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TOPICAL REVIEW

Nature's contributions to people and the Sustainable Development Goals in Nepal

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Abstract

Nature's contributions to people (NCPs) underpin the attainment of the Sustainable Development Goals (SDGs) but are declining globally. It is therefore critical to identify the drivers of changes in NCPs, and to understand how and where NCPs can contribute towards the achievement of the SDGs. By integrating the conceptual framework of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBESs) and the SDGs, we can obtain a better understanding of how changes in the state of NCPs support or hinder attainment of the SDGs, and how changes in NCPs are driven by development interventions. We conducted a systematic synthesis of the literature to determine the state of research on NCPs, trends in NCPs and their drivers, and the contribution of NCPs towards achieving the SDGs in Nepal, a low-income and highly biodiverse country. We found that NCPs contributed positively towards the achievement of 12 SDGs. However, NCPs were reported to be declining across Nepal, ultimately undermining Nepal's ability to achieve SDG targets. The major direct drivers of decline were land-use change, over-exploitation, and climate change. These direct drivers were linked to conventional development interventions, including agricultural expansion and the construction of road and energy infrastructure. However, some interventions, such as community forestry and protected areas, increased the supply of NCPs. Better integration of Indigenous knowledge and local practices was also reported to be effective in improving the provision of NCPs and contributing to improving livelihoods at local scales. We identified opportunities for further research in NCPs, particularly in increasing geographical representativeness and improving our understanding of non-material NCPs. Our approach of combining the IPBES conceptual framework and the SDGs enabled us to more comprehensively identify how progress towards the SDGs are mediated by NCPs and provides actionable guidelines for how to take more integrative measures to achieve the SDGs in Nepal and countries facing similar development challenges.

1. Introduction

The 2030 Agenda for sustainable development was adopted by governments worldwide to address the challenges of environmental degradation, biodiversity decline, and global poverty and inequality (United Nations General Assembly 2015). Central to the agenda are the 17 Sustainable Development Goals (SDGs), which aim to provide a guideline for countries to transition towards sustainable development by 2030. Among the 17 goals, goals 14 (Life below water) and 15 (Life on land) explicitly address targets related to the conservation and protection of biodiversity and nature. But there is growing evidence that nature and biodiversity also contribute to multiple other goals, and towards human well-being (Blicharska *et al* 2019, Pham-Truffert *et al* 2020, Obrecht *et al* 2021). These linkages between the contribution of nature to people and the SDGs have been explored at global scales (Anderson *et al* 2019, Kelly-Quinn *et al* 2020, Yang *et al* 2020). But as nature's contributions support SDGs primarily at local and sub-national scales (Blicharska *et al* 2019), we need localized and context-specific information on the linkages between nature's contribution and the SDGs (IPBES 2019).

The conceptual framework of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) can be used to establish potential linkages between nature's contributions and the SDGs (Díaz *et al* 2015). Nature (defined as the natural world with a focus on living elements incorporating, but not limited to, biodiversity), nature's contributions to people (NCPs; the material, non-material and regulating contributions of nature), and good quality of life are the three key foci of the conceptual framework, and along with other elements including anthropogenic assets, and direct/indirect drivers of change, the framework provides a lens for understanding social-ecological systems (Díaz *et al* 2015). By combining the SDGs and the IPBES framework, it is possible to investigate current trends in nature and NCPs, their drivers of change, and how these changes could potentially affect a country's commitment towards achieving the SDGs by 2030. As many of the direct and indirect drivers of changes in NCPs (such as land-use change) are associated with conventional development interventions, an integrated approach can help us to better understand how actions taken to achieve SDGs help or hinder the entire SDG agenda, via their impact on NCPs.

Understanding NCP-SDG linkages is particularly important in highly biodiverse, low-income countries with high levels of nature-dependence, as these countries urgently need to achieve development targets, but are at high risk of unsustainable development projects that harm biodiversity and nature-dependent livelihoods. Nepal is a prime example of such a country (Government of Nepal 2020a). NCPs are vital for many aspects of life such as agriculture, health, Indigenous knowledge, spirituality, and religion in Nepal (Government of Nepal 2014). However, the provision of NCPs is threatened by demographic change, poverty, weak law enforcement and governance, and inadequate conservation policies (Government of Nepal 2018). To realize Nepal's ambition to achieve SDG targets and become a middle-income country by 2030, Nepal might benefit from leveraging the connection between biodiversity conservation, NCPs, and the SDGs.

Nepal has a large body of research on NCPs (Kandel *et al* 2021), but no study to date has used the corpus of available literature to systematically synthesize information on the drivers of change in NCPs, and on the linkages of NCPs and SDGs. In this study, we therefore aimed to: (a) analyze current knowledge on trends in NCPs; (b) identify the direct and indirect drivers associated with these trends; and (c) understand how changes in NCPs affect progress towards the SDGs in Nepal using the IPBES conceptual framework. At the national level, the results of our study can serve to identify gaps in NCP research and potentially help derive solutions for safeguarding NCPs and making progress towards the achievement of SDGs. At a broader scale, we demonstrate the potential of combining the IPBES conceptual framework and the SDGs to understand the effects of anthropogenic drivers of change on nature, and their implications towards achieving Agenda 2030 in a given context.

2. Methods

To answer our research questions we opted for a systematic mapping of the literature on NCPs in Nepal (James *et al* 2016), which differs from systematic reviewing in being more exploratory and capable of accommodating studies with heterogeneous methods (James *et al* 2016). Systematic mapping starts with a pre-determined protocol of using relevant search strings, followed by screening for relevant articles against a set of inclusion criteria, and systematic data extraction. In our case, we employed the Search, Appraisal, Synthesis and Analysis (SALSA) protocol (Grant and Booth 2009) as follows (figure 1).

2.1. Search

Based on the IPBES conceptual framework (Diaz *et al* 2015) and a previous study by Martín-López *et al* (2019), we selected the following strings to query the Web of Science (Core collection, 'all Fields') and Scopus databases ('Article title, Abstract and Keywords') for peer-reviewed contributions:

- nature AND contribution AND Nepal
- ecosystem AND service AND Nepal
- ecosystem AND good AND Nepal
- nature AND gift AND Nepal
- nature AND benefit AND Nepal
- 'environmental service' AND Nepal
- 'environmental good' AND Nepal
- 'ecosystem function' AND Nepal

Although we aimed to review NCP research, we included search strings such as ecosystem service/good/function which predate the term 'NCP' but are conceptually similar. We performed the search in November 2020 and retrieved 567 peer-reviewed articles published between 1995 and October 2020 (figure 1).

