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RESEARCH ARTICLE

Nature's contributions to human well-being under climate change: Evidence from Central and Eastern Madagascar

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Abstract

1. Anthropogenic climate change has an unprecedented impact on ecosystems and their services, with severe consequences for human well-being, particularly for the marginalised and vulnerable members of society in the Global South. The well-being of communities relies not only on material and regulating services ecosystems provide but also on non-material services.
2. In this paper, we unravel the diverse ways that climate change impacts affect Nature's Contributions to People (NCP) and the well-being of rural populations in four sites in Madagascar—a biodiversity hotspot but one of the economically poorest countries in the world. We conducted participatory community workshops, mapping and semi-structured interviews with local residents across social subgroups to understand the mechanisms of climate-related degradation and the resulting impacts on different dimensions of human well-being through an NCP lens.
3. We found that non-material services are generally more often associated with well-being effects. Climate change degrades material and non-material services through sea level rise, biodiversity loss, drought, precipitation and temperature variability, with consequences for materials, companionship and labour, food and feed, and physical and psychological experiences. Loss of land and forests is expressed through ecological grief.
4. The outcome of our research provides evidence-based information to local policymakers, conservation practitioners, and climate change agencies.
5. This information can help improve government efforts toward holistic conservation and climate change adaptation by addressing the impacts on the physical and mental well-being of the most vulnerable communities.

KEYWORDS
Africa, degradation, environmental change, global warming, health, social-ecological systems

1 | INTRODUCTION

Climate change is a major driver of landscape change, biodiversity loss, and ecosystem degradation (Pörtner et al., 2021), exacerbating other anthropogenic stressors, such as land use change, overexploitation of resources, and pollution (Balvanera et al., 2019). As a result of such ongoing global changes, the human population is facing challenges associated with the loss of multiple Nature's Contributions to People (NCP) and unprecedented impacts on human well-being (Cardinale et al., 2012; Diaz et al., 2019). Nature's Contributions to People are the material and non-material benefits and disbenefits of nature for people and encompass the notion of ecosystem services (Díaz et al., 2018).

The effects of climate change on ecosystems and people's physical and mental well-being are not uniform across the globe, due to geographically and socially heterogeneous exposure and vulnerability patterns. Tropical regions are the most sensitive to climate and land use change (Newbold et al., 2020). These factors put the least developed countries and biodiversity hotspots like Madagascar, with its highly sensitive and exposed ecosystems and vulnerable society, on the front line of climate change. Interdisciplinary knowledge of the interplay between the degradation of natural systems, NCP loss and its consequence on the well-being of different social groups is urgently needed to achieve inclusive and sustainable development pathways (Whitmee et al., 2015).

There are still knowledge gaps on the multiple ways in which NCP influence good quality of life and how climate change affects them, particularly regarding vulnerable populations (Mastrángelo et al., 2019). Until now, most studies have investigated material contributions and services and their relation to human well-being. Recently, these factors have been believed to be the most important contributors to human well-being (Hausmann et al., 2015; Sandifer et al., 2015). Although the non-material benefits that people obtain from nature, such as spiritual, aesthetical, educational, and recreational values, engage different research communities, including climate science, biodiversity conservation, and social studies, their importance has long been overlooked (Díaz et al., 2018; Kosanic & Petzold, 2020; Milcu et al., 2013; Plieninger et al., 2013). One reason is that they are less tangible and suffer from poor quantification. However, there is increasing evidence of the high relevance of non-material benefits for human well-being (Huynh et al., 2022; Nowak-Olejnik et al., 2022).

Besides physical well-being, mental health impacts of ecosystem change remain a frontier with the potential for further research (Berry et al., 2010; Gibson et al., 2020). For example, the concept of 'ecological grief' (Cunsolo et al., 2020; Cunsolo & Ellis, 2018) deals with well-being (i.e. including mental health) challenges resulting from environmental change. Yet, this topic has hardly been considered within the research fields that assess NCP. Barnett et al. (2016) have explicitly suggested the science of 'loss' in climate change to address climate-related impacts on mental well-being. Research on the multiple non-material NCP to a good quality of life across different cultures lacks evidence from the Global South and concerning different social groups (Brauman et al., 2020; Díaz et al., 2018).

With Madagascar, we chose one of the most vulnerable social-ecological systems as a case study region to investigate NCP and well-being in relation to recent climate change impacts. Madagascar is one of the world's poorest countries in terms of socioeconomic indicators (World Bank, 2022), yet, one of the richest in terms of biodiversity (Myers et al., 2000) and among the most vulnerable to climate change (Hertel & Rosch, 2010). The overarching research question for this study is: How do climate-related ecosystem changes affect human well-being in rural Central and Eastern Madagascar?

We use a mixed-methods quantitative and qualitative approach to address four specific research objectives: (1) to identify evidence of climate change impacts on the environment across different study sites in Central and Eastern Madagascar; (2) to understand the links between climate-induced ecosystem degradation and the provision of NCP for local communities; (3) to assess the diversity of climate-related NCP changes and the range of impacts on human well-being of vulnerable local populations; (4) to highlight the potential for climate change-induced ecological grief. By linking the mechanisms of climate-related environmental changes with perceived effects on human well-being with evidence from a resource-dependent case study of the Global South, our study contributes to research on climate change impacts on vulnerable local communities, NCP and cultural ecosystem services, human-nature relationships, and ecological grief.

