A cross-scale investigation on the linkages between nature, nature's contributions to people, and human wellbeing in Nepal

Inaugural dissertation

of the Faculty of Science,

University of Bern

Presented by:

Biraj Adhikari

From Nepal

Supervisors of the doctoral thesis:

Prof. Dr. Markus Fischer

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Prof. Dr. Thomas Breu

Centre for Development and Environment

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The Dean

Prof. Dr. Marco Herwegh

Summary

In 2015, the United Nations General Assembly adopted the Sustainable Development Goals (SDGs) in an effort to concurrently achieve economic, social, and environmental sustainability by 2030. However, nations struggle to balance their urgent economic and social priorities with the conservation of nature and biodiversity. The lack of knowledge and understanding of the linkages between nature, nature's contributions to people (NCPs), and human wellbeing at varying scales and contexts, and a lack of recognition of the role of nature and biodiversity in achieving long-term economic and social goals is one of many barriers to achieving the SDGs. To address this knowledge gap, I used a mixed-method approach at varying scales, using a combination of literature reviews, online surveys with experts, field surveys, stakeholder interviews, and statistical analyses of online databases on SDG indicators to systematically examine the role of NCPs towards achieving the SDGs in Nepal, a low-income and highly biodiverse mountainous nation. In my thesis, I identify direct and indirect opportunities for Nepal, and other nations to achieve terrestrial biodiversity conservation goals in the face of other competing socio-economic goals.

For my first paper, I conducted a national-scale review of publications related to nature, biodiversity, and NCPs in Nepal. Results revealed that NCPs contributed to the achievement of 12 out of 17 SDGs. These findings validated the importance of NCPs for sustainable development in Nepal, in line with previous global studies. However, my results also found that most NCPs in Nepal were declining due to key drivers of change, including land-use change, climate change, and pollution. These direct drivers were in turn linked to conventional development interventions such as agricultural intensification as well as the expansion of roads and energy infrastructure, which were implemented in isolation and without taking biodiversity and the environment into consideration. The declining state of NCPs throughout Nepal is likely to undermine the country's long-term ambitions of sustainable development, considering their critical role in achieving the SDGs.

My second paper sought to uncover the interactions (co-benefits and trade-offs) between biodiversity conservation (SDG 15) and other socio-economic development goals in Nepal through expert surveys, key informant interviews, and statistical analyses. Results showed that SDG 15 synergized with most SDGs, and particularly with SDGs 4 (education), 5 (gender equality), 6 (clean water and sanitation), and 8 (sustainable economic growth). However, there were also trade-offs between SDG 15 and SDGs 1 (no poverty), 2 (zero hunger), 7 (affordable and clean energy), and 9 (industry and infrastructure). Informants identified several short- and long-term opportunities to address existing trade-offs between SDG 15 and other SDGs, including improving the governance of natural resources, particularly at local levels, addressing coordination gaps between different government stakeholders, developing contextualized

policies on conservation, and implementing capacity building and education programs for local government representatives and the broader public.

The objective of my third paper was to understand the interlinkages between nature, NCPs, and human-wellbeing at the sub-national scale, and to identify factors likely to influence these interactions. For this, I conducted a household survey along an elevational gradient in Eastern Nepal, gathering perspectives of local communities on how nature contributed towards their household wellbeing. In line with my first paper, the household survey confirmed the vital role of NCPs in ensuring a good quality of life, as participants perceived them as essential for various aspects of their daily lives, including food security, income, access to clean drinking water, energy for cooking, cultural identity, and relaxation. Participants from the mountain region, predominantly occupied by communities who were more directly dependent on nature, had the most favorable perceptions towards NCPs. Similarly, participants with higher levels of education, and those who perceived that they had better access to basic necessities were more likely to have positive perceptions towards NCPs. The household survey further showed that people's perceptions and priorities towards NCPs differ substantially based on geographic location and socioeconomic background.

My research has identified several opportunities for Nepal to enhance its conservation sector.

1) Addressing socio-economic trade-offs arising from conservation interventions might be key for the conservation sector of Nepal. Community forests and protected areas can divert their focus from investing into infrastructure development to developing pro-poor activities, such as employment generation and minimization of human-wildlife conflicts. Additionally, a pluralist approach to conservation planning that includes multiple value systems and knowledge can also help reduce trade-offs and conflicts arising from conservation interventions.
2) Since the advancement of multiple socio-economic goals can create trade-offs for biodiversity conservation, addressing these trade-offs require policy-makers from the conservation sector to collaborate with socio-economic development stakeholders, including various government ministries and departments at the federal and local level. Currently, opportunities lie in the proper implementation of environmental considerations in development projects through collaborative efforts amongst representatives of the newly established federal and local governments in Nepal.
3) It is essential to monitor progress towards the SDGs at sub-national levels while also taking into account the potential trade-offs that may arise from achieving specific targets.
4) To address biodiversity loss in non-protected areas throughout the country without creating access- and use-restrictions to communities, landscape-based conservation approaches and other effective area-based conservation measures (OECMs) might present an opportunity.

5) An indirect pathway towards achieving conservation goals involves harnessing co-benefits between SDG 15 and other SDGs, such as integrating community-based ecotourism and education, which can enhance both environmental stewardship at the local level and help communities generate alternative income, as well as supporting biodiversity conservation efforts.
6) to make more informed decisions regarding biodiversity conservation, potential research opportunities lie in exploring NCPs in non-protected areas as well as in montane, sub-alpine, and alpine regions of Nepal, investigating non-material and relational values of nature, and adopting a critical geography approach to understand the implications and trade-offs of conservation decisions at the local level.

Nepal, like many other countries, urgently needs to meet its economic and social goals, but a "by-all-means-necessary" approach could further jeopardize their socioeconomic status in the long-term by negatively affecting nature, the foundation upon which all SDGs depend. There is no perfect solution to these complex issues. However, gaining a comprehensive understanding of the role of nature and NCPs in promoting human wellbeing, as well as navigating the intricate interconnections between socio-economic priorities and conservation objectives at varying scales, can empower the government to make informed decisions on adopting development pathways that generate the maximum benefits for all stakeholders as well as for nature.

Acknowledgements

I expected my PhD journey to be fraught with numerous challenges, unprecedented hardship, and constant stress. And of course, I did have a fair share of these things from time to time. But my experiences with people I met during the last four years all made up for the challenges and stress I faced as a researcher. Each person I mention here has not only made valuable contributions towards my PhD thesis, but has profoundly impacted my outlook on life as a whole, inspiring me to be kinder, optimistic, and grateful. I only hope that I will be able to reciprocate and share all the positivity you have given me to the world.

I first thank all the focal persons in the three field sites who were generous beyond words, and provided me all the support I needed to live, eat, and work during my data collection in the three field sites. The passion, and the long-term dedication of Mr. Arjun Karki and Mr. Shankar Luitel to protect elephants in Bahundangi was awe inspiring, and I thank you for providing me with such a rich experience in Bahundangi which can never be reflected in a research article. I would also like to thank Mr. and Mrs. Siwa from Maipokhari. The hospitality in your homestay, the company, and the stories of Maipokhari you shared with me over mugs of Tongba in the evenings were few of the highlights of my entire fieldwork. Similarly, I thank Mrs. Leela Bhattarai, Mrs. Nim Lamu Sherpa, Mr. Gyabu Lama, and Mr. Krishna Gurung for their generosity in coordinating my field work, for hosting me in their homes, and for providing me information on their respective villages, its history, existing issues, and many other stories.

Thank you, Binayak, Leela, Bipana, Priyanka, Manisha, Kiran, Rajkumar, Aron, Bijayadip, Lakpa, Samjhana, Alisha, Sirjana, Mingma, Yangla, Ishita, Reena, Smriti, Sital, Punam, Pushpa, and Sabina for working tirelessly to collect data. I felt extremely lucky that I got to share my research, and knowledge with you all, and I hope that you enjoyed the survey as much as I did. Finally, with the bottom of my heart, I want to thank all the people from *Bahundangi*, *Sulubung*, and *Maipokhari*, the key informants, and all conservation practitioners who participated in the household survey, qualitative interviews, and expert online surveys respectively. I sincerely hope that I have been able to reflect your perceptions and concerns into this thesis.

Thank you, Dr. Nakul and Dr. Eklabya for providing me this amazing and unique opportunity to work as both a PhD student, and as a research fellow. I extend my gratitude to the ICIMOD family for welcoming me in into this incredible organization where I not only developed myself professionally, but also formed lasting friendships with many colleagues. Regarding the latter, I am grateful for Prakriti, Lily, Sijal, Kripa, and Yixin for their companionship especially in the initial years. Also, thank you Sunita didi for always being there for me, whether it was for personal matters, or for research-related queries and discussions. I know I have said this many times, but your political ecology commentaries on *Maipokhari* have greatly

inspired me, and even impacted my decision on a future career path. Thank you for this. I would also like to thank Rekha didi, Nabin dai, Kamal dai, Sushmita, and Bandana didi for supporting me in numerous instances in the last four years.

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during the earlier phases of the project, while designing my research chapters. But I am equally grateful that you helped me in developing my papers, and also provided extensive feedback in improving this thesis.

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Preface

My PhD journey officially began when I was enrolled as a PhD student in the University of Bern in 2021. But for me, although I didn't realize it at that time, this journey had already begun in 2015, in the mountains of Humla, one of the most remote and geographically isolated districts of Nepal. Connecting Humla to the rest of the world through roads was my first assignment as a fresh Civil Engineer, and I was excited to contribute my bit towards the "development for prosperity" narrative of Nepal. I lived in Humla for around one year, seeing first hand Nepal's poverty, undernourishment, and the harsh realities of the mountains, but also enjoying the spectacular views the mountains offered, jaw-dropping landscapes and biodiversity. I also marvelled at the lifestyle, culture, and traditions there, that were so different, although not so far from home.

However, I also became quickly disenchanted from the development narrative towards which I was so excited to contribute. I saw the frenzied attack of bulldozers commissioned by local government authorities ripping away cultural landscapes, fragmenting farmlands, polluting the environment, and destroying habitats. I saw the inadequateness of the procedures followed for environmental impact assessments, that were clearly taken up only as checklist items for development projects. I saw conflicts and power struggles between bureaucrats of different sectors of the governments, and the tendency to assign technical fixes through reductionist analyses to wicked problems. I found myself surrounded by people obsessed with development by any means necessary, and started doubting whether this model would really work for the society, environment, and economy in the long run. While the 2030 Agenda of sustainable development provided an opportunity for Nepal to tackle poverty, improve wellbeing, and simultaneously protect nature through a globally agreed blueprint of 17 Sustainable Development Goals (SDGs; United Nations General Assembly, 2015), Nepal's emphasis on economic growth and infrastructure development according to its Fifteenth five-year plan for development (Government of Nepal, 2020b) still places nature and the environment in considerable risk.

My experience as a civil engineer, and the ongoing debates around development and conservation in Nepal ultimately led me to conduct this work, which attempts to bridge the divide between conservation and development actors, and in some way, contribute to address the dilemma of a nation that is striving to meet urgent socio-economic needs, while struggling to safeguard its rich biodiversity.

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Core Concepts and definitions

To use common terminology, definitions, and assumptions of key components, and to analyze data, I have used the conceptual framework (CF; Fig.1; Díaz et al., 2015) derived by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The IPBES CF is "a highly simplified model of the complex interactions between the natural world and human societies" (Díaz et al., 2015, p. 3). The CF was developed to describe and explain socio-ecological systems using a shared terminology, and provide comparability to socio-ecological assessments in different regions and at different spatial scales (Díaz et al., 2015). The CF includes elements (in black), including concepts from both the western science (green) and knowledge systems (blue).

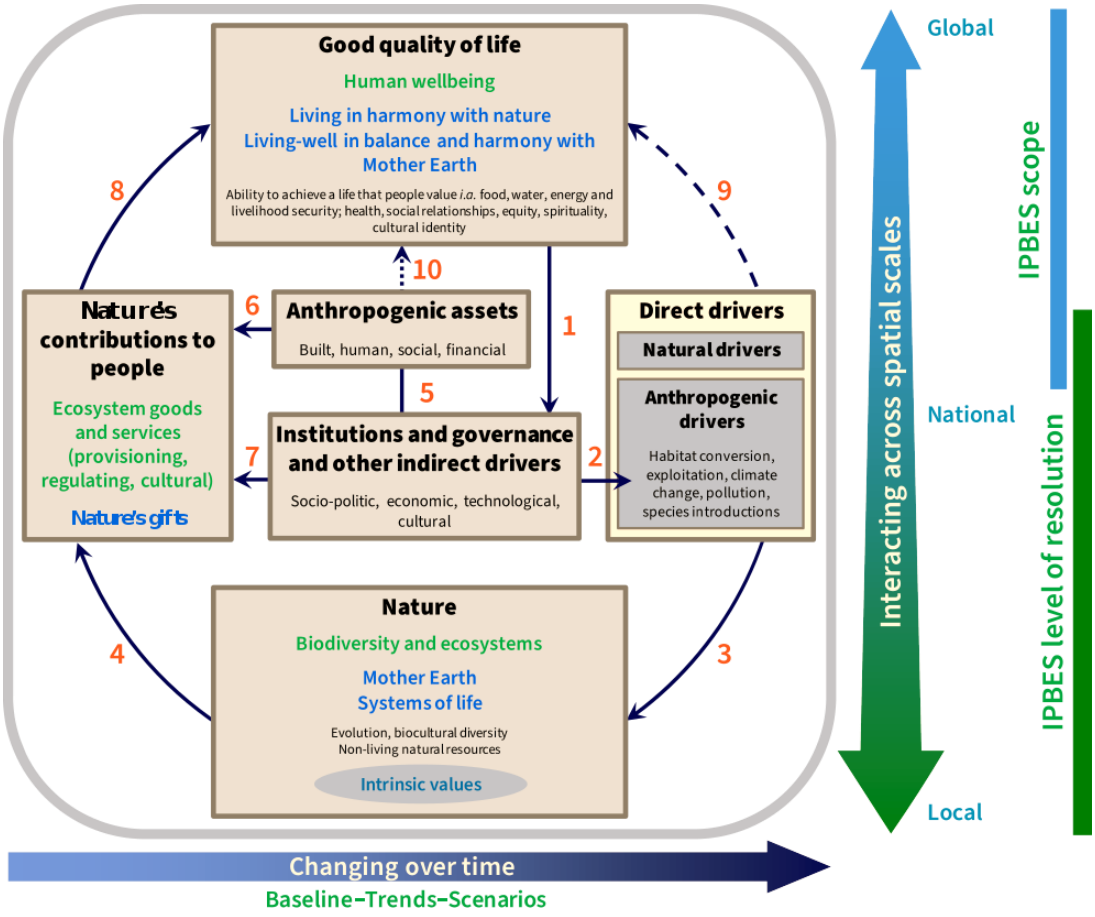

Figure 1: The conceptual framework of the IPBES (Diaz et al., 2015).

Nature forms the central element of the CF and consists of the living components of the natural world, including biodiversity, ecosystem structure and functions, the biosphere, as well as concepts of nature from other knowledge systems such as indigenous knowledge. The CF acknowledges that nature has different meanings and definitions for different people. Thus the definition of nature here also includes deities,

spiritual entities, symbolisms and culture, which is common in the context of South Asia (Coscieme et al., 2020). The CF focusses on "living" components, and thereby excludes non-living natural resources such as aquifers, wind, solar, and geothermal power, mineral and fossil resources.

Nature's contributions to people (NCPs) refer to all the contributions that nature makes to humanity. This includes the western concept of ecosystem goods and services (in green), which are the tangible and intangible benefits people obtain from ecosystems as well as concepts from other knowledge systems (in blue) including nature's gifts. Díaz et al. (2018) define 18 NCPs based on the previous concept of ecosystem services, categorized into material, non-material and regulating contributions. Material contributions are substances and objects that are typically consumed such as 'food and feed', 'energy', and 'materials, companionship, and labour'; non-material contributions are subjective or psychological aspects of nature that underpin people's quality of life, such as 'learning and inspiration' and 'supporting identities'; and regulating NCPs are the ecosystem functions that regulate the generation and maintenance of material and non-material contributions, such as 'habitat creation and maintenance', 'regulation of air quality', and 'regulation of climate'.

Direct and indirect drivers of change refer to the various factors that affect and influence nature and its contribution to people at different scales. Direct drivers consist of both natural direct drivers, such as natural climate and weather patterns, prolonged droughts, floods and earthquakes; and anthropogenic direct drivers, i.e., direct human influences and actions that affect nature, including overexploitation, land-use change, anthropogenic climate change, pollution, and invasive species (Díaz et al., 2015). Indirect drivers are the underlying causes of changes in nature, such as human values, governance systems, economic policies, innovation, and demographic changes. They are framed as 'indirect' because they do not affect nature directly (i.e., there is no arrow from indirect drivers to nature in Fig. 1), but through the direct drivers. However, indirect drivers of change can affect NCPs directly. For example, weak governance can lead to a decline in the provision of NCPs.

Good quality of life is the achievement of a fulfilled human life. It broadly consists of material components such as access to basic necessities including food, water, and shelter; as well as non-material components such as equity, cultural identity, security, freedom of choice, and action. As with nature and NCPs, good quality of life includes human wellbeing as a western perspective (green), and is defined as the state of physical and mental health of individuals. It also includes other knowledge perspectives (blue), especially Indigenous perspectives, including living in harmony of nature, and living in harmony with Mother Earth.

1 General Introduction

1.1 The declining state of nature and its contributions to people

Nature, and nature's contributions to people (NCPs; Díaz et al., 2018) are essential for human wellbeing, and underpin the achievement of sustainable development (Blicharska et al., 2019; Obrecht et al., 2021; Pham-Truffert et al., 2020). However, over the last 50 years, nature and NCPs have rapidly deteriorated (IPBES, 2019). Biodiversity intactness has declined globally (Newbold et al., 2016), species extinction rates are at unprecedented levels in comparison to pre-industrial times and higher than background extinction rates (Ceballos et al., 2015; Cowie et al., 2022; Humphreys et al., 2019), and ecosystem functions such as crop pollination (Giannini et al., 2017), efficiency of carbon sequestration (Cael et al., 2017), and net primary productivity (Li et al., 2020) have all declined.

The deterioration of nature and NCPs primarily stem from several direct human-induced factors, including alterations in land use, direct exploitation of resources, climate change, pollution, and the spread of invasive alien species (IPBES, 2019). These direct drivers, in turn, result from multiple underlying indirect drivers such as demographic changes, technological advancements, changes in societal values, behaviours and consumption patterns, and governance of natural resources at local, national and global levels (IPBES, 2019). For instance, the extraction of living biomass and non-living materials through activities such as agriculture, logging, fishing, forestry, and mining result from factors including the growing demands of the increasing population, globalization, economic incentives, and the prioritization of utilitarian values of nature that promote intensive resource extraction (IPBES, 2019). Extractive activities do indeed supply material NCPs such as food, biomass for energy, and construction materials for infrastructure, which contribute to improving various measures of wellbeing in the short-term (Raudsepp-Hearne et al., 2010). However, they do so at the expense of regulating NCPs such as soil productivity, pollinator diversity, and regulation of freshwater, which ensure the steady supply of these material NCPs in the long-term (IPBES, 2019). Thus, the ambition of achieving global sustainability cannot be met by current developmental trajectories, where the negative trends in nature and NCPs are projected to worsen (Baisero et al., 2020; Leclère et al., 2020; M. C. Urban, 2015; Warren et al., 2018).

1.2 Sustainable Development Goals and Life on Land

Amidst rising challenges from global change, along with growing global population and development centred on resource extraction and economic growth, a momentous resolution was adopted by all United Nations member states in 2015. This resolution, titled "Transforming our world: the 2030 Agenda for Sustainable Development," aimed to tackle global issues of biodiversity loss (CBD, 2020; IPBES, 2019),

climate change (IPCC, 2022), and rising social inequality (Alvaredo et al., 2018), and to secure a sustainable future for humanity by the year 2030 (United Nations General Assembly, 2015).

Agenda 2030 consists of 17 Sustainable Development Goals (SDGs), and 169 constituent targets, that aim at the simultaneous achievement of economic development, environmental sustainability, and social inclusion (United Nations General Assembly, 2015). SDG 15 (life on land) specifically focuses on terrestrial biodiversity conservation, and aims to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" through 12 targets and 24 indicators.

The SDGs are conceived as an "indivisible whole", meaning that achieving the 2030 Agenda requires all goals to be simultaneously achieved (United Nations General Assembly, 2015). However, this is very challenging, because the SDGs are by definition intricately linked, and the achievement of one goal may aid (co-benefit) or hinder (trade-off) the achievement of other goals (Le Blanc, 2015; Lu et al., 2015; Nilsson et al., 2016; Pradhan et al., 2017). Notably, while some scholars have identified that SDG 15 can act as a lever to achieve the 2030 Agenda at the global scale (Huan & Zhu, 2022; Obrecht et al., 2021; Pham-Truffert et al., 2020), others have highlighted the incompatibility between socio-economic SDGs and SDG 15 (Spaiser et al., 2017). Current development scenarios also demonstrate that the achievement of various SDGs lead to trade-offs towards SDG 15 (Anderson et al., 2022).

The challenges of concurrently meeting socio-economic goals and conservation goals is greater for low-income nations, which cannot afford conservation interventions that, in many instances, negatively affect the achievement of crucial socio-economic needs such as poverty alleviation (Pyakurel & Marasini, 2021). For instance, at the local scale, the creation and extension of protected areas has historically led to access restrictions to resources (Dudley et al., 2014), evictions and human rights violations (Sungusia et al., 2020), loss of ecological knowledge (Bocarejo & Ojeda, 2016), the erosion of livelihoods of local communities (Bocarejo & Ojeda, 2016), and conflicts with development actors in relation to land-use (Ghimire et al., 2021; Sloan et al., 2017). With new and ambitious targets set by international commitments, such as the protection of 30% of Earth's surface area by 2030 (Conference of Parties to the CBD, 2022), these trade-offs could increase significantly (Loos, 2021).

1.3 Balancing conservation and development

In the face of the rapidly declining state of nature and NCPs, and the apparent incompatibility between biodiversity conservation and other socio-economic goals, decision-makers are confronted with hard choices (McShane et al., 2011) regarding the priorities and resource allocation. In that context and to best inform decision-making, knowledge on (i) the specific linkages between NCPs, human activities, and

SDGs, (ii) the trade-offs and synergies between individual goals, and (iii) community perceptions of nature and NCPs is needed. Accounting for local communities' perceptions (Bernardo et al., 2021) is particularly important to ensure that the conservation of biodiversity is not adversely affecting the socio-economic conditions of people.

1.3.1 Linkages between nature, NCPs and good quality of life

A few studies have analysed the relationships between nature, NCPs, and the SDGs (as a proxy of human wellbeing) at the global scale, showing that NCPs can directly and indirectly contribute to all 17 SDGs (Anderson et al., 2019; Blicharska et al., 2019; Wood et al., 2018). However, studies that link NCPs and SDGs at the local scale are rare, even though almost all contributions of biodiversity towards the SDGs are delivered at that scale (Blicharska et al., 2019), and do not integrate the feedback loops between different components (arrows 1, 3, 4, 7, and 8) of socio-ecological systems (Mastrángelo et al., 2019). Understanding the linkages between NCPs and SDGs in the broader context of the direct and indirect drivers of change thus represents a gap in research, which , if addressed can help identify pathways towards achieving global and national sustainability targets (Mastrángelo et al., 2019).

1.3.2 Interactions between biodiversity conservation goals and socio-economic goals

Considering that biodiversity conservation can both act as a lever to achieve the 2030 Agenda, and generate multiple trade-offs with socio-economic goals, a contextual understanding of co-benefits and trade-offs between biodiversity conservation goals and other socio-economic goals can help decision makers identify, acknowledge, and address trade-offs (Sunderland et al., 2007).

A suite of methods is available in the literature to uncover interactions between goals, ranging from statistical methods (e.g., Pradhan et al., 2017), to "argumentative" methods (c.f. Horvath et al., 2022) that use both qualitative and quantitative approaches to assigning interactions between goals and targets (e.g., Nilsson et al., 2016; Weitz et al., 2018). A few number of studies have used one, or a combination of methods to study the interactions between biodiversity conservation in particular (SDG 14 – life below water and SDG 15 – life on land) and other goals (e.g., Huan & Zhu, 2022; Singh et al., 2018) at the global scale. However, although interactions are context-specific (Johansen et al., 2020; Mainali et al., 2018; Moyer & Bohl, 2019; Nilsson et al., 2018; Pradhan et al., 2017; Weitz et al., 2018), only a few studies exist on interactions between nature-specific goals and other goals at national scales (e.g., Hazarika & Jandl, 2019; P. Urban & Hametner, 2022). Thus, there is a need to fill this research gap, and understand interactions between biodiversity-related and other SDGs in the context of governance, policy, and institutional arrangements at the national scale.

1.3.3 Social perceptions on nature and NCPs

In many cases, trade-offs and conflicts between local communities and conservation interventions result from a lack of acknowledgement of the heterogeneity of people's needs and perceptions (Redpath et al., 2013), and the "messy" economic and social contexts in which conservation occurs (Adams & Sandbrook, 2013). For example, conservation efforts aimed at protecting marine mammals like sea lions without proper consultation with all stakeholders resulted in a decrease in fish availability for local communities, leading to conflicts (Davis et al., 2021). Levin et al., (2021) detail many such examples of how differences in perceptions between stakeholders can hinder conservation interventions, recommending the need to embrace epistemic pluralism, and to prioritize an inclusive process of biodiversity conservation.

