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Intertwined people-nature relations are central to nature-based adaptation to climate change

Bruno Locatelli (1*), Sandra Lavorel (2), Matthew J. Colloff (3), Emilie Crouzat (4), Enora Bruley (5), Giacomo Fedele (6), Adrienne Grêt-Regamey (7), Tobias Plieninger (8), Erik Andersson (9), Mick Abbott (10), James Butler (11), Tahia Devisscher (12), Houria Djoudi (13), Titouan Dubo (14), Alberto González-García (15), Paulina G. Karim (16), Claudia Munera (17), Margot Neyret (18), Fabien Quétier (19), Nicolas Salliou (20), Gretchen Walters (21)

(1) Forests and Societies, Cirad, Univ Montpellier, Montpellier 34398, France bruno.locatelli@cirad.fr, ORCID: 0000-0003-2983-1644, (*) Author for correspondence
(2) Laboratoire d'Ecologie Alpine, CNRS, Université Grenoble Alpes, Université Savoie Mont Blanc, Grenoble, France sandra.lavorel@univ-grenoble-alpes.fr, ORCID: 0000-0002-7300-2811
(3) Fenner School of Environment and Society, Australian National University, Canberra, Australia, matthew.colloff@anu.edu.au, ORCID: 0000-0002-3765-0627
(4) Univ. Grenoble Alpes, INRAE, LESSEM, France, emilie.crouzat@inrae.fr, ORCID: 0000-0001-5765-6543
(5) Institute for Environmental Sciences, University of Geneva, Switzerland, enora.bruley@unige.ch, ORCID: 0000-0003-3416-1868
(6) Conservation International, gfedele@conservation.org, ORCID: 0000-0001-9238-1020
(7) Planning of Landscape and Urban Systems, ETH Zürich, Switzerland, gret@ethz.ch, ORCID: 0000-0001-8156-9503
(8) Faculty of Organic Agricultural Sciences, University of Kassel; Department of Agricultural Economics and Rural Development, University of Göttingen, Germany, plieninger@uni-goettingen.de, ORCID: 0000-0003-1478-2587
(9) Ecosystems and Environment Research Programme, University of Helsinki, Helsinki, Finland; Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden; Research Unit for Environmental Sciences and Management, North-West University, Potschefstroom, South Africa, erik.andersson@helsinki.fi, ORCID: 0000-0003-2716-5502
(10) School of Landscape Architecture, Lincoln University, Lincoln, New Zealand, mick@wildlab.org.nz, ORCID:
(11) Cawthron Institute, Nelson, New Zealand, James.Butler@cawthron.org.nz, ORCID: 0000-0001-8333-947X
(12) Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, Vancouver, BC, Canada, tahia.devisscher@ubc.ca, ORCID: 0000-0002-0971-665X
(13) Center for International Forestry Research (CIFOR), Bogor, Indonesia, H.Djoudi@cifor-icraf.org, ORCID: 0000-0002-5140-4270
(14) Laboratoire d'Ecologie Alpine, CNRS, Université Grenoble Alpes, Université Savoie Mont Blanc, Grenoble, France, titouan.dubo@univ-grenoble-alpes.fr, ORCID: 0000-0002-8546-0561
(15) IRD, CNRS, Grenoble INP, IGE, Univ. Grenoble-Alpes, Grenoble, France; Laboratoire d'Ecologie Alpine, CNRS, Université Grenoble Alpes, Université Savoie Mont Blanc, Grenoble, France; alberto.gonzalez-garcia@univ-grenoble-alpes.fr, ORCID: 0000-0002-1969-3818
(16) College of Environmental Studies and Oceanography, National Dong Hwa University, Hualien 97401, Taiwan, scapeslab@gms.ndhu.edu.tw
(17) CSIRO Environment, Canberra Australia; Fenner School of Environment and Society, Australian National University, Canberra, Australia; Claudia.Munera@csiro.au, ORCID: 0000-0003-0601-2312
(18) Laboratoire d'Ecologie Alpine, CNRS, Université Grenoble Alpes, Université Savoie Mont Blanc, Grenoble, France, margot.neyret@univ-grenoble-alpes.fr, ORCID: 0000-0001-9435-1634
(19) Rewilding Europe, Wild Quarters, Monseigneur Suyslaan 4, 6564 BV Heilig Landstichting, The Netherlands, fabien.quetier@rewildingeurope.com, ORCID: 0000-0002-3767-0353
(20) Planning of Landscape and Urban Systems, ETH Zürich, Switzerland, nsalliou@ethz.ch, ORCID: 0000-0003-3960-2175
(21) Faculty of Geosciences and the Environment, Institute of Geography and Sustainability, University of Lausanne, Switzerland, gretchen.walters@unil.ch

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Summary

Adaptation to climate change is a social-ecological process: it is not solely a result of natural processes or human decisions but emerges from multiple relations within social systems, within ecological systems, and between them. We propose a novel analytical framework to evaluate social-ecological relations in nature-based adaptation, encompassing social (people-people), ecological (nature-nature), and social-ecological (people-nature) relations. Applying this framework to 25 case studies, we analyse the associations among these relations and identify archetypes of social-ecological adaptation. Our findings revealed that adaptation actions with more people-nature relations mobilise more social and ecological relations. We identified four archetypes, with distinct modes of adaptation along a gradient of people-nature interaction scores, summarised as: 1) nature control; 2) biodiversity-based; 3) ecosystem services-based; and 4) integrated approaches. This study contributes to a nuanced understanding of nature-based adaptation, highlighting the importance of integrating diverse relations across social and ecological systems. Our findings offer valuable insights for informing the design and implementation of adaptation strategies and policies.

Introduction

Climate change induces transformations in ecological processes but also in the way people interact among themselves and with nature (IPCC 2022). Climate change can have profound effects on ecosystem functioning and ecological interactions, including species distributions, phenology, and food webs (Fontúrbel et al., 2021; Scheffers et al., 2016), with implications for wildlife and human societies (e.g. Cissé et al., 2022; IPCC 2022). For example, climate-related disasters and changes in the availability of natural resources affect livelihoods and how people interact through competition or cooperation over those resources (Fazey et al., 2010; Pecl et al., 2017).

