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REVIEW ARTICLE

A systematic review of Nature's Contributions to People: impacts on science, policy, and sustainability

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Abstract

The conceptual framework of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) for natural resources management and conservation was materialised in the Nature's Contributions to People (NCP) approach in 2018. Since then, the application of the NCP framework has expanded significantly across diverse scales and case studies. In this systematic review, we assessed how the NCP approach has contributed to the scientific and policy fields, focusing on natural resource management, human–nature relationships, or social–ecological aspects. We identified the main strengths of the NCP approach, especially the relational values that emphasise the mutual benefits and co-production between humans and nature, and the applicability and communication of the NCP approach across different spatial scales, contexts, and audiences. Furthermore, we explore the integration of the NCP approach with the ecosystem services (ES) concept and the co-production perspective. While the NCP framework enriches scientific and societal engagement in nature conservation, its limited focus on abiotic (non-living) ecosystem components and processes presents a gap. These elements are critical for ecosystem functionality and the delivery of Nature's Contributions to People. To address this, we propose complementing the NCP approach with frameworks that explicitly incorporate ES typologies, fostering a more comprehensive and holistic perspective. Lastly, we present insights into the key topics that arose from our review, proposing further research and future developments that could be developed and framed within the NCP methodological approach.

Keywords IPBES · Ecosystem services · Indigenous and local knowledge · Relational values · Co-production perspective · Natural resource management · Sustainability science

Introduction

The Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) introduced the framework of "Nature's Contributions to People" (NCP), defining NCP as "all contributions, beneficial or harmful, that individuals, communities, societies, nations, or humanity as a whole derive from nature" (Díaz et al. 2015a, b, 2018a; Pascual et al. 2017). This framework emphasises the integration of sustainability principles, particularly through the inclusion of relational values in decision-making and discourse (IPBES 2019; Pascual et al. 2017).

The NCP approach highlights both the instrumental values of nature, such as tangible goods and ecosystem benefits, and the intrinsic, intangible relationships that connect individuals and communities to nature (Pascual et al. 2017). The human–nature relationships are inherently nonlinear and multifaceted, encompassing elements like a sense of place, cultural identity, and personal well-being (Chan et al. 2016). NCP and relational values acknowledge the central and constant role that culture plays in defining the values of nature or the relationship between nature and people, which has resulted in a more inclusive valuation discourse for well-being decisions (Chan et al. 2016; Ellis et al. 2019; Ishihara 2018; Fish et al. 2016; Schulz and Martin-Ortega 2018).

The IPBES conceptual framework acknowledges that culture influences how individuals value NCP (Pascual et al.

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2017). It also comprises a broader and more diversified range of knowledge systems, worldviews, and stakeholders, fostering inclusivity and expanding the diversity of perspectives at the science–policy interface (Hill et al. 2021; Pascual et al. 2017). The NCP framework advances existing approaches to human–nature interactions by moving generalised perspectives, particularly the ecosystem services (ES) framework. That is achieved by including a context-specific perspective that recognises local or cultural perceptions and their applicability in assessments and planning to achieve well-being and sustainable use (Kadykalo et al. 2019; Pascual et al. 2017). At the same time, the NCP approach maintains the concept of ES in terms of the ecological, economic, and socio-cultural values of nature initially provided by the Millennium Ecosystem Assessment (MA 2005; Kadykalo et al. 2019), alongside the incorporation of the intrinsic values into sustainability science (Pascual et al. 2017).

Sustainability science, an interdisciplinary field dedicated to understanding and addressing the complex interactions between social, economic, and environmental systems, requires frameworks for evaluating both the processes and outcomes of transformative change, creating reliable, transferable knowledge solutions. Moreover, it promotes interdisciplinary collaboration and aims to support the implementation of the Sustainable Development Goals (SDGs) (Lang et al. 2012; Bennett et al. 2015; Kajikawa 2008; Kates 2011; Keller et al. 2018; Saito et al. 2017; Norstrom et al. 2020). In response to these challenges, there is a growing need for methodologies that account for the current and future states of nature while incorporating all components of sustainability (IPBES 2024). In this regard, the NCP framework seeks to enhance the depth and inclusivity of ecosystem evaluations, promoting sustainability and well-being through a holistic and transparent understanding of human–nature dynamics (Goodwin et al. 2019; IPBES 2019, 2022; Stålhammar 2021).

In the last few years, since the creation of the NCP approach, researchers have been developing the application of NCP as a methodological tool. This review aimed to analyse to what extent the IPBES's "Nature's Contributions to People" (NCP) framework was applied, particularly on the management of natural resources and biodiversity conservation, on human–nature relation and social–ecological aspects. To the best of our knowledge, this is the first review paper covering the multiple applications of the NCP approach which have been published since its creation, aiming to answer to the following questions: (i) What are the benefits and drawbacks/challenges of the NCP approach and other alike frameworks and perspectives? (ii) What is the applicability of the NCP framework at different geographical scales? (iii) Which novel perspectives and outcomes were developed through the NCP approach? (iv) Which relevant limitations should be considered when using the NCP approach? (v) Which future prospects may be fostered under the NCP approach?

