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ORIGINAL ARTICLE

Historical reconfigurations of a social–ecological system adapting to economic, policy and climate changes in the French Alps

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Abstract

To ensure their quality of life, people adapt to multiple changes by maintaining or transforming the structure and functions of their socio-ecological systems (SES). A better understanding of mechanisms underpinning SES adaptation, especially the contribution of changes in human–nature interactions, is crucial to facilitate adaptation to future challenges. Using a chronosystemic timeline and based on literature, archives and local knowledge of inhabitants, we explored the past trajectory of a mountain SES (Pays de la Meije, French Alps) since 1900 by analysing drivers, impacts and responses. We hypothesised that adaptation has occurred through changes in the co-production of nature's contributions to people (NCP). We identified four historical periods of combined changes in agriculture and tourism with associated changes in NCP. Results show which and how drivers of changes have influenced NCP co-production, how NCP have been mobilised in adaptive responses and how human and natural capitals involved in NCP co-production have been reconfigured for adaptation. We show that drivers of change have been mainly exogenous and out of the control of local actors, like public policies, markets and consumption patterns. These drivers can directly impact the capitals involved in NCP co-production like amount of workforce, knowledge or skills, creating not only threats but also opportunities for the livelihood of the local community. Depending on the intensity of capital reconfiguration and the type of NCP involved, adaptive responses range from resistance to transformation of the governance system and socio-economic sectors. This analysis highlights existing path dependencies that could hinder future adaptation.

Keywords Co-production · Adaptation · Transformation · Ecosystem services · Past trajectories · Social-ecological system

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Introduction

Under global changes, social–ecological systems (SES) must adapt to maintain livelihoods and the natural resources they depend on (IPBES 2018). Adaptation is driven by changes in the interactions between social and natural systems over time and space (Nelson et al. 2014; Chhetri et al. 2019; Fedele et al. 2019). The adaptive capacity of a SES is strongly influenced by its past trajectory, as it shapes its current state (Dearing et al. 2015; Egan and Price 2017) and will constrain its future dynamics through legacy effects (Nelson et al. 2014; Plieninger et al. 2015; Antoni et al. 2019). Studying historical SES trajectories provides valuable information not only on how drivers of change have affected SES and led to adaptive responses (Costanza et al. 2012; Adamson et al. 2018) but also inform about future adaptive capacity (Bussey et al. 2012; Grier et al. 2017) and adaptation options (Fazey et al. 2015).

One critical dimension of changing human–nature interactions for adaptation regards nature's contributions to people (NCP), defined as the contributions of living nature to people's good quality of life, which can be material, non-material and regulating contributions (Diaz et al. 2015). To adapt to changes, societies can modify their interactions with nature to ensure the provision of important benefits to human quality of life by changing land uses, redefining natural resource governance or using new natural resources. These actions can aim to sustain the provision of existing NCP despite changes (i.e., NCP resilience) or to develop new NCP in changing contexts (i.e., transformation) (Lavorel et al. 2019).

Most assessments of NCP or ecosystem services have focused on a time snapshot, but there has been an increased interest in historical trajectories of NCP (Renard et al. 2015; Rau et al. 2018). Studies have linked increasing supply and demand of NCP over history with changing land use (Stürck et al. 2015; Egarter Vigl et al. 2016; Lavorel et al. 2017). Other studies highlight how historical analyses can help understand NCP synergies and trades-off (Tomscha and Gergel 2016), showing that NCP bundles depend on local biophysical and socio-economic context (Renard et al. 2015; Egarter Vigl et al. 2017), or assessing changing landscape capacity to supply NCP (Bürgi et al. 2015; Locatelli et al. 2017). While most studies consider socio-economic and institutional drivers (Dittrich et al. 2017), land use, landscape or SES dynamics (e.g., Munteanu et al. 2014, Ianni et al. 2015, Jepsen et al. 2015, Meyfroidt et al. 2018), few consider how these drivers of change of NCP have supported adaptation, or how NCP were involved in adaptive responses (Colloff et al. 2020).

Historical studies of NCP trajectories and their drivers rarely address a critical dimension of adaptation, which is agency, i.e., the capacity of people to make choices and act consciously, both individually and collectively (Davidson 2010; Fedele et al. 2017). For historical changes in NCP to be understood with an adaptation lens that can inform future adaptation, we need to document not only how NCP have changed but also the mechanisms underlying these changes, including human agency. Indeed, NCP are the joint outcome of social and ecological processes, constituting a process of NCP co-production that involves human intervention to deliver social benefits (Diaz et al. 2015; Palomo et al. 2016). Three steps of co-production can be distinguished along the benefit chain of NCP (Lavorel et al. 2020; Bruley et al. 2021): (CP1) ecosystem management (i.e., modifying ecosystem structure and function in order to obtain benefits, such as planting cereals or trees), (CP2) mobilisation, harvest and physical access (e.g., collecting plants or visiting a scenic place), and (CP3) appropriation and appreciation of benefits (e.g., transforming and selling dairy products, enjoying local products or feeling attached to a place). Different natural, human, social, manufactured and financial capitals are required in each of these steps (Palomo et al. 2016). This novel perspective complements socio-technical studies of transitions (e.g., Geels and Schot 2007) by explicitly considering the role of natural capital and its management.

We posit that the characterisation of adaptive responses over time through the reconfiguration of NCP co-production will advance the understanding of adaptation mechanisms. Reconfiguration is the process by which people modify their actions to alter ecosystems, NCP and ultimately quality of life. This analysis requires to understand how human-derived and natural capitals are impacted by internal and external drivers of change and the resulting vulnerabilities or opportunities. It also requires understanding how people's adaptive responses reconfigure capitals and the co-production of NCP to maintain livelihood. This perspective on adaptation improves our understanding of coupled social–ecological historical interactions and human agency involved in ecosystem-based adaptation to inform future responses and create opportunities for agency (Nelson et al. 2014; Fazey et al. 2015; Grier et al. 2017).

Mountain regions provide fruitful contextual settings to study adaptive capacity (Egan and Price 2017; Klein et al. 2019). Indeed, while they provide key NCP (Martín-López et al. 2019) and are biodiversity hotspots (Körner et al. 2005), they are also vulnerable to both environmental and socio-economic changes, like land use change, infrastructure, tourism development and climate change, with an important role of external drivers (Grêt-Regamey et al. 2012). Because of their remoteness, harsh topographical and climatic conditions, they have undergone continuous adaptation (Klein et al. 2019) and are experiencing rapid changes in response to current and anticipated global change (Palomo 2017).

This study aimed to understand past SES adaptation mechanisms as sets of causal relationships between drivers of change and social–ecological responses by reconfigurations through human agency for a mountain social–ecological system. We identified periods of historical adaptation and hypothesised that adaptation occurred through changes in

NCP co-production. Using the NCP co-production approach to better understand past adaptation trajectories we asked the following: (1) Which drivers of changes have affected the SES and led to adaptive responses? (2) How have drivers influenced NCP co-production? (3) On which NCP have adaptive responses relied? (4) How have capitals involved in NCP co-production been reconfigured for adaptation? Our results allowed us to characterise different types of adaptive responses and further discuss how such knowledge of adaptation mechanisms along historical trajectories of NCP can inform research on current dynamics and future adaptation.

