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The nexus between climate change, ecosystem services and human health: Towards a conceptual framework

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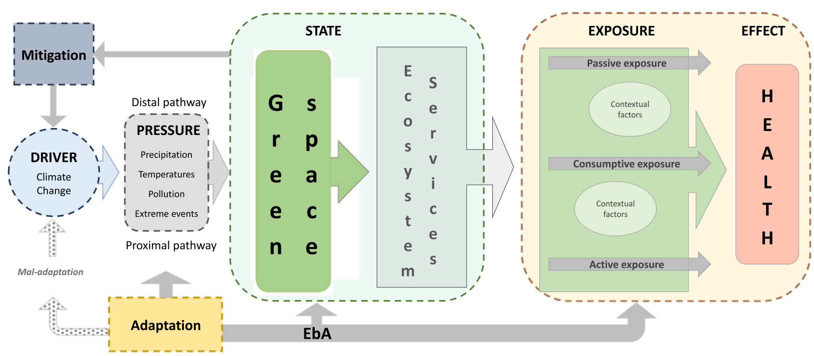
HIGHLIGHTS

- The model synthesises main links among climate, ecosystems and human health.
- Adaptation to climate change must consider health's relation to the environment.
- Adaptation actions could either increase or reduce existing pressure on ecosystems.
- Contextual factors and behavioural change affect this relationship through exposure.
- Multidisciplinary approaches are required when assessing ecosystem's health impacts.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper addresses the impact that changes in natural ecosystems can have on health and wellbeing focusing on the potential co-benefits that green spaces could provide when introduced as climate change adaptation measures. Ignoring such benefits could lead to sub-optimal planning and decision-making. A conceptual framework, building on the ecosystem-enriched Driver, Pressure, State, Exposure, Effect, Action model (eDPSEEA), is presented to aid in clarifying the relational structure between green spaces and human health, taking climate change as the key driver. The study has the double intention of (i) summarising the literature with a special emphasis on the ecosystem and health perspectives, as well as the main theories behind these impacts, and (ii) modelling these findings into a framework that allows for multidisciplinary approaches to the underlying relations between human health and green spaces. The paper shows that while the literature based on the ecosystem perspective presents a well-documented association between climate, health and green spaces, the literature using a health-based perspective presents mixed evidence in some cases. The role of contextual factors and the exposure mechanism are rarely addressed.

The proposed framework could serve as a multidisciplinary knowledge platform for multi-perspecitve analysis and discussion among experts and stakeholders, as well as to support the operationalization of quantitative assessment and modelling exercises.

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1. Introduction

Human health and ecosystems' health are inextricably linked. Our understanding of the interconnections between human health and the natural environment has increased rapidly in recent decades. The burden of disease from environmental risk factors is significant – from air pollution and water pollution to the impacts of UV radiation on skin cancer. Unhealthy environments cause just under 1 in 4 deaths globally (Prüss-Ustün et al., 2016). Beyond these proximal pathways to environment and health, recent work has focused attention on the distal pathways – affecting health through impacts on ecosystems (Reis et al., 2015). Contact with nature and ecosystem services (ES) have been shown to contribute to improved immune system functioning, mood and concentration, while reducing stress and increasing the benefits of physical exercise, with consequent expected reductions in the occurrence of non-communicable diseases (NCDs). ES capture all goods and services provided directly or indirectly by the natural environment (Millennium Ecosystem Assessment, 2005).

Impacts on health, such as heart disease, diabetes, cancer, and chronic respiratory illnesses, are now a global health epidemic. >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). Health impacts have a direct and indirect effects over the economy. Society can suffer from the loss of working hours and productivity, increases in sanitary costs, as well as intangible impacts (loss of quality of life, discomfort and pain) that should be added to the non-market costs of disease.

The impact of climate change on ecosystems includes a range of impacts that may have an effect on health – from changes in water availability in rivers to changes in biodiversity and vector borne diseases. Green spaces will probably be impacted by climate change in a number of ways – with consequent effects on human health.

Adaptation to climate change is also expected to have an impact on green space provision. There is increasing attention on the role of "nature-based solutions" to respond to the threat of climate change. These solutions will have consequences for human health. Such measures are often classified under the Ecosystem-based Adaptation term (EbA) (Vignola et al., 2009). These strategies cover a wide range of actions, aimed at a broad scope of impacts. The use of green spaces in order to increase urban permeability is one of the clear examples. Another frequently mentioned potential benefit is the reduction of the Urban Heat Island effect (or UHI, i.e. the excess temperature caused by urban heat retention) (Doick et al., 2014). Both increased flood risk and augmented temperatures are expected impacts of climate change.

This paper aims to synthesise the existing literature on the nexus between climate change and adaptation, green spaces, and human health and to bring together a conceptual framework to enable the identification of the impacts on health of changes in green spaces as a result of climate change and adaptation measures.

Conceptual frameworks have previously been applied in contexts such as the impact of changes in the water environment on health – and used as a way of identifying potential responses. This is the case of works such as that performed by Gentry-Shields and Bartram (2014), who took the Driving force-Pressure-State-Exposure-Effect-Action (DPSEEA) as the starting point in creating their framework. DPSEEA was designed by the WHO as a framework to develop environment health indicators (Kjellström and Corvalán, 1995). The modified DPSEEA extended this framework to explicitly consider the impact that context has on the environment-health relationship (Morris et al., 2006). A more recent model, the ecosystems-enriched DPSEEA considers the impacts that changes in ecosystems and associated ecosystem services can have on health (Reis et al., 2015). This paper builds on eDPSEEA as a first step towards a holistic perspective on health, climate change and green spaces that will give a better understanding of the factors that influence health outcomes in this context. The resulting framework may facilitate interdisciplinary communication in research in establishing the main aspects influencing the relation between EbA and wellbeing.

The paper is organized as follows. Section 2 discusses the interrelations among climate change, green space and human health by taking a perspective based on ecosystem services, ecological functioning and their potential capabilities. Section 3 takes the health perspective in order to summarise the literature analysing potential impacts of green spaces over human health, with a critical analysis of methods applied, health outcomes analysed and exposure. The importance of contextual variables is also discussed and how they can influence the relationship health-ecosystems. Section 4 presents a framework with key relationships between main elements of the system based on the eDPSEEA model and considering the interplay of contextual variables and types of exposure. Section 5 presents the main conclusions drawn.

2. Climate change, green space and human health: the ecosystem perspective

Greenspace, particularly in urban settings, is often viewed as a homogenous 'green area', with little consideration for the biological or ecological components of the landscape. This may be important when particular types and qualities of habitat types have been highlighted as having greater or less influence over the health benefit gained (Alcock et al., 2015; Wheeler et al., 2015). However, pressures on greenspace from both persistent urbanisation and effects of changing climates may also to lead to adverse health impacts (ecosystem disservices) associated with extremes in temperature, vector-borne diseases and water and air quality regulation (McMichael et al., 2006).

