Ecosystems and human health: towards a conceptual framework for assessing the co-benefits of climate change adaptation

Pablo Martinez-Juarez, Aline Chiabai, Sonia Quiroga Gómez
and Tim Taylor

April 2015

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Ecosystems and human health: towards a conceptual framework for assessing the co-benefits of climate change adaptation

Pablo Martinez-Juarez[a], Aline Chiabai[a], Sonia Quiroga Gómez[b] and Tim Taylor[c]

This paper focuses on the impact that changes in natural ecosystems can have on human health. Green and blue areas promoted as adaptation measures may provide a wide range of co-benefits which should be taken into account when designing adaptation options. Otherwise sub-optimal policy may result. Here we first present an overview of some key adaptation measures, their possible impacts on the natural environment and associated health implications. Second, we discuss the benefits associated with the exposure to green and blue areas and build a theoretical framework for analysing co-benefits of adaptation to climate change, where such adaptation affects the natural environment. Third, we present an overview of the key literature addressing the relationship between health and exposure to natural environment, while classifying the studies according to the methodological approaches, and discussing main results and key issues. Results in the literature show a positive correlation between health and green areas, while blue areas have attracted less attention. The wide range of differentiated approaches in the literature highlights the need for an integrated conceptual framework to assess the health co-benefits of adaptation that interrelates with the natural environment. We provide the basis for such a conceptual framework that allows identifying the different aspects of this interaction.

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[a]Basque Centre for Climate Change (BC3), Bilbao

[b]Department of Economics, Universidad de Alcalá

[c]European Centre for the Environment and Human Health, University of Exeter Medical School

1. Introduction

The natural environment is the foundation of human health, as clean water and air, recreation and appropriate environmental management are all crucial for public health. Moreover, direct contact with nature contributes to improved immune system functioning, mood and concentration, while reducing stress and increasing the benefits of physical exercise. Non-communicable diseases (NCDs), such as heart disease, diabetes, cancer, and chronic respiratory illnesses, are now a global health epidemic. More than 36 million people died in 2008 from NCDs, and the impact is projected to increase to 44 million by 2020, with higher vulnerability in urban areas and among economically disadvantaged groups (WHO, 2011). Prevention of NCDs can be done through lifestyle, some of which can also benefit urban biodiversity and a better adaptation to climate change.

The relationships between human health and the environment extend beyond the mere absence of illness; rather, they involve a holistic approach of health, defined by the World Health Organization (WHO) as "a state of complete physical, mental and social well-being." The introduction in 1948 of this definition implied therefore a positive approach to human health, while maintaining the lack of disease a relevant factor, which was an important breakthrough. The same document that introduces this definition, the foundational document of the WHO, acknowledges the importance of involvement of governments not only for the provision of health services, but by introducing different kinds of health and social measures. Among the prerequisites stated by the WHO in the *Ottawa Charter* (WHO, 1986), appear factors such as peace, adequate economic resources, food, and both a stable ecosystem and sustainable use of resources. The means by which ecosystems and biodiversity affect human health play therefore a crucial role in this context. Another interesting factor highlighted by WHO is the role of equity, or fairness, introduced by WHO's *Equity in health and Health Care* (Braveman and Gruskin, 2003) and related to the distribution of opportunities for the wide definition of health.

More than 65 years have passed since the creation of the WHO and the definition of health given by this institution, and some have advocated for the revision of the term's given meaning (The Lancet, 2009; Huber et al., 2011), while some even express the thought that defining health has become futile (Jadad and O'Grady, 2008). One of the arguments stated by these critics is based on one of the main characteristics of health in the 21st century, chronic disease (WHO, 2014). Alongside with this question Huber et al. (2011) are also critical with issues such as medicalization of society in order to attain the level of "complete" well-being, as well as the lack of functionality in the definition. They also argue in favour of considering changes in the demographical structure in order to deal with the new challenges for human health. But probably the definition most in line within the scope of the present study is the one that includes, among the physical, mental and social dimensions of well-being, the links to biodiversity and to the inanimate environment (The Lancet, 2009). Among the suggested definitions, a concept of health based on the interaction between the individual and its environment has also been proposed, where health is a consequence of a successful interaction while failure on adaptation leads to illness (Larson, 1999). The impact that changes in natural ecosystems can have on human health is analysed in the present paper within a context of adaptation to climate change. The paper focuses specifically on green and blue areas promoted as adaptation measures, the types of benefits they can provide and how the latter link with human health.

Green areas can be defined in different ways according to the different contexts and scopes of the use. What is common to all definitions is the presence of vegetation that makes the space 'green'. Public access to these areas is also a common feature, even if access does not imply a literal sense of presence, but different levels of involvement, from contemplation to that of rural dwellers. In this case we will not set further limits to the definition, as we will consider both urban and rural contexts,

regardless of their size or their environmental value. In an analogous way, blue areas are defined by the presence of accessible water, be it marine or fresh water. Again this concept will not be subject to further limits, though the studies reviewed were largely set in coastal environments.

Green spaces, as well as blue areas, can promote many beneficial effects or co-benefits. A first set of benefits is linked with the reduction of pollution and climate change impacts. These include a cooling effect in cities during heat waves, improvements in air quality due to capture of particulate matter pollution, and reduction of noise pollution by absorbing and deflecting sound. A second set of benefits comes from the nature itself and includes improvements of the ecosystem quality, through a better regulation of water or improved water purification for example. Appropriate valuation of these ecosystem services could lead to more sustainable management of natural resources. Thirdly, there are benefits related to social factors, such as the promotion of active lifestyles which contributes to reduced obesity and increasing longevity, the reduction of health inequalities, as well as improved community cohesion, sense of identity, education and learning. A fourth group of benefits relates to the possibility of enjoyment through recreational activities and rural tourism. These benefits are connected with the economy through the development of tourism, wellness centres, and similar. Finally, the last set of benefits would come from microorganisms. The so-called 'old friend theory' states that symbiotic relations with microbiome allow our immune system to develop correctly (Rook et al., 2014). Lack of contact with ecosystems would obstruct the spread of microorganisms in the human body (Rook, 2013).

