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ORIGINAL ARTICLE

Incremental and transformational adaptation to climate change among Indigenous Peoples and local communities: a global review

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Abstract
Around the world, Indigenous Peoples and local communities are exposed to different climate change impacts to which they respond in a myriad of ways. Despite this diversity, there are few comparative studies assessing the magnitude of livelihood system change resulting from Indigenous Peoples' and local communities' responses to climate change impacts. Drawing on the analysis of 210 peer-reviewed publications, we analyze 3292 Indigenous Peoples' and local communities' responses to climate change impacts, focusing on the magnitude of change they entail. Globally, Indigenous Peoples and local communities are actively adjusting their livelihood activities, most frequently applying incremental responses. However, in half of the case studies, communities fully or partially transform their livelihoods to respond to climate change impacts. Both incremental and transformational responses can have adverse impacts on Indigenous Peoples' and local communities' lives. Trends in the magnitude of livelihood changes are similar across climates and livelihoods except for responses in (semi-)arid climates, where most intermediate and transformational responses take place, and for responses in cultivation, where most incremental changes take place. When transformational adaptation occurs, Indigenous Peoples and local communities often not only give up their livelihood strategy, but also their culture and way of living.

Keywords Autonomous adaptation · Climate change adaptation · Coping · Local livelihood strategies · Systematic literature review · Transformative adaptation

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1 Introduction

Impacts from anthropogenic global warming are setting in motion cascading effects that affect a wide array of natural systems, which in turn affect humans and their livelihoods (Lawrence et al. 2020). For example, changes in the atmospheric system (e.g., changes in temperature and precipitation) affect the physical system (e.g., water availability), which in turn influences the biological system (e.g., abundance, distribution, and behavior of plants and animals), as well as human managed systems (e.g., crops and livestock). It is acknowledged that climate change impacts on human livelihoods result in a vulnerability increase, particularly among those who directly depend on nature for their subsistence (IPCC 2018; Reyes-García et al. 2019; Rosenzweig and Neofotis 2013). Indeed, in many regions of the world, climate change impacts, from declining Arctic sea ice (Min et al. 2008), to changes in hydrology (Rosenzweig and Neofotis 2013), or the increasing frequency of wildfires and coastal flooding (IPCC 2014), are hindering not only food production but also other living conditions such as access to shelter, sanitation, and water (Sommer et al. 2013).

Among the groups most affected by climate change are Indigenous Peoples (IPs) and local communities (LCs) (Reyes-García et al. in press), here defined as groups and individuals who self-identify as Indigenous (IPs) or as members of specific local communities (LCs) and who maintain intergenerational connection through livelihood, cultural identity and worldviews, institutions, and ecological knowledge (IPBES 2022). Many IPs and LCs have a long history of interaction with the environment and—in many cases—have experienced climate variability throughout history (Makondo and Thomas 2018). This experience can be important to deal with the changes associated with emerging climate change impacts (Anik and Khan 2012; Belfer et al. 2017; Fairhead et al. 2017). However, given the unprecedented speed and magnitude of current climate change (IPCC, 2021; Makondo and Thomas 2018), traditional responses to climatic change and variability may not be sufficient, particularly as climate change impacts often act in combination with other socioeconomic factors (IPCC, 2022; Junqueira et al. 2021; Kates et al. 2012; Magesa and Pauline 2019; Maru et al. 2014; Reyes-García et al. 2023). Greater magnitude and frequency of local climate change impacts increase the likelihood of surpassing traditional adaptation limits (IPCC 2022), forcing IPs and LCs to change their livelihoods in fundamental ways (Fedele et al. 2019; Magesa and Pauline 2019).

Local responses to climate change impacts have been discussed in terms of being "incremental" versus "transformational" (e.g., Barnes et al. 2017; Kates et al. 2012; Käyhkö et al. 2020; Magesa and Pauline 2019; Park et al. 2012; Tàbara et al. 2018; Termeer et al. 2017; Wilson et al. 2020). "Incremental" responses to climate change impacts refer to minor changes to existing and familiar practices while maintaining the state and function of a social-ecological system (SES) (Barnes et al. 2017; Fedele et al. 2019; Folke et al. 2010; Kates et al. 2012; Nelson et al. 2007; Termeer et al. 2017). Examples include the reduction of livestock or cultivated area or the increased use of fertilizer or water (Fedele et al. 2019). Contrastingly, "transformational" responses involve the creation of a fundamentally new state or system (Walker et al. 2004) or the recombination of the elements of a system in fundamentally new ways (Moore et al. 2014). Transformational responses are often described as innovative, multiscale, and addressing the root cause of vulnerability (Fedele et al. 2019), as the result of the sum of different kind of changes (Moore et al. 2014), as consisting of several phases in time (Olsson et al. 2004), and as encompassing a change in paradigm, power structures, and institutional arrangements (IPCC 2022). Transformational responses may include the adoption of practices at a large scale, the adoption of practices

that are truly new to a particular region or system, or shifts in locations (Kates et al. 2012). Examples of transformational responses include far-away migration (Birkmann et al. 2022) or giving up traditional livelihoods (Barnes et al. 2017; Dam et al. 2021). Transformational responses can be deliberate, if they are initiated as a precautionary measure by the people affected, or forced, if they result from an absolute necessity from changing environmental or socioeconomic circumstances (Folke et al. 2010; O'Brien 2012; Pelling et al. 2015). Deliberate transformation is not common because people tend to maintain the system they are part of "as they know it" and are generally reluctant towards large changes due to unfamiliarity and potential high costs, even if transformation would be more appropriate (Fedele et al. 2019; Kates et al. 2012).

Researchers have argued that incremental responses might potentially trap those who adopt them in an undesired state (Barnes et al. 2017; Rickards and Howden 2012). Examples of such traps include cases in which common water saving techniques have failed in countering climate change induced water scarcity (Magesa and Pauline 2019) or cases in which herders are forced to sell all their livestock at once, since the animals are so thin that selling only a part of the herd will not account for basic living expenses (Zhang et al. 2013). As climate change impacts intensify, transformational responses are becoming increasingly needed for avoiding these traps (Ajulo et al. 2020; Rickards and Howden 2012). Nevertheless, transformational strategies, particularly when traditional livelihoods are replaced, can also have far-reaching consequences for IPs' and LCs' livelihoods, such as the loss of traditional values, identity and knowledge, the loss of social bonds, or an increase in precarious living and working conditions when people migrate (Granderson 2017; Meldrum et al. 2018; Panikkar et al. 2018).

