliable evidence base. Of particular importance is identifying the specific ecosystem services, goods and processes through which biodiversity may generate good health and wellbeing.

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Biodiversity and good health and wellbeing

There is increasing consensus that the impacts of changes in biodiversity may have important repercussions for human health and wellbeing (Diaz et al. 2006; Mlambo 2012; Sala et al. 2009). Contemporary ecosystem service assessments (Millennium Ecosystem Assessment 2005; UK National Ecosystem Assessment 2011) sought to formalize an understanding of the complex interdependency of human health, society and economies on the natural environment. These reviews identified biodiversity as playing a key role in regulating and modulating ecosystem processes and functions, and the goods and services ecosystems provide (Balvanera et al. 2006; Cardinale et al. 2012; Norris 2011). Specific and direct links between biodiversity and human health exist (Convention on Biological Diversity. accessed 2013, D'Agnes et al. 2010; Huynen et al. 2004). For example, disturbance of ecosystems and in particular biodiversity loss may affect human health through an increase in the spread of zoonotic diseases (Keesing et al. 2010; Ostfeld 2009) or through losses of pharmacological opportunity (Chivian & Bernstein 2008). Disturbance of local biodiversity has also been linked to inadequate nutrition (Aswani & Furusawa 2007; Golden et al. 2011). However, whilst there is emerging evidence as to how biodiversity relates to good health and wellbeing through the supporting, regulating, and provisioning services it is only recently that attention has been paid to the role of biodiversity in relation to the cultural ecosystem services (Church et al. 2011). Cultural ecosystem services have been defined as the 'non-material' benefits that are derived from ecosystems and are related to factors such as promotion of wellbeing though aesthetics, leisure and recreation, and sense of place (Church et al. 2011).

Substantial proportions of the world's population are experiencing epidemics of non-communicable disease including heart and other circulatory diseases, diabetes type 2 and mental health disorders (Beaglehole & et al. 2011; Collins & et al. 2011). The management, and in some cases, prevention of these disorders can be linked to natural environments. The quantity and proximity of 'natural' spaces in the local (residential) environment is related to a reduction in the prevalence of several of

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these health outcomes and their risk factors (Bowler et al. 2010; Lachowycz & Jones 2011; Lee & Maheswaran 2010; Mitchell & Popham 2007, 2008). Active exposure to, and use of, the natural environment is also associated with better health (Keniger et al. 2013; Lee et al. 2011; Thompson Coon et al. 2011). Several studies linked health status, through both primary and secondary mechanisms, to the condition and state (both 'real' and 'perceived') of the local 'natural' environment (Cummins et al. 2005; Mitchell & Popham 2008; van Dillen et al. 2012). Environmental degradation, including biodiversity loss, appears to exert adverse impacts on health, especially mental wellbeing, greater than the primary adverse impacts associated with economic decline, nutritional threats and pollution (Speldewinde et al. 2009). The mechanisms underpinning these linkages are predominantly understood, though not exclusively as all the services are inherently interlinked, through the framework of the cultural ecosystem services. For instance an 'attractive' biodiverse natural environment may impact on health through the encouragement of greater physical activity, support tourism with wider impacts on local economies, or provide a focus for cultural activities. Underpinning the realization of these impacts are the other ecosystem services, from clean air to the nutrient cycles.

If research confirms that higher quality, more biodiverse natural environments do promote and support better health and wellbeing, then these environments might contribute to reducing the prevalence of non-communicable disease and their respective contributory risk factors, and in lowering the economic burden on health care systems worldwide (Beaglehole et al. 2011; Davies & Deaville 2008; Tzoulas & Greening 2011; Velarde et al. 2007). Both health and conservation organisations recognize this potential. For example, the World Health Organisation's Ottawa Charter (1986) specifically identified conservation of natural resources (including biodiversity) as necessary for the promotion of good health. Amongst environmental organizations there is an increasing focus on using natural resources to promote human health (Bird 2007; Environmental Protection Agency undated; European Environment Agency 2011). Evidence of positive impacts on human health would potentially provide further justification for increased support for, and greater protection of,

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biodiversity within natural ecosystems (Dearborn & Kark 2010; Kareiva & Marvier 2007; Mlambo 2012). These considerations provide important insights for policymakers.

Although the theoretical and partially evidenced pathways linking biodiverse natural environments to good health and wellbeing through cultural ecosystem services and goods are compelling, they are however, far from confirmed (Norris 2011). The aim of this systematic review was to identify, summarize and synthesize, where appropriate, all available evidence to provide answers to three key questions: 1) what is the state and nature of the current body of evidence, 2) do biodiverse environments promote good health and wellbeing, and 3) can any identified relationships be characterized?

The topic does not appear to have been previously addressed in a comprehensive and systematic manner. Whilst there are a number of related reviews (Bowler 2010; Brown & Grant 2005; Croucher et al. 2007; Dean et al. 2011; Keniger et al. 2013; Thompson Coon et al. 2011) none have examined the role of biodiversity in relation to health outcomes in a variety of contexts. The approach was deliberately inclusive in that all research which was self-described as having considered, or which related respective environmental factors to biodiversity was included (Pullin & Stewart 2006). This approach was taken in order to describe the broad state of knowledge regarding links between biodiversity and promotion of good health and wellbeing.

Methodological approach

Using robust and systematic methods, this review included research which specifically examined relationships between biodiversity and health or wellbeing outcomes in any population. All experimental or observational (including qualitative) evidence which was self-described as considering 'biodiversity' was included in the review of the state of the evidence (research question 1), however only papers using higher order methodologies were incorporated in the synthesis (research questions 2 and 3). As the focus was on the *promotion* and *support* of good health and wellbeing the ways in which factors such as zoonotic diseases, pathogens or the identification of

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organisms with pharmacological potential are related to biodiversity were not considered. These have been reviewed elsewhere (Keesing et al. 2010).

