Unravelling the mechanisms linking cultural ecosystem services and human wellbeing

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Abstract

Ecosystems contribute significantly to human wellbeing through the provision of ecosystem services. Despite the growing literature on cultural ecosystem services (CES), there is a lack of systematic understanding of how they are linked with human wellbeing. Here we conduct a systematic review of the peer-reviewed literature to identify the mechanisms and pathways underpinning the linkages between different CES and constituents of human wellbeing. Furthermore we identify their complex associations through Latent Class Analysis, Multiple Correspondence Analysis, and different visualisation tools. Overall we identify 16 major mechanisms linking CES and human wellbeing, via 70 distinct pathways. Beyond that we find five major assemblages of pathways featuring consistent associations among mechanisms mediating CES and human wellbeing. We critically discuss the main research trends and gaps, and propose future directions for research and practice in order to leverage the potential of CES for human wellbeing, and sustainability more broadly.

Keywords: Cultural ecosystem services, human wellbeing, nature's contributions to people, systematic review, trade-offs

Introduction

The academic community has repeatedly emphasised on the necessity to understand the complex human-nature relationships and unravel the pathways through which ecosystems contribute to human wellbeing via the provision of ecosystem services[1,2]. Understanding the underlying processes linking ecosystem services and human wellbeing, designing appropriate interventions to leverage the contribution of ecosystem services on human wellbeing, and mitigating the negative impacts of human activity on ecosystem services are essential for sustainable natural resource management[2,3]

Cultural ecosystem services (CES) are the diverse non-material contributions of nature to humans, such as, among others, recreation, spiritual enrichment, cognitive development, social relations, and aesthetic experiences[1,4,5]. Despite the growing attention of the academic community on CES, it has been exceptionally challenging to systematise in concrete terms their linkages with human wellbeing[6,7]. Unlike provisioning, regulating, and supporting services whose assessment, although often complicated, is usually possible through quantitative and consistent metrics, CES are often intangible, subjective, socially constructed, and dependent on human perception, requiring an entirely different set of tools, metrics, and approaches[4,8,9]. Hence, despite the importance of CES for sustainable resource management[10,11], their assessment and contributions to human wellbeing is often a context-specific and qualitative endeavour, which makes the effective incorporation of its outcomes into policy-making processes very challenging[6]. In this sense the systematic understanding of the linkages between CES and human wellbeing can offer valuable insights for policy and practice for ecosystem management and broader sustainability.

However, despite the ever-expanding body of literature discussing the interface of CES and human wellbeing, the current evidence is highly fragmented. First, the relevant literature tends to adopt different theoretical frameworks with various terminologies[4–7], resulting in fragmented information and inconsistent CES assessments and valuations. This is largely due to the fact that the underlying research comes from a very diverse range of academic fields, with often limited effort to synthesise knowledge in a cohesive manner[12]. Second, as both the provision of CES and the linkages to human wellbeing are highly context-dependent, their generalisation and systematic understanding tends to be riddled with challenges[12].

Here we aim to bridge these gaps through the comprehensive and cohesive systematisation of the linkages between CES and human wellbeing. In particular we conduct a systematic review and analysis of the relevant peer-reviewed literature to (a) delineate the mechanisms and pathways linking different CES and constituents of human wellbeing (b) compare the effects of the different mechanisms underpinning these linkages on human wellbeing, and (c) identify possible associations among the mechanisms. The outcome of this Review is a theoretical framework consisting of 16 individual mechanisms linking different combinations of CES and constituents of human wellbeing, as well as their complex interaction in terms of synergies and trade-offs. Beyond this we identify and critically discuss research trends and gaps at the interface of CES and human wellbeing, and offer recommendations for future research and opportunities for ecosystem management to leverage the potential of CES for human wellbeing, and sustainability more broadly.

Results

General literature patterns

The systematic review identified literature on the linkages between CES and human wellbeing across all continents. The reviewed studies span a total of 62 countries at various spatial scales, with 81.8% of papers focusing on the local scale (n=247 studies), 8.3% at the national scale (n=25 studies), 6.3% at the regional scale (n=19 studies), and 3.6% at the global scale (n=10 studies). In terms of the stakeholders represented across the different studies, almost all studies consider local communities, followed by tourists, indigenous communities, and farmers, fishers and business owners (Figure S5-S6, Supplementary Material).

Figure 1 shows the geographical distribution of the study sites considered in the respective literature, and the number of publications by region and ecosystem type. Most studies focus on Europe (42.1% of articles), Asia (21.7% of articles), and North America (18.5% of articles). Only a minority of studies focuses on Central and South America (6.5% of articles), Africa (5.8% of articles), and Oceania (5.4% of articles), despite being biodiversity-rich and large fractions of their populations depending on ecosystem services for their livelihoods. The reviewed studies mostly focus on CES from urban and semi-urban ecosystems (26.2% of articles), forests and woodlands (20.2% of articles), inland water (12.5% of articles), and coastal areas (8.9% of articles). Some of the reviewed studies also document the linkages between CES and human wellbeing in relatively less studied ecosystems such as the arctic and mountain tundra, desserts and scrublands, and savannas.

<<Insert Figure 1>>

Over time we see studies from diverse academic fields exploring the linkages between CES and human wellbeing (Figure S4, Supplementary Material). Initially, relevant studies came from a rather limited number of disciplines such as environmental studies, urban studies, and geography. However since about 2012 (which coincides with the establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services - IPBES), relevant studies came from a larger diversity of the academic fields. By 2020, studies were coming from diverse fields of the social sciences and humanities, cultural studies, psychology, pharmacology, medicine, and international relations, among others. It is worth noting that the reviewed studies have gradually adopted new and innovative tools from different disciplines for data collection and analysis. However, a closer examination of the theoretical frameworks and research tools (see Table S7, Supplementary Material) shows that knowledge integration cross the disciplines is still rather shallow and the diversity of the methodological portfolio is generally low.

Pathways and mechanisms linking CES and human wellbeing

Among the 301 reviewed studies and the 1138 observations of the pathways linking CES and human wellbeing, the 979 observations (86%) represent positive contributions, the 137 observations (12%) negative contributions, and the 18 observations (1.6%) two-way interactions, while 4 observations (0.4%) could not be categorised in terms of the direction of impact.

Our results suggest that the pathways linking CES and human wellbeing are multi-faceted and intricate. We identify 70 unique such *pathways*, each of which depicts a linkage through which the provision of (or change in) a single CES affects a single constituent of human wellbeing (see Methods for deeper explanation). Of these 70 *pathways*, 45 denote positive contributions to human wellbeing

and 25 negative contributions to human wellbeing. Table S12-S14 in the Supplementary Material provide an explanation of these 70 pathways, including examples from the literature. Subsequently through a critical analysis we systematise similar pathways across various "channels of interaction" and "mechanisms".

The four *channels of interactions* essentially denote the different ways in which people consciously and unconsciously engage with ecosystems and experience their benefits. According to our results, the four channels are *form, cultural practices, intellectual practices,* and *spiritual practices*. *Form* essentially denotes the interactions with nature through the physical and tangible aspects of ecosystems. People perceive the physical structure of nature via multiple qualities that reflect visual and other sensory experiences, with examples including the interactions from looking at the shape of the cliffs, feeling the sea breeze, smelling the flowers scent among others [13–15] *Cultural practices* denote the interactions with nature that provide an opportunity for playing and exercising, creating and expressing, producing and caring, and gathering and consuming[9,16]. *Intellectual practices* denote the interactions with nature that provide an environment for learning and gaining new knowledge, including, for example, the interactions that emerge from researching, learning, thinking about or knowing an ecosystem or its components[12,17]. *Spiritual practices* denote the interactions with nature that provide an opportunity for spiritual and religious activities, as for example rituals and religious activities carried out in sacred natural places or using plants and animals [18,19].

Through these channels, CES contribute to human wellbeing via very diverse *mechanisms*. We identify 16 types of mechanisms, namely (a) *cognitive,* (b) *cohesive,* (c) *communicative,* (d) *creative,* (e) *evolutive,* (f) *formative,* (g) *intuitive,* (h) *regenerative,* (i) *remunerative,* (j) *retrospective,* (k) *satisfactive,* (l) *transactive,* (m) *transcendentive,* (n) *apprehensive*, (p) *destructive,* and (q) *irritative* (Table 1). Of these, six mechanisms were adapted from a previous study[15] and ten mechanisms were newly defined by the authors following the qualitative data analysis (see Methods).