There are ways of shaping or enabling social and ecological interactions to achieve desirable, place-specific outcomes for nature and people, and particularly social-ecological adaptation to climate change (Berkes & Jolly, 2002; Salgueiro-Otero & Ojea, 2020). This is particularly true for nature-based adaptation (also known as nature-based solutions to adaptation or ecosystem-based adaptation), which is about harnessing biodiversity and ecosystem services and enhancing them to address the challenges of adaptation to climate change (Colls et al. 2009; Seddon et al., 2019; Chausson et al., 2020). Nature-based adaptation involves using ecosystem services and ecological processes to help people adapt to the impacts of climate change, while improving ecosystem resistance and resilience or facilitating ecosystem transformations toward a state that is both desirable and adapted to a changing climate (Lavorel et al., 2015; Peterson St-Laurent et al., 2021).

Adapting to climate change involves people collaborating, sharing and co-creating new knowledge, or developing alternative livelihoods to address the specific vulnerabilities of different social groups (Korhonen-Kurki et al., 2022; Wamsler, 2017; Wannewitz & Garschagen, 2023). People can manage, restore and protect ecosystems to ensure the supply of ecosystem services that reduce climate impacts; for example, planting or protecting mangroves can shelter coastal settlements from storms, managing wetlands can reduce floods and droughts, and urban parks can cool cities during heatwaves (Colloff et al., 2020; Pramova et al., 2012). Ecosystem properties also matter for adaptation: for example, the redundancy of functions between species and the dispersal of organisms and genes within a landscape influence ecosystem resistance, resilience and transformation (Lavorel et al., 2015; Peterson St-Laurent et al., 2021).

Adaptation to climate change is a social-ecological process that is not solely a result of natural processes or human decisions but emerges from multiple relations within social systems, within ecological systems, and between them (Barnes et al., 2017). Adapting to climate change requires a nuanced understanding of how social-ecological relations can be shaped to achieve desired outcomes for people and nature. Successful adaptation pathways involve leveraging these relations to achieve positive outcomes for people and nature (Bruley et al., 2021a; Welden et al., 2021). The need for rapid and extensive adaptation calls for transformations in people-nature relations, as well as in social relations (Colloff et al., 2021; O'Brien, 2021).

This perspective on social-ecological relations in adaptation to climate change is aligned to the perspectives of several epistemic communities applying systemic approaches in sustainability sciences. Systems thinking considers the role of system components, for example humans and non-humans, and the relations among them in determining system behaviour or dynamics (Williams et al 2017; Schoon & Van Der Leeuw, 2015). The concepts of social–ecological systems and coupled human- natural systems have proven useful for analysing the intertwined dynamics of social and ecological changes, including adaptation to climate change (Fischer et al. 2015). Social-ecological systems are sometimes studied as complex adaptive systems, which have the distinctive characteristic of being determined more by the relations among components than by the components themselves (Preiser et al., 2018). Relational ontologies, such as those found in various indigenous knowledge systems and in sustainability science, prioritize relations as foundational to understanding reality (West et al., 2020). Another example is social-ecological network analysis, which emphasizes the interactions and relations between social and ecological entities within coupled systems (Bodin et al., 2019).

Some epistemic communities have focused on relations either among people or between people and nature (see examples in Table 1). For instance, the concept of co-production is applied with two different perspectives in the literature. First, the concept has been used to describe collaborations between people within and across communities (People-People PP relations), such as decision makers, Indigenous peoples and local communities, scientists, and other people who play a role in creating knowledge or designing solutions to sustainability or adaptation problems (Bremer & Meisch, 2017; Chambers et al., 2021; Miller & Wyborn, 2020; Wyborn et al., 2019). The participation of diverse people and the recognition of their multiple knowledge and worldviews are essential for developing adaptive strategies that are context-specific and culturally sensitive (Miner et al., 2023; Norström et al., 2020). The second perspective describes the co-production of ecosystem services, which are not delivered to humans by nature alone but rather result from interactions between people and nature (PN) (Bruley et al., 2021b; Fischer & Eastwood, 2016; Kachler et al., 2023; Palomo et al., 2016; Torralba et al., 2018). This perspective has been applied to adaptation and the co-production of "adaptation services" (i.e., ecosystem properties and services that matter for adaptation) (Lavorel et al. 2015; Colloff et al., 2016).

There are two gaps in the literature on social-ecological relations in adaptation to climate change. One relates to the disconnect between the literature on social relations (PP) and relations between people and nature (PN) (Locatelli et al., 2024). Another is the absence of a perspective integrating ecological relations (or NN for Nature-Nature) together with other relations. These NN relations are ecological interactions between biotic or abiotic elements that help moderate climate impacts on social-ecological systems and help systems adapt to climate change (Lavorel et al. 2015). There is a need to adopt an integrated perspective on social-ecological relations in adaptation (Thonicke et al., 2020): relevant concepts and methods are available on ecological adaptation, social adaptation, ecosystem management, and ecosystem services, but have not been brought together (Mastrángelo et al., 2019; Norström et al., 2022; Schlüter et al., 2021). To address these gaps, we adopt a social-ecological perspective that includes a comprehensive range of relations, i.e., people-people relations (PP) and people-nature (PN), as well as nature-nature (NN) (Table 1). As a new framing of adaptation, this can help shape adaptation science, design and implementation of adaptation initiatives and policies, and improve their monitoring and evaluation.

Table 1: Different concepts and approaches studying social-ecological relations (PP: people-people, NN: nature-nature, PN: people-nature).

Relations	Outcomes	Concepts and approaches
Social-ecological (all PP, PN, NN relations)	System dynamics and resilience; Social-ecological adaptation to climate change	Social-ecological systems (Biggs et al., 2021); Complex adaptive systems (Preiser et al., 2018); Actor-network theory (Latour, 2007); Relational ontologies (West et al., 2020); Social-ecological networks (Bodin et al., 2019); Assemblage theory (Turker & Murphy, 2021); Regenerative approaches (Gordon et al., 2022)
Among people (PP relations)	Knowledge; Solutions; Governance; Societal change; Norms and rules	Social co-production of knowledge, societal change, and actions for sustainability (Chambers et al., 2021; Wyborn et al., 2019); Social learning (Galan et al., 2023); Participatory action research (Mapfumo et al., 2013); Transdisciplinary co-creation (Jacobi et al., 2022); Co-management, adaptive co-management, and collaborative governance (Armitage et al., 2009)
Between people and nature (PN relations)	Human well-being; Ecosystem services (and their flows or uses); Ecosystem management, protection or restoration	People-nature relational approaches, such as disconnection (Beery et al., 2023), reconnection (Ives et al., 2018), reciprocity (Ojeda et al., 2022), care (Jax et al., 2018); Biophilia (Wilson, 1984); More-than-human (non-human agency, co-designing with non-humans) (Dürbeck et al., 2015; Miller, 2020); Co-production of ecosystem services by people and nature (Bruley et al., 2021b);