Conservation efforts that consider the perceptions, needs, and priorities of local communities tend to be ecologically effective, and at the same time socially equitable, culturally appropriate, and politically viable (Bennett et al., 2017). Therefore, understanding the diversity of perceptions on nature and NCPs can provide an additional lens to complement knowledge and values captured through natural sciences (Hill et al., 2020; Tengö et al., 2017). The implementation of "hard choices" guided by an understanding of the needs and priorities of local communities might also ensure that these choices are not met with community push-back (McShane et al., 2011).

1.4 Research Context

1.4.1 Research Project

My PhD is part of a project funded by the Swiss Programme for Research on Global Issues for Development (R4D) named "Mountain Biodiversity and the Sustainable Development Goals: Knowledge for Synergistic Action". The objectives of the project were to better understand the specific challenges associated with the sustainable management and conservation of biodiversity (SDG 15) in the context of competing development goals, limited resources, and complex governance structures in mountain environments.

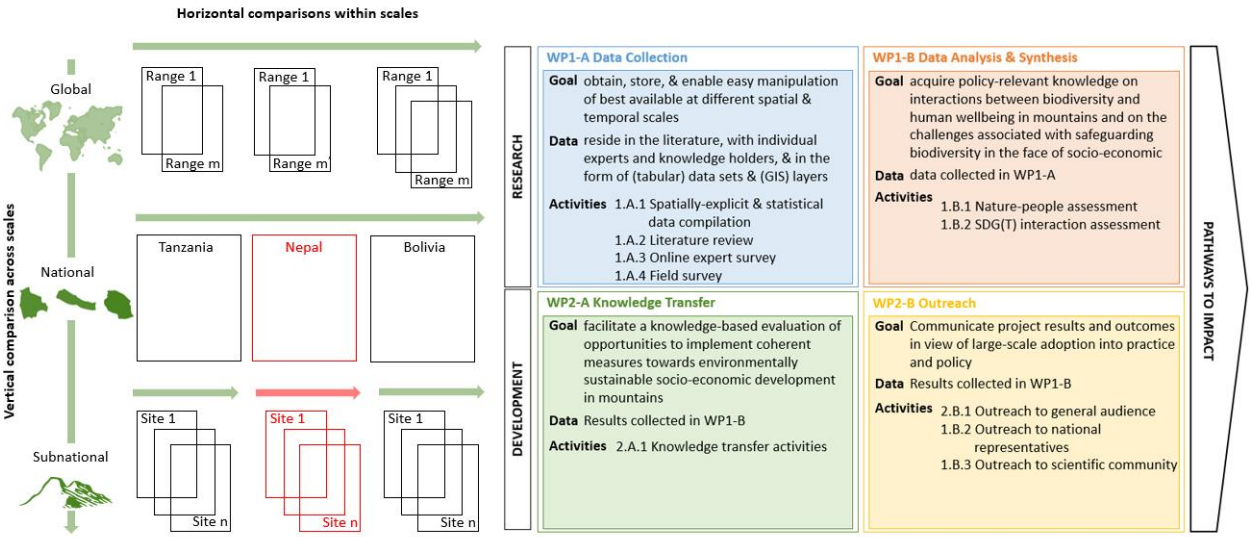

Figure 2: The scale where the research project operated, the scale at which I performed by PhD (in red), and the work packages of the r4d project (right)

Accordingly, the project's research activities were to analyze the relationship between nature, people, and their wellbeing in mountains, and uncover the interactions amongst SDGs that could contribute to the identification of realistic location- and scale-specific opportunities for the synergistic, coherent, and successful implementation of the SDGs. An important component of the research was to disseminate the results of the research to relevant stakeholders, and share policy-relevant information on opportunities for sustainable development at local and national scales. Over four years, the project team performed such analyses globally, nationally across mountains in Bolivia, Tanzania, and Nepal, and sub-nationally across mountain communities within these countries. These analyses were further performed on data residing in the literature, with experts and various groups of knowledge holders, and in the form of datasets (Fig. 2). The project therefore represents a novel multi-scale comparative analysis of the factors influencing biodiversity-human wellbeing relations in differing mountain contexts, and the linkages among various SDGs. My PhD is specifically conducted to answer the research questions (see section 1.5) of the project for Nepal at national and sub-national scales.

1.4.2 Nepal's social-ecological context

Nepal is a mountainous country situated in the Hindu Kush Himalayan (HKH) region. The HKH is one of the highest mountain region in the world, stretches over 3,500 km, and is home to the highest peaks on Earth (Sharma et al., 2019). Nepal's unique geographic position with wide altitudinal and climatic variations within a short horizontal span (Fig. 3) makes it immensely rich in biodiversity. 86% of Nepal's total land area is covered by mountains. These mountains comprise 118 complex mountain ecosystems,

harbor 6 biomes, 35 forest types, 160 endemic animal, and 286 endemic plant species (Government of Nepal, 2018). This makes Nepal a globally important place for achieving SDG 15.

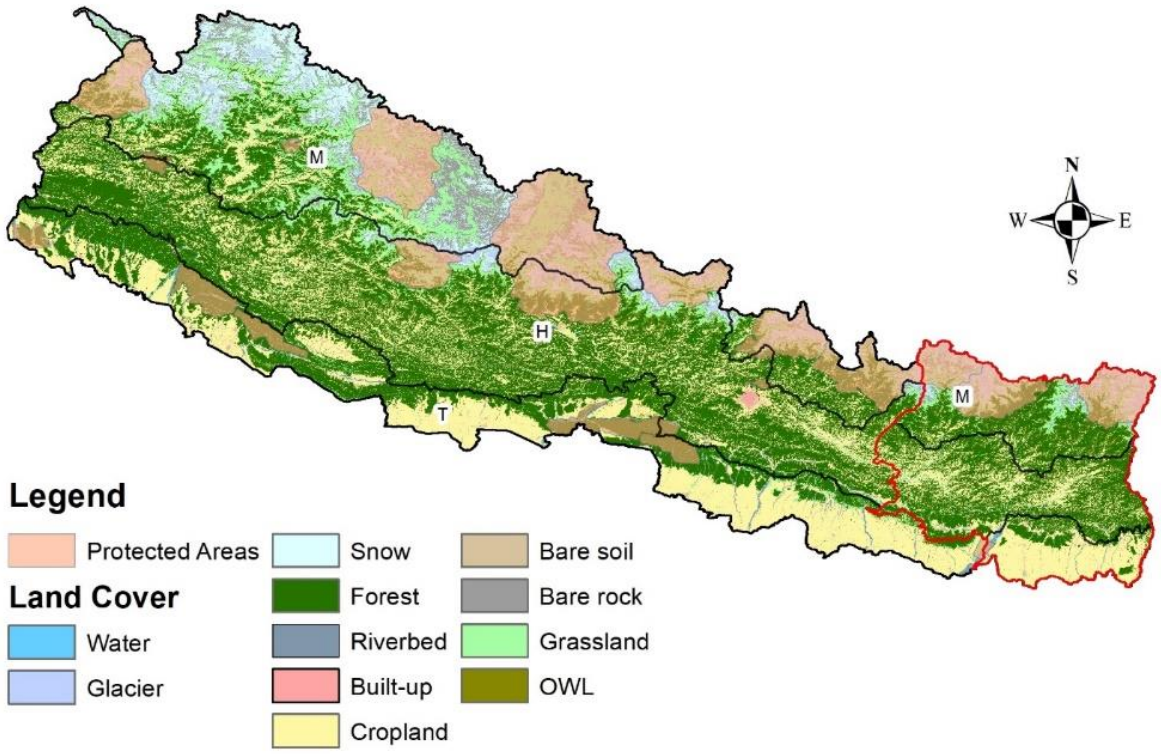

Figure 3: The land cover map of Nepal superimposed by protected areas and ecological region boundaries (in black). The red outline in the east represents Province 1, where I conducted the sub-national scale research (see Fig 4). OWL: Other Wooded Land.

1.4.3 Biodiversity Conservation in Nepal

Nepal legally initiated biodiversity conservation through the promulgation of the National Parks and Wildlife Conservation Act in 1973 and the establishment of Chitwan National Park. Since then, Nepal has gradually increased its protected area coverage, and has transitioned from a 'Fortress conservation model'—wherein people were excluded from land set aside for biodiversity conservation (Adams, 2004)—to more liberal, and people-centric landscape level conservation models aiming for the simultaneous achievement of conservation and socio-economic goals with the consultation of stakeholders (Bhattarai et al., 2017). At present, protected areas cover 23.29% of Nepal's land area (Government of Nepal, 2018) and 62.1% of mountain Key Biodiversity Areas(Roser & Mispy, Ortiz-Ospina, 2018). Nepal was one of the few countries that formally pioneered the community forest model through the the Forest Act in 1993, allowing the hand over of forests to community user groups for their conservation, management and optimal utilization (Banjade & Paudel, 2020). More recently, with its transition from a central to a federal state,

Nepal is in the process of re-assigning power and authority for the management of protected areas and forests to provincial and local levels of the government, in line with its new constitution to promote inclusive, participatory, and democratic rights to resources in the country (Thakali et al., 2018).

1.4.4 Sustainable Development Goals in Nepal

Nepal was one of the first countries to internalize the SDG framework in government actions and localize its implementation through newly formed sub-national and local governments (Government of Nepal, 2020a). Nepal's national SDG progress report states that between 2016 to 2019, Nepal made satisfactory progress towards achieving SDGs 1 (poverty reduction) and 10 (reducing inequalities), moderate progress towards achieving SDGs 4 (inclusive quality education), 5 (gender equality), 7 (clean energy), 15 (life on land), and 17 (partnerships), and slow to no progress on the remaining 10 goals (Government of Nepal, 2020a). Studies suggest that the COVID-19 pandemic has delayed, and even reversed much of the progress made towards meeting several goals (Joshi et al., 2022; Pradhan et al., 2021).

The SDG progress assessment report of Nepal in 2020 states that Nepal's 15th five-year development plan provides optimism that the newly established levels of government will incorporate and achieve major SDG targets, which in turn would enable Nepal to graduate from a least developed country to a middle-income country by 2030 (Government of Nepal, 2020b). However, Nepal's history of unplanned infrastructure projects and their negative impacts on biodiversity (Sharma et al., 2018) paints a bleak picture for conservation goals in the face of Nepal's ambitious development commitments.

1.5 Objectives of the PhD

The objectives and research questions of my PhD are guided by Nepal's current socioeconomic development ambitions, declining state of biodiversity, and gaps in knowledge (section 1.3.1 – 1.3.3). Addressing these gaps can aid science-based decision making towards development pathways that is more environmentally friendly and socially equitable:

Objective 1: To understand the trends in NCPs and their drivers as well as the linkages between NCPs and SDGs in Nepal

1.1 What are the trends in NCPs across Nepal and what are drivers of these trends?

1.2 How do NCPs contribute towards the achievement of SDGs in Nepal?

Objective 2: To identify the interactions between SDG 15 – Life on Land and other SDGs in Nepal

2.1 What are the co-benefits and trade-offs between SDG 15 and other SDGs in Nepal? Why do these interactions exist?

2.2 How can co-benefits be enhanced and trade-offs mitigated to enable the simultaneous achievement of conservation and development objectives?

Objective 3: To understand social perceptions of NCPs, the role of demographic and socioeconomic factors in mediating these perceptions, and implications towards conservation of biodiversity in Nepal

3.1 How do local communities perceive nature and its contributions to their wellbeing, and what socioeconomic variables influence these perceptions?

3.2 How can these perceptions inform effective biodiversity conservation measures for Nepal?

I addressed the first two objectives at the national scale, while I addressed the third one at the sub-national scale in three sites located along an elevational gradient of Province 1 (Fig. 4). The three sites are *Bahundangi* in the plains, *Sulubung* in the hills and *Yamphudin* in the mountain ecoregions of Nepal and fall within the Kangchenjunga conservation and development landscape.

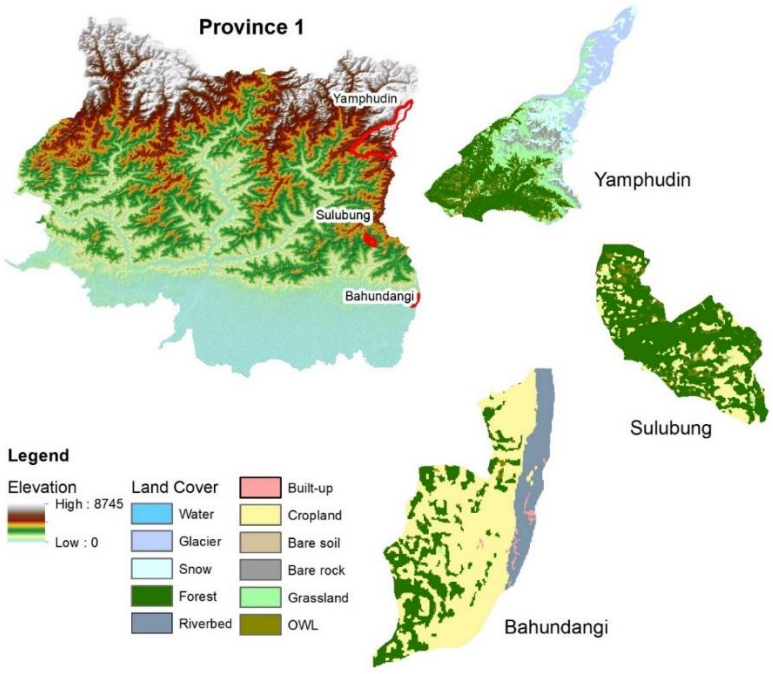

Figure 4: Elevational map of province 1, and land cover maps of the three case-study sites (Yamphudin, Sulubung and Bahundangi). OWL: Other Wooded Land

The sharing of research outputs to relevant stakeholders, and the dissemination of results to the wider public were performed through a national workshop (Picture 1; proceedings of the workshop available at https://lib.icimod.org/record/36267), and through a series of articles in national and regional magazines and newspapers.

Picture 1: Photo from outreach event on mountain biodiversity and the Sustainable Development Goals, with representatives form local, provincial, and federal government, community representatives, journalists, and focal persons

2 Methods

2.1 Data and Analysis

Table 1 provides an overview of the five methods employed for data collection, the geographical scale of analysis, and the respective contributions of each data type to each objective and paper of my thesis.

Table 1: Summary of research objectives, and approaches used to achieve them

Research Objectives	Method	Scale	Paper
1: Linkage between NCPs and SDGs in Nepal in context of drivers of change	Systematic Literature Review Household Survey	National	Paper 1
2: Co-benefits and trade-offs between conservation and development goals in Nepal	Expert Online Survey Temporal Analysis of SDG indicators Key Informant Interview Household Survey	National	Paper 2
3: Role of context	Household Survey	Sub-national	Paper 3

2.1.1 Systematic Literature Review

Although Nepal has a large body of research on NCPs (Kandel et al., 2021), no study at the time of my research had synthesized this literature to detect trends in NCPs and identify the factors driving theses trends. Similarly, although there was ample research that linked individual or multiple NCPs and the SDGs, there was no overview on how NCPs contributed towards the SDGs in Nepal.

I collected and systematically analysed 140 relevant articles on NCPs in Nepal to understand the state of and gaps in NCP research, trends in NCPs across the country, drivers of change in NCPs, and the contributions of NCPs towards individual SDGs. I used the Search, AppraisaL, Synthesis and Analysis (SALSA) framework (Grant & Booth, 2009) to systematize this literature review, and the IPBES CF to map various drivers of change reported in literature. This literature analysis also served as a starting point for my thesis, where I got up-to-speed with current research in NCPs, helped me formulate specific research questions for the following papers, and contextualize their results.

2.1.2 Expert Online Survey

I conducted an online survey adopted and modified from Wood et al. (2018) to understand experts' perception on synergies and trade-offs between SDG 15 and other SDGs in Nepal. This survey was in English. We asked the participants to use the seven-point scale on SDG interactions (Nilsson et al., 2016)

to quantify the strength of interactions between randomly chosen SDGs and SDG 15. Many researchers have applied the seven-point scale to rate SDG interactions. However, these ratings are mostly done by researchers themselves, given that it typically involves rating multiple interactions (a maximum of 169*168 target-target interactions). Thus, one of the shortcomings of this method is that it introduces biases and perceptions that are limited to the confines of the scientists performing the work (Nilsson et al., 2018). By asking conservation experts to rate interactions between only five random SDGs, we addressed this bias while keeping the number of interactions to rate low. The randomness ensured that the experts had no control over which SDG they would rate. Using a confidence scale for each of the answers addressed the fact that some respondents could not feel entirely confident in rating certain interactions that were outside of their field of expertise.

The survey also helped address the shortcomings of other quantitative methods by providing the strength and directionality of interactions at the target level. I aggregated all relevant answers to identify the SDGs that were most connected with SDG 15. Furthermore, through a systemic network analysis, I determined the buffers and multipliers of SDG 15 (Breu et al., 2021) to identify prominent co-benefits and trade-offs that need to be addressed to meet SDG 15. 65 experts mostly from the conservation sector participated in the survey.

2.1.3 Key Informant Interviews

Following up on the survey, I conducted in-depth interviews with 13 interviewees including conservation actors, government representatives, scientists, and NGO employees about co-benefits and trade-offs between conservation and socioeconomic development goals in Nepal. I performed most of these interviews by telephone. Key-informant interviews helped provide qualitative information on the interactions and establish causal links between SDG 15 and other SDGs. Importantly, through the lens of varying stakeholders, I uncovered several challenges in the conservation sector of Nepal, and also categorized their recommendations on how to address them. I used the framework method (Gale et al., 2013) to categorically identify the interactions. This method also served to reach out to stakeholders who couldn't contribute to the expert survey because of a lack of internet access (e.g., professionals working in the high-Himalayas) or who did not speak English.

2.1.4 Correlation Analysis of SDG Indicators

Correlation analyses of SDG indicators based on time series provide a rapid assessment of possible interactions between SDGs. The advantage of this method is that there is already a systematic procedure in place developed by Pradhan et al. (2017), which is widely used in literature (Horvath et al., 2022). Also, while online survey (2.1.2) and interviews (2.1.3) are subjective, and mostly at the conceptual level, this method provides results based on what has actually already occurred. I collected data on SDG indicators

from the Global SDG Indicators Database (https://unstats.un.org/sdgs/indicators/database/) and conducted pairwise correlation analyses following steps from Pradhan et al. (2017). This allowed me to retrospectively identify co-benefits and trade-offs between SDG indicators, which I compared with expert and key-informant opinions.

2.1.5 Household Survey

I conducted 572 household surveys in three chosen sites of Eastern Nepal with the help of trained enumerators to understand people's perception on NCPs. We asked all households about their perception on nature, its linkage with household wellbeing, and the status and trends in nature and ecosystems. We also asked them to identify which contribution from nature helped in what aspect of their life and coded these contributions according to the NCP categories. I ascertained the major socioeconomic variables that explain variations in perceptions towards NCPs. The household survey allowed me to get a deeper and local-scale understanding of the linkage between NCPs and household wellbeing, co-benefits and trade-offs between SDGs, and the role of contexts in shaping perceptions about nature and biodiversity conservation.

2.1.6 Overview of Publications

Table 2: Overview of research publications, including authors, journal, and state of publication

No.	Title	Authors	Publisher/peer-reviewed journal	Current State
1	Nature's Contribution to People and the Sustainable Development Goals in Nepal	**Adhikari, B.**, Prescott, G.W., Urbach, D., Chettri, N., Fischer, M.	Environmental Research Letters, Volume 17, Issue 093007 DOI 10.1088/1748-9326/ac8e1e	Published
2	A multi-methods approach for assessing how conserving biodiversity interacts with other sustainable development goals in Nepal	**Adhikari, B.**, Urbach, D., Chettri N., Sharma, E., Breu T., Geschke, J., Fischer, M., Prescott, G.W.	Sustainable Development DOI: 10.1002/sd.2582	Published
3	Linking nature's contributions to people and human wellbeing: a study on social perceptions in Eastern Nepal	**Adhikari B.**, Schenk, N.V., Chettri N., Fischer, M., Prescott, G., Urbach, D.	People and Nature	In Review

3 General Conclusion

3.1 Major findings

In this section, I summarize the major findings of each paper, synthesize the findings in the context of Nepal, and proceed to provide opportunities for achieving conservation goals in Nepal, as well as some general opportunities for other countries.

3.1.1 Paper I: Linkages between nature, NCPs, and good quality of life

This paper analyzed trends in NCPs, identified the drivers associated with these trends; and uncovered how changes in NCPs could potentially affect progress towards the SDGs in Nepal. From the synthesis of 140 journal articles, institutional working papers and reports, I found that 17 NCPs potentially contributed to the achievement of 12 SDGs in Nepal. Out of this, material NCPs had the highest number of potential contributions (52% of all statements reporting potential NCP-SDG linkages), followed by regulating (37%) and non-material (11%). Particularly, the NCPs 'food and feed', 'energy', and 'physical and psychological experiences' were reported to contribute towards SDGs the most. The SDGs that were reported to benefit from these contributions the most frequently were SDG 1 (no poverty), SDG 2 (zero hunger), and SDG 7 (affordable and clean energy).

However, most NCPs in Nepal were reported to be in a state of decline. 74% of 265 statements that reported trends in ecosystems were negative. Decline in NCPs were across all provisioning, material and non-material NCPs. The major direct drivers of these declines included land-use change (38% of all statements that linked direct drivers of changes to NCPs), direct exploitation of resources (23%), and climate change (18%). More than half of all negative drivers were linked to development projects such as the construction of roads and hydropower infrastructure, agricultural intensification, and expansion of transmission lines. This point towards possible trade-offs between biodiversity conservation and existing interventions aimed at achieving other socio-economic goals.

3.1.2 Paper II: Interactions between biodiversity conservation goals and socio-economic goals

The finding that development activities were the primary sources of drivers of NCP decline formed the basis for my second paper, which aimed to systematically uncover the interactions (co-benefits and trade-offs) between conservation (SDG 15) and development goals in Nepal. I used three methods to understand how terrestrial biodiversity conservation (SDG 15; life on land) interacted with other SDGs in Nepal.

Results from all three approaches (online survey, interviews, correlation analyses) showed that SDG 15 synergized with most SDGs, and in particular with SDGs 4 (education), 5 (gender equality), 6 (clean water and sanitation), and 8 (sustainable economic growth). In contrast, all three methods indicated the presence

of trade-offs between SDG 15 and SDGs 1 (no poverty), 2 (zero hunger), 7 (affordable and clean energy), and 9 (industry and infrastructure). Additionally, the online survey indicated that achievement of SDG 12 (sustainable production and consumption) positively influenced the achievement of SDG 15 (multiplier of co-benefits), while the achievement of SDGs 2 (zero hunger), 7 (affordable and clean energy), and 9 (industry and infrastructure) negatively influenced the achievement of SDG 15 (multiplier of trade-offs). Meanwhile, SDG 15 positively influenced the achievement of SDGs 6, 13 (climate action), and 17 (partnerships for the goals) (buffers of co-benefits) but negatively influenced the achievement of SDG 1 (no poverty) (buffer of tradeoff).

Key informant interviews revealed that interventions aimed at achieving SDG 15 faced a number of challenges, including a lack of coordination between local governments and outdated national policies; lack of participation of marginalized groups in conservation planning and increased human-wildlife conflicts; a lack of financial and human resources leading to ineffective monitoring; and the government's preference for fulfilling immediate socio-economic requirements over environmental concerns. Informants identified several short- and long-term opportunities to address these challenges, including clarifying the roles and responsibilities of Nepal's new regulatory environment to address coordination gaps, developing contextualized provincial policies on conservation, and implementing capacity building and education programs for local government representatives and the broader public.

3.1.3 Paper III: Social perceptions on nature and NCPs

My third paper gathered individual perspectives on how nature contributed towards household wellbeing, and uncovered what factors determined these perceptions. Based on the results from the previous chapters and on literature, I had three hypotheses: (i) perceptions on nature and NCPs differed considerably across the three villages, (ii) positive perceptions were influenced by levels of education and (iii) positive perceptions were influenced by people's access to basic necessities.

All three hypotheses were confirmed. NCP perceptions varied substantially in the three villages, with participants from the mountain region, predominantly occupied by communities who were more directly dependent on nature, having the most positive perceptions. Similarly, participants with higher levels of education, and those who perceived that they had better access to basic necessities, including access to energy for cooking, income and drinking water, were more likely to have positive perceptions towards NCPs. Apart from these variables, men, and participants who perceived higher levels of happiness were also more likely to have positive perceptions towards NCPs.

Similar to findings from the first data chapter, the NCPs that were most cited for their influence on participants' wellbeing were 'energy' in the form of firewood for cooking, 'regulation of air quality' for

good health, 'regulation of freshwater quality' for health and water access, 'supporting identities' for culture and education, and 'physical and psychological experiences' for recreation. The results reinforced views of conservation professionals that conservation activities needed to be contextual and driven by the needs and priorities of local communities. It also verified claims of conservation professionals that conservation interventions needed to be integrated with education, as these goals synergize with each other. The household survey also found that participants in all three regions rated nature's contribution towards recreation and culture the highest, signaling potential synergies between eco-tourism and conservation. This was also detected in the previous paper. With this paper, I demonstrated that different local stakeholders have different perceptions, needs, and priorities regarding nature and NCPs. Identifying, acknowledging, and bringing in these diverse perspectives can be key to designing effective conservation measures that build trust and encourage local participation.