Relatedly, both incremental and transformational responses to climate change impacts can turn out to be maladaptive. Juhola et al. (2016) describe three types of maladaptive outcomes: those that rebound vulnerability, those that shift vulnerability, and those that erode sustainable development. For example, an incremental response such as the application of agrochemicals can result in maladaptive outcomes that counteract sustainable development through the pollution of nearby water bodies and an increase in soil acidity above the required threshold for crop production (Guodaar et al. 2020). Similarly, a transformational response such as labor migration of an individual household member can shift and rebound household vulnerability by shortening available labor resources, thereby increasing food insecurity (Jacobson et al. 2019).

IPs' and LCs' responses to climate change are important to examine, not only because they affect the management of more than a quarter of global land areas (Garnett et al. 2018; Li et al. 2013), but also because IPs and LCs hold profound knowledge that is vital for environmental management, resulting from their direct dependence on nature for their livelihoods, cultures, and identities (Belfer et al. 2017; Birkmann et al. 2022; IPBES 2019). Therefore, it is increasingly acknowledged that Indigenous and local knowledge of the environment is key for successful climate change adaptation strategies (Baul and McDonald 2015; Brondízio et al. 2021; García-del-Amo et al. 2020; Li et al. 2021; Reyes-García et al. 2019; Savo et al. 2016) and that local responses to climate change can serve as an important source informing climate change adaptation at larger scales (Belfer et al. 2017; Fairhead et al. 2017; Makondo and Thomas 2018). For example, (sub)tropical forests, of which large parts are managed by IPs and LCs (Garnett et al. 2018), have the potential to mitigate up to 50% of greenhouse gas emissions in tropical nations, if managed to foster biodiversity (Griscom et al. 2020). Including IPs and LCs and their knowledge systems in national adaptation plans could contribute to this biodiversity support and improve local livelihoods at the same time (Reyes-García et al. 2022). However, despite their importance,

IPs and LCs responses to climate change are often overlooked in climate change adaptation policy and research (Petzold et al. 2020). Moreover, despite the wealth of literature on climate change adaptation, few scholars focus on the global variety of IPs' and LCs' responses (e.g., Schlingmann et al. 2021), and even fewer on the possible trends of transformational adaptation led by IPs and LCs (Surugu and Chutab 2021).

The main goal of this work is to assess the magnitude of livelihood system change resulting from the diversity of IPs' and LCs' responses to climate change impacts. To do so, we analyze local responses to climate change impacts by classifying whether IPs' and LCs' livelihood system change resulting from adopting these responses is incremental or transformational (Berrang-Ford et al. 2021; Pelling et al. 2015). Our work responds to calls for more comparative studies assessing the transformational character of responses to climate change in small SESs (Berrang-Ford et al. 2021; Fedele et al. 2019; Lam et al. 2020; Magesa and Pauline 2019). Compared to previous studies, our classification focusses on response magnitude, rather than on response processes (Mapfumo et al. 2017) and includes a larger variety of livelihoods (Dam et al. 2021; Rana and Moniruzzaman 2021; Vermeulen et al. 2018). Since we assess the magnitude of change associated with local responses to climate change impacts, it is beyond the scope of this paper to evaluate the need for adaptation, as well as to assess the potential benefits and impacts, including socio-ecological and financial aspects, arising from adaptation to climate change, although touched upon briefly in our discussion. Relatedly, some characteristics of transformational responses, as described in the literature, e.g., being the result of the sum of different kinds of changes (Moore et al. 2014) or addressing the root cause of vulnerability (Fedele et al. 2019), are not assessed here.

Our classification system serves as the basis for a descriptive analysis of trends in local responses to climate change by IPs and LCs. Since local responses to climate change are very context-specific (Berman et al. 2020; Ensor et al. 2019; Shaffril et al. 2020; Waugh et al. 2018; Zin et al. 2019), we assess trends of incremental and transformational responses across different climates and livelihoods.

Results from our work suggest that, to respond to climate change impacts, IPs and LCs mostly implement incremental responses, although the use of intermediate and transformational responses is also widespread. Observed trends in the magnitude of livelihood changes are similar across climates and livelihoods, except for responses in (semi-)arid climates, where most intermediate and transformational responses were found, and for responses in cultivation, where most incremental changes were reported. We also find that IPs' and LCs' incremental responses entail active adjustments of practices rather than a mere continuation of those practises. When transformational adaptation occurs, we find that IPs and LCs often not only give up their livelihood strategy, but also their culture and way of living.

2 Methods

2.1 Literature review and synthesis

We examined peer-reviewed publications appearing between 2002 and 2020 and reporting IPs' and/or LCs' coping and adaptation strategies to climate change impacts. Publications were selected through the web-based search engines Web of Science® (WOS) (http://science.thomsonreuters.com) and Scopus® (https://www.scopus.com/), using the search

keywords "climate change" AND ("indigenous knowledge" OR "local knowledge" OR "traditional knowledge" OR "traditional ecological knowledge") AND ("adapt*" OR "coping" OR "cope") appearing in titles, abstracts, and keywords. We found 1042 publications. From these, we only kept studies based on first-hand empirical data reporting IPs' and/or LCs' coping and adaptation strategies to climate change impacts. Publications in languages other than English, publications reporting non-human responses, and publications reporting responses to non-climatic drivers were discarded. Reflecting the inclusion criteria, 419 publications were excluded after reading the title and abstract and another 413 were excluded after reading the full text. A total of 210 publications met our inclusion criteria and were kept for assessment. For each selected publication, we collected bibliographic information (i.e., authors and publication year). As some publications reported more than one case study, our final sample includes a total of 313 case studies. From each case study we compiled (1) geographic location information (e.g., GPS coordinates, climate), (2) studied group characteristics (e.g., main livelihoods), and (3) responses to climate change impacts implemented. For further details on the review process, see Schlingmann et al. (2021).