2 | CONCEPTUAL FRAMEWORK

Anthropogenic interventions affect ecosystem dynamics with feedback on society (Ostrom, 2009). This paper focuses on anthropogenic climate change as a driver of ecosystem change. It uses an analytical framework (Figure 1) that builds on the adapted DPSIR (Driving forces, Pressures, States, Impacts and Responses; Nassl & Loffler, 2015) and the proposed conceptual framework linking NCP and human well-being (Rendón et al., 2019). The purpose of the framework is to guide the analysis of how anthropogenic climate change affects ecosystems, the benefits they provide and how the impacts of these benefits affect human well-being across vulnerable social groups, and the potential of such changes to result in 'ecological grief'. Groups particularly vulnerable to climate change and losing NCP are the poor, children, elderly, women or people with disabilities, especially in countries of the Global South (Otto et al., 2017).

Climate change affects ecosystems and their potential to provide NCP in various ways, such as through land degradation processes

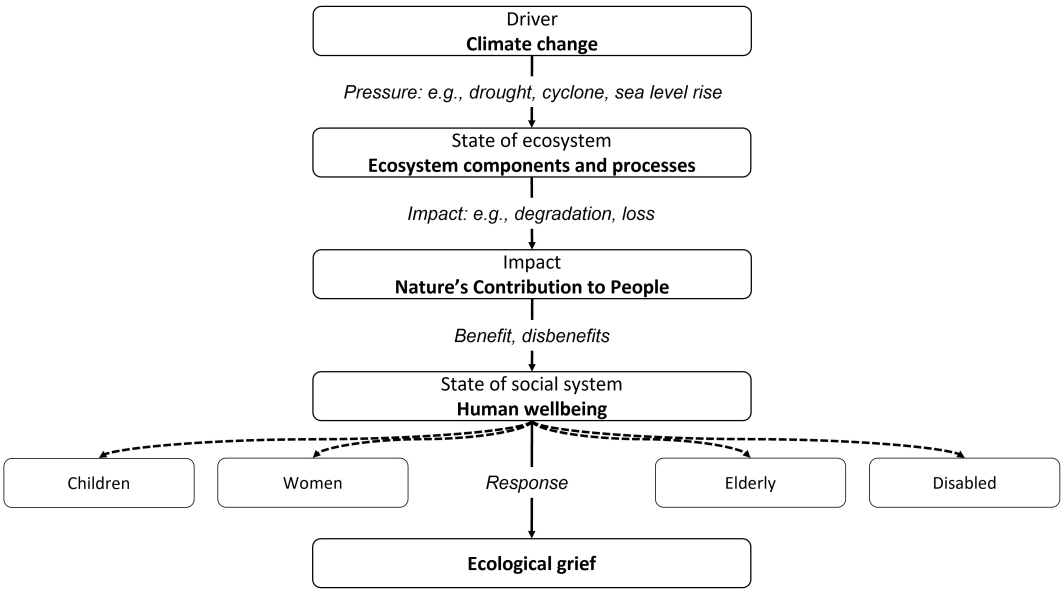

FIGURE 1 Conceptual framework, building on Nassl and Loffler (2015) and Rendón et al. (2019), for analysing the impact of climate change on Nature's Contribution to People, human well-being and ecological grief, across vulnerable social groups.

(Olsson et al., 2019). Rising temperatures cause changes in vegetation patterns, primary productivity and species decline (Moritz & Agudo, 2013). Changes in temperature and precipitation and the increasing frequency and intensity of extreme events (e.g. heat waves, droughts, and storms) cause habitat degradation and decline or loss of biodiversity (Balvanera et al., 2019). Climate change may even lead to the complete loss of landscapes (Barnett et al., 2016). Climate change can also affect the disbenefits and the negative aspects of human-nature interaction throughout different cultures (Lyytimäki, 2015).

The concepts of NCP, through ecosystem services and human well-being, have been closely linked from the start of the conceptualisation of ecosystem services in the Millennium Ecosystem Assessment (2003). Building on the Millennium Ecosystem Assessment framework, well-being is defined as the 'perspective on a good life that comprises access to basic materials for a good life, freedom and choice, health and physical well-being, good social relations, security, peace of mind and spiritual experience' (Díaz et al., 2015, p. 14). Material and provisioning services are often studied regarding human well-being (Hausmann et al., 2015; Sandifer et al., 2015). How non-material services – defined as 'nature's effects on subjective or psychological aspects underpinning people's quality of life, both individually and collectively' (Díaz et al., 2018)—contribute to the various aspects of physical and mental well-being, has received less attention and less methodological advancement (Kosanic & Petzold, 2020; Milcu et al., 2013). However, recent research increasingly focuses also on the non-material contributions and their effect on human well-being (Methorst et al., 2020), especially concerning resource-dependent communities (Elwell et al., 2020; Yoshida et al., 2022).

The NCP approach aims to be more inclusive and equitable than the ecosystem services framework by recognising that different views and cultural lenses exist and including the voices of different actors to be heard (e.g. Indigenous people; Díaz et al., 2018). Nature's Contributions to People can be analysed from generalised and context-specific perspectives. The generalised perspective distinguishes 18 categories in partly overlapping groups of regulating, material and non-material NCP (Díaz et al., 2018). However, each benefit does not necessarily match a specific group. For example, in Indigenous communities, fishing represents material NCP (i.e. for food) and non-material NCP (e.g. the practice/technique as a form of traditional knowledge). This example shows how a context-specific perspective on NPC allows us to better understand the specific relationships between people and nature (Díaz et al., 2018). Non-material benefits arise from human-nature relationships, placing them at the forefront of human well-being (Chan et al., 2012; Plieninger et al., 2013). Furthermore, they present a venue to explore their quantification through the multiple values of nature (e.g. relational values—understanding their emotional connections to species and place; and instrumental values—monetary or economic values), allowing us not only to understand human-nature relationships, but also relationships between different members of communities with nature (i.e. power dynamics and potential marginalisation within communities) (Chan et al., 2018; Christie et al., 2019).