The full aims and procedures of the review can be found in the protocol (for a copy please contact author). In brief, the objective was to identify and consider all papers detailing investigations undertaken using any recognized and reliable study design, published between January 1980 and December 2012, from any country, providing they met the following criteria: 1) an explicit (self-described, regardless of any external assessment of the plausibility of method) consideration of biodiversity, species richness and/or a setting protected because of its biodiversity, and 2) an explicit consideration of either a primary health-related outcomes including any self-report or objective measure of physical or mental health or wellbeing, or a secondary health-related outcomes including self-report or objective measures of improved health behaviors (e.g. physical activity).

Literature was identified through structured searches of over 20 academic and web databases. In addition, 14 journals, over 20 bibliographies and citation lists, and more than 40 governmental or organizational websites were hand searched. Suggestions for literature were elicited from leading researchers. Key search terms were developed following the inclusion and exclusion criteria established for the study and included groups of terms relating to: 1) biodiversity, 2) health outcomes and 3) health behaviors and activities (Supporting material). Search strategies were modified according to the requirements of each database

Initial screening of titles was undertaken by one reviewer, the inclusion criteria were then applied to abstracts with discussion to resolve differences in cases of disagreement. Full text assessment was undertaken by two of the researchers. A standardized data extraction form was used to extract key information relating to each piece of research. 'Quality', in terms of conduct and reporting (assessment categories can be found in the Supporting information), and risk of bias were assessed by four of the reviewers using frameworks appropriate to the respective study design (Centre for

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Reviews and Dissemination 2008; Downs & Black 1998; Wallace et al. 2004). Publications were not excluded from the review if they were deemed to be of 'low quality'.

Due to the heterogeneity of the literature selected (in terms of approach, key concepts, designs and methods) a form of narrative analysis was applied (Popay et al. 2006). Narrative analysis, which adopts a textual approach to the synthesis, is a widely recognized and validated approach and is used where there are considerable differences in terms of design, methods, outcomes and analysis. It was developed for use where more traditional statistical meta-analyses were unsuitable. In applying this analytical method during the analysis, patterns across studies were sought according to important factors such as design, measures of the environment and health, and findings. Primary quantitative evidence of any type was used to answer research question 1, however only the quantitative studies which used higher order designs (experimental, longitudinal, comparative or un-controlled before and after study designs) were included in the formal synthesis of the evidence to answer questions 2 and 3 (Higgins & Green 2011). Qualitative studies were included to facilitate an understanding of perceived benefits and of potential mechanisms of action (Dixon-Woods et al. 2006; Lorenc et al. 2012).

The search process led to the identification of over 17,000 references. Screening at title and then abstract reduced this number to 263 references. The majority of the references initially excluded at this stage clearly did not meet the inclusion criteria or did not report primary research. Full text screening with the application of the inclusion/exclusion criteria identified 17 papers of specific relevance to this review (Table 1). The primary reason for exclusion at abstract/full text was due to a lack of the specific consideration of biodiversity within the environmental measures.

The state and nature of existing research into the links between biodiversity and good health and wellbeing

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The 17 studies deemed relevant to the review were varied in disciplinary origin and included papers from ecology, epidemiology, psychology, anthropology, public health, and urban/landscape design. All studies stated that they had examined, wholly or in part, the relationships between biodiversity and one or more health or wellbeing outcomes. A variety of study designs (Table 1) were used to examine the central question of whether greater biodiversity is related to better health, and included 1 experimental study (Jorgensen et al. 2010), 1 longitudinal comparative study (Annerstedt et al. 2012), 8 un-controlled before and after or comparative studies (Barton et al. 2009; Björk et al. 2008; Dallimer et al. 2012; de Jong et al. 2012; Fuller et al. 2007; Grahn & Stigsdotter 2010; Luck et al. 2011; Tilt et al. 2007), 4 epidemiological analyses of secondary datasets (Huby et al. 2006; Huynen et al. 2004; Poudyal et al. 2009; Sieswerda et al. 2001), and 1 cross-sectional questionnaire survey (Lemieux et al. 2012), qualitative participatory study (Pereira et al. 2005), and ethnography (Curtin 2009).

In general authors hypothesized (explicitly or implicitly) that exposure to or proximity to environments with greater biodiversity might exert a positive, health promoting impact. The majority of the selected studies assessed geographical associations (exposure or proximity) between specific or general environments (with differing degrees of biodiversity) and various health or wellbeing outcomes. None assessed the impacts of changes in biodiversity on health and wellbeing outcomes. Several studies considered biodiversity as a variable when examining the effects of an activity (for example holidays, walking or commuting) undertaken in specific environments (Annerstedt et al. 2012; Barton et al. 2009; Curtin 2009; Dallimer et al. 2012; Fuller et al. 2007; Lemieux et al. 2012; Pereira et al. 2005; Tilt et al. 2007). In other studies the deliberate 'use' of the environment was not considered: instead general relationships between the presence or proximity of environments of differing quality and the health of populations according to residence were investigated (de Jong et al. 2012; Huby et al. 2006; Huynen et al. 2004; Luck et al. 2011; Poudyal et al. 2009; Sieswerda et al. 2001). None of the publications reported dose-response relationships (i.e. to environments of greater or lesser biodiversity) within individuals or populations.

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The scales at which the relationships were examined ranged from the local (Dallimer et al. 2012; Fuller et al. 2007) to global (Huynen et al. 2004; Sieswerda et al. 2001). The specific environments considered included: the global populated landmass (Huynen et al. 2004; Sieswerda et al. 2001), a specific nation state (the USA)) (Poudyal et al. 2009), geographical regions in Sweden (Annerstedt et al. 2012; Björk et al. 2008; de Jong et al. 2012; Grahn & Stigsdotter 2010), the United Kingdom (UK) (Huby et al. 2006), Australia (Luck et al. 2011), and Portugal (Pereira et al. 2005), and specific places including biodiverse sites of high natural heritage in the south-east of England (Barton et al. 2009), selected urban green spaces in Sheffield, UK (Dallimer et al. 2012; Fuller et al. 2007), protected natural environments in Quebec and Ontario, Canada (Lemieux et al. 2012), Andalucía, Spain (Curtin 2009), California, USA (Curtin 2009), and urban neighborhoods in Seattle, USA (Tilt et al. 2007). The 2 global epidemiological studies included all countries for which relevant data were available (Huynen et al. 2004; Sieswerda et al. 2001). However only Sieswerda et al. (2001) actually listed the 203 countries included in their analysis: the countries represent a spread from developed and developing worlds, both northern and southern hemispheres and each continent. Two studies used 'hypothetical' environments to examine the impact of biodiversity: Jorgensen et al. (2010) used photographs of environments with differing complexity (linked to biodiversity by the author), while Grahn and Stigsdotter (2010) used ranked, preferred features of natural environments.