All these benefits translate into beneficial effects on human health, which is affected in different ways. For example, air pollution and heat waves cause a deterioration of pre-existent cardiovascular and respiratory diseases in the elderly especially, so that any improvement of air quality or reduction of the outdoor and indoor heat will have a beneficial effect on health. Furthermore, the simple contact with nature promotes many benefits on health. Besides the positive effects on the cardiovascular and respiratory systems, we mention the reduced risks of dementia and mental stresses, obesity (through a more active lifestyle) and diabetes. Life expectancy is generally increased and mental health is improved due to the calming and restorative effects of nature. An appropriate level of exposure to microorganisms by the human body is also necessary for its own adaptation to external influences such as allergens. Other health benefits are more indirectly linked with a healthy environment, and are related to the reduced risk of mortality and injuries due to flooding for example.

The first objective of this paper is to discuss the benefits associated with the exposure to green and blue areas and build a theoretical framework for analysing co-benefits of adaptation to climate change where such adaptation affects the natural environment. Second, we present an overview of the key literature addressing the relationship between health and exposure to natural environment, while classifying the studies according to the methodological approaches used, and discussing main results and key issues.

The paper is organized as follows. Section 2 discusses a theoretical framework for analysing the co-benefits related to green and blue environments within a context of adaptation to climate change. Section 3 discusses the evidence on the linkages between health (and wellbeing) and the natural environment. Finally, Section 4 discusses next steps and main conclusions.

2. Natural ecosystems and human health: a conceptual framework

Climate change adaptation is an important issue for planning and development in urban and rural areas in Europe. Actions to adapt through the natural environment may have significant co-benefits in

terms of health. These may arise from factors such as changes in activity levels or improvements in environmental quality – or following a number of other pathways. In recent years there has been an increasing amount of research addressing the relationship between green and blue areas and health. This relationship has been perceived by societies for a long time, but research about the nature of this relation (i.e. investigations about the causes, scope and its effects) has been carried out in the last three decades, since the first paper observing better post-surgical recovery rates in patients with access to windows (Ulrich, 1984). Results in the literature show a positive correlation between health and green areas, though there is a clear need for a detailed explanation of the processes involved in this, while the effect of blue areas has attracted less attention. The wide range of differentiated approaches taken in the literature in this area highlights the need for an integrated conceptual framework to assess the health co-benefits of adaptation that interrelates with the natural environment. The aim of this section is to provide the basis for such a conceptual framework that allows identifying the different aspects of this interaction.

The starting point of the framework is the set of adaptation measures designed to reduce the impact of climate change. Among them we take the spread of green and blue areas and analyse the health benefits that they provide. These benefits are linked to a diverse group of mechanisms that we have classified in five sets of benefits. They may have a direct impact on human health or interact in one way or another with the social, demographical and economical context as well as the habits of the individual before affecting his health.

The challenge of adaptation to climate change includes the need to respond to increased temperatures, increased precipitation and extreme events (including floods and heat waves). Both "hard" and "soft" adaptation options exist for this purpose. Hard paths for adaptation may have significant impacts on the quality of the natural environment, while requiring inflexible and capital intensive technologies and the use of non-renewable resources. The protection of green and blue areas is regarded as a "soft" measure, but it may also help to avoid some of the negative impacts of hard adaptation measures. An example would be the development of sustainable water management and flood control systems by creating green areas along waterways.

An overview of some key adaptation options, their possible impacts on the natural environment and associated health implications is given in Table 1 below. It is important that the assessment of adaptation options takes into account these co-benefits, as otherwise sub-optimal policy may result. Health benefits may not be the primary reason for adaptation – e.g. in the case of sustainable urban drainage systems (SUDS) reduction in material damage from flood risk may be the major target, but appropriate design of adaptation should take into account the health benefits as well. In the case of flood defences, a path may be constructed at the same time as the defence is built to ensure that it provides other kinds of benefits.

Table 1: Adaptation, the natural environment and health implications: some examples

Adaptation measure	Possible impacts on natural environment	Potential health implication
Sustainable urban drainage systems	Potential for green corridors for recreation	Possible increase in recreational walking and cycling, improved physical and psychological health
Green roofs	Potential improvement in views, potential increase in biodiversity	Possible improved psychological health
Flood defences	Potential to provide paths for walking	Possible increase in recreational walking and cycling, improved physical and psychological health
Emergency warning systems	Limited potential to reduce impacts	Direct impacts in terms of reduced mortality and morbidity
Improved wetlands for flood defence	Increased coverage of wetlands and biodiversity benefits	Possible increase in recreation
Urban forests	Increased coverage of forests in urban area, cooling and biodiversity benefits	Reduced heat stress and potential for increase in recreational walking and cycling, improved physical and psychological health

Source: authors

Green and blue areas promoted as adaptation measures provide a wide range co-benefits which can be classified in five main categories that serves as a pathway in the interaction between natural environment and human health. The five sets of benefits are also linked with the concept of ecosystem services, which are defined as the benefits that people derive from the ecosystem (Daily et al., 1997).