<<Insert Table 1>>

The empirical research on these mechanisms linking CES and human wellbeing constituents is uneven. Figure 2 depicts an alluvial diagram illustrating the frequency of the documented mechanisms across the reviewed studies. Recreation and tourism and aesthetic value are the most popular CES among the identified studies, accounting respectively for 31.8% and 17.6% of the total observations. Similarly there is large representation for some mechanisms and constituents of human wellbeing, as for example CES contributions to "mental health" (15.8% of observations), "physical health" (10.6% of observations), and "subjective wellbeing" (13% of observations) via *regenerative* mechanisms. Equally well documented are CES benefits to "social connectedness and belonging" (12.7% of observations) via *communicative* and *cohesive* mechanisms. However, the role of CES in influencing many constituents of human wellbeing is still overlooked, such as for example the contributions of CES to "learning and capacity", "personal identity and autonomy", and "sense of security and certainty".

<<Insert Figure 2>>

Relative contribution of individual mechanisms

Upon unravelling the pathways, channels of interactions, and the mechanisms between CES and human wellbeing, we normalise the effects for every observation through expert judgement, assigning scores between -2 to +2 (see Methods). We develop three matrix maps (Figure 3) that represent the level of impact of each mechanism to specific constituents of human wellbeing (denoted by the colours) and the overall quantity of the empirical literature (denoted by the size of the squares). Overall, there is a higher prevalence of high magnitude positive CES impacts on human wellbeing, while the prevalence of lower magnitude or negative impacts is relatively lower in the literature.

<< Insert Figure 3>>

When looking at the positive contributions of CES to human wellbeing our results suggest that the highest such contributions are for "mental health" and "physical health", with average scores of 1.99 (n=150, SE=0.014) and 1.97 (n=108, SE=0.02) respectively. Among individual CES, recreation and tourism and aesthetic value exhibit the highest contributions to human health via the regenerative mechanism. "Connectedness and belonging" is the wellbeing constituent that benefits the second most from CES with an average score of 1.92 (n=131, SE=0.03). CES can also have significant positive effects for personal "learning and capability"**,** with an average impact level of 1.91 (n=114, SE=0.04). The average scores are more moderate for other constituents of human wellbeing such as "economic wellbeing" (score=1.88, SE=0.09, n=61), "certainty, sense of control and security" (score=1.86, SE=0.072, n=19, "identity and autonomy" (score=1.84, SE=0.042, n=71), "spirituality" (score=1.79, SE=0.05, n=81), "inspiration and fulfilment of imagination" (score=1.72, SE = 0.03, n=84), and "subjective wellbeing" (score=1.71, SE=0.34, n=125).

The negative contribution of CES to human wellbeing manifest through (a) cultural ecosystem disservices (Table S12, Supplementary Material), and (b) the degradation of CES provision (Table S13, Supplementary Material) (see Methods for definitions). Among all wellbeing constituents, the results suggest that the highest negative effects are liked to "mental health**"** (score=-1.98, SE=0.02, n=26), via the *destructive* mechanisms. Some disservices also profoundly hamper "certainty, sense of control and security" (score=-1.88, SE=0.44, n=15 via *apprehensive* mechanisms. These are mainly associated with aesthetic value and recreational and tourism, with a common underlying concern over safety, which is directly associated with how some natural elements are perceived. CES degradation sometimes also has negative effects on "spirituality" via the *destructive* mechanism (score=-1.94, SE=0.06, n=10. Interestingly, in terms of "economic well-being", via the *remunerative* mechanism human wellbeing can be significantly affected by the financial loss caused by the degradation of CES (score=-1.96, SE=0.08, n=17).

Pathway assemblages, synergies and trade-offs.

Beyond the individual effects outlined above, CES and the pathways through which they contribute to human wellbeing, also tend to interact with each other in complex ways. Following the LCA we identify 'CES pathway assemblages', which refers to a collection of pathways linking CES and wellbeing that appear significantly related (see Methods for definitions).

Overall, we identify five CES pathway assemblages that refer to (a) sensory affection, (b) learning and development, (c) health and leisure fulfilment, (d) social vibrancy, and (e) spiritual and heritage resources. Table 2 summarises the main features and synergies among these assemblages, the relevant constituents of human wellbeing, as well as the underlying mechanisms and affected groups.

Table 2: Characteristics of CES pathway assemblages.

Pathways assemblage	CES	Well-being constituents	Mechanisms	Ecosystems	Beneficiaries
Sensory affection	-Recreation and tourism -Aesthetic value -Sense of place -Authentic wilderness	-Certainty, sense of control and security -Economic well-being -Mental health -Subjective well-being	-Apprehensive -Irritative -Destructive	-Inland water -Ocean and marine -Urban and semi-urban	-Tourists -Local community
Learning and development	-Education value -Knowledge system -Cultural heritage/cultural diversity value	-Learning and capability	-Cognitive -Communicative -Formative	-Forest and woodland -Cultivated areas -Ocean and marine	-Indigenous community -Local community
Health and leisure fulfilment	-Recreation and tourism -Aesthetic value	-Mental health -Physical health -Subjective well-being	-Regenerative -Satisfactive	-Urban and semi-urban -Inland water	-Tourists -Local community
Social vibrancy	-Recreation and tourism -Aesthetic value -Social relations	-Connectedness and belonging -Economic well-being	-Cohesive -Communicative -Remunerative	-Urban and semi-urban -Forest and woodland	-Tourists -Local community -Farmers and fishers -Business owners
Spiritual and heritage resources	-Spiritual value -Cultural heritage/ Cultural diversity -Inspiration value -Aesthetic value	-Spirituality -Identity and autonomy -Connectedness and belonging	-Intuitive -Retrospective -Creative	-Forest and woodland -Ocean and marine -Urban and semi-urban -Coastal areas	-Local community -Indigenous community -Tourists

Subsequently we identify trade-offs between these assemblages through Multiple Correspondence Analysis (MCA). Regarding the associations between CES, wellbeing constituents, and affected groups, the significant associations of CES account for 7.3% of the first dimension (axis x) and 6.9% of the second dimension (axis y) (Figure 4). Trade-offs occur among three assemblages, namely "health and leisure fulfilment", "spiritual and heritage resources", and "learning and development". Below we examine some specific cases to illustrate these trade-offs better. On the second dimension, "spiritual and heritage resources**"** is assessed as a trade-off to "health and leisure fulfilment**" (Figure 4)**. These trade-offs are mainly associated with traditional and indigenous communities. Furthermore, we observe trade-offs between "health and leisure fulfilment" and "learning and development" on the second dimension (Figure 4).

<<Insert Figure 4>>

Discussion

Mechanisms linking CES and human wellbeing

Following the critical analysis and synthesis of the findings of the 285 empirical case studies and their 1138 observations, we identify 16 distinct mechanisms that mediate the linkages between CES and human wellbeing (Table 1). Six of these mechanisms are adapted from the literature[15], while the remaining ten were systematised by the authors. This has resulted in a comprehensive mapping of the interface between CES and human wellbeing, and constitutes a conceptual advancement that can have both theoretical and practical application.

In terms of theoretical application, these mechanisms can influence the development of conceptual frameworks that explore the interface of ecosystem services and human wellbeing in more nuanced ways. For example, this can help refine conceptual frameworks proposed by large-scale assessments[1,2,20], international initiatives[21], and individual studies[4,5,7,8].

In terms of practical applications, the findings of this study can guide studies that seek to identify better how such mechanisms unfold in different real-life contexts and inform the design of appropriate interventions to enhance human wellbeing through the provision of CES. This latter point echoes a large number of studies arguing for the need to capitalise on the intangible benefits provided by green spaces for enhanced human wellbeing, especially in urban contexts[22–25].

Relative effects of mechanisms

Figure 3 strongly suggests that the different mechanisms have quite different effects on human wellbeing. To the authors' best knowledge this is the first comprehensive attempt to systematically quantify the impacts of CES on human wellbeing through a global systematic review. As the value and contribution of many CES is subjective and intangible, the literature often adopts descriptive and qualitative approaches, which make it challenging to undertake a systematic analysis across studies[4,7,9].

The results of our analysis suggest that CES tend to have the highest positive contribution to constituents of human wellbeing such as "physical health" and "mental health" via *regenerative* mechanisms (Figure 3). These denote interactions with nature that create positive restorative outcomes such as stress reduction, relaxation, tranquillity, escapism, physical exercises, increased longevity, and recovery from sickness[12,26–29].

Strong positive effects are also observed for "connectedness and belonging" via "cohesive" mechanisms (Figure 3). Here people communicate and develop meaningful personal relationships through interactions with ecosystems [15,30–32]. For example, nature-based activities such as recreation, hiking, and camping foster social cohesion via socially healthy behaviours and stewardship[30]. Studies have consistently pointed that the social bonding mediated by interactions with nature can create networks that emerge beyond the physical boundary of the sites and reinforce the existing relationship at both personal and collective levels[33].