Ecological grief has been defined as a human response to ecological loss, including the loss of valued species, ecosystems, landscapes, and cultural identity, impacting both mental and physical well-being (Comtesse et al., 2021; Cunsolo & Ellis, 2018). Ecological grief can be community-based and related to the inability to participate in self-sustaining, land and ocean-based activities, such as hunting, farming, fishing or a personal response to the loss of environmental knowledge, cultural, personal and physical identity or traditional knowledge. There are three types of ecological grief: (1) grief from experienced physical ecological loss; (2) grief from loss of

environmental knowledge or identity; (3) anticipatory grief (Cunsolo & Ellis, 2018). Ecological grief is suggested to be a common theme, especially within all communities that sustain their livelihoods in a close relationship with nature (Clark et al., 2021).

The experience of nature provides diverse benefits to people through different sensory experiences (i.e. sight, hearing, taste, touch and smell; Bratman et al., 2019; Hartig et al., 2011). Therefore, NCP have different benefits and values for different social groups (Caretta & Morgan, 2021). The loss of such benefits and values can negatively impact mental well-being, whereas, access and availability of NCP in different forms of sensory inputs (e.g. visual, olfactory, auditory or tactile) could minimise the 'ecological grief effect'. Therefore, a better understanding of ecological grief requires analyses of diverse valuations and NCP across vulnerable social groups.

3 | MATERIALS AND METHODS

3.1 | Context and setting of the study

Madagascar is the fourth largest island in the world (with an area of 580,000 km^2) and lies about 500 km off the east coast of Africa, in the Indian Ocean. It has a diverse climate and distinct ecosystems that have developed due to its split from Africa's mainland approximately 160 million years ago. A recent increase in human activities, such as slash-and-burn agriculture, logging and mining, and an exponentially increasing population, threatens the island's unique biodiversity (Ralimanana et al., 2022). In addition, climate change has affected and is predicted to have a further impact on different sectors in Madagascar, including water resources, agriculture, fisheries, human health and terrestrial and coastal ecosystems (Weiskopf et al., 2021). Madagascar's current population is 28,571,000 people, with 18 ethnic groups (of which our study covers three) coexisting on the island. The World Bank classifies Madagascar as a low-income country in the Sub-Saharan region, with 70% of the population below the poverty line of $2 a day (United Nations, 2022). Due to a high endemism rate, with most animal and plant species found nowhere else, Madagascar is one of the world's biodiversity hotspots for conservation priority (Myers et al., 2000).

We chose four rural communes to conduct this research: Ambohimalaza and Mantasoa in the Analamanga Region, Andasibe in the Alaotra Mangoro Region and Andovoranto in the Atsinanana Region (Figure 2). The selected study areas extend from central to eastern Madagascar. The main reason for choosing these sites was that each site had different ecosystems and ethnic groups whose cultural practices (traditions and beliefs) also vary (see Supplementary Material 1, Table SM1).

The central part of Madagascar is also called the 'highlands of Madagascar' and represents the wealthy and fertile centre of this large island. In this part of the country, vegetation is dominated by small relics of evergreen forests, mostly limited to a few valleys, protected sites and vast areas of dry, secondary grassland (Moat & Smith, 2007). Agriculture production systems are diversified and determined primarily by access to water. Rice dominates in flood zones; vegetable farming is practised elsewhere when water is accessible; and small livestock (ducks, geese, poultry and pigs) or a few dairy cows are often found (Aubry et al., 2008).

The eastern side of the island is home to tropical rainforests (Goodman & Benstead, 2003), with rich and unique biodiversity (UNESCO, 2018). However, it is characterised by its weak economy, the insufficiency of its institutional and human resources and its vulnerability to natural disasters (Chaboud et al., 2010).

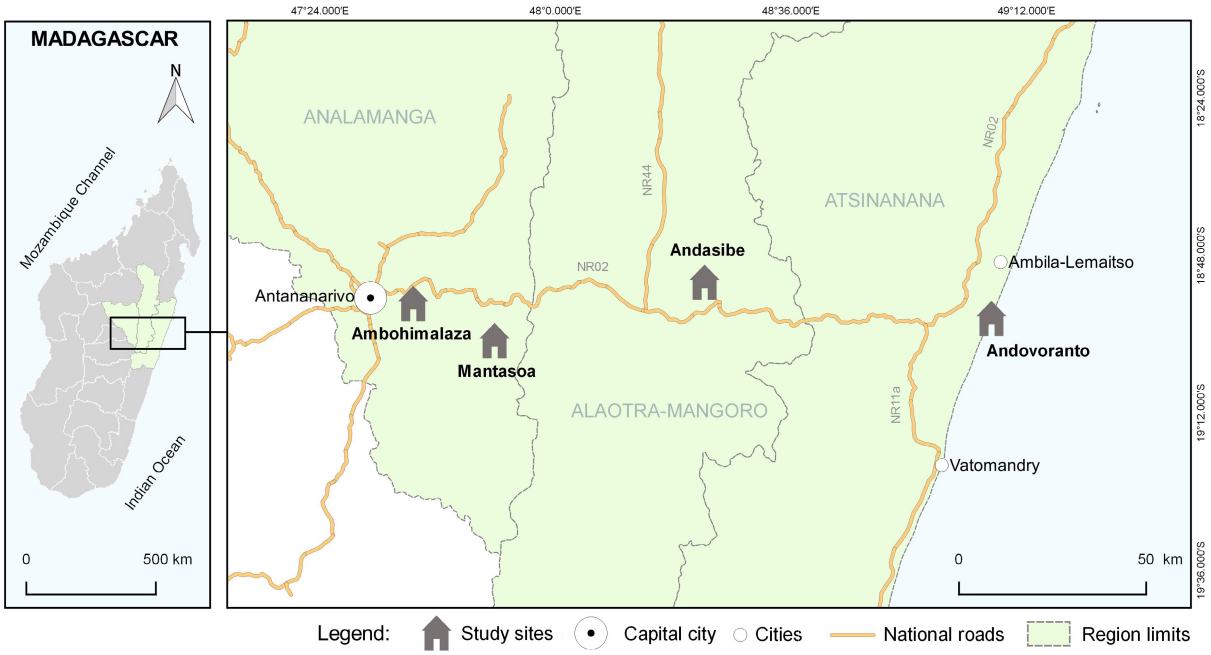

FIGURE 2 Map of Madagascar and the locations of the four study sites.