Additional sources of grey literature included Scopus and repositories of the World Wildlife Fund Nepal, International Union for Conservation of

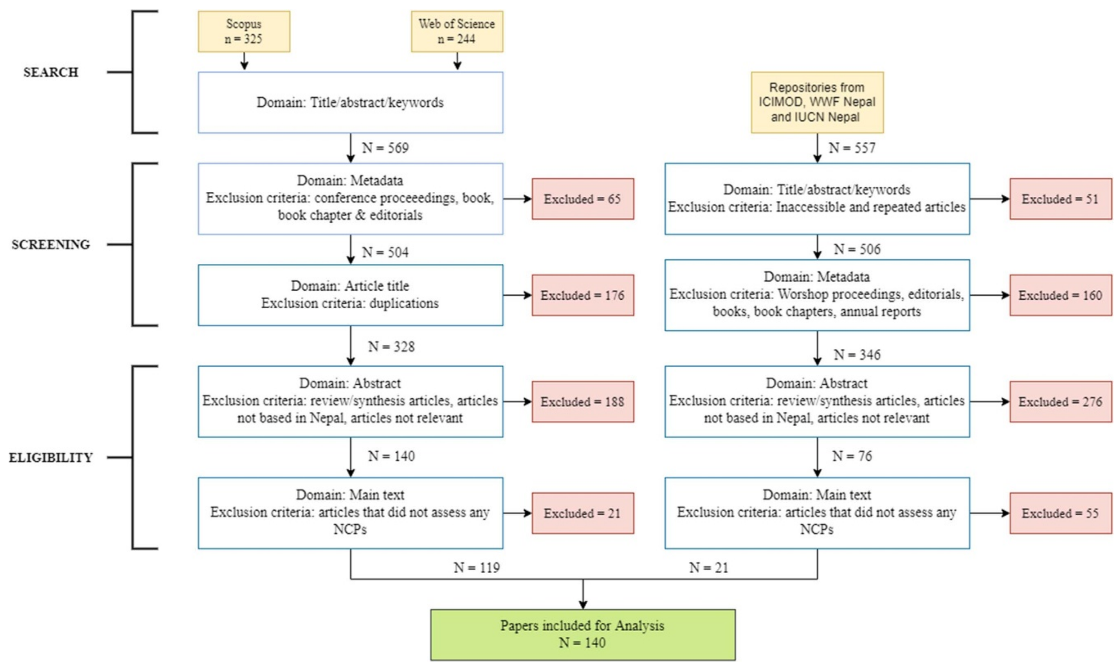

Figure 1. Visualization of the steps followed in the SALSA framework as a part of systematically screening and selecting articles for analysis.

Nature Nepal, and International Center for Integrated Mountain Development. This further search led to an additional 557 grey literature items (figure 1).

2.2. Appraisal

We appraised the peer-reviewed and grey literature in parallel through screening and eligibility checks (figure 1). We excluded conference proceedings, editorials, books, book chapters, institutional financial reports, workshop proceedings, action plans, information booklets, and brochures. During this screening phase we also removed duplicates and inaccessible articles. We then read the abstract of each article against the following exclusion criteria:

(a) Review and synthesis articles;
(b) Articles not based in Nepal despite mentioning Nepal in the abstract and/or keywords;
(c) Articles that did not assess trends in NCPs (or associated concepts such as ecosystem services), drivers of NCP trends, or links between NCPs and the achievement of SDGs.

Out of 1126 grey and peer-reviewed articles, we retained 140 articles for analysis (figure 1).

2.3. Synthesis and analysis

2.3.1. State of knowledge on NCP research

To understand the current state of knowledge on NCP research, we extracted information on geographical and altitudinal coverage, temporal trends in publication, methods of analysis (classified as per Harrison *et al* 2018), ecosystems (classified into forests, freshwater, farmland, grassland, and others), and NCPs studied (table S2).

2.3.2. Trends in NCP supply and associated ecosystems

To obtain an overview of the state of knowledge on trends in NCP supply, we extracted statements from the main text that implicitly or explicitly reported positive or negative changes in NCPs (Adhikari *et al* 2022). We then classified these statements by NCP category and trend (positive or negative). For example, we categorized the statement '*based on the survey, water available for agricultural use is insufficient and furthermore stream-flow is decreasing*' (Regmi *et al* 2019) as a negative trend for 'Regulation of Freshwater Quantity, Location and Timing'. Additionally, we also extracted and classified trends pertaining to ecosystems. We then tallied the number of positive and negative trends of each ecosystem and NCP.

2.3.3. Drivers of trends in NCP and ecosystems

Where available, we extracted statements that linked direct and indirect drivers with trends in NCPs or ecosystems (Adhikari *et al* 2022). We categorized the direct and indirect drivers as per the IPBES classification (IPBES 2019; direct drivers: land-use change, climate change, direct exploitation, pollution, invasive alien species and others; indirect drivers: demographic and sociocultural, economic and technological, institutions and governance, and conflicts). As per the IPBES framework, direct drivers only affect NCPs through changes in nature (in our case, ecosystems) whereas indirect

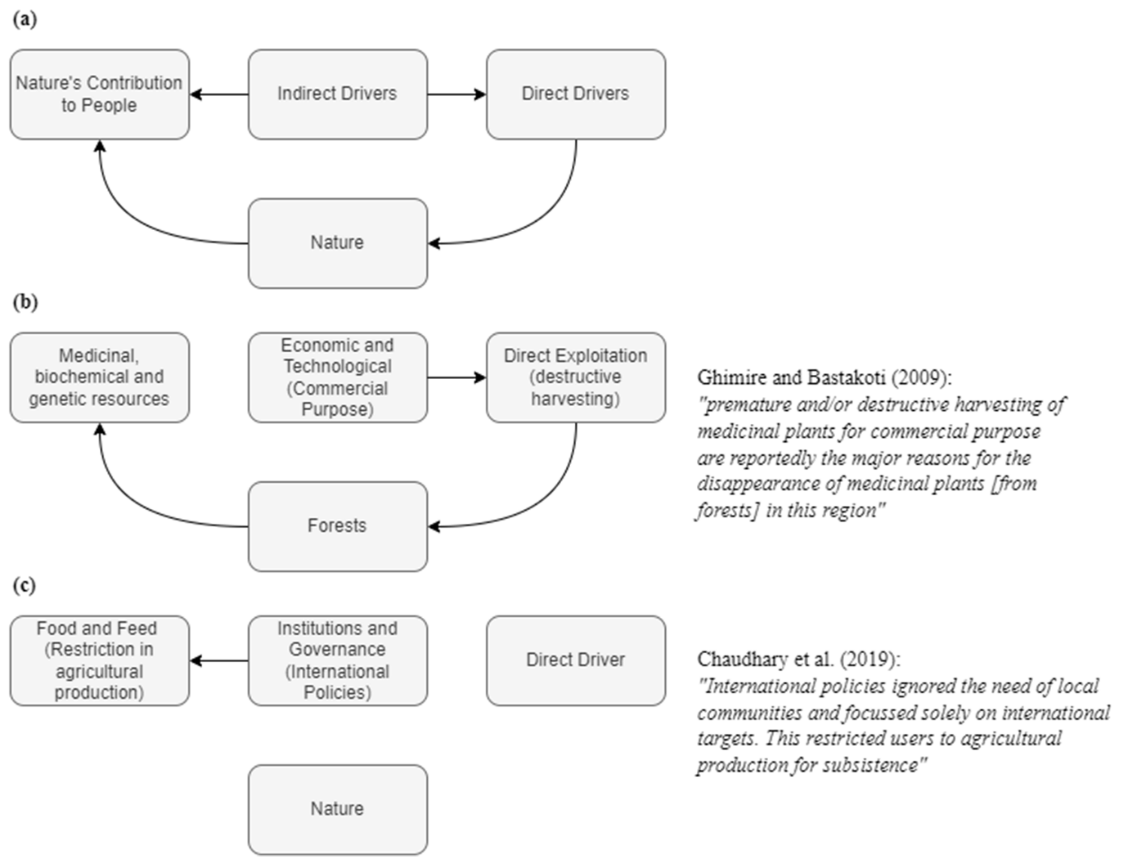

Figure 2. A conceptual diagram representing (a) linkages between direct drivers, indirect drivers, nature and NCPs, adapted from the IPBES conceptual framework (Díaz *et al* 2015), (b) examples of the influence of indirect drivers on NCPs via direct drivers, and (c) influence of indirect drivers on NCPs directly.

drivers affect NCPs either directly or through direct drivers (figure 2(a)). We aggregated and visualized the links between each IPBES component (indirect driver, direct driver, ecosystem, NCP) described above using Sankey diagrams (e.g. figures 2(b) and (c)) created with 2022 the 'networkD3' package (Allaire *et al* 2017) in R version 4.1.2 (R Core Team 2022).