To adapt to climate change, societies need to build on, strengthen, and transform interdependent relations among people (PP), between people and nature (PN), and among non-human entities and ecological processes (NN). Many positive associations have been proposed between the three types of relations. For example, the supply of ecosystem services that help people adapt to climate change (PN) relies on ecological functions and ecosystem capacity for resistance, resilience, and transformation (NN) (Lavorel et al., 2015). People need to collaborate (PP) to manage ecosystems for protecting or restoring key ecological relations or keystone species (NN) and ensuring the supply of these ecosystem services (PN) (Olsson et al., 2004). People relations (PP) also result in governance arrangements, including the governance of PN relations (Isaac et al., 2022). Reconnecting people to nature (PN) can build social cohesion needed for collective adaptive actions (PP) (Chan et al., 2016; Ives et al., 2018). There is also a growing body of research in the field of environmental psychology that suggests an association between the way people relate to other people (PP) and to non-human entities (PN), based on potential associations between prosocial behaviour and environmental concern (Lengieza et al., 2023; Paul, 2000; Van Doesum et al., 2021).

Our objective in this paper is to identify associations and archetypes of social-ecological relations in nature-based adaptation (people-people, nature-nature, and people-nature relations) from an assessment of 25 case studies distributed globally. Archetypes in sustainability science are representative configurations or patterns of behaviours, system dynamics, or people–nature interactions (Sietz et al. 2019). They help identify common patterns and general lessons learned across cases, without erasing particularities (Eisenack, 2012).

We hypothesise that adaptation actions that mobilize more relations between people and nature (PN) mobilise more social relations (PP) and ecological relations (NN). We also hypothesise that archetypes are mainly differentiated by their consideration of people-nature relations (PN). Although all PP, NN, and PN relations matter for adaptation, PN relations can be seen as levers to ensure that the mobilisation of PP and NN relations helps achieve social-ecological adaptation. For example, actions that reconnect people with nature or keep people connected with nature have been identified as leverage points to transform modern society towards sustainability (Ives et al., 2018).

Analytical framework

The analytical framework was developed from key literature and discussions during a workshop in March 2023 bringing together 21 researchers at Sainte-Croix (Drôme, France). From the literature (cited in the introduction of this paper), workshop participants identified the key social-ecological relations that can be mobilised to adapt to climate change. By 'mobilised', we refer to adaptation actions that build on existing relations or change them to facilitate adaptation. By 'relation', we refer to the connections, interactions, or associations between the elements of a social-ecological system. Following Kramer & De Smit (2012), we consider both the relations of an element with other elements and the relations of an element with the whole. The former type of relations includes direct interactions, for example the predation of one animal by another or the use of natural resources by humans. The latter type includes the influence of system elements on system properties (such as species diversity, landscape connectivity, or collective action) and vice-versa (such as institutions incentivizing individuals to act).

Based on the literature and workshop discussions, participants identified 18 relations, six in each of the three groups (PP, NN, and PN) (Fig. 1; details and examples in Supplementary Material SM1). We use the sequence PP, NN and PN, in that order, because adaptation actions were initiated by people (PP), who mobilised and managed specific ecological NN relations, depending on their PN relations.

Six types of people-people (PP) relations are considered, based on previous research on the collaborative co-production of knowledge, action and societal change (Chambers et al., 2021). The first three focus on people's participation in an adaptation process, while the last three refer to underlying contextual drivers or outcomes of social relations. 'Capacity' (PP1) considers how adaptation actions build on or increase people's capacities to collaborate through capacity building, technology or skills transfer, or multi-directional learning. 'Diversity' (PP2) focusses on relations that ensure that the world views, knowledge systems, and values of diverse people are recognized in decision-making (Loos et al., 2023; Pascual et al., 2023; Tengö et al., 2014). 'Reframing' (PP3) is about how relations help reframe problems, imagine new solutions, open new political debates, and shift narratives (Chambers et al., 2021). 'Equity' (PP4) relates to relations that lead to distributive equity, e.g., whether rights, benefits, or costs are fairly distributed among people. 'Power' (PP5) is considers whether relations among participants in an adaptation process enable the engagement and empowerment of marginalised or powerless actors (Chambers et al., 2021). 'Institutions' (PP6) refers to whether institutions (including policies) support adaptation, are strengthened, or created for governance of adaptation and collective action (Agrawal, 2008; Berkhout, 2012).

The six nature-nature (NN) relations consider various processes and properties underpinning ecological adaptive and transformative capacity (Lavorel et al., 2015). The first three types focus on components of diversity, and the latter three on ecological mechanisms. 'Taxonomic' (NN1) refers to the diversity, complementarity, and redundancy of biota at different levels, such as genotypes, species, life forms, habitats, communities, and novel biota (e.g., genetic diversity in crops). 'Functional' (NN2) focuses on the diversity, complementarity, and redundancy of functions within and across functional groups (e.g. herbivores, carnivores, scavengers). 'Response' (NN3) deals with the diversity of responses of species or individuals to climate variations (e.g., diverse cultivated species that have different responses to droughts). 'Disturbance' (NN4) considers ecological properties that regulate disturbance regimes in the ecosystem or in the surroundings (e.g., low flammability or fire-tolerance of plant species, or water infiltration into soils to mitigate downstream floods). 'Stabilisation' (NN5) refers to strengthening stabilising feedbacks, buffers, stocks, and reservoirs, (e.g., water storage in aquifers or species with banks of propagules) or decreasing amplifying feedbacks (e.g., feedback between fire occurrence and fire-tolerant invasive species). 'Connectivity' (NN6) relates to flows and interactions across landscapes (e.g., corridors to facilitate the movement of plants or animals to adapt to a changing climate).