Betsimisaraka and Bezanozano, the main ethnic groups, are characterised by their swidden agricultural system and wild harvest (Poudyal et al., 2018).

3.2 | Research design

Our research followed a mixed-methods quantitative-qualitative design to identify local evidence of the connections between climate-related ecosystem degradation and impacts on human well-being. Our research population was at the local community level. We used a quantitative descriptive approach for the first two research objectives (identifying climate change impacts on the environment across the study sites and linking ecosystem degradation and the provision of NCP). We used a qualitative approach for the in-depth assessment of the diverse climate-related NCP changes and well-being impacts as well as the potential for climate change-induced ecological grief.

The main study variables built on the key components of our research framework, namely climate hazard, the process of degradation, NCP (including disservices) and well-being (including ecological grief). We adopted the categorisation of climate hazards used, among others, by Berrang-Ford et al. (2021) (excluding the loss of Arctic sea ice, which does not apply to the research context of Madagascar). The variables for degradation processes were adopted from Olsson et al. (2019), NCP according to Díaz et al. (2018) and well-being according to the original categorisation in the Millennium Ecosystem Assessment (2003). The two additional aspects of disservices and ecological grief were open categories; however, we understood them according to the definitions of Lyytimäki (2015) and Cunsolo and Ellis (2018), respectively (see Supplementary Material 1, Table SM2, for a complete list of categories and codes).

3.3 | Data collection and analysis methods

Data collection was built on participatory community workshops, mapping and semi-structured one-to-one interviews with local residents, complemented by direct observation of evidence of ecosystem degradation. In each of the four case study sites, the research began with a participatory workshop facilitated by the village chief and open to all community members, except at Ambohimalaza where due to local organisational matters, the workshop was carried out on the second day and several semi-structured interviews were already conducted beforehand. Over the days following the workshop, village members who had not attended the workshops were selected randomly, and through the snowball method, for individual semi-structured interviews, with the aim of balancing gender, representing children, elderly people and people with disabilities as much as possible.

A first visit to the study regions was made from 15 July to 18 July 2019 to identify the villages of interest. We targeted villages where residents lived close to nature and where people have lived for many years or their whole life there. However, the final choices for the villages were made by the local authorities (mayors and heads of the communes) according to the requirements for research and the safety of the research team in the field. Following a preparatory workshop with the entire research team, the workshops and interviews were conducted simultaneously by two groups of paired research team members from 27 July to 4 September 2019, with a stay of three to 4 days in each village. The duration of the interviews ranged from 6 min to 1 h.

The workshops and semi-structured interviews were structured along a guidance note addressing open questions about (1) the most important parts of nature for the community, (2) observations of ecosystem change and (3) the impacts of these changes on individual or collective well-being. While the main interest of the study lies in climate-related ecosystem change, the interviews followed an inductive bottom-up approach and did not specify this focus, to avoid potentially biased responses. Participatory mapping was used to locate specific sites and landscapes concerning the questions of interest (cf. Plieninger et al., 2013). The principal investigator's university ethics committee confirmed compliance with its ethics guidelines. Informed consent to participate in the study was obtained verbally from all participants. All workshops and interviews were conducted in the Malagasy language, recorded as much as possible or otherwise summarised and subsequently transcribed and translated into English. We attempted to reduce the loss of nuanced information due to translation through the involvement of the local research team in the whole research process, including the reflection and interpretation of research findings, using field notes and observations as complementary tools.

All interviews and workshop transcripts were independently coded by two researchers according to the core variables of the conceptual framework (see Supplementary Material 1, Table SM2) using the software MAXQDA (Kuckartz & Rädiker, 2019). The quantitative part consisted of descriptive statistics, including frequencies, cross-tabulations of overlapping coded segments and the MAXQDA tool for complex code configurations (Section 4.1). The qualitative part was based on the extraction of quotes that described explicit links between climate-related degradation that affects NCP and human well-being (Section 4.2).

4 | RESULTS

The following sections first present the overall observations of climate-related ecosystem degradation and the different NCP types related to different aspects of human well-being, as reported by the participants (Section 4.1). This part builds on the quantitative descriptive analysis. Section 4.2 identifies and explores in-depth the diversity of how specific climate hazards affect different types of NCP and well-being, explicitly considering the site's and individual participant's context. This exploratory section draws especially on the qualitative analysis.

4.1 | Observations of climate-related ecosystem degradation and NCP effects on human well-being

The research results reveal a wide range of observations of ecosystem degradation. Where a process of degradation could be linked to a specific hazard, overall, climate hazards (92 observations) were more often mentioned than non-climate-related hazards (66). The link between climate hazards and degradation was especially evident with regard to precipitation variability that causes the drying of continental waters (10); organic matter decline (5); sea level rise and storms and cyclones that cause coastal erosion (6 and 5, respectively); and drought that causes species loss and drying of continental waters (5 times each). Non-climate-related hazards were most often associated with increased burning (21), pollution (16) and organic matter decline (11) (see Supplementary Material 1, Figure SM1).