Materials and methods

Nature's Contributions to People: definition and evolution

In 2015, the development of the IPBES conceptual framework began with the first description of "Nature's Benefits to People" (Díaz et al. 2015a, b), an inclusive concept across knowledge systems that embraces the concept of ecosystem services and refers to all the benefits that humanity obtains from nature. This conceptual framework includes 18 specific reporting categories (Díaz et al. 2015a). The IPBES multidisciplinary expert panel then changed the name of "Nature's Benefits to People" to "Nature's Contributions to People" (NCP), retaining the IPBES conceptual framework (Pascual et al. 2017). The word "benefits" was deemed unsuitable due to its predominantly positive connotation, which could potentially lead to confusion due to its diverse interpretations (Stenseke and Larigauderie 2018). Thus, the NCP methodological approach emerged as "all contributions, beneficial or harmful, that individuals, communities, societies, nations, or humanity as a whole derive from nature" (Pascual et al. 2017; Díaz et al. 2018a). The NCP approach encompasses not only the positive outcomes of nature for people and human societies, but also the negative and harmful aspects of nature (Díaz et al. 2018a), commonly referred to as ecosystem disservices (Saunders 2020).

NCP encompasses three broad categories: regulating, material, and non-material (Fig. 1). Regulating NCP refers to the functional and structural aspects of ecosystems and biodiversity that contribute to societies' well-being by modifying environmental conditions and regulating the provision of material and non-material NCP. Material NCP are elements collected from ecosystems and biodiversity that directly contribute to people's physical existence through supplies, such as food, energy, or raw biotic materials. Non-material NCP are nature's effects on the subjective and psychological aspects of people's well-being, including recreational and aesthetic experiences, learning and inspiration, and supporting identities, which may be regarded as people's satisfaction knowing that a particular species exists or a sense of place attachment to an area or landscape (Díaz et al. 2018a).

Systematic review

We conducted a systematic literature review in the SCOPUS database, searching the string "Nature's Contributions to People" (in quotation marks) in the Abstract, Title, and Keywords sections without using any other filters, which

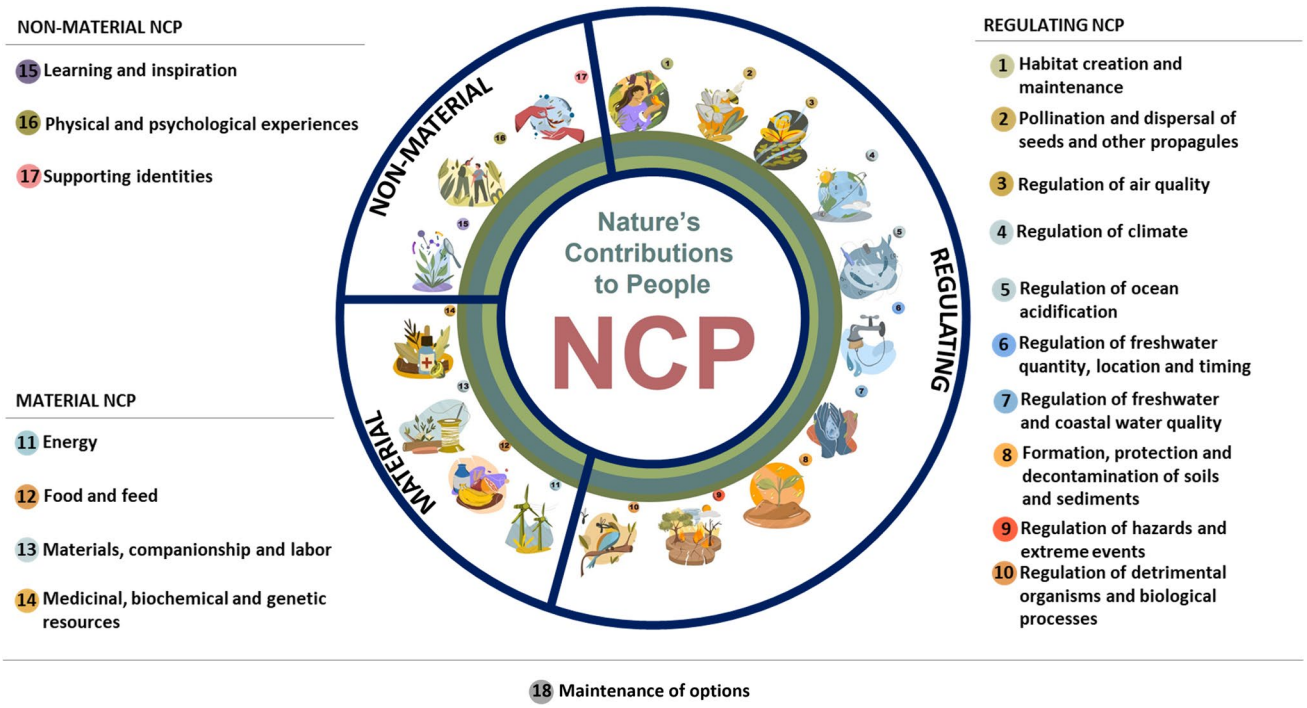

Fig. 1 The Nature's Contributions to People (NCP) classification presenting the 18 categories (1–18) and the 3 categories division (regulating, material, and non-material) from Díaz et al. (2018a) (adapted from Moreira et al. 2024)

retrieved 355 results, with no duplicates (up to December 2023). The first publications date from February 2017 (two articles), and after the publication of the NCP approach framework in 2018 (Díaz et al. 2018a), the number of literature outputs in SCOPUS highly increased up to 2021 (19 papers in 2018, 32 in 2019, 49 in 2020, and 88 in 2021), followed by a slight decrease in 2022 (81 papers), with 84 papers published during 2023.

We followed the guidelines from the PRISMA protocol (Moher et al. 2009; Page et al. 2021) for systematic reviews. We only considered English-written literature and excluded six publications in other languages. Studies that only mentioned the NCP approach or IPBES framework in the introduction and/or keywords without further developments were excluded, totaling 230 papers. An additional 42 publications, such as conceptual analysis, opinion/perspective articles, or studies without a defined geographical scope, were also excluded from further steps, although they were important for the discussion. For a complete visualisation of the selection process, please see the PRISMA flow diagram presented in Figure S1 in the supplementary material.