Within urban areas, greenspaces may vary significantly in quality (i.e. biodiversity), size and morphology and may have a multi-functional role within an urban area. The health benefits we derive from ecosystems are delivered as a consequence of the biodiversity, ecological composition and processes (Cardinale et al., 2012; Diaz et al., 2006) within the greenspace. The interactions between organisms within their physical environment results in a variety of ecosystem processes (e.g. decomposition), which in turn enables the ecosystem to perform functions (e.g. nitrogen cycling). These ecosystem functions, in turn deliver a number of important ecosystem services (e.g. crops) which support the health and wellbeing of the population (Alfsen et al., 2011).

Perturbations from stressors such as climate change on the ability of the greenspace to perform these functions will likely impact on the delivery of many of these ecosystem services and consequently the health and wellbeing of the local population (McMichael et al., 2006). Climate change will likely impact on the distribution of tree species (e.g. Benito Garzón et al., 2008) and measures may need to be taken in certain green spaces to plant climate resilient species. Extreme events, including droughts and floods, impact on green spaces in different ways. Drought impacts on grassed areas and the hardness of soil underfoot for those exercising in green spaces. Flooding can reduce accessibility to green spaces – though yielding benefits in terms of flood protection through sustainable urban drainage systems, recreational benefits to health may be reduced.

The wider human health vulnerabilities to climate change have been highlighted by a number of key climate change studies (Haines et al., 2006; Haines and Patz, 2004; Hames and Vardoulakis, 2012; Smith et al., 2014; Wolf et al., 2014; Hajat et al., 2010) and international reporting (Confalonieri et al., 2007; European Environment Agency, 2015) and by having a better understanding of how the physical properties of vegetation, water bodies and ecological processes of greenspaces (Elmqvist et al., 2015) may actively have a protective effects on health are only just being considered.

Harnessing ecological processes and working with natural systems more broadly, can provide a variety of additional co-benefits to both ecosystems and improving public health by enhancing the natural capital rather than depleting it. For example, urban tree planting, plays a key role in mitigating against the impacts of air pollution by retaining particulates and thus improving air quality and improving respiratory related infections/disease, particularly in children (Lovasi et al., 2008).

By 2050 70% of the global population will reside in towns and cities. Continued urbanisation and climate change will interact and exacerbate the health effects of urban heat islands, increased risk of flooding and urban heat islands. In urban settings, greenspaces deliver several key services to adapt to these health impacts. These include, but are not limited to, (i) regulation in microclimates though modifying local temperature regimes so as to reduce the urban heat island (UHI) effect, (ii) acting as a buffer to reduce air and acoustic pollution, (iii) regulate water flow to alleviate flood risk and improve water quality, (iv) promote opportunities for improved wellbeing (Table 1).

2.1. UHI effects

Some of the most important impacts of climate change 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 (Benmarhnia et al., 2016; Day, 2008; Li et al., 2015; Tobías et al., 2014; Yu et al., 2010). The Urban Heat Island (UHI) effect refers to the warmer temperatures typically experienced in urban areas compared to the surrounding suburban and rural areas (Heaviside et al., 2017). Changes in land cover and land use through the process of urbanisation can interact with climate change effects and alter local microclimates, consequently the risk of heat related illness or mortality may increase (Heaviside et al., 2017, Vardoulakis et al., 2014). Urban greenspaces have been shown to have lower air temperatures by approximately 1 °C cooler than the surrounding countryside (Bowler et al., 2010). This cooling effect is attributed to shading from broadleaved vegetation, but also from the ecosystem process of evapotranspiration. This process cools leaf surfaces and air temperatures as solar energy is absorbed and stored (Edmondson et al., 2016). Furthermore, unlike impermeable surfaces such as roads and buildings, leaf surfaces reflect solar radiation back into the atmosphere thereby maintaining a lower temperature (Grant et al., 2003). However, these cooling effects are subject to variation owing to the different sizes, shapes and species composition of the greenspaces.

2.2. Air pollution

Urban pollution is also another cause of health problems that takes special part in urban ecosystems (Gordian et al., 1996; Pope III 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. In urban settings, trees have beneficial impacts on the aesthetics of local environments. However, their impact on air pollution regulation is more complex and there is evidence of mixed net effects of trees on health due to air pollution (Salmond et al., 2016).

Trees remove pollution from the air by capturing particulates on the leaf surface. Different species may be more efficient at capturing a variety of particulate matter and increasingly, the evidence suggests that the structural complexity, type and species are all important in maximising the health benefits and indeed, avoiding the dis-services, of maintaining and creating greenspaces. For example, in a wind tunnel experiment, coniferous tree species (*Pinus sylvestris*) was found to be more efficient at particle capture than broadleaved species (Räsänen et al., 2013). Similarly, vegetation with more complex leaf structures and combinations of species on green walls are likely to maximise particulate retention (Weerrakkody et al., 2017). However, understanding species appropriateness (i.e. ecophysiological responses to pollution or heath stress) for the proposed location is a key consideration so as to avoid health dis-services such as respiratory conditions due to low level ozone (O_3) formation (Calfapietra et al., 2013; Knight et al., 2016) and/or increases allergic responses to pollen (Escobedo et al., 2011; Cariñanos and Casares-Porcel, 2011).

2.3. Water regulation

In the UK, climate change will increase heavy rainfall and as a result, risks from fluvial and surface flooding (Defra, 2017). Greenspaces, particularly urban greenspaces have significant potential to alleviate the risks posed to urban centres. Absorption of rainfall by soil and canopies can play a role in diminishing the hazard of floods (Claessens et al., 2014; Graceson et al., 2013; Warhurst et al., 2014). Reduction of flood impacts could also be obtained through the retention of debris. Green areas can therefore 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) to climate change.

Trees and other broadleaved vegetation intercepts rainfall and slows the transfer to the ground, thus reducing the risk of flooding. Owing to the reduction in excess water, water quality is improved as surface pollutants (e.g. nitrate, phosphates) washed into receiving water bodies are much reduced. Upstream land management of greenspaces for flood prevention has received much recent attention. For example blanket bogs act as natural sponges and retain rainfall to slow its passage

Table 1
Summary of the key ecosystem services of greenspaces for adapting climate change impacts on health. Key ecosystem processes and functions that contribute to their delivery and example health outcomes.