We found various links between degradation and different NCP types (Figure 3). Especially the material NCP food and feed (35 observations) and materials, companionship and labour (32) were linked to processes of degradation. Among the non-material NCP, this applies mostly to physical and psychological experiences (28), and among the regulating NCP to the regulation of freshwater quantity, location and timing (17); formation, protection and decontamination of soils and sediment (15); and regulation of climate (13).

Our results show a diversity of reported links between NCP and individual well-being (Figure 4). Among the non-material NCP, physical and psychological experiences were mostly associated with health and physical well-being (72 observations), peace of mind and spiritual experiences (41) and basic materials for a good life (26). Supporting identities were, in many cases, associated with peace of mind and spiritual well-being (62). Among the material NCP, the strongest links were between basic materials for a good life and materials, companionship and labour (81) and food and feed (61). These NCP types were also associated with health and physical well-being (20 and 13, respectively). Among the regulating NCP, especially the regulation of air quality was linked to well-being in terms of health and physical well-being (14) and basic materials for a good life (10).

4.2 | Identifying context-specific climate-related degradation of NCP and impacts on well-being

Drawing on a qualitative analysis, the following sections highlight specific examples from the four case studies that provide evidence of the diverse pathways of how climate change causes different kinds of ecosystem degradation affecting different types of NCP, human well-being and ecological grief (see Supplementary Material 1, Figure SM2, for general patterns of relevance of NCP across the sites).

4.2.1 | Impacts of regulating NCP change on well-being

Decreased air quality, warming and scarcity of rain have indirect implications on the quality of life of farmers and fishermen due to a lower comfort of outdoor work and that of village women for having to walk longer distances to find available water sources:

> I can see that the air we breathe is dirtier. And I said before that there is less rain and it's sparser. The sun is too strong. It's too hot.
>
> (Male, Andovoranto)

> If the forests keep decreasing, the rainfall could decrease too, be at the lowest, and that will have a negative impact on the agriculture.
>
> (Male with disability, Ambohimalaza)

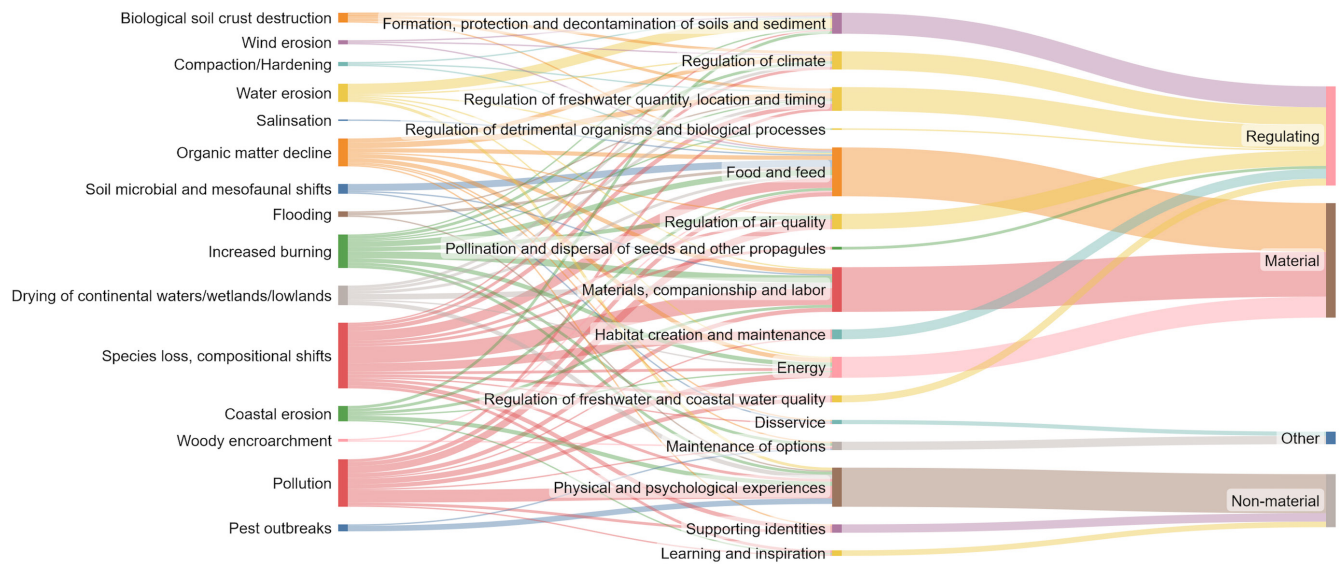

FIGURE 3 Linking degradation and Nature's Contributions to People (NCP). The figure shows the number of coded segments containing processes of degradation linked to specific NCP types and aggregated by NCP category.