The detailed analysis of each publication for eligibility used as inclusion criteria the mention to research/assessment on the management of natural resources and/or biodiversity conservation, on human–nature relations, or on social–ecological aspects, which resulted in a final corpus of 77 publications that apply the NCP framework as follows: 50 local, regional, or national case studies; 4 multinational and 6 global studies; and 17 review papers.

Results

Results overview

The results of the literature search for the NCP approach included a wide variety of findings covering a range of different approaches, as well as a substantial number of case studies implemented on a broad geographic scale. Here, we provide an overview of the applicability of the NCP approach across various scopes of analysis by framing our literature outputs in the following groups: (i) global and multinational assessments, providing different views and methods for large-scale assessments based on the NCP scheme; and (ii) national and regional assessments, where particular case studies in smaller-scale assessments are presented; and (iii) review papers that scoped their analysis under the NCP approach.

The applicability of the NCP approach

Global and multinational assessments

We found four studies that addressed global assessments based on the NCP methodological framework. Brauman

et al. (2020) present a comprehensive 50-year global trend assessment across all 18 NCP classes by characterising literature outputs since the 1970s to assess the distinct aspects of NCP. Chaplin-Kramer et al. (2019) provided a spatially explicit modelling framework for operationalising the NCP methodological approach based on people's demands. More recently, Chaplin-Kramer et al. (2023) mapped the results of a global assessment of 14 NCP based on the locations of critical natural assets, and Liu et al. (2023) used a spatial approach to assess all 18 NCP globally by using hydrological basins as global geographical units.

In a lower-scale spatial perspective, six studies focus on multinational case studies, framing the NCP approach: Christie et al. (2019) presented the IPBES' Europe and Central Asia (ECA) evaluation; O'Connor et al. (2021) examined European priority areas for terrestrial wildlife conservation and cultural and regulating NCP by following a bio-ecosystem approach; Shröter et al. (2020) tested a set of social–ecological indicators to experimentally analyse NCP relationship values at regional and continental scales; Takahashi et al. (2022) examined NCP synergies between social–ecological productive landscapes in 10 biodiversity hotspot regions of the world; McKenzie et al. (2021) used the NCP scheme to analyse seagrass habitats' beneficial and detrimental effects on people's quality of life in the Pacific Island Countries and Territories; Isaac et al. (2023) conducted a policy document analysis to assess anthropogenic assets involved in forest NCP co-production, biodiversity conservation, and their governance, from local (three protected areas in Germany) to supra-national level (European Union policies).

National, regional, and local assessments

We compiled all the case studies from the literature search outputs that applied the NCP approach at a local, regional, or national scale. We considered only scientific-practical methods other than solely literature review-based approaches, such as participatory and questionnaire/survey methods, fieldwork, and statistical and/or modelling-based assessments. For each study, we analysed the NCP groups that were considered in the respective methodological approach, as presented in Fig. 2. Thus, we considered each NCP group individually (regulating, material, and non-material), as well as all three groups combined. Nonetheless, we distinguished when studies included or not the NCP 18 "Maintenance of options" due to its specificities (as described further in NCP 18 "Maintenance of options"). These case studies covered mostly all regions of the world (Fig. 2), following different methodological approaches and scopes, and encompassed several types of ecosystems, species, populations, and social–ecological perspectives. For a short description of each study, please see Table S1 in the supplementary material.

Fifty studies were included in this analysis, where four studies (8%) assessed regulating NCP, while eight studies (16%) focused only on the non-material NCP group in their study framework (NCP 15, 16, and 17). We did not retrieve any studies fitting solely the material NCP group (NCP 11–14). The remaining 38 studies (76%) were broader and included all groups (Fig. 2). Twenty studies included NCP 18, whereas 18 did not. Note that few studies included more than one country from the same continent or countries from different continents (for more details, see Table S1 in the supplementary material). In total, 30 countries were encompassed in national, regional, or local case studies under the NCP approach, covering all continents. Europe presented the highest number of case studies (20) distributed across 12 countries, with Spain being the country with the highest number of case studies (6) (Fig. 2).

NCP framework as scoping tool

The NCP approach was also widely used as a scoping tool for scientific review papers, as we denoted from 17 papers. Most of the available review papers framed under the NCP approach are specific to ecosystem type(s), species group(s), or focused on human–nature relations or social–ecological aspects. Some topics were found that used the NCP approach to explore human–nature connections, such as in mountain ecosystems (Martín-López et al. 2019), dry rivers (Dean et al. 2021), pastoral systems (Nicolás-Ruiz et al. 2021), and land abandonment (Quintas-Soriano et al. 2022). Kraft et al. (2021) investigated how simulation models can help assess and predict the role of agroforestry in NCP provision, and Kachler et al. (2023) compiled existing empirical evidence on NCP co-production based on anthropogenic capital indicators.

Regarding particular species, Pascual-Rico et al. (2021) evaluated the available scientific evidence on human–wild ungulate interactions, and Rodrigues et al. (2019) summarised the current knowledge regarding the ecosystem services provided by armadillos (Xenarthra, Cingulata). In the same line, Bondé et al. (2020) presented a conceptual model and management scenarios under different policies for the shea tree (*Vitellaria paradoxa*) and Ainsworth et al. (2023) reviewed what is known about cephalopod food systems, value and supply chains, and the associated market drivers. Quintero-Uribe et al. (2022) conducted a literature review to evaluate the integration of rewilding and NCP into participatory scenario narratives.