Sample size varied considerably among the studies: ranging from an *n* of 20 (Curtin 2009) through to the millions, or possibly billions in the analyses of global populations (Huynen et al. 2004; Sieswerda et al. 2001). Participant type also differed: these included university students (Jorgensen et al. 2010), urban park users (Dallimer et al. 2012; Fuller et al. 2007), wildlife tourists (Curtin 2009), visitors to country parks and sites of natural heritage (Barton et al. 2009; Lemieux et al. 2012), and residents of specific regions as detailed above. The participants of the majority of the studies (apart from Huynen et al. 2004; Poudyal et al. 2009; Sieswerda et al. 2001) appeared to be adults.

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Few of the studies included an explicit articulation of the authors' understanding and definitions of health and wellbeing, similarly there was little discussion as to why the aspects considered may relate to or be affected by biodiversity. The conceptualizations of health and wellbeing ranged from functional approaches (life expectancy) to more 'holistic' understandings where health encompasses factors such as sense of place or self-esteem. Reflecting the breadth of apparent conceptualization of health and wellbeing, there was considerable variation in the outcomes considered and, therefore, of the measures used between the studies. Three of the secondary data analyses employed life expectancy as an indicator of general health status (Huynen et al. 2004; Poudyal et al. 2009; Sieswerda et al. 2001). Huynen et al. (2004) also considered infant mortality rate, incidence of low weight babies and disability adjusted life expectancy. Amongst the remaining studies the objective and/or self-report outcomes included health behaviors such as physical activity (Annerstedt et al. 2012; Björk et al. 2008; de Jong et al. 2012; Luck et al. 2011; Tilt et al. 2007), physiological state (Tilt et al. 2007), general or specific physical health status assessed using a variety of scales or measures including the validated Short Form 36 (Björk et al. 2008; de Jong et al. 2012; Grahn & Stigsdotter 2010; Lemieux et al. 2012), general psychological or emotional health, wellbeing or status assessed using a variety of measures or scales including the General Health Questionnaire 12, Profile of Mood States scale and the Rosenberg Self-Esteem Scale (Annerstedt et al. 2012; Barton et al. 2009; Björk et al. 2008; Dallimer et al. 2012; Fuller et al. 2007; Huby et al. 2006; Jorgensen et al. 2010; Lemieux et al. 2012; Luck et al. 2011), and community level wellbeing (de Jong et al. 2012; Luck et al. 2011; Pereira et al. 2005) .

As with understanding of health and wellbeing, few of the authors articulated their conceptualization and definitions of biodiversity. Some authors appeared to have used the term in accordance with the definition from the Convention on Biological Diversity (accessed 2013), particularly in relation to diversity within and between species (Dallimer et al. 2012; Fuller et al. 2007; Luck et al. 2011). Others, however, used the term in less specific and scientifically accepted ways, relating 'biodiversity' to similar constructs such as natural environments with greater or lesser

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visual or perceived complexity or 'lushness' (Annerstedt et al. 2012; Barton et al. 2009; Björk et al. 2008; de Jong et al. 2012). In 3 of the studies biodiversity was assessed using standard ecological survey techniques (Dallimer et al. 2012; Fuller et al. 2007; Luck et al. 2011). Participant assessment of biodiversity was employed as a primary measure by Pereira et al. (2005) and as an additional measure by both Dallimer et al. (2012) and Fuller et al. (2007). In 2 studies satellite imagery data was interpreted using the Normalized Difference Vegetation Index (NDVI), which was related by the authors to biodiversity and environmental structure (Luck et al. 2011; Tilt et al. 2007). A further 3 papers used the Scania Green Score which is an approach to the interpretation of the type and structure of the natural environment, assessed using interpreted satellite imagery, according to the presence of certain 'green qualities' including a biodiversity related factor: *'Lush, a place rich in species'* (Annerstedt et al. 2012; Björk et al. 2008; de Jong et al. 2012). Several of the secondary data analysis studies used % land area protected as a proxy for biodiversity (Huby et al. 2006; Poudyal et al. 2009; Sieswerda et al. 2001). Factors, such as proportion of threatened species and of highly disturbed land, were used to indicate decreased biodiversity in 2 studies (Huynen et al. 2004; Sieswerda et al. 2001). In 4 of the studies biodiversity was not directly assessed, however the natural heritage 'value' of the environments was demonstrated through formal designation (Barton et al. 2009; Curtin 2009; Lemieux et al. 2012; Pereira et al. 2005). For instance, both study locations considered by Lemieux et al. (2012) were International Union for Conservation of Nature's category II. Jorgensen et al. (2010) visually assessed the complexity or 'vegetation layers' of the 4 environments used in their experimental study and suggested that vegetal layers relate to biodiversity. Grahn and Stigsdotter (2010) used factor analysis to code participant reports of preferences for different environments including biodiversity-related factors.