Strong positive effects are also observed for "learning and capability" through *cognitive* and *evolutive* mechanisms (Figure 3). For example via the *evolutive* mechanism, nature-based recreation has a positive effects on childhood growth and gradually equips children with knowledge and skillsets that are beneficial in the future[34,3617,35]. These contributions can also be manifested via the *cognitive* mechanism through which nature acts as the source of learning about history, culture, the natural world and social relationships[37], or an opportunity for scientific development, outdoor education and learning from previous generations[38,39]. It is worth noticing that "learning and capability" is one of the constituents of human wellbeing that has been relatively overlooked in the CES research landscape, as

for example it was not included in the conceptual framework of the Millennium Ecosystem Assessment[1]. However, here we find the centrality of this constituent as almost all CES provide benefits to it via various mechanisms. For example, via the *cohesive* and *communicative* mechanisms, educational values, knowledge systems, social relations and recreation and tourism are the CES that contribute the most to this wellbeing constituent, but again through very different mechanisms.

When it comes to negative contributions, the constituents of human wellbeing that are most negatively affected by cultural ecosystem disservices and CES loss tend to be "mental health" and "certainty, sense of control and security" via *apprehensive*[14,40] and *destructive*[41–43] mechanisms (Figure 3).

It is well documented that cultural ecosystem disservices such as noise from wildlife, wild and messy landscapes, and the presence and movement of pests give rise to perceptions of disorder, while animal waste and plant litter many cause disgust[40,44]. For example, obsessive fear can emerge through encounters with natural features via visual (or sometimes auditory) interactions, such as scary animals, dangerous predators, animal blood, and areas that are dark and covered by high trees[12,14,40]. Many people have a limited frame of reference for recognising and construing such unfamiliar sensory experiences, and may develop a sense of overwhelming "cognitive chaos" and alienation towards nature[12]. Landscape planning, eco-tourism development, socioeconomic background, and childhood interactions with nature are some of the external factors that tend to mediate these mechanisms[44,45].

When it comes to *destructive* mechanisms, the point of departure are the benefits that nature provides to many people through spiritually transcendental experiences which transform something from within[42,43]. These are closely linked with religion, places for customary rituals and worship[18]. Often environmental degradation, urbanisation and/or overexploitation cause the gradual loss of spiritually important landscapes[46,47] or plants/animals that with religious/spiritual importance[48] , causing the decline/loss of ritual activities and related spiritual wellbeing for some people[49].

It is worth noting that many people might not always be well aware of the benefits offered by ecosystems. Yet they can be significantly affected by the financial loss caused by the degradation of CES via the *remunerative* mechanism (Figure 3). For example, climate change or environmental degradation can cause significant loss in tourism revenue, thereby reducing the incomes of people working in these sectors and hindering their capability meeting basic needs[50,51]. Some of the reviewed studies suggest that when money enters the picture, it can sometimes shift the way people frame their wellbeing, appreciation of nature, and motivations behind their interactions with nature[52,53]. The extent of how these changes manifest varies from case to case and between different social groups. Thus it is not possible to elicit a universal conclusion here. Nevertheless, in the discussion related to wellbeing and CES, the usefulness of money to meet several wellbeing needs remains elusive[54].

When looking these findings critically there seems to be a dominance of studies about the positive contribution of CES on human wellbeing associated with transient, immediate, and significant impacts. Much fewer studies have focused on possibly negative or low magnitude CES impacts. Furthermore, Figure 3 visually highlights many blank areas, which indicate many possible missing pathways between CES and constituents of human wellbeing via the identified mechanisms. These imbalances and missing pathways could be attributable to three possible reasons. The first could be publication bias, which refers to the selective publication of studies based on the magnitude and direction of the results and/or the areas of interest of the authors[55]. However, due to the type of data and analytical procedure it is not possible to formally test for publication bias, as is common in meta-analyses[56] (see limitations in Methods). Second, the missing pathways in Figure 3 linking a specific CES to a particular wellbeing constituent via a specific mechanism might not exist in reality. Third, these pathways might exist but have not been empirically identified in academic studies.

Considering the above, this systematic review seeks to provide a level of evidence and possibilities to inform future research and practice at the interface of CES and human wellbeing to reduce the biases

in the areas that "we know", fill in the knowledge gaps in the areas that "we do not know", and hint to explore the areas that "we do not know we do not know" (see Implications, recommendations and future research directions).

Synergies and trade-offs between mechanisms

We find some consistent associations among the pathways and mechanisms through which CES contribute to human wellbeing between studies. Overall, the results seem to confirm that different mechanisms are more relevant to certain CES types and affect specific sets of wellbeing constituents. This points to that it might be practical and beneficial to identify such synergistic relationships to inform landscape and urban planning, natural resource management, and biodiversity conservation. In particular we identify five assemblages representing the collections of associated pathways namely "sensory affection", "learning and development", "health and leisure fulfilment", "social vibrancy", and "spiritual and heritage resources". Some implications can emanate from the characteristics of these assemblages.

First, when it comes to "sensory affection", while natural aesthetic values can enhance subjective wellbeing[12,57], authentic wilderness with disordered and frightening landscapes can also cause fear and negative feelings to some people[14,40]. This could raise some interesting debates about the promotion of "authentic" natural landscapes or planning "false wilderness" to reconnect people to nature[58].

Second, "health and leisure fulfilment" and "social vibrancy" assemblages tend to be more prevalent in human-dominated landscapes such as urban areas (Table 2). This points to the synergistic effects and cost-effectiveness that urban green and blue infrastructure can have for meeting multiple needs for urban residents[14,59,60].

Third, related to "learning and development", the results show many similarities in how ecosystems shape the way people think[61], their choices in life[13], and the development of their worldview and cultural significance between Indigenous people and modern communities[12]. Regardless of their culture and level of dependence on ecosystems for their livelihoods, this points to longstanding associations between ecosystems and the personal lives of people through intimate knowledge of (and adaptive integrity with) the local environment, which significantly contributes to personal growth[61].

Fourth, in terms of "spiritual and heritage resources", identity appears to be the core determinant of the synergies and trade-offs effects[62,63]. Thus, the inclusion of local communities' identities and cultural practices can create substantial benefits for ecosystems management in areas that such associations are visible[64].

Finally, we identified trade-offs among three assemblages, namely "learning and development", "health and leisure fulfilment", "spiritual and heritage resources" (Figure 4). Trade-offs between "spiritual and heritage resources" and "learning and development" seem to be linked to religious or sacred landscapes. In particular some traditional and Indigenous communities are sceptical about the research potential and educational value of such areas[65]. This is often due to diverse challenges and barriers (e.g. technical, perception, communication), as well as differences in values, which have alienated on many occasions the active engagement of indigenous communities in the formulation of ecosystem management plans in such areas[65–67].

Another trade-off is between "spiritual and heritage resources" and "health and leisure fulfilment" (Figure 4). Such trade-offs are again mainly associated with traditional and Indigenous communities for which ecosystems (and nature more broadly) invoke spiritual experiences, e.g. the Earth and its elements are perceived as living entities valued for their own sake[17,42]. Sometimes tourism and recreational activities that can provide leisure opportunities for improving health and subjective

wellbeing to tourists are sometimes perceived to violate sacred places [68]. Indeed, some studies have suggested that tourism activities sacrifice spiritual and intrinsic values (e.g. sacredness and the spiritual connections between the sites and people) for instrumental benefits (e.g. tourism revenue)[69].

A final trade-off is between "health and leisure fulfilment" and "learning and development" (Figure 4). This is usually associated with the fact that some tourism and recreational activities can alter livelihoods at community level and encourage young people to leave their traditional livelihoods[37,70]. The environmental degradation associated with intensive tourism combined with the risks of changing livelihood structure may result in significant loss of local knowledge systems and skills[71]. In other cases, the inappropriate planning of tourism activities can hinder the educational value of historically, culturally, and ecologically important areas[69,72].

The above findings could effectively inform practice and decision-making processes to anticipate what types of human wellbeing trade-offs are to be expected in areas where such CES are provided, for example due to tourism[73–75] or economic development[76,77]. This can guide the identification of possible context-specific solutions to prevent or mitigate CES-driven trade-offs in human wellbeing.

Implications, recommendations and future research directions

The findings of this systematic review can have major implications for policy and practice. Here we draw upon the emerging concepts of 'landscape multi-functionality'[78] and 'reconnecting people to nature'[79] to guide the design of effective policies and interventions to enhance human wellbeing (and sustainability more broadly) via CES.