2.3.4. Contribution of NCPs towards achieving SDGs

We also extracted statements that reported the potential contribution of NCPs towards achieving the SDGs, and the ecosystem that contributed to those NCPs (Adhikari *et al* 2022). When single NCPs were possibly contributing to multiple targets, they were attributed to all potential SDGs. For example, the statement '*Due to forest and vegetation, landslides and erosion have decreased especially in the upland area as trees and vegetation act as a buffer against these kind of hazards*' (Adhikari *et al* 2018), was classified as **Forests → Regulation of hazards and extreme events (NCP 9) → SDG 1.5 (Reduce vulnerability to disasters), SDG 11.5 (Reduce the adverse effects of natural disasters) and SDG 13.1 (Strengthen resilience and adaptive capacity to climate related disasters)**. For each SDG, we aggregated and visualized the links between individual SDGs and NCPs.

3. Results

3.1. State of research on NCPs

3.1.1. Temporal trends and methods

Throughout the study period (1995–2020), we detected a progressive increase in the number of peer-reviewed and grey literature articles on NCPs published per year, with a pronounced increase between 2015 and 2018 (figure 3). Out of 140 articles, most ($n = 58$) applied sociocultural approaches, followed by monetary ($n = 37$) and bio-physical ($n = 29$) approaches. Sixteen articles applied mixed approaches that used a combination of bio-physical and sociocultural ($n = 14$), or monetary and sociocultural ($n = 2$) methods to assess NCPs.

3.1.2. Geographic distribution

The studies (across peer-reviewed and grey literature) we assessed covered 90% of Nepal's 77 districts (figure 4). Most studies were conducted at district or regional scales and some studies were performed locally at village or municipal level. Nearly 40% of all local studies focused on protected areas in the Chitwan and Kaski districts of central Nepal. 47% of the reviewed articles reported studies conducted in Hill ecoregion districts, while 25% and

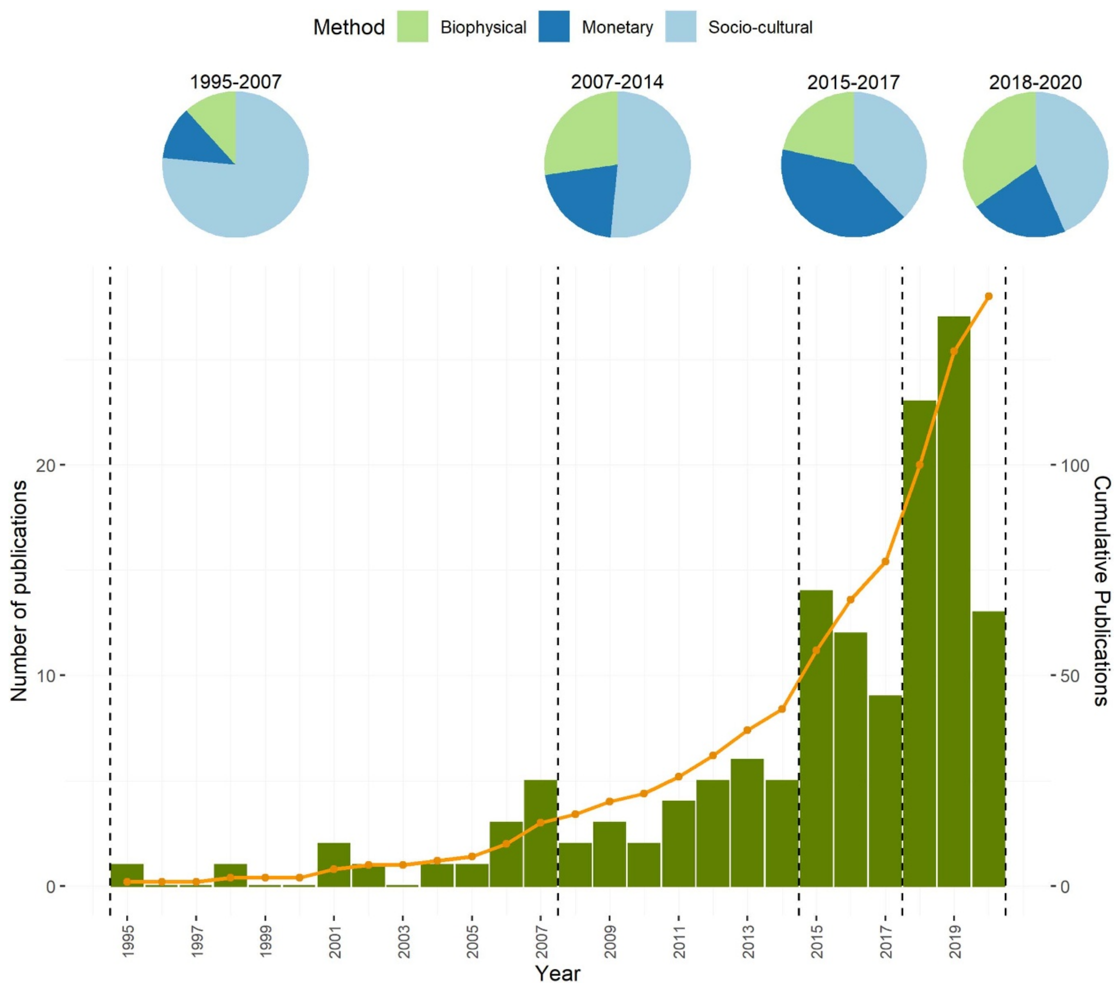

Figure 3. Temporal trends of published articles on NCPs in Nepal. The time periods are divided on the basis of Jenks natural breaks optimization (Jenks 1967). Green bars represent number of articles published per year. The orange line represents cumulative numbers. Pie charts represent the fraction of articles that used biophysical, sociocultural, and monetary methods. Grey literature is excluded in this chart.

28% were based in the Mountain and Terai (lowland) ecoregions respectively. 62% of all local studies were based in the tropical and sub-tropical zones (below 1000 m), 25% were based in temperate zones (1000–3000 m), and 13% were based in sub-alpine and alpine zones (above 3000 m). The maximum elevation of a case study was 4996 m, and the median elevation of case studies was 1474 m.

3.2. Trends in ecosystems and NCPs

Of the 140 papers we selected, forest ecosystems were the most studied (48% of all papers), followed by freshwater (25%), farmland (10%), and grassland (7%; figure S1). 30% of the papers were classified into 'Other ecosystems' which included mosaic ecosystems such as mountains, agroforests and human settlements. Overall, 74% of 265 statements that reported on trends in ecosystems were negative. Freshwater ecosystems had the highest proportion of negative trends (90% of all statements reporting trends on Freshwater ecosystems), followed by grassland (88%), farmland (82%), others (67%), and forest (61%).