Figure 1 shows the proposed framework that summarizes the five paths by which green and blue spaces are meant to affect health and wellbeing.
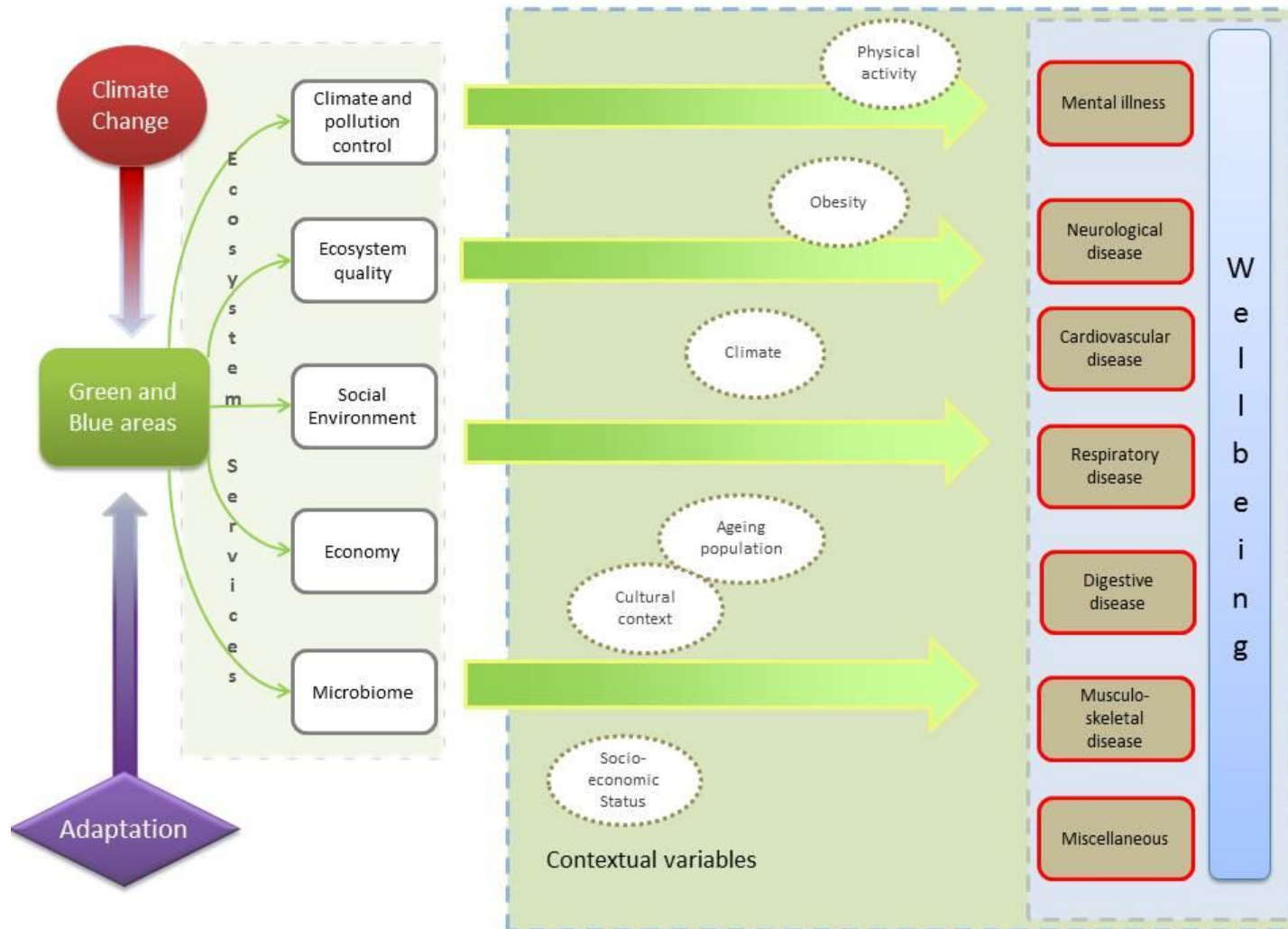
Figure 1: Natural environment and health co-benefits: A conceptual framework

The first set of benefits identified by this framework relates to the prevention of the effects of climate change and different forms of pollution. Some of the most important impacts are derived from changes in temperatures. Heatwaves are a source of potential losses in terms of health, especially in an urban context and for certain social groups, including ageing population (Tobías et al., 2014). Urban green and blue areas may help to solve this problem by a cooling effect than could be around one degree on average for urban green spaces (Bowler et al., 2010). Another benefit provided by green areas in events such as excess precipitation would be the retention of water. Absorption through soil and canopies can play a role in diminishing the hazard of floods. Reduction of flood impacts could also be obtained through the retention of debris. Green areas can serve as an adaptation measure in a short term scenario (Opperman et al., 2009), especially in plans involving sustainable flood management and Ecosystem-Based Adaptation (EbA) (UNEP, 2014).

Urban pollution is also another cause of health problems that takes special part in urban ecosystems (Gordian et al. 1996; Pope et al. 2002). Green areas can help to capture some of the particles that cause health problems, even if it is also suspected that particulate retention may be just temporal (Ould-Dada and Baghini, 2001). Acoustic pollution has also been identified as a health problem, not only with respect to potential loss of hearing capacity (Stansfeld and Matheson, 2003). In this context, urban green areas can help relieving the stress by a psychological reduction of its impact (Yang et al., 2011).

The second aspect to be regarded is the impact on the quality of the ecosystem. For example, well-functioning wetlands play a big role in water regulation, both on the sides of supplying water and improving its quality. Their capacity to store and treat waste water avoids eutrophication of other ecosystems providing therefore a cleaner environment. Green areas also provide aesthetic values that can potentially relieve from stress and improve mental health (Hansmann et al, 2007), especially among the elderly (Takano et al., 2002). The mechanics are yet to be determined, though Attention Restoration Theory (ART) —which concentrates on the ability of human to focus their thoughts— has been mentioned by some authors (Kaplan 1995; Berman et al., 2012 Hansmann et al., 2007) while others employ a psychoanalytical approach (Rose, 2012).

A third set of benefits relates to the social aspects of health or social environment. Public open green and blue spaces may have various forms of interaction with health also in these aspects. Active lifestyle promotion (Giles-Corti et al., 2005) and the development of social networks may play an important role as underlying factors in capturing such benefits from green and blue spaces (Maas et al., 2009). The relation between health inequalities and the green environment has been also observed, notably by Mitchell and Popham (2008). Mitchell and Popham, based on English data, found a negative relationship between green spaces and health inequalities, which means that deprived socio-economic groups may benefit in greater degree from health benefits of nearby green areas, which would narrow the gap in health issues among income groups. Germann-Chiari and Seeland (2004) found that urban green spaces are not optimally distributed in terms of social cohesion in the case of Swiss cities. Among other aspects analysed in this context the matter of access to parks has also been discussed (Cohen et al., 2013).