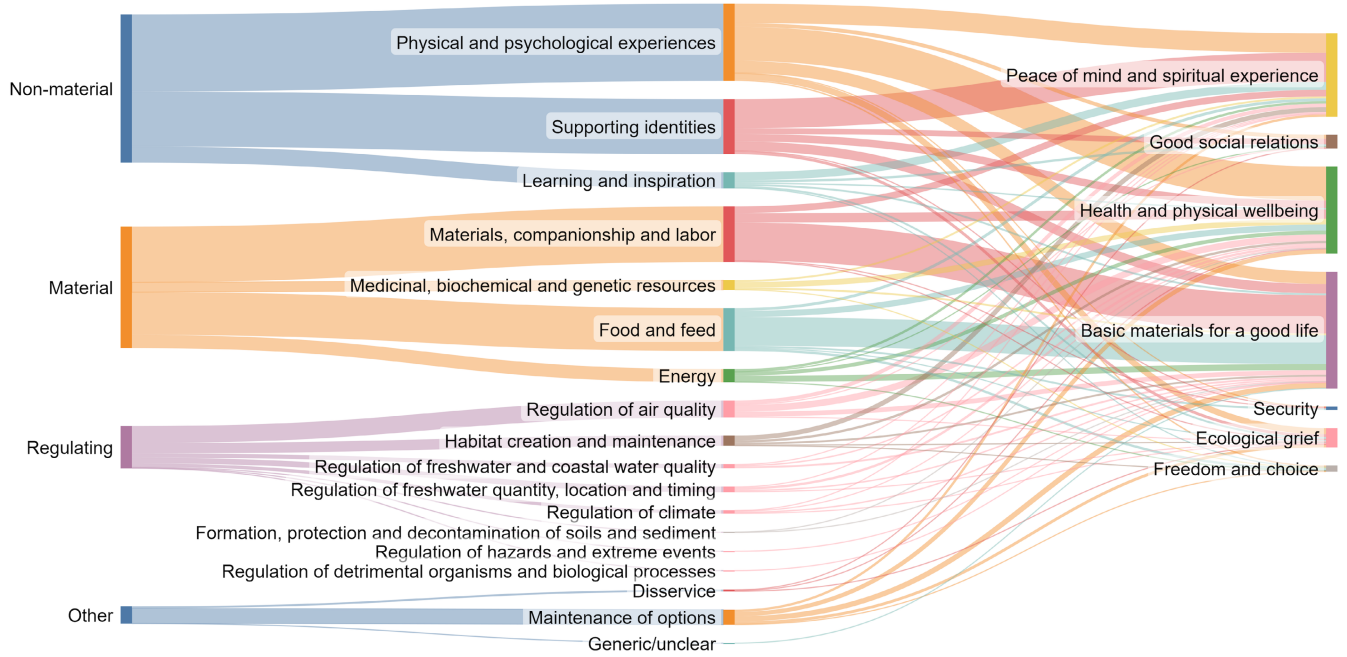

FIGURE 4 Linking Nature's Contributions to People (NCP) to well-being. The figure shows the frequency of coded segments containing the different NCP categories, disaggregated by NCP type, linked to specific dimensions of well-being.

> There is no rain; we are waiting for the next rainy season. We used to have enough water even during the winter, but now we are facing this scarcity.
>
> (Female, Ambohimalaza)

4.2.2 | Impacts of material NCP change on well-being

Rising sea level and increased frequency of cyclones caused coastal land erosion, affecting littoral forests and arable lands. These impacts threaten the access to wood for building materials and energy, and to land for cultivation:

> It represents a threat to us. The land area is already small, and the sea decreases it more. We use palm for roofing because sheet metals get easily damaged by the coastal wind. The problem is that the sea reaches the fields and when it dries, the salt decreases the fertility of the soil; hence, the production. There is no chance for the rice to grow.
>
> (Male and female, Andovoranto)

> I see that the sea became rough, and the fishermen became few. They are scared when they sail, whereas most people here use sea products as a source of income. (…) the seashore is getting nearer to the village and threatens people. Besides, we have cyclones almost yearly, damaging the houses and the farms.
>
> (Female, Andovoranto)

Water scarcity affects crop production and, therefore, the self-sufficiency of the villagers:

> This water scarcity impacts agriculture's quality and products because agriculture needs water, and we don't have enough. We can't just make it; we are struggling. Vegetables don't grow in normal conditions, and we have problems. Some green leaves don't even survive because of that.
>
> (Female, Ambohimalaza)

> When there is no rain, when everything is dry, there is not enough water, when we need water to water the plants, to give the animals something to drink….
>
> (Female, Ambohimalaza)

Human pressure on forest resources threatens livelihoods in the Andovoranto area. For example, there is a lack of building material and the production of seafood is decreasing:

> Certainly, that loss of trees and forest are parts of people's actions, for example, the slash and burn. People cut trees for house construction and some people do charcoal production. Those activities threaten the forest and the socioeconomic life here. (…) The last I noticed is the diminution of sea products (fish). Fishing is the main source of income here, and it is now reduced because of the foreign boats.
>
> (Female, Andovoranto)

A quote from a person with disability shows how changes in material NCP have a particular impact on the disabled, due to constrained access to nature:

> For years now, I have been facing difficulties with the wood supply. Forests are more and more scarce and inaccessible.
>
> (Female with disability, Andasibe)

4.2.3 | Impacts of non-material NCP change on well-being

The prospect of a sea level rise scares many villagers. Most villagers depend on the sea for their livelihoods, but due to coastal erosion and sea level rise, they have reduced their interactions with the sea:

> We are scared that the ocean will flood the village and kill us, and we know we are powerless. (...) The sea became rough and got nearer to the village, which is scary. (...) If you go farther in the east, you will see the sea level rising and swallowing the shore from both sides, so we are trapped between.
>
> (Female, Andovoranto)

People with financial means bought land far from the seashore to escape the rising sea level. However, many cannot afford to relocate and must adapt to the shoreline change:

> People are buying lands far from the coast. I am not doing that because I have money issues.
>
> (Female, Andovoranto)

Unsustainable practices lead to the scarcity of sacred trees such as the 'Hasina', which are used to perform traditional rituals:

> Another change I have noticed is the loss of sacred trees used during circumcision rituals and to protect the house and wealth. Sometimes, the 'elder men' used them for their sacred sticks, which is part of cultural habits.
>
> (Female, Andovoranto)

Besides its impacts on agricultural production, drought also impacts on non-material NCP. For example, reduced availability of water affects cooking and recreational practices:

> Because of this, I couldn't play in the river because even the water to make the food was scarce. All this because of the dryness.
>
> (Female, Andasibe)