Where articulated the theoretical underpinnings and conceptual frameworks tended to reflect the dominant understandings of environment-health linkages within respective research disciplines. Amongst the social science studies, the Biophillia hypothesis (Kellert & Wilson 1995), attention restoration (Kaplan 1995) and psycho-evolutionary stress reduction theories (Ulrich et al. 1991) were

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used to describe the potentially innate connection of humans to the natural world, indicating that greater exposure results in better health outcomes (Annerstedt et al. 2012; Barton et al. 2009; Curtin 2009; Dallimer et al. 2012; de Jong et al. 2012; Fuller et al. 2007; Grahn & Stigsdotter 2010; Jorgensen et al. 2010). Aesthetics, preferences and connection to or sense of place explained potential benefits in studies which focused on use of the natural environment for physical activity or other health behaviors (Annerstedt et al. 2012; Barton et al. 2009; Björk et al. 2008; Dallimer et al. 2012; Fuller et al. 2007; Grahn & Stigsdotter 2010; Lemieux et al. 2012; Tilt et al. 2007). More functional theories were discussed in the epidemiological publications, for instance greater wellbeing through access to sufficient natural resources (Pereira et al. 2005; Poudyal et al. 2009; Sieswerda et al. 2001) or the negative influence of compromised ecosystem function (Huynen et al. 2004). A number of the selected studies were not based within theoretical frameworks and did not articulate why biodiversity may be related to better health and wellbeing, or through which mechanisms positive outcomes may arise.

Whilst the reporting of key details with regard to methodology, sample strategy and characteristics, and precise analytical approach was occasionally inadequate, overall the studies could be described as of acceptable quality and in most cases the results appear 'reliable' when considered within their methodological paradigm (Supporting material). However, specific aspects of some studies were of relatively low quality. For example, implicit (and in some cases explicit) assumptions that greater biodiversity does support better health and wellbeing may have introduced bias in a number of the studies.

Is there evidence to suggest that biodiverse environments promote better health and wellbeing and can any relationship identified be characterized?

Fourteen of the 15 quantitative studies identified during the search process used higher order study designs (experimental, longitudinal, comparative or un-controlled before and after study designs). Only these 14 were included in the quantitative assessment of links between biodiversity and health

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(Tables 1, 2 and 3). The 2 qualitative studies facilitated an understanding of the perceptions of relationships (Tables 1 and 2).

Ten of the 16 studies included in the analysis (Tables 2 and 3) highlighted one or more positive associations (assessed or perceived) between biodiversity and one or more health or wellbeing outcomes (Barton et al. 2009; Björk et al. 2008; Curtin 2009; Dallimer et al. 2012; de Jong et al. 2012; Fuller et al. 2007; Grahn & Stigsdotter 2010; Huby et al. 2006; Luck et al. 2011; Poudyal et al. 2009; Tilt et al. 2007). Eleven of the studies reported results which suggested either no clear relationship or were inconclusive as to the direction of the relationship (Annerstedt et al. 2012; Björk et al. 2008; Dallimer et al. 2012; de Jong et al. 2012; Fuller et al. 2007; Grahn & Stigsdotter 2010; Huynen et al. 2004; Jorgensen et al. 2010; Pereira et al. 2005; Sieswerda et al. 2001; Tilt et al. 2007) and 2 reports suggested an inverse relationship between biodiversity and aspects of health (Dallimer et al. 2012; Huynen et al. 2004).

Quantitative results

i. Environmental measures

There was little consistency in the patterns of relationships according to type of environmental/biodiversity measure and direction of health outcome in which to be confident (Tables 2 and 3). In the 3 studies that used, arguably, the most robust measure of biodiversity (primary ecological surveys), each found some moderately positive relationships (though not all results were positive, many were inconclusive and one negative) between aspects of biodiversity and wellbeing outcomes (Dallimer et al. 2012; Fuller et al. 2007; Luck et al. 2011). The 2 publications considering degraded environmental state, assessed using factors such as % threatened species, revealed no clear associations with some indication of negative relationships (Huynen et al. 2004; Sieswerda et al. 2001). Where proximity to biodiverse or protected environments was considered, results tended to be moderately positive (Huby et al. 2006; Poudyal et al. 2009; Tilt et al. 2007) or

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inconclusive (Sieswerda et al. 2001). The 4 studies to consider settings defined by perceived environmental dimensions (with objectively assessed or self-report exposure) failed to detect clear relationships between the presence of 'lush' environments and mental or general health and wellbeing (Annerstedt et al. 2012; Björk et al. 2008; de Jong et al. 2012; Grahn & Stigsdotter 2010) but some positive relationships with physical activity emerged (Björk et al. 2008; de Jong et al. 2012).

ii. Objective measures of health

Poudyal et al.'s (2009) analysis of secondary aggregate datasets suggested a moderate but significant positive association between life expectancy and an indicator of exposure to biodiversity in the USA. Sieswerda et al. (2001) found that initial positive associations (between % highly disturbed land, % threatened species, % forest remaining since pre-agricultural period and life expectancy at a global scale) were lost after controlling for Gross Domestic Product. Similarly Huynen et al. (2004) reported that associations between indicators of decreased biodiversity and infant mortality and incidence of low weight babies were also lost after adjusting for socio-economic factors. Huynen et al. (2004) described an inverse of the expected relationship with increases in % threatened species associated with greater life expectancy and Disability Adjusted Life Expectancy. Tilt et al. (2007) found an interactive effect with greater objective accessibility related to lower Body Mass Index (BMI) though only in areas of higher 'greenness' assessed using NDVI.

iii. Self-report physical or mental health and wellbeing

In an experimental setting no clear effect was evident in assessments of psychological state after exposure to environments of differing complexity following a stressor (being shown a frightening film) amongst university students (Jorgensen et al. 2010). Huby et al.'s (2006) analysis of associations between mental wellbeing and indicators of biodiversity in rural England revealed a moderate positive association. A study conducted in urban Australia found that both personal wellbeing and neighborhood satisfaction (termed neighborhood wellbeing) rose in relation to greater species

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richness and abundance and with increased vegetative cover and density (assessed using standardized ecological surveys) (Luck et al. 2011). There was inconsistency in the direction of associations between various indicators of biodiversity and psychological wellbeing in the two studies which used broadly similar methodologies and were both carried out in urban Sheffield, UK though in different types of urban green space (Dallimer et al. 2012; Fuller et al. 2007). In both studies bird species richness was positively associated with measures of wellbeing while butterfly species richness was shown to have no association. The findings diverged when examining plant richness: Fuller et al. (2007) found that enhanced wellbeing was related to increased plant species richness, whereas Dallimer et al. (2012) reported a decline in wellbeing under such circumstances. Similarly variation was observed in relation to tree cover: with Dallimer et al. (2012) reporting a positive relationship with wellbeing and Fuller et al. (2007) finding no association.