We found studies on all NCPs except 'Regulation of Ocean Acidification'. 'Food and Feed' (FOD) was the most studied NCP and was mentioned in 59% of all articles reviewed (line graph, figure 5). This was followed by 'Habitat Creation and Maintenance' (HAB), and 'Materials, Companionship and Labor' (MAT). 'Physical and Psychological Experiences' (EXP) was the most frequently reported non-material NCP. Studies addressed a mean of four NCPs per study. Non-material NCPs had the highest proportion of negative trends (86% of all statements reporting trends on non-material NCPs), followed by regulating NCPs (84%) and Material NCPs (80%). Predominantly negative trends were reported for all NCPs except 'Energy' (NRG) and 'Maintenance of Options' (OPT) (figure 5). Among the studied NCPs, 'Regulation of Hazards and Extreme Events' (HAZ), 'Regulation of Detrimental Organisms and Biological Processes' (ORG), 'Regulation of Air Quality'

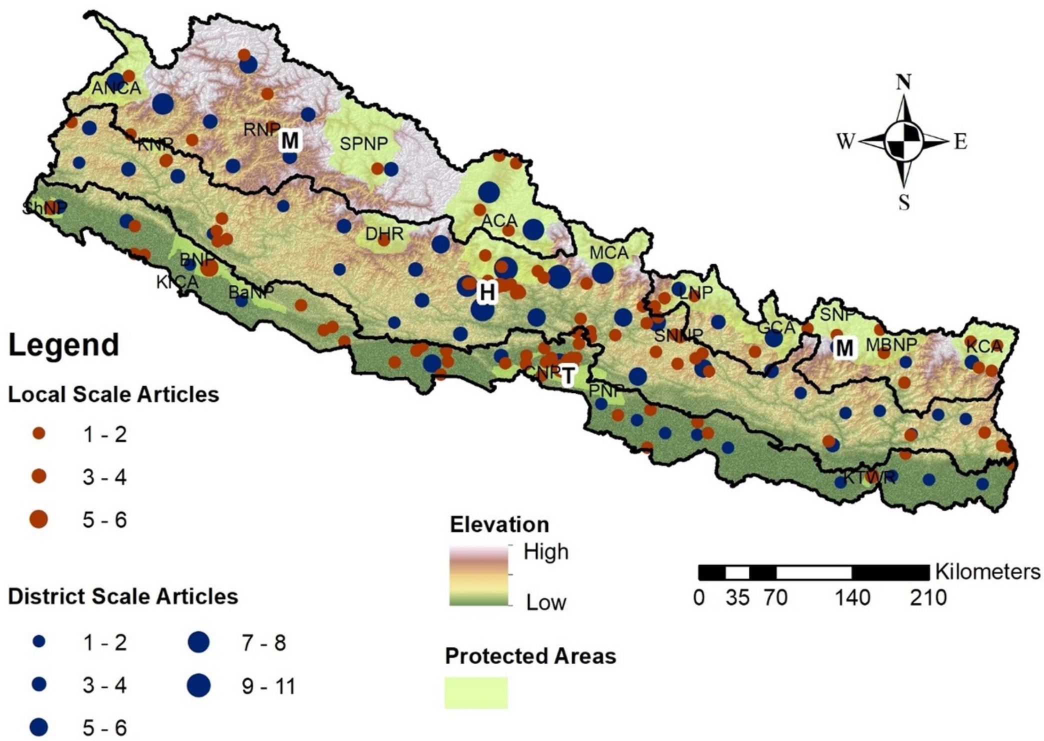

Figure 4. Number of articles from 1995–2020 on NCPs published by geographic area superimposed by protected areas (comprised of wildlife reserves, hunting reserves, national parks, and conservation areas) and elevation; and grouped into three ecoregions, viz. mountains (M), hills (H) and the Terai (T). For district scale articles, the centroid of the districts where the study were based are taken. Protected areas are Chitwan National Park (CNP), Langtang National Park (LNP), Sagarmatha National Park (SNP), Rara National Park (RNP), Shey Phoksundo National Park (SPNP), Khaptad National Park (KNP), Bardia National Park (BNP), Makalu Barun National Park (MBN), Shivapuri Nagarjun National Park (SNNP), Banke National Park (BaNP), Shuklaphanta National Park (ShNP), Parsa National Park (PNP), Koshi Tappu Wildlife Reserve (KTWR), Dhorpatan Hunting Reserve (DHR), Annapurna Conservation Area (ACA), Kanchenjunga Conservation Area (KCA), Manaslu Conservation Area (MCA), Api Nampa Conservation Area (ANCA), Gaurishankar Conservation Area (GCA) and Krishnasar Conservation Area (KrCa).

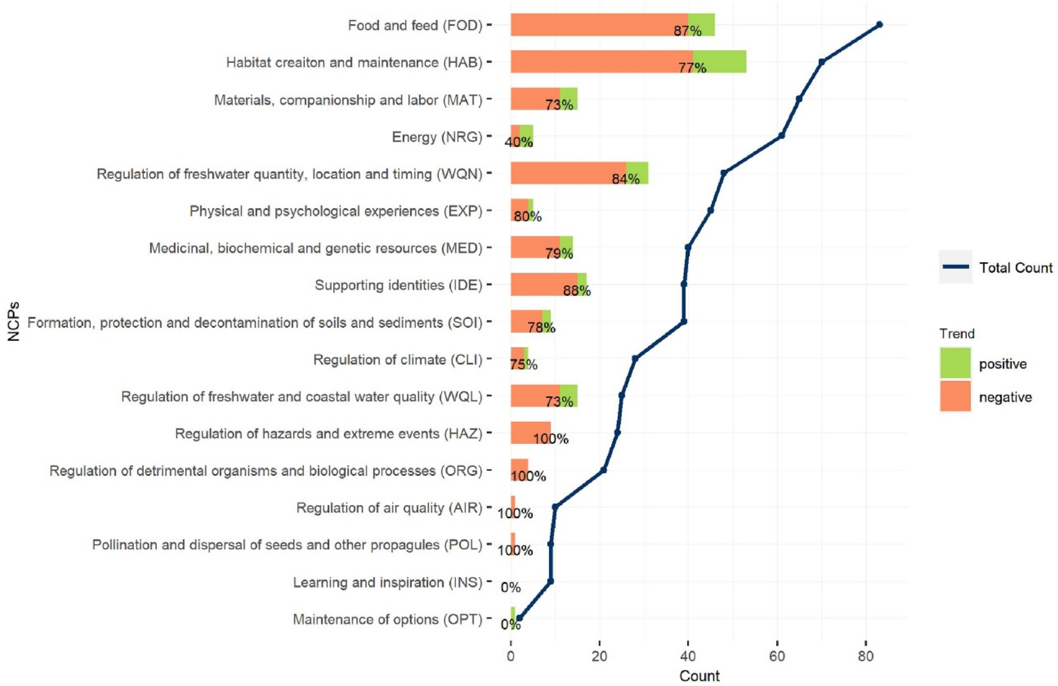

Figure 5. Number of articles focusing on individual NCPs (line graph) and the proportion of statements reporting increasing or decreasing trends in NCPs (bar graphs). The labels in the stacked bar charts indicate the percentage of negative trend reported in the literature for each NCP.