The fourth cluster involves the effects generated through the development of economic activities. An important example of this would be the effect that ecosystems have on tourism. An example is given by the Spanish IMSERSO program which promotes social tourism among senior citizens (Molina Hoyo and Cánovas Valiente, 2013). The conjunction between social tourism and ecotourism might bring important health and wellbeing benefits, especially among vulnerable groups (McCabe et al., 2010). Promotion and development of new forms of tourism would have an impact on a region's economy. Evaluation of the economic impacts from green areas go further than the

financial benefits of activities related to them, but must take into account all benefits provided. Recreational activities performed in a park, for example, do not necessarily imply market transactions, but have an impact on wellbeing. Methodologies that evaluate these impacts have been developed and discussed in the economic literature, and include approaches that value environmental goods through alternative markets known as revealed preferences (such as the costs of visiting a place or the costs of restoring it after its loss), or stated preferences (such as the willingness to pay of individuals to maintain the good or the willingness to accept a compensation for the loss of the good).

Finally, there are the benefits that can be derived from the contact of humans with different microorganisms. An increasing number of diseases affecting urban populations in developed regions are related to problems in immunoregulation and regulation of inflammatory responses (Rook, 2013). The microbiome is present in most of the human body (Proctor, 2011), it affects in many cases physiological health, and it does so in different ways (Bisgaard et al., 2011; Huffnagle, 2010) through complex interactions (Clemente et al., 2012). There is still much work to be done, as research in human microbiota is restrained by the difficulties of laboratory analyses of most of these organisms (Han et al., 2012). Aseptic environments, most easily achieved in urban contexts, could block the set of processes that are triggered by these commensal organisms, among them the development of tolerance to some of the organisms themselves, case that generates some of the most common health problems in the developed world according to the WHO[1]. According to the text of Rook (2013), exposure to natural environments and green spaces, along with the microecosystems, would help the correct development of human immune system. There are, of course, also potential risks from exposure to certain microorganisms, for example the potential for infection, including antibiotic resistant bacteria (Wellington et al., 2013).

All these five elements have an unequal effect among the different dimensions of human health and wellbeing. The decomposition of health into different clusters responds to the need to identify these patterns of interaction. It must be also noted that intermediate paths can be also identified and must be taken into account.

This framework draws on the ecosystems enriched Driver, Pressure, State, Exposure, Effect, Action (eDPSEEA) model (Reis et al., in press) and explicitly includes changes in ecosystem services and their impact on human health and wellbeing.

The drivers include climate change, as well as other more standard drivers such as population growth. These put pressure on green space, leading to a potential change in the amount or quality of that space (the "state"). This might lead to a change in the provision of ecosystem services, which will affect the use of or perception of the site (the "exposure"). Depending on a range of contextual factors, which may include the socio-economic characteristics of the impacted group – e.g. incomes, ages, beliefs – and environmental factors – e.g. baseline climate, availability of alternative sites – these changes may impact on health either directly or indirectly (the "effect").

Policy actions may be used to increase health co-benefits arising from climate change adaptation, and may fall at any stage in the process. For example, educational activities may increase the responsiveness of individuals to improvements in the state. An action to give better training to the elderly in physical activity may lead to improved health outcomes. Adaptation itself may be seen as an action, if climate change would otherwise lead to impacts on the green space.

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[1] http://www.who.int/chp/en/

The framework shows the interactions between green and blue adaptation measures and human health. We can see the different types of linkages, both theoretical and empirical, that can be found in the literature. The framework is centred on the interactions between green and blue areas, regarded as adaptation measures, and health. On it, health issues have been grouped according to the different definitions, sights and dimensions analysed by the literature.

Specifically for the construction of this framework we have classified health impacts based the same seven clusters as Maas et al. (2009). This allows us to specify how different sets of co-benefits affect human health and wellbeing through diverse aspects of health. The cleaning of the atmosphere from particulate matter and gases such as SO_2 or NOx can, for example, affect health through the reduction of respiratory diseases and probability of developing cancer (Ohshima and Bartsch, 1994). It must be noted that various species of plants may also have a negative impact on health, as they can trigger allergies through their pollination process. On the other hand, there have been studies that link the visit to parks to a reduction of migraines (Hansmann et al., 2007), which would be related to the provision of recreational use of ecosystems. A straightforward cause of an improvement would be the reduction in stress. Some of the studies have paid special attention to the effects of green areas over the health of deprived communities (Thompson et al. 2012; Mitchell and Popham, 2008). Increased economic output can also lead to an increase of the resources allocated to healthcare. Other effects may be regarded as ambiguous. As plants can also spread allergens while they retain contaminants, the microbiome may have both good and bad effects over human health. The presence of microorganisms can cause a wide range of effects on human wellbeing, from immunoregulatory functions (Rook, 2013) to bacterial caused diseases. Immunoregulation and allergy would have important effects on respiratory illnesses (Rook, 2013; Huffnagle, 2010), while microorganism-caused diseases affect many physiological functions, though not all the interactions could be related to the presence of ecosystems (Han et al., 2012; Clemente et al., 2012).