2.2 Classifying incremental and transformational responses

Based on the relevant literature on transformations in SES (e.g., Berrang-Ford et al. 2021; Fedele et al. 2019; Johnson et al. 2018; Kates et al. 2012; Moore et al. 2014; Surugu and Chutab 2021; Walker et al. 2004), we developed a classification that allows us to capture the *magnitude* of change in responses to climate change impacts. Our classification distinguishes between *incremental*, *intermediate*, and *transformational* responses. Incremental responses entail small alterations in *livelihood features*, allowing for a preservation of the livelihood system as a whole (Barnes et al. 2017; Folke et al. 2010; Kates et al. 2012; Magesa and Pauline 2019; Nelson et al. 2007; Termeer et al. 2017). For example, changes in the planting and harvesting time (changes in "time management") and the adoption of new crops species and varieties (changes in "livelihood product") are classified as "incremental" (Ash et al. 2012; Fedele et al. 2019; Magesa and Pauline 2019; Maru et al. 2014; Nguyen et al. 2013; Nhemachena and Hassan 2007; Wilson et al. 2020). Contrary to Fedele et al. (2019), we classified reactive (coping) as well as anticipatory responses as "incremental" (Ash et al. 2012; Magesa and Pauline 2019; Wilson et al. 2020). To capture the diversity of alterations embedded in incremental responses, we differentiated between responses that *revitalize*, *maintain*, *adjust*, *shift*, or *switch* a livelihood feature, where "revitalize" is the weakest and "switch" the strongest change of a livelihood feature (Fig. 1).

Transformational responses are those that fundamentally change the *livelihood system* (Barnes et al. 2017; Birkmann et al. 2022; Kates et al. 2012; Magesa and Pauline 2019; Moore et al. 2014; Walker et al. 2004). Hence, responses classified as transformational consist of changes such as permanent far-away relocation and a full switch of livelihood activity (Barnes et al. 2017; Birkmann et al. 2022; Kates et al. 2012). As the boundary between responses that "preserve" (i.e., incremental change) and those that "transform" a system is not unambiguous (Kates et al. 2012; Nelson et al. 2007; Termeer et al. 2017), we added a third, intermediate, response category (named "intermediate") capturing responses that only partially change the livelihood system. Examples of intermediate responses are *temporary* relocation (Penning-Rowsell et al. 2013; Warner and Afifi 2014), diversification of livelihood categories, or partial engagement with commercial trading (Nelson et al. 2007).

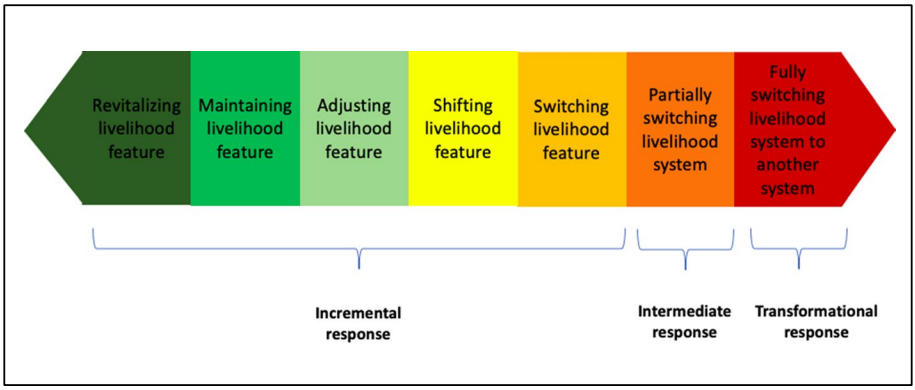


Fig. 1 Response categories organized according to the magnitude of change they entail, from incremental (left) to transformational (right)

To apply our classification (Table 1), we first grouped all reported responses according to the 3-level classification system proposed by Schlingmann et al. (2021). Specifically, each response was classified according to (1) the *response sector*, which defines the main livelihood activities in which a response occurs (i.e., cultivation, livestock rearing, hunting/gathering, fishing/aquaculture, and "other activities," which includes low and non-nature-based income such as off-farm work and aspects related to housing and community life in general), (2) the *response domain*, which describes the *livelihood features* of a response (i.e., changes in time management, location, practices and techniques, livelihood product, productive resource input, social and human capacity building, or a change regarding the full livelihood system), and (3) the *response type*, which specifies the quantitative or qualitative character of a response (i.e., changes in the number versus the composition of livestock or cultivated crops). As a last step, responses were classified as "incremental," "intermediate," or "transformational" based on the *direction of change* (e.g., increase or decrease of livelihood practices, see *Supplementary Materials A:* Table 1) and *temporal dimension* ("temporary" or "permanent"). See *Supplementary Materials A:* Table 2 for the resulting classification table.

We provide a descriptive analysis of the resulting classification including (*i*) the distribution of case studies reporting at least one type of response and (*ii*) the absolute and relative shares of different categories. We also examine the distributions of response categories across different climates and response sectors. To test whether differences observed were statistically significant, we used a generalized linear model (GML) including the ratio of incremental, intermediate, or transformational responses detected to all other responses as dependent variable and climate (or response sector) as explanatory variable, with a binomial distribution and a logit link (Zuur et al. 2007). Analysis was carried out using the Python IDE Spyder 4.1.5 (Raybaut 2009) and R 4.2.2 (R Core Team 2022). Graphs and Artwork were created using Microsoft Office package 16.67.