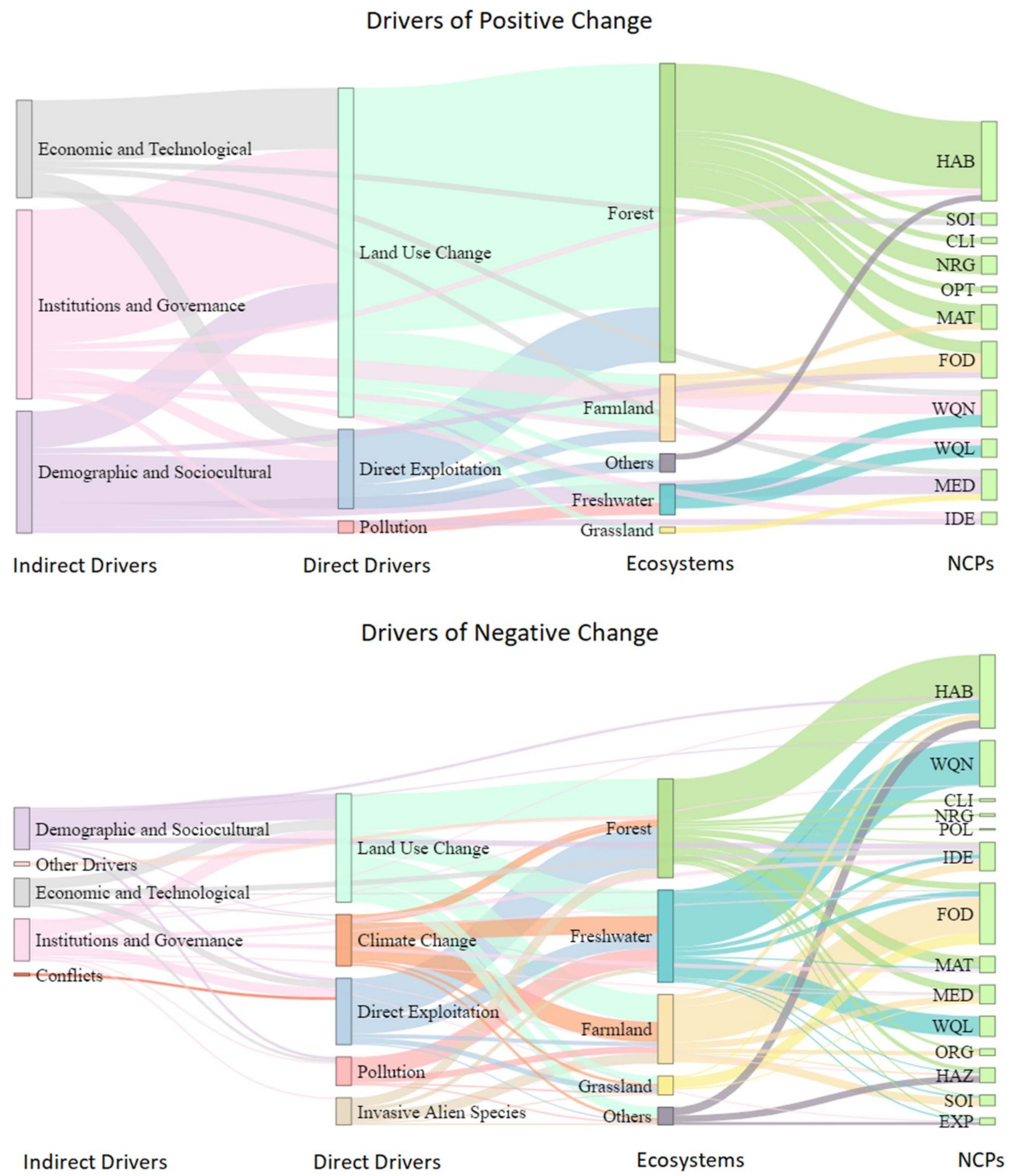

Figure 6. Direct and indirect drivers of changes in ecosystems and NCPs. The height of each node represents frequency of occurrence of that node occurred in statements within the peer-reviewed and grey literature we assessed.

(AIR) and 'Pollination and Dispersal of Seeds and Other Propagules' (POL) were not reported to have increased in any studies.

3.3. Direct and indirect drivers of change in ecosystems and NCPs

About 35% of all drivers were reported to have positive effects (drivers of positive change) while the remaining 65% were reported to have negative effects (drivers of negative change) on ecosystems and NCPs (figure 6). The most frequently co-occurring combinations of direct and indirect drivers of change, ecosystems, and NCPs from the selected literature are summarized in table 1.

3.3.1. Drivers of positive change

The direct positive drivers of change in ecosystems and NCPs were land-use change ($n = 54$, or 78% of all statements on positive direct drivers), direct exploitation ($n = 13$, or 19%), and pollution ($n = 2$, or 3%). These direct drivers were influenced mostly by three key indirect drivers: institutions and governance ($n = 31$, or 46% of all statements on positive indirect drivers), demographic and sociocultural ($n = 20$, or 30%), and economic and technological ($n = 16$, or 24%). Government implementation of protected areas, community forestry, and other conservation interventions were one of the major positive indirect drivers, constituting 31% of all positive indirect

Table 1. Summary of drivers to nature/nature's contribution to people (NCPs) and key interactions between NCPs and the Sustainable Development Goals (SDGs) in Nepal. The direct drivers land-use change and direct exploitation are explained within various indirect drivers, and therefore do not have their own rows. Number of statements that were attributed to the particular direct/indirect driver and SDG-NCP linkage denoted with 'n ='.

Positive drivers	
Indirect driver: institutions and governance ($n = 31$)	Most positive drivers arose from management of protected areas and community forests leading to better land use and a decrease in the exploitation of natural resources. This led to an increase in forest cover and better condition of freshwater resources that positively impacted NCPs such as HAB, WQN, and WQL.
Indirect driver: demographic and sociocultural ($n = 20$)	Indigenous knowledge, beliefs, and practices were major positive drivers that triggered better land use practices, and sustainable resource consumption. Religion played a big role in these beliefs—the health of nature and biodiversity were linked to religion, thereby encouraging the preservation of forests. Traditional farming systems also helped preserve plant genetic diversity (MED) and the health of soil (SOI) in farmlands. Increased out-migration from villages led to fallowing of farmlands that were eventually converted to forests and decreased pressure on forest resources.
Indirect driver: economic and technological ($n = 16$)	Increased access to biogas and fuel-efficient stoves improved the condition of forests leading to better habitat quality for biodiversity (HAB) and availability of non-timber forest materials (MAT). Infrastructure development and road access (linked to SDG 9) helped local authorities to effectively monitor the forests leading to its improvement.
Negative drivers	
Indirect driver: institutions and governance ($n = 31$)	Inadequate implementation of conservation policies and corruption encouraged direct exploitation of resources and deteriorated the condition of forest and freshwater which in turn affected HAB, WQL, WQN and HAZ. Conflicts between conservation management and local authorities and restrictions imposed from conservation efforts affected locals' access to various services such as livestock grazing (FOD), access to medicinal herbs (MED), and traditional cultures related to nature (IDE). Unplanned and haphazard construction of infrastructure also impacted habitat (HAB) and increased vulnerability to natural hazards (HAZ).
Indirect driver: demographic and sociocultural ($n = 31$)	While population growth led to conversion of forest lands into farmlands that affected biodiversity (HAB) in some areas, out-migration led to fallowing of land and decrease in crop production (FOD) in others. Urbanization also led to land conversion of farmlands to built-up areas, thereby reducing food production (FOD). The growing interest in off-farm employment of younger generations has led to declines in traditional farming practices (IDE), the reduction of farm diversity (MED) and use of medicinal herbs (MED).
Indirect driver: economic and technological ($n = 21$)	Increased access to markets encouraged destructive harvesting of timber (MAT) and wild food (FOD) from forests, medicinal herbs (MED) from grasslands, and overfishing (FOD) from freshwater ecosystems leading to their decline as well as causing habitat destruction (HAB). Illegal hunting was also frequently reported that threatened the population of mega-fauna.
Indirect driver: conflicts ($n = 2$)	The Maoist-led civil war in Nepal from 1996–2006 was cited twice as reasons for increase in exploitation of forest resources and illegal poaching (HAB).
Direct driver: climate change ($n = 39$)	Climate change created diverse problems in all ecosystems, such as reduction in flow of water (WQN), the emergence of detrimental organisms and pests (ORG), and erratic rainfall or droughts that affected food production (FOD). Heavy rainfalls eroded fertile soils (SOI), increased the incidence of landslides and floods (HAZ), and reduced water quality (WQL) due to sedimentation. Reduction in habitat, local extinction of plants, and changes in plant species composition (HAB) were also directly attributed to Climate Change.
Direct driver: invasive alien species ($n = 21$)	Invasive weeds and introduced species led to a reduction in the natural regeneration of local tree species (HAB) and suppressed the emergence of grasses required for livestock (FOD). Invasive alien species mostly affected farmlands and reduced the productivity of crops (FOD).
Direct driver: pollution ($n = 21$)	Use of chemical fertilizers and agricultural intensification were the major drivers of soil pollution (SOI). The runoff of excess fertilizers to freshwater led to reduction in water quality (WQN), habitat loss (HAB) and a decline in cultural activities tied to freshwater ecosystems (IDE).