The six types of people-nature (PN) relations are based on metaphors of how humans relate to nature (Raymond et al., 2013). These PN relations are associated with different values of nature; for example, instrumental (i.e., values of nature as means to achieve human ends), relational (i.e., values that derive from interactions between people and nature or among people in or about nature), and intrinsic (i.e. values inherent to nature) (Pascual et al., 2017). The first three types belong to a 'nature for people' framing, with a focus on

instrumental values, whereas the last three refer to a 'people and nature' framing, with a focus on relational and intrinsic values (Mace, 2014). Adaptation actions can mobilise these different relations to build adaptive capacity. 'Services' (PN1) describes the production metaphor; a utilitarian view focused on instrumental values, whereby nature produces ecosystem services that contribute to quality of life (Pramova et al., 2012). 'Management' (PN2) considers that nature-based adaptation includes managing sustainably, restoring and protecting ecosystems to ensure the supply of ecosystem services (Fedele et al., 2017). 'Flow' (PN3) considers that nature-based adaptation includes managing landscapes and human activities to ensure that ecosystem services reach beneficiaries (e.g., physical access of people to nature, experiential connections between people and nature, transformation and transportation of nature's benefits) (Bruley et al., 2021b; Ives et al., 2018). 'Concern' (PN4) is about moral duty and concern for nature, including emotional connections with nature (Ives et al., 2018), feelings about places or other species (Pramova et al., 2022), and intrinsic values of nature (Pascual et al., 2017). 'Web-of-life' (PN5) considers the strong web-of-life interconnections among species, including humans, and the embeddedness of humans within ecological systems (Raymond et al., 2013). 'Spiritual' (PN6) includes spiritual dimensions, for example, the connections among land, family, ancestors, and the spiritual realm (Irvine et al., 2019; Ives et al., 2020).

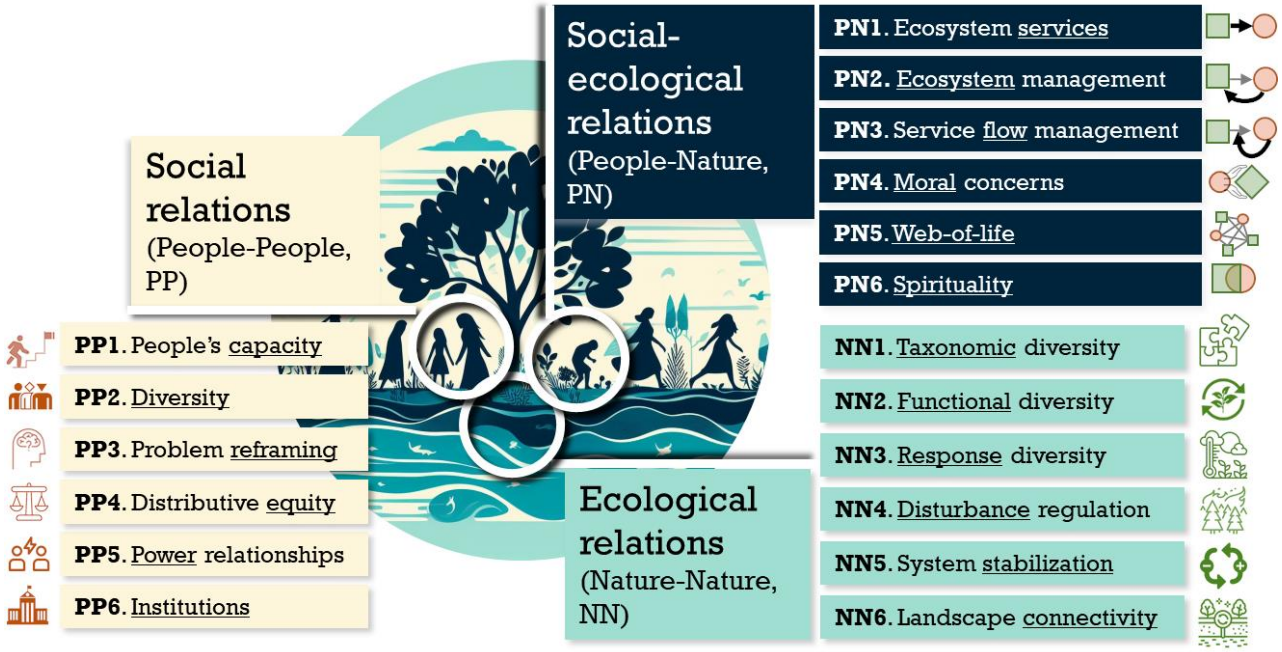

Figure 1: Analytical framework to assess social-ecological relations in the nature-based adaptation to climate change.

Materials and methods

We applied case study synthesis methods, widely used for comparing and contrasting multiple cases (Khan & VanWynsberghe, 2008). These methods typically involve selecting case studies, defining a set of variables to describe them, gathering data to score these variables (sometimes with expert judgment), and analysing the resulting scores using statistical techniques. This approach has been applied for several purposes, such as identifying archetypes of social-ecological systems (Sietz et al. 2019), evaluating adaptation efforts (Magnan et al. 2023), or assessing communities at risk of wildfire (Paveglio et al. 2017)

We selected 25 case studies of adaptation actions that fulfilled three criteria (Table 2; details in SM2). First, the selected cases were about place-based collective processes aiming for, or resulting in, adaptation to climate change, either in planned or autonomous ways. Second, the adaptation actions applied social-ecological approaches that considered both people and nature (e.g., reducing vulnerability of ecosystems and human communities or harnessing the contributions of ecosystems to adaptation for people). Third, the cases had been the subject of engagement (research, planning, implementation, or evaluation) by at least one co-author

of this paper (called the case experts hereafter, which were 1 to 3 per case studies) and were also documented in scientific publications or reports. Eleven pilot case studies were presented by participants at a workshop in March 2023 and used to test and refine the framework. Additional 14 case studies were then identified through our networks to increase diversity of geographical locations and settings (urban, rural, and coastal or marine). Case study experts were 17 scientists from different disciplines (including ecology, geography, economics, sociology, and political sciences), working on social-ecological systems with interdisciplinary approaches, and familiar with the literature cited in this paper. Given the exploratory nature of our analysis, we accepted the potential bias in our opportunistic selection of case studies, choosing those familiar to the workshop participants and their networks.

To assess each of the 25 cases, experts first wrote a narrative description of their cases (including context, stakeholders, ecosystems and their services, climate vulnerability, nature's values, justice issues, etc.). This description was needed for understanding the assessment but was not directly analysed. Case experts then completed a questionnaire template (SM1), which included two questions for each of the 18 relations of the analytical framework: (i) To what extent has an adaptation action mobilised the relation for adaptation? (ii) In what ways was such relation mobilised? The answers to the first question were given ordinal scores (0 = not at all, 1 = to some extent, 2 = much or very much), whereas the answers to the second were narrative. Narratives and questionnaires were completed after the workshop, between May and June 2023. The experts discussed the responses with the lead authors of this paper (BL and SL) between September and November 2023 and, if there were disagreements on scores, discussions and deliberations led to a consensus between study experts and lead authors and an adjustment of the scores, as done in previous research with cases coded for archetype development (e.g., Aggarwal & Anderies, 2023). All interactions after March 2023 workshop took place online. Despite some degree of unavoidable subjectivity in the scores, our iterative approach with several discussions between case study experts and lead authors, as well as between the two lead authors, helped align perspectives and ensure coherence across case studies. The process based on consensus may enhance the validity of the scoring due to the combined expertise and discussion (Martin *et al*., 2012).