Biophysical structure/process of greenspace	Ecosystem function	Ecosystem service	Example health outcome	References
Trees and shrubs mix	Evapotranspiration; solar radiation reflectance; carbon sequestration	Climate regulation: Reduce UHI effect	Reduced urban mortality rates	(Feyisa et al., 2014, Edmondson et al., 2016, Knight et al., 2016, Wang and Akbari, 2016, Fares et al., 2017, Gunawardena et al., 2017, Heaviside et al., 2017, Hiemstra et al., 2017, Kabisch and van den Bosch, 2017)
Trees, mixed vegetation	Leaf wax/hair trap particles on leaf surface Absorption of Co2 for photosynthesis	Waste services: Reduce air pollution	Reduction in cardiovascular and respiratory conditions	(Litschke and Kuttler, 2008, Petroff et al., 2008, Zhao et al., 2010, Nowak et al., 2014, Rao et al., 2014, Wang et al., 2015, Weerrakkody et al., 2017)
Multi-level vegetation, grass, soil	Water retention by canopy, absorption of precipitation by soil, reduced runoff, drainage	Flood protection: Flood risk alleviation and water quality	Reduction in mental health conditions and economic costs associated with flood exposure; improved water quality	(Sanders, 1986, Bartens et al., 2008, Carroll et al., 2009, Paranjothy et al., 2011, Kaźmierczak and Cavan, 2011, Armson et al., 2013, Liu et al., 2014, Zhang et al., 2015, Zellner et al., 2016)
Biodiverse; pathways; amenity areas	Primary productivity, biodiversity	Recreation: Health and wellbeing of exercise	Opportunities for recreation and physical activity; stress reduction; lower blood pressure, obesity and diabetes	(Mitchell and Popham, 2007, Mitchell and Popham, 2008, Maas et al., 2006, Rook, 2013, Lovell et al., 2014, Gascon et al., 2015, Wheeler et al., 2015)

Source: authors.

downstream (Pilkington et al., 2015). Furthermore, 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 waters under certain circumstances (such as grey waters and their use as tertiary treatment in wastewater treating procedures) avoids eutrophication of other ecosystems providing therefore a cleaner environment (Millennium Ecosystem Assessment, 2005).

2.4. Health and wellbeing

Public open green spaces may encourage various forms of interaction among humans, promoting community cohesion, sense of identity, education and learning. Active lifestyle promotion (Almanza et al., 2012; De Jong et al., 2012; Fan et al., 2011; Gidlow et al., 2016; Giles-Corti et al., 2005; Mytton et al., 2012) and the development of social networks (Dadvand et al., 2016; Eriksson and Emmelin, 2013; Fan et al., 2011; Maas et al., 2009a) may play an important role as underlying factors in capturing such benefits from green spaces. 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 (Barton and Pretty, 2010; Carter and Horwitz, 2014; Cohen et al., 2013).

Furthermore, greenspaces play a key role in tourism and recreational activities. An example is given by the Spanish IMSERSO program which promotes social tourism among senior citizens (Hoyo and Valiente, 2010). 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).

Humans are affected by the contact with different microorganisms. An increasing number of diseases affecting urban populations in developed regions are related to problems in immune-regulation 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). Human physiological responses to 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).

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

3. Green spaces and wellbeing: the health perspective

Green spaces have diverse impacts on human health and wellbeing, and this is reflected in the diversity of the studies performed in the exploration of the relationships between ecosystems and health in this context. Human health is highly dependent on the environment. It has been postulated since early times (Ward Thompson, 2011) that being surrounded by nature improves human wellbeing. With the arrival of the industrial revolution the impact of pollution became more relevant for public health (Ward Thompson, 2011), so that the role of urban green areas can be key in this context. The links between natural environments and improved health are well documented (Alcock et al., 2015, Maas et al., 2006, Shanahan et al., 2015a,b, Triguero-Mas et al., 2015), however. the mechanisms remain elusive. Evidence suggests that access to and availability of urban green and blue spaces provide a wealth of opportunities for health promotion, such as reductions in stress, anxiety and depression, reductions in diabetes, and cardiovascular and respiratory disease through an increase in opportunities for physical activity (Hartig et al., 2014, Shanahan et al., 2016).

We performed a search through web resources such as Web of Knowledge and Google Scholar combining terms related to the areas of environment and health. A series of combinations including health-related terms (health, disease, life expectancy, mortality, epidemiology, etc.), environment-related words (environment, nature, ecosystem, pollution, green spaces/areas, etc.) were used. Complementary terms (such as qualitative, statistical, literature review, etc.) were introduced when necessary. Snowballing from the literature, particularly literature reviews, was another source of references. We included previous literature reviews and meta-analysis looking at quantitative health impacts, qualitative studies using empirical data from surveys looking at subjective perceptions, and finally a number of studies offering theoretical approaches and discussions to analyse the interaction. In total 117 studies were identified that investigated these relationships.

The whole reference list of the reviewed studies is displayed in Appendix A (Supplemenatry Data), including a table (A) which classifies all studies by methodology and health outcome(s).

The diversity of the literature with quantifiable results spans throughout three main axes which we can classify as: broad methodological approach, heath outcome and exposure. In Table 2 we present a selection of the reviewed 117 studies with quantifiable results, classified by the three categories above. Methodological approaches used in the literature were classified into three groups (Martinez-Juarez et al., 2015a). Namely we distinguished among "objective studies" (using objective measurements of health), "subjective studies" (relying on subjective or survey-based measurements) and "proxy measure based-studies" (relying on proxies that can be precursors of health problems). In the next three sub-sections we discuss some key studies identified in each of the three groups, commenting the specific methodology used and main results obtained. Based on the analysis of the 117 studies we subsequently propose different types of exposure characterising the type of individual involvement with nature, and finally present a discussion on the role of contextual factors in the interaction health-environment.

3.1. Objective studies

Objective studies use different types of health data such as hospital admissions for specific health conditions, changes in life expectancy or mortality, all of which could be measured in an objective manner using risk factors and statistical metrics. Studies of this type include

Table 2
Summary of articles describing impacts of green spaces over health.
Source: authors.