(Continued.)

Table 1. (Continued.)

NCP-SDG linkages	
SDG	Remarks
1 NO POVERTY	FOD ($n = 31$): selling agricultural produce from farmlands, wild edibles from forests and fish from freshwater contributed to poverty reduction. MAT ($n = 15$): locals diversified their income by selling NTFPs and timber, especially in mountain ecoregions. EXP ($n = 8$): tourism activities, especially in mountain ecoregions contributed to increasing income generation.
2 ZERO HUNGER	FOD ($n = 74$): the dependence on forest and agroforest ecosystems for fodder and wild edibles; farmland for crops; and freshwater ecosystems for aquatic species was high, and crucial for food security. ORG ($n = 19$): human wildlife conflicts severely impacted food security in Nepal, especially in the vicinity of protected areas where crop raiding from wildlife had increased. Major species reported in conflicts were elephants, wild boars, and snow leopards. WQN ($n = 16$): farmers depended on freshwater ecosystems to irrigate their crops. SOI ($n = 11$): farmers utilized leaf-litter for composting which increased productivity of crops. Composting and the use of animal manure was particularly important for farmers who could not afford chemical fertilizers.
3 GOOD HEALTH AND WELL-BEING	MED ($n = 18$): medicinal herbs were particularly valued in rural communities with limited access to health centers. Medicinal plants were associated with traditional practices and cures for diverse diseases and ailments. ORG ($n = 8$): encounters of village people with wildlife led to injury or even death. Human wildlife conflicts were all reported in villages in vicinity of protected areas.
4 QUALITY EDUCATION	EXP ($n = 3$): eco-tourism motivated locals to take up education for tourism activities. Income generated by ecotourism allowed villagers to send their children to school. INS ($n = 3$): areas of socio-ecological significance were used to deepen knowledge on biodiversity and nature
5 GENDER EQUALITY	EXP ($n = 1$): homestays operated by women increased their income and empowered them to start cooperatives and new businesses. MAT ($n = 1$): processing of NTFPs allowed women to have alternative sources of income NRG ($n = 1$): biogas was associated with decreased time spent collecting wood, and increased time spent in other productive activities for women such as education.
6 CLEAN WATER AND SANITATION	WQN ($n = 25$): freshwater ecosystems mainly provided material services such as drinking water, while forest ecosystems regulated water flow through groundwater recharge. In some cases, reforestation, especially of palm trees, actually reduced groundwater recharge because of large rates of evapotranspiration. WQL ($n = 5$): forests, biodiversity and soil were important for the rehabilitation and purification of water sources.

(Continued.)

Table 1. (Continued.)

NCP-SDG linkages	
7 AFFORDABLE AND CLEAN ENERGY	NRG ($n = 43$): fuelwood was the primary source of energy in most studies. Biogas and cattle dung were alternative sources of energy for some households. WQN ($n = 5$): water from rivers were being used for off-grid power generation in rural areas. Increase in forest cover led to increase in water availability, leading to higher generation of energy.
8 DECENT WORK AND ECONOMIC GROWTH	EXP ($n = 25$) and IDE ($n = 2$): the natural and socio-cultural capital of Nepal provided tremendous opportunities for tourism activities in the country, ranging from homestays and cultural immersions to trekking, bird watching, aesthetic experiences and leisure.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	MAT ($n = 28$): timber from forests was used for the construction of houses and small infrastructures in villages, and its supply was done through community forests. Agroforests were also contributing by providing resources for building infrastructure at local levels.
11 SUSTAINABLE CITIES AND COMMUNITIES	HAZ ($n = 19$): vegetation and forest cover provided protection against landslides and floods due to their capacity to reduce surface runoff and prevent soil erosion. Wetlands controlled flooding by absorbing excess water.
13 CLIMATE ACTION	CLI ($n = 14$): forest ecosystems contributed to a reduction in greenhouse gas emissions by sequestrating carbon and storing it in above and below-ground biomass.
15 LIFE ON LAND	HAB ($n = 16$): forests, farmlands and freshwater ecosystems provided habitat to a variety of species. Healthier ecosystems were linked with higher number in species. SOI ($n = 9$): trees and plants contributed towards nutrient enrichment, soil retention and enhancement of soil fertility. IDE ($n = 4$): religion is intrinsically tied to nature for many Indigenous communities, motivating their conservation.

drivers reported in literature. These interventions led to better land-use practices and sustainable resource use, thereby improving the status of forests and the services they provided. Similarly, interventions that increased access to renewable energy such as biogas from manure and agricultural waste led to a lower dependence of local populations on forests for firewood, thereby sustaining other forest-based services as well, such as HAB, MAT and MED. Indigenous knowledge, local land-use practices, and traditional systems of sustainable resource consumption were also reported as major reasons leading to positive effects on nature and NCPs.

3.3.2. Drivers of negative change

The direct drivers of negative changes in ecosystems and NCPs were land-use change ($n = 80$, or 38% of all statements on negative direct drivers),

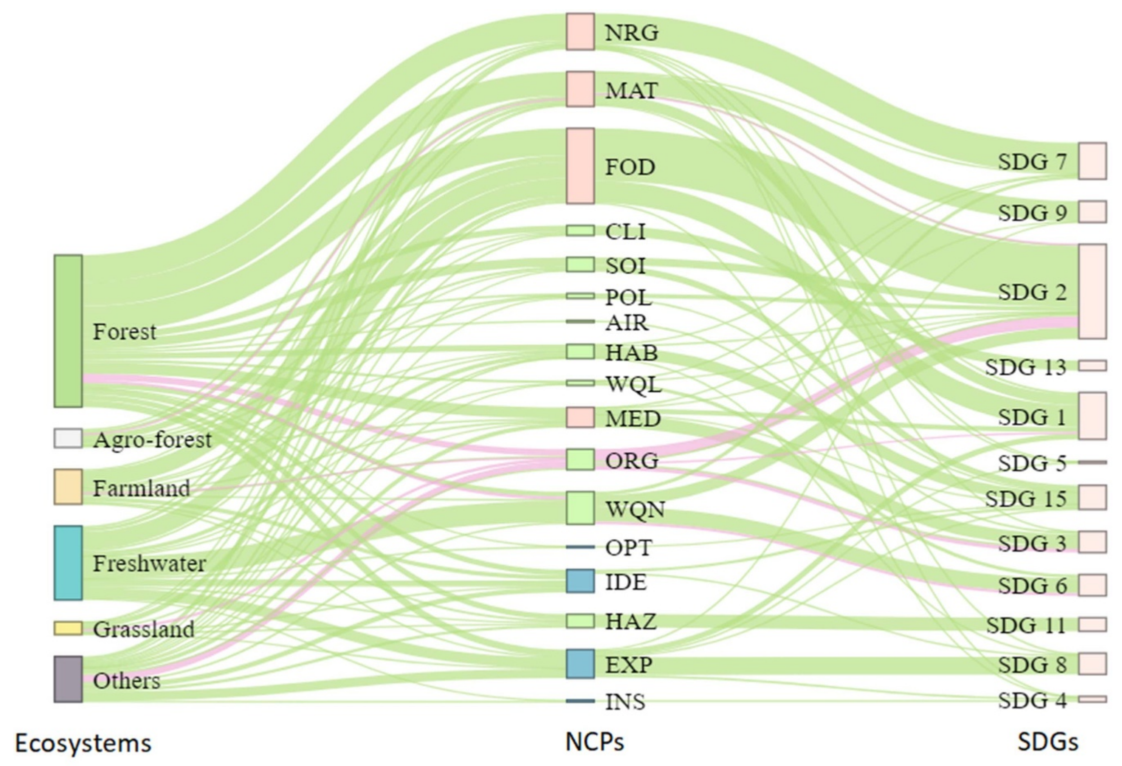

Figure 7. Positive (green) and negative (purple) linkages between ecosystems, NCPs, and SDGs. The NCP nodes are color coded according to their primary type as material (pink), regulating (green) and non-material (blue). The height of each node corresponds to the frequency of occurrence of that node occurred in statements within the peer-reviewed and grey literature we assessed.