First, the results on CES assemblages, synergies and trade-offs support the view of landscape multi-functionality, and the possible value addition of interventions and policies promoting the interactive and simultaneous provision of CES. The outcomes of this research can provide the basis for **a scoping toolkit** for anticipating the possible human wellbeing impacts of different policies and interventions that provide or compromise CES, and vice versa (i.e. identify policies and interventions that can improve human wellbeing via CES provision). For example, if policy-makers have set initial goals for specific aspects of human wellbeing in a given locality (e.g. enhance physical and mental health in a city), then it could be possible to track back the pathways linking the designated set of wellbeing constituents to the CES that would be needed to achieve this (e.g. provide green spaces for exercise, promote landscape elements with aesthetic values associated with stress release and escapism, enhance spiritual fulfilment in designing urban green infrastructure). By knowing the mechanisms permeating these pathways (e.g. regenerative, satisfactive, transcendentive), and comprehending the most likely beneficiaries and landscapes (and landscape elements) that can deliver these CES then it could be possible to inform the development of specific interventions and policies that meet these objectives, and ideally promote synergistic effects while reducing trade-offs. In this sense, the comprehensive systematisation of the 70 pathways of possible non-material interactions between human and nature (Table S12-S13-S14, Supplementary Material) provides a clear roadmap that can assist practitioners and decision-makers in predicting the outcomes of policy options and practical application, possibly providing meaningful benefits at different stages, from planning to implementation.

Second, while there is a consensus that policies and interventions seeking to reconnect people to nature can have multiple benefits to human wellbeing and sustainability[79], it is not always clear how this can be achieved. By utilising the notion of 'leverage points', which is defined as points in a complex system where interventions can alter the overall system behaviour[79], we argue that incorporating **what really matters to people** and **what really harms people** in the policy-making process can create these deep leverage points and bring about more effective and meaningful 'reconnections'. The results suggest that 'inner' connections such as cognitive connections to enhance

‘learning and capability’, cohesive and emotional connections to promote ‘connectedness and belonging’ and psychological connections to enhance ‘mental health’ are more likely to have a stronger effect on human wellbeing outcomes rather than the ‘outer’ connections such as remunerative connections (Figure 3, Table S8 and S9). As CES have often received less attention in policy-making progress than provisioning or regulating services[4,8], the authors emphasise the necessity of reconnection strategies that aim to influence the behaviour of individuals and alter the paradigms that underpin the actions and decision-making for ecosystem management.

Despite the wealth of studies exploring the interface of CES and human wellbeing we identify several knowledge gaps that future research should target. First, the research at this interface tends to focus on individuals. While this is undoubtedly important, the fact remains that there has been less focus in the reviewed studies on understanding the effect of CES on collective wellbeing. However, in several studies we observed that due to trade-offs the provision of CES has improved the wellbeing of individuals, but reduced collective wellbeing[80], and vice versa[81]. Although this has been recognised in the individual studies, there is a lack of multi-level wellbeing assessments, which would be necessary for better assessing ecosystem services trade-offs and synergies.

Second, when observing the evidence imbalances and missing pathways (see Figure 3 and ‘Relative effects of mechanisms’), there is a need to fill in the knowledge gap in the areas that (a) ‘we know’, (b) ‘we do not know’, and (c) ‘we do not know we do not know’. Regarding (a), there is a need to advance the currently available knowledge and address publication biases. For the former, research should explore in-depth how these mechanisms manifest in the less studied ecosystems and understand their differentiated effects to various stakeholders. The underlying factors mediating these impacts and the drivers of changes in CES provision would also need more dedicated attention. For the latter, scholars should be able to publish high quality research regardless of “uninteresting” results or novelty. Low magnitude, negative or incremental impacts of CES provision on human wellbeing should also be captured. Regarding (b), our work could be utilised as a summary of the current research landscape, which highlights the many missing pieces that need to be found. The blank areas in Figure 3 could offer some starting points to explore whether the missing pathways exist or not in reality. Regarding (c), we should point that there is a possibility that more mechanisms link CES and human wellbeing considering the large biological and cultural diversity across the globe, and the often very tight human-nature interactions in many geographical contexts. In this sense there is a need to move beyond the conventional way of thinking and upgrade research approaches and framings to unravel the unknown unknowns in human-nature relationships. We hypothesise that missing mechanisms could be present in ecosystem-dependent communities, and especially traditional and Indigenous communities, considering their very unique relations with nature. In this sense there would be a need to enhance even more the current efforts to promote the collaboration between scientists and Indigenous and Local Knowledge (ILK) holders[82].

Overall, following this systematic review, we argue that the fuller understanding of the complex linkages between CES and human wellbeing can help navigate towards outcomes that promote effectively both wellbeing and ecosystem management and contribute to meeting global sustainability challenges. The conceptual framework develop can possibly move the current debate forward.

Methods

Conceptual framework and key concepts

Through the systematic review outlined in this paper we synthesise the literature about the linkages between cultural ecosystem services (CES) with human wellbeing. Many assessment reports[1,2,20], international initiatives[83]and individual studies[4,5] have developed or refined different conceptualisations and typologies of CES, as well as conceptual frameworks linking them to human wellbeing. Similarly, many studies have delineated the different constituent of human wellbeing in relation to the benefits people derive from nature, including CES [12,84].

Acknowledging this large diversity of typologies of CES and constituent of human wellbeing (and their linkages), in this study we adopt (and expand) the conceptualisations and typologies of (a) CES from the Millennium Ecosystem Assessment (MA)[1] and (b) constituents of human wellbeing proposed by Russell et al (2015).

We adopt the MA's conceptualisation and typology of CES, as despite its criticisms [85,86] it has a long history shaping much of the academic literature on CES, allowing at the same time the integration of knowledge from multiple disciplines. According to the MA, CES are defined as the non-material benefits people obtain from nature directly and indirectly[1]. For the purpose of this systematic review we adopt the full list of CES included in the MA (2005), namely: (a) recreation and tourism, (b) aesthetic value, (c) religious value, (d) educational value, (e) cultural heritage value and cultural diversity, (f) inspiration, (g) sense of place, (h) knowledge system, and (i) social relations. We then complement this initial list with other CES found in the reviewed documents that are not explicitly delineated in the MA, but identified as such in the source literature. Table S2 in the Supplementary Material provides the full list of CES (and their definitions) considered in this study.

Similar to CES, human wellbeing is a broad and contested term that has been interpreted in various ways without a commonly agreed definition[12,84]. At a generalised level, human well-being can be perceived as a synergistic and multi-dimensional concept that consists of multiple constituents, which when combined, they characterise the positive state of individuals[12]. Although the concept of human wellbeing has drawn the attention of policymakers, researchers, and practitioners globally, there is insufficient knowledge within the literature on how it is linked with the natural environment and the ecosystem services it provides[84].

In our systematic review we use eleven constituents of human wellbeing, most of which are adopted from Russel et al. (2013). Namely the constituents of human wellbeing considered in this study include: (a) physical health, (b) mental health, (c) spirituality, (d) certainty, sense of control and security, (e) learning and capacity, (f) inspiration and fulfilment of imagination, (g) identity and autonomy, (h) connectedness and belonging, (i) subjective wellbeing, (j) cultural fulfilment, and (k) economic wellbeing.

We need to point that although we have used these conceptualisations and typologies of CES and constituents of human wellbeing to form the conceptual framework of the systematic review, we have not limited the review to the studies that only used these explicitly. For example, for CES we do not only review studies using the MA terminology/typology, but included studies that adopted different terminologies/typologies (e.g. IPBES, CICES, TEEB). Acknowledging the slight differences among terminologies [i.e. non-material nature's contributions to people (IPBES) vs. cultural ecosystem services (MA)], we use these terms interchangeably in the context of this review. Similarly we acknowledge that the current frameworks of the constituents of human wellbeing are imperfect and that there are blurry distinctions among them[12].

Considering the above this review does not seek to present an argument on the accuracy of the adopted typologies, but instead focuses on covering all the studies using different terminologies to ensure the widest possible capture of studies to elicit the linkages between CES and human wellbeing. Our use of certain conceptual frameworks does not seek to imply the superiority of the one over the other, but their functionality within this review.

Literature identification and selection

For this systematic review we identified peer-reviewed literature that report observations about the contribution of CES to human wellbeing both quantitatively and qualitatively. We identified the literature though Elsevier Scopus and ISI Web of Science Core Collection. We employed three categories of search words that were guided by the conceptual framework presented above. The three levels of search words reflect (a) ecosystems or ecosystem services, (b) specific CES, (c) human wellbeing or quality of life.

The specific keywords are: ("Ecosystem*" OR "Ecosystem service*" OR "social-ecological system*" OR "Nature's contribution*") AND ("cultural ecosystem service*" OR "aesthetic*" OR "recreation*" OR "spiritual*" OR "inspiration*" OR "place attachment" OR "social relation*" OR "knowledge system" OR "sense of place" OR "educational value* OR "Non-material nature's contribution*") AND ("Quality of life" OR "wellbeing" OR "human needs" OR "well-being").