Study site

Pays de la Meije, at the head of the Romanche valley in the central French Alps, covers 205 km^2 and ranges from 1135 to 3984 m. Located at the edge of two administrative regions the two municipalities, La Grave (484 inhabitants) and Villar d'Arène (322 inhabitants), have a low population density (less than 5 people/km^2), across two villages and seven hamlets with numerous secondary and touristic residences (~60% of the accommodation capacity). The region reached its largest population (2500 inhabitants) at the beginning of the nineteenth century followed by a strong rural exodus from 1850 to 1970. Tourism has become an essential sector since 1970 and is now at the core of the local economy, with large contributions to off-farm jobs and incomes (Schermer et al. 2016). It is based on mountain sports and on cultural tourism enhanced by the Ecrins National Park, created in 1973. A traditional mountain livestock farming system based on fodder self-sufficiency and summer transhumance, is the second pillar of the local economy and identity (Quétier et al. 2010). Local life strongly depends on surrounding regions for jobs (in nearby ski resorts) and services (education, health and retail). The climate is alpine with Mediterranean influences. Forest exploitation in the Middle Ages produced an open landscape on the south-facing slopes, shaped by terrace cultivation. Subsistence agriculture changed to livestock farming during the early twentieth century and now maintains a cultural landscape of terraced grasslands and summer pastures (Quétier et al. 2007). North-facing, steeper slopes are forested below 2200 m following cessation of timber production during the nineteenth century. Sparse vegetation, rocks and ice at higher altitude are located in the core area of the Ecrins National Park and in an off-track skiing basin.

Methods

Our study included three stages: (i) preliminary analysis with secondary literature, databases and exploratory interviews, (ii) timeline construction from interviews and workshops, and (iii) timeline interpretation.

The first stage included two steps in order to obtain an overview of the SES dynamics with the main social and ecological trends and events since 1900. First, we analysed the history of the valley from existing grey and scientific literature and databases on demographic and social data (INSEE 2016), agriculture (Agreste), climate (temperature and precipitations—Météo-France), risk (ONF-BD-RTM) and municipality archives (for details on data used see appendix 1). Second, the interviews of thirteen inhabitants were done in June 2018 (farmers, tourism professionals, elected officials, association representatives and multisector people) who had lived at the site for at least 20 years and knew its history well (details in appendix 2). These semi-directed interviews elicited descriptions of the SES and its subsystems, the past social, political, economic, ecological changes and their impacts. These information and data fed the timeline construction, by the identification of relevant themes.

In the second stage, we applied a timeline analysis, which is a deductive qualitative method for the systemic and temporal analyses of the past trajectory of a SES (Bergeret et al. 2015; Spiegelberger et al. 2018). The chronosystemic timeline construction follows four steps. First, we defined the problem addressed with the associated spatial and temporal scales, which here is the past adaptation of the SES of Pays de la Meije from 1900 to 2015. Second, we identified main themes where change has occurred over this period. Based on our preliminary analysis, we selected eight themes: external policies, local governance, social dynamics, agriculture, tourism, landscape dynamics, ecosystem management and climate. Third, we set milestones which are moments or periods associated with key events (punctual, repeated) and trends (with gradual changes or possibly state changes). Fourth, we described how interactions among milestones (e.g., causality, feedback loops, succession, collaboration, inertia and conflicts) led to the changes revealed by the timeline. The last two steps were performed during two participatory workshops including respectively two and six local stakeholders (see appendix 2). Based on their experience, knowledge and perceptions, participants identified and discussed the milestones for each theme and analysed their interactions. Finally, participants also identified and dated the main historical periods of change revealed by the timeline. From these, we were able to select four periods that display different responses of the SES to changes linked to agriculture, tourism or the entire SES. The elements of the timeline identified by the participants were, as far as possible, compared with information obtained from the literature, public information and databases available and were integrated into the narrative. The chronosystemic timeline obtained was presented to local stakeholders during a feedback event, allowing us to validate our construction, enrich and correct it where necessary.

In the third stage, for the four periods of change, we investigated the processes that led to adaptation by identifying (1) the drivers that induced changes in the SES, (2) the impacts of the drivers on capitals, NCP or quality of life and the resulting

vulnerability or opportunities and (3) the adaptive responses of the SES in terms of reconfiguration of NCP co-production (Fig. 1a). Once these elements and their causal relationships were identified, we investigated their implication for the three steps of NCP co-production within the IPBES framework (Diaz et al. 2015) focusing on the change between "Nature", "Nature's contributions to people" and "Good quality of life" (Bruley et al. 2021) (Fig. 1b). Thus, NCP impacted by and involved in these adaptations were deduced qualitatively from the evolution of human activities based on IPBES classification (Díaz et al. 2018); only NCP related to agriculture was analysed based on previous work at the site (Lavorel et al. 2017). We also identified the reconfigurations of human, social, financial, manufactured and natural capitals involved in the three steps of NCP co-production.

Results

The analysis of past social–ecological dynamics through the lens of NCP co-production revealed four periods since 1900 with distinct adaptive responses to external drivers. These periods of change are related to agriculture (periods 1, 2 and 4) and tourism (period 3), with temporal overlaps between the last two periods: (1) 1900–1960: gradual transformation from subsistence agriculture to a dairy production system, (2) 1965–1975: shift in livestock production towards heifer and lamb breeding, (3) 1976–2000: societal transformation following tourism development, and (4) 1990–2015: agricultural system resistance to change (Fig. 2). For each period, we analyse changes of NCP and their co-production (Table 1). To describe each period, we present indicators of the SES trajectory related to population, agriculture, tourism, natural disasters or climate emerging from a combination of our multiple sources of information (Fig. 3).

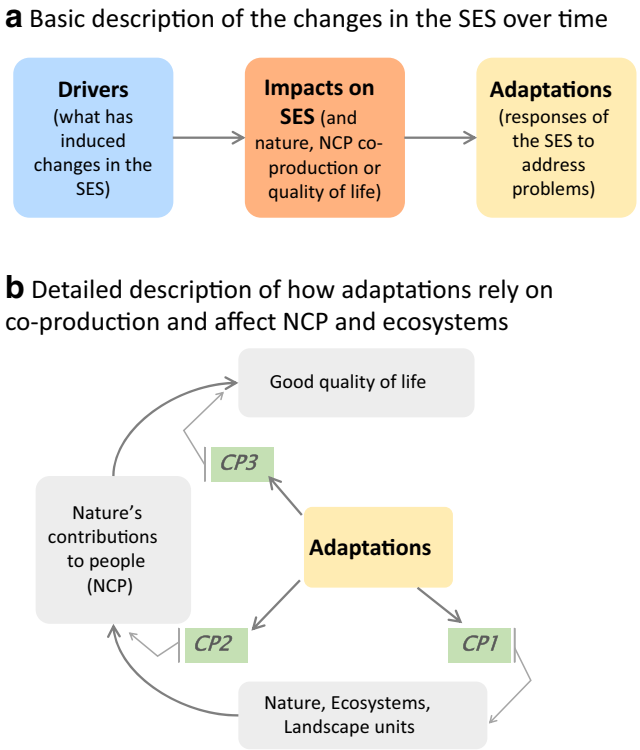

Fig. 1 Analytical framework to describe changes in the social–ecological system (SES) and their links to nature's contributions to people (NCP) co-production. **a** Drivers–Impacts–Adaptive response cascade. **b** Description of how adaptation occurs and affects NCP co-production steps (CP1: ecosystem management; CP2: mobilisation, harvesting and physical access; and CP3: appropriation, appreciation and social access to benefits). Based on Bruley et al. (2021)