2.3 Caveats

We acknowledge several caveats in our work. First, as our review did not include grey literature and non-English publications, e.g., reports about adaptation projects supported by NGOs (Piggott-McKellar et al. 2019) or publications covering climate change adaptation actions by IPs or LCs written in Spanish (Fernández-Llamazares et al. 2014), relevant

Table 1 Response categories with their response domain, description, and an example

Response domain	Description	Example
Incremental		
Time management, location, practices and techniques, livelihood product, productive resource input, social and human capacity building	*Revitalization* (reuptake or readoption) of a measure/strategy applied in the past	Reintroducing indigenous salt-tolerant rice varieties and fish species to address increased water and soil salinity (Singh et al. 2019)
	Purposely *maintaining* and preserving (or slightly enforcing) measures/strategies already in place or remaining at the place of living/livelihood	Maintaining collective fishing agreements to deal with the shallowing of lakes in the dry season (Oviedo et al. 2016)
	Slightly *adjusting* current practices, e.g., timing, frequency, quantity, and close-by relocation	Decreasing the use of water to respond to water challenges (Makondo and Thomas 2018)
	Shifting towards or from a certain practice within livelihood, but not totally abandoning older practices	Reducing cereal farming and instead grow vegetables that demand less water to deal with high temperatures and decreased rainfall (Baul and McDonald 2015)
	Switching (stop or start) a livelihood practice/feature	Change to drought-tolerant crop species to respond to increasing droughts (Rankoana 2016)
Intermediate		
Location	*Temporary* far-away relocation of livelihood activities	Migrating temporarily to preserve livelihood (agriculture) during droughts (Ogalleh et al. 2013)
Livelihood system (livelihood category)	*Start diversification* of different nature-based livelihood categories	Complementing fishing with crops or cattle farming to reduce vulnerability to climate hazards (Audefroy and Sánchez 2017)

Table 1 (continued)

Response domain	Description	Example
Livelihood system (income)	*Start diversification* by additionally practicing other (low) nature-based livelihood and income	Complementing main livelihood (cultivation) with bee farming to respond to water shortage (Kupika et al. 2019)
	Start diversification by additionally practicing other non-nature-based livelihood and income	Complementing main livelihood (agriculture) with off-farm occupations to address water challenges (Sada et al. 2014)
	Start or *stop* commercial trading of livelihood products	Starting to grow and trade cash-crops instead of traditional crops to deal with multiple climatic stresses (Meldrum et al. 2018)
	Start or *stop* taking insurance	Starting livestock (Gentle and Thwaites 2016) or risk insurance (Kassie et al. 2013)
	Start or *stop* getting financial support, remittance, loans, credits, and borrows	Raising a loan to react to ENSO-related droughts (Binternagel et al. 2010)
Transformational		
Location	*Permanent* far-away relocation of livelihood activities	Migrating permanently as a reaction to adverse climatic conditions for agriculture/livestock rearing (Zampaligré et al. 2014)
	Start or *stop* seasonal migration/nomadic lifestyle	Giving up pastoralist nomadic lifestyle due to changes such as increasing droughts (Omolo and Mafongoya 2019)
Livelihood system (livelihood category)	*Start* practicing a new nature-based livelihood category or *stop* practicing familiar nature-based livelihood category	Starting to practice agriculture and giving up fishing in response to unstable climate, monsoons, more severe and frequent storms, and declining fishing resources (Sereenonchai and Arunrat 2019)
Livelihood system (income)	*Start* or *stop* practicing other (low) nature-based livelihood & income	Starting to sell prepared food as an alternative source of income to deal with climatic changes (Egbe et al. 2014)
	Start or *stop* practicing other non-nature-based livelihood and income	Changing from fishing to rickshaw pooling as a reaction to climatic stresses (Barua et al. 2020)

information from these sources that potentially could change the observed trends was not accounted for. Second, we acknowledge that our sample might not be representative of adaptation sectors and locations, as we identify sectorial and geographical biases in the case studies analyzed. Third, as our unit of analysis is the case study, our work does not capture response variability at the household level, hiding potential internal differences in adaptation. Given these biases, reported trends might not fully reflect actual trends in underrepresented regions, climates, and sectors or might hide intrahousehold differences. Further work could improve the accuracy of results by enlarging the sample and incorporating responses adopted at the household level.

3 Results

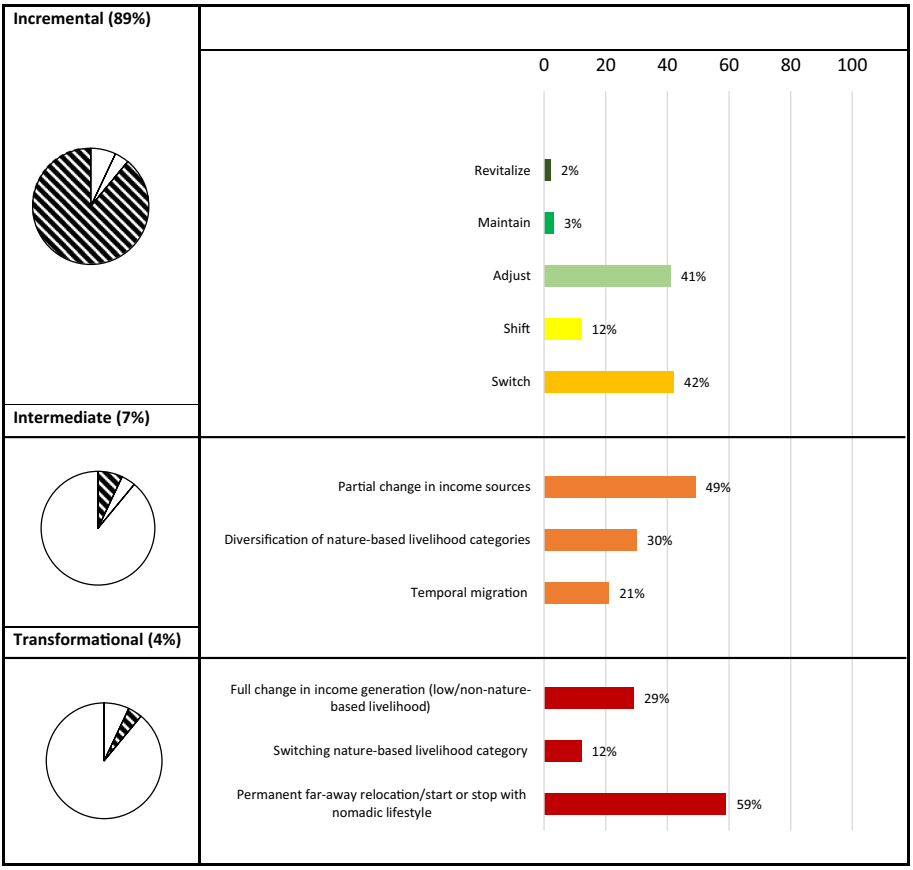
The 210 reviewed publications report 313 case studies located in 65 different countries. Most case studies are in Asia (37%) and Africa (35%) and correspond to tropical (34%) and temperate climates (28%) (for more details, see Fig. 1, *Supplementary Materials A:* Fig. 1 *and Supplementary Materials B*). Three out of four case studies (76%) report responses in several livelihood categories. Agriculture is the most frequent livelihood activity, practiced in 82% of the case studies, followed by animal husbandry (48%), and fishing/aquaculture (32%) (*Supplementary Materials A:* Fig. 1).