The Sustainable Development Goals (SDGs) (UN 2015) have also been addressed under the NCP approach regarding literature reviews. Smith et al. (2019) reviewed the literature on the topic of the different land-based greenhouse gas removal

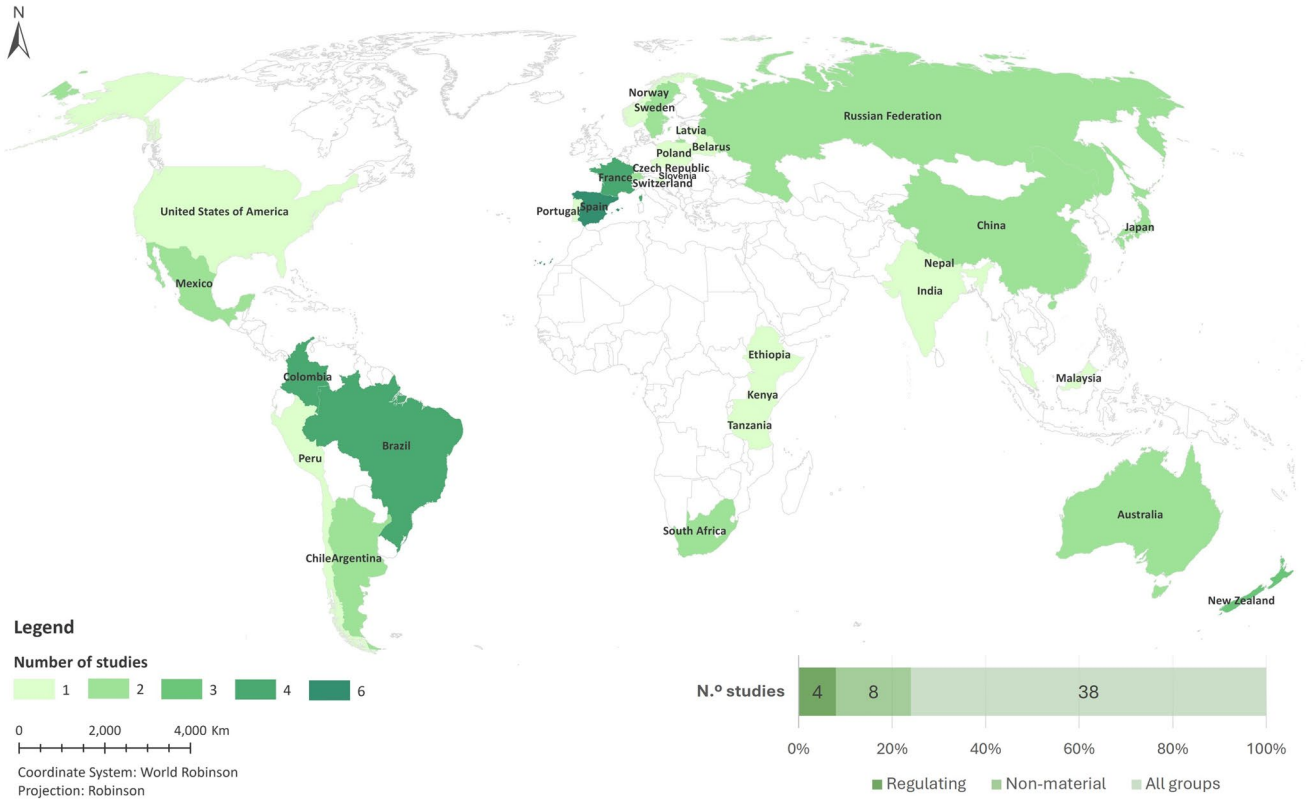

Fig. 2 Geographical coverage of NCP approach application: number of case studies per country regarding national, regional, and local case studies and the corresponding assessed NCP groups

options, retrieving its potential impacts and the contribution of NCP to each of the SDGs. Smith et al. (2021) presented an assessment regarding the contributions of soils to the SDGs from a general perspective, while Adhikari et al. (2022) conducted a systematic synthesis of the literature to determine the contribution of NCP towards achieving the SDGs in Nepal.

Other review papers addressed more complex topics, such as Des Roches et al. (2021), which presented a review on how intraspecific variation supports essential ecological functions, and NCP, and Stange et al. (2021), which showed how some classic genetic and genomic methods translate to the NCP approach. Wiederkehr et al. (2019) approached the emergent topic of "environmental migrants", arguing that the pluralism of the NCP approach fits well with the interdisciplinary environmental migrant community. These studies highlighted the potential and innovation brought by the NCP approach for the addressed study topics.

Discussion

The results of our literature review clearly show a significant increase in publications using the NCP approach since 2018, which reflects the versatility of the framework and its wide range of scopes. Therefore, in this section, we delve into the topics that were mostly remarked on and outlined across the literature as follows: (i) the applicability of the NCP approach and its scope; (ii) the relation between the NCP approach and other frameworks and perspectives; (iii) the novelties brought by the NCP approach; (iv) the NCP approach limitations; and (v) future prospects and opportunities that may be fostered and framed under the NCP approach.

Applicability of the NCP framework at different geographical scales and scopes

The NCP approach proved to be widely applicable, with geographical ranges spanning from global assessments to regional or local case studies. That wide geographical span produced several new perspectives that are inherently attached to the whole span of the NCP classification scheme. Nevertheless, the NCP conceptual framework underscores the inseparability of non-material values from the remaining ecosystem functions, whether they are regulatory or material providers (Díaz et al. 2018a; Pascual et al. 2017).