Contextual variables may be important, including factors of socioeconomic status of the impacted demography, the age profile of the population, the baseline climate and existing levels of health issues including obesity. The role of these aspects may vary, ageing can have a negative effect on health through increased risks of some illnesses such as mental health or cardiovascular diseases, while obesity may affect gastric and respiratory functions as well as the cardiovascular system. Active lifestyle can by itself generate improvements in a wide range of health aspects, but will also reduce the impact of ageing and obesity, though it can have both positive and negative impacts over the musculoskeletal system. There are also relations among these variables, such as the decrease of obesity generated by active lifestyles and the reduction of some of the negative effects of ageing. Ageing, in any case, can be a factor generating a decrease in physical activity. These aspects are related to green areas through different links. Active lifestyles can be considered a product of cultural ecosystem services, as it has been theorized that aesthetically appealing environments may enhance the performance of different activities (Richardson, 2013). The level of involvement on active lifestyles can also be affected by air quality, as contaminants may dissuade individuals from participation in physical activity. The pathways between green areas and the negative effects of ageing are not clear in the literature. The positive effect on health of senior citizens provided by the fact of having a place for a stroll near their residence (Takano et al., 2002) can be regarded as an ecosystem service. The social involvement may also play a role on the impacts of ageing on human wellbeing, as active communication and preference of life in the same community are related to survival rates among the elderly (Takano et al., 2002).

These aspects have been labelled as contextual factors, as changes from baseline levels affect health outcomes. Social, economic and demographic characteristics not only influence health, but also

affect the way in which green space interacts with it. The evolution of demographics, as explained previously through the case of ageing population, may require a special focus. This may particularly be true for vulnerable socioeconomic groups, such as migrant populations and poorer groups, among others.

3. Benefits of green and blue areas and healthy environments: evidence from the literature

In order to study the relationship between green and blue areas and health, a wide variety of methods have been used in the literature. These studies are based on different methodologies and approaches where three aspects are usually involved.

The first aspect is the degree of involvement of the individuals with nature; this issue can be measured through different indicators including the distance from the residence of the study participant to the nearest green area, the percentage of green space in a defined area from the residential point or a measure of the presence of green in a certain neighbourhood. Geographic Information Systems (GIS) play a major role in the development of more accurate ways to deal with this question.

The second aspect is the statistical technique employed, where there are a great variety of choices again, going from the simple comparison of different experimental and control groups to more complex econometric analysis and Monte Carlo simulations for sensitivity analysis.

The third aspect is the health outcome, which can be measured through two types of data: objective data and self-reported measures of health.

The studies employing objective data can be referred to as objective analysis. This approach uses data from physiological measurements and statistical databases from governments and medical authorities based on objective indicators. We can find indicators referring to the impact of diseases measured in an objective manner, such as one-year persistence of different illnesses, incidence ratios or odds of hospitalization among others. Other measures can also be used that do not measure illness *per se* but an important proxy (e.g. cortisol levels or brainwave activity).

A second subset of studies that we name self-reported health approaches use the second type of data, which are gathered through questionnaires. This approach has been applied in a number of contexts, though there are important variations among studies. The observations obtained through these measurements usually depend on the questionnaires completed by participants of the study about their perception on general health, and specific aspects concerning a specific illness or wellbeing. Other health issues questioned by researchers may include related aspects such as degrees of physical activity or other habits related to well-being and health, including a healthy diet. Interviews may also include questions about other variables such as involvement with nature, leisure or socioeconomic characteristics. Although self-reported measures exhibit a number of biases, they have many advantages when analysing subjective perception and psychological health.

A third group of mixed approach studies combines both objective and self-declared health levels.

Many studies have empirically analysed the effects of green spaces on human health using some of the methodologies described above. The main problem shown by the literature review is the heterogeneity of methodologies used, as well as the variety of outcomes analysed, which requires a case-by-case description of both methods and results and may impact on comparability of studies. It

must be noted that these studies have been selected among a wide literature. We do not intend here a systematic review, but to give insights into the key studies conducted in the field.

Following the classification above, we first discuss studies that use objective measurements of the health outcome, including those that use proxy values. A second group gathers the analyses made through self-reported health measures. And finally, we present examples of the mixed approach analysis which perform a double analysis employing both objective data and self-reported health measures.

3.1 Objective analysis

Within the objective analysis, one of the most extended approaches was taken in the study performed in the Netherlands (Maas et al., 2009). The analysis was performed with data of almost 350 thousand Dutch residents (n = 345 143). The study relies on objective indicators reporting levels of health. In this case, the dependent variable was structured around the 1 year prevalence of all diseases detected in the records of a number of general practitioners in the Netherlands. These diseases were grouped in 24 distinct clusters which were classified into 7 groups (Cardiovascular, musculoskeletal, mental, respiratory, neurological, digestive and miscellaneous). Involvement with ecosystems was calculated according to the percentage of green space in the area within a 1 or 3 km radius from the postal code coordinates. A ratio was calculated between the base probability of prevalence of the disease on one side and the probability when green space was increased by 10%. A fall was observed in 23 of the 24 clusters when analysing the 1km radius, this decrease was significant in 15 of the cases, affecting all of the seven groups above mentioned. When taking into account the calculations performed for the 3 km radius, significant falls were observed in only 3 of the clusters (anxiety disorders, infectious diseases of the intestinal canal and medically unexplained physical symptoms).

Another interesting example raises the question about the importance of the effects of dense urban environments in determining optimal public space development. In this context, Takano et al. (2002) studied the effects of different kinds of environmental features that might affect longevity in senior citizens of densely populated cities: Tokyo in this case study. 3 144 individuals born in 1903, 1908, 1913 or 1918 consented to a follow up process that studied their five year survival rate. The research analysed a varied set of environmental aspects related in some degree with the presence of green areas. These aspects included the presence of space for taking a stroll, urban greenery such as parks and tree lined streets, noise (from roads or industry), safety of the area, sunlight hours, the presence of a garden in the residence, the existence of an adjacent road used by a bus line, social aspects related to social interaction and willingness to stay in that specific community. Results presented different degrees of significance for each of the variables. The presence of space for taking a stroll, the amount of sunlight hours and satisfaction with the community were found to be strongly correlated to the survival rate, while the presence of urban green elements had a much lower statistical significance. Results also depend on gender: noise reduction was found highly significant among males but not among females. On the other extreme, active communication was only found to be significant for female individuals.