3.1 Incremental, intermediate, and transformational responses

We documented a total of 3292 responses to climate change impacts. Most of the reported responses were "incremental" (89%), while 7% were "intermediate," and 4% "transformational." Incremental responses largely comprised of a switch (42%) or adjustment (41%) of livelihood features, such as switching livestock breeds, or adjusting the sowing time (Table 2 and *Supplementary Materials A:* Table 3). Intermediate responses mostly included a change in income generation (49%), such as a switch in commercial trading or complementing the main nature-based livelihood with additional non-nature-based income generation, followed by the diversification of nature-based livelihood categories (30%). Transformational responses predominantly included drastic changes in location (59%), such as migration, or in income generation activities (29%), e.g., a complete switch to a non-nature-based livelihood.

An average of 11 responses were documented for each case study. In *all* case studies, *at least one* response was classified as "incremental," and in 93% of the case studies at least one incremental response referred to an adjustment of existing livelihood practices (Fig. 2a). In many case studies (88%), people switched livelihood features to completely replace most affected ones (e.g., highly damaged crop species). In more than half of the case studies (58%), people responded to climate change impacts by shifting the relative weight of livelihood activities, instead of completely abandoning a livelihood activity; thereby maintaining a certain degree of diversity. Only in a few case studies, the active continuation of established practices (16%) and the revitalization of traditional practices (12%) were mentioned as local responses to climate change. Remarkably, in 51% of the case studies at least one intermediate (41% of case studies) *or* transformational response (26%) was reported.

Table 2 Frequency in percentages of incremental ($n=2936$), intermediate ($n=236$), and transformational ($n=120$) responses to climate change impacts reported in the literature ($n=3292$). See *Supplementary Materials A:* Table 4 for more detailed distributions of intermediate and transformational responses



3.2 Response categories across climates

The distributions of response categories across climates (Fig. 2b) did not differ much from the distribution of the whole sample (Fig. 2a). In all climates, the shares of case studies with incremental responses that "adjust" or "switch" a livelihood feature were the highest, and the percentages of case studies with incremental responses that "revitalize" or "maintain" a livelihood feature were the lowest. Similarly, the incremental response "shift" was the third most frequent response in most climates, although in the cold/boreal climate this type of incremental response was less frequent.

The share of case studies reporting *at least one* intermediate (59%) or transformational response (35%) was highest in "(semi)-arid" climates ($p=0.0102$ and $p=0.0373$, respectively, see *Supplementary Materials* B). The share of case studies reporting *at least one* transformational response was also high in temperate climates (32%). In all climates, the share of case studies reporting transformational responses was lower than the share of those reporting intermediate responses, except in cold/boreal climates, where the share of case studies reporting intermediate responses was the lowest (13%).

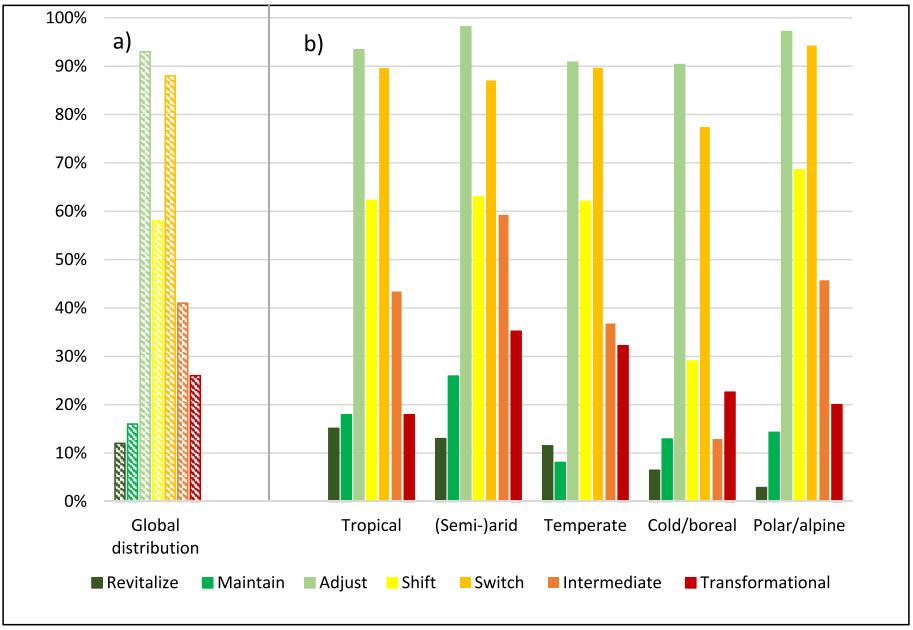


Fig. 2 Percentages of case studies in which a response category was reported at least once. **a** Global distribution. **b** Distribution of sites located in tropical ($n=106$ case studies), (semi-)arid ($n=54$), temperate ($n=87$), cold/boreal ($n=31$), and polar/alpine ($n=35$) climates, following the Köppen-Geiger classification (Kottek et al. 2006). Totals are higher than 100% because in each case study, multiple responses occurred in different response categories

3.3 Response categories across sectors

Incremental responses mostly occurred in the response sector "cultivation" (75% of case studies), e.g., rainwater harvesting for crop production; followed by the sectors "other activities" (65%), e.g., using mosquito nets to protect against malaria; and "livestock" (39%), e.g., slaughtering livestock during drought periods (Fig. 3a). Most intermediate (Fig. 3b) and transformational responses (Fig. 3c) occurred in the response sector "other activities" (75% and 71%, respectively), e.g., diversifying income sources with tourism (intermediate) or giving up the traditional livelihood and switching to a non-nature-based livelihood (transformational).

