INTRODUCTION TO PART I

Impacts of climate and global change on local social-ecological systems

Learning from Indigenous and local knowledge

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Climate change is a global threat affecting all ecosystems and societies in the world (IPCC 2022). Temperature rise, changes in precipitation patterns, and increases in the frequency and intensity of extreme events such as droughts, floods, and storms have been extensively documented by scientists in the last decades, and are a reality across most of the planet (Gulev et al. 2021; Seneviratne et al. 2021). Changes in weather and atmospheric systems are linked to multiple other changes in aquatic and terrestrial physical systems, such as the melting of glaciers and permafrost, sea level rise, ocean acidification, and soil erosion (Fox-Kemper et al. 2021). These changes in atmospheric and physical systems have large and diverse impacts in biodiversity, affecting species distribution, composition, behaviour, reproduction, diseases, as well as the dynamics and functioning of entire ecosystems (Armstrong Mckay et al. 2022; Cooley et al. 2022; Parmesan et al. 2022). Altogether, these biophysical changes have large consequences for socio-ecological systems, as they directly affect resource use and management systems, food, water and economic security, infrastructure and human physical and mental health (Xu et al. 2009; Cissé et al. 2022; García-del-Amo et al. 2022).

Impacts of climate change on socio-ecological systems are very diverse, heterogeneous, and show an uneven geographic distribution. In regions characterised by extreme environmental conditions such as polar regions, deserts, coastal areas, small islands, and mountains, climate change impacts are manifesting with higher intensity (IPCC 2019a, 2019b, 2021). Also, while climate change affects societies all over the world, Indigenous Peoples and local communities are considered particularly vulnerable to its impacts, mostly due to their high dependence on nature and their historical social and economic marginalisation, often due to colonialism (Fayazi et al. 2020; Sultana 2022; Carmona 2024, Chapter 12). Indeed, there are many well-documented examples of Indigenous Peoples and local communities harshly affected by climate change impacts, with effects that compromise different elements of their strongly nature-based livelihoods and culture (Crate 2011). For example, in Chile, Mapuche communities express concern about climate change impacts on araucaria forests (*Araucaria araucana*) as, due to the cultural and economic importance of the species for their society, such impacts might become a threat to Mapuche culture and livelihoods (Carmona 2024, Chapter 12). Similarly, Indigenous Peoples and local communities living in mountainous regions with perpetual snow relate the disappearance of the snowpack to the loss of their local identity, beyond the loss of water resources for their survival (Konchar et al. 2015).

At the same time, Indigenous Peoples and local communities are increasingly recognized as key actors in the challenge of understanding climate change impacts and adapting to them.

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Through their historical and intimate relationship with local ecosystems, Indigenous Peoples and local communities have developed a rich and detailed body of knowledge, based on which they manage nature and identify subtle changes, being the first to react to them (Reyes-García et al. 2016; Savo et al. 2016). In addition, many of them live in remote areas, where historical records and scientific studies are scarce (Rosenzweig and Neofotis 2013). The recognition of the potential of Indigenous knowledge and local knowledge systems in identifying and adapting to climate change impacts is reflected by the recent exponential increase in the number of publications on the topic (Reyes-García et al. 2019; Petzold et al 2020), and by the increasing, although incipient, inclusion of Indigenous Peoples and local communities into climate action (McElwee et al. 2020; Pörter et al. 2021; Schipper et al. 2022; Ford et al. 2016; David-Chavez and Gavin 2018).

As research and policy initiatives on the interface among Indigenous Peoples and local communities, their knowledge systems, and climate change have evolved in the last decades, new research topics, perspectives, and refined understandings also have emerged (see also Orlove et al. 2023). Chapters in this first part of the book bring insights from Indigenous Peoples and local communities experiencing climate change impacts around the world, represented by 12 case studies located in Albania, Italy, Portugal, Romania, Russia, Spain, Argentina, Bolivia, Chile, Peru, and the Caribbean sea region. The case studies featured cover a wide environmental and cultural diversity, including Indigenous Peoples and local communities who practise different livelihood activities (e.g., agriculture, fishing, hunting-gathering) and inhabit different ecosystems such as mountains, polar regions, coastal areas, tropical forests. In this introduction, we discuss insights and advances brought by these chapters on the following three main topics: (1) the place-specific, nuanced, and patterned nature of local knowledge about climate change impacts; (2) the holistic and interconnected understanding of climate change impacts from the perspective of Indigenous knowledge and local knowledge systems, and (3) the local understanding of interactions between climate change and other drivers of socio-environmental change.