Statistical analyses involved three steps. First, we assessed Spearman rank correlations between PP, NN, and PN relation scores (i.e. the sums of scores of the corresponding relations, which measured how many relations were mobilized and to what extent). Second, we applied factor analysis to test whether the six relation scores within each PP, NN, and PN group could be reduced to fewer factors. Factor analysis is often undertaken to identify a few unobservable factors from the original data, which can be used for further analyses, such as clustering (Paveglio et al., 2017). Factor analysis with ordinal data assumes that unobserved continuous variables (latent variables) underlie the ordinal variables. As a result, the factors are generally treated as continuous (Bartholomew, 1983; Agresti, 2010). We performed factor analysis from a Spearman correlation matrix (given the ordinal nature of the data) with the *fa* function in the *psych* R package (Revelle, 2023), using two factors for each PP, NN, and PN group, the *minimum rank* factoring method, and *oblimin* oblique rotation. Third, we used the six factors to cluster the case studies and identify archetypes (or typical configurations) of social-ecological relations in adaptation. Clusters, which are empirical groupings based on observable similarities within a specific dataset, can help identify configurations that resemble archetypes (Sietz et al., 2019). We applied fuzzy k-means clustering using the *FKM* function in the *fclust* package in R, with the *silhouette* cluster validity index to select the number of clusters (Ferraro et al., 2019). With fuzzy clustering, one case study can belong to more than one cluster, which reflects the common situation where some case studies can be intermediate between two or more archetypes (Sietz *et al.*, 2019). Case studies with membership greater than 0.50 in a cluster were associated with this cluster, whereas other cases were associated with all clusters to which membership was between 0.25 and 0.50. We represented the clustering results in a principal component biplot (as a dimension reduction technique to transform the six factors into the two dimensions of the graph).

Table 2: List of case studies

#	Id	Country	Location	Details
01	AU	Australia	Murray–Darling Basin	Re-allocating water from irrigation to the environment and adapting to water scarcity
02	BO	Bolivia	Chiquitania Region	Managing wildfires in the Bolivian Amazonia in a context of climate change
03	CO	Colombia	Alto Fragua National Park	Future-oriented conservation and adaptation in a national park
04	ES1	Spain	Barcelona City	Resilience thinking in Barcelona's green plan
05	ES2	Spain	Extremadura Region	Community-based wildfire management through fostering productive fuelbreaks
06	FR1	France	Alps Region	'Alpages Sentinelles', a transdisciplinary R&D network on adaptation to climate change in mountain pastures
07	FR2	France	Alps Region	'Sem' les Alpes': Producing seeds of local grass species for restoring degraded areas
08	FR3	France	Drôme Valley	Nature-based climate adaptation for the Drôme Valley
09	FR4	France	Grenoble City	A 'Canopy Plan' for limiting heatwave impacts in Grenoble urban area
10	FR5	France	Haute-Loire Department	Innovative water governance with land commons
11	FR6	France	Pays de la Meije, Alps	MountainPaths: Ecosystem-based adaptation pathways in a mountain region
12	MG1	Madagascar	Antananarivo Region	Soil mining and adaptation in the hinterlands of Antananarivo
13	MG2	Madagascar	Eastern Madagascar	Adaptation of smallholder farmers in forested agricultural landscapes of eastern Madagascar
14	ML1	Mali	Lake Faguibine	New forest-based livelihoods by women adapting to the disappearance of a lake
15	ML2	Mali	Lake Faguibine	Attempts to restore water flows in order to replenish a dried lake
16	PE1	Peru	Andean Mountains	Pine plantations for adapting to droughts
17	PE2	Peru	Ayacucho Region	Rainwater harvesting for facing drought
18	PE3	Peru	Lima Region	Ancestral pre Inca practices of aquifer recharge ('amunas')
19	PG	Papua New Guinea	Bismarck Sea	Climate resilient development pathways for seascapes
20	SB	Solomon Islands	Solomon Islands	Empowering communities to design and implementing climate adaptation pathways
21	SE1	Sweden	Lapland Region	Landscape-scale rewilding initiatives with adaptation as a co-benefit
22	SE2	Sweden	Öland Island	Building capacity for collective actions to adapt to a changing climate - water management on Öland
23	SE3	Sweden	Stockholm City	Promoting multifunctionality in multifunctional mosaic landscapes undergoing rapid urbanisation
24	TW	Taiwan	Xinshe, Hualien County	Integrated landscape seascape approach for socio-ecological revitalisation
25	ZA	South Africa	Garden Route National Park	Futures orientation and adaptation in the management of a park

Results

The correlation analysis (Fig. 2) showed that a higher score for relations between people and nature (PN) was significantly associated with greater scores for people-people relations (PP) and nature-nature relations (NN). However, a higher score for people relations (PP) was not significantly associated with a greater score for nature-nature relations (NN).

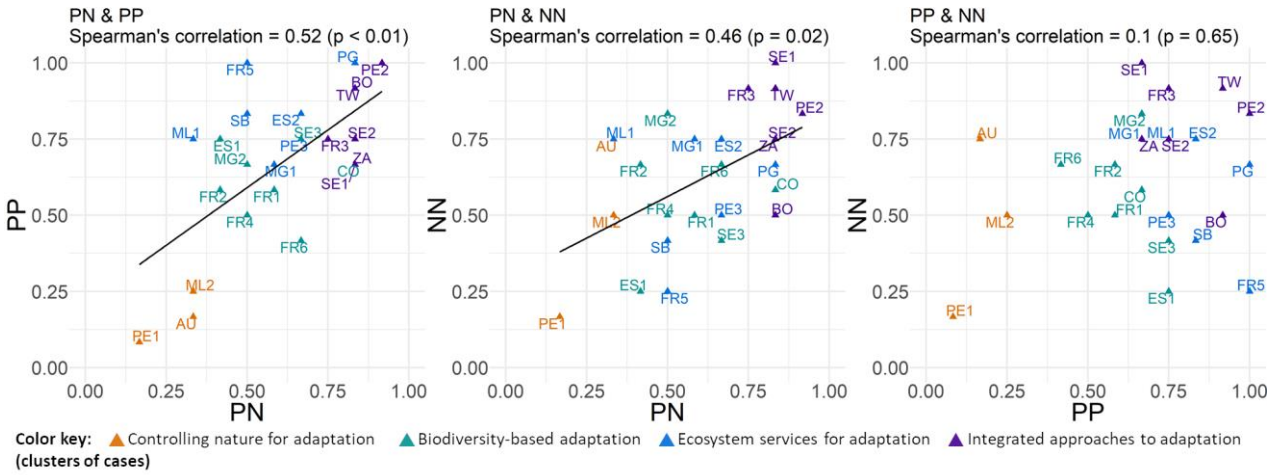

Figure 2: Scatterplots representing the associations between PP, NP, and NN relation scores across the case studies. Regression lines are drawn only where the correlation coefficient is significantly different from zero. Colours refer to the cluster in which a case has the highest membership (Figure 4).