Positive associations between participant assessment of species (bird, butterfly and plant) richness and self-report wellbeing were detected by Dallimer et al. (2012), however they found no association between perceived and actual species richness (which suggests that the participants were unable to accurately assess species richness). While Fuller et al. (2007) did not specifically examine associations between perceived richness (bird, butterfly and plant) and wellbeing they did find that their participants were able to accurately assess species richness, therefore the associations between participant assessed biodiversity and wellbeing may have been consistent with those of the objective assessments.

Positive impacts on mood and self-esteem following time spent in environments of 'high natural heritage value' (scores of individuals newly arrived to the sites were compared with those leaving) were reported by Barton et al. (2009). Hypothetical environments categorized as 'rich in species' (according to a factor analysis of reported preferences for environmental features) were found to be the preferred place types for restoration amongst people who reported higher symptoms of stress-related conditions (Grahn & Stigsdotter 2010). The three studies using the Scania Green Score (a

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method of classifying environmental type using satellite imagery and/or participant report) found no clear associations between environments categorized as 'lush, rich in species' and self-report mental health (Annerstedt et al. 2012), general health (Björk et al. 2008), or the 'vitality' domain of the Short Form 36 (SF36) (Björk et al. 2008). A positive association between objective assessment of the presence of 'lush' environmental features and neighborhood satisfaction, although only for those living in a flat or student room, was found by de Jong et al. (2012).

iv. Health and wellbeing related behaviors

Bjork et al. (2008) showed that the participants with 'lush' environmental features within 300m of the home residence engaged in greater self-report physical activity than those with other environmental feature types. Similarly de Jong et al. (2012) detected a positive association between 'lush' environments and physical activity, although Annestedt et al. (2012) noted no association. Tilt et al. (2007) also found positive associations between walking and subjective assessments of overall 'greenness' but they did not detect a clear relationship between an objective assessment of greenness (assessed using NDVI and linked to biodiversity by the authors) and walking.

Qualitative findings

Both studies using a qualitative approach were able to document conflicting impacts of biodiversity on wellbeing. The residents of the Sistelo region of Portugal, when questioned regarding the importance of biodiversity to their wellbeing and quality of life, reported ambiguity and mixed feelings: "*residents did not immediately think of biodiversity as something important to their well-being"* (Pereira et al. 2005. pp53). Although biodiversity was appreciated for its inherent value and beauty this was tempered by the perception of potential harm to their agro-pastoral practices, with residents giving the example of wild boar damaging crops. A study of wildlife tourists documented the perceived psychological benefits of trips to biodiverse regions of Andalucía and California and of wildlife closer to their homes in the UK (Curtin 2009). Participants generally described highly positive

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psychological, emotional and spiritual experiences: Curtin (2009) noted that the tourists struggled to find adequate words to express the depth of emotion and euphoria resulting from their encounters with wildlife. However, these experiences did occasionally result in negative emotions, such as frustration following missed opportunities or the fear of looking incompetent in front of fellow wildlife enthusiasts. Curtin (2009) concluded that *sharing our world with abundant flora and fauna enhanced day-to-day wellbeing and happiness which in turn has significant psychological and other health benefits* (pp468).

Reflections on the health and wellbeing benefits of biodiverse environments

The aim of this review was to provide a systematic synthesis and assessment of available evidence which examined potential linkages between biodiversity and good health and wellbeing. Despite a purposely broad and inclusive strategy, only 17 primary research studies that stated any intention to examine this relationship were identified. All included papers were published in the past 12 years, originated in the developed world and primarily focused on relationships in western developed countries. The lack of a comprehensive body of research regarding the health and wellbeing benefits of specific environment types, states or conditions has been alluded to elsewhere (Bowler et al. 2010; Lachowycz & Jones 2011).

The synthesis of the results of the 14 quantitative studies conducted using higher order study designs (i.e. of an adequate robustness to reliably indicate relationships, if not actually show cause and effect), showed that there is some evidence to suggest that biodiverse natural environments may be associated with good health and wellbeing. Nine of the 14 studies showed one or more positive relationships. These benefits were manifested in a number of ways: from better mental health outcomes following exposure, to associations with increased health promoting behaviors. The relationships were most evident at a local scale, following immediate encounters or through presumed repeated exposures (e.g. via proximity to residence), and were found across the different study types and approaches. The findings from the 2 qualitative studies suggested that the

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relationships between biodiversity and aspects of health are complicated but that awareness of and mere presence of biodiversity evokes positive feelings. The synthesis demonstrated, however, that much of the evidence is inconclusive (10 of the quantitative studies reported one or more inconclusive findings) and fails to identify a specific relationship or role for biodiversity in the promotion, or otherwise, of better health. Further, there is some evidence (in 2 of the quantitative studies) of negative relationships. Overall, there was no clear pattern of relationship identified in relation to strength and reliability of assessment of biodiversity, study design or to the specific aspect of health and wellbeing considered. The body of evidence is therefore not yet of the extent or strength necessary to uncover mechanisms or characterize the role of biodiversity in relation to health and wellbeing. The review of how the evidence was generated highlighted the lack of robust experimental and controlled designs which could elucidate the specificity, strength and direction of relationships. Much of the available evidence emerged from uncontrolled and observational studies and is therefore of limited inferential power. Whilst the multi-disciplinary nature of the body of existing evidence is interesting and of some value, the small scale and heterogeneity of the body of evidence contributes to uncertainty within the synthesis and leaves many key factors within the relationship unclear.