The literature search was conducted for the literature title, abstract and keywords, and was limited to peer-reviewed articles in English. The search was performed in July 2020 with no restriction on the publication time frame. We followed the PRISMA principles for systematic review[87].

In total, 463 articles were found in Elsevier Scopus, and 251 documents were found in ISI Web of Science Core Collection. We then removed duplicates leaving 502 articles for further screening. Subsequently two filters were applied. For the first round, the first author read the studies' titles and abstracts to remove non-relevant literature. For the second round, the remaining articles were downloaded and read by the first author in full to determine whether they met the inclusion criteria. The inclusion criteria were:

a) The study should report cultural services provided by nature or ecosystems (i.e. non-ecosystem related cultural services were excluded);
b) The study should report CES or non-material contributions of nature (i.e. other ecosystem services or material contributions were excluded);
c) The study should be empirical or a review of empirical studies (i.e. conceptual, theoretical and simulation studies were excluded);
d) The study should report observed changes in human wellbeing (i.e. studies not mentioning change in wellbeing were excluded)
e) The study documents should be Articles or Reviews (i.e. Editorials, Books, and the Proceedings of conferences and meetings were excluded).

Among the 502 documents identified after the search, a total of 356 documents appeared to match the inclusion criteria mentioned above after the first screening round. The first author then read the full text of these 356 documents and ended up with 302 documents (285 empirical studies and 17 review papers) that were deemed eligible for further analysis. Figure S1 in the Supplementary Electronic Material contains the different stages of study selection.

Critical appraisal of studies

As systematic reviews draw conclusions based on multiple individual studies, it is necessary to evaluate the reliability of evidence at the individual study level[88]. In this study we adopted a series of appraisal guidelines for ecosystem services and conservation studies[88] and created a checklist for assessing the reliability of the evidence contained in each reviewed study. The checklist includes

questions related to internal validity in terms of the research aim, data collection, data analysis, results and conclusions, and design-specific aspects (see Table S3, Supplementary Material). Each study is then categorised as having "very strong evidence" (score: >75%), "strong evidence" (score: 50-74%), "moderate evidence" (25-49%), or "weak evidence" (<25%).

Overall, the quality appraisal indicated that 92.4% of all studies included in this systematic review (279 out of 302 studies) are categorised as having "very strong evidence", 7.3% (22 studies), as having "strong evidence", and only one study as having "weak evidence". The mean value of the quality score across all studies is 83.5%.

To ensure the high quality of the database, while at the same time highlighting the diversity of the research landscape, we include in this systematic review the broadest possible range of the studies. Thus we only remove the single study with "weak evidence". Thus the final database used for the data extraction included 301 studies, of which 285 were empirical studies and 16 review papers of empirical studies.

Coding and meta-data extraction

Three broad categories of meta-data was extracted from each paper, and subsequently used for the analysis and visualisation. Table S1 in Supplementary Material shows the summary of coding for meta-data extraction.

The first type of meta-data reflected the general study characteristics, including the (a) site location, (b) publication year, (c) spatial and temporal scale, (d) research types and objectives, and (e) the types of stakeholder engagement. We used Google map to collect the longitude and latitude coordinates of the studied sites for those studies that did not provide actual coordinates. We created a heat map using ArcGIS version 10.5, illustrating the geographical distribution of the study sample.

The second type of meta-data extraction focused on the study methodologies. This includes the information related to (a) data collection tools, (b) data analysis methods, (c) research framework, and (d) the broad academic field. This meta-data was used to explore the interdisciplinarity and the evolution of research methodologies through time using visualisation tools that illustrate the diversity of the disciplines and fields represented in the reviewed studies.

The third type of meta-data forms essentially the central part of the analysis, and relates to the mechanisms through which CES contribute to human wellbeing. Data extraction was guided by a series of questions designed to unravel the mechanisms, including information related to: (a) type of ecosystem, (b) type of CES, (c) observed changes in CES provision, (d) reason for changes in CES provision, (e) affected group, (f) constituents of human wellbeing that CES contribute to, (g) direction of the impact, (h) magnitude of the impact, (i) outcome of the impact, and (j) description of the mechanism in open text.

These variables are both closed-ended using coded ranges and open-ended using narrative answers. The former facilitates quantitative categorical analysis, while the latter facilitates the narrative for qualitative content analysis. Observations of mechanisms in which CES contribute to human wellbeing were extracted only from the empirical studies, and not from the review papers in the authors' database (see above).

From the 285 empirical studies, the authors identified 1138 observations of mechanisms linking different CES to different constituents of human wellbeing, which were divided as explained below. The elicitation of meta-data described above was performed by the first author, in close consultation with the second author on a case-by-case basis in case of inconsistencies or emerging new categories. This was to allow for the consistent elicitation of the meta-data, while at the same time ensuring an added lens for challenging cases.

Elicitation of mechanisms linking CES and human wellbeing

A relational content analysis was conducted for the 1138 observations of the mechanisms linking different CES with different constituents of human wellbeing. The relational analysis allowed for the

exploration of the relationships between the concepts and the identification of themes and patterns[89]. Inductive coding was applied to allow for the new concepts and narratives to emerge from the data itself. Figure S2 (Supplementary Material) shows the flowchart of data analysis.

In order to identify the pathways linking CES and human wellbeing we conducted two coding iterations. During the first coding, the 1138 observations were systematised across 231 pathways. For the purpose of this study, we define a *pathway* as the linkage through which the provision or change in a single CES affects a single constituent of human wellbeing.

During the second coding iteration we condensed the initial 231 pathways into 70 *pathways* based on similarity. These are explained in greater detail in Table S12-S14 in the Supplementary Material, with 45 having a positive effect on human wellbeing, and 25 negatively (of which 17 are associated with CES degradation/loss and 8 are disservices). For the purpose of this paper we define ecosystem disservices as "the ecosystem generated functions, processes, and attributes that result in perceived or actual negative impacts on human wellbeing"[90], e.g. unwanted pests, pollen allergy, vector-spread diseases, noise from wildlife, and frightening natural landscapes[91,92]. We view CES degradation as the process through which natural and anthropogenic drivers of ecosystem change disrupt the provision of individual or multiple CES, having detrimental impact on human wellbeing[13,46,93–96].

Further content analysis allowed the grouping of these 70 *pathways* into 4 channels of *human interactions with ecosystems*, and 16 types of *mechanisms*. This is because although some of the pathways link different CES with different wellbeing constituents, these linkages manifest in relatively similar ways in their functions to how they affect human wellbeing. Of the 16 identified mechanisms, 6 were adapted from another study[15] and 10 were defined by the authors.

Following an iterative content analysis, we systematised the evidence from the literature in this new typology and conceptual framework that links CES and human wellbeing, which is the main conceptual contribution of this systematic review. Table S12-S14 in Supplementary Material outlines all of the 70 pathways, identifying the CES, constituents of human wellbeing and mechanisms of interaction, citing examples from the literature.

Finally, the authors re-coded the entire dataset using this new typology of mechanisms. The final coded variables were all categorical variables, which were then used for further quantitative data analysis and visualisation as outlined below. We used alluvial diagrams to visualise the frequency of the mechanisms documented in the reviewed studies.

Quantification of the effect of different mechanisms

Considering that the different studies used quite different quantitative and qualitative measures for the contribution of CES (or their change) to human wellbeing it was not possible to conduct a proper meta-analysis. Instead we used a semi-quantitative normalisation approach that normalised the contribution of CES to human wellbeing between studies. This normalisation approach relied on expert judgement and followed the process proposed in Berrang-Ford *et al*[97].

In summary, the criteria used for the normalisation were the magnitude and direction of the impacts. The direction of impact was coded as: (a) positive, (b) two-way, (c) negative, and (d) not concluded. The magnitude was designated as (a) high negative impact (score=-2), (b) low negative impact (score=-1), (c) no significant effect (score=0), (d) low positive impact (score=+1), and (e) high positive impact (score=+2).

The data for the magnitude of impact (score -2 to + 2) was extracted in two steps. First, this came from the text of each study where the studies' authors explicitly indicated whether the impacts are high or low as perceived by their respondents. Second, for the studies that did not clearly clarify the impact magnitude, we used expert judgement to provide the scores using a series of criteria, namely depth, scale, and speed (Table S11, Supplementary Material)[97]. Any observation, that met one of the conditions for high depth, scope or speed, was classified as a high magnitude impact.

Upon calculating the impact scores for each observation, we grouped together the observations belonging to the same pathway linking a particular CES to a constituent of wellbeing. Three matrix heat maps were produced to show (a) the average impact scores for these mechanism, and (b) the frequency of their presence in the reviewed studies.