Disservices, such as different diseases and bad health conditions, were mentioned across the study sites (e.g. lung disease, acute headache, fatigue and even an unknown illness in Ambohimalaza) and were mentioned to be directly associated with changes in the natural environment or weather:

> Climate change causes different diseases in people. Especially the change in temperature in one day causes fever.
>
> (Female, Mantasoa)

4.2.4 | Ecological grief

Our research provides examples of diverse expressions of ecological grief. Sadness about losing nature was the most common feeling among the interviewees. There was a general agreement that the forest ecosystem provides the most valuable resources not only for people's economic activities but also for their well-being. The decrease in biodiversity and keystone species such as the fig tree (*Ficus* sp.) was mentioned as a considerable loss:

> If the forest disappears, I would feel really sad.
>
> (Female, Ambohimalaza)

> As a person with disability, I feel so sad because life is getting harder.
>
> (Female with disability, Andovoranto)

Some farmers are close to giving up. Loss of natural resources and the resulting lower quality of life lead to feelings of hopelessness and discouragement. Climate change is the root of most obstacles to a decent life:

> The damage caused by climate change is robbing us of all our assets. Worry and fatigue are eating away at me. I no longer have the courage to go through with it. Life's trials and tribulations only exhaust me. About wood, as I told you, if I don't buy wood elsewhere, I can no longer get it from the forest. Our standard of living is getting lower and lower. Right now, we have six or eight feet of chayotes that bring in money during the rainy season. Their cultivation requires wooden stands.
>
> (Male, Ambohimalaza)

In addition to the negative emotions generated by climate change, culpability and victims were raised during some interviews and workshops, leading to tensions between different generations. The current generation accuses the previous generation of being responsible for their vulnerability and poor health condition:

> It makes me sad; it makes me angry, but it makes me feel overcome. I'm sad because it's not us in 2019 who caused all this, but the people before us. So, the previous generations have done this, and it's us who suffer the consequences, so it makes me really sad. This sadness is related to the subject of health. We have become fragile people because of this climate change.
>
> (Workshop participant in Mantasoa)

At the coastal site, Andovoranto, people lived in constant fear of losing housing and farming areas, combined with feelings of frustration and powerlessness.

> We are worried about the land mass, which is constantly decreasing. The sea swallows more areas. The sea is getting closer, maybe 100 metres from the road. When I was 10, the sea didn't cross this path. We don't know what action to take. Even if we plant trees, it will be useless because it is a natural phenomenon.
>
> (Male, Andovoranto)

5 | DISCUSSION

Our findings provide evidence that climate change is already affecting Central and Eastern Madagascar's ecosystems in various ways, such as through water scarcity, coastal erosion, biodiversity loss and increased air temperatures. These findings are in line with regional observations and projections of temperature increase, shifting seasons and rainfall decrease, as well as longer dry seasons (Alizany et al., 2010; Jury, 2022). Future impacts on livelihoods and biodiversity may also result from the predicted increased frequency and intensity of cyclones (Rakotoarison et al., 2018; Weiskopf et al., 2021). Cyclones and possible storm surges could further increase coastal erosion, as has been observed at our coastal study site, Andovoranto. Ultimately, coastal land loss can trigger forced relocation. While managed retreat in response to sea level rise has been observed in coastal areas in the Global North (Hino et al., 2017), the sociocultural implications of such a perspective are particularly critical in local and Indigenous communities of the Global South (McMichael et al., 2019).

Our findings show how observed climate-related ecosystem degradation has concrete impacts on the provision of different types of NCP and mental and physical well-being for resource-dependent rural communities in Central and Eastern Madagascar. For regulating services, the reduction of air quality can be associated with an increase in temperature, but also with anthropogenic activities (e.g. slash-and-burn practices), which are characteristic of many rural tropical communities (Pedroso-Junior et al., 2009). Changes in material NCP, such as the lack of water for drinking and irrigation—a source of income and food—are mainly related to decreased precipitation. Similar impacts have also been reported across Africa (Sintayehu, 2018), in China (Yang et al., 2021), Nepal (Bhattarai, 2017) and the United States (Weiskopf et al., 2020). The increased unpredictability of seasons affects agriculture with particular consequences for people dependent on rainfed agriculture (Sintayehu, 2018). Also, recreational activities (i.e. non-material NCP) in our study sites, such as swimming, are affected by climate change, due to Water deficiency and lower water quality (Grizzetti et al., 2019; Lin et al., 2022).

Despite limitations in our study due to the limited sample size, we can draw conclusions on the basis of the comparison of the four case study sites which highlights the importance of considering the context-specificity of NCP and well-being when addressing environmental and climate change (McElwee et al., 2022). Across all sites, various material and non-material NCP contribute to well-being in different ways. In Ambohimalaza, non-material NCP was mentioned more often than other NCP categories. At this site, with its 12 sacred hills and remnants of primary forest, supporting identities were more important compared to the other sites. In Mantasoa, where the local population relies on the hydroelectric power station and material for construction, firewood and charcoal production, energy is more important NCP, compared to the other sites. The dense rainforest in Andasibe is an important place, especially for physical and psychological experiences, but also for materials, companionship and labour. In Andovoranto, it is the coastal and forest environment that people rely on for food and feed, as well as materials, companionship and labour and its sacred sites, for supporting identities.