Hu et al. (2008) performed their analysis in the Escambia and Santa Rosa counties in northwest Florida. The study aimed to find the relation between different environmental variables and stroke mortality. This research used geographical information data on pollutants, income and greenness. The data were analysed through a Bayesian hierarchical model and contrasted by 95% confidence intervals through Markov Chain Monte Carlo simulations. The study found a significant positive relation between health and all variables of air pollution considered (i.e. traffic air pollution effect, emission density of point source polluters monitored in the area and simple point density of

point source polluters). For the aspects of income and greenness, the relation was inverse: an increase in the income or will likely to reduce the risk of deadly strokes and the same apply for an increase in the green areas.

Some studies do not only analyse health itself, but address related issues such as health inequality. For example, Mitchell and Popham (2008) focus on the proportional difference in incidence of a certain type of mortality (circulatory diseases) and overall data represented by all-cause mortality. The study sample was based on English population younger than retirement age, which was divided in a dimension of income deprivation (4 groups) and of exposure to green areas (5 groups). The study observed that the Incidence Rate Ratio (IRR), that is the proportion of mortality between two socio-economic groups, varied according to the exposure to green area. The reference group taken was the least deprived, and the IRR between most and least deprived groups was 1.93 in the least green areas. This ratio diminished to 1.43 in more green areas. This result was found significant. In the case of circulatory disease, the IRR moved from 2.19 in least green areas to 1.54 in most green areas. Again, these results suppose a significant reduction on the differential of mortality between most and least deprived groups in England.

As we have mentioned before, measurements of the health outcomes not only depend on the measurement of physiological benefits, but may also rely on proxy variables. An example of this could be the consumption of different kinds of medications, measured trough the amount of prescriptions. This way of measuring has been used to track the possible increase of suffering anxiety, depression or psychosis in urban environments (McKenzie et al., 2013). The difference in the consumption patterns of specific psychotropic medication used to fight anxiety, depression and psychosis was measured. McKenzie et al. (2013) constructed a classification to measure urbanity, which identified six categories ranging from the most urban to the most rural. Socioeconomic variables were included in the study, such as income, employment, education and recorded crime. The results showed a significant positive correlation between urban environments and anxiety, depression and psychosis. The study also suggested a reduction in medication use in rural environments.

Other kinds of approaches have been used, such as the analysis of body activity, including brain wave activity (Yang et al., 2011), instead of the direct disease-based approach. Yang et al. (2011) performed two different analyses in a controlled experiment. The individuals were 20 male and 20 female students from Zhejiang Forestry University ranging ages from 21 to 25. The study analysed the brainwave activity of the group members with an electroencephalogram (EEG). The individuals were subjected to noise stimulation while different images were displayed to them through video glasses, one showing traffic while the other involved green elements. It was observed that both beta-1 and beta-2 waves were significantly more stimulated by noise in those observing the traffic scene. Reaction of alpha waves showed no significant difference between the traffic scene group and the green space group. Theta and delta waves also showed no significant difference between traffic and landscape groups.

Another indirect source of information about health used in studies in this area is the analysis of cortisol in individuals. This approach was undertaken by Thompson et al. (2012) to analyse the linkage between green spaces and stress patterns in deprived communities. Thompson et al. (2012) analysed people not in work due to different reasons in the city of Dundee, Scotland, with the aim of finding whether the quantity of green spaces in the environment around people's homes was related to stress in deprivation conditions. Stress was measured not only via cortisol secretion levels, but also by self-reported scales that ask for stress and general wellbeing. 25 participants were involved in the study, though complete data was only obtained for 20 of them. Measurement of green space was based on the percentage of green space present in each of Dundee's 31 wards. The study analysed the

mean value and the slope of the cortisol presence pattern during 3 to 12 hour period post-awakening. A higher mean value was correlated with a steeper slope of the evolution and with greater wellbeing, but it was not statistically significant in relation with other measures taken into account such as physical activity, reported stress or presence of green. Steep cortisol slopes were related to all the measures, showing correlation with increased levels of wellbeing, physical activity and presence of green space, while the relation with self-perceived stress was the inverse.

3.2 Self-reported health approaches

Within the second group of studies focusing on the self-reported health approaches, Van Herzele and De Vries (2012) compare the levels of self-reported physical activity, health, stress and well-being depending on green space and accessibility. This study took two neighbourhoods from the city of Ghent, in Belgium, which were comparable in statistical terms but differed on the presence of green public space and accessibility to it (including the presence of street trees, flower beds, green facades, front gardens, flower tubs and neighbourhood or city parks according to their size). 190 individuals from both areas (93 from the less green Saint-Jacobs and 97 from the more green Dierentuin) responded a questionnaire about health status and well-being. This included physical activity levels (adapted from the Short Questionnaire to Assess Health Enhancing Physical Activity –SQUASH–) perceived stress and ability to concentrate, neighbourhood satisfaction and social cohesion, and background characteristics. Comparison between the two neighbourhoods was performed through linear or logistic regressions. The aim of the process was to compare both neighbourhoods according to the responses about general health, physiological functioning and happiness. The only significant result in this area concerned well-being, as the more green Dierentuin presented better results.

The impact of blue areas has also been studied through self-reported health approaches. In these cases research included methods such as the use of census data (Wheeler et al., 2012) or the wider approach of using the English Household Panel survey (White et al., 2013). Both studies concentrate in coastal areas and do not analyse freshwater bodies, even if the combination of built environments and blue areas seems to be more appealing for individuals (White et al., 2010). Both studies used the Lower-layer Super-Output (LSOA) division provided by the 2001 English census and calculated the distance from its population centroid to the nearest coast line. While the first of the studies (Wheeler et al., 2012) classified distances in five groups (0-1 km, 1-5 km, 5-20 km, 20-50 km and +50 km) and used the last group as baseline, White et al. (2013) reduced the categories to three (0-5 km, 5-50 and 50+ km) and used the central one as reference. In both studies self-reported health was taken as the dependent variable. With first of the studies employing the 2001 Census question about health as a whole in the previous 12 months, and White et al. (2013) using the BHPS measures based on General Health Questionnaire (GHQ) as well as general wellbeing. Wheeler et al. (2012) found significant correlation between coastal proximity and human health after a likelihood ratio test. As the authors point up, results adjusted better and showed more clear patterns for increasing degrees of urbanization. White et al. (2013) also found evidence of a relation between health and proximity to the coast. The study found a significant improvement of general and mental health when comparing the reference group (5-50 km) and those living next to the coast. Results showed lower degrees of significance between the reference group and those living further from the coast. This drop was slightly lower in the case of mental health, where results were still considered significant, and more abrupt in the case of general health. Results for overall life satisfaction were more ambiguous.