Study type	Reference and location	Health outcome	Exposure	Main contribution	Results
Objective	(Maas et al., 2009b) Netherlands	Persistence of disease (grouped in clusters).	Presence of green space in residential area.	To assess whether physician-based morbidity outcomes are related to green space in living environments.	Reduction in morbidity in 15 of the 24 disease clusters when quantity of green space in the 1 km radius area was 10% above average, significance limited to 3 clusters when 3 km radius is analysed.
	(Takano et al., 2002) Tokyo (JP)	Five-year survival rate.	Range of neighbourhood characteristics, including green items.	To find the relation between public areas' greenery in residential environments and elderly populations' longevity in densely populated urban contexts.	Space for taking a stroll, street parks and tree lined near the residence found to be positively related to survival rate, though not always with significant relationship.
	(Hu et al., 2008) Escambia and Santa Rosa counties (US)	Stroke mortality.	Greenness and pollutants measured through GIS.	To determine the relation between stroke mortality and a series of factors (air pollution, income and greenness).	Significant correlation found between mortality reduction and green areas.
	(Mitchell and Popham, 2008) England (GB)	General health and on cardiovascular disease (CVD) among other factors.	Statistical area classification according to percentage of greenspace.	To test whether health inequalities correlated with income would be less pronounced in populations more exposed to greenery.	Significant reductions in health inequalities both for all-cause mortality and for circulatory disease correlated to the presence of green space.
	(Pampalon et al., 2006) Québec (CA)	Life expectancy and different cause mortality.	Census areas according to their urbanisation level.	To compare the health contexts of rural and urban areas in Québec.	Impact of urbanity level varying among variables. Health problems often greater in rural areas.
	(Cusack et al., 2017) Texas (US)	Preterm births, small for gestational age cases and term birth weights as birth outcome measures.	Normalized Difference Vegetation Index (NDVI).	To study birth outcomes with respect to residential greenness in the Texan context.	Term birth weight presented the only significant results in fully adjusted models. Birth weights for mothers in greener environments were 1.9 g higher than the baseline.
	(Hanski et al., 2012) Eastern Finland	Atopic sensitization/allergic disposition analysed in a sample of adolescents.	Surrounding biodiversity in residence area.	To provide evidence to the “biodiversity hypothesis”, that reduced contact with environmental features is related to the increase in prevalence of certain illnesses.	A relationship was found among surrounding biodiversity, presence of skin microbiota and lower levels of atopy.
	(Henke and Petropoulos, 2013) Wales (GB)	Measures of limiting long term illnesses, mortality, physical activity guidelines met and life expectancy.	Recreational areas in Wales were identified and their extension measured as proportion of each local authority.	To explore the interconnections among ecosystem services, human health and deprivation in a context where green ecosystems are abundant.	Low levels of correlation were found between relative amount of recreational areas and life expectancy or long-term disease.
	(Huynen et al., 2004) Not local	Disability adjusted life expectancy, infant mortality and percentage low-birthweight babies.	Different indicators were used to calculate biodiversity loss: percentage of threatened species, changes in forest cover and the percentage of land highly disturbed by man.	To address the potential relation between biodiversity loss and health at a global scale.	Significant effects of biodiversity loss were found for some variables, but authors were not able to provide obtain a general association between biodiversity loss and health.
	(Tamosiunas et al., 2014) Kaunas (LT)	Both CVD-related deaths and non-fatal cases.	GIS data on parks larger than 1 ha were taken. Use of parks was also considered.	To study the interrelations between distance and sue of green areas on the one hand and prevalence of CVD and its risk factors on the other.	Health benefits were found in certain cases studied such as when considering males and distance to parks or female park use.
Subjective	(Van Herzele and De Vries, 2012) Ghent (BE)	Self-reported health and well-being.	Two neighbourhoods were selected similar in all terms except the availability of green spaces.	To study the connection between local environment's greenness and health and wellbeing of those living in such environment.	No significant results for self-reported health.
	(Dunstan et al., 2013) South Wales (GB)	Self-reported general health.	Three tertiles were constructed through the Residential Environment Assessment Tool (REAT), which includes environmental elements	To investigate the relation of health with residential environment's quality taking an objective measure of the latter.	No significant effects were found when analysing natural elements.
	(de Vries et al., 2003) Netherlands	Survey based on diagnostic interviews for mental health assessment, focusing on anxiety disorders, mood disorders, substance abuse and common mental disorders (CMD).	Presence of green space in residential area.	To address the question of whether greener areas' populations are healthier by studying self-reported health of Dutch populations in combination with land use data.	The study found significant results for the effects of presence of green space over CMD and anxiety disorders.
	(De Jong et al., 2012)	Self-reported: Neighbourhood satisfaction (NS), physical	Scania Green Score (SGS): Index based on perceived green	To implement the SGS index in the context of analysing health	When analysing SGS and GIS-based greenness in separate

(continued on next page)

Table 2 (*continued*)

Study type	Reference and location	Health outcome	Exposure	Main contribution	Results
	Scania (SE)	activity (PA) and general health (GH).	neighbourhood qualities, "culture", "serene", "lush", "spacious" and "wild"; as well as perception over each of the components. GIS-based objective greenness was also a measure taken.	and wellbeing of Scanian population	regressions, it was found that both measures implied higher levels of physical activity, while subjectively measured green spaces also implied improved self-reported health. This last relation disappeared when using GIS. When including both greenness measures within simultaneous regressions, results were similar except for the link between GIS-based greenness and general health, which turned negative.
	(Mansor et al., 2012) Taiping (MY)	Questions on the relation between green space and wellbeing were included in the questionnaire.	Combination of a questionnaire survey and semi-structured interview on urban green areas of the city chosen.	To study the attitudes of citizens with respect to green infrastructure in relation with wellbeing.	Green infrastructures were found to be influencing levels of physical activity. Perceptions on greenness diversity was correlated to perceptions on the wellbeing effects.
Proxy	(Grazuleviciene et al., 2015) Kaunas (LT)	Systolic and diastolic blood pressures (SBP; DBP), heart rate (HR) and recovery, and exercise duration.	Two randomised patient groups exposed to different walking settings: urban and green. All of them were exposed to 30-minute walks during a 7-day period.	To assess whether walking in a green environment has an increased effect over coronary artery disease.	Effects appeared for all variables after the 7-day period, which implied a cumulative effect of green exercise over hemodynamic variables.
	(McKenzie et al., 2013) Scotland (GB)	Medication prescriptions as a proxy for mental health.	Urban and rural classification of neighbourhoods.	To analyse the potential association between living environments and mental health problems such as anxiety, depression and psychosis.	Urban areas accounted for a higher proportion of prescriptions for mental illnesses.
	(Witten et al., 2008) New Zealand	Body Mass Index and measures of activity.	Car travelling times as proxy measure for distance between neighbourhoods and parks and beaches	To tackle the question of whether access to public space can lead to increased levels of physical activity.	No significant outcomes found when including all of the controls, but correlation found between BMI and access to beaches.
	(Grazuleviciene et al., 2014) Kaunas (LT)	Four blood pressure categories (optimal -baseline-, normal, high-normal blood pressure, and hypertension).	Subjects were classified among three groups according to distance between residence and the nearest park. Apart from this discrete measure, continuous distance was also used.	To analyse the effect of distance to urban parks over blood pressure categories during the early stages of pregnancy.	Once adjusted to risk factors, data the study indicated an increase in OR for intermediate groups with respect to the baseline group when comparing lower distance group with those living closest. Another significant increase was found when analysing distance continuously. For the case of the hypertense group increased OR diminished and lost statistical significance.
	(Li et al., 2011) Tokyo (JP)	Blood and urine measurements before and after the activity.	Two randomised subject groups (all healthy male) exposed to different settings: urban and green. They spent a day within the assigned environment, walking for 2 h in the morning and afternoon.	To study the effects of walking in forests over cardiovascular and metabolic indicators of male subjects.	Blood pressure, dopamine and urinary noradrenaline levels were found to be significantly reduced in the group spending the day in the greener location. Serum adiponectin and dehydroepiandrosterone sulphate (DHEA-S) on the contrary were found to be significantly higher.
Combined subjective and objective measurements	(Min et al., 2017) South Korea	Depression referring to the immediate 12-month period, depressive symptoms through a standardised questionnaire.	Extension of parks and green areas in each residential geographical code along South Korea.	To scale the research on the potential benefits of parks and green spaces over mental health from the local to the national level.	Individuals living in the least low area quartile presented odds of suffering from depression and presenting suicidal indicators a 16–27% higher than those living in the greenest quartile.
	(Pereira et al., 2012) Perth (AU)	Coronary heart disease (CHD) and stroke based on self-reported cases and analysis of records of hospitalizations.	NDVI	To investigate in a specific manner the greenness of a neighbourhood in relation to CHD.	Overall greenness no significantly related to decreased odds of diagnosed coronary disease and stroke. Variance of the NVDI inside wards was found to be relevant on stroke risk.
Combined subjective and proxy	(Ward Thompson et al., 2012)	Cortisol levels and self-reported stress and well-being measures in individuals in vulnerable	Percentage of green zone over the total area of the neighbourhood.	To study health benefits of green areas using "ecologically valid objective measures" and to	No significant correlation between mean values of cortisol and green areas, but a link was