3.2 Synthesis of findings

Nepal's 15th five-year plans place significant emphasis on poverty eradication, increasing access to renewable energy, improving food productivity, promoting ecotourism, and expanding physical infrastructure (Government of Nepal, 2020b). NCPs underpin the achievement of all of these goals (1st chapter). In fact, strategies laid out by the government to achieve these goals aim to do so by leveraging NCPs. For example, nature-based interventions such as community forestry, agroforestry, sustainable harvesting of non-timber forest products and medicinal herbs, and eco- and cultural tourism are integral to the government's plans for disaster risk reduction, climate change mitigation, gender equality, and poverty reduction (Government of Nepal, 2020b). Thus, in line with previous global studies (Blicharska et al., 2019; Wood et al., 2018), I confirmed the importance of prioritizing the achievement of SDG 15 for the 2030 Agenda, as it sustains and improves the provision of NCPs which, in turn, contributes towards achieving multiple SDGs.

Interventions aimed at achieving SDG 15 is not just important because it sustains the provision NCPs. Various targeted investments from revenue generated by community forests and protected areas, the dominant SDG 15 measures taken to conserve nature and biodiversity in Nepal co-benefits multiple other SDGs (1st, 2nd chapter). Revenue generated from community forests are utilized for improving access to renewable energy (SDG 7), granting soft loans for poor households (SDG 1), rehabilitating schools and providing professional skills to teachers (SDG 4), constructing latrines and conserving springs (SDG 6), and constructing hospitals (SDG 3), libraries, community buildings, and roads (SDG 9). Meanwhile protected areas provide employment to local communities in ecotourism (SDG 8) and make contributions that are similar to those from community forests in buffer zones.

However, interventions aimed at achieving SDG 15 also produce trade-offs towards other goals in many instances (2nd chapter). The biggest challenge for community forests is the unequal sharing of benefits among local communities. For example, forest resources are not distributed equitably, higher value loans are granted only to economically well-off households, and representation of poor and marginalized communities are inadequate (Chaudhary et al., 2018; Gritten et al., 2015; Sapkota et al., 2020). This further marginalizes vulnerable communities (SDG 10; SDG 5) and widens income inequality (SDG 1). Meanwhile, protected areas restrict the utilization of natural resources such as medicinal herbs, non-timber forest resources, and firewood, thereby affecting the access to basic necessities (Garrard et al., 2012; Lamichhane et al., 2019). They also restrict the mobility of farmers, breaking traditional practices of grazing, and forest-farm dependence, adversely affecting their culture and lifestyle (Chaudhary et al., 2019; Ingty, 2021). This possibly stems from protected areas exclusively prioritizing global-, and national-scale NCPs such as carbon sequestration, and habitat restoration (see Allendorf et al., 2019), while local communities overwhelmingly value local-scale NCPs such as food and feed, energy, regulation of water quantity, and cultural identity (3rd paper). This mismatch in prioritizations can create trade-offs and can waver support to the conservation interventions not just from local communities, but also government representatives, ultimately leading to their failure.

3.2.1 Opportunities for policy, practice, and research

Based on the results of my three papers, and the broader context of Nepal's development aspirations, changes in regulatory environments, international commitments, and global discourses on conservation, I detail opportunities for biodiversity conservation in Nepal in the following section. These opportunities may hold relevance for other countries, provided they consider their unique ecological and socio-economic contexts.

Addressing trade-offs arising from SDG 15 towards other SDGs

First, I believe that policy makers in conservation and natural resource management can benefit from addressing the trade-offs arising from biodiversity conservation towards other goals. The first step would therefore be to acknowledge and communicate that different conservation interventions do, in fact, lead to different trade-offs, and do generate winners and losers (McShane et al., 2011). This explicit acknowledgement, and the understanding of consequences of the trade-offs can nudge stakeholders to make informed decisions and prioritizations, and may also encourage them to address them. For low-income nations like Nepal, where conservation interventions are notorious for negatively affecting particularly poor and marginalized households (Anaya & Espírito-Santo, 2018; Ban & Frid, 2018; Dahal et al., 2014; Subedi, 2020), community forests and protected areas can focus more on employment generating activities (e.g., through forest based employment), targeting low-income and marginalized households, and on activities

that, for example, minimize human wildlife conflicts rather than invest on public goods such as infrastructure (Baral et al., 2019; Lamichhane et al., 2019).

The mismatch in priorities between conservation interventions and local communities stem from a greater emphasis of conservation interventions on NCPs that contribute to humanity at the global scale, rather than that at the local-scale (Kovács et al., 2015; Nepal & Spiteri, 2011; Seeland, 2000). Understanding NCPs of particular importance for local communities, negotiating use-limitations, while concurrently defining areas reserved for habitat restoration and carbon sequestration in a participatory manner can reduce conflicts between conservation actors and local communities (Bhattarai et al., 2017). Additionally, the prioritization of one form of perspective and knowledge over others can also generate trade-offs with other socio-economic goals (Levin et al., 2021). Thus, the adoption of a more pluralist approach to conservation planning, which encompasses multiple value systems and knowledge; as well as greater inclusion of locals in decision-making (Bennett et al., 2017; Levin et al., 2021; McShane et al., 2011) can be key to resolving trade-offs.

Addressing trade-offs arising from other SDGs towards SDG 15

Second, achieving biodiversity conservation goals (SDG 15) is impossible without addressing trade-offs arising from interventions aimed at achieving other socio-economic goals. SDG 15 has been found to be a systemic buffer of trade-offs in the 2030 Agenda, meaning that it is influenced negatively by the achievement of other goals (Huan & Zhu, 2022). My 2nd paper also confirmed that SDG 15 was a negative buffer of trade-offs for Nepal. Trade-offs are not inherent to targets or goals themselves, but are the result of inadequate governance and coordination between different sectors (Breuer et al., 2019), which can be improved. However, policy makers from the conservation sector alone cannot address these trade-offs, and must engage with the development community, and negotiate compromises that minimize, and possibly nullify trade-offs (McShane et al., 2011). Even if policies exist that reflect the negotiations between conservation and other-socioeconomic goals, there are multiple examples globally where these are seldom effective at the local scale (Ghimire et al., 2021; Oyanedel et al., 2020; Prescott et al., 2017; Solomon et al., 2015). For Nepal, its shift from a centralized to a federal democratic republic in 2015 presents an opportunity to enforce environmental policies at the local level that minimize environmental impacts from developmental projects.

Improving the monitoring of progress towards the achievement of SDGs

Third, the acknowledgement of existing trade-offs can also be reflected in the monitoring of progress towards the achievement of SDGs. Nepal's progress assessment (Government of Nepal, 2020a), and Voluntary National Reviews (Government of Nepal, 2020c) on the SDGs report progress towards the 2030

Agenda through a siloed reporting of individual SDGs. For example, Nepal reported that it surpassed its 2019 target to provide electricity to 81% of all households (Government of Nepal, 2020a), in line with its 15th National Plan to provide access to clean energy to 99% of households through rapid hydropower infrastructure (Government of Nepal, 2020b). However, this does not account for the implications this may have on other SDGs such as SDG 15 (as shown in the 2nd paper). Similar siloed reporting are also apparent in voluntary reviews of other countries (see O'Sullivan, 2023), and they mask the reality of development trade-offs and give continuity to these environmentally exploitative developmental interventions. Therefore, it is extremely urgent to include more accountability in reporting SDG indicators by including and addressing tradeoffs that might exist in other sectors.

Conserving biodiversity beyond protected areas

Fourth, despite the progress Nepal has made in conserving and restoring biodiversity within protected areas (Government of Nepal, 2020a), my review found that Nepal still faces ongoing challenges of habitat destruction and biodiversity loss outside of these designated zones, similar to worldwide trends (Gray et al., 2016). Expanding protected areas poses a significant obstacle as many existing ones are continuing to create multiple trade-offs for local communities (Allendorf, 2022; Dhakal et al., 2022), and may aggravate existing conflicts. There is an opportunity to address this issue through the implementation of Other Effective area-based Conservation Measures (OECMs; Conference of the Parties to the CBD, 2018). These measures enable the recognition of conservation efforts led by local communities and managed through traditional and indigenous practices, allowing indigenous people to retain governance over these initiatives (Donald et al., 2019). By embracing OECMs, countries like Nepal can extend biodiversity conservation beyond existing protected areas, safeguarding wildlife and habitats without compromising the wellbeing of local populations (Alves-Pinto et al., 2021). OECMs can also play a crucial role in achieving Target 3 of the Kunming-Montreal biodiversity framework, which aims to protect 30 percent of land and sea areas for biodiversity by 2030 while minimizing conflicts and preserving traditional and indigenous territories (Dudley et al., 2018; Maxwell et al., 2020).

Harnessing co-benefits between SDG 15 and other SDGs

Fifth, indirect pathways to biodiversity conservation lies in harnessing co-benefits arising from other SDGs towards SDG 15. Based on my 2nd and 3rd paper, SDG 15 shares the highest co-benefits with ecotourism promotion (SDG 8.9) and education (SDG 4). Development of ecotourism is widely supported by local communities as it helps boost the local economy (den Braber et al., 2018), while at the same time provides revenue for implementing conservation interventions (K C et al., 2021; Upadhaya et al., 2022). However, it is important for policy makers to carefully ensure that the benefits of ecotourism are equally distributed

among communities, since there are many cases where elite capture of ecotourism benefits have further marginalized vulnerable communities in Nepal, and elsewhere (Bennike & Nielsen, 2023; Ghosh & Ghosh, 2019; S. Kandel et al., 2020; Tchakatumba et al., 2019). Since activities that contribute to the livelihoods of all residents receive more support (Birendra et al., 2018), community-based tourism will likely be more beneficial (Mudzengi et al., 2021; Regmi & Walter, 2017). Similarly, education and awareness can be considered another indirect pathway to garner support towards conservation, since higher levels of education corresponded to positive perceptions towards nature in my study sites (3rd paper), similar to many other studies elsewhere (Masao et al., 2022; Sena-Vittini et al., 2023; Vodouhê et al., 2010). Conservation practitioners also believed that the positive perceptions towards biodiversity conservation through education can influence local-level governments towards environmental stewardship in the long term (2nd paper). Leveraging these positive feedback loops between SDG 15, and SDGs 4 and 8 can prove vital for achieving SDG 15 targets.

Addressing existing knowledge gaps

Sixth, bridging existing knowledge gaps on NCP research in Nepal and elsewhere can be beneficial for biodiversity conservation. My literature review (1st paper) identified limited research on NCPs in non-protected areas, and in montane, sub-alpine and alpine regions of Nepal. Filling this geographic research gap can identify new opportunities for ongoing biodiversity loss in non-protected areas. Additionally, in order to reveal new patterns or processes in socioecological systems that can inform local and national policies, research across multiple scales is essential in mountainous countries like Nepal, where diverse human-nature interactions are shaped by sharp biological and socio-economic gradients (Payne et al., 2017; Payne et al., 2020). Importantly, although there are some studies that apply a critical political ecology lens to understand the distribution of benefits and trade-offs of conservation decisions at the local scale in Nepal (Basnyat et al., 2018; Chaudhary et al., 2018, 2019; Dahal et al., 2014), this is only limited to a few case-studies, warranting extensive research in this field, especially in protected area vicinities of Nepal, and beyond.

3.3 Strengths, caveats, and reflections on my research

As a result of the Covid-19 pandemic, the duration of the household survey, originally planned for six months, was significantly reduced to just two months. While I was planning to solely collect data myself, condensing the survey to two months meant that I had to train and employ local enumerators to carry out the data collection. The data collection was satisfactory, but I cannot discount the fact that results could have been different, had I done all the data collecting by myself. Principally, I had planned to focus more on qualitative and open-ended questions, by, e.g., following up on participants' responses, or making

verbatim transcriptions. This was not the case when enumerators collected the data, and a certain degree of subjectivity and data loss might have already occurred during the interaction between participants and enumerators.

There might also be a linguistic caveat to my research approach. I exclusively used English language in all research approaches. I only collected English language literature in my review (1st paper), although non-English language literatures can also have essential information relating to biodiversity (Amano et al., 2023). Similarly, although most interviews with key informants, and household surveys were in Nepali, I translated data into English, and only then proceeded to do qualitative analyses on them. I made these choices because of my limited skills in Nepali typing, and I could not digitize transcripts and data into the computer. Furthermore, the Nepali script was not completely compatible in software such as MS excel, MAXQDA, and R. Thus, I might not have been able to capture key literature in Nepali language, or might have lost some information during translation of qualitative data.

Conservation and development decisions are also influenced by stakeholders, the power dynamics and tensions between them (Basnyat et al., 2018; Hazra et al., 2017), global and regional discourses on conservation and development (Chaudhary & McGregor, 2018; Laudari et al., 2020), and other aspects such as vested interests, and corruption from actors at different levels (Basnyat et al., 2023; Bhatta et al., 2022). Many actors might not want for the status quo to change, because of benefits from the current situation, economically, or politically (see Ahebwa et al., 2012; Nelson & Agrawal, 2008), or because of historical conflicts between different stakeholder groups (see Marshall et al., 2007; Przesdzink et al., 2022; Sterling et al., 2017) preventing them from working together. Thus, the opportunities I present in the previous section can be significantly influenced by these factors, and must therefore also be considered.

Finally, the use of the IPBES CF in my thesis provided some insights in terms of its applicability and novelty. I found the framework indeed to be intuitive and useful for participatory research, although scholars argue that CF still presents limitations in terms of achieving shared understanding between different stakeholders (Löfmarck & Lidskog, 2017; Masao et al., 2022). In my experience however, the framing of nature's contributions into 18 NCPs worded into very accessible language proved useful to teach enumerators to distinguish between very apparent contributions of nature such as food and energy, to abstract contributions such as nature's value in shaping worldviews, culture, and people's relationship with land. This was important since I didn't want enumerators to miss non-material contributions and introduce bias. It was equally useful when I shared results with key local stakeholders. Similarly, the interconnections between different elements of the CF (through arrows) also made attribution of indirect and direct drivers of change towards nature and NCPs relatively simple during data analysis.

Apart from these aspects, I did not find substantial novelty in the NCP concept. It appears that the purported novelty of the NCP concept is primarily semantic (Kenter, 2018), and many researchers have expressed concern that the use of multiple terms to mean the same thing could confuse policy-makers (Braat, 2018). Despite these concerns, the fact that the IPBES CF was constructed in an inclusive, participatory, and transparent manner through workshops with stakeholders from multiple disciplines, worldviews, and countries (Díaz et al., 2015), in my opinion, is a positive step towards the integration of pluralistic values and knowledge on human-nature relationships. Given that the NCP concept is relatively recent, I am hopeful that lively debates surrounding NCP and ecosystem services will simulate efforts to refine this concept further and address its concerns.

3.3.1 Positionality and Reflexivity

The identities of both the participants, and the researcher has the potential to impact the research process (Bourke, 2014). Throughout my research, I have been aware of how my worldview and positionality in various contexts can shape the design, data collection, and analysis of the study.

I am a male, Brahmin ("upper" caste) researcher from a middle-class family in Nepal and have spent most of my life in an urban setting. Living in the capital of Nepal certainly exposed me to a different set of circumstances compared to the participants living in rural communities I was studying. Some focal persons with whom I developed personal relationships with would call me a *Sahariya* (roughly translated in this context to "city-boy"), a term with general implications of aloof outsider status and lack of familiarity with rural challenges. Indeed, I was always conscious of the disconnect between my own life experiences, and the lived realities of the people I was working with, and I had to be very mindful to pick up subtle cues, and interpret experiences of people in the correct way.

Similarly, the lingering effects of systemic injustices in Nepal rooted in the Hindu caste system (Gellner, 2007) continue to be felt, and disadvantaged groups understandably exhibit hesitancy towards those perceived as belonging to the "elite" castes. With inter-caste marriages seen as a taboo even as late as my parent's generation, people in Nepal can still discern castes of other people with reasonable accuracy just by looking at them. Thus, as a Brahmin, interacting with marginalized and disadvantaged groups was difficult. It took time and effort for me to garner a sense of trust and openness, which was really important because the project aimed to bring different knowledge and perspectives together, particularly of those who were marginalized. This was especially challenging in the mountain village where more than 90% of households were from tribal backgrounds. However, I believe that my extended stays in each village, and the support from the enumerators and focal persons in each village garnered some familiarity which helped bringing in the perspectives of marginalized and tribal communities.

As someone affiliated to a large regional organization such as ICIMOD, I was mindful of the potential power-dynamics that might come into play in my interactions. ICIMOD has made investments into biodiversity conservation and enhancing wellbeing of local communities in the region where I collected my data. Hence, it was important for me to interact with local communities in a way that did not create false expectations among local representatives. In certain instances, I found it necessary to identify myself as a student from a foreign university rather than as an employee of ICIMOD. Throughout my fieldwork, I took care to differentiate genuine issues raised by participants from those raised with the expectation of future support from ICIMOD.

Throughout my research journey, I remained conscious of my positionality, including my affiliation and socio-economic background, and made sincere efforts to maintain reflexivity in every step.

3.3.2 Novelty and Relevance of the thesis

My research investigated the interactions between nature, NCPs, and human-wellbeing at multiple scales and contexts in a mountainous country. I consider this novel and relevant, because research on linkages between various social-ecological elements at multiple scales is considered a key knowledge gap in mountain research (Payne et al., 2017). I conducted my research both at the national and sub-national level. For the sub-national level research, I examined these linkages along an elevational gradient, allowing for a deep understanding of NCPs and human wellbeing across various ecological, geographic, cultural, socio-economic and governance dimensions. Another methodological novelty of my research is the combined use of the IPBES CF and the SDGs. While certain studies have employed the concept of NCPs to map the ways in which nature contributes to the attainment of the SDGs (see Anderson et al., 2019), none have done so within a broader socio-ecological context that incorporates other IPBES elements such as nature and the drivers of change. This combined approach allows for a more holistic examination of how nature's contributions, influenced by various drivers of change, interact with the goals and targets outlined in the SDGs. This cross-scale examination is also highly relevant for Nepal, for devising appropriate conservation and management strategies that support the wellbeing of local communities and for protecting the country's fragile mountain biodiversity and natural heritages.

In my research on SDG interactions, I incorporated three distinct methods from existing literature. Studies that have employed three or more methods to uncover SDG interactions remain scarce (Horvath et al., 2022). Additionally, none of these studies have compared the outcomes of their analyses, and do not offer methodological insights into the strengths and weaknesses of different approaches. In contrast, my research addresses this gap by conducting a comparative analysis of the results and offering valuable methodological insights into the advantages and limitations of different approaches. Similarly, the identification of contributions of nature towards the achievement of SDGs, as well as interactions between SDGs are mostly

top-down and desk-based, involving biophysical assessments without sufficient integration of knowledge from a range of stakeholders (Bennich et al., 2020; Martín-López et al., 2019). In contrast, I have taken a participatory approach, involving various stakeholders such as academics, conservation practitioners, community-based organizations, local communities, and government representatives to answer my research questions, as well as to validate my findings through a knowledge sharing workshop. One particular aspect of relevance is the inclusion of local community perspectives, which are often overlooked or inadequately understood in biodiversity conservation efforts (Bernardo et al., 2021). By involving local communities in my research, I tried to integrate their knowledge, experiences, and aspirations, which can provide more informed decision-making towards biodiversity conservation.

3.4 Concluding Remarks

I believe that the narrative of conservation *or* development stems from a long history of conservation-related conflicts that pitted conservation and development as opponents. But this narrative is slowly changing globally, with governance, responsibility, and accountability towards biodiversity conservation slowly being decentralized from the state to local communities. However, for a nation like Nepal, where the immediate needs of food security, livelihoods, and economic development often take precedence over long-term conservation efforts, bridging the two "opponents" is still a challenge. During my field work, a quote from a participant from the mountain region really left a lasting impression. He said*: "We cannot conserve on an empty stomach"*. Indeed, balancing conservation and development is a complex issue with no easy answers, and there will always be "winners" and "losers", support and opposition, vested interests and negative externalities, and negotiations and compromises.

In light of this, I hope that my thesis can contribute to shifting the narrative in Nepal from conservation *or* development to conservation *for* development. I believe that my work can contribute to stimulating meaningful discussions and collaborations among engineers, natural resource managers, forest rangers, conservation wardens, local government representatives, local communities and academics, and finding informed pathways for more inclusive and sustainable approaches that benefit both nature and people. In a broader sense, I hope that my thesis can help inspire similar research in other low-income nations that are also grappling with the challenge of balancing conservation and other socio-economic development goals.

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Research Papers

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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

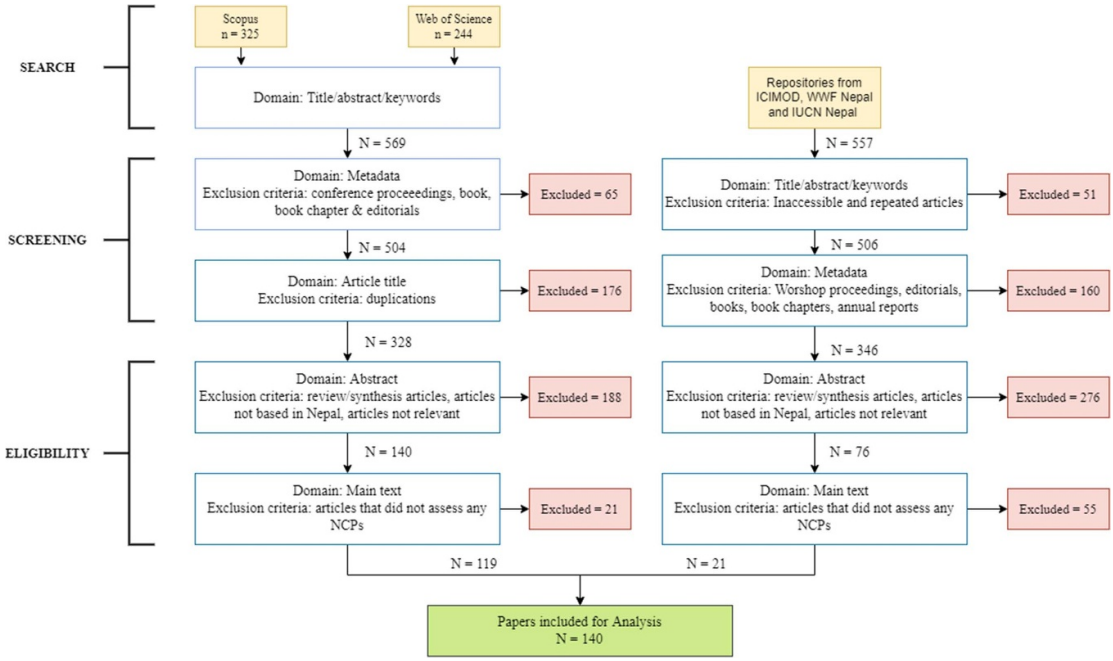

Figure 1. Visualization of the steps followed in the SALSA framework as a part of systematically screening and selecting articles for analysis.