Latent Class Analysis and Multiple Correspondence Analysis

We performed Latent Class Analysis (LCA) to identify possible CES synergies. LCA is a statistical tool that allows for the analysis of multivariate categorical data to identify the latent classes based on similar patterns[98]. In this study we use LCA to identify the CES assemblages through unobserved or "latent" classes[99]. We extracted eight unweighted variables that characterised the observed mechanisms including (a) type of ecosystem, (b) type of CES, (c) channel of interaction, (d) affected group, (e) constituent of human wellbeing, (f) type of mechanism, (g) direction of impact, and (h) magnitude of impact. Table S1 in the Supplementary Material provides the actual codes of these variables.

The analysis was conducted using the open access *PoLCA* R package. We conducted the analysis for up to 6 classes, re-estimating the model until identifying the maximum likelihood solution. The Bayesian information criteria (BIC) were used to determine the appropriate number of classes to select. Detailed information of the BIC, sensitivity, specificity and accuracy tests can be found in Table S8 in the Supplementary Material. The general patterns and characteristics of each class were drawn to characterise the underlying ecosystem services assemblages and synergies.

We have to point here that we introduce this notion of *assemblages*, as CES (and the pathways through which they contribute to human wellbeing) also tend to interact with each other in complex ways. By the terms "CES pathway assemblages" we refer to subsets of the 231 identified pathways linking CES and wellbeing that appear significantly related and interactive. Each assemblage tends to contain a set of pathways that likely link a specific set of CES and contribute to a specific set of human wellbeing constituents via some explicit mechanisms with some potential synergies and trade-offs[1]. We loosely adopt this concept of assemblages from philosophy[100] to emphasise the complexity and the relationship between the part (single CES, single pathways) and the whole (assemblage of CES and pathways). In this sense while a single CES via a single pathway can influence autonomously human wellbeing, when these interact in the assembled whole they create synergies, trade-offs and a dynamic whole.

We then performed a Multiple Correspondence Analysis (MCA) to supplement the results of the LCA and to explore further the trade-offs and synergies among specific sets of variables. The MCA method could be seen as a generalisation of the Principle Component Analysis (PCA) when the analysed variables are categorical instead of quantitative[101], which is applicable to our dataset. Through the MCA we produced plots that summarise and display the relationships between categorical variables by calculating the chi-square distance between the categories of the variables and individuals[102]. We conducted the MCA with subsets of variables to investigate a more explicit correspondence among ecosystems, users, and their wellbeing.

For all analyses, we presented and interpreted the first two dimensions as the eigenvalues decrease regularly with small difference after the third dimension[101]. We filtered results by selecting variable categories with higher contributions to a dimension, which exceeded the expected average value. The MCA and related visualisations were performed through the *FactoMineR* packages in R software[103].

[1] Synergies refer to situations where the delivery of multiple ecosystem services is enhanced simultaneously having reinforcing effects to multiple constituents of human wellbeing[116]. Trade-offs refers to situations where the delivery of one service is at the cost of reducing the delivery of another service, which consequently increasing some constituents of human wellbeing while reducing others [116,117].

Challenges and limitations

Despite its extensive focus, the systematic review presented in this paper has a series of limitations. These include the (a) non-inclusion of grey literature, (b) keyword selection, (c) quantification method and synergies/trade-offs analysis, and (d) publication bias.

Regarding (a), the systematic review included only peer-reviewed literature and excluded grey literature. The authors consciously made this decision to ensure the reliability and reproducibility of the results. We are aware that a large fraction of the documents reporting the benefits people obtain from ecosystems are not peer-reviewed papers. This is because practitioners and government agencies that implement relevant projects are less likely to write academic papers about their actions. Furthermore, most of the relevant knowledge linking CES and human wellbeing from Indigenous and local communities is not found in peer-reviewed papers[7] despite its importance for understanding human-nature relations[104] In this sense while this systematic review can indicate the current scientific evidence about the pathways linking CES and human wellbeing, it should not be taken as the totality of the evidence about these linkages.

Regarding (b), even though this review uses a wide range of keywords, these terms were confined to the conception of CES and human wellbeing in the broad fields of ecosystem services and biodiversity conservation. In this sense it was not possible to include all keywords related to possible constituents of human wellbeing and the interaction between humans and nature brought up in other fields and disciplines such as sociology[105] and psychology[106]. With that in mind the authors carefully considered and refined all search terms based on the prevailing terminologies in the field. Although we believe that the search terms allow for the very good identification of the research landscape and related trends at the interface of CES and human wellbeing, we also acknowledge that the keyword selection might have possibly underrepresented literature outside the ecosystem services and biodiversity conservation fields.

Regarding (c), there are limitations associated with normalisation and the statistical methods used for quantitative analysis. The quantification of the impacts of CES (and their change) on human wellbeing may oversimplify the relationship between humans and nature. The authors only focused on the positive and negative contributions of CES to human wellbeing, and did not take into consideration the complexity of two-way impacts and feedback loops. Many studies depict the positive or negative human-nature feedback loops that reinforce or balance the impacts of nature on humans and vice versa [107,108]. For example, people with stronger inclination towards nature interact with green spaces and biodiversity more intensively, which in turn, increases their attachment and inclination towards nature[34]. Due to the complexity of the quantification such feedback loops were not captured in our analysis. Finally, the normalisation approach used for the quantifying the effects of CES on human wellbeing was based on expert judgement. Although we followed an established approach[97] and very clear criteria (Table S11, Supplementary Material) the fact remains that this expert approach may introduce certain uncertainties and biases, which should be kept in mind when reading and generalising our findings.

Regarding (d), we acknowledge the possibility of publication bias in the reviewed studies, which refers to the selective publication of studies based on the magnitude and direction of the results and/or the areas of interest of the authors[55]. In qualitative research, factors that may lead to publication bias include findings that are against current belief and value systems, not in line with research funding, and viewed as unpopular by the decision-makers[56]. However, unlike the meta-analyses of quantitative research where publication bias can be formally tested, there is little knowledge on methods of detecting such biases in meta-syntheses of qualitative research like ours[56]. This sensitivity on detecting the publication bias is a recurring criticism of meta-syntheses of qualitative research[56], and needs to be taken into consideration when generalising our results.

750

751 **TABLES**

752 **Table 1:** Mechanisms linking CES and human wellbeing.

No	Type of mechanism	Definition	Example			
			Sample cultural ecosystem service	**Channel of interaction**	**Sample constituent of wellbeing**	**Description**
1	Cognitive*	The development of knowledge and understanding through interaction with nature.	Education	Intellectual practice	Learning & Capability	Ecosystems are a source of learning and knowledge about the environment, history, culture and human relationship. Ecosystems provide opportunities for scientific research, environmental education, and learning from older generations. The education of children within/through the natural environment can assist in the development of knowledge, skillsets and a sense of wonder for the world[17,35]
2	Cohesive	The development of meaningful relationships between people via interaction with nature.	Social relation	Cultural practice	Connectedness & Belonging	People can develop bonds with family members, friends and other individuals through the interaction with nature. Social interactions and activities in natural setting such as camping trips and social events in natural settings can strengthen ties, reinforce fundamental values and inspire respect, responsibility, solidarity and caring for others, broader communities and the environment[63]
3	Communicative*	The development of social communication and conversation via interaction with nature.	Knowledge system	Intellectual practice	Learning & Capability	In some cultural contexts, the knowledge of the culture and the practices needed for survival are part of the people' capacity for self-determination and personal development. These are often transmitted via communication between elderly people and young people at cultural events in natural settings, which are essential in this process. For example, indigenous communities transmit via communication in natural settings knowledge systems that are important for their personal development and livelihoods[109].
4	Creative*	The experience of new and original situations that inspire artistic work, aesthetic appreciation, creativity, and freedom (among others) via interaction with nature	Inspiration value	Cultural practice	Inspiration & Fulfilment of Imagination	Nature has inspired people throughout the history of humanity for artistic expression. Such examples can be inspiration to paint, draw, take photos, be active/get out, conserve, manage, protect, discover, explore, and generally think about things[15]
5	Evolutive	The gradual change of people's personality, moods, feelings, attitude, perception, behaviour, values and belief systems over time (more often internal change) via interaction with nature.	Recreation and tourism	Cultural practice	Learning & Capability	On many occasions the natural environment tends to make people more friendly, playful, elated, and affectionate over time[17]. In some cases nature-based recreation activities are gratifying and gradually increase courage or self-esteem[35]
6	Formative	The change of people's moods, feelings, attitudes, perception, behaviours, and values that is relatively instant or over short periods of time (more often internal change) via interaction with nature	Aesthetic value	Form	Identity & autonomy	Ecosystems offer spaces for individuals to instantly express their personal distinctiveness and identity without feeling constrained by external factors such as the norms and values imposed by society. In some cases being in nature immediately enables achieving a personal sense of freedom and escapism from the social boundaries created by extrinsic factors of society. The sense of freedom and autonomy inspired by wild nature in that moment can allow individuals to strengthen their own intrinsic values and beliefs and to feel they can be free and make their own choices in lives[110]
7	Intuitive*	The sensual experiences, human instincts and feelings (often of a spiritual and religious nature) via interaction with nature	Spiritual value	Spiritual practice	Spirituality	Many people experience something deeply spiritual when they interact with nature. In some geographical contexts people find meanings in nature from the time they are born to the time they die, while the sense of spirituality attached to nature can bring hope, faith, personal beliefs/values, and empowerment[43]
8	Regenerative*	The generation of restorative outcomes (e.g. alleviation of fatigue and emotional stress) through recreation, leisure, tourism,	Recreation and tourism	Cultural practice	Mental health Physical health Subjective	Interaction with nature can improve mental health by helping to (a) reduce stress, anxiety and depression, (b) reduce visits to psychologists, (c) improve sleeping quality, (d) reduce the use of antidepressants, sleeping medicine and sedatives, (e) increase