In terms of ecosystem goods and services, it is not clear through which pathway biodiversity may foster good health and wellbeing (Norris 2011). The global epidemiological studies included in this review indicate a nonlinear relationship at a national population scale (Huynen et al. 2004; Poudyal et al. 2009; Sieswerda et al. 2001). The authors of one of these studies hypothesized that until a certain threshold is reached, loss of biodiversity may not result in direct negative impacts on health or wellbeing (Sieswerda et al. 2001). By linking health to the availability of exploitable natural resources, through for example the provisioning ecosystem services, the authors suggest that developed societies may be able to maintain the sustained levels of consumption which support better health through the use of resources outside of their nations' borders. This potentially further confounds the relationships between biodiversity and socio-economic development (Fisher &

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Christopher 2007). Local scale studies, which predominantly focused on links between biodiversity within the living environment or leisure spaces and self-report wellbeing, suggest that these types of exposure may have more linear and demonstrably positive impacts on health (Dallimer et al. 2012; de Jong et al. 2012; Fuller et al. 2007; Tilt et al. 2007). Mechanisms of impact are likely to include improved quality of life, aesthetics and the provision of preferred spaces for stress reduction and relaxation, factors which may be considered as relevant to cultural ecosystem services (Church et al. 2011). However, the results from preference studies (not included in this review due to having not considered links to health) indicate that this relationship may not be straightforward either, with some variation in preferred environment type according to population characteristics and other socio-cultural factors (van den Berg & Koole 2006).

One of the key issues which may explain some of the variation in the evidence relates to the definition, use and assessment of each of the key concepts addressed. 'Biodiversity', 'health' and 'wellbeing' are somewhat contentious concepts and there is acknowledged variation in application not only between disciplines, but also within (Gaston 2009; Huber et al. 2011). Both 'health' and 'wellbeing' are complex and mutable concepts (Huber et al. 2011) and this is reflected in the variety of health or wellbeing outcomes assessed in the different studies. This heterogeneity raises issues in comparability: is it justifiable to compare evidence based on BMI scores with that based on subjective wellbeing derived from a sense of place? The evidence as to whether biodiversity is related to good health is further confounded by the questionable efficacy and validity of the measures used to assess the health or wellbeing outcome intended.

Further, the approach taken to characterize the physical environment varied greatly and also raises questions regarding the suitability of the approaches taken to the assessment of biodiversity and comparability of differing conceptions and measures of biodiversity across disciplines. It appears that the term 'biodiversity' is not necessarily used according to its formal, scientific definition outside of the biological, ecological and conservation sciences. As with health, various aspects of

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biodiversity were assessed using an assortment of different measures, which may not be cross-comparable or, indeed, valid. The question of cross-study comparability is highlighted by the study by Dallimer et al. (2012) where variance in health outcome according to whether biodiversity was participant or expert assessed was found. Biodiversity is a complex and multi-faceted environmental concept, encompassing many dimensions which may vary in their impact on human health and wellbeing (Fischer & Young 2007; Mace et al. 2012). For instance there may be differing impacts stemming from species richness and abundance, or from ecosystem diversity. Clearly it is not, as the results of this review indicated, as simple as the uncritical assertion, which has been made elsewhere, that greater biodiversity results in better health. Ecosystems with low levels of biodiversity occur naturally, estuaries being one example, but are not associated with adverse health outcomes. Indeed, humans appear to congregate in such localities and may benefit from doing so (Wheeler et al. 2012). Similarly, increase in biodiversity, particularly in urban or amenity landscapes, may have negative consequences for health and wellbeing.

Implications and opportunities for future research

Mace et al. (2012) suggested that new approaches are needed if one is to advance understanding of the role and processes through which biodiversity may promote better human health and wellbeing. At the most basic level this field of study demands truly interdisciplinary research, with integration of social, health and natural sciences. Of particular importance is identifying the specific ecosystem services, goods and processes through which biodiversity may impact on good health and wellbeing. It is likely that the relationships between human health and biodiversity are multi-dimensional and subject to numerous confounders. For example, habitat destruction, pollution, climate change all result in changes in biodiversity, but also affect human health and wellbeing in numerous ways. There is not always a simple relationship between these factors and biodiversity, in some cases biodiversity may be increased while human health is adversely affected. Similarly it is crucial to identify the potential mechanisms through which exposure to biodiverse environments may result in

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biochemical and physiological changes necessary to manifest as improvements in physical and mental health (Depledge et al. 2011).

Future research conducted using the most robust approaches to the assessment of biodiversity and health, with a greater emphasis on longitudinal and experimental designs, making use of mixed-methodologies (i.e. drawing on techniques and approaches from the natural and social sciences, and wider humanities) and with adequate controlling and sampling strategies would strengthen the evidence base and allow for a more nuanced understanding of these complex relationships. In addition the purposeful use of natural experiments, where researchers take opportunities offered though policy change, new projects and programs or other interventions, could provide meaningful and valuable evidence. Regarding specific focus, future research could consider potential variation in the impacts of biodiverse environments in relation to:

- Population type and, in particular, according to certain socio-demographic factors (though it should be noted that socio-demographics were considered as potential confounding factors in a number of the studies (Björk et al. 2008; Luck et al. 2011; Poudyal et al. 2009)). Previous research indicated that the benefits of proximity to natural environments are not distributed equally among socio-economic groups (Maas et al. 2009; Richardson & Mitchell 2010).
- Socio-cultural determinants. Preference studies indicated that environmental responses and perceptions also vary across populations and that this may be driven by socio-cultural factors (van den Berg & Koole 2006). It is feasible that this variation might affect any potential health or wellbeing benefits of biodiverse environments.
- Geographical or landscape context. It is possible that the impacts of biodiverse environments may be mediated by the type of landscape in which the study environment is situated. For instance, although an urban brownfield site may be relatively biodiverse any beneficial impacts may be affected by perceptions of safety, restrictions on use or access, or lack of awareness of

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the value of the particular environment (Angold et al. 2006). Latitude, season or weather may also act as mediatory factors.