Gradual transformation of the agricultural system (1900–1960)

In the nineteenth century, because of the steep topography and harsh winters in this high-altitude SES, people faced severe access restrictions and organised their activities to achieve food self-sufficiency through a system of family mixed farming and livestock rearing (cow and sheep for meat, dairy products and wool). These practises were essentially based on natural capital and widely available human workforce, skills, knowledge and collective organisation (Rousset 1992). These assets were central to the farming system, especially for building terraces that enabled crop production. The rural exodus caused by the new attractiveness of cities and industries led to a gradual population decline (INSEE) (Fig. 3, top row) and in particular the departure of youth (Girel et al. 2010). This trend persisted until the 1980s and made labour-intensive agriculture impossible to maintain; only summer transhumance of sheep and cattle persisted. As agricultural supply chains were getting more organised and market demand was growing at the national level (Marshall plan 1947), mountain agriculture turned partly into dairy production because of the high potential of alpine meadows for fodder production. As a result, a market was established in the Briançonnais region, with a cooperative and milk collection in the villages for dairy production (Girel et al. 2010). From 1900, supported by the development of milk transformation infrastructure, farming families gradually transformed their activity towards dairy farming and stopped cropping. Formerly ploughed terraces were transformed; the most accessible and least steep ones into hay meadows and the others into pasture (Girel et al. 2010). The lack of workforce was compensated by technical innovation that emerged in the 1950s (motorised mower). This process was facilitated by the improved accessibility, with the Lautaret pass opening to vehicle traffic during winter (1955). This especially supported food supply, which was less and less locally produced.

During this period, the main driver was the emigration and the associated loss of workforce, which affected food NCP co-production at all steps. By taking advantage of the opportunity

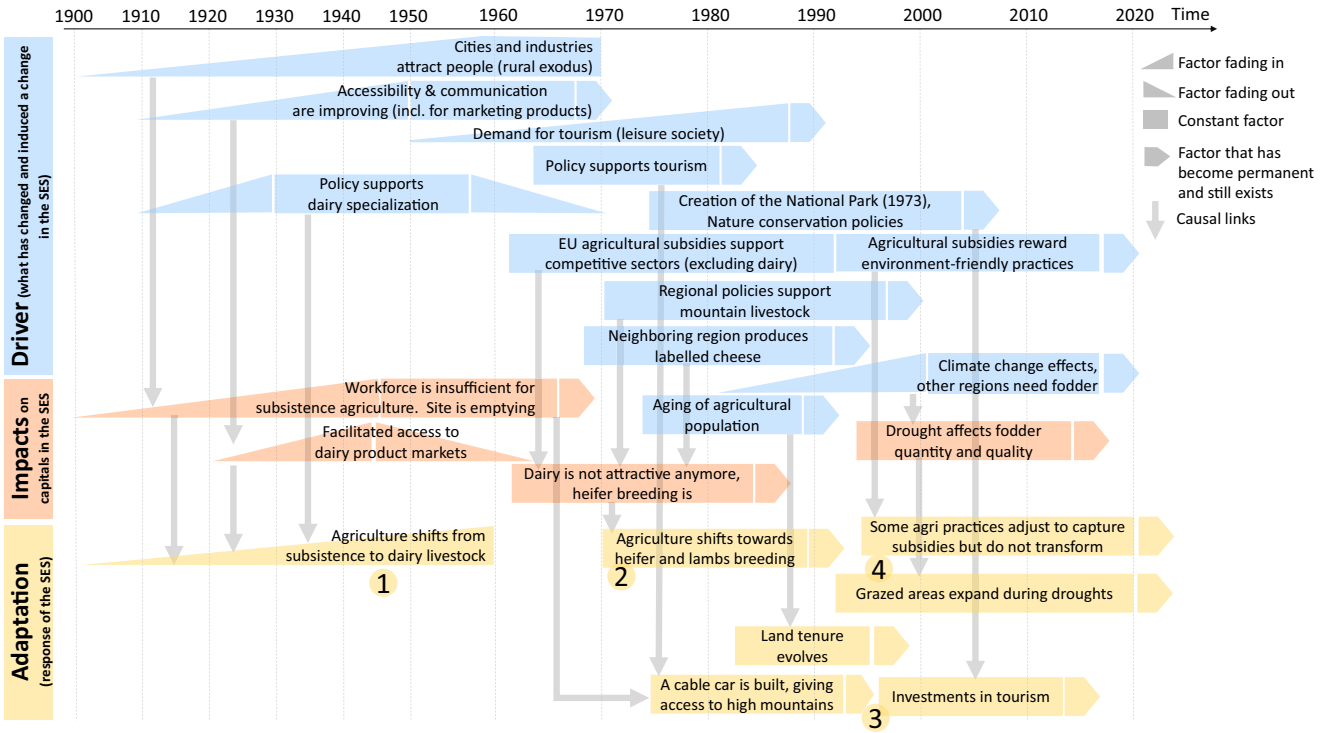

Fig. 2 Trajectories of drivers, impacts and adaptive responses of the social–ecological system (SES) of le Pays de la Meije, from 1900 to 2020. Grey arrows represent how drivers lead to adaptation. The four adaptation periods detailed in this paper are represented by numbers (1, 2, 3 and 4)

offered by dairy specialisation, farmers profoundly transformed the agricultural NCP co-production system. Agroecosystem management (CP1) shifted from ploughed terraces to fertilised grasslands. The mobilisation of production (CP2) was simplified from harvesting multiple products (cereals, vegetables, fodder, pasture, etc.) to mowing and grazing, supported by mechanisation from the 1950s. Finally, the multiple forms of appropriation and transformation of benefits (CP3) were progressively abandoned, replaced by larger infrastructure (dairy cooperative) to support milk transformation and trade. There was a profound change in the capitals mobilised for the co-production of these NCP with less labour, less animals and more machinery. This transformation was accompanied not only by a loss of traditional knowledge and skills associated with subsistence agriculture but also by a shift in families and their lifestyle to a modern system, in which farming is a business. This adaptation also significantly impacted natural capital, through a transition from a cultivated to a grassland landscape, and a resulting increase in hay meadow biodiversity, fertility and soil stability (Lavorel et al. 2017).

Agriculture shift towards heifer and lamb breeding (1965–1990)

With the establishment of the Common Agricultural Policy (CAP) in 1962, the search for food self-sufficiency at national and European levels gradually led to the prioritisation of the most productive or efficient activities and the decline of others. Because milk production in Pays de la Meije had no comparative advantage (Girel et al. 2010), this activity declined, the cooperative closed and milk collection ended shortly before 1970 (Martin-Noel 1962). The future of agriculture was once again jeopardised, leading to farmland area and farm number decline until the 1990s (Fig. 3, second row). Following a different trajectory, some neighbouring valleys (in Savoie and Haute-Savoie for cattle and South French Alps for lambs) maintained agriculture by value-adding to products through geographic indication labels, such as the European Protected Designation of Origin like the creation of the Beaufort cheese label in 1968 in nearby valleys (Beaufort, Tarentaise and Maurienne). Farmers in these areas did not see value in raising non-productive heifers (juvenile and non-lactating cows) on high-quality grazing land. Local farmers seised this opportunity to establish a trading link with breeding and selling heifers for these valleys. Livestock farming adapted to the new context by shifting herds towards heifer and lamb breeding during the 1970s. This new production system was strengthened by growing mechanisation (tractors) and supported by subsidies from the CAP, in particular the compensatory allowances for permanent natural handicaps (ICHN) for disadvantaged regions from 1975 (Schermer et al. 2016). The agricultural economy was also supported by the concurrent development of tourism, which offered an opportunity for multi-activity.