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

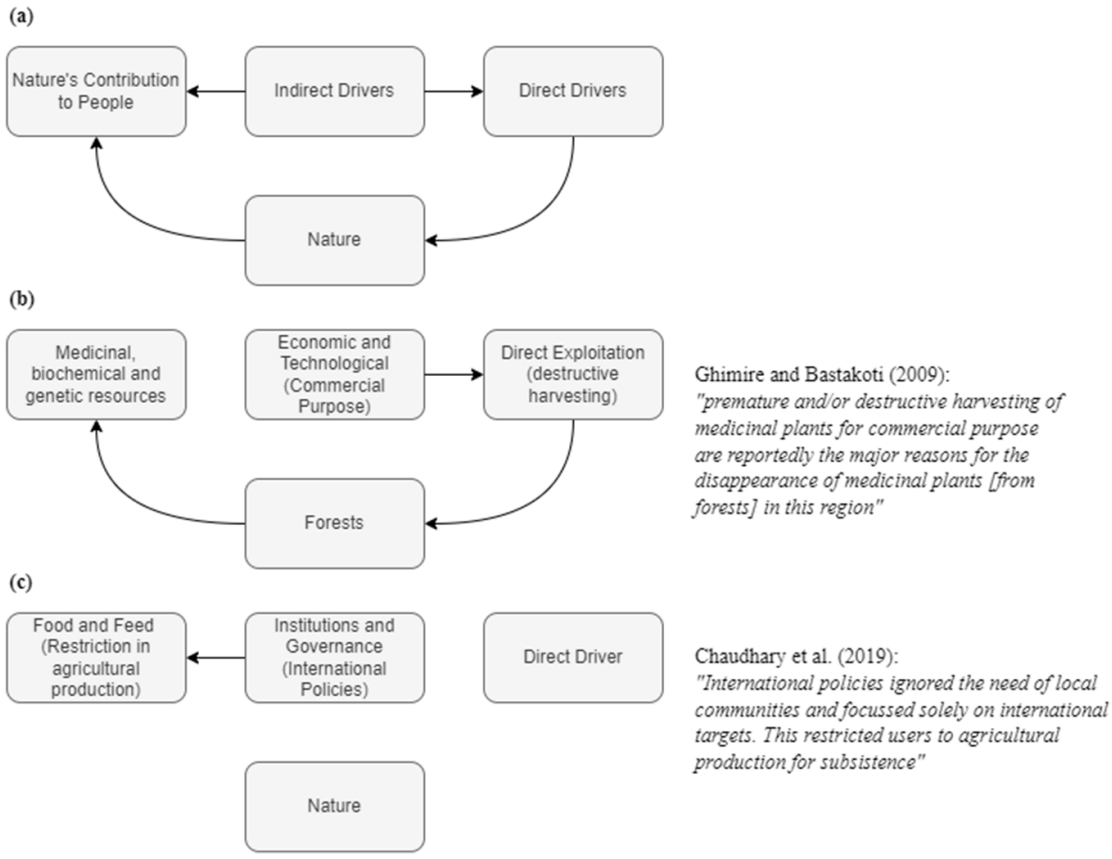

Figure 2. A conceptual diagram representing (a) linkages between direct drivers, indirect drivers, nature and NCPs, adapted from the IPBES conceptual framework (Díaz *et al* 2015), (b) examples of the influence of indirect drivers on NCPs via direct drivers, and (c) influence of indirect drivers on NCPs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

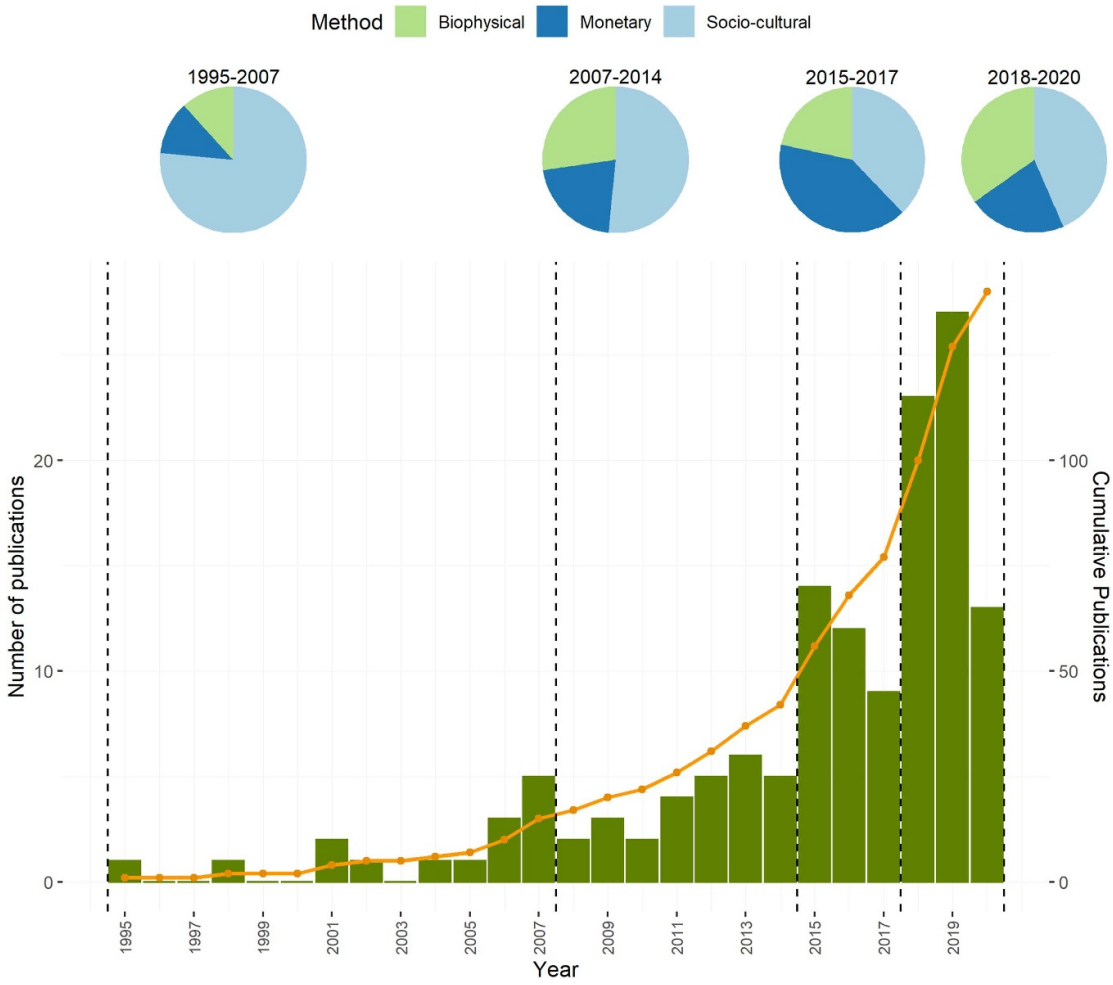

Figure 3. Temporal trends of published articles on NCPs in Nepal. The time periods are divided on the basis of Jenks natural breaks optimization (Jenks 1967). Green bars represent number of articles published per year. The orange line represents cumulative numbers. Pie charts represent the fraction of 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'

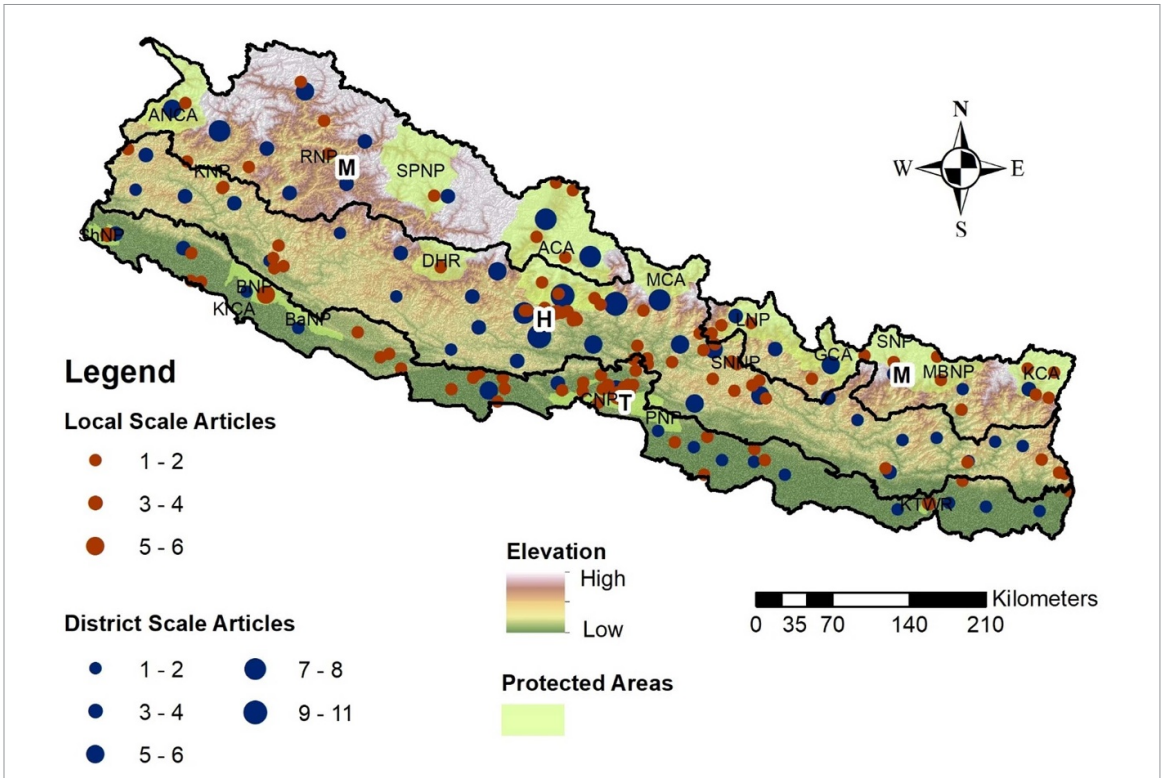

Figure 4. Number of articles from 1995–2020 on NCPs published by geographic area superimposed by protected areas (comprised of wildlife reserves, hunting reserves, national parks, and conservation areas) and elevation; and grouped into three ecoregions, viz. mountains (M), hills (H) and the Terai (T). 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).

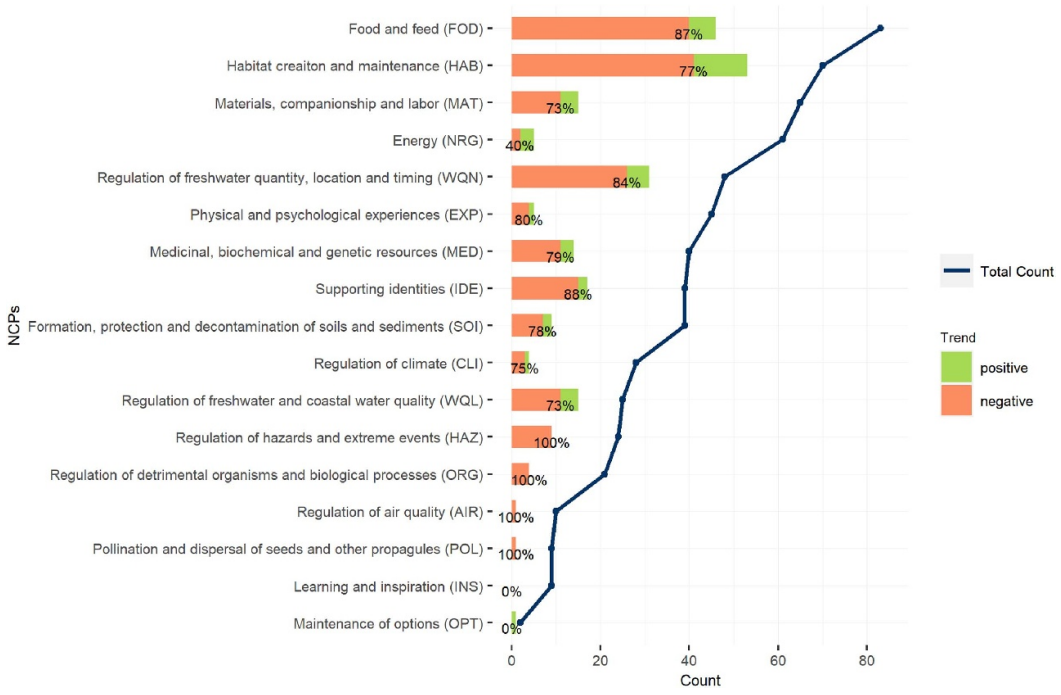

Figure 5. Number of articles focusing on individual NCPs (line graph) and the proportion of statements reporting increasing or decreasing trends in NCPs (bar graphs). The labels in the stacked bar charts indicate the percentage of negative trend reported in the literature for each NCP.

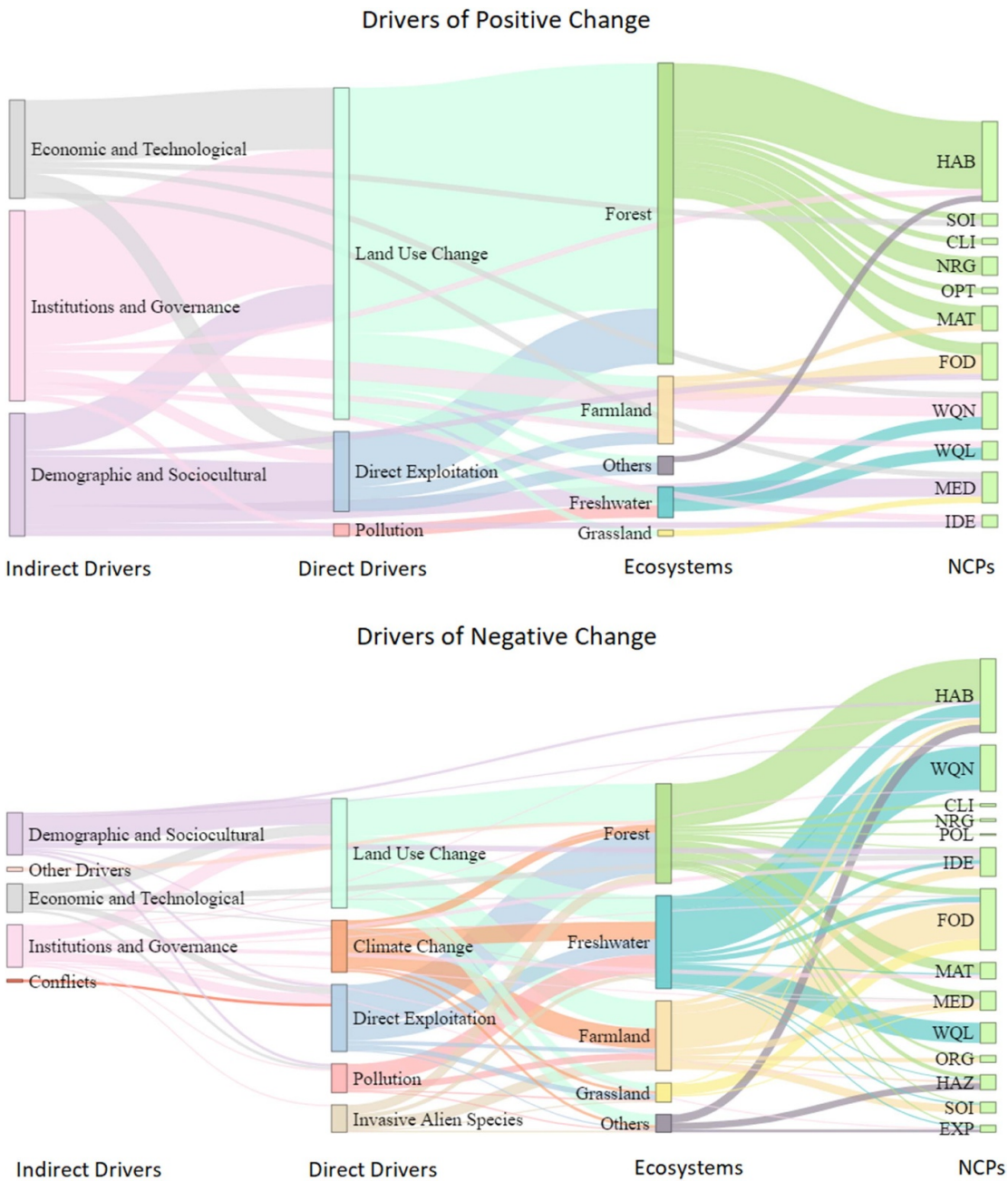

Figure 6. Direct and indirect drivers of changes in ecosystems and NCPs. The height of each node represents frequency of occurrence of that node occurred in statements within the peer-reviewed and grey literature we assessed.

(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
	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.
	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.
	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.
	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
	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.
	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	
	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.
	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.
	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.
	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.
	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.
	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 fire-wood, 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),

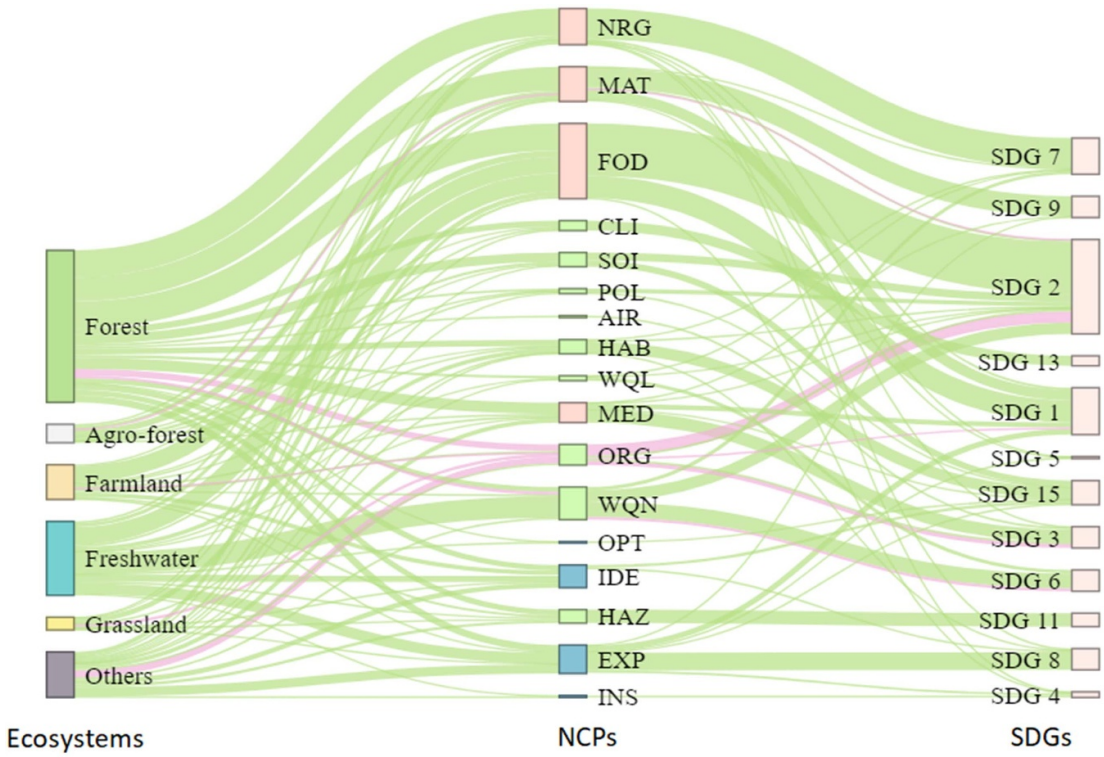

Figure 7. Positive (green) and negative (purple) linkages between ecosystems, NCPs, and SDGs. The NCP nodes are color coded according to their primary type as material (pink), regulating (green) and non-material (blue). The height of each node corresponds to the frequency of occurrence of that node occurred 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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Paper II: A multi-methods approach for assessing how conserving biodiversity interacts with other sustainable development goals in Nepal

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A multi-methods approach for assessing how conserving biodiversity interacts with other sustainable development goals in Nepal

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Abstract

Achieving the sustainable development goals (SDGs) requires a context-specific understanding of how actions to achieve one goal interact with others. We analyzed statistical data, and conducted online surveys and interviews with conservation professionals to understand how terrestrial conservation goals (SDG 15: Life on land) influence and are influenced by other goals in Nepal. Our findings suggest that SDG 15 synergized with economic growth (SDG 8), gender equality (SDG 5), water access (SDG 6), sustainable production and consumption (SDG 12), and climate action (SDG 13), but traded off with food security (SDG 2), energy access (SDG 7), poverty alleviation (SDG 1), and infrastructure development (SDG 9). Increased multi-sectoral collaboration between conservation and development stakeholders is urgently needed to address the negative impacts of other goals on SDG 15. Additionally, conservation measures in Nepal can benefit from being more people-focused, participatory, and contextualized to mitigate negative impacts on socioeconomic goals.

KEYWORDS
agenda 2030, buffers and multipliers, co-benefits and trade-offs, cross-sectoral collaboration, life on land, participatory conservation, sustainable development goals, synergies

1 | INTRODUCTION

The 2030 agenda comprises 17 sustainable development goals (SDGs) and 169 constituent targets that guide countries toward the simultaneous achievement of "economic development, environmental sustainability and social inclusion" (United Nations General Assembly, 2015). Among these 17 goals, SDG 15 (Life on land) and 14 (Life below water) are considered to be particularly important because biodiversity fundamentally underpins human wellbeing and is thus considered central to the achievement of multiple SDGs (Blicharska et al., 2019; Brooks et al., 2015; Obrecht et al., 2021; Opoku, 2019; Pham-Truffert et al., 2020; Wood et al., 2018). Despite the global importance of biodiversity, competing economic and social development goals are often prioritized nationally, which has resulted in rapid declines in biodiversity worldwide (Eisenmenger et al., 2020; United Nations, 2022). Additionally, current development scenarios show that conservation objectives negatively interact with other socioeconomic goals (Anderson et al., 2022). Therefore, to avoid costly trade-offs between achieving economic prosperity, social wellbeing, and environmental sustainability in the future, it is important to improve our understanding of the interactions between nature-related goals and other goals.

A variety of approaches have been developed to quantify interactions between SDGs, each providing different types of information (Horvath et al., 2022). These range from argumentative methods (i.e., qualitative and quantitative methods) that apply expert knowledge (Horvath et al., 2022), such as the seven-point typology of Nilsson et al. (2016), and cross-impact matrix (Breu et al., 2021; Weitz et al., 2018), to quantitative model simulation and statistical methods, such as correlation and regression analysis (Pradhan et al., 2017). Since each method has its own sets of strengths and limitations (see Horvath et al., 2022), applying a mixed-methods approach is likely to provide a deeper understanding and a more complete picture of interactions between different goals (Horvath et al., 2022; Pradhan, 2023).

Interactions between the SDGs are context-specific (McCollum et al., 2018; Moyer & Bohl, 2019). However, most studies that have mapped interactions between nature-related goals and other goals have done so at global scales. Scherer et al. (2018), for example, examined interactions between social and environmental goals, the latter consisting of SDGs 6 (Clean water and sanitation), 13 (Climate action), and 15. Huan and Zhu (2022) analyzed interactions specifically between SDG 15 and other SDGs through a literature review. Similarly, Singh et al. (2018) focused on interactions between SDG 14 and other goals. However, besides a few examples (see Hazarika & Jandl, 2019; Urban & Hametner, 2022), studies that examine interactions between nature-specific and other goals are uncommon at national and subnational scales.

The identification of such interactions is particularly important in highly biodiverse low-income countries, such as Nepal, where achieving economic and social goals is as urgent as achieving biodiversity goals (Eisenmenger et al., 2020). Existing studies on SDG interactions between subsets of goals in Nepal include that by Aryal et al. (2020), who analyzed the contribution of Nepal's community forestry toward the SDGs. However, and despite the urgency of addressing environmental issues in Nepal, no study to date has attempted to understand synergies and trade-offs between nature-related and other goals.

Here we fill this gap by assessing interactions between conservation (SDG 15) and development goals (other SDGs except SDG 14) at the national scale for Nepal, using a multi-method approach. We discuss key interactions detected by all methods as well as divergences and conclude with an attempt to identify pathways to strengthen co-benefits and address trade-offs between goals and targets in our study context.

2 | METHODS

Based on analyses of the strengths and limitations of current methods for assessing SDG interactions (Breuer et al., 2019), on data availability, and following Pradhan (2023) and others (e.g., Horvath et al., 2022; Urban & Hametner, 2022), we took a multi-methods approach and performed both argumentative (*sensu* Horvath et al., 2022) and statistical analyses. We used the seven-point typology (Nilsson et al., 2016) and structured elicitation of expert information as argumentative methods and a pairwise correlations method (Pradhan et al., 2017) as our statistical one. Data will be available at: https://doi.org/10.5281/zenodo.7835714.

2.1 | Argumentative method: SDG interaction scores

We conducted an online survey with experts (similar to Wood et al., 2018) from the conservation sector of Nepal to score the interactions between achieving SDG 15 and other goals on a seven-point ordinal scale following Nilsson et al. (2016). Because of the broad definition of SDG 15 (see United Nations General Assembly, 2015), and to avoid selecting only a subset of its targets, we asked the survey participants to rate the interactions between SDG 15 at the goal level and specific targets of the remaining 15 goals. While the seven-point scale is typically used to rate interactions between two targets, we believe that it is conceptually flexible enough to be applied for the rating of interactions between a goal and a target.

2.1.1 | Selection of SDG targets

First, we reduced the 169 targets to a limited set relevant for the Nepalese context. We did so by excluding the "means of implementation" targets (targets that create an enabling environment for outcome targets, e.g., target 1.a mobilization of financial resources for poverty alleviation) and retaining only the "outcome" targets (conditions to be attained, e.g., target 1.1 achievement of poverty eradication). We reduced the resulting set ($n = 126$) to targets prioritized by Nepal's government ($n = 42$) based on its 15th National Development Plan (Government of Nepal, 2020b) and the national review on progress toward the SDGs (Government of Nepal, 2020a). Finally, we further removed an additional 12 targets based on an internal assessment of redundancy, relevance, and broadness (see Data S1 for details). In total, we considered 30 targets.

2.1.2 | Online expert survey

We used Kobo Toolbox (Kobo Inc., 2022) to deploy our survey between May and June 2022. We disseminated the survey to experts working in governmental, intergovernmental, and non-governmental organizations. We identified additional experts within academic institutions familiar with conservation in Nepal. These people were chosen from institute mailing lists and networks and contacted primarily through emails and LinkedIn. To increase participation, we asked respondents to share the survey in their professional networks. Because we employed purposive and snowball sampling techniques, we have only calculated summary statistics (Hirschauer et al., 2021).