Therefore, it may be important to acknowledge that one component from nature, such as tangible goods, specific

locations, animals, or landscapes, can simultaneously belong to different NCP categories (see also NCP 18 "Maintenance of options"). That was also evidenced in our literature findings regarding the NCP conceptual framework applicability, specifically to ecosystem multifunctionality frameworks (Giling et al. 2019). Multifunctional landscapes are of great importance since they support the sustainable management and supply of various locally relevant NCP, particularly in agriculture, forest, and open vegetation areas (Cusens et al. 2024).

In addition to its geographical applicability, the NCP approach also provided the development of new prospective NCP supply and biodiversity monitoring frameworks (Kass et al. 2023; O'Connor et al. 2020, respectively). Equally, the integration of conceptual comprehensive endeavours to frame people's perceptions and their relationship with nature was also found to be supported by the NCP approach (e.g. Beery et al. 2021; Govigli and Bruzzese 2023; Lehnen et al. 2022; Managi et al. 2022; O'Neill et al. 2008; O'Connor and Kenter 2019).

The NCP approach and their relation to other frameworks and perspectives

NCP and ecosystem services

There is a close connection between the NCP and ecosystem services (ES) concepts. Kadykalo et al. (2019) claim that NCP expands the scope of ES, introducing NCP as a supra-concept to ES. The NCP classification frames the ES concept, namely the classification typology defined by the Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin 2018). CICES latest version (5.1) encompasses the correlation between the NCP categories and CICES classes, except for NCP 5, 'Regulation of ocean acidification', which has no direct correspondence with any CICES class. The NCP 5 is, in fact, a new category brought by the NCP framework, enhancing the importance of oceans in global climate regulation, which was not yet addressed by the common ES typology. In contrast, CICES includes abiotic ES, which has no corresponding categories in the NCP approach, since IPBES considers only the biotic components of the natural world, particularly biodiversity, in their framework (Díaz et al. 2015a; IPBES 2019).

In a general comparative perspective, the NCP regulating class is highly convergent with the ES maintenance and regulation section, the NCP material class with the provisioning ES section, and the NCP non-material class with the cultural ES section. Nevertheless, Martín-Forés et al. (2020) claimed that ES focuses on intangible ecological processes that people cannot perceive easily (e.g. flood prevention, erosion control), while the NCP focuses instead on how people experience nature under specific conditions created by living organisms and the biotic components of ecosystems.

The NCP approach is seen as a better way to improve communication and understanding between a wider range of stakeholders, addressing land system decision-making with a greater and more pluralistic scope than the ES concept (Hill et al. 2021). The IPBES expert panel developed the NCP approach, aiming to engage a diversity of stakeholders and worldviews, including policymakers, civil society organisations, and, more particularly, Indigenous and local knowledge (ILK). Thus, NCP acknowledges the importance and relevance of the old values and also focuses on relational values to understand the complex links between nature and people (Christie et al. 2019; Díaz et al. 2018a; IPBES 2019, 2022; Pascual et al. 2017). That enhancement is accomplished by expanding the ES approach, which follows the common framing of nature's value as either intrinsic or instrumental (Klain et al. 2017).

NCP broadens ES scope by putting a stronger emphasis on the importance of context-specific worldviews beyond the more standardised and general assessment provided by ES frameworks (Ellis et al. 2019; Kadykalo et al. 2019). Accordingly, the introduction of the NCP 18 "maintenance of options" (see "NCP co-production"), which covers all three NCP categories, brings new perspectives and broadens the relatively static concept of ES (Peterson et al. 2018). The NCP approach may also aid in the communication of complex findings, enhancing ES approaches, whereby, for different communities, stakeholders, or countries, the term "ecosystem services" is not readable or may constitute conflict-based jargon (Maes et al. 2018). Also, Pires et al. (2020) intended to understand the practical differences between using both approaches and found that researchers who use quantitative methods predominantly use the ES approach, while researchers using qualitative methods tend to follow the NCP scheme. The authors proposed that the perception of the people–nature relationship primarily determines whether it is based on human demands (ES) or from a co-production perspective (NCP). That idea is corroborated by other studies, which point out that the notion of nature as a "service provider" is rejected in different cultural contexts (Kohler et al. 2019; Wiederkehr et al. 2019).

De Groot et al. (2018) argued that both ES and NCP should be regarded from a synonym perspective, reinforcing the notion that the two concepts promote the development of a sustainable future, where the semantics should only differ according to the target audience or purposes. The synergy between the concepts may increase the potential to reach multiple audiences, since both terms enhance the importance of nature to human well-being (Díaz et al. 2018b; Dean et al. 2021; Kadykalo et al. 2019; Maes et al. 2018; Peterson et al. 2018; Pires et al. 2020). Indeed, this literature search has proven that both concepts and approaches may

be used synergistically, therefore improving the potential target audience of their outcomes, such as, e.g. Ausseil et al. (2022), Bhattacharjee et al. (2022), Daněk et al. (2023), Hou et al. (2022), Konstantinova et al. (2021), Martín-Forés et al. (2020), Masao et al. (2022), Matuk et al. (2020), Rey et al. (2023), Rodrigues et al. (2019), and Shmelev et al. (2023). These studies considered the NCP approach as the baseline for their assessment, but also included the ES discourse and/or classification typology within their study's approach.

NCP co-production

The NCP approach established the reciprocal notion that people's values of nature have a positive influence on the benefits they can receive under a co-production perspective (Christie et al. 2019; Díaz et al. 2018a; Pascual et al. 2017). Co-production can be defined as a synergistic co-relation where humans and nature both benefit from a harmonious interaction (Díaz et al. 2015a, b), where the main inputs are based on physical and/or human capital (for regulating and material NCP) and social capital (for non-material NCP) (Kachler et al. 2023). That is the case for NCP, which are highly dependent on human intervention, such as food and feed (NCP 12), materials (NCP 13), and medicinal resources (NCP 14) (Bruley et al. 2021; Vallet et al. 2023). Also, agricultural activities enhanced by co-production frequently present an "umbrella" for other NCP, such as pest control (NCP 10) or pollination (NCP 2), providing their supply (Grosinger et al. 2022).