Table 1 Changes in nature's contributions to people (NCP) co-production steps (CP1,2&3), ecosystems and NCP during the four periods of adaptation of the social–ecological system (↗: increasing or gain; ↘: decreasing or loss; ↕: switch or transformation)

Phase # (in Fig. 2.a)	Main adaptation	Years	Effect on NCP	Changes in CP1 (ecosystem management)	Changes in CP2 (NCP mobilisation)	Changes in CP3 (NCP appropriation)	Effects on ecosystem
1	Dairy agriculture: agriculture shifts from subsistence to dairy livestock	1900–1960 (Progressive change)	Decrease of material NCP: ↘ food for self-consumption ↗ fodder for livestock ↕ identity link to agricultural practises	↘ cropping and terraces maintenance ↗ meadow fertilisation	↘ harvesting crop production ↗ mowing and grazing on terraces	↘ local food transformation ↗ milk transformation and trading, loss of cultural identities	↘ crops ↗ meadow and pasture, ↗ soil fertility, soil maintenance and biodiversity
2	Breeding: agriculture shifts towards heifer and lambs breeding	1965–1993	No changes	No or limited changes	No or limited changes (mostly linked to increased mechanisation)	End of milk transformation (remain marginal) ↗ trading with Beaufort heifer market and Alpes lambs' market	No changes
3	Tourism development: a new cable car in 1976 opens access to high mountain	1976–2000	Increase of non-material NCP: recreational, leisure, physical and spiritual experience, ↕ sense of place/ identity	↗ urbanisation and infrastructure, ↗ Nature protection (no strong management)	↗ physical access to natural landscape (cable car, roads, paths, signage...)	↗↗ appropriation, appreciation and ↕ place attachment from rural to leisure	↗ urbanisation and infrastructure, ↘ Protection of natural areas
4	Resistance to change: Some agriculture practises adjust for capturing subsidies but do not transform	1990–2015	No changes in agricultural NCP	↗ financial capital, better land allocation, ↘ fertilisation (practicses facilitated by mechanisation, re-parcelling, subsidies, local organisation and management)	↘ mowed surface (↗ on drought years)/↗ grazed surfaces (↗↗ on drought years) ↗ livestock number (cattle and sheep by transhumance) (practises facilitated by mechanisation, re-parcelling, subsidies, local organisation and management)	No changes	↘ biodiversity in grazed grasslands

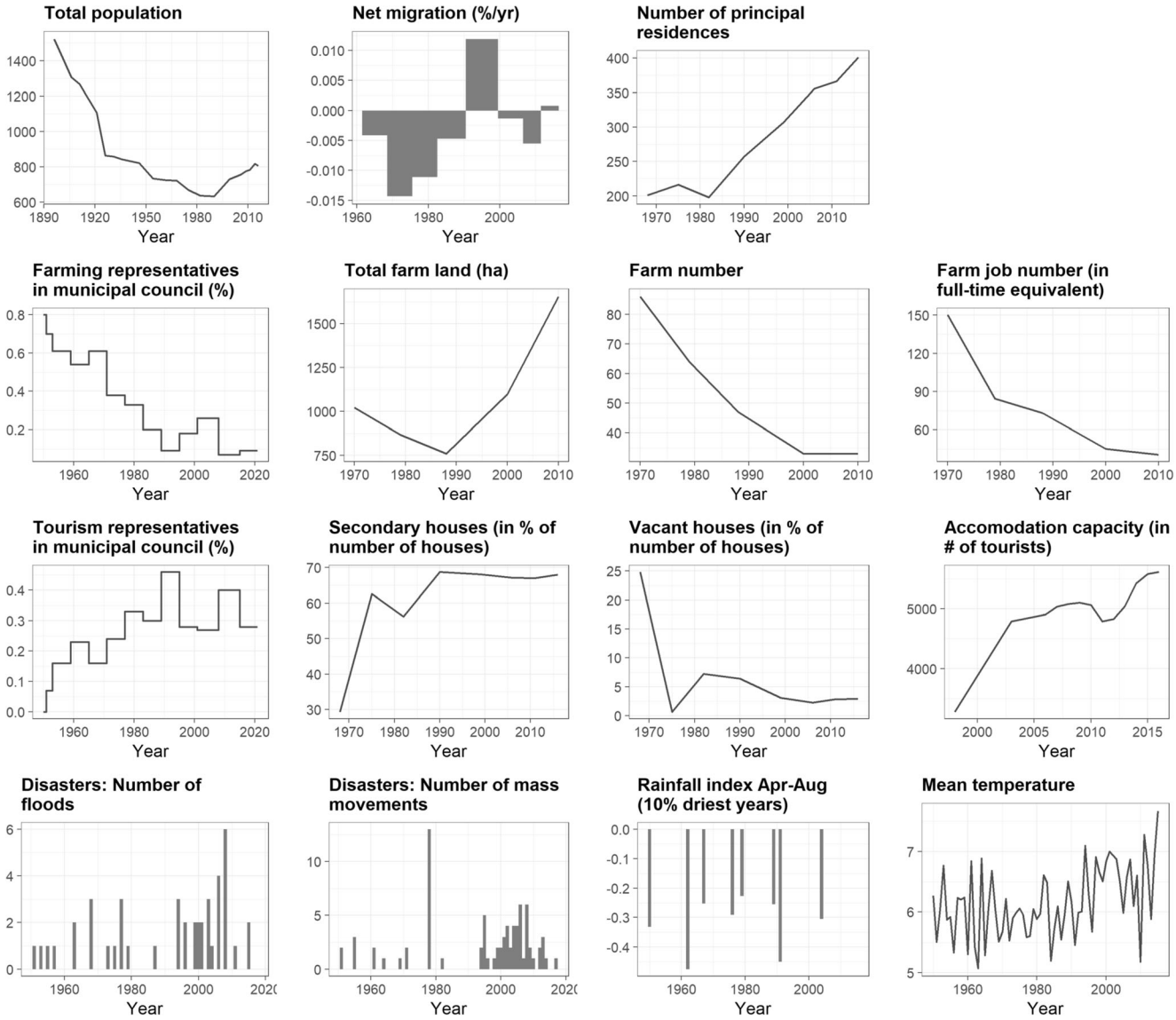

Fig. 3 Historical changes of indicators related to population (top row: INSEE), agriculture (second row: Agreste), tourism (third row: INSEE) and disaster or climate (bottom row: Météo-France; ONF-BD-RTM) in the study area. For drought, we used a rainfall index representing the mean value over the months of April to August of the Standardized Precipitation-Evapotranspiration Index (Vicente Serrano et al. 2010), and we highlighted remarkable drought years by displaying only the 10% years with the lowest values

During this period, the collapse of the milk supply chain in the region forced local farmers to reorient the appropriation of benefits (CP3) from the sale of milk to the sale of heifers and lambs. As the management of meadows and pastures (CP1) and mowing and grazing practises (CP2) remained nearly the same, this adaptation had little impact on ecosystems and NCP other than animal productions.