Before taking the survey, respondents received information about the survey's purpose as well as the seven-point interaction method and had to indicate their past and current affiliation as well as the number of

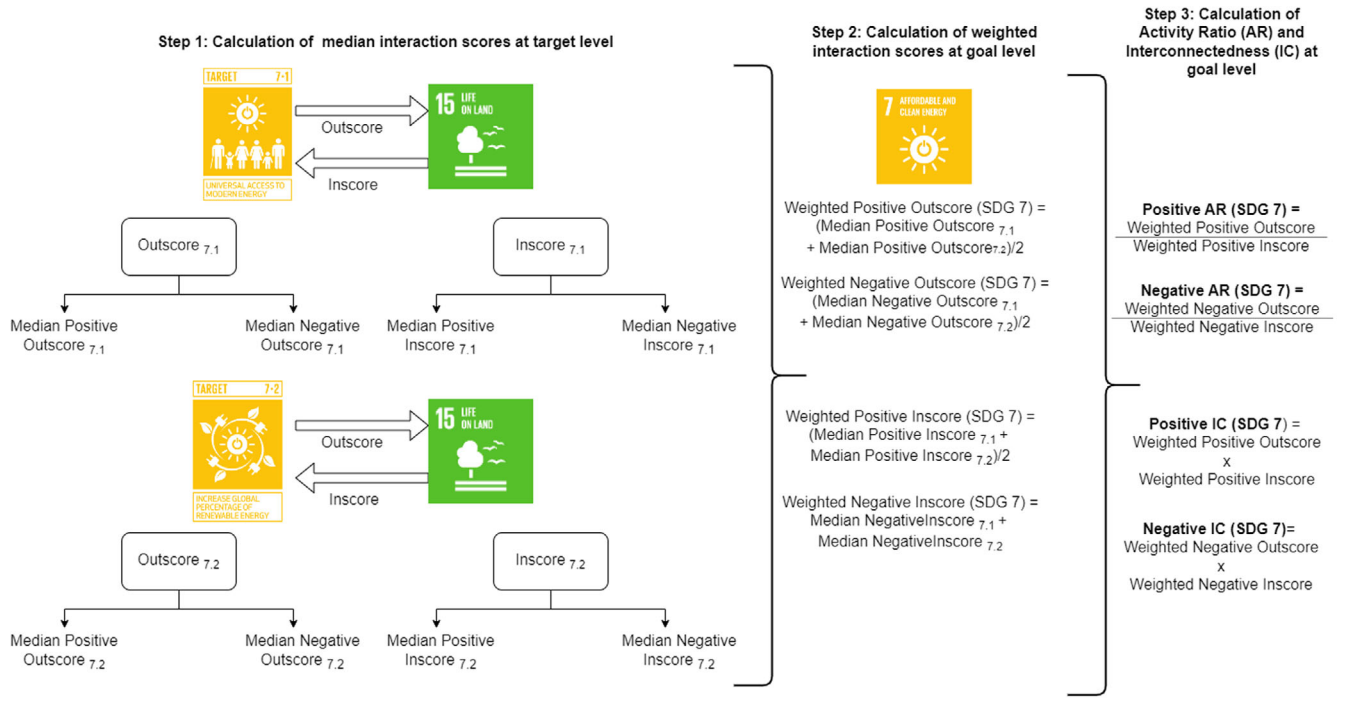

FIGURE 1 Calculation of activity ratio (AR) and interconnectedness (IC) for SDG 15 and SDG 7, including the calculation of median interaction scores at target level, calculation of weighted interaction scores at goal level, and calculation of AR and IC. A detailed explanation of each step is provided in Data S1. [Colour figure can be viewed at wileyonlinelibrary.com]

years of experience in Nepal's conservation sector (0, 1–2 years, 2–5 years, and >5 years). Then, we asked each respondent to score (i) the effect of achieving five randomly selected targets on SDG 15 (outgoing interactions, or outscore), and (ii) the effect of achieving SDG 15 on the same randomly selected targets (incoming interactions, or inscore) using the seven-point scale. For each answer, respondents had the option to explain the reason for the scores they gave. Since we assigned targets regardless of the participants' background and expertise, we also asked them to rank their confidence in their answer from 1 (completely certain) to 4 (very uncertain). A sample of the online survey is available in Data S2.

2.1.3 | Analysis of responses

For each selected target, we calculated the proportion of responses ($N = 65$) for each category of the seven-point scale for both outscores and inscores (Figure 1). Following Pham-Truffert et al. (2020) and Breu et al. (2021), we also identified multipliers (i.e., goals that influence the achievement of SDG 15) and buffers (i.e., goals that are influenced by the achievement of SDG 15) through measurements of *activity ratio* (AR; the ratio of outscore by inscore; a target with AR >1 is a multiplier) and *interconnectedness* (IC; the product of outscore and inscore; high IC stand for strong interaction with SDG 15). For each goal, we calculated the AR and IC separately for positive and negative interactions.

We plotted the AR and IC in a coordinate system, with the logarithmic value of AR in the x-axis and IC in the y-axis. This helped us identify (i) buffers of co-benefits (positively interacting goals whose AR <1), (ii) buffers of trade-offs (negatively interacting goals whose AR <1), (iii) multipliers of co-benefits (positively interacting goals whose AR >1), (iv) multipliers of trade-offs (negatively interacting goals whose AR >1). To identify whether SDG 15 is a systemic buffer or multiplier, we calculated its AR as ratio of weighted out-degree centrality of SDG 15 by the weighted in-degree centrality of SDG 15, and the IC as the product of weighted out- and in-degree centralities (see Breu et al., 2021). Here, the weighted out/in-degree centrality of SDG 15 is the sum of inscore/outscore values respectively. Detecting negative buffers and multipliers was important as they point to trade-offs in need of particular attention for the achievement of SDG 15.

2.2 | Statistical method: Correlation analysis

We used time series of SDG indicators for Nepal from the Global SDG Indicators Database (https://unstats.un.org/sdgs/indicators/database/), with the requirement of a minimum of three data points between 1990 and 2020 per indicator. For Nepal, the database held data for 17 indicators out of the 30 selected targets, and four indicators for targets within SDG 15, that is, 21 indicators in total (see Data S3).

We conducted a pairwise correlation analysis for the 420 indicator pairs (21*20 indicators) using Spearman's rank correlation (ρ), following Pradhan et al. (2017). We used a statistical significance threshold of $\alpha = .05$ and grouped data pairs whose correlations

were not significant as "neutral." For the correlations that were statistically significant, we adopted an interaction threshold of ±0.6 for the correlation coefficient, that is, we classified the correlations as "positive" if ρ was greater than 0.6, "negative" if ρ was less than −0.6, and "neutral" if ρ lied in between. We reversed the sign of indicators that measured undesirable phenomenon (such as infant mortality rate), to avoid misleading interpretation of correlation results. We used R v. 4.1.2 (R Core Team, 2022) for all statistical calculations.

2.3 | Argumentative method: Expert elicitation

2.3.1 | Data collection

We conducted semi-structured interviews with 13 informants from the conservation sector. These informants included community forest chairpersons, wardens of national parks, NGO employees, as well as researchers. All had experience in different parts of Nepal. Except for one in English, all our interviews were in Nepali and covered the background of the informants, challenges in implementing conservation activities and possible solutions, and co-benefits and trade-offs with development activities (see Data S4). The interviews took between 20 and 60 min and we conducted them between August and October 2021.

2.3.2 | Data coding and analysis

We used MAXQDA v. 20.4.1 (VERBI Software, 2021) to store and analyze our qualitative data. The lead author translated all interviews to English and transcribed them. We attributed each development intervention mentioned by the informants to the SDG it could help achieve, and recorded whether the intended progress toward that SDG led to a co-benefit or a trade-off with SDG 15 targets. We also recorded whether achieving SDG 15 could lead to co-benefits or trade-offs with other SDGs. Accordingly, we coded each interaction as incoming (effect of SDG 15 toward other SDGs) and outgoing (effect of other SDGs toward SDG 15). For example, we coded "Another issue is from transmission lines and poles. Obviously, trees were cut down because of this, but this also impacted animals because they are constructed in dense forests where biodiversity is high" as SDG 7 (Affordable and Clean Energy) and classified as an outgoing trade-off.

We categorized the challenges in implementing conservation activities that informants mentioned using the framework method (Gale et al., 2013). Following this method, we first went through our transcripts line by line and assigned initial codes (Saldana, 2013) to answers pertaining to conservation challenges. We then assigned the initial codes to four broader categories of challenges. We repeated the same steps to uncover opportunities to address the existing challenges (Section 3.3.3).

2.4 | Synthesis of findings from the three approaches

We aggregated the results of the interaction scoring and the correlation analysis at the goal level to compare results of all three methods. For this, we aggregated the number of co-benefits and trade-offs (both incoming and outgoing) of targets with SDG 15 obtained from the SDG interaction scores to their respective goals and calculated the proportion of co-benefits and trade-offs of each goal with SDG 15. We followed the same steps for the correlation analysis.

2.5 | Research ethics

No local research ethics committee was available to approve the proposed online survey and interviews. To meet ethics standards for collecting consents, we collected personal information from the online survey on a voluntarily basis from participants who were interested in further contributing to the study. We informed respondents of the online survey and the interview about the use of their anonymized responses in scientific publications before starting data collection. All participants consented. Responses that could lead to the identification of respondents are not included in this manuscript.

3 | RESULTS

3.1 | SDG interaction scores

Sixty-five individuals participated in the survey, scoring 325 interactions between SDG 15 and specific targets. Besides five unspecified participants, respondents were affiliated to international and regional government organizations (31%), international and national non-government organizations (26%), government (21%), research institutes and universities (19%), and private institutions (3%). Most respondents (63%) had worked more than 5 years in the conservation sector in Nepal, while 20% and 7% had worked there between two to 5 years, and up to 2 years, respectively. We excluded data from the remaining 10% who reported no experience.

3.1.1 | Co-benefits and trade-offs with SDG 15

More than two-third of all interaction values were positive (from +1, enabling, to +3, indivisible) for both outgoing and incoming interactions between SDG 15 and selected targets (Figure 2). All respondents assigned positive outgoing interactions for all selected targets under SDG 13 (Climate action), as well as for targets 12.2 (Sustainable management of natural resources) and 5.5 (Participation of women in leadership positions). SDG 8 (economic growth) targets, as well as targets 11.4 (conservation of natural and

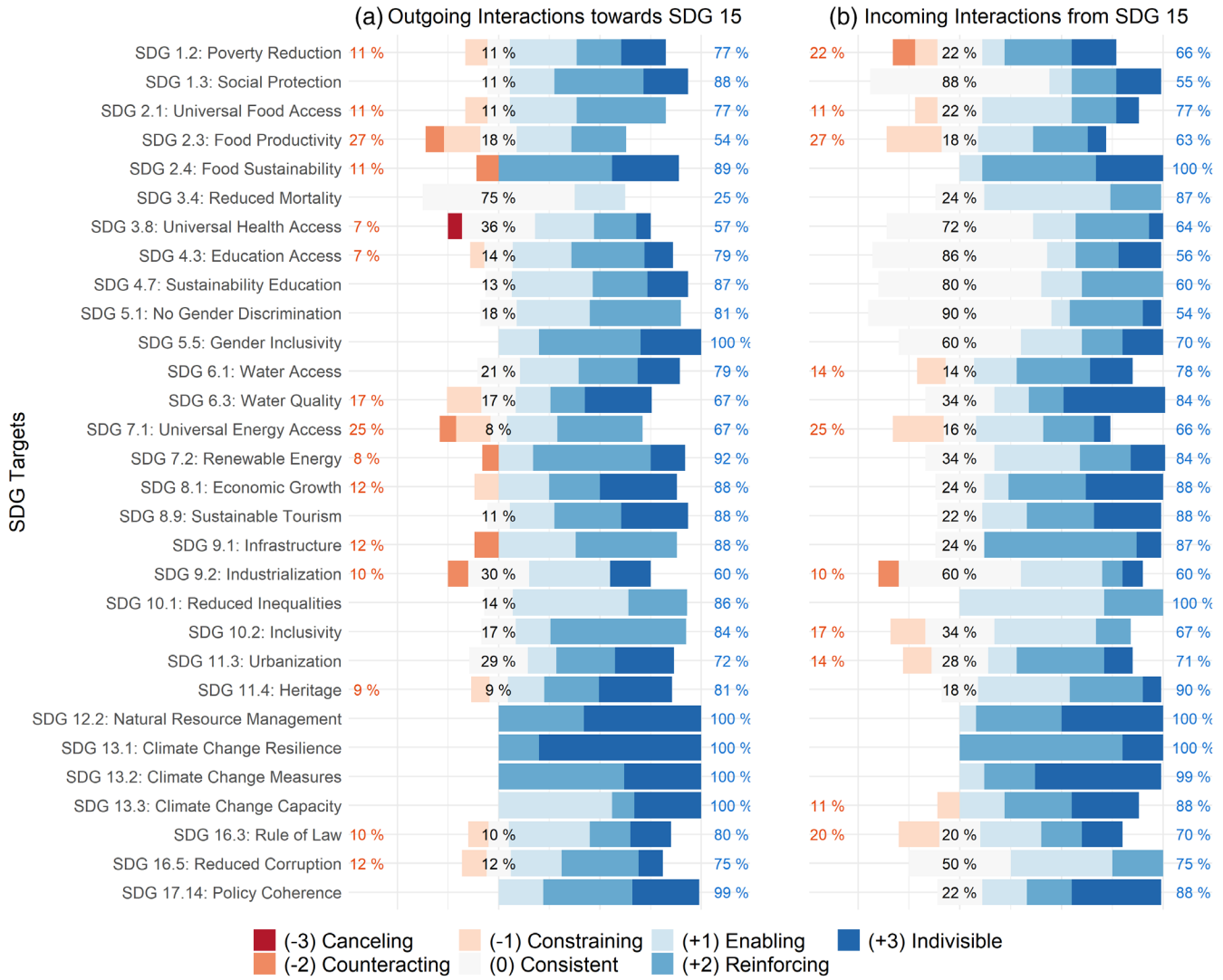

FIGURE 2 Levels of (a) outgoing and (b) incoming interactions between SDG 15 and each target as assigned by the experts. The sum of percentages indicates more positive (blue) than negative (red) interactions. The black percentage values represent percentage of neutral interactions. [Colour figure can be viewed at wileyonlinelibrary.com]

cultural heritage), 7.2 (renewable energy), and 10.1 (reduced inequalities) also had high proportions of positive outgoing interactions. Negative outgoing interactions were mostly concentrated around targets 2.3 (Double the productivity of small-scale food producers) and 7.1 (Access to modern energy).

Every respondent assigned positive incoming interactions for targets 13.1 (Resilience to climate related disasters), 13.2 (Integrate climate change measures into policies), 12.2 (Sustainable management of natural resources), 10.1 (Reduce income inequalities), and 2.4 (Sustainable food production and resilient agricultural practices). SDG 8 targets also had high proportions of positive incoming interactions. Negative incoming interactions were concentrated around targets 1.2 (Reduction of poverty), 2.3 (Double the productivity of small-scale food producers), 7.1 (Access to modern energy), and 16.3 (Promote rule of law and ensure equal access to justice).

3.1.2 | Buffers and multipliers of SDG 15

Based on the AR and IC values we calculated for each goal (Figure 3a), we observe that:

- Influences between SDGs are primarily positive (predominance of blue points, coherent with the high proportion of positive interactions described above) and positive influences are stronger than negative ones (IC values are higher for positive interactions)
- Sustainable production and consumption (SDG 12) is the biggest multiplier of co-benefit for SDG 15 (positive multiplier with the highest IC).
- Clean water and sanitation (SDG 6), climate action (SDG 13), and partnership for the goals (SDG 17) are the biggest buffers of co-benefits of SDG 15 (positive buffers with the highest ICs). These SDGs have a high proportion of "Indivisible" (+3) outgoing interactions (Figure 2).

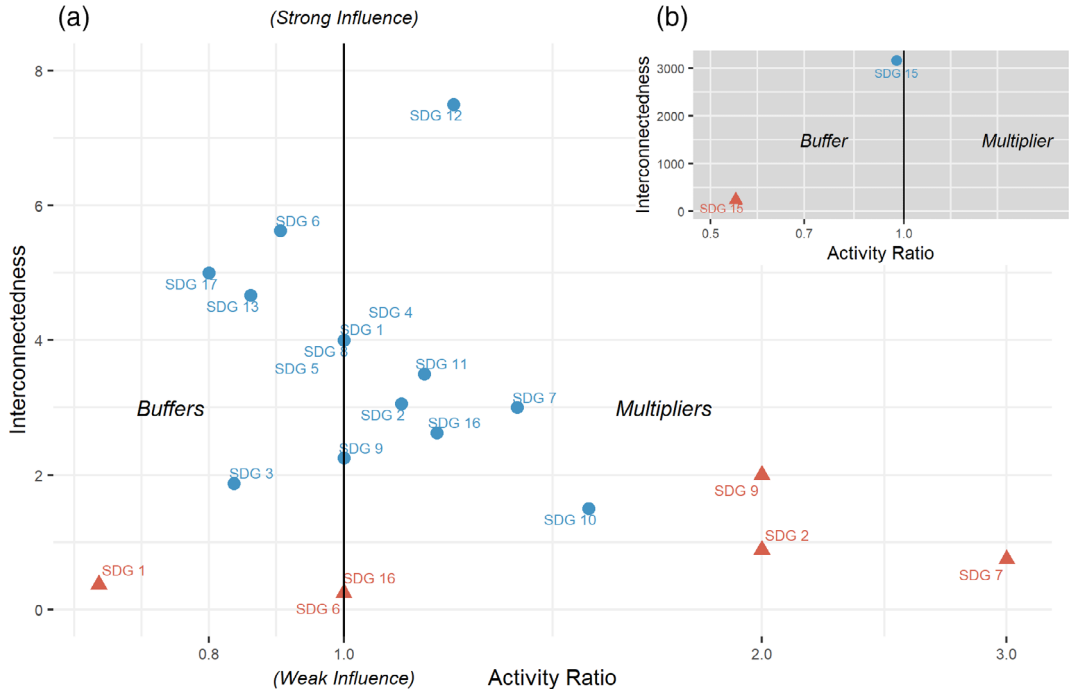

FIGURE 3 (a) SDG targets that act as buffers (AR <1) and multipliers (AR >1) toward SDG 15. Blue circles indicate positive and red triangles indicate negative buffers/multipliers. (b) AR and IC values of SDG 15. Two separate plots are used because the ICs are incomparable for SDG 15 and other SDGs. [Colour figure can be viewed at wileyonlinelibrary.com]

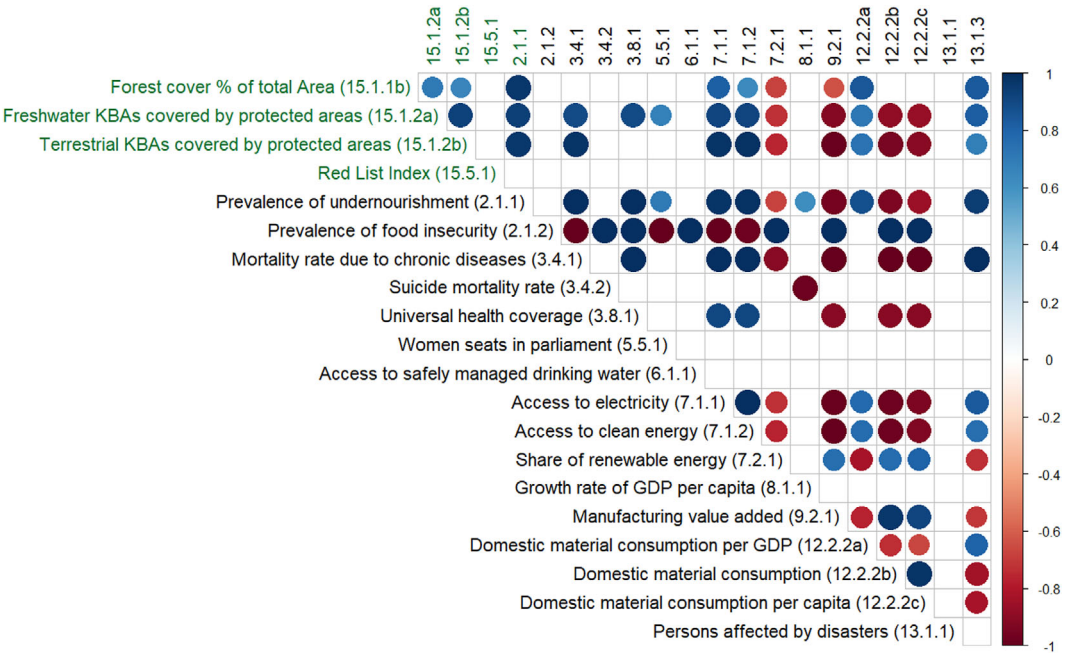

FIGURE 4 Plot of significant correlations between indicator pairs. DRR, disaster risk reduction; GDP, gross domestic product; KBA, key biodiversity area. Green labels are indicators of SDG 15. Blue and red dots indicate positive and negative correlations, respectively. The bigger the size of the dots, the stronger the correlations between indicator pairs. White cells indicate no significant correlation. Detailed description of each indicator is provided in Data S3. [Colour figure can be viewed at wileyonlinelibrary.com]

- Industry and infrastructure (SDG 9), affordable and clean energy (SDG 7), and zero hunger (SDG 2) are the multipliers of trade-offs for SDG 15 (negative multipliers with highest IC)
- Poverty alleviation (SDG 1) is the only buffer of trade-offs of SDG 15 (negative buffer)
- At the systemic level, SDG 15 serves as a buffer for both co-benefits and trade-offs (Figure 3b). The positive effects from other

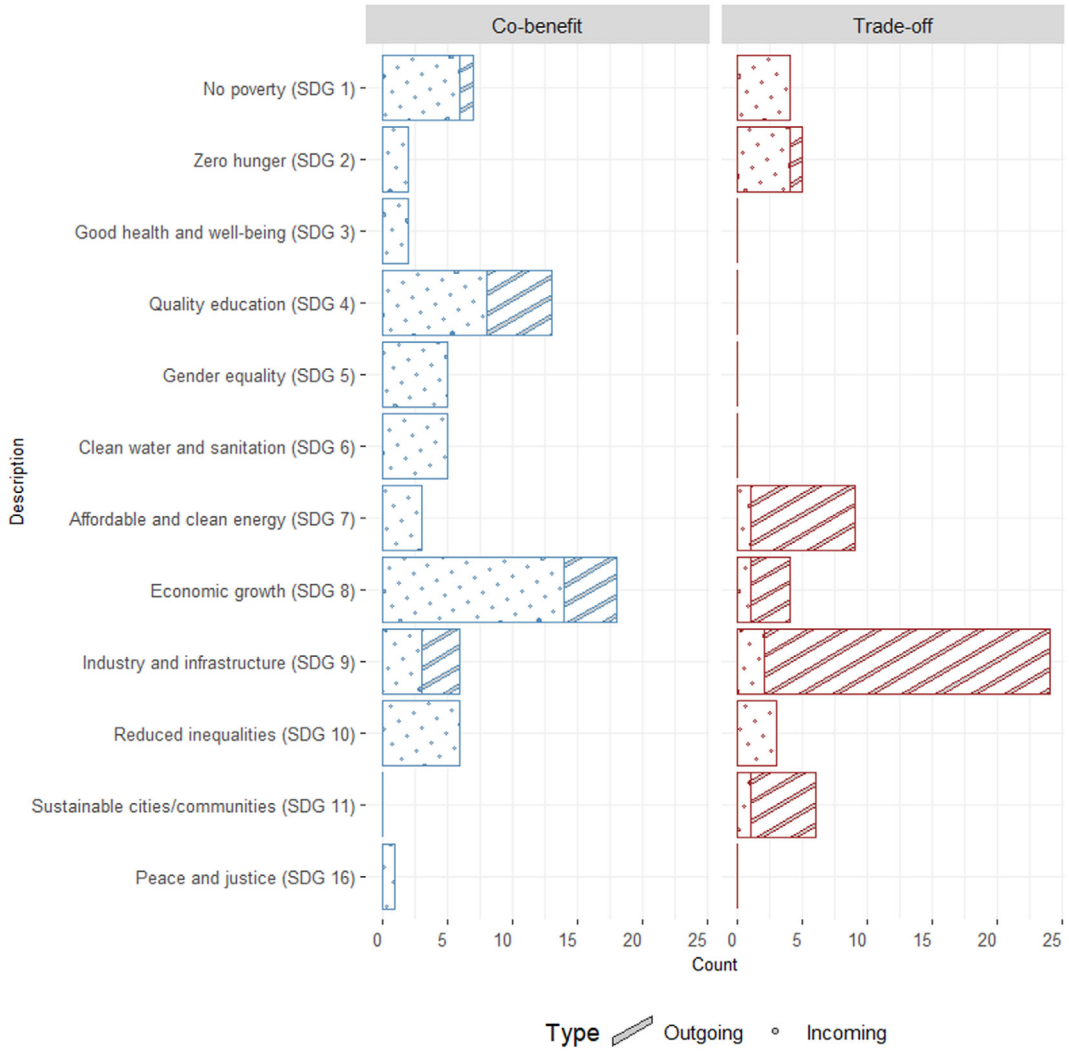

FIGURE 5 Outgoing/incoming co-benefits and trade-offs between SDG 15 and other goals according to informants. The counts correspond to the number of times each co-benefit/trade-off was mentioned in the transcript. [Colour figure can be viewed at wileyonlinelibrary.com]

goals are stronger than the negative effects (higher IC for the co-benefits compared with the trade-offs).

3.2 | Correlation analysis

Out of 420 data pairs from the 21 selected indicators, we identified 33% positive, 21% negative, and 46% neutral correlations (Figure 4). Indicators 2.1.1 (Reduction in undernourishment), 7.1.1 (Access to electricity), 7.1.2 (Clean energy), and 13.1.3 (persons affected by disasters) had the highest proportion of co-benefits with SDG 15, while indicators 7.2.1 (Share of renewable energy), and 9.2.1 (Manufacturing value added) had the highest trade-offs. While SDG 15 had co-benefits with domestic material consumption per capita (12.2.2a), they had trade-offs with 12.2.2b (domestic material consumption) and 12.2.2c (domestic material consumption per capita).