The three factor analyses, conducted separately on each group of relations (PP, NN, and PN), showed that our case studies could be described by two factors in each group (which explained 50-66% of the variance) (Fig. 3; SM3). This analysis resulted in six factors, which we labelled based on the relations most correlated with them. The first factor, correlated with PP1 (capacity), PP2 (diversity), and PP3 (reframing), was labelled '*PP_CoCreation*' because it emphasized collaboration among stakeholders with diverse perspectives, leveraging their capacities to collectively reframe problems. The second factor was labelled '*PP_InclusGovern*' (for inclusive governance) because it referred to a governance approach that ensures distributive equity (PP4), addresses power imbalances (PP5), and strengthens institutions (PP6). For NN, a first factor '*NN_Processes*' focused on ecological functions and mechanisms that drive ecosystem resilience or transformation and the supply of ecosystem services (NN4: disturbance; NN5: stabilisation; NN6: connectivity). The other factor was labelled '*NN_Diversity*' because it was related to the diversity of ecosystem components and their properties (NN1: taxonomic; NN2: functional; NN3: response). For PN, a factor was correlated with PN1 (services) and PN3 (flow) and was labelled '*PN_Utilitarian*' because it focused on the provision and flow of ecosystem services for human benefits. The other factor, labelled '*PN_Holistic*', was correlated with non-instrumental relations between people and nature and intrinsic or relational values (PN4: concern; PN5: web-of-life; PN6: spiritual), as well as ecosystem management (PN2).

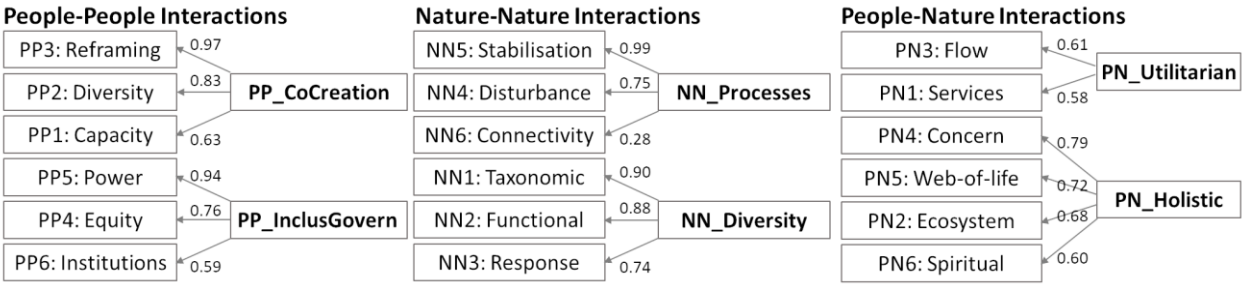

Figure 3: Factor analysis outputs showing the major loadings on each of the six factors (in bold text). All loadings with an absolute value above a cut-off point of 0.25 are represented as a path.

The cluster analysis based on six factors identified four groups, or archetypes, with distinct mobilized social-ecological interactions (Fig. 4). The case studies in the different clusters were clearly separated in the PN-PP scatterplot (Fig. 2 left), which showed they differed mostly according to their PN relation scores (low for cluster 1, medium for 2 and 3, and high for 4) and PP relation scores (low for 1, medium for 2, high for 3 and 4). The different clusters were not as clearly separated in the other scatterplots (Fig. 2 centre and right) because NN relation scores did not discriminate between them.