Societal transformation following tourism development (1976–2000)

Benefiting from the first national development plan for mountain resorts (Snow Plan), the creation a small ski resort and a tourism office in the 1960s was a first attempt to develop tourism with the objective of reinvigorating the local economy heavily affected by rural exodus and a shrinking agriculture (Muscella 2004). However, as customers were attracted by larger skiing resorts, several tourism businesses closed in the 1970s (Girel et al. 2010). To address this challenge and respond to the growing demand for mountain outdoor activities, the municipality of La Grave intended to build a cable car to access the Meije high mountain massif, already well known for alpinism (Muscella 2004). This project took more than 10 years to be achieved, facing much resistance from public authorities, investors and the local population. Another key driver of change in this period was the creation of the Ecrins National Park, which conflicted with local tourism development objectives and associated ecological impacts of the cable

car. Following tough negotiations, the Park decree was ratified by municipalities (1973), followed by the release of the authorisation and funding for the cable car by regional authorities (1976–77) (Siniscalchi 2008). Once the cable car was in place, the local society transformed gradually from an agricultural to a leisure- and tourism-oriented economy mainly based on nature, as evidenced by the increase in accommodation during the 1990s (Fig. 3, third row). The transformation process peaked in the 1990s with the popularity of off-piste skiing at La Grave (Muscella 2004). The cable car infrastructure brought financial benefits for local businesses (e.g., accommodation, shops and tourism professionals). The composition of municipal councils, which are competent authorities in many land use decisions, mainly composed of farmers until the 1970s, diversified to include more tourism professionals (Fig. 3, second row). The entire local community and many newcomers attracted by nature proximity for outdoor sports turned their activities towards mountain tourism (Martin 2014). Summer and winter mountain sports gradually developed and shifted from elite (alpinism and off-piste skiing) to more popular activities. The cable car and the National Park thus contributed to making an array of nature activities (e.g., hiking, climbing, skiing and wildlife watching) widely accessible.

The accessibility provided by the cable car infrastructure, as well as the national park, facilitated the co-production of many non-material NCPs. For example, nature experiences, leisure activities in the mountain landscape and a new supporting identity driven by a change in the values for nature as a playground. Simultaneously, structural adjustments of power relations occurred in local institutions with the decreasing representation of the agricultural sector in favour of tourism. There was significant capital involved in CP2 and CP3, but very limited capital in CP1: physical access (CP2) became essential to support development through the construction of transport infrastructure, particularly the cable car. Not only the professionalisation and construction of tourist facilities but also the creation of the imaginary around mountains increased social access, appreciation and appropriation of the benefits of nature (CP3). However, very limited changes in ecosystem management (CP1) apart from a low level of land take and soil sealing were necessary to allow this nature-based tourism development. Tourism was based on landscape beauty, which is partly the result of landscape management through agricultural activities (CP1). It can also be noted that a large part of the area was protected within the core area of the Park, which restricted the consequences of this transformation on landscapes and natural environments (CP1).

Agricultural system resistance to change (1990–2015)

Since 1990, multiple external drivers have pressured the farming system, which has been able to cope with small adjustments, without engaging in major transformation. Firstly, several changes in the CAP (in 1984, 1992, 2003 and 2015) to support rural development and the environment modified the requirements for obtaining subsidies (Schermer et al. 2016). The livestock breeding practises implemented in Pays de la Meije did not face restrictions to access subsidies, as they were already extensive enough to meet environmental requirements. Moreover, since 2003, with the help of the regional agricultural institutions and the Ecrins National Park, local farmers have been able to receive additional subsidies (agri-environment-climate measures) without modifying their practises, which has supported rural livelihoods and regional identity. Local land governance became more collective (creation of pastoral land associations), and land distribution changed (with fewer larger farms because of ageing population and the low rate of farm takeovers). The decrease in the number of farmers also caused a reduction in mown area and fertilisation, in favour of grazed area (Lavorel et al. 2017). Since the 1980s, fodder availability as well as livestock breeding has been affected by recurrent droughts and increasing temperatures (Fig. 3, bottom row), which have led to increased mowing in less accessible grasslands or purchases of outside fodder (Lamarque et al. 2013). At the same time, the demand for transhumant grazing in high-altitude grasslands has increased from pastoralists in the Southern Alps and Provence. Finally, tourism development has continued to support farming families through multi-activity.

During this period, there was a reconfiguration of capitals without change in the co-production of fodder. Financial capital from subsidies supporting CP1 and CP2 has evolved, power relations at municipal level did not change significantly, tourism representation remained strong and the governance of land management (CP1) was reorganised by the establishment of bottom-up collective strategies. Because of droughts, the least accessible areas were remobilised for mowing and grazing (CP2), and the demand for transhumance (CP2) increased. Therefore, financial capital and rural identity, along with the preservation of biodiversity as a condition for subsidies, became the main support for the co-production of fodder. These reconfigurations of capital have not led to changes in the landscape, but to declining fertility in hay meadows and declining biodiversity in grasslands converted from mowing to grazing (Quétier et al. 2007; Grigulis et al. 2013). While non-material NCPs (such as recreation, tourism, leisure and aesthetic enjoyment) have greatly increased since the 1970s because of tourism, material NCP have remained stable and linked to forage production.

Discussion

We studied the past trajectory of a social–ecological system to understand adaptive response mechanisms by analysing how human–nature interactions have changed over time through reconfiguration of NCP co-production. This systemic

approach described adaptations through actors' agency in NCP co-production. In the following, we discuss the drivers of change, their impacts on NCP co-production associated mechanisms of adaptive responses and the nature of adaptive responses.

Drivers of change and impacts on nature contributions to people co-production

We found that multiple external drivers affected directly or indirectly the Pays de la Meije SES through multi-scale interactions. In Europe, changes in regional, national and EU policies, markets or consumption patterns have strongly influenced agriculture and tourism (Levers et al. 2015; Plieninger et al. 2016). Changes also often stemmed from interactions with trajectories of others systems (region, national) at various spatial and temporal scales (Fazey et al. 2015). For example, as observed in many mountain regions, demographic fluctuations reflect regional trajectories, with rural exodus resulting from loss of local farm employment, new job opportunities in close industrialising cities of the region, and the national urbanisation (Hinojosa et al. 2016). We observed that drivers may impact all the co-production steps through capital reconfigurations, by affecting NCP supply with ecosystem management or mobilisation (CP1/CP2), and/or NCP demand through appreciation and appropriation (CP3). For example, changes in societal demand for food combined to the development of new markets and agricultural policies affected all co-production steps, thus affecting both supply and demand of agricultural NCP. Social and environmental policies as well as changing leisure preferences and habits have led to the emergence of new tourism-related NCP demand and supply. These drivers have long been identified as having indirect effects on ecosystems (Nelson et al. 2006). However, here, we highlight these drivers' impact through the co-production of NCP. Numerous capitals were thus reconfigured, such as access conditions to financial capital, modification of power and local agency affecting collective and individual decisions, new perception and relation to nature, or shift in preferences and values of societies. These results reflect the prevalent role of external drivers, especially socio-economic and policies, in SES adaptation dynamics (Prokopová et al. 2018).