Indicators that a had higher proportion of positive correlations with other indicators had desirable trends (i.e., trends that were in line with meeting SDG targets). For example, percent forest cover of total area (SDG 15.1.1), which has increased in Nepal from 40% to 42% between in 1990 and 2020 (Government of Nepal, 2020a), has positive correlations with other indicators that are also following desirable trends such as indicators 2.1.1 and 7.1.1. Conversely, the proportion of negative correlations were higher in SDG 12.2 (Domestic consumption), 9.2 and 7.2, whose current trends over the time period were not desirable.

3.3 | Expert elicitation

3.3.1 | Co-benefits and trade-offs between SDG 15 and other SDGs

According to the 13 informants, there was a higher proportion of co-benefits than trade-offs between interventions that aimed to achieve socioeconomic goals and environmental goals (Figure 5). A higher proportion of co-benefits (80%) were incoming (i.e., from SDG 15 toward

other SDGs) while most trade-offs (70%) were outgoing (i.e., from other SDGs toward SDG 15). Data S1 provides a synthesis of co-benefits and trade-offs mentioned by informants.

The SDGs benefiting most from progress toward nature conservation (incoming co-benefits) were SDG 8 (specifically ecotourism), because of increasing forest coverage and biodiversity. SDGs 1, 2, 4, 5, 6, 9, and 10 also benefited as a result of targeted investments of protected areas and community forests into poverty alleviation, food security, education, gender equality, sanitation, infrastructure, and participation of marginalized communities, respectively. SDG 15 in turn benefited most (outgoing co-benefits) from the increase in education and awareness (SDG 4), which led to better participation in conservation activities; ecotourism (SDG 8), which provided revenue for the operation of protected areas, and roads and infrastructure (SDG 9), which made rural areas accessible for monitoring and also increased participation.

Progress toward SDG 15 was impeded most (outgoing trade-offs with SDG 15) by measures taken toward SDG 9 through nationwide road expansion and SDG 7 through the building of hydropower infrastructures, which both led to deforestation and habitat degradation. Unregulated use of chemical fertilizers and pesticides (SDG 2) also caused pollution of rivers and streams. Measures taken to achieve progress toward SDG 15, in turn, were reported to impede progress toward SDG 1 and 2 through restricted access of local communities to income sources, and agriculture as well as grazing, respectively (incoming trade-offs).

3.3.2 | Challenges in implementing conservation activities

Informants mentioned several challenges in implementing conservation activities in Nepal. We divided them into four categories (statements are taken from the interview):

Governance

The establishment of Nepal as a federal democratic republic in 2015 allowed newly formed autonomous local governments to take major decisions within their constituency (e.g., building roads and extracting riverbed resources). These decisions were often taken without environmental considerations and have substantial impacts on ecosystems and biodiversity. The introduction of local authorities also created coordination challenges between different government sectors, stakeholders, and local communities for the management of various conservation projects. An additional challenge resulted from the use of national policies and national park management guidelines that were outdated, not completely participatory, and not contextualized.

Sociocultural

Lack of adequate participation of marginalized groups in conservation planning exacerbated poverty as conservation measures led to restrictions on income generating activities. This was mostly prevalent in geographically remote and economically isolated regions of Nepal. An additional challenge resulted from increasing human-wildlife conflicts, which exacerbated the animosity of local communities toward conservation.

Financial

The lack of financial resources and the need for comparatively more resources in mountain regions were major challenges, which were exacerbated by the lack of field-based staff resulting from the harsh working conditions. This led to ineffective monitoring of activities and to the discontinuation of conservation interventions.

Socioeconomic

In attempts to meet urgent socioeconomic requirements through, for example, energy infrastructure, increased export, and intensified agriculture, environmental considerations were not diligently incorporated, leading to trade-offs with conservation targets through, for example, deforestation, habitat fragmentation, and landscape degradation. These challenges, as well as increases in needs, standard of living, and consumption patterns were perceived as by-products of development, with which conservationists needed to balance out.

These four challenges were exacerbated by distance and climatic conditions. The implementation of participatory activities was often hindered because communities were geographically dispersed, state-based support within specific conservation programs remained inaccessible for remote communities, and because of the short working season in the high-Himalayas.

3.3.3 | Opportunities to address the challenges

Informants identified numerous opportunities to address contemporary challenges in conservation. In the short-term, a priority is to clarify the roles and responsibilities of the regulatory environment introduced by the new constitution as well as the challenges and opportunities associated with local governments. The election of many community forestry members as local government representatives, for example, offers an opportunity as these members can spearhead the coordination gap and drive the conservation and development sectors together. This can even lead to improved participatory approaches, which could potentially solve conflicts between communities and conservation actors. Additionally, the new constitution also provides the opportunity for provincial governments to develop new provincial policies for protected area governance, which can address context-specific socioecological and economic challenges and trade-offs.

Informants also emphasized the importance of incorporating biodiversity values into development efforts. For this, they stressed the need for local governments and development stakeholders to collaboratively find solutions that balance both socioeconomic and conservation needs. For example, hydropower developers could coordinate their interventions with the departments of forests and roads, respectively, to minimize disturbances by aligning transmission lines with roads and adding wildlife corridors.

According to the informants, convincing local governments about the importance of conservation emerged as an additional pathway toward a streamlined implementation of conservation actions in the long-term. Capacity building of local officials on, for instance, integrating environmental aspects in project selection criteria, or on the SDG Agenda could encourage sustainable development at the local level. Awareness and education programs on conservation to the broader public could also positively influence public support toward conservation.

3.4 | Synthesis of results

A comparison of results of interactions across the three methods at the goal level (Figure 6) showed that the interaction scores method had the highest proportion of co-benefits (78%) and the lowest proportion of trade-offs (6%), while the expert elicitation method revealed that co-benefits and trade-offs were almost equally shared (co-benefits: 54%, trade-offs: 46%). Co-benefits were lowest from correlation analysis (only 28%), partly because of a high proportion of neutral interactions (57%).

Comparing results of interaction with SDG 15 by individual SDGs (Figure 7), we found the following:

- Although SDG 12 showed the greatest co-benefit based on SDG interaction scores, it exhibited a greater percentage of trade-offs according to correlation analysis and was reported to have no interactions by informants from expert elicitation.
- Likewise, SDG 17 and 13 demonstrated numerous co-benefits according to SDG interaction scores, which was not reflected in the other two methods.
- SDG 7 and 9 had a high proportion of trade-offs with SDG 15 based on all three methods and SDG 2 had the highest proportion based on both argumentative methods.
- Overall, co-benefits with SDG 15 were generally high for SDGs 1, 3, 4, 5, 6, 8, 10, 13, and 16 whereas trade-offs with SDG 15 concentrated on SDGs 2, 7, and 9 (Figure 7).

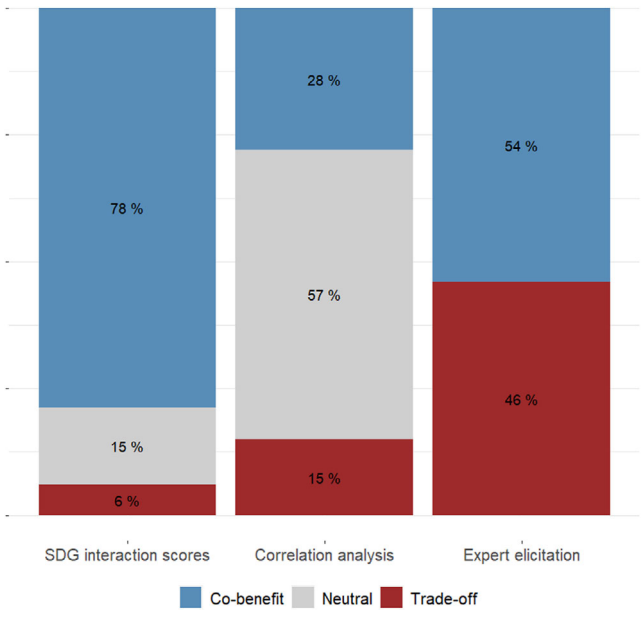

FIGURE 6 An overall synthesis of co-benefits, trade-offs, and neutral interactions between SDG 15 and other SDGs from the three different methods applied in the study. [Colour figure can be viewed at wileyonlinelibrary.com]

4 | DISCUSSION

4.1 | Insights from a Nepalese case study

In line with others, we found that co-benefits between SDGs were more numerous than trade-offs, irrespective of the approach adopted (Breu et al., 2021; McCollum et al., 2018; Pradhan et al., 2017; Warchold et al., 2021) and that conservation and development goals are largely synergistic with each other (Aryal et al., 2020).

Both argumentative methods showed that SDG 15 shared the highest mutual co-benefit with SDG 8. Specifically, protecting terrestrial biodiversity promoted eco-tourism (SDG 8.9). This is consistent with other findings that eco-tourism and conservation are synergistic in different contexts (Mossaz et al., 2015; Olmsted et al., 2020). Specifically for Nepal, the increase in eco-tourism was attributed to habitat restoration near protected areas (den Braber et al., 2018). The mutual co-benefits between these two goals indicates a positive feedback loop. Based on the number of outgoing and incoming co-benefits detected with the argumentative methods, another possible positive feedback loop exists between SDG 15 and SDG 4 (Quality education) (Figures 2 and 5). Education and awareness is one of the major levers toward biodiversity conservation in local communities (Bhattarai & Fischer, 2014; Karanth & Nepal, 2012; Pérez et al., 2019) and revenues from conservation activities are in turn essential to support education. Significant portions of community conservation revenue in Nepal are already allocated toward supporting education, including initiatives such as teacher remuneration and school infrastructure development (Aryal et al., 2020; Bhandari et al., 2019). This highlights both that achieving SDG 4 targets is important for advancing SDG 15 and that actions taken toward SDG 15 are critical to achieving SDG 4.

We detected additional co-benefits between SDG 15 and SDG 6, likely because SDG 15.1 integrates conservation and restoration of freshwater ecosystems, which can ultimately contribute toward improving water availability (Vörösmarty et al., 2018). Finally, the co-benefits we detected between SDG 15 and SDG 5 and 10 might be due to community forestry policies that stipulate that at least 50% of the executive committees' positions need to be filled by women and that implementation programs need to be focused on economically and socially marginalized groups (Sapkota et al., 2020), which helps

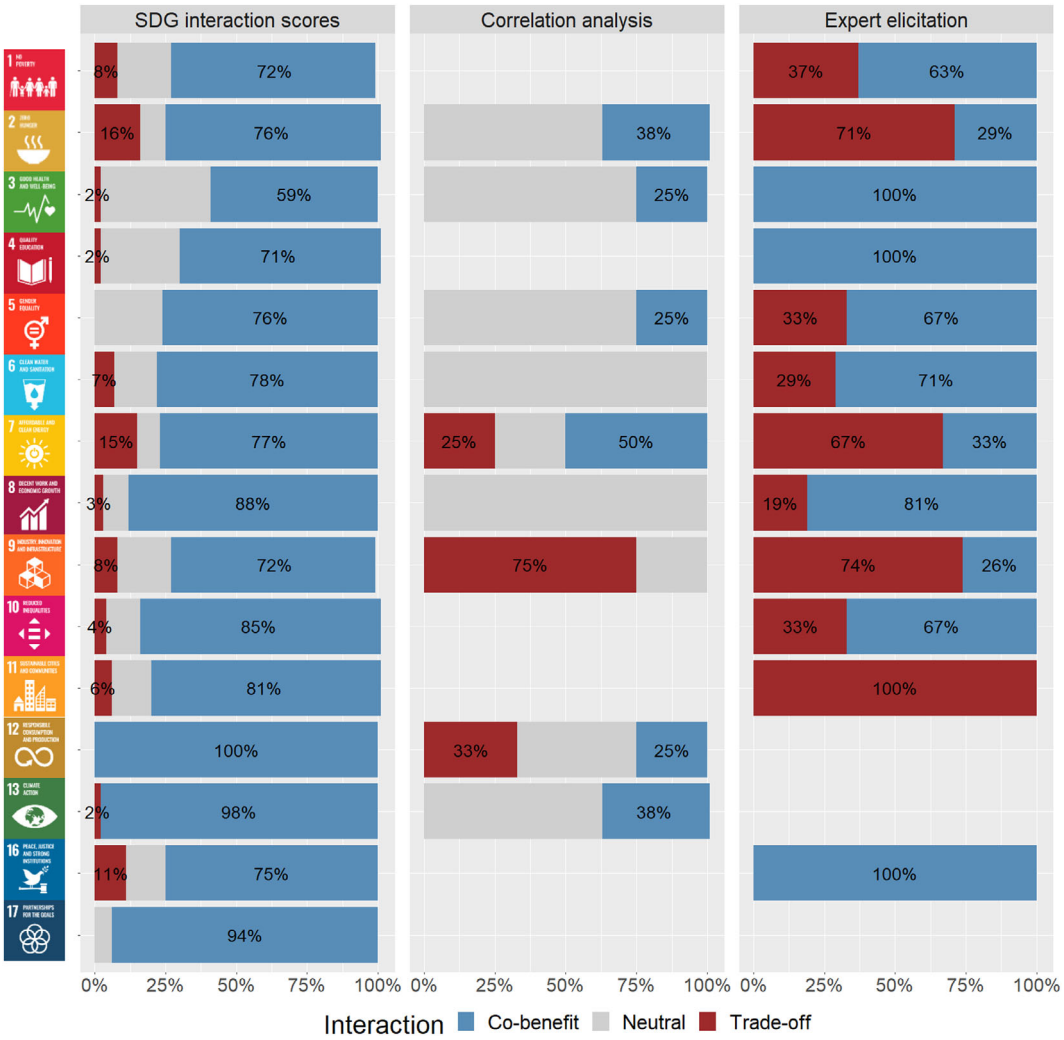

FIGURE 7 A synthesis of co-benefits, trade-offs and neutral interactions between SDG 15 and other goals from the three different methods applied in this study by individual SDGs. Co-benefits in blue, trade-offs in red, neutral in white, and no fill for interactions with no data. [Colour figure can be viewed at wileyonlinelibrary.com]

empower women and marginalized communities (Sapkota et al., 2019).

As for trade-offs, all three methods detected trade-offs between SDG 15 and SDGs 7 and 9. Infrastructure projects in Nepal, particularly road expansion, is one of the leading causes of habitat degradation, fragmentation, spread of invasive species, and consequently biodiversity loss (Adhikari et al., 2020; Adhikari et al., 2022; Quintana et al., 2022). Infrastructure development has also been found to be the biggest source of trade-off for SDG 15 in another global study (Mantlana & Maoela, 2020). Additionally, energy infrastructure, particularly hydropower, is associated with deforestation in the wider Himalayan region (Verma et al., 2021). SDG 15 meanwhile, was found to negatively impact the achievement SDG 1 and SDG 2 in some instances. These negative effects stemmed from conservation activities that restrict access to forest resources, farming, and grazing. Other studies have also reported that these restrictions hinder progress toward poverty alleviation, food security, and social equality (Aryal et al., 2020; Dhakal & Thapa, 2015). In line with previous research (Bhattarai et al., 2019; Bhattarai & Fischer, 2014), other trade-offs involved increase in wildlife (from successful conservation measures) that resulted in crop depredation, economic losses, and human injuries and fatalities.

4.1.1 | Differences across the three methods

The three methods produced some conflicting results (see Section 3.4). The interaction scores method revealed co-benefits between SDGs 15 and 12 while correlation analysis showed trade-offs. One reason for this is the data used. Different units of measurement of indicator 12.2.2 produced differing results from the correlation analysis. Thus, interpretation of results from correlation analysis should consider the source and unit of data used, since detection of interactions from correlation is sensitive to the data used (Warchold et al., 2022). Another reason may be because sustainable production and consumption is conceptually linked to better environmental health (e.g., see Adhikari & Prapaspongsa, 2019; Akenji & Bengtsson, 2014), which

might be why experts assigned co-benefits between the two goals. However, Nepal's plan to graduate from a least-developed country status means that it needs to achieve certain economic objectives, including an increase in domestic material production and consumption (Baniya & Aryal, 2022), which is at odds with SDG 12 targets. So, although ideally SDG 12 and 15 are synergistic (cf. interaction scores), increasing material production and consumption of developing countries in particular (United Nations Statistics Division, 2021) leads to trade-offs between the two goals (cf. correlation analysis).

Another difference in results was the interaction between SDG 15 and SDG 13. Consistent with other studies (Breu et al., 2021; Pham-Truffert et al., 2020), the interaction scores and correlation analysis found that SDG 13 co-benefitted SDG 15. However, this correlation was barely mentioned in the expert elicitation method. This may be because informants focused on local contexts, while progress toward SDG 13 likely synergize with SDG 15 at regional or global scales (e.g., see van Soest et al., 2019).

Generally, the interaction scores detected a higher frequency of co-benefits than trade-offs in comparison to the other two methods. This may be because when we asked experts how the achievement of one SDG affects another, they might have inherently referred to prospective interactions if interventions were sustainably carried out, as framed by the 2030 Agenda (Urban & Hametner, 2022). An implication of this is that asking people to score interactions based on what has happened in practice, rather than what would ideally happen, will give different responses. Therefore, a degree of caution is required while interpreting results of interactions derived through expert opinions (Breuer et al., 2019; Nilsson et al., 2018), since differently phrased questions can yield different results (Sutherland & Burgman, 2015).

4.2 | Opportunities for addressing conservation and development trade-offs in Nepal

Progress toward SDG 15 in Nepal is influenced by the achievement of other goals. Road development (SDG 9), in particular, is a significant threat to future conservation efforts in Nepal, as the country aims to expand its road infrastructure significantly over the next decade, including through protected areas (Quintana et al., 2022). Similarly, despite examples of the negative impacts of hydropower projects (SDG 7) on biodiversity and the environment (Anderson et al., 2018; Jumani et al., 2017), more than half of all future hydropower projects lie within Nepal's highly biodiverse areas (Ghimire & Phuyal, 2022).

Trade-offs are not inherent to targets or goals themselves, but rather stem from inadequate governance and lack of coordination among different sectors (Breuer et al., 2019). We found that SDG 15 is a buffer of trade-offs at the systemic level, in line with other global studies (Huan & Zhu, 2022; Pham-Truffert et al., 2020), meaning that addressing challenges to SDG 15 will largely depend on actors from other sectors considering and addressing trade-offs between SDG 15 and other goals. Therefore, policy-makers responsible for SDG 15 need to work together with relevant ministries and departments across all levels of the government, especially including Nepal's Ministry of Energy, Water Resources and Irrigation, and Ministry of Physical Infrastructure and Transportation in this case. Bowen et al. (2017) suggest various ways to do this, including collaboration, secondments of officials across ministries, cross-sectoral training, and co-production of knowledge through research.

Even with collaboration, a win-win situation is not always possible, and difficult compromises are inevitable (Bowen et al., 2017). As Nepal is a low-income country, its government prioritizes socio-economic development with various nation-wide infrastructure projects, while subsistence requirements will always be a priority for local communities (Sharma et al., 2018), despite generally high awareness and positive attitudes toward biodiversity and conservation (Dhungana et al., 2022; Hanson et al., 2019). However, if key interlinkages across SDGs are identified, conservation officials can negotiate compromises with relevant actors to generate outcomes that minimize trade-offs. The compensatory plantation of trees felled by development projects that is already ongoing is one outcome of such negotiations. However, in practice, development projects rarely comply with environmental considerations, even though they are mandated by environmental impact assessments (Ghimire et al., 2021). Accordingly, conservation stakeholders in the government need to coordinate with local governments to ensure that compensatory measures are enforced and trade-offs are thereby minimized.

Conservation interventions, in turn also need to be considered in the light of the negative impact they have on goals such as poverty and hunger-reduction. These impacts often stem from a failure to include the diverse needs and values of communities that directly depend on nature for their wellbeing (Chaudhary et al., 2018). All measures taken to achieve all SDGs, including SDG 15, are likely to benefit from placing considerable emphasis on including poor and marginalized communities in the decision-making process (Bowen et al., 2017; Henfrey et al., 2023), since this can not only contribute toward ameliorating trade-offs, but also drive the success of any conservation activity (De Jong et al., 2018).

Finally, there are other opportunities for Nepal to achieve the SDG 15. Existing successes in conservation are mostly limited to protected areas (e.g., Nepal has already met target 15.1, including meeting its targets on forest coverage and protected area coverage (Government of Nepal, 2020a)). However, there is still ongoing habitat destruction affecting biodiversity outside of these areas (Government of Nepal, 2018). Nepal already has existing landscape-based conservation measures focusing on connectivity of wildlife corridors, as wells as on prioritizing community livelihood (Government of Nepal, 2016). The expansion of conservation landscapes along with other Effective Area-based Conservation Measures offers viable alternatives for Nepal to expand protected area coverage and simultaneously preserve traditional landscapes and indigenous territories (Gurney et al., 2021).

4.3 | Methodological considerations

Following previous recommendations (McCollum et al., 2018; Pradhan, 2023; Pradhan et al., 2017), we applied multiple methods for

identifying SDG interactions. Argumentative methods are effective in detecting the direction, polarity, and degree of interactions, providing the flexibility to include context-based quantitative and qualitative information, and are easily interpretable (Horvath et al., 2022). Although the Nilsson scale does not typically allow for the detection of directionality of interactions (Horvath et al., 2022), we specifically asked experts to rate bi-directional interactions, thereby ameliorating this methodological limitation. In view of the fact that structured elicitation of expert knowledge is one of the most effective methods for revealing contextualized SDG interactions (Horvath et al., 2022), we included in-depth interviews to obtain rich qualitative information on interactions and the possible reasons behind them. Finally, the availability of national data on SDG indicators in Nepal allowed us to incorporate correlation analysis as a statistical method, since it provides easily interpretable quantitative information on possible interactions with relatively limited time and effort (Horvath et al., 2022). While the multi-methods approach to assessing SDG interactions is increasingly adopted, our study is among the few that apply three rather than two methods simultaneously (Horvath et al., 2022).

A trade-off of involving independent experts in scoring interactions between the SDGs through an online survey, is that we had to be mindful of not overburdening experts with too many interactions to score, and thus restricted our focus on interactions with a single SDG (SDG 15) and not between all SDGs. Focusing on more SDGs would have required each expert to rank interactions between 380 target pairs and a substantially larger sample size of experts. This still could not completely address biases since we used purposive sampling in the online survey. However, the method can produce insightful results for advancing a particular SDG, taking into account its interrelationship with other goals. Additionally, since a majority of experts and informants for our argumentative methods come from the conservation background, our insights are limited to a conservation lens. This bias could potentially influence the perceived co-benefits and trade-offs in our results.

Selection of priority targets, particularly during deliberations between co-authors, also involved a certain degree of subjectivity. Since it is not always possible to provide a comprehensive assessment of all interactions across all targets (Nilsson, 2017), most studies select relevant targets as the first step in the interaction scoring approach (although there are examples of studies that take into account all possible interactions; see Pradhan et al., 2021). This might lead to important interactions being left out of the study. Systematic methods for target selection (e.g., see Breu et al., 2021) require additional participants, time, and resources. In case of a lack thereof, defining criteria for target selection and filtering them through national priorities and deliberation, as we have done, appears to be an acceptable alternative.

5 | CONCLUSION

Successfully achieving the 2030 Agenda requires nations to adopt innovative policies that benefit multiple SDGs, and identify solutions to address trade-offs between competing goals. A suite of tools for recognizing potential co-benefits and trade-offs already exists in the literature. In our case study, we have provided an example of how multiple tools can be used and complement each other to identify such synergies and trade-offs as well as opportunities for the conservation sector of Nepal. Specifically, addressing trade-offs between road and energy infrastructure development and conservation objectives through multi-sectoral collaboration and negotiations is urgently needed. Additionally, to avoid negative consequences on other socio-economic goals such as poverty alleviation and food security, conservation interventions need to be people-focused, participatory, and guided by contextualized policies.

The combination of SDG interaction scores, correlation analysis, and expert elicitation proved to be effective in gathering broad ranging qualitative and quantitative information on interactions between conservation and development goals for Nepal. The suite of methods we used can be complementarily used to investigate interlinkages with a focus on a different goal, and for different countries at national, sub-national or regional scales.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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Paper III: Linking nature's contributions to people and human wellbeing: a study on social perceptions in Eastern Nepal

Linking nature's contributions to people and human wellbeing: a study on social perceptions in Eastern Nepal

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Abstract

1. The declining state of biodiversity and nature's contributions to people (NCPs) calls for effective conservation measures that consider the needs, priorities, and perceptions of multiple stakeholders.
2. Using qualitative and quantitative data from semi-structured household surveys, we investigated social perceptions of nature and NCPs along an elevational gradient in eastern Nepal. We used linear and ordinal regressions to identify the factors influencing these perceptions, and qualitative analysis to understand NCP preferences of local communities.
3. NCP perceptions were the most positive in the mountains, which is predominantly inhabited by communities with a strong dependence on nature for their wellbeing. Higher levels of education, perceived wellbeing, and happiness also influenced positive perceptions towards NCPs.
4. 'Energy', 'regulation of freshwater quality', 'regulation of air quality', 'food and feed', 'supporting identities', and 'physical and psychological experiences' were the most frequently cited NCPs contributing to household wellbeing. Among nine wellbeing dimensions, NCPs were reported to contribute the most to cultural identity and recreation.
5. Our results reinforce the need for conservation interventions to be contextualized and participatory, particularly involving women and marginalized communities. Results also imply that interventions enhancing landscape multifunctionality and integrating ecotourism and conservation education are more likely to receive public support.
6. We show that social perception studies designed to uncover nuanced stakeholder needs and priorities are crucial in identifying effective conservation measures.
7. The NCP framework proved useful for studying social perceptions at the local level using semi-structured household surveys.