		escapism, and therapy via interaction with nature			wellbeing	vitality, (f) decrease cognitive decline, (g) increase ability of recovery and healing from crisis, and (h) reduce mental fatigue and illness[12,28] Benefits to physical health through interaction with nature include (a) lower body mass index, (b) reduced prevalence of disease, (c) reduced obesity, (d) lower somatisation level, (e) decreased cognitive decline, (f) reduced blood pressure, heart rate and muscle tensions, (g) improved immune system, (h) increased restoration and healing, and (i) lower mortality risk[12].
9	Remunerative	The economic benefits people obtain from ecosystems through non-material benefits in cash or other forms of money	Recreation and tourism	Cultural practice	Economic wellbeing	Nature-based tourism can directly or indirectly contribute to the livelihoods of local communities and broader economic growth. Examples include the direct generation of revenue from accommodation, transportation, guided tours and food and beverage sales. Broader indirect contributions include poverty alleviation and employment generation[111,112]
10	Retrospective*	The personal memories and reflections of the past through prior interaction with nature	Sense of place	Form	Identity and Autonomy	Natural landscapes are important to some people as they have evolved emotional and cognitive bonds, becoming parts of their personal and collective memory and their life stories[113]
11	Satisfactive	The feeling of satisfaction and fulfilment of expectations and needs associated with interaction with nature	Cultural heritage value	Cultural practice	Subjective wellbeing	Engaging in ecosystem-related livelihood activities can instil pride and sense of satisfaction. In many cases farmers through their livelihood engagement with nature feel fulfilled, have pride for their lives, and a sense of purpose in life when putting a good day at work[110].
12	Transactive	The social benefits people obtain by bartering or trading the products of ecosystems	Cultural heritage value	Cultural practice	Economic wellbeing Connectedness and belonging	For many indigenous communities, particular species carry a special cultural heritage value that can be utilised for exchange and trades among kins to sustain the reciprocal relationships essential to their functioning[114]
13	Transcendentive	The benefits that lie beyond the ordinary experiences and the regular physical realm, more often associated with religious or spiritual values through interaction with nature	Spiritual value	Spiritual practice	Spirituality	Many people and communities experience ecosystem-inspired feelings related to "entities larger than themselves"[115]. For some people being in natural settings makes them appreciate people's connection to all things in the Universe[17].
14	Apprehensive	The anxious and fearful feeling generated from interaction with nature.	Aesthetic	Form	Certainty, sense of control and security	Some people are afraid of their safety when encountering certain natural features via visual or auditory interactions, such as scary animals, dangerous predators, animal blood, and areas that are dark with high tree cover, among others [12,14,40]
15	Destructive	The direct damages caused to health, relationships, finance, and capability (among others) due to interaction with nature of the loss of CES	Aesthetic	Form	Economic wellbeing	Some ecosystem disservices associated with CES can increase the direct cost for repairs and maintenance, control or remove unwanted species. For example damage to physical structures can be caused, by accelerating corrosion due to bird excrements, or the destruction of pavements due to tree roots or animals digging nesting holes[44]
16	Irritative	The unpleasant and annoying feelings people obtain through their interaction with nature.	Aesthetic	Form	Mental health	Some ecosystem disservices associated with CES cause negative feelings such as annoyance and discomfort, e.g. annoyance or disgust wildlife noise, animal excrements or plant litter (Lyytimäki *et al.*, 2008; Hussain *et al.*, 2019)

Note: The six mechanism indicated with (*) are adapted from previous study[15], while the other 10 mechanisms are defined by the authors. For each of the mechanisms we provide as an example a unique pathway of CES-mechanism-constituent of human wellbeing. It should be noted that some mechanisms mediate more CES-human wellbeing connections. A comprehensive explanation of the different pathways for each mechanism can be found in Table S12-14 in the Supplementary Material. Due to certain overlaps the positive (No. 1-13) and negative (No. 14-16) mechanisms are presented in alphabetical order rather than some other taxonomy.

FIGURES

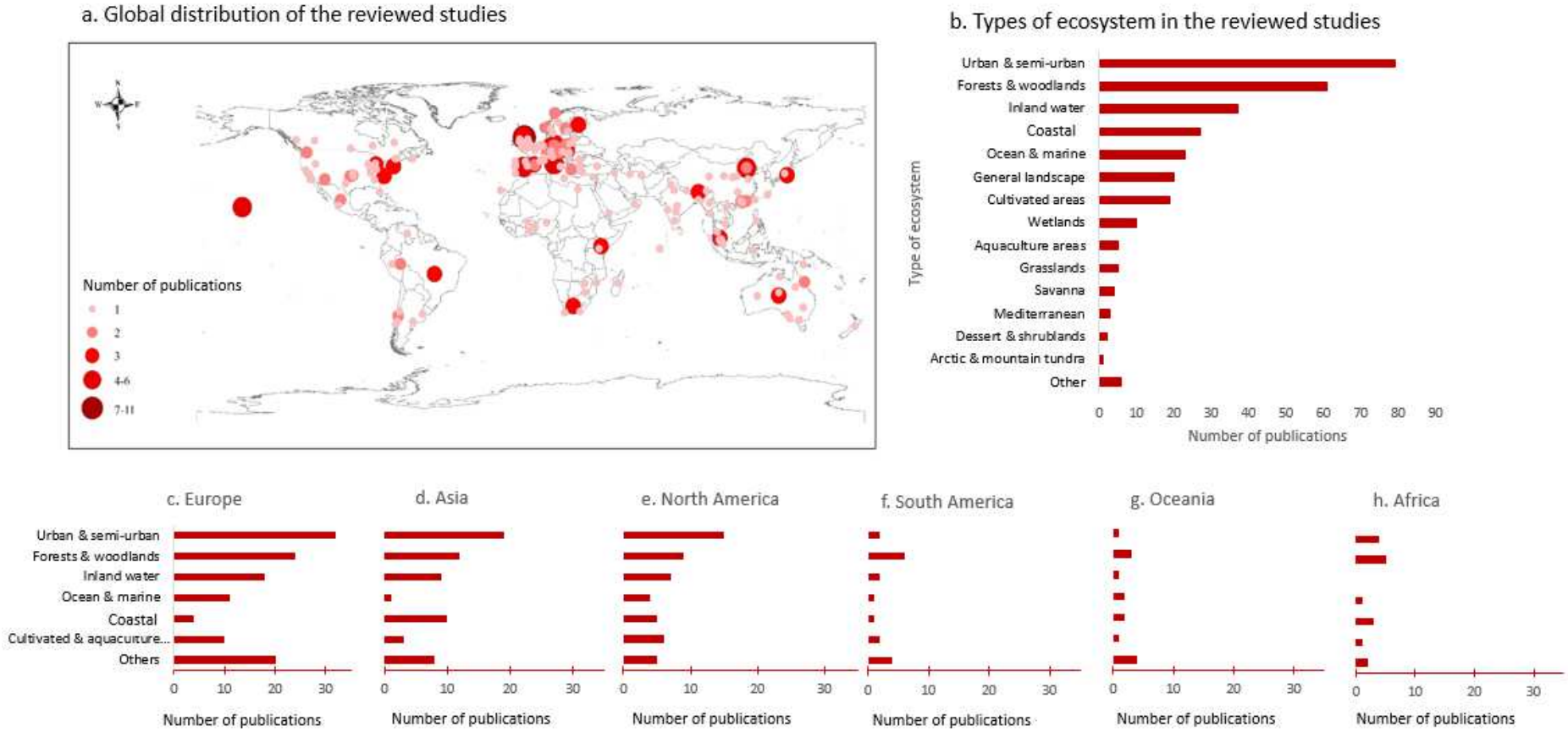

Figure 1: Focus of the articles used in the systematic review. Panel (a) contains a heat map showing the spatial distribution of the reviewed studies globally. Panel (b) contains a bar chart of the total number of publication by ecosystem types. Panels (c) – (h) contain bar charts of the total number of publication by region for different ecosystem types.