3.3 Mixed approach studies

The third group of studies combines both objective and self-declared health levels. In this group we include the observational study by Pereira et al. (2012) extended its reach to 11,404 adults aged of 25

and older in the Perth metropolitan area who fulfilled the Western Australian Health and Wellbeing Survey between years 2003 and 2009. 74% of those who fulfilled these conditions consented to data linkage and entered the study. The variable related to health studied in the paper was based on Self-reported data of previously diagnosed heart disease and stroke. The measure of greenness was the Normalized Difference Vegetation Index (NDVI). The analysis adjusted the statistical estimation for socioeconomic and demographic, biological and behavioural factors, and a proxy for air quality. The results of the study suggest that after adjusting for all these factors, the odds ratio for both (self-reported) coronary heart disease and stroke was 0.84 for moderate levels of greenness (middle tertile), while it rose to 0.94 for the higher tertile of exposure levels to greenness. The 95% confidence intervals went up to 1.02 and 1.15 respectively, making these results not significant at that level. The same happened with hospital admissions and levels of greenness. Better adjustments were made when measuring the standard deviation of the NDVI. In this case, moderate variability implied a 0.76 odds ratio in self-reported medical diagnosis and a 0.63 odds ratio in hospital admissions. Moreover, a high level of variability in greenness was associated to a 0.82 odds ratio, again a significant value for the 95% confidence interval.

Another study that combined two types of measurements included the Body Mass Index (BMI) alongside with self-reported measures. Witten et al. (2008) used this measure as a proxy for physical activities and the relation with open spaces, in this case, parks and beaches. To measure the level of access to the studied areas, the authors calculated the travel time by car from 38 350 neighbourhoods in New Zealand. Neighbourhoods were divided in quartiles, resulting on access time of less than 08 minutes for the first, 0.8-1.4 minutes the second, 1.4-2.4 the third and more than 2.4 minutes the last. BMI and physical activity were extracted from the New Zealand Health Survey, covering 12 529 participants from 1 178 of the neighbourhoods. The study calculated a regression of BMI and sedentary/non-sedentary behaviours according to distance and control variables. The study found less sedentary behaviours in neighbourhoods with worse access to parks, though this result was no significant at a 95% confidence if socio-economic status was taken into account.

The results obtained by the above described studies have been summarized in the Table 2, which includes information about the methods employed by the researchers with respect to the three basic aspects for our analysis (i.e. involvement with ecosystems, health or wellbeing outcome and statistical technique).

Table 2: Studies showing links between the natural environment and health outcomes

Approach	Reference	Location	Environmental involvement	Health outcome	Statistical Technique	Results	Health cluster
Objective	Maas et al., 2009	Netherlands	Percentage of green space in a radius of 1 or 3 km	1 year persistence of 24 different clusters of illnesses	Multilevel logistic regression analysis	Significant reduction in morbidity in 15 of the 24 clusters when quantity of green space in the 1 km radius area was 10% above average. Significant reduction is limited to 3 clusters when 3 km radius is analysed	All
Objective	Takano et al., 2002	Tokyo	Environmental characteristics included a wide range of aspects, such as space for taking a stroll, parks and tree lined streets near the residence, noise from automobiles and factories or the presence of a garden at the residence	Five year survival rates	Authors checked five year survival of 3144 people born in 1903, 1908, 1913 or 1918 and analysed them through multiple logistic regression analysis	The study found evidence at different significance levels of an increased survival rate for some of the aspects, including space for taking a stroll, streets with parks and tree lined near the residence or senior citizens' preference to continue to live in their current community	All

Objective	Hu et al., 2008	Escambia and Santa Rosa, Fl (USA)	geographical information data on pollutants, income and greenness	Stroke mortality	Paper tries to find the relation between pollution income and nearby greenness, and stroke mortality through a Bayesian hierarchical model	95% interval on the effect of greenness over stroke mortality showed a negative tendency for all the range (-0.289, -0.031)	Cardiovascular disease
Objective	Mitchell and Popham, 2008	England	Statistical areas were classified according to percentage of green space	Incidence Rate Ratio on general health and on cardiovascular disease	Ratio between differences in the incidence of different dise11ases	Reductions in the differentials (IRR) both for all-cause mortality and for circulatory disease	All Circulatory disease
Objective	McKenzie et al., 2013	Scotland	Differences in urban and rural land.	This study used medication prescriptions as a proxy for mental health	Examined the differences in mental illness in urban and rural Scotland. The research divided environments according to a 1-6 scale and performed a regression on consumption patterns.	A positive and significant relationship was found between urbanity and drug prescription even after controlling for socioeconomic status.	Mental health
Objective	Yang et al., 2011	Zhejiang, China	Access to landscape plants	Brain response to sound stimuli	Choice experiment Two analyses were performed: One questioned the subjects about noise reduction by landscape plants. The other researched brain response of the	Subjects tended to overestimate noise reduced by landscape plants. Beta-wave activity showed different patterns among those who saw a natural landscape and those exposed to images of traffic, suggesting a psychological effect of the perception of natural environments. Other brain-waves	Wellbeing

					subjects to sound stimuli while displaying images of landscape plants or traffic scenes	did not change their pattern between groups	
Objective	Thompson et al., 2012	Dundee, Scotland	Green space as percentage of green areas in a ward	Deprived individual's stress levels. Measures taken through the amount of cortisol secreted and self-reported levels of stress and wellbeing	Analysis of correlations	No correlation was found between mean values of cortisol and green areas or wellbeing	Mental health
Self-reported	Van Herzele and de Vries, 2012	Ghent (Belgium)	Two neighbourhoods of the city of Ghent in Brussels were selected based on the 'Green Space Monitoring Tool', which measures accessibility depending on the urban grid characteristic to the area	190 participants responded questions about visibility of green elements, health and well-being, physical activity, stress levels, neighbourhood satisfaction and social cohesion	Results divided by neighbourhood were compared through statistical regressions.	There was no relation found between general health and bodily functioning, but differences were found when asking for well-being	Wellbeing Mental health