Climate change impacts: place-specific, socially and environmentally patterned

While Indigenous knowledge and local knowledge of climate change may have initially been approached as a static and uniform entity, there is increasing evidence unveiling how this knowledge is nuanced and patterned, contingent on socio-economic, cultural and environmental factors (Armah et al. 2015). Echoing patterns found for Indigenous knowledge and local knowledge in general, local understandings about climate change impacts vary across livelihood activities, gender, age, ethnicity, and are influenced by external factors such as access to information or policy initiatives (Crona et al. 2013; Mwangi et al. 2024, Chapter 19). For example, in Chapter 5, García-del-Amo et al. (2024), working with local communities from the mountains of Sierra Nevada, Spain, show how local ecological knowledge about climate change impacts is contingent on the level of engagement with agricultural and livestock activities. In the same line, in Chapter 6, Ferrara and Lindberg (2024), working with local communities in Sicily, show how communities' experiences of 'changing weather' or 'changing climate' are partially culturally constructed and influenced by changes in lifestyles. The way in which Indigenous Peoples and local communities experience climate change impacts is also historically and socially constructed, as demonstrated by Carmona (2024) in Chapter 12 with the case of Mapuche communities in Chile. Similarly, Gerkey and Sharakhmatova (2024), working with local communities of the Kamchatka Peninsula in Russia, show in Chapter 2 how perceived impacts of climate change are aggravated and influenced by the socio-political context where they take place – in their case, by social changes that took place in the post-Soviet era.

This refined understanding of Indigenous knowledge and local knowledge is crucial to leverage the inclusion of Indigenous Peoples and local communities into policy agendas, as well as to foster

dialogues between Indigenous knowledge and local knowledge and scientific knowledge (Ford et al. 2016; Xu et al. 2021). Indeed, some of the chapters in this part allude to how a deeper, thorough understanding of Indigenous and local knowledge can favour bridging knowledge systems and hence leverage the development of climate policies and adaptation strategies. For example, in Chapter 1, Mattalia et al. (2024) explored correspondences between climate knowledge from Hutsul communities in Romania and instrumental records, highlighting how the complementarity between knowledge systems can provide a robust basis for co-developing effective climate policies. Comparing evidence derived from local knowledge with instrumental records is a common practice in studies focusing on Indigenous Peoples, local communities and climate change (e.g., Savo et al. 2016; Fernández-Llamazares et al. 2017; Chen and Chen 2020; Paudel et al. 2020). Importantly, and as shown in examples from this volume where local knowledge has been compared with instrumental data (Babai 2024, Chapter 4; Ferrara & Lindberg 2024, Chapter 6; Lippi & Sanfilippo 2024, Chapter 7; Mattalia et al. 2024, Chapter 1), rather than validating one knowledge system with information from another one, this approach should foster identifying complementarities and favouring dialogues between knowledge systems.

While exploring synergies and complementarities between different knowledge systems allows building an 'enriched picture' (Tengö et al. 2014) of climate change impacts, there are still many barriers to the actual engagement of Indigenous and local knowledge into climate policy and action. For example, in the third chapter, McConney et al. (2024) analyse the potential contribution of local knowledge to address an environmental problem derived from climate change impacts in Caribbean countries. During the last decade, massive influxes of pelagic sargassum seaweed have intermittently inundated the Caribbean Sea coasts, disrupting coastal and marine social-ecological systems. The authors show how, in spite of the lack of institutionalised mechanisms for influencing policy, local knowledge has the potential to inform how coastal area ecosystems and livelihoods have been impacted by the sargassum influxes and to guide local coping measures, especially in small-scale fisheries.

The holistic and interconnected understanding of climate change impacts

Through their intimate and historical connections with territories, Indigenous Peoples and local communities have developed holistic worldviews and knowledge systems, in which elements of the natural, human and spiritual world are seen as indissociable, interconnected and interdependent. This understanding is also reflected in how they experience and interpret climate change impacts (Crate 2011; Nakashima and Krupnik 2018). While local knowledge systems may indeed be capable of identifying a change in isolation, for example, a decrease in rainfall, they can also be powerful to map the interconnections between this and other changes, as well as its cascading impacts that extend to different elements of local livelihoods (Junqueira et al. 2021; García-del-Amo et al. 2024, Chapter 5). Cascading effects are a common phenomenon in complex systems, where all components are interconnected, and it is also a fundamental topic in resilience, sustainability and social-ecological frameworks (Xu et al. 2009; Turner et al. 2016; Burton et al. 2020; Haro-Monteagudo et al. 2020). Cascading effects of climate change have been demonstrated (e.g. Bahlai et al. 2021; Rocha et al. 2018), with research showing that they could be able to trigger the extinction of species (Folke et al. 2004; Krönke et al. 2020; Armstrong Mckay et al. 2022). Some of the contributions in this part of the book document reports of cascading effects of climate change derived from Indigenous and local knowledge. In Chapter 4, Babai (2024) examines perceptions of farmer communities in the Eastern Carpathians of Romania, describing how changes in the atmospheric system (in particular changes in the temporal distribution of rainfall, mean temperature, seasonality, and drought intensity) lead to changes in crop productivity, phenology and quality,

and trigger local responses such as shifts in the agricultural calendar and practices. In Chapter 7, Lippi and Sanfilippo (2024) document that smallholder farmers in Albania also report atmospheric changes leading to cascading effects in agricultural systems and triggering adaptation responses.