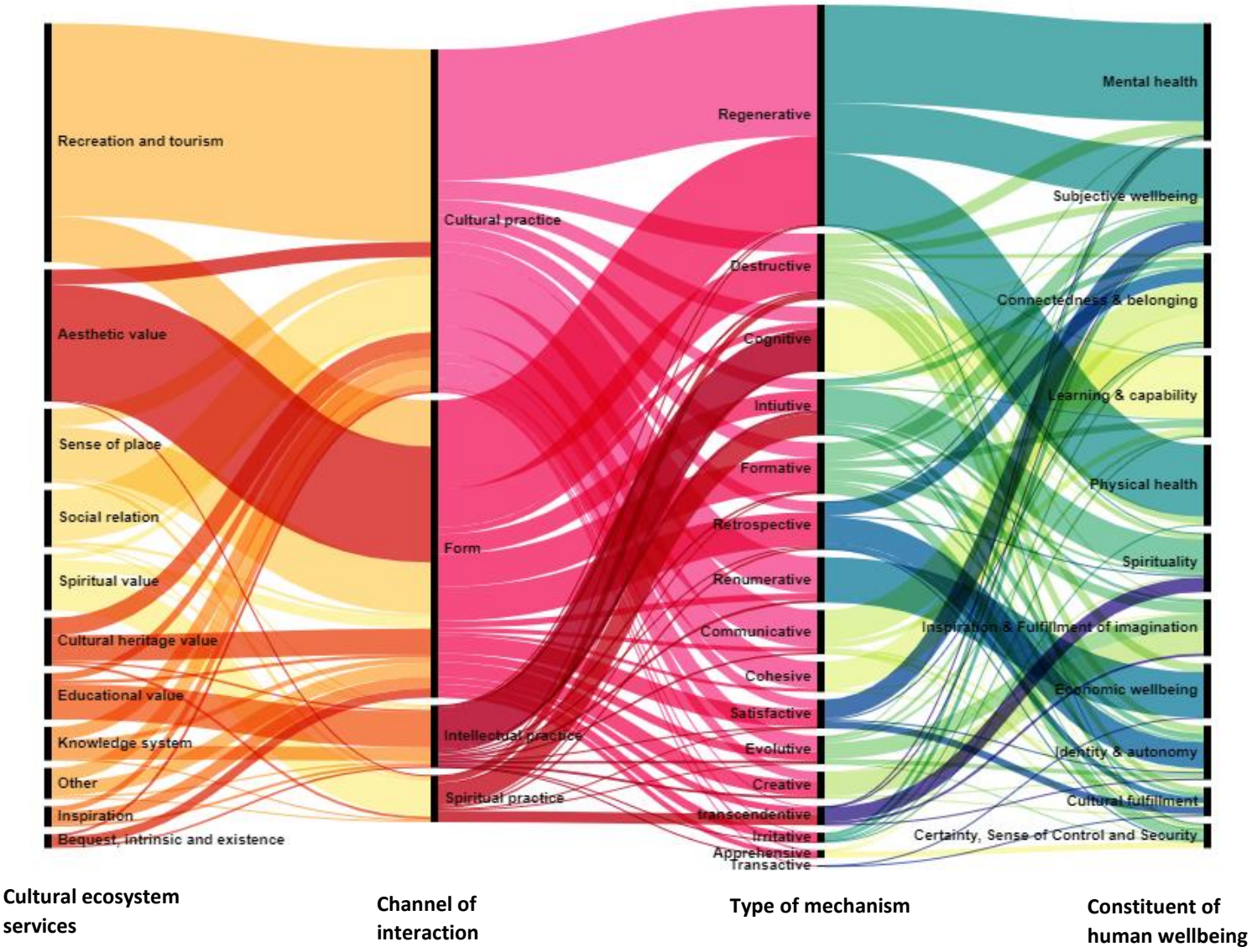

Figure 2: Frequency of the mechanisms documented in the reviewed studies. The width of each line linking any two elements in the alluvial diagram represents the number of relevant observations (out of the unique 1138 total observations). This essentially represents the popularity/visibility in the reviewed literature and should not be perceived as a metric of importance/weight linking any two components.

Figure 3: Relative contribution of individual pathways to human wellbeing. Each box or empty space represents a unique pathway of a single CES to a single constituent of human wellbeing via a single mechanism. For simplicity we list all of the 16 mechanisms explained in Table 1 for each CES (y-axis) and cross map them to each constituents of human wellbeing (x-axis). Boxes indicate a unique combination of CES-mechanism-human wellbeing found in the literature (i.e. in the 1138 observations divided into 231 unique pathways during the first iteration of the coding; see Methods – Elicitation of mechanisms linking CES and human wellbeing), while blank spaces indicate unique combinations not found in the literature. The size of each box represents the number of studies that captured the specific pathway. The colour of each box represents the average effect of the specific CES to the specific constituent of human wellbeing via the specific mechanism after normalising each relevant observation with a score of -2 to +2.

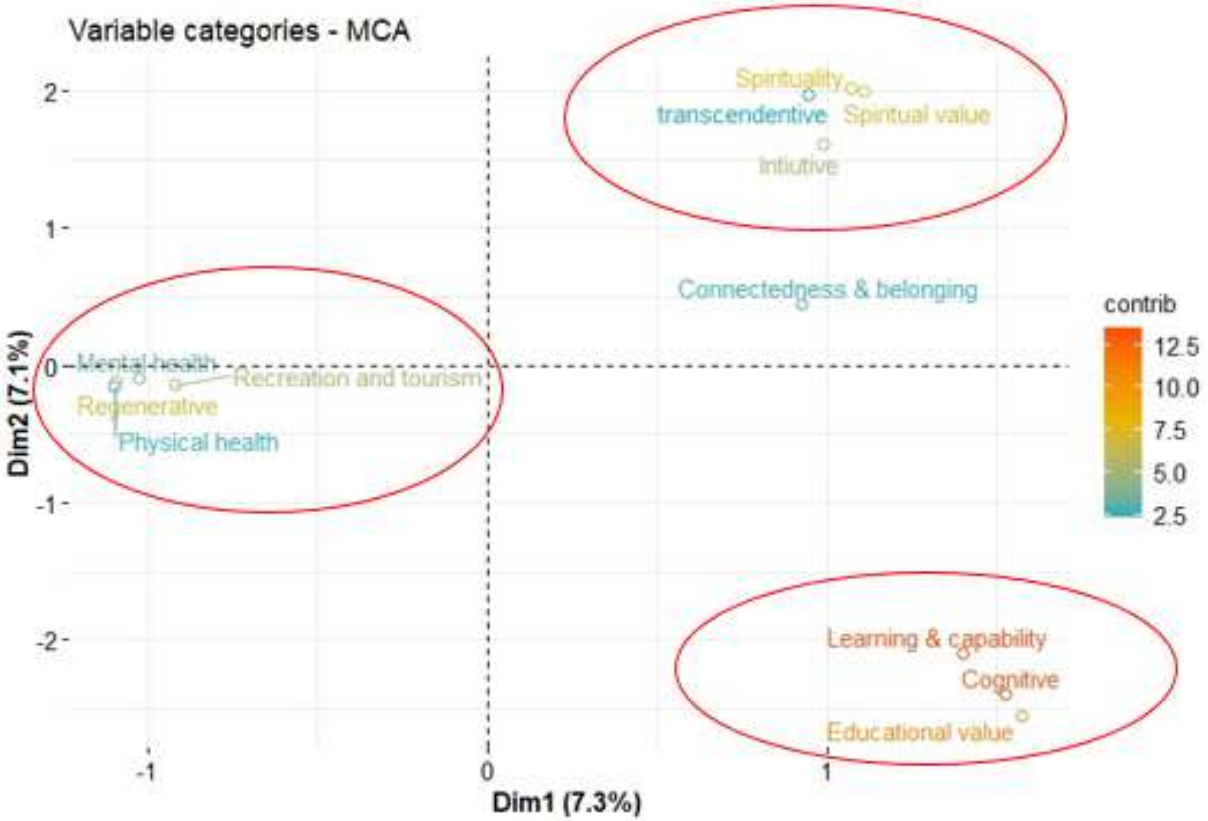

Figure 4: Trade-offs and synergies between CES, constituents of human wellbeing and mediating mechanisms. The clusters are identified through Multiple Correspondence Analysis (MCA). The significant associations account for 7.1 % of the variance of the first dimension (axis x) and 7.3% of the variance of the second dimension (axis y).

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