The distribution of responses by sector (Fig. 4) shows that the incremental responses that "switch" and "adjust" livelihood features were highly common for all sectors, while the total share of intermediate and transformational responses reached a maximum of only 19% in the sector "other activities." In the cultivation sector, most responses were incremental (97%, $p<0.001$, see *Supplementary Materials* B), with a high share (48%) corresponding to the incremental responses that 'switch' livelihood features (e.g., replacing traditional crop varieties by new ones). Intermediate and transformational responses only represented 2% and 1%, respectively. Relatively often, intermediate responses referred to hunting/gathering activities (13%, e.g., livelihood diversification by complementing the main livelihood with the hunting of alternative wild animals and gathering of different fruits), followed by "other activities," fishing/aquaculture, and livestock (12%, 11% and

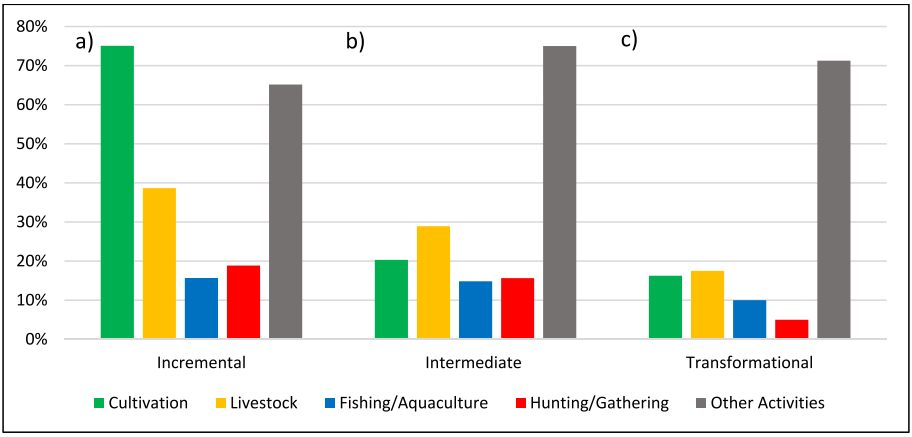


Fig. 3 Percentages of case studies in which a response sector was reported at least once. **a** Incremental responses ($n=313$ case studies); **b** intermediate responses ($n=128$); and **c** transformational responses ($n=80$). Totals are higher than 100% because in each case study multiple responses occur in different response sectors. See *Supplementary Materials A:* Fig. 2 for the distribution of response sectors across different kinds of incremental responses

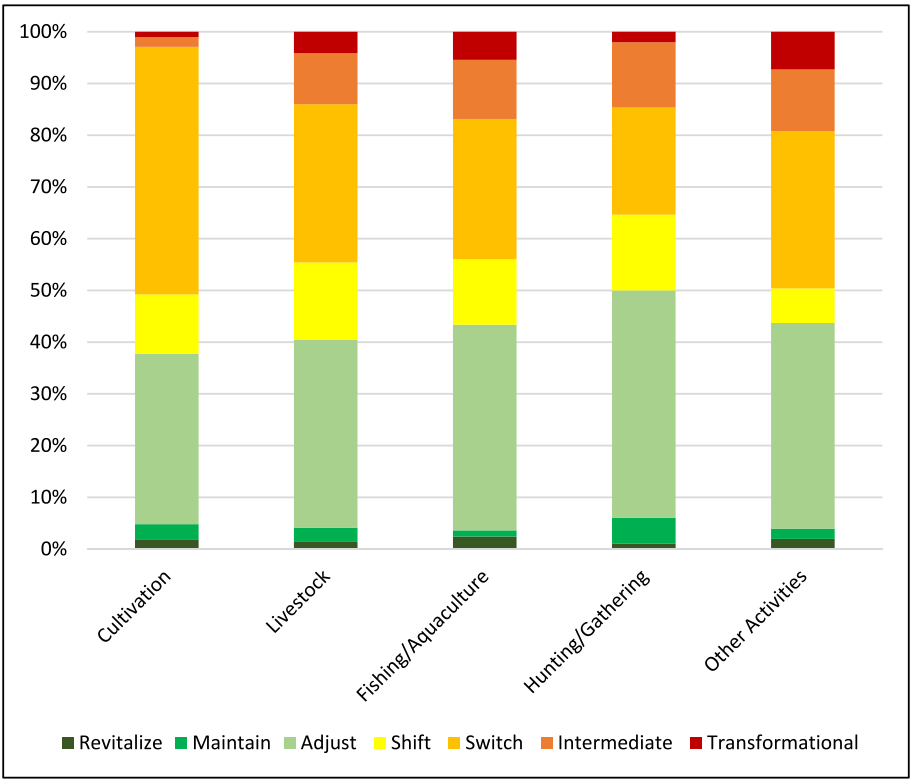


Fig. 4 Percentages of response categories across response sectors. See *Supplementary Materials A:* Fig. 3 for the distribution of response sectors of the sample

10%, respectively). Shares of transformational responses were highest in the sectors "other activities" (7%) and fishing/aquaculture (5%), e.g., permanent migration to other fishing grounds.

4 Discussion

We derive two main important findings from this work. First, the results suggest that, in response to climate change impacts, IPs and LCs modify their livelihood activities by implementing mostly incremental responses. Nevertheless, although the number of intermediate and transformational responses documented is low, their occurrence is widely spread, as they are reported in half of the case studies analyzed. Second, our findings also point at some trends. Namely, the distribution of incremental, intermediate, and transformational responses is similar across different climate types except for (semi-)arid climates, where most intermediate and transformational responses take place. Across sectors, incremental responses are proportionally higher in crop cultivation. In this section, we discuss these two findings before comparing them with general findings from the adaptation literature.

4.1 Types of responses to climate change impacts by IPs and by LCs and their implications

We found that most recorded responses to climate change impacts are incremental, which suggests that, to face climate change impacts, IPs and LCs mostly change some elements within their livelihood system, keeping it generally unchanged. The tendency to maintain the system "as they know it" has also been found in previous work (Fedele et al. 2019; Kates et al. 2012; Magesa and Pauline 2019). However, our work reveals that most incremental responses are an active adjustment of known practices, rather than a mere continuation of those practices, as indicated in the high number of case studies reporting responses that "adjust," "shift," or "switch," instead of those that "revitalize" and "maintain" livelihood features.