Table 2 (*continued*)

Study type	Reference and location	Health outcome	Exposure	Main contribution	Results
measurements	Dundee (GB)	situation.		determine whether salivary cortisol may be used as a biomarker in the research of stress levels.	found with self-reported measures.
	(Yang et al., 2011) Zhejiang (CN)	Brainwave activity, complemented by a questionnaire	Visual stimuli of areas with different degree of greenness	To address the psychological side of noise reduction provided by plants.	Additional subjective noise reduction perception in group watching greener environments.
	(Roe et al., 2013) Dundee (GB)	Salivary cortisol and perceived stress in jobless men and women residing in deprived districts. Wellbeing using shortened version of the Warwick and Edinburgh Mental Well-being Scale (SWEMWBS).	Green space measured according to percentage of green spaces in the Census Area Statistics.	To analyse the mechanisms operating under the relation between the environment and mental health, particularly in the context of stress in jobless populations.	Positive correlation was found between cortisol slope and physical activity and green space, and higher amount of neighbourhood green space was found to be related to lower perceived stress. The regression performed to analyse the relations found perceived stress to be negatively and significantly related to the green space percentage. The presence of a garden in home was only a relevant factor for males.

epidemiological studies such as the one performed by Maas et al. (2009b). The authors analysed one-year persistence rate of illnesses aggregated in 24 clusters in order to study the effect of greener living environments on health. Positive impacts were found in most of the health clusters for greener areas located closer living environments (1 km radius), while effects diminished when more distant areas were taken (3 km). Mental health impacts were most notable. According to their results, green spaces impacted anxiety in a higher degree, with a decreased odds ratio (OR) of 0.95, while depression exhibited a reduction in persistence associated with an OR of 0.96. Both results were significant at the 95% significance level. Other illnesses with significant decreased ORs were coronary heart disease (0.97 odds ratio), several musculoskeletal complaints, such as back and neck complaints (with OR diminishing to 0.98), asthma, COPD and upper respiratory tract infection (OR of 0.97), neurological disorders (ORs between 0.97 and 0.98), and digestive infectious disease of the intestinal canal (OR 0.97).

A different approach was taken by Takano et al. (2002), who analysed changes in survival rates in the city of Tokyo, and found that environmental aspects such as the presence of space for taking a stroll, streets with parks and trees near the residence areas were associated with higher survival rates. This study found that spaces for taking a stroll could significantly increase survival rates both for males and females. For example, parks and trees were positively related to overall survival rates, showing an increase from 66.2% to 74.2% when parks and trees increased from a minimum amount (defined qualitatively as “very little”) to a maximum (defined as “plenty”). The relationship was, however, not always significant when analysing specific subgroups of the population (e.g. females).

While also objective, a somehow different approach was taken by Hu et al. (2008), who analysed stroke mortality in two US counties and also found evidence linking greener environments to improved health conditions. Their specificity in the approach lies in the proposed model which uses a combination of mapping with Bayesian hierarchical modelling combined with Monte Carlo analysis. The resulting figures showed that greenness presented a mean effect of −0.161, with a credible set spanning from −0.289, to −0.031, which implies a significant reduction of stroke mortality in greener areas. Air pollution also had relevant effects, though of the opposite sign.

Mitchell and Popham (2008) also considered mortality rates in their study, though their finding was that not only green spaces could have a positive impact over health, but that this impact could be stronger in groups with lower income levels, having thus an reduction effect over health inequalities. Incidence rate ratios (IRR) varied among groups. For all-cause mortality, IRR between most and least deprived areas in least green areas was of 1.93, while in the greenest areas IRR was reduced to 1.43. Circulatory disease mortality showed a change from 2.19 to 1.54 under same circumstances.

Another study considering mortality we wish to highlight was performed by Pampalon et al. (2006). The study was centred over the differences in health between urban and rural areas. Mortality in rural areas was found to be significantly higher, compared to urban areas. The study also emphasised the importance of contextual factors in this relationship. In this study, improved health in urban areas resulting from improved access to healthcare puts a limit over the greener-is-better relation.

3.2. Subjective studies

A second group of studies use self-reported measures of health, which we named “subjective studies”. Health questionnaires are used in order to obtain measures of general health as well as to tackle specific health problems as anxiety or cardiovascular health. Likert scales are often used in this type of studies in order to facilitate respondents in reporting their perceived health status. Semi-structured interviews and Yes/No question sets or inquiring over the number of symptoms remembered over a time period can also help in analysing population's health. Although self-reported measures exhibit a number of biases, they can ease the task of addressing health in a subjective way. These methods are often combined with different measurement metrics such as proxy indicators which can detect a health problem. Such mixed analyses are included in the third group of studies and described later.

Van Herzele and De Vries (2012), used a questionnaire in order to ask for the health status of inhabitants of two neighbourhoods in Ghent, one being substantially greener than the other, while other characteristics being similar. Inquiry over self-reported health used a 1–7 Likert scale to ask for general health and added a question over the number of symptoms experienced by individuals. The study found no significant improvement in self-reported symptoms, but it did find higher levels on reported general wellbeing in the greener neighbourhood. A different questionnaire was used by de Vries et al. (2003) when conducting their research on the relationship between greenspace and health. They examined the amount of green in the study subjects' living environments and found a positive relation between greener environments and self-reported health. The latter was measured combining a five-point Likert scale for perceived general health combined with an inquire to recall symptoms in the last 14 days. In this case, a version of the General Health Questionnaire was used to determine propensity of participants to psychiatric morbidity. De Jong et al. (2012) used self-reported levels of physical activity as well as perceived green qualities in their study, finding a positive association among these variables. In their analysis of a series of neighbourhoods in South Wales, Dunstan et al. (2013) studied reported levels of poor health and objectively measured neighbourhood quality. REAT (Residential Environment Assessment Tool) serves as index for neighbourhood quality, and is comprised by a series of 28 items encompassing aspects such as physical nuisance and incivility, territorial functioning, defensible space, natural elements and miscellaneous other factors. Natural elements (green spaces and infrastructures) had however no significant impact over health in this analysis.