Indigenous and local knowledge can also help unveiling other imbricate and complex connections between climate change impacts. In Chapter 5, García-del-Amo et al. (2024) used a network analysis to investigate climate change impacts reported by local communities from the mountains of Sierra Nevada, Spain, identifying triggering impacts, cascading effects, and mapping the network of interconnections between changes. Likewise, Reyes-García et al (2024), in Chapter 10, unveil how the Tsimane´ understanding of environmental change in Bolivian Amazonia involves a complex network of interconnected social and environmental changes and drivers. Altogether, these examples demonstrate how Indigenous Peoples and local communities´ holistic understanding of nature is also expressed in their understanding of climate change impacts. This holistic understanding unveils the complexity of climate change impacts and their interrelations, allowing the identification of overseen impacts of climate change, of their consequences on the functioning of social-ecological systems, and provides a strong basis for designing local adaptation plans.

The local understanding of interactions between climate change and other drivers of socio-environmental change

While climate change is indeed a major societal challenge and one that is disproportionately impacting Indigenous Peoples and local communities all over the world, its actual impacts on socio-ecological systems depend on interactions with other environmental and socio-political factors. During the last decades, researchers have demonstrated the substantial influence of human activities on ecosystems through direct and indirect drivers of change (Eyring et al. 2021). Land-use change, overexploitation of nature, pollution of waters and soils, or emission of GHG are direct drivers of change affecting ecosystems (Arneth et al. 2020). Indirect drivers of change include rural exodus, economic pressures, policy regulations, and other socio-political factors (Díaz et al. 2019). Together, these drivers are leading to changes in ecosystems, lifestyles, and societies in several aspects and at a pace never seen before in human history (Butchart et al. 2010; Steffen et al. 2015; Díaz et al. 2019; IPBES 2019).

Several of the contributions presented in this volume demonstrate how understanding socio-environmental change from the perspective of Indigenous and local knowledge systems can help in unveiling the complexities of the interactions between multiple drivers of change – including climate change –, and how they are expressed in local socio-ecological systems. Combining information from local knowledge with meteorological records and a long-term reconstruction of climatic and societal past in Sicily, Italy, in Chapter 6, Ferrara and Lindberg (2024) show how environmental changes have been the norm rather than the exception in the region. Such changes are driven by a combination of climatic fluctuations, human agency, and long-term ecological dynamics. In Chapter 8, Izquierdo and Schlingmann (2024), working in the Argentinian Puna, show how local communities see climate change as one among multiple drivers of socio-environmental change, and also how certain drivers (such as the arrival of new technologies and the improvement of transportation conditions) are associated with positive changes, while others (e.g., climate change, migration) are mostly associated with negative ones. Similarly, Stratoudakis et al. (2024) in Chapter 9, demonstrate how fishing communities on the coast of Portugal understand the changes that have affected their fishing practices in the last decades as the product of interactions among multiple socio-economic and environmental drivers, including climate change. In Bolivian Amazonia, Reyes-García et al. (2024) show in Chapter 10 how the Tsimane' complex understanding of environmental change acknowledges the importance of the interactions between different drivers, including social, political, ecological and spiritual elements.

Importantly, many of the socio-environmental changes and drivers acknowledged by Indigenous Peoples and local communities are rooted in the colonialism and/or marginalisation to which they have been historically exposed (Whyte 2017, 2020). For example, Lippi and Sanfilippo (2024), in Chapter 7, demonstrate how smallholder farmers in Albania acknowledge that their livelihoods have been deeply affected by socio-economic changes following the collapse of the communist regime (e.g., land fragmentation, lack of government support, migration). This situation also poses severe barriers to their capacity of implementing adaptation responses to climate change. Likewise, Hirsch (2024) in Chapter 11 discusses how Quechua farmers in the Peruvian Andes have been shifting to market-oriented agriculture stimulated by decades of development projects, which has resulted in reduced food and economic sovereignty, now further aggravated by the challenges of an unpredictable climate. In a similar tone, Carmona (2024) in Chapter 12 debates how the current vulnerability of Mapuche-Pehuenche communities in the Chilean Andes to climate change is 'socially constructed', rooted in a historical process involving changes in land use, pressures for the extraction of forestry resources, and the implementation of public policies. Taken together, these examples bring important insights, rooted on Indigenous and local knowledge, about how social and environmental changes, with the complexity of their multiple drivers, historical and political dimensions, affect socio-ecological systems.

Based on examples from diverse environmental and socio-cultural contexts, the contributions presented in Part I advances the understanding of how climate change and other drivers of global change interact, are expressed in local socio-ecological systems, and are experienced by Indigenous Peoples and local communities. They also demonstrate the potential of Indigenous and local knowledge to disentangle the nuanced and interconnected nature of climate change impacts and drivers. As climate change impacts aggravate the historical vulnerability of Indigenous Peoples and local communities (Birkmann et al. 2022), these advances are timely and crucial to identify pathways for the development of effective climate policies and adaptation strategies.

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