Importantly, although intermediate and transformational responses are low in number, their occurrence is widely spread. For half of the case studies, we documented responses implying more far-reaching changes and for more than a quarter of the case studies these changes are transformational in the sense that they report profound changes of locations (far-away relocation) and livelihood systems (livelihood category switch). Examples of the analyzed case studies include the outmigration of pastoralists in the Hindu-Kush region as a response to climate change induced food insecurity (Wu et al. 2014) and switching from cocoyam farming to livestock rearing in Southeastern Nigeria as a response to extreme climatic interannual variability (Ifeanyi-obi et al. 2017). The widespread use of intermediate and transformational responses suggests that IPs and LCs are being forced to transform their livelihoods considerably as a reaction to an increase of climate change impacts, a finding consistent with the latest IPCC-report on impacts, adaptation, and vulnerability (Birkmann et al. 2022).

The literature reviewed shows that the implications of applying either incremental or transformational responses are context dependent (Enfors 2013; Ensor et al. 2019; Latham-Sprinkle et al. 2019; Rickards and Howden 2012). For example, Penning-Rowsell et al. (2013) show how women in Bangladesh are trapped in a risky home environment when

male family members migrate to seek for employment in response to climate hazards. In other South Asian cases, remittances from migrants actually improve material well-being for those who did not migrate (Maharjan et al. 2020). Importantly, responses to climate change, either incremental or transformational, can have adverse local impacts. On the one hand, several authors have shown how applying incremental responses might result in being trapped in undesirable situations (Adams 2016; Barnes et al. 2017; Warner and Afifi 2014), with negative consequences such as increased vulnerability, e.g., through increased food insecurity (Adams 2016; Sommer et al. 2013) or distress because of environmental changes (or "solastalgia") (Albrecht et al. 2007). On the other hand, the adoption of transformational responses might also result in drastic disruptions of people's lives (Birkmann et al. 2022). For example, one of the most maladaptive reported transformational responses entailed the resorting to begging by farmers in Eastern Uganda, as a response to climate change induced food insecurity (Egeru 2012). Another case study showed how farmers in Burkina Faso, who's transformational response entailed the migration to another area to continue practicing agriculture, encountered conflicts with pastoralists in the new area due to the increased pressure on the available land (West et al. 2008). Similarly, a case study of the Dassanech in Ethiopia showed how their migration to the borderlands of Kenya as a response to drought resulted in conflicts on scarce natural resources with the Turkana people (Gebresenbet and Kefale 2012). Other transformational responses entailing migration, such as the case of farmers in Myanmar, resulted in household labor shortage (Zin et al. 2019). Comparably, several authors have discussed how transformational responses involving migration, particularly to urban areas, result in an increased risk of precarious living and working conditions (Latham-Sprinkle et al. 2019), but also grief and other strong social impacts related to loss (Adger et al. 2013; Clarke et al. 2018). Relatedly, urbanization and abandonment of nature-based livelihoods inevitably lead to a loss of Indigenous knowledge, because of the absence of contact with historical and sacred Indigenous sites (Hari 2020) and because of the pressures from non-Indigenous governance systems and technology (Sirayi and Beauregard 2021). Moreover, transformational responses that entail migration can also impact local ecosystems due to the loss of management practices. When Aboriginal peoples were removed in the 1960s from their ancestral homes—the central deserts of Australia, which they had actively managed for tens of thousands of years—their home area experienced uncontrolled wildfires and biodiversity loss. The eventual return of the Aboriginals to their land resulted not only in the improved health and well-being of the people, but also in a wildfire reduction and biodiversity increase (Fletcher et al. 2021).

4.2 Trends across different climates and response sectors

Although IPs and LCs living in different climates use similar and mainly incremental responses to climate change impacts, there is a higher occurrence of intermediate and transformational responses in (semi)-arid climates. As it has been found that reports of climate change impacts partly depend on climate (Reyes-García et al. in press), we argue that differentiated responses by climate might be caused by the magnitude of climate change impacts in (semi-)arid climates and livelihoods. Globally, there has been a significant warming in (semi-)arid areas, resulting in frequent droughts (Mirzabaev et al. 2022). Droughts are reported to be among the natural hazards with the highest negative impacts on human livelihoods, e.g., by relating to a higher risk of undernutrition (Mirzabaev et al. 2022; Mishra and Singh 2010). Thus, it is possible that the large magnitude of climate change impacts forces communities living in (semi-)arid areas to respond in a more drastic

way. For example, one of the case studies analyzed showed how farmers on the Bolivian Altiplano increasingly seek off-farm work as a response to worsening climate conditions for crop farming (Meldrum et al. 2018).

Although incremental responses are the most common type of responses across sectors, this is particularly the case in the cultivation sector, where responses mainly consist of switching livelihood features (Baul and McDonald 2014; Gyasi and Awere 2018; Meldrum et al. 2018). For example, it was reported that peasants in Nepal switched to other sources for water, such as a different natural spring, as a response to climate change induced water shortage (Baul and McDonald 2015). This prevalence of incremental agricultural responses might be inherent to the characteristics of agriculture, compared to other livelihoods, as—for example —switching target fishing species may be more difficult for fishers, who might need to switch fishing gear (Muringai et al. 2022), than switching crop varieties is for farmers, especially when new varieties are distributed by NGOs or extension services (Mulesa et al. 2021). Conversely, a transformational change may be more feasible for fishers, who relocate far-away seeking for new fishing grounds (Belhabib et al. 2016), than for farmers, who might face limited access to land when relocating (Oladehinde et al. 2018). Hence, our results provide the basis for arguing that changes of similar magnitude may face different barriers across sectors. This means that for successfully discerning the enablers of local adaptation, a framing of adaptation is required that goes beyond understanding adaptation as a response to climate change impacts but that also considers how the lived experience (e.g., sectoral and socio-economic circumstances) of the adapting community determines adaptation (Ensor et al. 2019).