Keywords: ecosystem services, nature's contributions to people, conservation, biodiversity, Nepal, perception, attitude, Sustainable Development Goals.

1 INTRODUCTION

Biodiversity and nature's contributions to people (NCPs; Díaz et al., 2018) are essential for achieving international commitments such as the United Nations Agenda for Sustainable Development (Anderson et al., 2019; Blicharska et al., 2019) and the ambitious goals defined in the Montreal-Kunming Global Biodiversity Framework (Conference of Parties to the CBD, 2022). However, rapid declines in biodiversity and decreasing access to NCPs for many people whose wellbeing directly depend on them, call for the design and implementation of effective management and conservation measures (Leclère et al., 2020).

Direct dependence on NCPs is particularly strong for local communities living in a rural areas (Iniesta-Arandia et al., 2014). Their engagement in conservation and management of natural resources is thereby directly motivated both by a fundamental need to maintain continual access to the NCPs they value and depend on, and by their relationship to nature (Castro et al., 2016; Karimi et al., 2020; Lescourret et al., 2015). Accordingly, a lack of knowledge on social representations of what nature and biodiversity mean for local communities can lead to misunderstandings and barriers between these communities and the different actors of conservation and natural resource management, resulting in push-back against conservation interventions (Bernardo et al., 2021). Conversely, conservation efforts that consider the perceptions and needs of local communities are typically ecologically effective, socially equitable, culturally appropriate, and politically viable (Bennett et al., 2017). Such efforts result in more positive attitudes towards conservation and ultimately lead to interventions that are beneficial for nature and people alike (Eklund & Cabeza, 2017).

Both social perceptions on nature and biodiversity as well as conservation priorities tend to widely differ depending on the type and condition of the landscapes and ecosystems in which people live (Bernardo et al., 2021) and according to education levels (Kideghesho et al., 2007; Manfredo et al., 2020). Moreover, people's perceptions and priorities regarding biodiversity and natural resources differ, and often compete based on social, economic, cultural as well as geographic factors (Caballero-Serrano et al., 2017; Elwell et al., 2018; Riechers et al., 2018). Therefore, to account for such differences and minimize conflicts between conservation objectives and the specific needs and constraints of local communities (Silva & Lopes, 2015), social perceptions are best collected along socio-economic gradients (Caballero-Serrano et al., 2017; Manfredo et al., 2021).

In Nepal, national scale research on the state of ecosystems shows that biodiversity and most NCPs are declining all across the country as a result of land-use change, overexploitation of resources, and climate change (Adhikari et al., 2022). This has resulted in increasing conflicts related to resource use, inequality, and poverty (Chaudhary et al., 2018; Dhakal et al., 2022). Hence, conservation measures are urgently

needed to bend the curve of biodiversity degradation and loss, and to fulfil the country's sustainable development agenda in the context of conflicting interests between socio-economic and environmental goals (Adhikari et al., 2023). However, various factors are hampering effective conservation in Nepal, including inadequate information on the needs and priorities of local communities, a lack of adequate participation of all stakeholders (Adhikari et al., 2023), and an insufficient integration of cultural and non-material NCPs in the design of conservation interventions (Chaudhary et al., 2019).

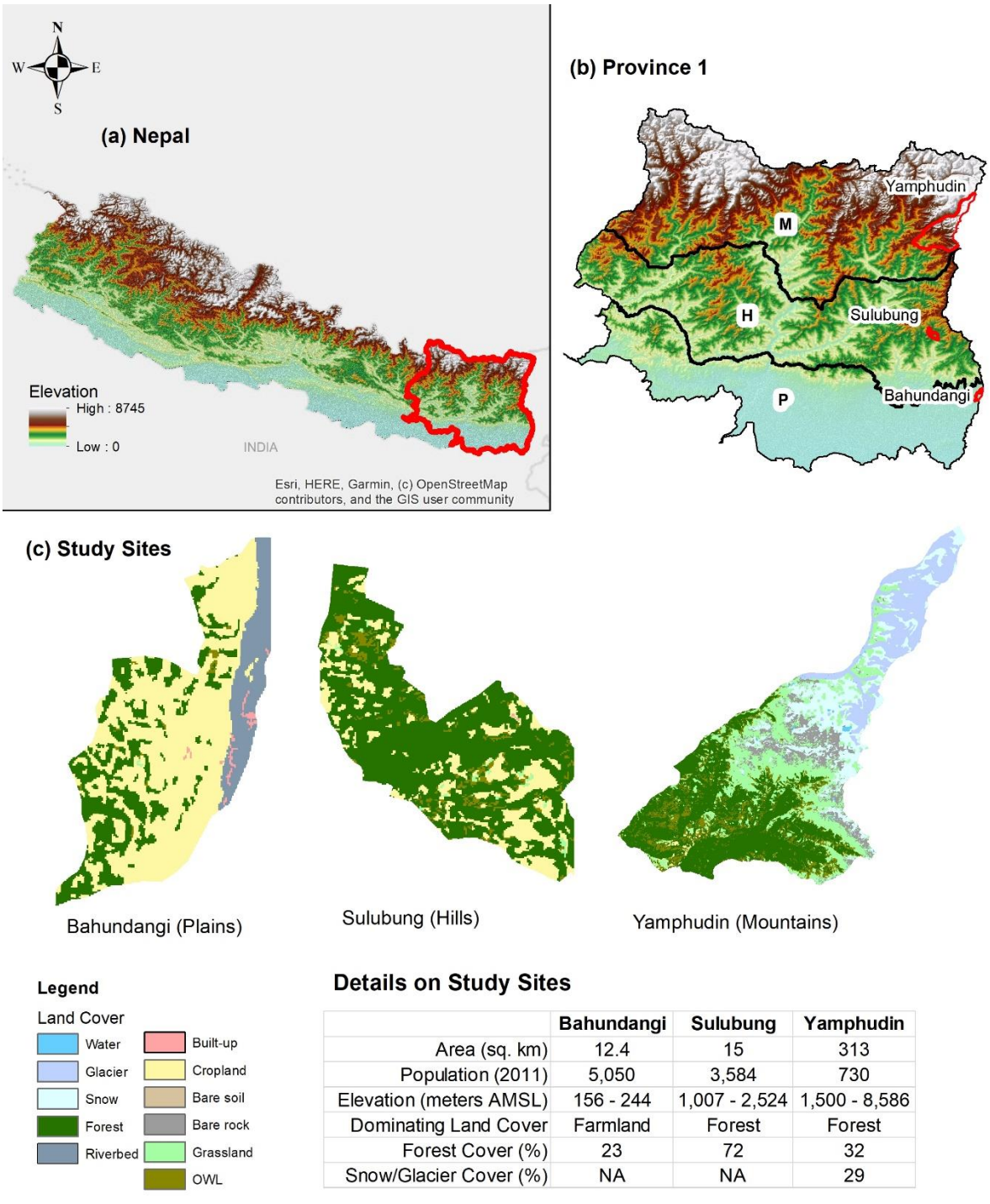
To address the current lack of information on the needs and priorities of local Nepalese communities, on the perceived linkages between NCPs and human wellbeing, and on changes in nature, we conducted a household survey in three villages of Nepal situated along an elevational and socio-economic gradient. Our objective was to understand how local communities perceive the contribution of nature towards their wellbeing and what socioeconomic variables explain potential differences in perception, with a particular focus on location, education levels, and perceived wellbeing. By doing so, we contribute to the literature on social perceptions of nature and its contribution to human wellbeing along socio-economic gradients, and provide an additional lens to complement knowledge and values captured through natural sciences (Hill et al., 2020; Tengö et al., 2017).

2 METHODS

We conducted household surveys in three locations in Eastern Nepal between January and February 2022. The survey consisted of both qualitative and quantitative questions, and we analysed the results following a mixed-methods approach. We performed quantitative analysis using R v. 4.1.2 (R Core Team, 2022) and qualitative analysis using MAXQDA v. 20.4.1 (VERBI Software, 2021).

2.1 Study area

Our three study sites – Bahundangi (plains), Maipokhari (hills), and Yamphudin (mountains) (Fig. 1) – follow an elevational and ecological gradient along the North-South transect of Province 1, eastern Nepal. The three sites span across an elevational gradient of approximately 4,000 meters, and fall within the Kangchenjunga Transboundary Landscape, which is considered to be one of the most complex ecosystems of Nepal, and representative of climatic, ecological, and socio-economic data across the wider Hindu Kush Himalayan region (Chettri et al., 2012). Details are presented in supplementary material S1.



Details on Study Sites

	Bahundangi	Sulubung	Yamphudin
Area (sq. km)	12.4	15	313
Population (2011)	5,050	3,584	730
Elevation (meters AMSL)	156 - 244	1,007 - 2,524	1,500 - 8,586
Dominating Land Cover	Farmland	Forest	Forest
Forest Cover (%)	23	72	32
Snow/Glacier Cover (%)	NA	NA	29

Figure 1: (a) Map of Nepal showing the location of Province 1; (b) map of Province 1 showing the tree study sites, representative of 3 ecozones of Nepal – mountains (M), hills (H), and plains (P). Both are superimposed with a digital elevation model; (c) the study sites – Bahundangi, Sulubung, and Yamphudin, superimposed with a land-cover change map. The figures in (c) are not to scale.

2.2 Survey design

We used population data from the most recent census (Government of Nepal, 2011) to determine the total number of households in each village and conducted the survey on a sample of households through random walks, which are preferable when sampling frames are unavailable (Jones, 2007; Lau et al., 2021). Over the course of the two months, we collected data from 211, 210, and 151 (total 572) households in the plains, hill, and mountain sites, respectively. The 45-90 min survey was conducted in Nepali by five to eight local enumerators per site.

Since nature is typically defined differently by people from different places, communities, ethnicities, and culture; we started the interviews by asking each participant for an own definition (Coscieme et al., 2020; Ducarme & Couvet, 2020). To uncover whether participant's definition of nature affected their perceptions, we coded their definitions into four exclusive categories, including 'living', 'non-living', 'living and non-living', and 'abstract and spiritual'.

We defined household wellbeing by nine dimensions: (i) food sufficiency (ii) income sufficiency, (iii) good health, (iv) access to water, (v) access to energy, (vi) education, (vii) resilience from natural disasters, (viii) engaging in recreation, and (ix) cultural identity, based on the definition of 'good quality of life' used in the IPBES conceptual framework (Díaz et al., 2015), the SDGs, and through prioritizations and various rounds of discussions among co-authors and other researchers, as well as multiple rounds of piloting. To understand local communities' perceptions on the importance of NCPs for household wellbeing (NCP perceptions), we asked how nature contributes to each of the nine dimensions in a 5-point Likert scale (1 – Helps a lot; 2 – Helps a bit; 3 – Has no effect/I don't know; 4 – Harms a bit; 5 – Harms a lot). We assessed the drivers of the nine NCP perceptions through ordinal regression analysis (Section 2.3) and followed up on their answer with an open-ended question on why they gave that rating for qualitative analysis (Section 2.4).

We collected information on potential drivers (explanatory variables) of NCP perceptions (response variables), including location, eight indicators of household wellbeing (sufficient food, income, access to drinking water, health, electricity, energy, and education, and whether the household had gone through a natural disaster in the last ten years), and eight demographic indicators (participant's age, caste, level of education, gender, occupation, percent of household food obtained from farming activities, tropical livestock units, a standardized measure of amount of livestock owned; see Cedamon et al., (2017), and price of land owned). The analysis incorporated the caste variable because individuals' identity within the Hindu hierarchical caste system or as ethnic groups not within the caste system was observed to have diverse

social attitudes towards natural resource management (Chaudhary et al., 2018). See S1 for details and descriptive statistics of explanatory variables.

In addition to treating each NCP perception independently and to have an overall understanding of people's attitude towards NCPs, we calculated the mean of the nine NCP perceptions as an attitude score. To ensure that the individual NCP perceptions measured the same underlying construct before combining multiple Likert items (Croasmun & Ostrom, 2011), we assessed the internal consistency and reliability of the nine items by calculating Cronbach's alpha (Tavakol & Dennick, 2011). Given the resulting value of 0.79 (values between 0.7 and 0.95 indicate sufficient consistency; Bland & Altman, 1997), we decided to use the attitude score as the response variable for the multiple linear regression.

2.3 Statistical analyses: linear and ordinal regression

We conducted one linear (with the attitude score as response variable) and nine ordinal regressions (one for each of the nine NCP perceptions) to understand the drivers of NCP perceptions.

Out of 572 households, 101 (17%) had missing data for at least one explanatory variable due to participant reluctance or enumerator error. To avoid information loss and biased estimates due to incomplete data (Penone et al., 2014), we imputed the missing values (Nakagawa, 2015; Nakagawa & Hauber, 2011) with a random forest algorithm using the "missforest" package (Stekhoven & Bühlmann, 2012). We conducted 50 imputations each for the response and explanatory variables, replacing the missing numerical values with the mean of the 50 imputations, and missing categorical variables with the most frequently imputed class.

We checked for multi-collinearities between independent variables (Harrell, 2001) using Pearson, polyserial, and polychoric correlations through the "polycor" package (Fox, 2022) and a commonly used threshold of 0.7 (Dormann et al., 2013). We found high correlations between location and caste (-0.67) and therefore decided to retain location as a proxy for both caste and location. We also performed a sensitivity analysis replacing location with caste to determine the impact of interchanging the location and caste variables on the effect estimates (Table S2).

To use the same set of explanatory variables across the 10 regression models, we conducted model selection on the NCP attitude score among the 17 explanatory variables (excluding caste). Since we were especially interested in understanding variations in perceptions based on location, education levels, and perceived wellbeing, we defined a set of eight variables which were included in all models because they were central to our research question. These were location, education, food and income sufficiency, perceived health, access to water and energy, and participants' history with natural disasters. We further subjected the

remaining nine variables, and the interaction effects between location and other essential variables (i.e., location and education, location and food sufficiency, location and income sufficiency, …, location and history with natural disasters).

We used the "MuMIN" package (Barton, 2022) for model selection, calculating the Akaike Information Criterion (AIC) of every possible combination of these variables, and selected the best models whose AIC were within 2 units of the lowest AIC (Burnham & Anderson, 2004). Given the number and complexity of the models, we did not use model averaging but selected the most parsimonious model from this set. We performed a sensitivity analysis to evaluate the stability of estimates across the set of best models (Table S3). The selected model included three additional variables: gender, the percentage of household food derived from farms (FarmPercent), and perceived overall happiness on a 0-10 scale (Happiness), as well as two interaction effects (Location * Healthy and Location * IncomeSufficiency):

$$\begin{aligned} NCP\ Index = {} & \beta_o + \beta_1.Location + \beta_2.Education + \beta_3.FoodSufficiency \\ & + \beta_4.IncomeSufficiency + \beta_5.Healthy + \beta_6.WaterSufficiency \\ & + \beta_7.EnergySufficiency + \beta_8.FreeFromDisasters + \beta_9.Gender \\ & + \beta_{10}.FarmPercent + \beta_{11}.Happiness + \beta_{12}Location * HealthStatus \\ & + \beta_{13}.Location * IncomeSufficiency + \epsilon \end{aligned}$$

The same model was used for the nine ordinal regressions, where we replaced the continuous NCP index score by the discrete NCP perception scores for each of the nine wellbeing variables.

2.4 Qualitative analysis

The first author translated all qualitative answers in English. We then used the 18 NCPs defined by Díaz et al. (2018) to code participants' responses on the aspects of nature that contributed to the nine wellbeing dimensions. By doing so, we were able to identify the NCPs that were commonly mentioned by participants as well as link them with the various dimensions of wellbeing. For example, we categorized the response "*We get medicinal herbs from nature which we can sell*" as Medicinal, biochemical and genetic resources → Income.

2.5 Research ethics

As there was no local research ethics committee available to approve the proposed household survey, we obtained oral consent from participants about the use of their anonymized responses in scientific publications prior to commencing the survey. There are no responses in the manuscript that could potentially lead to the identification of participants.

3 RESULTS

3.1 Demographic characteristics

We surveyed 304 female (53%) and 267 male (47%) participants (Table S1). 110 participants were illiterate (19%), 254 participants had basic literacy (44%), 127 participants completed primary education (22%), and 80 (14%) participants completed secondary education or more. According to our classification of caste, 229 (40%) participants were of the ‘higher’ caste, 37 (7%) participants were of the ‘lower’ caste, and 305 participants (53%) belonged to ethnic groups that do not fall under the Hindu hierarchical caste structure. The average age of respondents was 45 years (SD = 15). Demographic traits are representative to Province 1 of Nepal.

3.2 Quantitative results

3.2.1 Proportion of responses

About half of the participants (51%) believed that nature has a positive impact on their wellbeing, with 23% responding that it "helps a lot" and 28% stating that it "helps a bit" (Fig. 2). Likewise, 37% gave neutral responses or indicated that they did not know and 12% perceived nature as having a negative effect, with 10% reporting that it "harms a bit" and 2% stating that it "harms a lot".

Overall, nature's contribution towards culture received the highest proportion of positive responses (69%), closely followed by recreation (66%), energy (66%), and food (50%) (Fig. 2). Conversely, the highest proportion of negative perceptions towards nature were towards education (22%), income (24%), food (19%), and health (18%). We also found that many participants were uncertain or neutral towards nature's contribution to protection from disasters (56%), education (50%), and health (40%).

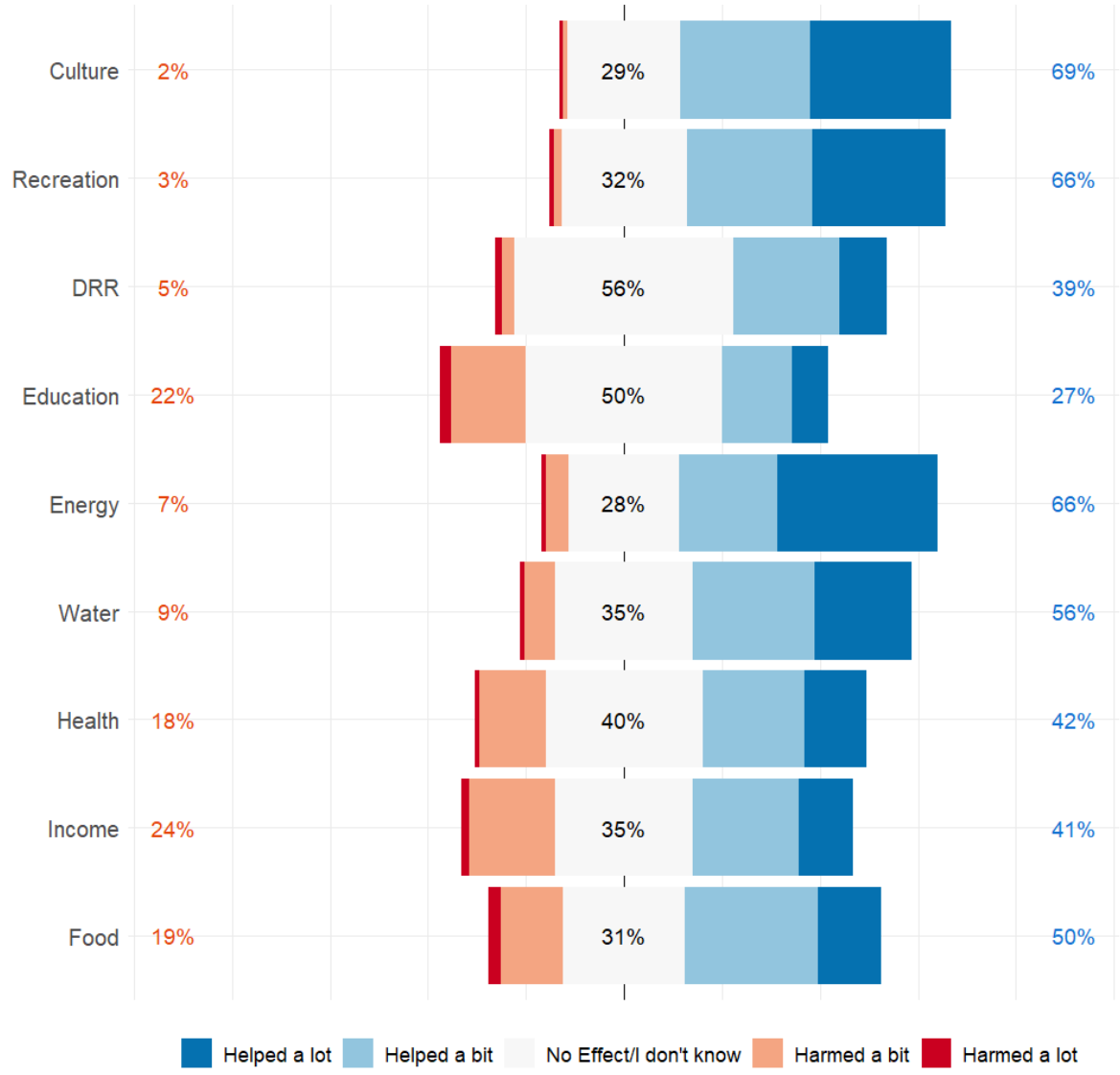


Figure 2: Proportions of Likert-scale answers received from participants. The percentages in the left (in red), centre (in grey), and right (in blue) of each bar indicate percentages of negative, neutral, and positive responses towards nature's contributions, respectively.

3.2.2 Results of linear and ordinal regressions

The adjusted R^2 of our linear model was 0.469 (F-Statistic: 28.95 on 18 and 552 df; $p < 0.01$). The linear regression model did not violate any assumptions of multicollinearity (variation inflation factor for all model covariates < 2), linearity, homoscedasticity, and normality (see diagnostic plots in supplementary material). The sections below detail the results of linear (Table 1) and ordinal (Table 2) regressions.

3.2.2.1 Variations in perceptions across location, education level, and perceived wellbeing

The multiple linear regression analysis (Table 1) showed that the location of participants had the strongest influence on NCP attitude score (Fig. 3a). Although overall NCP perceptions were positive across all three regions, individuals living in the mountain site (predominantly people from ethnic backgrounds that did not fall under the Hindu hierarchical structure) had the most favourable attitudes, followed by those in the hills (predominantly belonging to "higher" and "lower" castes) and plains (mixed castes; $p < 0.01$).

Ordinal regression analysis (Table 2; Fig. 3b) indicated that the relatively high positive NCP perceptions held by mountain inhabitants in comparison to those from plains applied to all nine wellbeing dimensions. Participants from the hilly region, meanwhile, had comparatively more positive NCP perceptions towards water, energy, education, and disaster protection in comparison to participants from the plains, and had the most positive NCP perceptions towards culture and recreation compared to participants from the plains and mountain locations.

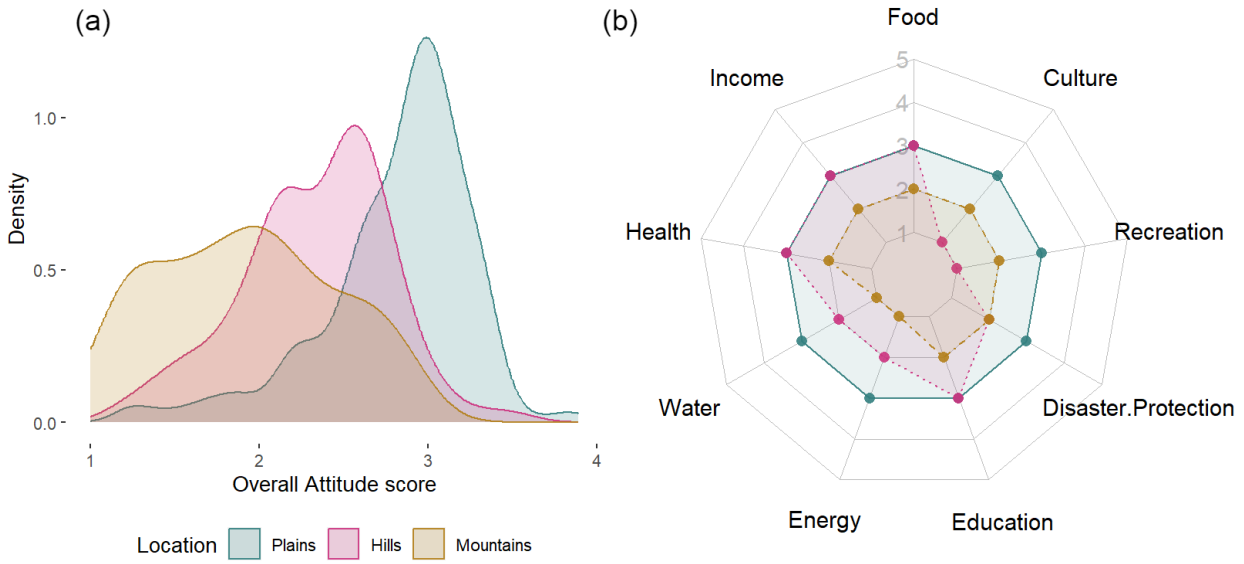


Figure 3: (a) Density Plot of the Overall Attitude Score by location. (b) Radar chart showing the median Likert scores of participants by location. As we progress from 1 to 5, the perception progresses from positive to negative.