Another interesting concept that was raised from the NCP approach was the 'People's Contributions to Nature' (PCN) perspective (Washington and Maloney 2020). That perspective incorporates the importance of the interaction between people and natural processes, which inherently impacts ecosystems and biodiversity conditions, and is in line with the NCP co-production perspective. Interestingly, Matuk et al. (2020) suggested the same term and perspective, presenting a particular case study regarding an Indigenous community in Brazil. Matuk et al. (2020) recognise that the NCP approach includes PCN to a certain extent, since Díaz et al. (2018a, b) acknowledge that the NCP approach already incorporates the co-produced perspective. Furthermore, that approach aligns with the vision from Comberti et al. (2015), who previously presented the "Services to Ecosystems" (S2E) perspective, by bringing the reciprocal relationship between humans and ecosystems to the ES discourse. This study highlighted the inclusion of the so-called intangible interactions, which were posteriorly highly developed as the relational values concept by, e.g. Chan et al. (2016), Ishihara (2018), Klain et al. (2017), or Schulz and Martin-Ortega (2018). The relational values are deeply rooted in the NCP approach, which brought a novel vision over the previous assessments of how humans make decisions over natural resources and functions (Christie et al. 2019; Pascual et al. 2017).

NCP strengths

Novel perspectives and outcomes developed through the NCP application

Díaz et al. (2018a) provided a pluralistic approach through the NCP approach, emphasising how important it is to include different and less common knowledge systems. The NCP methodological approach encompasses rights-based conservation initiatives, as it can take the form of contributions to the cultural identity of specific groups of people, embracing the natural elements with whom they have significant interactions (James 2020). That may lead to the protection of those natural entities by appealing to the relevant people's legal right to their own cultural identity, which is regarded under the so-called "Indigenous and local knowledge" (ILK) empowerment (Christie et al. 2019; Kadykalo et al. 2019; Pascual et al. 2017). Such ILK perspectives were not included in previous regional ecosystem assessments (Maes et al. 2018). The ILK narrative emphasises the significance of non-material NCP by highlighting their relational values, which foster a harmonious relationship with nature, including the relevance of their attachment to a particular place (Christie et al. 2019). In addition, ILK might present an important and valuable form of knowledge for ensuring the sustainable coproduction of medicinal plants (NCP 14) (Vallet et al. 2023). Thus, the creation of the NCP approach brings a shift in values integration concerning nature and human benefits interplay by providing a unified vocabulary and targets for decision-makers and researchers to better identify and quantify NCP holistically (IPBES 2022; Pascual et al. 2017; Stange et al. 2021).

Furthermore, the topics of land and ecosystem management benefitted from NCP's novel approach. Land system science may better integrate the diversity of value systems of stakeholders and institutions through the lens of NPC to better understand and improve land system governance more fairly (Ellis et al. 2019). These ecosystems are becoming more important because they support biodiversity, along with farmers' sociocultural perceptions and values that are co-produced in agroecosystems (Albizua et al. 2019). NCP also provides a powerful tool to assess the sustainability of agricultural intensification, since the framework could incorporate how agricultural land systems change the impacts of agricultural production and its sustainable outcomes. NCP therefore offers stakeholders an informed choice between different intensification options that they need to know about (Helfenstein et al. 2020).

Additionally, scavenger species were particularly focused on the NCP literature. In previous assessments, scavenging

benefits were not considered, particularly in standard classifications of ecosystem services (Martín-López et al. 2019). Yet, the NCP 10, "Regulation of detrimental organisms and biological processes", promoted a new perspective on these species (Christie et al. 2019). It brought the recognition of the importance of scavenging benefits, such as the role of wolves (Christie et al. 2019) and vultures (Zuluaga et al. 2022) with carrion removal for maintaining wildlife ecological functions (such as disease control) in fragmented habitats, alongside the scavengers' provision of non-material NCP (Aguilera-Alcalá et al. 2020; Bhattacharjee et al. 2022; García-Jiménez et al. 2022).

NCP 18 "Maintenance of options"

One major novel feature of the NCP methodological approach is the inclusion of the 18th NCP group, "Maintenance of options", which is described as "the capacity of ecosystems, habitats, species, or genotypes to keep options open to support a good quality of life" (Díaz et al. 2018a). The NCP 18 group does not fit into a single class, yet it spans the three regulating, material, and non-material categories. The concept of the NCP 18 group intends to expand the link between people and nature, recognising and including the multitude of views and relational values (Peterson et al. 2018). The category of maintenance of options enhances social values within sustainability regarding the potential that natural ecosystems can provide for people's well-being when it comes to perceptions, behaviour, ethics, and experiences (Stålhammar 2021).

Some views sustain that the inclusion of NCP 18 introduces the idea of a relational value of biodiversity, which reflects some people's concern about the benefits of biodiversity conservation for future generations (Faith 2021). Aligned with that view, Martín-Forés et al. (2020) integrated species richness and abundance using the Shannon diversity index as a proxy for NCP 18, while Roldán et al. (2022) considered marine mammals (southern elephant seals) as fundamental components of biodiversity within NCP 18. Also, Grosinger et al. (2021) incorporated a material NCP (milk production) alongside its non-material values, such as the maintenance of the identities of local producers, under the NCP 18 scope. The dimension of the maintenance of options may also correspond to the "bequest values" regarded in previous assessments (Shmelev et al. 2023).