Commonly with many marginal systems, three drivers played a predominant role in Pays de la Meije's past socio-ecological trajectory. First, accessibility was a prerequisite for the local development, for supporting local livelihoods and tourism development (Geneletti and Dawa 2009; Schirpke et al. 2019). Second, external policies triggered local agency as Common Agricultural Policy subsidies, national regional development and tourism policies, national urban planning rules and nature protection imposed by national conservation policy (Briner et al. 2013; Gretter et al. 2018; Antoni et al. 2019). Finally, outgoing (farm) and incoming (tourism) migratory flows have determined population size and composition across time. These drivers are shared characteristics of mountain SES and associated paradoxes of "Policies by outsider" and "in and out migration" (Klein et al. 2019), along with ageing population (Ianni et al. 2015). While many mountain regions have experienced similar trajectories (Locatelli et al. 2017), other trajectories have been observed, particularly in terms of agricultural and tourism development (Spiegelberger et al. 2018). For example, as few regions have been able to maintain agricultural activity, land abandonment is widespread in the Alps causing significant landscape transformation (Hinojosa et al. 2019; Schirpke et al. 2019). Rural activity has often given way to intensive tourism which is still ongoing today (Morán-Ordóñez et al. 2013). Moreover, some regions have been able to develop other types of activities such as industry, or to take advantage of close proximity to large urban areas. While in their past trajectories, each SES experiences variations in the NCP mobilised, archetypes of NCP bundles can be found depending on the local context and their adaptive responses (Renard et al. 2015).

We note that in this SES, adaptation has occurred in response to socioeconomic changes that threatened livelihoods, mainly in relation to economic and employment security. This contrasts with many other places where changes in natural capital have been the force towards SES transformation (Colloff et al. 2020). However, climatic and environmental drivers were rarely perceived by participants as main drivers impacting their livelihoods, although they can play an important role on natural capital reconfiguration. When climatic drivers were perceived by stakeholders (particularly droughts), we observed a difference between perceptions and climatic data. Some droughts did not appear in precipitation records but were perceived as such by farmers for years of lower fodder yields due to specific events like cold springs or rainy harvests. This finding is consistent with previous studies suggesting that farmers' perceptions are influenced by economic and psychological rather than purely biophysical impacts (Foguesatto et al. 2020). Despite actors perceiving recent signals of environmental changes, their discourses did not report past reconfiguration of NCP co-production due to change in natural capital. While climatic and environmental stressors are central to adaptation research, they are often not reported by actors as primary drivers of adaptation or of livelihood vulnerabilities (Mcdowell and Hess 2012; Räsänen et al. 2016). This may reflect their diffuse nature, along with intrinsic adaptation to harsh environments of SES subject to floods, drought, natural hazards or high climate variations like in mountain regions (Boissière et al. 2013; Klein et al. 2019). This may also be due to the interactions between multiple types of drivers, which blur the specific roles of individual drivers.

Mechanisms of adaptive responses

Changes in the availability or accessibility of capital created vulnerabilities or opportunities triggering local communities' decisions. We observed two types of adaptive responses to these changes. First, during periods 1 and 2, farmers were forced to adapt their practises in order to avoid the collapse of the agricultural system and livelihoods creating a trade-off between the loss of traditional knowledge and skills, and the gain in economic and social conditions. In contrast, during period 3, local communities seised the opportunity to improve their livelihoods by developing tourism. This observation relates to a distinction often made to explain decisions (e.g., entrepreneurship and migration decisions), between push motivation (the need to avoid an undesirable situation) and pull motivation (the willingness to reach a desirable situation) (Zimmermann 1996; Dawson and Henley 2012). Moreover, types of responses will strongly depend on the local context. Indeed, under the influence of the same large-scale drivers, other SES will take different trajectories due to local specificities and depending on the role of the affected NCP in local livelihoods (Jaligot et al. 2019). Collective or individual agency triggering adaptive responses is then facilitated or limited depending on threats or opportunities generated by changes among capitals involved in NCP co-production.

We observed multiple responses to drivers involving reconfiguration of NCP co-production and cascading effects on other co-production steps leading sometimes to systemic change. Drivers can directly affect one or several capitals involved in NCP co-production. All co-production steps may be impacted though cascading effects, as when loss of human capital (workforce) due to rural exodus reconfigured the entire food production system (period 1) and crop production ceased (CP1). Cascading effects can also be avoided when only one step of co-production is impacted, such as when change in dairy products markets (period 2) impacted value creation (CP3) and threatened the whole co-production of dairy farming (CP1/CP2/CP3). Systemic change was avoided during this period when local farmers seised the opportunity of a new market for heifer breeding (CP3) without changing the management or mobilisation of fodder production (CP1 and CP2). This was also observed in period 3 when increased demand from tourists for mountains activities (CP3) led locals and newcomers to co-produce new recreation NCP by increasing access, infrastructure and technical skills (CP2 and CP3) without requiring dedicated ecosystem management (CP1). Lastly, part of the capital may reconfigure without impacting co-production actions as described in the maintenance of the farming system from 1990 (period 4). Mechanisms of adaptive responses can then be characterised by the degree of reconfiguration of the capitals they induce. These mechanisms, and thus adaptive capacity, therefore depend on the access to different capitals that is facilitated or hindered by the drivers of change (Freduah et al. 2019).

Nature of adaptive responses

This study has identified adaptive responses of different natures, ranging from incremental to transformational based on degree of reconfiguration of NCP and their co-production steps, and the amount of capital required for adaptation. We highlighted the role of agency in these adaptive responses and how path dependency and resistance to change have emerged. Our analyses showed that the SES has undergone two major transformations since 1900 (periods 1 and 3), considering that responses are transformative when a SES fundamentally shifts its social and/or ecological properties and functions (Feola 2015; Colloff et al. 2017; Fedele et al. 2019). We observed that transformative responses required reconfigurations of multiple NCP co-productions, which were accompanied by important changes in human-derived capitals but not always in natural capitals (i.e., change in ecosystem types, structures and functions).

The reconfiguration of NCP co-production leading to transformation can take two forms. First, existing NCP can be intensified, as shown by the transformative responses in period 1, when people shifted from subsistence agriculture to a market-oriented activity for few families (i.e., livestock rearing), creating significant societal change and shift in values (Carrer et al. 2020). Moreover, transformation of farming practises, here to fodder and dairy production, required the reconfiguration of all co-production steps using new capitals, such as skills, knowledge, tools and governance (Krausmann 2004) causing change in mountain landscape (Egarter Vigl et al. 2016). Second, new NCP whose social or economic value has increased can appear, as shown by the transformative responses in period 3, when arrival of new populations in the Alps (workers and tourists) attracted by nature and leisure activities caused a societal transformation, also called "amenity migrants" (Perlik 2006; Martin 2014). This transformation resulted from the massive mobilisation of new human-derived capital to co-produce new recreational NCP, for example rules, skills, knowledge and funds needed for tourism businesses or building of trails and infrastructure (Kariel and Kariel 1982). Thus, the development of a tourism-oriented population as well as the transformation of the local economy was generated by reconfigurations in values by putting leisure at the centre of local society, knowledge systems and in power relations with the growing importance of the tourism sector in decision making (Corneloup et al. 2004). The amount of human capital required for NCP co-production appears as a characteristic of transformation (Chhetri et al. 2019). Indeed, both transformations were accompanied by change in the values, rules and knowledge systems shaping the decisional context. This shift in decisional context, influencing community's agency and adaptive capacity, was necessary for a paradigm change leading to social transformation (Gorddard et al. 2016; Colloff et al. 2017).