3.3. Proxy measure based-studies

The third type of studies are those relying on proxy measures. These proxy measures can be intended as a precursor to disease and health status, so they are particularly relevant to detect health benefits from exposure before the disease can manifest. This is the case of cholesterol measures, cortisol presence, prescription of medications, Body Mass Index (BMI), etc. Some of the studies using such variables combine them with other measurement types such as perceived health from survey-based analysis. We include here examples of the use of proxy measures and of combined systems.

Yang et al. (2011) studied brainwave activity through electroencephalogram (EEG) in order to assess psychological noise reduction gained when using landscape plants as buffering system. The study involved visually and stimulating participants with either green images or images showing traffic elements while noise stimulation was also applied. A control group was also employed as reference. The study relied too on subjective measurements provided by participants. These last measurements showed that there was a widespread belief that landscape plants had an impact over noise reduction, 90% of respondents believed so, with an 80% of participants considering them the most efficient option. Participants tended to overrate the noise reduction capacity of plants measured, with 55% of them overstating the capacity, 40% giving accurate values and 5% underestimating the effect. Significant variations were found un beta-1 and beta-2 waves between those subjected to green stimulation, and traffic and control groups. Variations in alpha-1 and alpha-2 waves were restricted to a couple of brain areas. No significant changes in delta and theta waves was found. They found an additional reduction caused by the use of these elements.

McKenzie et al. (2013) used drug prescription levels in order to analyse mental health in different settings in Scotland, finding that urban settings were more prone to the use of prescription drugs targeting depression and anxiety. Blood pressure is another common measure in studies. Such are the cases of two studies performed in Lithuania (Grazuleviciene et al., 2014, 2015). Both studies found improvements in their measuring in groups more influenced by parks and green areas. In the 2015 study, researchers tested whether coronary artery disease (CAD) patients' hemodynamic parameters would show more positive effects after park walks than after urban strolls. Systolic (SBP) and diastolic (DBP) blood pressures as well as heart rate (HR) were analysed at rest, after exercise (differences after 1 and 30 min) and after a 7-day exercise period. Effects appeared for all variables after the week. The second study analysed blood pressure in the early pregnancy. Participants were classified into four groups, ranging from optimal (blood pressure) to hypertension. In order to measure exposure to ecosystems distance of residence to a park was used, both continuous and discrete (<300 m, 300–1000 m, >1000 m). OR were calculated by comparing odds of being classified in a higher-blood pressure group according to proximity of residence to an urban park. OR adjusted to risk factors indicated increased OR for intermediate groups with respect to the baseline group (optimal) when comparing lower distance group with those living closest. Increase was also significant when analysing distance continuously. For the case of the hypertense group increased OR diminished and lost statistical significance.

Similarly, Li et al. (2011) took measurements of participants' blood pressure after walks in different contexts (a walk in a forest park and an urban walk). These measurements were combined with urine samples which were used to calculate noradrenaline and dopamine levels. Evaluation of the proxy variables led researchers to determine a positive effect of walking in greener contexts. Among those that employed different proxy measures we can find Witten et al. (2008), who combined BMI, sedentary behaviour and physical activity levels. The aim of the study was to analyse the impact of access to public open space over those variables. In order to determine access to parks and beaches, minutes of travel by car were used as variable via GIS. They found access to parks not linked to reduced BMI or sedentary behaviours, though they found a correlation when studying access to beaches.

Ward Thompson et al. (2012) took a combined approach when analysing stress in deprived communities. They used salivary cortisol as their main measure for stress, complementing it with a self-reported measure. Salivary cortisol was measured at different points during the day. Between 3 and 12 h after the awakening time. Greenness and deprivation measure were based on participants' postal areas. Self-reported stress was found to be correlated to greenness. Steeper cortisol evolving patterns (higher in the early hours after awakening and lower after 12 h) were correlated to wellbeing, physical activity and greenness, as well as with improved self-reported stress. Mean levels of cortisol were not associated to greenness or lower levels of stress. These relations were significant at the 95% level.

3.4. Type of exposure

How exposure to green areas is conceived is another source of variance in the literature. Following the previous proposal of classifying exposure to green spaces into active, consumptive and passive exposures (Martinez-Juarez et al., 2015b), we comment hereby some studies from the literature based on this classification. The relevance of this classification lies on the importance of the engagement with green areas and its effect over the analysed relation. Several of the positive (and negative) health impacts of green areas over human health is associated to either active, consumptive or passive forms of engagement or exposure.

Active exposure requires involvement of the subject. This type of connection can include actions such as taking a stroll in a park (Roe and Aspinall, 2011; Takano et al., 2002), social interactions in green public open space (Eriksson and Emmelin, 2013; Fan et al., 2011; Fleming et al., 2016; Maas et al., 2009a; Wood et al., 2010) or exercising in green areas such as an urban forest (Hansmann et al., 2007; Kerr et al., 2006; Scully et al., 1998). The study performed by Lachowycz and Jones (2014) tested the hypothesis that walking explained lower mortality levels appearing in areas with higher access to green space. They found that inhabitants of greener neighbourhoods were between 13% (when taking neighbourhood green space) and 18% (when considering green space within a 5 km radius) more prone to engage in recreational walking in the last 30 days.

We classify as consumptive means of exposure those interactions with nature that involve consuming some of its products or services. Though ecosystem services provide health benefits through consumptive exposure (e.g. the provision of medicines and the regulation of products such as clean water that are consumed by individuals allowing them for healthier lifestyles), these services are not common in small green areas. A case for increased health through consumptive exposure to green areas is green tourism.

The mere presence of green areas may also have an impact over health, whether or not individuals actively interact with them, case which we classified as passive exposure. Green areas can provide health benefits reducing air pollution (Sæbø et al., 2012); by regulating climate, particularly reducing the UHI effect (Bowler et al., 2010); or by creating a suitable environment for the developing of healthier microbiotic conditions (Hanski et al., 2012; Rook, 2013; Rook et al., 2013).