- Type and frequency of, and reason for exposure. The majority of the studies included in this review assessed only proximal relationships and were unable to ascertain the relevance of active or passive engagement with an environment. Valuable contextual information regarding frequency and justification of the use of environments was missing from a number of the studies (Barton et al. 2009; Dallimer et al. 2012; Fuller et al. 2007). It is feasible that health benefits may vary between users who travel specifically to an environment for leisure use and people passing through on a daily commute.
- Time frame of impacts. It is not clear when exposure to biodiverse environments might subsequently affect health or wellbeing, nor for how long those benefits might be expected to last.

Concluding observations

Both public health and conservation sciences have called for greater clarity regarding the role of the environment in determining good human health and wellbeing. This review responds through a systematic examination of, first, the nature and state of existing research and, second, the evidence for the direction and characteristics of any links between biodiversity and good human health and wellbeing. It was shown that the current body of evidence is multi-disciplinary and has been produced using a variety of different approaches and methods. Although much of the evidence was inconclusive, 10 of the studies included in this review indicated that exposure to or use of biodiverse environments does have some association with various indicators of better health and wellbeing. However uncertainty remains and relationships are, as of yet, uncharacterizable. The lack of a definitive conclusion as to whether biodiversity is causally related to better health and wellbeing amongst human populations is due to a number of factors: 1) small body of evidence, 2) heterogeneity of research design, methodological approach and measures (both environmental and

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health), 3) suitability of the research design, methods and measures to assess the relationships, and 4) complexity and multi-dimensionality of any link between biodiversity and good health. Currently there is not enough strong and reliable evidence to robustly inform environmental or health policy, however the existing 'weight of evidence' does suggest that there is value in continuing to explore associations between biodiverse environments and good health and wellbeing, and to bear this potential relationship in mind during future policy development.

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Supporting Information

The study protocol may be requested from the author and the search strategy and quality assessments (Supporting material 1 and 2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Abbreviations

BMI	Body Mass Index
NDVI	Normalized difference vegetation index
SF36	Short Form 36
UK	United Kingdom
USA	United States of America

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Tables

Table1. Study characteristics

Study design	Paper	Objectives	Environmental measures/data	Health outcome and measures/data	Population	General result
Experimental	(Jorgensen et al. 2010)	Explored the impact of the complexity of environment on psychological 'restoration'	Simple visual allocation of landscapes according to complexity	Mood (Profile of Mood States) and restoration (Deep Restoration Scale)	UK , students (from single university) age 17-40, n102	No clear relationships – environmental complexity not related to wellbeing indicator
Longitudinal comparative	(Annerstedt et al. 2012)	Explored the impact of the presence of environmental qualities to mental health and physical activity over 5 year period	Scania Green Score: Perceived environmental dimensions. Corine land cover data	Self-report mental health (GHQ-12) and physical activity 'habits'	Southern rural and suburban area of Sweden, age18-80, n24945	No clear relationship - no effects of the more 'biodiverse' environmental dimensions
Comparative and un-controlled before and after	(Barton et al. 2009)	Explored the impacts of walking in high natural value environments	None - some description of sites	Self-report self-esteem (Rosenberg self-esteem scale) and mood (Profile of Mood States)	South-eastern UK, day visitors to sites during sampling period, age 19-70, n137	Positive - time spent in high value environs related to better health scores
	(Björk et al. 2008)	Explored the impact of the presence of preferred environmental dimensions in promoting health and wellbeing	Scania Green Score: Perceived environmental dimensions. Corine land cover data	Self-report physical activity, body mass index, physical and psychological health, and 'vitality' (SF36)	Southern rural and suburban area of Sweden, age 18-80, n24819	No clear relationship - but dimensions associated with greater species diversity related to better health

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(Dallimer et al. 2012)	Explored the role of species richness in riverine environments in promoting health/wellbeing	Bird, butterfly and plant species richness; Habitat diversity; Tree cover; Perceptions of species richness and the ability to identify common riparian wildlife.	Self-report psychological wellbeing	Sheffield UK, age 16-70+, users of green spaces during sampling period, n1108	Generally positive - greater species diversity related to wellbeing though some individual results indicated no or negative relationships
(de Jong et al. 2012)	Explored associations between environmental dimensions and three self-report indicators of wellbeing: neighbourhood satisfaction, physical activity and general health	Scania Green Score: Perceived environmental dimensions. Corine land cover data	Self-report neighbourhood satisfaction, physical activity and general health	Southern rural and suburban area of Sweden, age18-80, n24847	No clear relationship - one dimensions indicating greater species diversity associated with physical activity, another dimension negatively associated with neighbourhood satisfaction
(Fuller et al. 2007)	Explored the benefits of species richness in urban green space to human wellbeing	Plant communities; Butterfly diversity; Bird species; Perceived diversity (plant, butterfly, birds); Habitat diversity; Tree cover	Self-report psychological wellbeing	Sheffield UK, age 16-70+, users of green spaces during sampling period, n312	No clear relationships for most results but some positive relationships, with greater species diversity related to better wellbeing
(Grahn & Stigsdotter 2010)	Attempted to identify the 'dimensions' of nature people prefer and use for stress-relief	Perceived environmental dimensions	Self-report physiological and mental health and wellbeing	Central and southern urban areas of Sweden, adult (age not given), n733	No clear relationship - 'biodiverse' environments not preferred by those experiencing stress