Transformative adaptation often requires changes in ecological processes and relies on latent, sustained or novel NCP (Lavorel et al. 2020). The reported societal transformation in period 3 required only few changes in the ecological system. First, due to the low intensity of ecosystem management and the ecosystem protection thanks to limited infrastructure development and landscape conservation resulting from national rules and local willingness to preserve the landscape. Second, due to the type of NCP, indeed, non-material NCP often required less direct ecosystem management and more appropriation and appreciation actions (Bruley et al. 2021). Moreover, other NCP co-productions, e.g., food and fodder production management, contribute greatly to the development of new non-material NCP, like scenic beauty, by shaping the landscape. Also, synergies among different NCP co-production steps were required in transformative responses to allow new NCP co-production, such as the combination of natural landscape conservation (CP1), creation of access to nature (CP2) and practise of tourism professionals (CP3) for many non-material NCP developed.

We also observed incremental responses characterised by adjustment of the current system functioning while maintaining its fundamental characteristics (Chhetri et al. 2019; Fedele et al. 2019) when adjustments in NCP co-production allowed tourism and agricultural activities to persist (periods 2 and 4). First, adjustments occurred in the capital involved in NCP co-production without changing the nature of co-production. For example, we observed adjustments of farmers' collective governance, land allocation and farming practises in response to twenty years of changing institutional, financial and climatic conditions to maintain local livelihoods (period 4) (Schermer et al. 2016). Secondly, some incremental responses modified only one NCP co-production step to ensure that other co-production steps could be maintained. During period 2, farmers adjusted the transformation and valorisation of livestock products (CP3) while maintaining the other practises of livestock farming and fodder production (CP1 and CP2). While this is not a systemic transformation for the SES, this transition from dairy to heifer production resulted in a significant change in the identity of farmers. Indeed, this adaptation led not only to the dependence of their activity on external actors, but also to a loss of added value and local valorisation through the relocation of part of the activity (CP3). Thus, a significant change in the identity of a sub-system linked to a co-production step was not enough to trigger the transformation of the system. In these two examples, farmers maintained "business as usual" and avoided the costs and risks of developing new NCP co-production.

The entire trajectory of the Pays de la Meije SES reveals how path dependency and resistance of the system have increased over time, partly because of the dependence of agriculture and tourism on external drivers. After their transformation, farmers became dependent on heifer and lamb external markets, on European subsidies (more than 60% of farm incomes) and on tourism (providing off-farm jobs). The local tourism sector became dependent on the consumption patterns or preferences of tourists, on accessibility and on climatic conditions (snow for winter sports). Agricultural subsidies and winter sports constitute powerful economic attractors that encourage communities to maintain their activities and resist change (Bussey et al. 2012). Local communities have developed resistance to change and the SES is in a phase of accumulation of capitals. Using the metaphor of the adaptive cycle defined by Gunderson and Holling (2002), we can consider that the SES is in a conservation phase, characterised by stabilisation and accumulation (periods 3 and 4). In the adaptive cycle, a conservation phase follows phases of reorganisation and growth (which could be our periods 1 and 2) but leads to a progressive loss of flexibility and is followed by a phase of collapse or release (Antoni et al. 2019). We believe that period 4 and its increased climate change vulnerability illustrates such a conservation phase in spite of small adjustments, for example in farmers' practises (Lamarque et al. 2014; Nettier et al. 2017) and in the subsidy system (Darnhofer et al. 2017). Actors will need to imagine new attractors in order to overcome dependencies that weaken the systems resilience over the long term.

The main capitals underpinning these dependencies are social and human capital related to institutions (e.g., external policies), formal and informal rules, power relations (e.g., farmers vs. tourism professionals), values (e.g., leisure society) and preferences (e.g., consumption patterns). Social capital has been shown to play a key role in adaptive capacity, particularly in interactions with natural capital (Adger 2010; Barnett et al. 2015). As an example, the Pays de la Meije SES experienced a major crisis in 2015, when its main road access kept closed during 9 months after a large landslide. Although livelihoods were threatened by this road closure and had to adjust temporally, there was not enough coordination among actors to seise the opportunities of this crisis, engage in transformative responses, and reduce structural vulnerabilities (Bally et al. 2020). Resistance mechanisms constitute a barrier to future adaptation if communities cannot adjust to ongoing changes, including facing climate change (Chhetri et al. 2019) and fall into social–ecological traps (Boonstra and De Boer 2014). There is indeed a risk of entering an unwanted future trajectory, linked to the high level of specialisation, the rigidity of the agricultural and tourism systems, the lack of local actor's influence and marginality of this SES facing increasing signals of biodiversity loss and climate change that could alter supporting ecosystems (Cumming 2018).

Conclusion

The last decade of sustainability research has strongly focused on adaptation of social–ecological systems, promoting a better understanding of mechanisms underpinning social–ecological adaptation. Empirical studies of historical trajectories have been suggested as a way to evaluate the adaptive capacity of social–ecological systems. In this study, we identified several mechanisms, from resistance to transformation, that influence ecosystem-based adaptation. We characterise them by the nature of associated changes in natural and anthropogenic capitals, the level of reconfiguration of NCP co-production for adapting, and by the degree of change in agency, mainly associated with changes in human and social capitals.

This study highlights the need for scientists to engage with local stakeholders and decision makers to co-produce knowledge based on past trajectories for informing future adaptation pathways. Along with improving our understanding of transformative adaptation, such engagement can help local actors identify their strengths (mechanisms and capitals that supported past adaptation) and weaknesses (vulnerability and dependence on certain capitals, often external) in facing global changes. Importantly, nature appeared as an important capital supporting adaptive responses and on which actors can act. In addition, identifying dependencies on capitals on which actors cannot act could be an important step for increasing adaptive capacity. This was the case here with subsidies for agriculture: they are indispensable but the dependence of farmers on them could be reduced by developing direct sales and moving to higher value-added production. Also, the local economic dependence on tourism could be reduced by diversifying winter activities to ensure income despite the impacts of climate change on snow cover or by developing activities in other sectors.

We encourage more numerous historical studies in other socio-ecological contexts for exploring adaptation mechanisms. Additional place-based research is needed to better understand how future adaptation plans can be informed by the analysis of past trajectories of human and nature interactions. Our results also suggest that a more in depth understanding of agency in adaptive responses would be required, informing heterogeneity and inequalities in adaptive capacity across actors, their power relations and access to capitals for NCP co-production.