direct exploitation (n = 49, or 23%), climate change (n = 39, or 18%), pollution (n = 21, or 10%), and invasive alien species (n = 21, or 10%). Most direct drivers were influenced by four indirect drivers: Institutions and Governance (n = 31, or 36% of all statements on negative indirect drivers), Demographic and Sociocultural (n = 31, or 36%), Economic and Technological (n = 21, or 25%), and Conflicts (n = 2, or 3%). 51% of reported negative drivers were attributed to the consequences of government-led development projects such as the construction of road and hydropower infrastructure, intensification of agriculture, as well as expansion of urban areas and transmission lines. These development projects led to land-use change and exploitation of resources, impacting forest and farmland ecosystems in particular. Meanwhile, climate change and pollution were most frequently reported as causes of negative trends in freshwater ecosystems and related NCPs.

3.3.3. NCPs and SDGs

The 17 NCPs reported in the literature potentially contributed to the achievement of 12 SDGs (see table 1 for detailed statements of contributions). Material NCPs had the highest number of potential contributions towards the advancement of the SDGs (52% of all statements reporting potential NCP-SDG linkages), followed by regulating (37%) and non-material (11%). WQN, FOD and PHY were the highest reported regulating, material, and non-material NCPs that contributed towards the advancement of different SDGs, respectively. Overall, FOD had the largest number of positive associations with SDGs, followed by NRG. SDGs 2 (zero hunger), SDG 7 (affordable and clean energy), and SDG 1 (no poverty) benefited the most (figure 7). NCPs contributing positively towards SDG achievement were mostly associated with forest, freshwater, and farmland ecosystems. The few instances of NCPs contributing negatively towards the achievement of SDGs were almost exclusively related to human-wildlife conflict, which negatively affected the food security and health of local communities. Studies did not report potential contributions between NCPs and the attainment of SDG 10 (reduced inequalities), SDG 12 (responsible production and consumption), SDG 14 (life below water), SDG 16 (peace, justice and strong institutions), and SDG 17 (partnership for the goals).

4. Discussion

We uncovered an extensive corpus of research on NCPs in Nepal. NCP research has been widely distributed throughout the country (figure 4), and is steadily increasing in volume, especially since 2015. In contrast to the dominance of natural science and economic approaches in global and mountain ecosystem service discourse (Díaz *et al* 2018, Martín-López *et al* 2019), NCP research in Nepal is characterized by a tendency towards using socio-cultural methods, potentially indicating that researchers have recognized the importance of local and cultural values in shaping human-nature interactions in Nepal.

4.1. Multiple drivers of declines in NCPs

NCPs across all three categories—regulating, material and non-material—and most ecosystems are in decline across Nepal. Habitat maintenance NCP was reported to be declining in many parts of Nepal, for a range of ecosystems including forests, farmlands, wetlands and rangelands. This is in line with regional trends in habitat loss across the wider Hindu Kush Himalayan region (Jantz *et al* 2015). Nepal has had some recent successes in conserving megafauna such as the greater one horned rhino (National Trust for Nature Conservation 2014) as a result of habitat restoration efforts. However, these successes have been limited to a few protected areas in the country, and ongoing habitat destruction is still presently affecting many species of birds, mammals, reptiles, amphibians, and other freshwater species (Government of Nepal 2018). Other reported declines in regulating NCPs included regulation of freshwater quantity and quality. Availability of drinking water relative to demand was reported to be decreasing by most studies, in line with global trends (IPBES 2019). Scarcity of drinking water was further exacerbated by pollution and climate change, which are major drivers of freshwater ecosystem decline globally (IPBES 2019) and in the Hindu Kush Himalayas (Pandit *et al* 2016, Singh *et al* 2019, Payne *et al* 2020).

The majority of studies also reported declines in material NCPs (figure 4). Although overall food production is increasing in Nepal (Government of Nepal 2021), a large number of studies reported declines in the potential of ecosystems to sustainably produce food, driven mostly by climate change, land-use change, and overexploitation. Similarly, studies reported negative trends in the provision of medicinal herbs and non-timber forest products (NTFPs), considered crucial for health and income of the most rural communities in high-elevation regions of Nepal (Kalauni and Joshi 2018) due to climate change and lack of sustainable practices. This is especially concerning in light of the immense potential of these NCPs to alleviate poverty in rural regions (Gioli *et al* 2019).

The few studies that focused on non-material NCPs also reported mostly negative trends. This was prominent for spiritual values, cultural identities and Indigenous knowledge on aspects such as farming, entomology, agrobiodiversity and medicinal plants. These declines were in spite of the recognition of the importance of traditional and Indigenous knowledge for maintaining ecosystem services in Nepal (Sharma *et al* 2009), and were also indirectly driving the declines in other NCPs such as MED and FOD. Given the immense value of Indigenous and Local Knowledge for climate change adaptation (IPCC 2022), the decline of Indigenous knowledge is of major concern and requires urgent attention.

Several interventions that aimed to advance development objectives led to unintended negative consequences on NCPs, ultimately undermining Nepal's development aspirations. For example, Nepal's Agriculture Development Strategy of 2015 aims to double food productivity and have a tenfold increase in food exports by 2035 (Government of Nepal 2015). This is currently addressed, in part, through commercialization of agriculture by increasing the import of chemical fertilizers and encouraging their use through subsidized distribution (Government of Nepal 2015). However, the use of chemical fertilizers in inappropriate quantities has led to multiple negative consequences such as pollution in rivers and reduction in farmland diversity, thereby negatively affecting the supply of multiple NCPs in Nepal, in line with regional (Hinz *et al* 2020, Verma *et al* 2021) and global trends (Timko *et al* 2018, Frank and Schäffler 2019). Similarly, infrastructure development including the improvement of road networks, construction of hydropower plants, and expansion of electricity transmission lines led to land fragmentation, overexploitation, soil erosion, landslides, decreases in water quality and destruction of habitats, causing negative trends in NCPs. While the framing of policy documents calls for many objectives, including biodiversity conservation, to be pursued in an integrative way, we observed that many interventions taken to pursue individual goals in isolation had negative consequences for the provision of NCPs and, ultimately, Nepal's ability to achieve an integrated suite of development goals.

4.2. NCPs are central to the SDG agenda

Nepal's commitment to graduating from the list of Least Developed Countries, and to continuing the aspirations of the Millennium Development Goals that were not achieved by 2015, has led the government to prioritize eliminating poverty, increasing access to renewable energy, increasing food production, investing in ecotourism and improving infrastructural development (Government of Nepal 2020a). NCPs could underpin the achievement of several of these goals, as we have detailed in this study. The fifteenth five-year plan, which is currently the principal roadmap for development in Nepal, has already introduced measures to achieve some of these goals by leveraging their dependance on the NCPs. For example, Nepal has placed special focus on sustainable management and commercialization of NTFPs, recognizing that NTPFs could contribute to the poverty alleviation (Bista and Webb 2006) along with reduction in inequality and improvement of food security (Gauli and Hauser 2009, Government of Nepal 2020a). Several other development strategies laid out in the fifteenth five-year plan such as rural development, disaster risk reduction, climate change mitigation, and gender equality are, in part, planned to be achieved by nature-based interventions such as ecotourism, community forestry, agroforestry and sustainable harvesting of medicinal herbs that focus on improving the supply of NCPs (Government of Nepal 2020a).