Our results demonstrate how negative emotions linked to climate change affect local populations in different ways. The quotes of worry, fear and anger, due to these changes, exemplify ecological grief as a form of human emotional response at the individual and collective level. Negative impacts on well-being were detected through changes in material NCP, such as rising sea level that affects fishing and the availability of drinking water, with consequences for both physical and mental well-being. The drop in productivity in Ambohimalaza and Andasibe, and the loss of forest in Mantasoa, manifest in economic stress, also triggering physical and mental well-being impacts. Fear associated with mental distress was the response of local populations, especially adults, to the loss of land mass due to sea level rise in Andovoranto. Other reports confirm this observation, as powerful cyclones impacted several settlements in Eastern Madagascar with thousands of houses destroyed, resulting in fear and triggering acute distress impacting mental well-being (Rakotoarivonjy, 2022). The loss of wild animal species in Andasibe, which is surrounded by tropical forests, was felt as a tragedy due to their value for touristic activities and as part of their heritage. In terms of supporting identities, the potential loss of specific species used in sacred rituals in Andovoranto exemplifies grief associated with disruptions to environmental knowledge systems and feelings of loss of identity. Hence, our findings provide context-specific evidence of all three dimensions of ecological grief (i.e. grief from experienced physical ecological loss, loss of environmental knowledge or identity and anticipatory grief; Cunsolo & Ellis, 2018).

Our bottom-up approach includes the voices of different social subgroups and stresses the importance of considering aspects of demography and intersectionality connected to concerns of availability of nature benefits through all sensory forms (i.e. sight, hearing, taste, touch and smell) and access to nature under changing environmental conditions (McElwee et al., 2022), for example, for the well-being of people with disabilities (Kosanic et al., 2022) and the specific impacts on women (Romanello et al., 2022). Additionally, a generational shift is leading to changes in human-nature and human-human relationships and potentially reduced adaptive capacity due to a lack of environmental awareness and loss of customs, confirming observations from other sites in Madagascar (Raharinjanahary & Gueunier, 2006; Rakotomalala et al., 2001). Similar concerns have been observed around the issue of demographic change and loss of environmental knowledge in the context of climate risks in many countries, not only in the Global South (Gómez-Baggethun et al., 2013). At the same time, evidence of the pressure on the local ecosystem and communities through warming, the unpredictability of seasons, drought and more frequent cyclones, needs to be seen against a background where strong human interventions are occurring and contributing to environmental degradation, especially impacting vulnerable populations in the Global South (Pörtner et al., 2023).

Urgent measures must be taken to reduce the pressures on ecosystems (e.g. deforestation, overexploitation) as their consequences are most likely exacerbated by climate change and decrease the quality of life of already vulnerable populations. Effective measures could benefit from successful conservation actions implemented by various NGOs (e.g. Chances for Nature, Lemur Love) in other locations in Madagascar, which connect nature conservation to community development. Such actions must be adapted to meet the context-specific needs and expectations we found in this study, and could include environmental education, income generation, sustainable resource management, solar electrification and energy-efficient cooking alternatives. Furthermore, pilot projects to incentivise reduction of carbon emissions from deforestation and forest degradation (REDD+) in protected areas on the island proved promising but social safeguards should equally benefit people in forest-dependent communities (Poudyal et al., 2016).

6 | CONCLUSIONS

We used the NCP lens to link climate change impacts to ecosystem degradation and its various effects on human well-being (i.e. including mental well-being) and different dimensions of ecological grief in four resource-dependent rural communities in Central and Eastern Madagascar. Our findings demonstrate the existential challenges for these populations due to increasing climate-related ecosystem degradation—not only due to impacts on material contributions, but also on regulating and especially the non-material ones. In this way, our study contributes to a better understanding of the value of non-material well-being benefits for resource-dependent communities of the Global South—beyond monetary terms (McElwee et al., 2022).

We recommend that future work focuses on multiple values of nature (in particular, 'relational values') that can deepen our understanding of their impact and interconnection with our well-being. A deeper understanding of people's relationship and connection with nature can foster mental health benefits, pro-environmental behaviour and more equitable conservation strategies that lead to sustainable and just futures (Pascual et al., 2023). Finally, our research may contribute to a better understanding of how to achieve the UN SDGs on climate action, ecosystem conservation and human well-being. Our findings stress the need for co-created knowledge on climate change impacts and well-being to develop adequate response strategies for local communities in the Global South, which depend on the functioning of their local ecosystem.

AUTHOR CONTRIBUTIONS

Jan Petzold, Aleksandra Kosanic, Felana Rakoto Joseph, Princy Rajaonarivelo Andrianina, Onintsoa Ravaka Andriamihaja and Mialy Razanajatovo conceived the ideas and designed the methodology; Jan Petzold, Felana Rakoto Joseph, Princy Rajaonarivelo Andrianina, Sitraka Mireille Ranaivosoa-Toandro and Onintsoa Ravaka Andriamihaja collected the data; Jan Petzold, Aleksandra Kosanic, Felana Rakoto Joseph, Princy Rajaonarivelo Andrianina, Sitraka Mireille Ranaivosoa-Toandro, Onintsoa Ravaka Andriamihaja and Lara Thien analysed the data; Jan Petzold, Aleksandra Kosanic and Mialy Razanajatovo led the writing of the manuscript; All authors contributed critically to the drafts and gave final approval.

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CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

All data for this publication is available for download from the Open Data repository of the library of the Ludwig-Maximilians-University Munich, München, Germany, at: https://doi.org/10.5282/ubm/data.383.

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SUPPORTING INFORMATION

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

Supplementary Material 1. Table SM1. Details related to ecosystems, ethnic groups, activities, uses, and customs for the four study sites.

Table SM2. Coding framework.

Table SM3. Workshop participants per study site and social subgroup.

Table SM4. Interviews per study site and social subgroup.

Figure SM1. Hazards and degradation. Distribution of overlapping coded segments on hazard and process of degradation (note that rising ocean temperature and ocean acidification were not coded and therefore omitted from the figure).

Figure SM2. Nature's Contributions to People (NCP) per study site. Percentage of NCP types reported by local respondents per case study site.

Supplementary Material 2. Interview guide; Workshop guide.

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