Likewise, our analysis indicated that there was a positive link ($p < 0.01$, Table 1) between higher education levels (secondary education and above) and positive NCP perceptions, particularly regarding food, income, and recreation (Table 2). We also found that participants who had better access to necessities generally had more favourable perceptions. Linear regression showed that individuals with sufficient income ($p<0.01$), energy ($p=0.021$), and better perceived health ($p=0.015$) had more positive NCP perceptions (Table 1). However, the association between better perceived health and favourable NCP perception was the opposite

in the hill region (p=0.019). Similarly, in the mountain region, participants with better access to water had more positive NCP perceptions, while there was no such association in the other two locations ($p < 0.01$).

These results were further supported by the ordinal regression. Participants who perceived that their household's wellbeing was high with regards to income, health, water, and energy were 1.5, 1.8, 2.2, and 2.2 times more likely to have favourable NCP perceptions towards income, health, water, and energy, respectively, making them the most important predictors. Energy access was particularly important in mountains, where participants having sufficient energy for cooking were four times more likely to have positive NCP perception towards energy. Additional links that were particularly strong in mountains were detected between NCP perception towards education, recreation and culture and access to water.

3.2.2.2 Other drivers of NCP perceptions

We found that irrespective of location, male participants had more favourable attitudes towards NCP ($p<0.01$; Table 1) and favourable perceptions particularly towards health, water, energy, education, and protection from disasters (Table 2). Moreover, respondents who reported higher levels of happiness also had more favourable NCP perceptions ($p<0.01$; Table 1), particularly towards food, health, and energy (Table 2). Finally, participants who had higher food self-sufficiency (i.e. higher farm percent) also had more favourable attitudes towards NCP ($p < 0.01$; Table 1). Participant occupation, definitions of nature, and land and cattle holding size had no influence on NCP perceptions.

3.2.2.3 Sensitivity Analysis

When replacing location with caste, the overall direction and size of the effects remained constant (Table S2). Caste was the most important predictor of an individual's attitude towards NCP, with people from higher and lower castes exhibiting more unfavourable attitudes towards NCP ($\beta = 0.32$ and 0.30, respectively), compared to communities belonging to ethnicities outside of the caste system. The adjusted R^2 of the model with caste (0.284) was lower than that of the model with location (0.469), which supports our decision to focus on location as a primary predictor and interpreting the location effect as a combined effect of both location and caste since we could not fully disentangle them with our study design.

Table 1: Results of Linear Regression on NCP attitude score. Negative attitude increases as the attitude score increases from 1 to 5 (positive estimates indicate shifts towards negative attitude and negative estimates indicate shift towards positive attitude). Significant effects are highlighted in green (more positive attitude) and red (more negative attitude).

	Estimate	**Std.Error**	**t value**	**P-value**
(Intercept)	3.018	0.089	33.952	0
Location Hill (Sulubung)	-0.412	0.064	-6.48	0
Location Mountain (Yamphudin)	-0.835	0.064	-13.151	0

Gender Male	-0.098	0.037	-2.626	0.009
Happiness	-0.025	0.009	-2.655	0.008
Farm percent	-0.002	0.001	-2.502	0.013
Food sufficiency No	-0.044	0.08	-0.552	0.581
Income sufficiency No	0.094	0.039	2.401	0.017
Healthy No	0.15	0.061	2.443	0.015
Water sufficiency No	0.001	0.063	0.023	0.982
Energy sufficiency No	0.135	0.058	2.314	0.021
Education Basic literacy	-0.031	0.051	-0.605	0.546
Education Primary	0.003	0.058	0.053	0.958
Education Secondary or more	-0.22	0.068	-3.226	0.001
Free from disasters No	-0.061	0.053	-1.154	0.249
Location Hill: **Healthy** No	-0.227	0.097	-2.349	0.019
Location Mountain: **Healthy** No	-0.146	0.106	-1.38	0.168
Location Hill: **Water sufficiency** No	0.021	0.086	0.244	0.807
Location Mountain: **Water sufficiency** No	0.432	0.118	3.671	0

Table 2: Summary of ordinal logistic regression. Results are presented as Odds Ratios (OR), which is the change in odds of the response variable when the categorical level of the predictor is changed. Example interpretation: For households in the mountains, the odds of having more negative perceptions towards nature on food is (1-0.144)*100% = 86% lower than households in plains. Alternatively, people from mountains are 1/0.144 = 7 times more likely of having more positive perceptions towards nature on food. Therefore, OR<1 (green cells) indicates more favourable attitudes while OR>1 (red cells) represents more unfavourable attitudes towards NCP in comparison to reference predictor categories. White/grey cells are ORs that are not statistically significant. Edu. = Education, Dist. Prot. = Protection from Disasters, Recr. = Recreation.

	Food	**Income**	**Health**	**Water**	**Energy**	**Edu.**	**Dist. Prot**	**Recr.**	**Culture**
Location Hill (Sulubung)	1.345	1.431	1.02	0.288	0.142	0.278	0.198	0.13	0.095
Location Mountain (Yamphudin)	0.144	0.159	0.149	0.099	0.056	0.059	0.168	0.235	0.181
Gender Male	1.278	0.984	0.696	0.689	0.701	0.667	0.636	0.812	0.783
Happiness	0.885	0.93	0.875	0.933	0.866	1.025	0.978	0.979	1.017
Farm percent	0.994	0.997	0.991	0.992	0.996	1.003	0.995	0.997	0.994
Food sufficiency No	0.752	1.798	1.076	0.992	0.813	0.677	0.45	1.567	0.676
Income sufficiency No	1.292	1.501	1.618	1.397	1.397	1.166	1.142	0.914	0.954
Healthy No	1.64	1.805	1.797	1.541	1.832	0.604	0.866	1.762	0.854

Water sufficiency No	1.794	1.026	0.951	2.183	0.79	0.659	0.997	0.525	0.894
Energy sufficiency No	0.934	1.123	1.539	2.239	4.87	0.881	1.168	1.07	0.836
Education Basic literacy	0.646	0.756	1.142	1.218	1.61	0.79	0.821	0.768	0.926
Education Primary	0.679	1.166	1.312	0.968	1.387	0.948	0.91	0.714	1.103
Education Secondary or more	0.286	0.412	1.054	0.571	1.155	0.545	0.563	0.348	0.629
Free from disasters No	0.777	0.918	1.09	0.741	0.772	0.816	1.129	0.67	0.916
Location Hill: **Healthy** No	0.265	0.285	0.445	0.305	0.291	1.454	1.823	0.648	2.242
Location Mountain: **Healthy** No	1.059	0.779	0.689	0.733	0.73	0.817	0.812	0.562	0.787
Location Hill: **Water sufficiency** No	0.597	0.829	1.193	1.016	2.155	1.513	0.762	1.269	1.048
Location Mountain: **Water sufficiency** No	1.419	1.727	2.296	2.698	4.572	4.412	2.674	5.688	2.961

3.3 Qualitative results

3.3.1 Definitions of nature

A vast majority of participants (48%) answered that nature was the combination of living (e.g., forests, biodiversity, plants, animals, greenery) and non-living things (air, water, hills, mountains, rocks, land, natural resources) around them (Fig. 4). 27% of participants answered that nature consisted exclusively in the non-living world, while 13% participants answered that it was exclusively living entities. Among participants who thought that nature was living and/or non-living things, 3% explicitly included humans, livelihoods, and modified ecosystems as a part of nature. 6% of the participants gave abstract conceptualizations of nature, such as day and night, sun and shadow, gifts of God, the passage of time, visible and invisible things, and truth.

Figure 4: Word cloud formed from participant's definition of nature. The font size of the words corresponds to the number of times a given word was mentioned. Colours are only for graphical representation.

3.3.2 NCP-wellbeing linkages

In average, we received 3 examples per person on how NCP contributed towards different wellbeing dimensions. However, average number of examples varied by region (7, 3, and 2 examples in the mountains, hills, and the plains, respectively). Among the examples provided, energy (NRG) was the most cited, accounting for 73% of the responses (Fig. 5). Energy contributed mostly towards household's energy for cooking, as well as towards food and income (Fig. 6). This was followed by 'Regulation of air quality' (AIR; 53%), which contributed towards good health and education. Other frequent attributions were 'Regulation of freshwater quality' (WQL; 44%) towards good health and water access, 'Food and feed' (FOD; 43%) towards access to food and income generation; 'Regulation of freshwater quantity, location and timing' (WQN; 28%) for water access and income; and 'Regulation of climate' (CLI; 24%) for income and access to food.

Non-material NCP were also mentioned frequently, with links between 'Supporting Identities' (IDE; 17%) and culture and education as well as between 'Physical and psychological experiences' (PHY; 11%) and

recreation. The least reported NCP were 'Regulation of detrimental organisms and biological processes' (ORG; 0.5%). Based on our attributions, none of the participants acknowledged 'Pollination and dispersal of seeds and other propagules' (POL) and 'Maintenance of options' (OPT).

Participants perceived that some wellbeing dimensions were largely dependent on a single NCP, such as energy and culture, while others, such as income and food, were dependent on a range of different NCPs (Fig. 6). Almost all respondents exclusively attributed energy in the form of firewood as a contribution from nature to their household energy. Similarly, participants perceived that culture was mostly dependent on IDE, as 91% of participants mentioned that nature influenced their cultural rituals, values, festivals, and identities, as well as guided them in spirituality. In contrast, participants attributed a range of NCPs such as the sale of agricultural products (FOD), regulation of climate (CLI), sale of non-timber forest products ('Materials, companionship and labor'; MAT), as well as sale of firewood for energy as contributing to their household income. Participants perceived that food (particularly high crop yield) was also linked to several NCPs such as CLI, WQN, WQL, and the 'Formation, protection and decontamination of soils and sediments' (SOI). Similarly, education also depended on AIR and WQN, as clean air and water allowed for their children to stay healthy and not miss school. Participants also perceived that nature itself was a source of education, thus attributing 'Learning and inspiration' (INS) to Education.

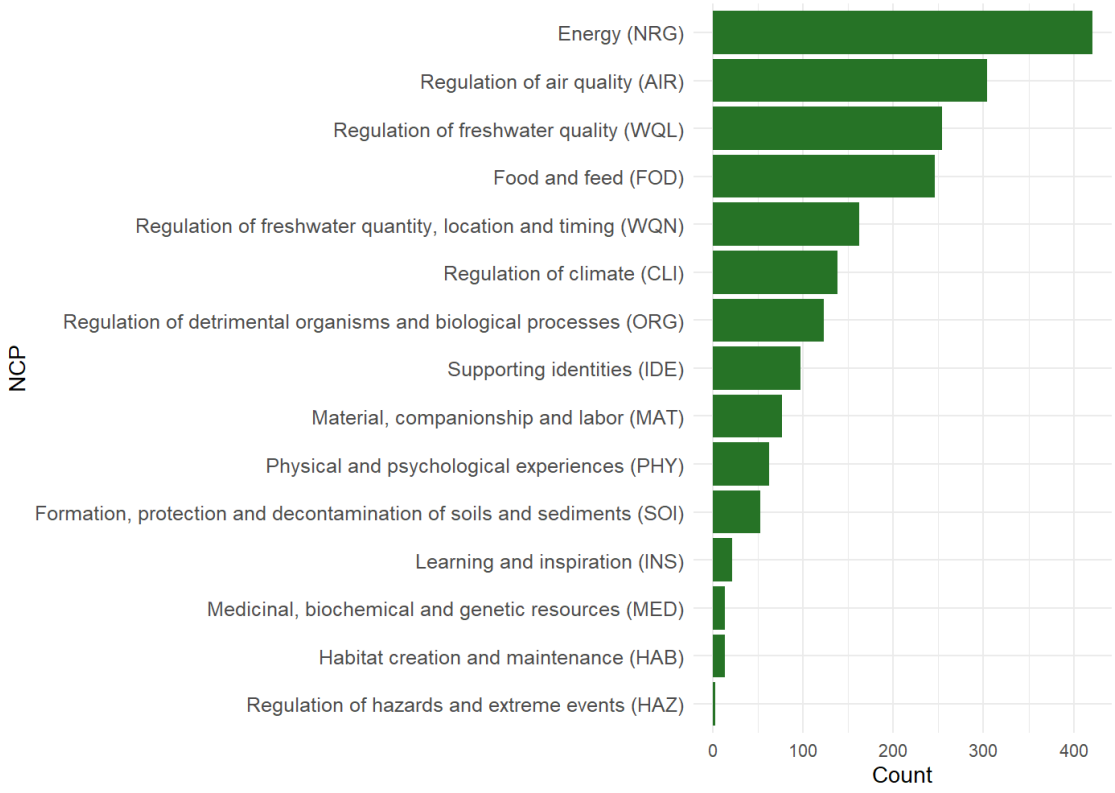


Figure 5: Frequency of occurrences of each NCP in examples provided by participants.

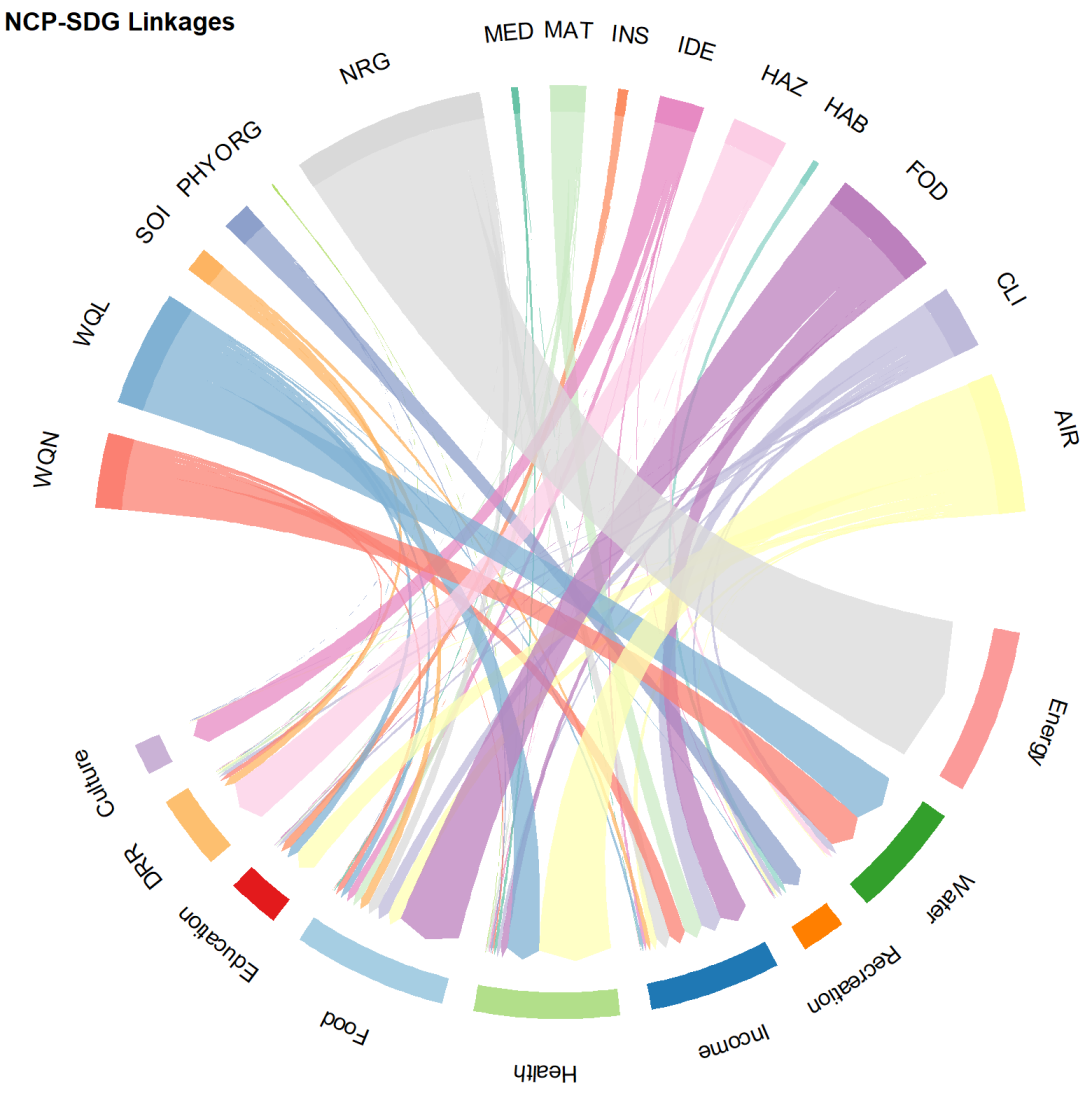


Figure 6: Chord diagrams showing flows from NCP (upper nodes) towards wellbeing (lower nodes).

Negative contributions of NCPs were related to human wildlife conflicts, especially in the plains. Participants mentioned that elephants frequently came into their fields and destroyed crops and houses. Additionally, they also described COVID-19 and its consequences as an example of nature contributing negatively to household health, food, income, and education. In other instances, participants attributed negative contributions of nature, not to NCPs *per se*, but to direct and indirect drivers of change towards NCPs such as pollution (water and air pollution negatively affecting health), land-use change (haphazard construction of roads leading to floods and landslides thereby affecting food, income, and increasing risk to disasters), and climate change (erratic weather patterns affecting crop production leading to negative effects on food, income and water access).

4 DISCUSSION

Participants from all three study sites felt that their lives and wellbeing were deeply connected to nature and its contributions. This echoes another national-scale investigation, which found that NCPs supported multiple aspects of human wellbeing, including income, food security, sense of place, health, and education, and were vital for achieving the sustainable development goals in Nepal (Adhikari et al., 2022). However, perceptions differed based on various factors.

4.1 Factors that influenced social perceptions towards NCPs

Our quantitative analysis found that people's perception of NCPs differed substantially between locations. Such results are in line with multiple studies elsewhere which also found that perceptions towards biodiversity and ecosystem services significantly differs based on participant's location (García-Llorente et al., 2020; Oteros-Rozas et al., 2014) Factors such as the state of the environment (Stapp et al., 2016), conservation management strategies (Martín-López et al., 2012), and dependency on natural resources (Moutouama et al., 2019), which are known to influence people's perceptions and attitudes, vary also between locations in our study area. For example, the three locations are situated in three distinct ecozones of Nepal that vary in climate, biogeography, land-use, elevation, and issues related to environmental degradation (Chalise et al., 2019; Paudel et al., 2020). Further, differences exist in conservation strategies in protected areas, which are typically more focused on livelihoods in mountains than in lowland areas (Bhattarai et al., 2017).

Participants from the mountain region, had more positive perceptions and provided more diverse examples of how NCP contributed to their wellbeing. This is likely explained by the fact that the mountain site primarily consisted of indigenous farmers and transhumant yak herders who depend heavily on nature, the trade of yak products, and the sale of medicinal plants and spices like large cardamom for their livelihood. Such a causal link between the direct dependence on nature to secure a livelihood and positive attitudes towards nature aligns with the findings of another study conducted in Nepal (Nepal & Spiteri, 2011).

Explanations for the particular emphasis put on culture and recreation by the participants from the hills were twofold. First, the hilly study site of Sulubung is regarded as a sacred site that holds tremendous cultural value for local communities (Chaudhary et al., 2019). Second, it is a designated Ramsar site and many inhabitants are involved in catering to the numerous tourists by operating homestays, hotels, selling local products, and participating in cultural performances. High incidences of human-elephant conflicts in the plains (see Sharma et al., 2020) in turn, likely explain why respondents had negative attitudes towards nature's contribution to their household and in particular, towards food and education, since elephants raid

subsistence crops, and children are often involved in night-patrolling, which impacts their education (Dhakal & Thapa, 2019).

Higher levels of education also corresponded to more favourable NCP perceptions, in line with studies in Nepal and other regions (Dhungana et al., 2022; Hanson et al., 2019; Masao et al., 2022; Shahi et al., 2023). Furthermore, consistent to our findings, other studies have also reported that income sufficiency and access to basic necessities such as water and energy, as well as higher levels of perceived happiness explain positive attitudes towards nature and conservation of biodiversity (Kideghesho et al., 2007; Masud & Kari, 2015; Pham et al., 2021).

4.2 Implication towards conservation

Currently, many conservation policies in the Global South are guided by a blue-print approach originating from international normative discourses, and are based on the expertise of government officials without much concern for the needs and priorities of local communities (Aryal et al., 2021). Accordingly, ample examples exist on global discourses and policy on conservation having net negative consequences on biodiversity and society locally (Davis et al., 2021; Guerra, 2019; Kolding & van Zwieten, 2011). Our results suggest that conservation policies that are co-formulated by multidisciplinary actors (Aryal et al., 2021) and strongly contextualized (Adhikari et al., 2023) are likely to simultaneously help conserve biodiversity, fulfil the needs of local communities, and gather community support.

The correlation between education and positive NCP perceptions suggests that prioritizing education programs for rural communities with high illiteracy could be effective for promoting positive attitudes of people towards conservation. In a study by Adhikari et al., (2023) for instance, experts believed that education is the key pathway to reinforce positive attitude of local communities towards nature. Particularly, conservation interventions that integrate conservation education are found to be very successful in generating community support towards biodiversity conservation (Ardoin et al., 2020; Pérez et al., 2019; Sakurai & Uehara, 2020). This is exemplified in our mountain site, which is located within a conservation area that has historically invested in school infrastructures and conservation education programs for local communities. Consequently, the participants were more aware about various conservation activities in their locality and found greater number of links between nature and wellbeing.

Nepal has a few examples of how the systematic integration of ecotourism with biodiversity conservation led to successful outcomes towards both conservation and local livelihood (Walter et al., 2018). Accordingly, the high positive perceptions of nature's contribution to culture and recreation in all three locations supports such indications for a strong synergy between ecotourism and conservation. Increase in ecotourism is also found to be highly synergistic with conservation activities, as they mutually support each

other's success (Adhikari et al., 2023). However, the benefits of ecotourism are often not shared equally among communities. Indigenous and economically disadvantaged communities are often left out, leading to dissatisfaction and further marginalization (Bennike & Nielsen, 2023; Kandel et al., 2020). Since ecotourism activities likely receive more support if they are focused on improving the economic wellbeing of all residents (Birendra et al., 2018), conservation interventions can benefit from the integration of community-based tourism to aid the economic development of rural communities (Pasanchay & Schott, 2021) and to gather support towards restrictive interventions such as protected areas.

The relatively unfavourable views of women towards NCP suggest that women may not be adequately involved in conservation decision-making (Allendorf & Yang, 2013). Research in the area indeed indicate a serious lack of meaningful participation of women in natural resource governance, despite conservation policies emphasizing their equitable involvement (Chaudhary et al., 2018). As greater female participation in natural resource management is associated with better conservation outcomes (Leisher et al., 2016; Leone, 2019), it is crucial to establish more rigorous methods to ensure and monitor the meaningful involvement of women and marginalized communities.

Our qualitative analysis indicated that only very few participants perceived a connection between habitat creation and maintenance and their wellbeing (Fig. 5), although this NCP is important in achieving development goals for Nepal (Adhikari et al., 2022). Perceived lack of linkage between habitat conservation and wellbeing possibly explains the lack of community support towards protected area interventions that primarily focus on habitat restoration (Nepal & Spiteri, 2011). Indeed, conservation interventions that focus solely on enhancing a particular natural or ecosystem service can result in trade-offs with other important services that contribute to human wellbeing (Corbera, 2012; Jessop et al., 2015). Our study suggests that certain aspects of participant wellbeing, such as income, depends on a range of interconnected NCPs rather than just one (Fig. 6). To avoid unintended negative impacts on other services and to promote a comprehensive conservation approach, interventions that aim towards the management of multiple NCPs that collectively work together as "ecosystem bundles" (see Raudsepp-Hearne et al., 2010) for human wellbeing could be prioritized. Thus, conservation interventions aimed at enhancing the multifunctionality of ecosystems at a landscape scale may be more favourably received than interventions that only prioritize species protection or carbon sequestration, for example (see Corbera, 2012).

5 CONCLUSION

With our study, we strengthen the view that the needs and priorities of local communities vary profoundly based on contextual aspects, and that conservation interventions that support community wellbeing and education can generate positive perceptions towards nature. Accordingly, we highlight the importance of

social perception studies in uncovering the nuanced differences in needs and priorities of stakeholders, and in identifying pathways for effective conservation measures that garner trust and increase local participation. The variations in social perceptions we detected further highlight the need to develop contextualized policy with the involvement of local actors with particular focus on participation of women and marginalized communities. Participants' perception on NCPs also revealed the need to prioritize multifunctional landscapes instead of measures that enhance individual NCPs. Finally, our results point to potential synergies between the sectors of conservation, education, and ecotourism, which, if promoted, could increase community participation and support towards conservation interventions.

Our experience revealed that the NCP framework was a useful tool for analysing social perceptions at the local level. By enabling the classification of complex ecosystem functions into simple language with 18 categories, this framework can be effectively used in socioecological systems research to understand human-nature interactions in a participatory manner.

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DISCLAIMER

The views and interpretations in this publication are those of the authors and are not necessarily attributable to ICIMOD.

DATA AVAILABILITY

Data and codes used for analysis will be uploaded in https://doi.org/10.5281/zenodo.7894475 after publication.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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