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	(Luck et al. 2011)	Examined the relationships between biodiversity and residents' personal wellbeing, neighbourhood wellbeing, and connection to nature.	Species richness of birds; Abundance native birds; Vegetation cover; Understory, midstory and overstory cover; Impervious surface cover	Self- reported personal wellbeing; neighbourhood wellbeing; neighbourhood activity level; general activity level	Urban neighbourhoods in Victoria and New South Wales Australia, age not given, n3545	Some (weakly) positive relationships - greater species richness associated with better personal and neighbourhood wellbeing
	(Tilt et al. 2007)	Examined the influence of vegetation on walking trips and body mass index	Normalized difference vegetation index (NDVI); self-report natural features	Frequency of walking trips; BMI	Urban neighbourhoods in Seattle USA, age not given, n529	No clear relationship - measure associated with greater species richness associated with one indicator of better health though not with another.
Secondary analysis of aggregate data	(Huby et al. 2006)	Explored the integration of natural and social sciences data to understand relationships between environment and society (of which mental wellbeing was considered a factor)	Bird species richness; Percentage area covered by National Park 2001; Percentage area covered by Areas of Outstanding Natural Beauty 2005; Percentage area covered by Sites of Special Scientific Interest 2005; Percentage area covered by Special Protection Area designation	Mental health deprivation indicator score of English Indices of Deprivation	Residents of rural England aggregated (at Super Output Area level), no age or n given	Positive – indicators of biodiversity were associated with mental wellbeing

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	(Huynen et al. 2004)	Explored the association between health and biodiversity loss at a global scale	The proportion threatened species as percentage of known species; Current forest as percentage of original forest; Percentage of land highly disturbed by human activities	Life expectancy at birth; Infant mortality rate; Incidence of low-weight babies; Disability Adjusted Life Expectancy (DALE) calculated at birth.	Global populations	Majority of results showed no relationship but some were negative – greater biodiversity had an inverse relationship with health and wellbeing
	(Poudyal et al. 2009)	Examined how environmental factors relate to health and wellbeing in USA	Distance in mile to the nearest entrance of national park from the county centroid	Life expectancy	USA population	Positive - distance to national park (proxy for exposure to biodiverse environment) related to life expectancy
	(Sieswerda et al. 2001)	Examined whether global life expectancy is linked to large scale declines in ecological integrity	Percentage of land highly disturbed by human activities; Percentage of threatened species; Percentage of landmass total or partially protected; Percentage of forest remaining since pre-agricultural times; and the average annual change in forest cover.	Life expectancy	Global populations	No clear relationship – no association between indicators of biodiversity and health and wellbeing measures
Cross-sectional survey*	(Lemieux et al. 2012)	Explored the perceived health and wellbeing outcomes associated with visiting protected areas.	None- good description of study sites (both IUCN category II)	Self-report perceived health and wellbeing	Ontario and Quebec, Canada, visitors to protected areas during sampling period , age 19-66+, n166	Positive – perception that visiting sites associated with psychological/emotional and social benefits

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Qualitative participatory	(Pereira et al. 2005)	Explored the links between ecosystem services and human wellbeing from the perspective of a rural mountain community in Portugal	Assessed biodiversity known to local residents	Community defined measure of wellbeing (criteria: very important to unimportant for a good life)	Sistelo region of Portugal, local residents, age not given, n86	No clear relationship –both positive and negative impacts to wellbeing were reported
Ethnographic	(Curtin 2009)	Explored the psychological benefits of wildlife tourism to bodiverse environments	None - some description of sites	Psychological impacts	Anadalucia, Spain and Sea of Cortez, Baja California, wildlife tourists, age 30-70+, n20	Positive - experience of wildlife in biodiverse environments results in perceived positive psychological experiences

*Study design not suitable for inclusion in the synthesis of results

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Table 2. Trend of results by study type

Study type	**Some/all results positive** ***Greater biodiversity associated with better health (and vice versa)***	**Some/all results show no relationship or unclear** ***Could be -/+ or no relationship***	**Some/all results negative** ***Greater biodiversity is not associated with better health (and vice versa)***
Experimental		(Jorgensen et al. 2010)	
Longitudinal survey		(Annerstedt et al. 2012)	
Comparative and un-controlled before and after	(Barton et al. 2009) (Björk et al. 2008) (Dallimer et al. 2012) (de Jong et al. 2012) (Fuller et al. 2007) (Luck et al. 2011) (Tilt et al. 2007)	(Björk et al. 2008) (Dallimer et al. 2012) (de Jong et al. 2012) (Fuller et al. 2007) (Grahn & Stigsdotter 2010) (Tilt et al. 2007)	(Dallimer et al. 2012)
Secondary aggregate data analysis	(Huby et al. 2006) (Poudyal et al. 2009)	(Huynen et al. 2004) (Sieswerda et al. 2001)	(Huynen et al. 2004)
Participatory qualitative		(Pereira et al. 2005)	
Ethnographic	(Curtin 2009)		

Papers may be included more than once if variation in individual results.

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Table 3. Trend of results (where relevant) by health and environmental measure

	Health measure		
Environmental measure	**Objective health outcomes (life expectancy etc)**	**Self-report, survey measured general physical, mental or social health and wellbeing**	**Self-report behaviour measures (e.g. physical activity)**
Area or distance based secondary data proxies for degraded environments	(Huynen et al. 2004) (--ooooooooo) (Sieswerda et al. 2001) (o)		
Area/distance based secondary data proxies for protected or high biodiversity environments	(Poudyal et al. 2009) (+) (Sieswerda et al. 2001) (o) (Tilt et al. 2007) (+)	(Huby et al. 2006) (+)	(Tilt et al. 2007) (o)
Primary ecological surveys or classification		(Dallimer et al. 2012) (++++o-) (Fuller et al. 2007) (++++ooooooo) (Luck et al. 2011) (++)	
Exposure to environments defined by perceived environmental dimensions		(Annerstedt et al. 2012) (o) (Björk et al. 2008) (o) (de Jong et al. 2012) (+o) (Grahn & Stigsdotter 2010) (o)	(Annerstedt et al. 2012) (o) (Björk et al. 2008) (+) (de Jong et al. 2012) (+) (Tilt et al. 2007) (+)

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Investigator reported biodiversity	(Jorgensen et al. 2010) (o)
No assessment	(Barton et al. 2009) (+++)

Each '-,o, +' symbol represents the direction of each individual result reported in the paper. Papers may be included more than once if variation in individual results.

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