3.5. The role of contextual factors

Certain issues appear throughout the literature and have an important role modulating the interrelationships between the ecosystem and health. We consider these as contextual variables which can have different roles and degrees of importance, but must be considered in order for health impacts to be appropriately measured. Demography is an important factor that can influence ecosystem's impacts over health. Population density, ageing, health status are some examples. There is a direct relation between population density and pollution that could imply higher benefits in health. This would be due to the increased marginal impact of green spaces in a more polluted environment. On the contrary, congestion of parks and green spaces could deter people from using parks or reduce the restorative effects of park visitation. Age has been another factor considered. Ageing populations could benefit from clean air and open space to walk and engage in social activities. Takano et al. (2002) deal with diverse demographic aspects by focusing the research on elderly populations in a densely populated environment and providing gender-specific results. Socioeconomic questions such as income (Mitchell and Popham, 2008) or joblessness (Roe et al., 2013; Ward Thompson et al., 2012, 2014) have also been considered in the literature. Social aspects may also influence attitudes towards green spaces influencing the relation, such as time spent in open space or use of such areas to perform physical activity (Wendel et al., 2011). Studies can handle these variables in different ways. Some studies overlook them entirely, whereas others consider them as control variables. Age, gender and socioeconomic conditions are central in several studies. We therefore consider them as a key aspect in the construction of the conceptual framework as discussed more deeply in the next section.

4. The conceptual framework based on eDPSEEA

We propose a framework which draws on the "*ecosystems enriched*" Driver, Pressure, State, Exposure, Effect, Action (eDPSEEA) model (Reis et al., 2015) and explicitly integrates climate change and potential co-benefits that green areas could provide in terms of adaptation actions through population exposure and contextual factors. Ignoring such benefits would conduct to sub-optimal planning and decision-making (Fig. 1). For this purpose, the eDPSEEA model has been adapted to specifically link impacts of climate change and adaptation action on the environment and how this can affect human health through different types of exposure.

Findings from the literature reported in the previous sections and taking into account both the ecosystem (Section 2) and health perspectives (Section 3), were analysed in order to create a framework that could incorporate cause-effect interactions among climate, ecosystem services, exposure and health impacts in a schematic and synthetic manner.

The "*driver*" in our model is climate change and includes basically GHG emissions and concentrations which put a "*pressure*" on green spaces in terms of increased temperature and precipitation patterns, heat and air pollution as well as extreme weather events. The pressure will lead to a potential change in the amount/size or quality of that space (the "*state*"), producing alterations in terms of ecosystem functioning which will in turn affect the terrestrial distribution of natural areas as well as the flow of ecosystem services they provide in the short and long run. The state has been characterised in our framework by six types of ecosystem services (as discussed in Section 2), which can affect the use or perception of the site through "*exposure*": UHI effect, air pollution, water regulation, social environment, recreation and tourism, and microbiome.

Depending on a range of contextual factors, which may include socio-economic characteristics of the impacted group (e.g. incomes,

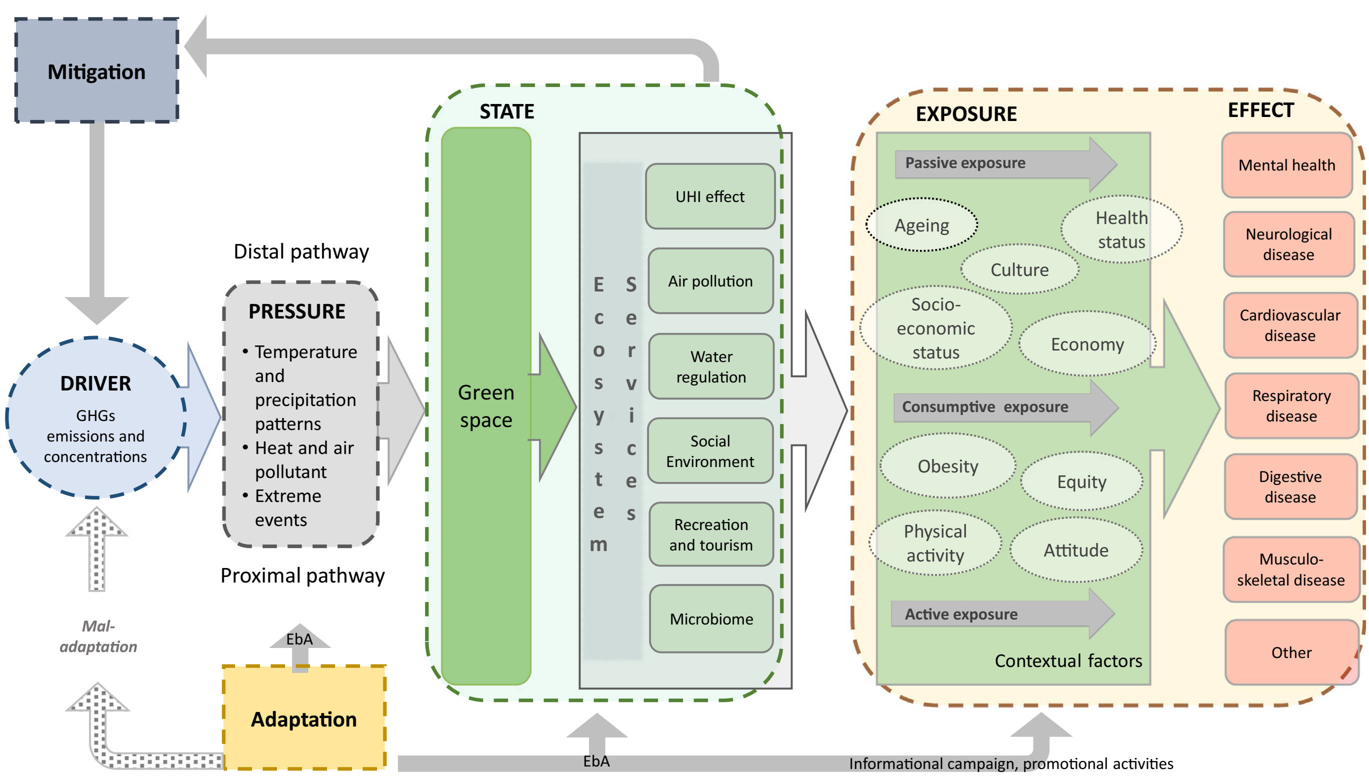

Fig. 1. Climate change, ecosystem services and human health: A conceptual framework.

ages equity), health status (e.g. obesity), culture, attitudes and beliefs, and environmental factors (e.g. baseline climate, availability of alternative sites), these changes may impact on health either directly or indirectly, positively or negatively (the "effect").

"Actions" refer here to any intervention affecting green spaces and population exposure, which can impact ultimately on human health. In this context, adaptation will play a crucial role as it could increase the existing pressure on natural areas ("mal-adaptation") or, on the contrary, reduce it with appropriate solutions such as those based on ecosystem-based adaptation (EbA) (UNEP, 2014). EbA interventions will show both direct benefits in terms of positive impacts on the provision and quality of ecosystem services, as well as additional co-benefits in terms of population health due to exposure to an improved state of the ecosystem.