In another perspective, NCP 18 facilitates the integration of intangible values conveyed by native languages, which are regarded as the link to the physical environment. This connection often serves as a means for humans to develop, preserve, and disseminate cultural values and environmental knowledge (Bravo-Monroy 2021). That NCP group may also represent the importance of genetic diversity, both within species (phenotypic or genetic) or across species (often measured as phylogenetic diversity), as its scope encompasses the role of evolutionary history and genetic diversity (Stange et al. 2021). Some human–wildlife interactions are also being regarded within NCP 18, such as in the analysis of perceptions of the scavenger guild presented by García-Jiménez et al. (2022), the intercultural linkages among Andean communities and native camelid species (Vilá and Arzamendia 2022), and the assessment of human–wild ungulate interactions (Pascual-Rico et al. 2021).

The inclusion of the NCP 18 scope by IPBES also promoted the novelty of some approaches, such as Colloff et al.'s (2020) "Nature's Contribution to Adaptation" (NCA) conceptual framework. As well, Stange et al. (2021) advocate that NCP 18 may also be considered "insurance", since it captures the potential for current genetic variation to provide future unknown benefits. From the author's perspective, initiatives such as the EU biodiversity strategy "Natura 2000" are recognised within the NCP 18 scope, particularly to facilitate future options for a diversity of edible plants (Stange et al. 2021). This is in line with Nicolás-Ruiz et al.'s (2023) study, which highlighted the role that some species adapted to droughts may play in the provision of new foods and essences in dry river regions.

Relevant limitations to consider when using the NCP approach

As already mentioned in the previous sections, the literature provided several examples where the rationale behind the NCP classification scheme was acknowledged to be more inclusive, e.g. regarding the multiple views and perceptions of nature from the ILK and the inclusion of relational values. Despite that, Daněk et al. (2023) claimed that, with regard to their quantitative study approach, the ES CICES classification scheme was more suitable for distinguishing between the different classes concerning the non-material NCP group, by noticing a dilution of different social and psychological perceptions within the same level of classification. This is in line with the findings of Pires et al. (2020), who emphasised that researchers using quantitative methods predominantly use the ES approach.

Other NCP categories lack a thorough integration of all natural components, such as ecosystems' abiotic components and functions. The material NCP 11 (Energy) does not include sources of energy production other than biomass-based fuels (Díaz et al. 2018a), excluding mineral and other abiotic renewable energy sources. NCP categories do not include water yield (surface or groundwater for drinking in the CICES classification), which led Cusens et al. (2023) to prefer the ES typology, while Kockelkoren et al. (2023) decided to create a separate category. CICES justifies the absence of NCP correlation in water yield and hydropower production as an energy source by stating that "Hydrological

NCP are fundamentally conceived as regulating NCP, because the primary impact of ecosystems on the water is the modification of its flows, not the creation or breakdown of water molecules" (Haines-Young and Potschin 2018). The IPBES perspective acknowledges that non-living organisms and other natural assets are considered important suppliers of human well-being, yet they are not considered within the NCP approach (Díaz et al. 2018a; IPBES 2019). Although abiotic natural resources, e.g. deep aquifers, mineral and fossil reserves, wind, solar, geothermal, and wave power, are considered to benefit people's quality of life, their contributions are not focused on IPBES framework, since they are not mediated by non-human living organisms (Díaz et al. 2015a).

Furthermore, the absence of abiotic factors within the NCP approach may limit a comprehensive assessment of functional components within an ecosystem, which could underestimate its importance. That was evidenced by Giling et al. (2019), who showed how important abiotic factors are for some plant species, like soil compaction (for root health and nutrient uptake), the importance of physical soil properties for habitats (such as water retention), or the importance of chemical soil properties (such as the effects of biogeochemical cycling on nutrient availability). Samaddar et al. (2021) also highlighted the importance of the abiotic properties of soil, particularly in the dynamics of microbiological communities, and their fundamental roles in the mechanisms of disease regulation in plants.

Some studies (examples listed in "NCP and ecosystem services") have adopted a kind of mixed assessment approach, which takes into account how people manage and perceive natural resources within the ES typology, while also incorporating the NCP discourse. Hence, in our view, when a study aims to encompass the whole diversity of goods and benefits provided by the targeted ecosystems, the mixed ES–NCP approach might be more suitable for a more complete and deep assessment.

Future prospects that may be fostered under the NCP approach

The potential engagement of the NCP approach with existing conceptual networks and views is of major importance, such as the United Nations 2030 Agenda and its 17 Sustainable Development Goals (SDGs) (UN 2015). There are important synergies between SDG goals and NCP supply, particularly when tackling land and climate challenges (McElwee et al. 2020). As well, the achievement of the SDGs can be based on clustering priority relationships between important NCP–SDG linkages (Anderson et al. 2019). Besides that, NCP may aid in the planning and application of emerging concepts like nature-based solutions (NbS) (Ausseil et al. 2022; Peterson et al. 2018; Xie and Bulkeley 2020). That includes the implementation of specific solutions based on the knowledge of local stakeholders, such as using ponds (Cuenca-Cambronero et al. 2023) or tackling climate change hazards in the European Alpine region (Dubo et al. 2023). NbS may be key to the successful integration of biodiversity and ecosystems into policymaking and spatial planning (Maes et al. 2018).