The policies to conserve nature and NCPs that are already in place in Nepal have also shown overarching benefits towards multiple development goals. Community forestry and protected areas, the dominant policy measures undertaken to conserve nature and biodiversity in Nepal not only resulted in progress towards achieving SDG 15 (Life on land), but also reduced poverty (SDG 1, den Braber *et al* 2018), increased eco-tourism (SDG 8, Paudyal *et al* 2019), and stimulated investment in alternative energy programs (SDG 7, Jones 2007), schools (SDG 4), hospitals (SDG 3), roads (SDG 9) and sanitation facilities (SDG 6, Stapp *et al* 2016). These nature-based solutions also increased adaptive capacity towards climate change (SDG 13, Sapkota *et al* 2019). Focusing on policy and interventions that conserve nature and NCPs across Nepal therefore does not only improve the flow of NCPs but also aids the achievement of Nepal's priority development goals.

4.3. Nature-based solutions for the SDGs

Nepal is already implementing some nature-based solutions for countering development and conservation issues through interventions such as community forestry. It has been one of the most successful countries in doing so (FAO 2016). Nepal could adapt other nature-based interventions that have been found to support the achievement of multiple SDGs, such as wetlands coupled with green instead of grey infrastructures for water purification and supply (SDG 6, Liquete *et al* 2016), horticulture therapy for improved mental health and well-being in urban areas (SDG 3, Vujcic *et al* 2017), restoration of forest ecosystems for improved carbon sequestration (SDG 13, Jin *et al* 2020), green infrastructure in cities for flood reduction (SDG 11), groundwater recharge (SDG 6), urban heat island reduction and increased habitat for wildlife (SDG 15, Newell *et al* 2013).

Some viable nature-based solutions are already researched and recommended to solve specific challenges in Nepal. Landscape restoration approaches are considered promising for multiple challenges of the food-water-energy nexus (Melo *et al* 2021), including food security challenges that are common in Nepal: low productivity, high production costs, decreasing food diversity, depleting water levels and weak climate resilience in agriculture (Subedi *et al* 2020). Prioritizing energy-efficient, nutritionally dense, and climate resistant traditional foods such as buckwheat and millet (Adhikari *et al* 2019), and incentivizing agrobiodiversity, and the promotion of climate-smart agriculture models (Subedi *et al* 2019) are additional pathways with the potential to simultaneously increase supply of NCPs and advance food security. Community-based landscape approaches to conservation also present opportunities to incorporate developmental activities within conservation (Doyle-Capitman *et al* 2018, Dale *et al* 2019) and have been shown to simultaneously conserve NCPs and achieve sustainable development targets locally and regionally (Gurung *et al* 2019).

Addressing existing tradeoffs between development goals and conservation is another alternative strategy to sustain NCPs and thereby make progress towards the achievement of SDGs. The tradeoffs between traditional development and conservation approaches are present in other low-income high-biodiversity countries, and many insights can be translated across contexts. As in many low-income agriculturally-dependent countries, farmers in Nepal lack support for soil testing and knowledge on the use of fertilizers. The excessive use of chemical fertilizers and its negative consequences for the environment could be addressed by integrating trainings on chemical fertilizer use and extensive soil testing services (Pandey *et al* 2018). Haphazard road construction is a source of multiple negative drivers to NCPs around the world, but can be ameliorated through optimally engineered alignments, drainage and bioengineering (Sudmeier-Rieux *et al* 2019). Likewise, greater prioritization is required for safeguarding the environment from infrastructure development projects such as roads and hydropower in Nepal. Although these mechanisms already exist through environmental impact assessments, hydropower projects are not compliant (Ghimire *et al* 2021), as in other countries in Asia (Prescott *et al* 2017). Nepal's shift towards decentralization presents a good opportunity to introduce environmental policies at the local level that encourage safer and sustainable road development. Finally, an immediate set of actions that Nepal could take is to acknowledge the indivisibility aspect of the SDGs in their monitoring and reporting framework. Instead of reporting progress in individual SDG indicators, as practiced in Nepal (Government of Nepal 2017, 2020b), reporting on the interconnectedness of targets and the implications of progress of one target towards achieving others could help to more explicitly encode the systematic nature of the SDGs into policy practice. The use of nexus monitoring can be one such example of how multiple goals could be monitored simultaneously by composite indicators (Mabhaudhi *et al* 2021).

4.4. Knowledge gaps and implications for future research

Although the coverage of NCP research in Nepal was very broad, some geographical areas were relatively over-researched. For instance, comparatively more research has been performed in protected areas than in non-protected areas in Nepal, even though non-protected areas support critical NCPs in the Himalayan region (Thapa *et al* 2021). Research in protected areas has been dominated by local-scale studies, and has usually focused on the direct effects of implementation of protected area policy on nature and local communities. To uncover novel patterns or processes in socioecological systems that can guide local and national policy, research across multiple scales is necessary (Payne *et al* 2017, Payne *et al* 2020), but lacking, especially for mountainous countries like Nepal where sharp biological and socio-economic gradients shape diverse human-nature interactions. We also found that non-material NCPs and community-based management of natural resources and Indigenous knowledge were underexplored, in line with a survey of the NCP literature in mountains (Martín-López *et al* 2019). Similarly, montane, sub-alpine, and alpine regions of Nepal still remain under-explored. Research using the landscape approach could address all three knowledge gaps (scale, geographic coverage and integration of diverse knowledge systems). The landscape approach 'constitutes an arena in which entities, including humans, interact according to physical, biological and social rules that determine their relationships' (Sayer *et al* 2013). By definition, the landscape approach is characterized by the need to understand socioecological systems at multiple scales, to include multiple stakeholders and value systems, and to focus on multifunctionality of ecosystems that reconciles both development and conservation beyond protected areas (Sayer *et al* 2013). Finally, we recommend utilizing comprehensive conceptual frameworks such as the IPBES which has not yet been fully used in Nepal's context, but could be vital to further understand the interrelations between nature and humans.

5. Conclusion

Our synthesis, along with numerous other global studies on NCP-human linkages has shown that multiple benefits can potentially be derived from sustaining and improving the provision of NCPs. Yet, translating such scientific findings to workable policy solutions remains a challenge. The forthcoming IPBES nexus assessment is one example that tries to address this gap globally, by highlighting viable policy solutions to the challenges faced by biodiversity and NCPs. This needs to be done at local scales as well. We have initiated steps for this in Nepal by first documenting and consolidating an extensive body of literature on NCPs, and then preliminarily linking them to the achievement of SDGs. A next step is to investigate the conditions under which NCPs are causally linked to SDG attainment and to investigate viable policy options that can strengthen the provision of NCPs and thereby contribute towards the advancement of SDGs. More generally, by integrating the IPBES Conceptual Framework and the SDGs, we were able to identify the risks posed by narrowly focused development projects. Development projects that only advanced single SDGs, such as hydropower projects and fertilizer subsidies, undermined achievement of the entire set of SDGs by depleting NCPs. Our methodological approach can be applied to other settings to understand context-specific opportunities and challenges to enhance NCPs and meet the 2030 Sustainable Development Agenda.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors DOI: https://doi.org/10.5281/zenodo.7058496.

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Conflict of interest

The authors declare no conflict of interest.

Ethics statement

No ethical approval was needed as no human or animal subjects were involved in experimental procedures.

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