In terms of adaptation, both "hard" and "soft" options exist to respond to increased temperatures, precipitation and extreme events. 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. On the other side, the creation or safeguard of green 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 3 below. It is important that the assessment of adaptation options takes into account all risks and 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 (Ellis et al., 2004). In the case of flood avoidance, a path may be constructed at the same time as the defence is built to ensure that direct benefits arising from the structure can be complemented by co-benefits such as those arising from active leisure such as walking.

In our framework we include also other actions linked with EbA, which have a direct effect on people exposure and health. These are for example promotional and educational activities fostering responsiveness of individuals to improvements in the state or promoting recreational and physical activities among general population and vulnerable sub-groups.

Impacts on health (the "effect") have been grouped according to the different definitions and dimensions analysed by the literature (Section 3). Specifically for the construction of this framework, we have classified health impacts based on the same seven clusters as Maas et al. (2009b). 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 NO_X (provided by green areas) 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 improvement would be the reduction in stress. 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 immune-regulatory functions (Rook, 2013) to bacterial caused diseases. Immuno-regulation 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 (Clemente et al., 2012; Han et al., 2012).

Contextual variables, as mentioned in Section 3.5, 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. Contextual variables can affect the relation addressed in various ways according to how subjects are exposed to them. Age, climate and general health conditions, for example, affect all types of exposures – as different age groups may have different responses, climatic conditions may affect recreational uses or perceived amenity and the health of the individual may affect use and the impact that exposure has on health. Obesity has a clear link with consumption, though cultural context is also related to consumption patterns. Finally, active lifestyles and socioeconomic status require an active engagement on behalf of the individual. Some of the studies have paid special attention to the effects of green areas on the health of deprived communities (Ward Thompson et al., 2012; Mitchell and Popham, 2008).

The role of these aspects may vary considerably. While ageing can have a negative effect on health through increased risks of some illnesses such as mental health or cardiovascular diseases, 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 negative impacts related with ageing and obesity, though it can have both positive and negative impacts over the musculoskeletal system. 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 et al., 2013). The level of involvement on active lifestyles can also be affected by air quality, as contaminants may dissuade individuals from involving in physical activity. 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 also regarded as an ecosystem service. Finally, the social

Table 3
Ecosystem-based adaptation and impacts on the natural environment: some examples.
Source: authors.

Measure	Possible impacts on natural environment	Potential health implication	Related bibliography
Sustainable urban drainage systems	Potential for green corridors for recreation	Possible increase in recreational walking and cycling, improved physical and psychological health	(Ellis et al., 2004)
Green roofs	Potential improvement in views, potential increase in biodiversity	Reduction of pollutants and UHI effect	(Rowe, 2011; Santamouris, 2014)
Flood defences	Potential to provide paths for walking	Possible increase in recreational walking and cycling, improved physical and psychological health	(Mansor et al., 2012)
Structural measures implanted in wetlands	Increased coverage of wetlands and biodiversity benefits	Possible increase in recreation	(Opperman et al., 2009)
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	(Tyrväinen et al., 2014)

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).

All 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 ageing populations and poorer groups, among others (Finlay et al., 2015; Maas et al., 2009a).

Finally, following Martinez-Juarez et al. (2015a, 2015b), and as introduced in Section 3.4, exposure is considered in the framework in terms of active, consumptive and passive. As previously defined, active exposure is dependent on the activities of the individual and may involve the use of green spaces, for example, to walk or exercise. Apart from physical activities, social activities may also be related to active modes of exposure. In the analysis of the framework, a key role is plaid by attitudes and beliefs of people in this context, which is strictly linked with peoples' empowerment having the purpose of personal growth. Consumptive exposure refers to the consumption of certain elements produced or regulated by the natural ecosystem. Clean water consumption and extraction of pharmacological products from the ecosystems can be mentioned in this sense. Finally, passive exposure (when active engagement is not required and potential benefits come from the sole presence of green spaces, and climate regulation) is a form of involvement in which the nature can improve health by its mere presence. This classification is an added value to the eDPSEEA model and it can help in identifying different types of values linked with exposure, such as recreational or passive use values, which are evaluated using different types of methods in the economic literature (based on stated or revealed preferences).

5. Conclusions

The interlinkages between climate change, ecosystems and health need to be properly understood in order to better plan adaptive responses and to ensure potential health co-benefits can be taken into consideration in the design of adaptation measures, particularly where nature-based solutions are being proposed. To date, promising evidence of links between human health and green areas has been found. This evidence was the basis to develop a conceptual framework, which we constructed on the basis of the eDPSEEA framework, with the intent of showing the pathways by which green areas interact with human health. The eDPSEEA-based framework that we propose could help in the development of improved empirical analysis, for example by serving as multidisciplinary platform for discussion among experts and stakeholders. It could also help to identify which relations are more or less covered in the literature and to identify key indicators (both qualitative and quantitative) in each cause-effect relation among elements in the system. This analysis would support future research in providing a basis for operationalising quantitative assessment and modelling health impacts from green areas using statistical approaches.

When analysing the literature, it becomes clear that some aspects have been more thoroughly analysed than others. The implications of this are that some evidence is not uniformly distributed across the framework, which leads to another core for future research. The literature review on the relation between climate, green spaces and ecological functioning from an ecosystem services perspective showed a well-documented association. However, when looking at the specific health impacts from exposure to green spaces (with a health-based perspective), evidence is mixed and not always clear. 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. The diversity of methodologies and metrics used for measuring exposure and health outcomes, makes it difficult to compare studies and implies an added difficulty in obtaining results that are adequate to be generalised through a quantitative meta-analysis. Giving some uniformity in order to allow for a statistical analysis of the data described in the literature is another task requiring further research.

Another important point is the role of contextual variables which are rarely put into focus in the specific literature using the health-based perspective, and when they have been, this has been done in an exclusive way, not taking into account interacting variables. Similarly, research is still needed on how variables such as physical activity, that could be positively correlated with both green spaces and health, may affect the overall relationship. The role of external aspects such as ageing, active lifestyle and diet, has been another major point of the present findings. These factors, that have themselves a big impact on health, should be related to the study of the impact of natural ecosystems on health. They are often risk factors in the appearance of NCDs, such as the case of sedentary lifestyles or eating habits. This implies that analysis of the health impacts of green spaces should incorporate these risk factors in the most comprehensive manner, while the analysis of the literature has shown that this is often a gap. As discussed in the framework, role and implications of these contextual variables is a key issue with a need for further research. Finally, the differing types of exposure considered in this analysis have not either been intensively researched. In our study we made an attempt to classify existing studies according to the type of exposure (passive, consumptive or active), but future research is needed to assess quantitatively the health benefits according to the type of exposure.

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Appendix A. Supplementary data

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