Additionally, we highlight the scope of the NCP approach as an integrator of less considered relational values, such as childhood experiences with nature. The nature–child experience relationship exhibits a clear reciprocal quality, serving as a crucial pathway for cultivating a lifelong interest in nature and ecosystems (Beery and Lekies 2021). In fact, Díaz et al. (2018a) embodied "sounds, scents and sights associated with childhood experiences" in the NCP 17 "Supporting identities" description. The importance of connectedness to nature in childhood was highlighted, which in turn may potentiate sustainable behaviours towards a more resilient and sustainable future (Beery and Lekies 2021). Thus, those intrinsic values need to be better represented in the perception and action of ecosystem valuation in environmental policy, where NCP semantics may provide an important communication vehicle (Beery and Lekies 2021; Goodwin et al. 2019).

The emerging NCP approach made clear that there was a need to connect the different ways in which societies relate to nature (Klain et al. 2017). Policies for land use changes should account for a plurality of views and be relevant to the needs of people with different socio-economic characteristics (Vanbergen et al. 2020). This may help land use governance systems have a better common basis by addressing how societies connect to nature and how their assets ensure that with the sustainable provision of nature's goods, which is grounded in the NCP's conceptual assessment and aims (Ellis et al. 2019; Isaac et al. 2022; Vanbergen et al. 2020). By taking it into account, it may support better decisions for sustainable management of natural resources and environmental governance (Isaac et al. 2022; Peterson et al. 2018).

Overview and final remarks

Our systematic literature review highlights the transformative impact of the IPBES conceptual framework, operationalised through the Nature's Contributions to People (NCP) approach, on sustainable natural resource management and human–nature relationships. By adopting a more inclusive and holistic perspective, the NCP framework enhances communication across generational and cultural divides, facilitates dialogue with non-expert audiences, and simplifies technical jargon, making it more accessible to policymakers and decision-makers.

The most frequently acknowledged improvement in the literature is the NCP approach's inclusivity, particularly its incorporation of relational values. This represents a significant step forward in nature conservation by aligning ecological and social values as mutually reinforcing. The inclusion of Indigenous and local knowledge (ILK) fosters a plurality of perspectives and promotes equity in sustainable land management policies. When integrated into governance processes, local ecological knowledge enhances public participation and provides critical insights for territory management. Furthermore, the NCP framework's emphasis on simplifying semantics aids these processes by bridging disciplinary divides and engaging diverse stakeholders.

The inclusion of childhood experiences within the NCP framework further underscores its value in capturing diverse biocultural perspectives and enriching sustainable management strategies. Across the reviewed literature, there is strong consensus on the importance of relational values highlighted by the NCP lens, reflecting how societies and communities connect with nature. Concepts such as "Services to Ecosystems" (Comberti et al. 2015) are seamlessly integrated into the NCP framework, particularly in co-production models that emphasise reciprocal benefits between humans and nature.

A notable advancement within the NCP framework is its acknowledgment of new categories, such as NCP 5, 'Regulation of ocean acidification.' This category highlights the ocean's role in global regulatory processes, an aspect previously overlooked in traditional ecosystem services typologies. This innovation aligns the NCP framework with global agendas, including the UN's 2030 Agenda for Sustainable Development and the design of nature-based solutions, positioning it as a strategic roadmap for addressing current and future sustainability challenges.

The NCP framework's alignment with sustainability science emphasises engaging local actors in decision-making processes and fostering transformative societal changes. Its inclusivity and focus on co-creation make it a promising tool for operationalising sustainable development practices within the SDGs framework. By integrating less-explored perspectives, such as ILK and childhood experiences, the NCP approach establishes a robust foundation for advancing sustainable resource management. It may then support evidence-based decision-making, allowing policymakers, stakeholders, and communities to understand the consequences of environmental changes, land use decisions, or policy interventions on ecosystems and human well-being.

Despite its strengths, the IPBES framework has a significant limitation: it does not account for abiotic components, despite their essential role in ecosystem functioning and NCP provision. This omission may hinder comprehensive assessments of natural resource management and conservation, particularly in contexts where abiotic factors are critical. To address this gap, a mixed approach combining the ecosystem services (ES) and NCP frameworks may provide a more comprehensive understanding of human–nature interconnections. Several studies have demonstrated the broader applicability and relevance of such integrated approaches in addressing the complexity of sustainable natural resource management.

To maximise its potential, the NCP framework requires expanded research efforts in underrepresented regions and ecosystems to capture diverse human–nature relationships. Currently, many studies are concentrated in the Global North, particularly in Europe and North America. Developing countries in Africa, Asia, and Latin America often lack comprehensive NCP research despite being biodiversity hotspots and areas where human–nature interrelationships are critical for livelihoods. For example, tropical rainforests, savannahs, and arid regions are underrepresented in NCP assessments, even though these ecosystems provide significant contributions like climate regulation, water provisioning, and cultural identity. Similarly, oceans and coasts, critical for global sustainability, remain underexplored, particularly in regions such as the Pacific Islands, Arctic, and smaller archipelagic nations.

As final remarks, we propose the following key topics for future research directions addressing the NCP approach:

1. Investigate interactions between material contributions (e.g. food production) and non-material ones (e.g. cultural heritage) to better understand the interplay of diverse NCP categories.
2. Expand interdisciplinary approaches to explore the relational values, ILK, and non-material NCP, fostering collaboration between natural and social sciences.
3. Assess how climate change affects underrepresented NCP groups, such as the regulation of soil and water cycles.
4. Prioritise research on regulating contributions such as "Regulation of ocean acidification", "Regulation of soil erosion", and "Regulation of freshwater quantity".
5. Address gaps in marine-related categories, such as fisheries, coastal protection, and the role of mangroves and seagrass meadows.
6. Integrate the contributions of microbiomes (e.g. soil or aquatic microbiomes) to human well-being into the NCP framework.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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