Notably, we find that IPs' and LCs' intermediate and transformational responses to climate change impacts are more often related to non-nature-based livelihood activities, e.g., one of the analyzed case studies showed how Vietnamese farmers engage in construction work as a response to impacts of flooding (Le and Bond 2017). This finding is important as it suggests that for IPs and LCs transformational responses to climate change impacts entail not only abandoning traditional livelihoods, but also their way of living in close contact with the natural environment. The associated implications are illustrated by the case of farmers on the Bolivian Altiplano, where the migration of young people to seek non-nature-based work contributed to a loss of traditional knowledge on practices for crop rotation, seed selection and cleaning, and traditional food recipes (Meldrum et al. 2018).

4.3 IPs' and LCs' responses within the adaptation literature

Most observed adaptations to climate change impacts are reported to be incremental, fragmented, and small in scale (Berrang-Ford et al. 2021; IPCC 2022). So, the observed high occurrence of incremental responses among IPs and LCs found here is no exception. Indeed, responses to climate change impacts in mining industries (Loginova and Batterbury 2019), large cities (Heikkinen et al. 2019), or the transport sector (Aparicio 2017) have been reported to be incremental. However, there are numerous differences between responses to climate change by IPs and LCs and responses by other actors at different levels, scales, livelihoods, and circumstances. For example, as IPs' and LCs' responses typically occur at the individual/household level, they tend to be more reactive and responding to specific climate change impacts (e.g., altered resource availability) compared to responses at the institutional level, which are typically more anticipatory and typically respond to climate change in general (Berrang-Ford et al. 2011). Also, as responses by IPs and LCs usually occur at the personal or household scale, both the extent to which

they can alleviate climate change impacts as well as their potential maladaptive outcome is possibly smaller compared to autonomous responses from actors acting at a larger scale. For example, autonomous climate change adaptation by large-scale farmers in Europe is found to be widely contributing to the mitigation of negative climate change impacts on crop yields, but these responses are also highly impacting European irrigation water withdrawal, thus adversely affecting Europe's environment and exacerbating atmospheric carbon dioxide concentration anomalies (Leclère et al. 2013). Further, as IPs and LCs have a strong dependency on nature for their livelihoods, they are more directly affected by climate change impacts (IPBES 2019; McIntyre-Tamwoy et al. 2013) and hence more forced to respond, and possibly, to respond more drastically (as indicated by the considerable number of case studies found here applying intermediate and transformational responses) compared to individuals with livelihoods less affected by climate change impacts, such as citizens in developed countries (Kasemir et al. 2000), although the latter may also become subject to increased risk in the future if climate change mitigation efforts are insufficient, e.g., projected sea level rise in Northwestern-Europe (Nicholls and Cazenave 2010; van de Wal et al. 2022).

In concert with their dependence on the environment, the amplified vulnerability of IPs and LCs to climate change impacts is related to their frequent position of socially marginalized group (IPCC 2022; Maru et al. 2014). As a result, their responses to climate change impacts are often shaped by their socioeconomical possibilities and needs (Junqueira et al. 2021; Maru et al. 2014) and are often autonomous of character, with little institutional support. That is, IPs and LCs are often overlooked in climate change adaptation policies (Ford et al. 2016; Witter et al. 2015), which potentially results in a mismatch between governmental adaptation plans and local needs (Herse et al. 2020). Moreover, government support in climate change responses is generally low in low-income countries (Berrang-Ford et al. 2011), where a considerable number of IPs and LCs live (Patrinos and Hall 2012), compared to those in high-income countries. Also, many funded adaptation actions in low-income countries involve capacity building, rather than implementation of tangible actions that support individual responses (Biagini et al. 2014). Additionally, institutional adaptations often target cities (Berrang-Ford et al. 2021), rather than the remote areas where IPs and LCs generally live (IPBES 2019). Hence, it is clear that IPs and LCs are often overlooked in institutional climate change adaptation plans compared to others, despite the acknowledgment of their exacerbated vulnerability to climate change, and the importance of their knowledge for climate change adaptation plans (Baul and McDonald 2014; Belfer et al. 2017; Fairhead et al. 2017; García-del-Amo et al. 2020; Garnett et al. 2018; Li et al. 2021; Makondo and Thomas 2018; Reyes-García et al. 2022; Savo et al. 2016).

5 Conclusion

To respond to climate change impacts, IPs and LCs most frequently implement incremental responses, although the use of intermediate and transformational responses is also widespread. Trends in the magnitude of livelihood changes are similar across climates and livelihoods, except for responses in (semi-)arid climates, where most intermediate and transformational responses take place, and for responses in cultivation, where most incremental changes take place. When transformational adaptation occurs, IPs and LCs not only give up their livelihood strategy but also their culture and way of living. Compared to other groups, IPs and LCs are particularly forced to respond to climate change impacts,

resulting from the dependence on the environment for their livelihoods. Although IPs' and LCs' responses to climate change impacts are frequently incremental, such responses entail active adjustments of practices rather than a mere continuation of those practices. IPs' and LCs' responses stand out as being reactive and autonomous, based on the household scale, and are often being shaped by IPs' and LCs' socioeconomic possibilities and needs. They typically respond to specific climate change impacts rather than to climate change in general, and both the extent to which they can alleviate climate change impacts as well as their potential maladaptive outcomes for the environment are small.

Because both incremental and transformational responses can have far-reaching implications for IPs' and LCs' future resilience, livelihoods, cultures, and general well-being, we argue that a full understanding of the consequences of responses to climate change impacts should include a focus on the magnitude and on the outcome of these responses. Our work provides a metric for magnitude, and in future research, it should be complemented by other tools able to measure the social and ecological impacts of responses. IPs and LCs and their responses to climate change impacts should be considered more in policy and research, because of their vulnerability to climate change impacts, and because of the importance of their knowledge for informing institutional adaptation strategies on locally attuned climate change responses that both support biodiversity as well as local livelihoods.

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Author contribution MZ and AS conceptualized the research questions and design and were responsible for the final selection, coding, and quality check of the analyzed publications. The classification system was developed by MZ and supported by AS. The online literature search was carried out by AS. VRG and DGA provided advice on the research conceptualization and methods. MZ was responsible for the data analysis, methods, and writing of the original draft. All co-authors contributed to and commented on drafts of the final manuscript.

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Declarations

Competing interests The authors declare no competing interests.

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