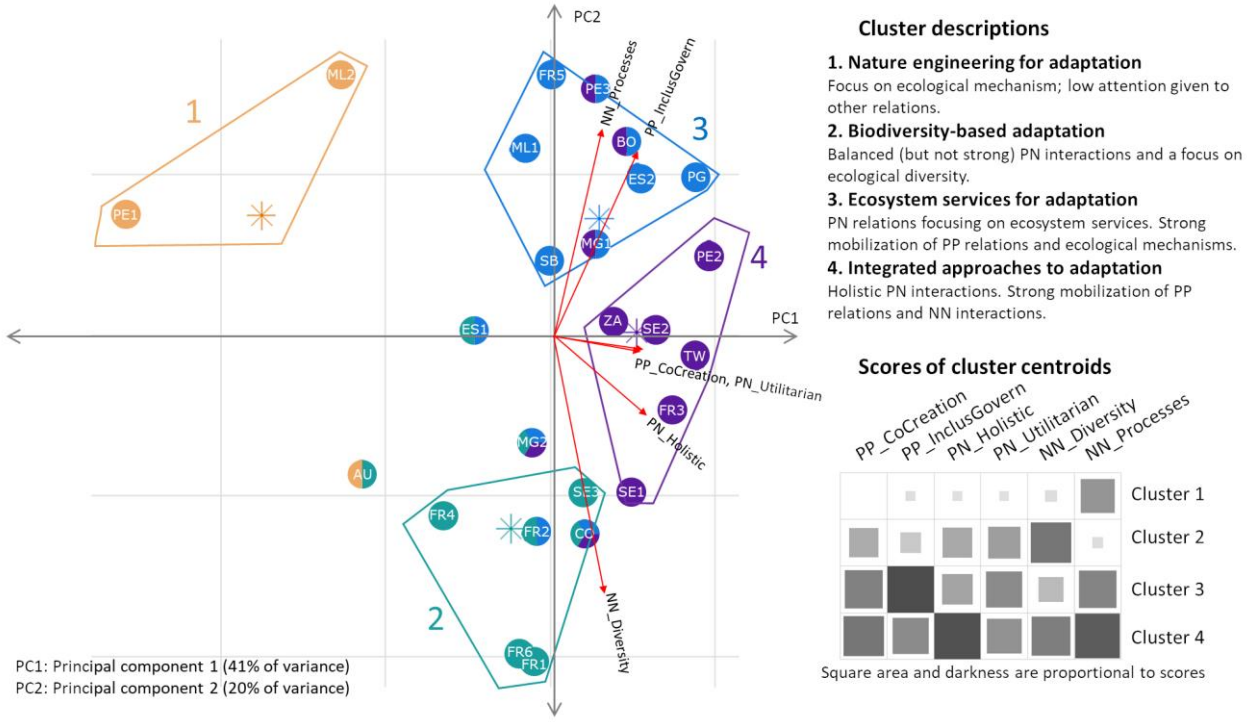

Figure 4: Clustering results. The scatterplot (left) is a principal component analysis biplot showing the 25 case studies (circles, whose colours indicate clusters with membership above 0.25), the four cluster centroids (stars), the four envelopes drawn around the cases belonging to only one cluster and the centroid, and the six factors (arrows with labels). The bottom-right plot shows the mean values of the six factors in the clusters.

In the cluster named 'Controlling nature for adaptation', the case studies mobilised few relations between people and nature as well as few people-people relations, or biodiversity. Only ecological mechanisms were mobilised, particularly for water regulation and disaster risk reduction. These case studies were top-down adaptation projects, for example, one supported by international organisations to refill a dry lake in Mali using hydrological engineering and ecosystem management (ML2), and a program in Peru (PE1) in which authorities decided to plant fast growing tree species to improve water availability during dry seasons,

despite the concerns of local communities and scientists about the high water consumption of these trees (Bonnesoeur et al., 2019). In these case studies, decisions were made by a few people without considering the knowledge or world views of other stakeholders (thus low PP scores). . These cases proposed practical solutions to single problems of local relevance (e.g., water availability) and mobilized only the ecological mechanisms of relevance to the problems, without considering trade-offs or broader issues. They focused on specific instrumental values, such as the role of ecosystems in regulating water for human uses.

Case studies in the 'Biodiversity-based adaptation' cluster mobilised various people-nature relations (either utilitarian or more holistic), but not strongly. Key relations were related to ecological diversity, although people's relations were also moderately considered. The case studies were typically nature-based adaptation projects that focused on biodiversity and its different values, instrumental or not. For example, urban projects emphasised the diversity of planted tree species that resist climate change impacts or the diversity and complementarity of ecological structures at the landscape scale (FR4 in Grenoble or SE3 in Stockholm). Two mountain projects mobilised the taxonomic and functional diversity of grassland species to facilitate adaptation (FR1 and FR6). Although some of these cases faced challenges for involving diverse stakeholders and were driven by authorities and experts or scientists, their proposed interventions were not only practical but also addressed governance issues.

In the 'Ecosystem services for adaptation' cluster, the key relations between people and nature were related to ecosystem services, thus mostly with utilitarian values. These case studies had a strong focus on people relations and ecological mechanisms for the production of material and regulating contributions to adaptation. These cases were locally-driven initiatives for natural resource management (e.g., water managed on land commons in FR5, trees for charcoal production, local livelihoods and adaptation in ML1) and risk management (e.g., wildfires in ES2 and BO, partly in this cluster). They were also about local communities designing climate resilient pathways, based on managing multiple ecosystem services for livelihoods (PG and SB). In addition to practical interventions, these cases also addressed governance issues (e.g., collaborative governance of water and common lands in FR5) and power or equity (e.g., inclusive decision-making processes in PG or inclusion of traditional ecological knowledge in ES2).

A few case studies considered both ecosystem services and biodiversity were located between clusters 2 and 3. For example, a case in Madagascar aimed at improving ecosystem services and biodiversity for the resilience of smallholders in tropical forests (MG2) and another in France promoted the use of diverse local seeds for restoring grasslands and controlling soil erosion in mountains (FR2).

The 'Integrated approaches to adaptation' cluster typically mobilised all types of relations and strongly considered holistic relations between people and nature, in addition to utilitarian values. Examples included a pioneering and transformative territory-based project in France, with co-management arrangements and integrated, inclusive processes of planning and governance (FR3), a landscape-level initiative to promote socio-ecological revitalization in Taiwan following principles of the Satoyama Initiative including ecological, social, cultural, spiritual and economic benefits (TW), and a project that restored ancestral practices of water management in Peru, combining management interventions with cultural, social, and environmental practices (PE2). Cases in this cluster stood out from the others by their inclusive and power-sensitive processes that recognized local and Indigenous worldviews, various non-instrumental values (e.g., sense of place in SE2), and multiple types of connections between people and nature (e.g., spirituality in PE2 or TW). They often considered cultural, social and environmental practices (e.g., rituals in PE2) and combined interventions related to governance and personal beliefs or behaviours (e.g., shifts in attitudes in SE1).

Discussion

In this study, we have analysed social-ecological relations in 25 case studies of nature-based adaptation globally. We found that the mobilisation of ecological and social relations is significantly associated with the mobilisation of people-nature relations. We also found that adaptation archetypes are differentiated based on how they mobilise people-nature relations and social relations.

Method strengths and limitations

Our analytical framework proved useful in assessing a diversity of social-ecological relations. Some overlaps between relations were apparent during the application of the framework (e.g., between NN4 'Disturbance' and NN5 'Stabilization', which resulted correlated) but some degree of overlap is acceptable given the relatedness of the topics considered in some pairs of relations. With factor analysis, the number of variables was reduced in an internally consistent way, as indicated by the high factor loadings of relations on their respective factors, confirming the relevance of relations considered.

Scoring the relations involved a degree of subjectivity, but discussions between experts and lead authors of this paper were effective in addressing disagreements and reaching consensus, thus ensuring score consistency. The limitations of this assessment based on consensus are the lack of independent verification and the possibility of groupthink (particularly given that all case experts were researchers, even though from diverse disciplinary background). Further research could analyse the views of more diverse experts on the cases, not only academics.

Expert judgement was the only practical method available to assess such a diverse set of relations, given that there was no empirical data for most relations considered in the framework. To advance our understanding of social-ecological relations in nature-based adaptation, further research could develop methods for empirical data collection on relations. Another limitation of our analysis was the possible bias in the case study selection, which calls for further research with a more diverse and comprehensive set of case studies.