Self-reported	Wheeler et al., 2012	England	Lineal distance from statistical nucleus to the sea to provide the ecological measure	Self-reported general health	Performed a question about general health to the participants.	Positive relation between nearness to the coast and self-reported general health. This improvement was more marked in urban areas.	All
Self-reported	White et al., 2013	England	Lineal distance from statistical nucleus to the sea to provide the ecological	Self-reported general and psychological health	The question about general health to the participants was complemented in the second case with questions about mental health and wellbeing.	Improvement in mental health between the regions nearest to the coast, and no significant pattern in the case of happiness	All Mental health
Mixed	Pereira et al., 2012	Perth Metropolitan Area (Australia)	Greenness was studied through the Normalized Difference Vegetation Index (NDVI)	11,404 adults from the metropolitan region of Perth were asked for diagnosed coronary disease and stroke while records of hospitalizations were analysed	The odds ratio for the illnesses were calculated depending on the tertiles where laid each ward according to NDVI on amount and variance	No significant evidence was found at the 95% confidence intervals that greenness reduced the odds of diagnosed coronary disease and stroke. The study found some relations when analysing the variance of the NVDI inside wards	Coronary diseases
Mixed	Witten et al., 2008	New Zealand	Distance between neighbourhoods and parks and beaches (measured in time required for car travelling)	Body Mass Index (BMI) and measures of activity in lifestyle	Regression models and correlation analysis	The study did not obtain relevant and significant outcomes when including all of the control variables for parks, but it was found a correlation between BMI and access to beaches described as weak and significant, which implied lower BMI in participants with better access to beaches	Cardiovascular

Source: Authors

The differences in methods and variables used in the different studies make them difficult to compare. Most of them find a positive and significant relationship between green areas and health for some of the aspects considered in their research. Anyhow, this relation is neither constant nor of comparable magnitudes, which shows the need for methodologies that encompass the different lessons learned in the field.

4. Conclusions

Climate change adaptation has potentially significant health co-benefits arising from impacts on the natural environment, including green and blue spaces. These co-benefits need to be taken into account in designing adaptation, to ensure that they are optimized where possible.

To date, limited but promising evidence of links between human health and natural environments has been found. This evidence is, however, enough to allow us to draw a framework that shows the paths by which natural ecosystems interact with human health. This framework should be able to help in the development of better empirical analyses, which could themselves help a better understanding of the nature of the relation, in a feedback and retro-feedback process. Among the aspects that could be improved in this building of a framework would be the differentiation among the sets of interactions. The interrelations between sets could be taken into account, even if this question lies apart from the scope of the study, must be regarded as important.

An example could be the effect of changes in temperatures and precipitation patterns that might affect flooding. An increase in the risk of flooding may imply a difference in the functioning of green areas in the prevention of harm. Climate change may also affect the economic structure of the country, for example by its impact on agricultural output and productivity, which could imply transformation of green spaces on farmland or the conversion of farmland into touristic areas. Economic structures may also affect accessibility to ecosystems by providing more or less of them, or by affecting individuals' leisure time. Another important question still remaining is if there are new pathways to be discovered. The difference between general health studies that deal with a global approach of health and those concentrating in concrete effects and illnesses, such as stroke mortality or mental diseases, show important differences in the magnitude and significance of their results, which could suggest the existence of undescribed mechanisms behind the relationship. Particularly, the studies based on mental health and wellbeing are in general less conclusive and most of them do not find quantitative evidence of the impacts analysed. The matter of it being a cause of unspecified mechanisms or just a consequence of the differences among methodologies is a question that requires further investigation.

Another important issue, even if seemingly tangential, is the role of external aspects such as ageing, active lifestyle and diet. These topics, that have themselves a big impact on health, may be as well related to the study of the impact of natural ecosystems on health. Therefore it can be considered to have a double role, first as health determinants by themselves and then as catalyst for the effect of green areas on health. An example may be the impact of physical activity. In this case, benefits from active lifestyles have been well documented, but the capacity of green areas to promote non-sedentary behaviours has been disputed (Lee and Maheswaran, 1999).

The literature review that allowed the construction of this framework showed moderate evidence towards a positive relationship between green and blue spaces and human health. Even if most of the papers show some degree of correlation between health improvement and the environmental aspect analysed, positive and significant effects are not found in all the aspects examined. Therefore results must be handled with caution, as not all environments affect all aspects of

health in the same way. Work done in the distinction and identification of the interactions may help in isolating the effects of nature according to the different variables, which could provide a better basis for empirical analysis.

Another important focus for future research is the comparability among studies. Divergence in methodologies and variables make it difficult to compare the results of different studies and extract a comprehensive outlook of the matter. This implies that the job of synthesizing the results of different studies gets complicated. Literature reviews on the issue are based by necessity on textual instead of statistical analysis (Lovell et al., 2014). This highlights the need for an integrated conceptual framework as a first step for a quantitative analysis.

Finally, it is yet to be defined the different roles played by blue and green areas, are yet to be fully defined as well as the possible interactions between them. The analysis of blue space is still in an early stage of development as compared to green areas. Few studies have tried to look at the health effects of blue areas, though the analysis has been performed from psychological perspectives (White et al., 2010). In this sense it may be noted the great impact of wetlands over a wide range of aspects of human activity (Gren, 1995), these impacts may also have meaningful effects over human health.

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