Archetypes

Our cluster analysis identified archetypes of adaptation based on social-ecological relations, which is a novel approach compared to previous archetype development. Archetypes of social-ecological systems have often been built from system state variables rather than variables describing relations between system elements. For example, many archetype analyses have used variables describing social systems (e.g., population density) or ecological systems (e.g., water availability) and the trends of these variables (Sietz et al., 2017; Neudert et al., 2019; Rocha et al., 2020). A few archetype analyses were based on social relations; for example, power relationships (Aggarwal & Anderies, 2023), conflicts (Magliocca et al., 2019), or social learning (Dabard et al., 2024). When people-nature relations were considered, there were often limited to ecosystem services (i.e., from nature to people) and human impacts (i.e., from people to nature) (Pacheco-Romero et al., 2021; Yang et al., 2023). Other types of people-nature relations, like the intangible ones we included, have been rarely considered (but see the different views of nature considered in the archetypes developed by Aggarwal & Anderies, 2023).

Our consideration of the three of PP, NN and PN relations has enabled identifying new types of archetypes of social-ecological systems from cases of nature-based adaptation. The four archetypes correspond to different framings of people-nature relations, depending on how adaptation is designed and implemented. Drawing inspiration from the nature conservation framings proposed by Georgina Mace ('nature for itself', 'nature despite people', 'nature for people', 'people and nature') (Mace, 2014), we label our adaptation framings. The nature control archetype frames 'adaptation *despite* people', because social-ecological relations are poorly mobilised, whereas the integrated approach archetype represents a framing of 'people and nature adapting *together*'. The two other archetypes are about 'people adapting *from or with* nature' but the framing is clearly more anthropocentric in the ecosystem services archetype (a framing of 'people adapting *from* nature') than for the biodiversity-based archetype (a framing of 'people adapting *with* nature').

Further analyses of larger sets of cases deliberately selected to represent the diversity of social and ecological contexts globally are needed to confirm the applicability of the archetypes in other contexts and to possibly

identify other archetypes. These analyses could also try to explain why different archetypes occur, depending on particular contextual conditions, on how adaptation actions are design, and on the values, rules and knowledge of participants (Colloff et al., 2017; Oberlack et al., 2019).

Central role of people-nature relations and values of nature

The association between people-nature relation scores and the scores for the other two groups of relations (which were not directly associated) suggests a central role of people-nature relations in nature-based adaptation. This role is also highlighted by the differentiation of the four archetypes along a gradient of people-nature relation scores. On one side of this gradient, relations are poorly mobilised by the nature control archetype, with its focus on ecological mechanisms and a low consideration of social relations. On the other side, the integrated approach archetype mobilises a diversity of people-nature relations, as well as many natural and social relations.

The mobilisation of social relations is a second discriminant of archetypes. The biodiversity-based archetype weakly mobilises social relations and focuses on biodiversity to ensure multiple benefits from resilient ecosystems. The ecosystem services archetype is problem-focused and builds strongly on social relations and considers issues of power and equity, in part because the adaptation actions are locally driven to respond to locally-relevant problems.

Surprisingly, the ecological relation scores do not discriminate between archetypes. What makes a difference is the type of ecological relations mobilised, between relations related to mechanisms (prioritised in nature control and ecosystem services archetypes) and those related to diversity (prioritised in the biodiversity-based archetype).

As people-nature relations discriminate archetypes, they probably have a central role in the design, implementation and outcomes of nature-based adaptation (Welden et al., 2021). The narrative descriptions of cases in integrated approach archetype show adaptation cases that maintain relations or reconnect people with nature in multiple ways, including material, experiential, cognitive, emotional, and philosophical (Ives et al., 2018). Whereas all four archetypes consider material relations, the integrated approach archetype is particularly strong in mobilising non-tangible relations (i.e., cognitive, emotional, and philosophical), which are generally considered as deep leverage points for adaptation (Abson *et al*., 2017; Richardson et al., 2020; Riechers et al., 2021). There is a need for further research to explore the transformative potential of cases in the four archetypes. For example, we need to assess adaptation outcomes to understand how adaptation cases and their mobilized relations contribute to adaptability or transformability.

Values of nature are central to relations between people and nature and thus differ according to the archetypes of nature-based adaptation (O'Brien & Wolf, 2010). How social-ecological systems adapt to climate change thus depends on the values people give to nature, for example instrumental, relational, and intrinsic values (Pascual et al., 2017), or broader deeply-held values, i.e. individual and collective moral and ethical framings that motivate priorities and guide actions (Schwartz et al., 2012). The narrative descriptions of cases showed that, whereas the nature control archetypes focused on instrumental values, the other archetypes mobilized more diverse values. This was particularly clear for the cases with integrated approaches, which mobilized relational values such as sense of place or intrinsic values related to spirituality. However, despite the archetypal differences, adaptation cases are often based on a constellation of values and not purely on intrinsic, instrumental, or relational values, as shown in previous research (Dabard et al. 2024; Ortiz-Przychodzka et al. 2014). As literature on values emphasizes that shifts towards holistic values could foster progress towards sustainability (Horcea-Milcu et al., 2023), further research is needed to better understand to the effects of prioritizing values of coexistence with nature over utilitarian values of nature for adaptation to climate change.

Implications for transformative adaptation

Our analysis of social-ecological relations in adaptation has implications for adaptation practice. We found that the three types of relations (people-people, nature-nature, and people-nature) are intertwined, which means that the design of nature-based adaptation should consider all three together. For example, rather than employing instrumental and engineering approaches for working with nature, our findings show that it is possible to implement integrated approaches that put attention to the intricate web of interrelations between

climate change, ecological processes, and human actions and the social-ecological relational nature of adaptation (Salgueiro-Otero & Ojea, 2020). Considering the multiple relations at play in adaptation practice can help planners and policymakers identify potential synergies, conflicts, and trade-offs that will lead to more informed decision-making and transformative solutions (Colloff et al., 2021; Palomo et al., 2021). The need for a systemic understanding is not a new conclusion per se, but our results also suggest a way to overcome the apparent inertia to act on it. Further development and active use of *relational approaches* seem key to moving towards adaptation planning and practice grounded in holistic understandings and collaborative approaches (Garcia et al. 2022; Rammig et al., 2020; Andersson et al., 2021).

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Author Contributions

BL, SL and MJC conceptualised the research. BL and SL defined the approach. Workshop participants (BL, SL, EC, EB, GF, AGR, TB, MA, AGG, MN) developed the framework. BL and SL collected data with workshop participants (EC, EB, GF, AGR, TB) and additional case study leaders (EA, JB, TD, HD, TD, PGK, CM, FQ, NS, GW). BL analysed data and prepared the first draft. All authors discussed the approach, reviewed and edited the manuscript.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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