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References

Adamson GCD, Hannaford MJ, Rohland EJ (2018) Re-thinking the present: the role of a historical focus in climate change adaptation research. Glob Environ Chang 48:195–205. https://doi.org/10.1016/j.gloenvcha.2017.12.003

Adger WN (2010) Social capital, collective action, and adaptation to climate change. In: Voss M. (eds) Der Klimawandel. VS Verlag für Sozialwissenschaften. pp 327–345

Antoni C, Huber-Sannwald E, Reyes Hernández H, van't Hooft A, Schoon M, et al (2019) Socio-ecological dynamics of a tropical agricultural region: historical analysis of system change and opportunities. Land Use Policy 81:346–359. https://doi.org/10.1016/j.landusepol.2018.10.028

Bally F, Gabillet M, Laforgue D, Lavorel S, Peyrache-Gadeau V, et al (2020) L'étude de la « Crise du Chambon » pour penser les rapports entre territoire, institutions, populations et sciences. Nature, Sciences et Sociétés 28:24–34. https://doi.org/10.1051/nss/2020019

Barnett J, Evans LS, Gross C, Kiem AS, Kingsford RT, et al (2015) From barriers to limits to climate change adaptation: Path dependency and the speed of change. Ecol Soc:20. https://doi.org/10.5751/ES-07698-200305

Bergeret A, George-Marcelpoil E, Delannoy J, Piazza-morel D (2015) L'outil-frise : une expérimentation interdisciplinaire - comment représenter des processus de changements en territoires de montagne ? Les Carnets du Labex ITEM <hal- 01230027>

Boissière M, Locatelli B, Sheil D, Padmanaba, Michael Sadjudin E (2013) Local perceptions of climate variability and change in tropical forests of Papua , Indonesia Ecol Soc 18: . https://doi.org/10.5751/ES-05822-180413

Boonstra WJ, De Boer FW (2014) The historical dynamics of social-ecological traps. Ambio 43:260–274. https://doi.org/10.1007/s13280-013-0419-1

Briner S, Elkin C, Huber R (2013) Evaluating the relative impact of climate and economic changes on forest and agricultural ecosystem services in mountain regions. J Environ Manag 129:414–422. https://doi.org/10.1016/j.jenvman.2013.07.018

Bruley E, Locatelli B, Lavorel S (2021) Nature's contributions to people: co-producing quality of life from multifunctional landscapes. Ecol Soc 26:12. https://doi.org/10.5751/ES-12031-260112

Bürgi M, Silbernagel J, Wu J, Kienast F (2015) Linking ecosystem services with landscape history. Landsc Ecol 30:11–20. https://doi.org/10.1007/s10980-014-0102-3

Bussey M, Carter RW (Bill., Keys N, Carter J, Mangoyana R, et al (2012) Framing adaptive capacity through a history-futures lens: lessons from the South East Queensland Climate Adaptation Research Initiative. Futures 44:385–397 . https://doi.org/10.1016/j.futures.2011.12.002

Carrer F, Walsh K, Mocci F (2020) Ecology, economy, and upland landscapes: socio-ecological dynamics in the Alps during the transition to modernity. Hum Ecol 48:69–84. https://doi.org/10.1007/s10745-020-00130-y

Chhetri N, Stuhlmacher M, Ishtiaque A (2019) Nested pathways to adaptation. Environ Res Commun 1:015001. https://doi.org/10.1088/2515-7620/aaf9f9

Colloff MJ, Martín-López B, Lavorel S, Locatelli B, Gorddard R, et al (2017) An integrative research framework for enabling transformative adaptation. Environ Sci Pol 68:87–96. https://doi.org/10.1016/j.envsci.2016.11.007

Colloff MJ, Wise RM, Palomo I, Lavorel S, Pascual U, et al (2020) Nature's contribution to adaptation: insights from examples of the transformation of social-ecological systems. Ecosystems and People 16:137–150. https://doi.org/10.1080/26395916.2020.1754919

Corneloup J, Bourdeau P, Mao P (2004) Le marquage culturel des territoires touristiques de nature. Revue de géographie alpine 92:11–20. https://doi.org/10.3406/rga.2004.2317

Costanza R, Kubiszewski I, Heckbert S, Hibbard KA, Costanza R, et al (2012) Scholar developing an integrated history and future of people on earth (IHOPE). 4:106–114. https://doi.org/10.1016/j.cosust.2012.01.010.This

Cumming GS (2018) A review of social dilemmas and social-ecological traps in conservation and natural resource management 11:1–15 . https://doi.org/10.1111/conl.12376

Darnhofer I, Schermer M, Steinbacher M, Gabillet M, Daugstad K, et al (2017) Land use policy preserving permanent mountain grasslands in Western Europe : why are promising approaches not implemented more widely ? Land Use Policy 68:306–315. https://doi.org/10.1016/j.landusepol.2017.08.005

Davidson DJ (2010) The applicability of the concept of resilience to social systems: some sources of optimism and nagging doubts. Soc Nat Resour 23:1135–1149. https://doi.org/10.1080/08941921003652940

Dawson C, Henley A (2012) "Push" versus "pull" entrepreneurship: an ambiguous distinction? Int J Entrep Behav Res 18:697–719. https://doi.org/10.1108/13552551211268139

Dearing JA, Acma B, Bub S, Chambers FM, Chen X, et al (2015) Social-ecological systems in the Anthropocene : the need for integrating social and biophysical records at regional scales. https://doi.org/10.1177/2053019615579128

Diaz S, Demissew S, Carabias J, Dı S, Joly C, et al (2015) The IPBES conceptual framework — connecting nature and people. 1–16 . https://doi.org/10.1016/j.cosust.2014.11.002

Díaz S, Pascual U, Stenseke M, Martín-López B, Watson RT, et al (2018) Assessing nature's contributions to people. Science 359:270–272. https://doi.org/10.1126/science.aap8826

Dittrich A, Seppelt R, Václavík T, Cord AF (2017) Integrating ecosystem service bundles and socio-environmental conditions – a national scale analysis from Germany. Ecosyst Serv 28:273–282. https://doi.org/10.1016/j.ecoser.2017.08.007

Egan PA, Price MF (2017) Mountain ecosystem services and climate change. A global overview of potential threats and strategies for adaptation, UNESCO. Paris

Egarter Vigl L, Schirpke U, Tasser E, Tappeiner U (2016) Linking long-term landscape dynamics to the multiple interactions among ecosystem services in the European Alps. Landsc Ecol 31:1903–1918. https://doi.org/10.1007/s10980-016-0389-3

Egarter Vigl L, Tasser E, Schirpke U, Tappeiner U (2017) Using land use/land cover trajectories to uncover ecosystem service patterns across the Alps. Reg Environ Chang 17:2237–2250. https://doi.org/10.1007/s10113-017-1132-6

Fazey I, Wise RM, Lyon C, Câmpeanu C, Moug P, et al (2015) Past and future adaptation pathways. Clim Dev 8:26–44. https://doi.org/10.1080/17565529.2014.989192

Fedele G, Donatti CI, Harvey CA, Hannah L, Hole DG, et al (2019) Transformative adaptation to climate change for sustainable social-ecological systems. Environ Sci Pol 101:116–125. https://doi.org/10.1016/j.envsci.2019.07.001

Fedele G, Locatelli B, Djoudi H (2017) Mechanisms mediating the contribution of ecosystem services to human well-being and resilience. Ecosyst Serv 28:43–54. https://doi.org/10.1016/j.ecoser.2017.09.011

Feola G (2015) Societal transformation in response to global environmental change: a review of emerging concepts. Ambio 44:376–390. https://doi.org/10.1007/s13280-014-0582-z

Foguesatto CR, Artuzo FD, Talamini E, Machado JAD (2020) Understanding the divergences between farmer's perception and meteorological records regarding climate change: a review. Environ Dev Sustain 22:1–16. https://doi.org/10.1007/s10668-018-0193-0

Freduah G, Fidelman P, Smith TF (2019) A framework for assessing adaptive capacity to multiple climatic and non-climatic stressors in small-scale fisheries. Environ Sci Pol 101:87–93. https://doi.org/10.1016/j.envsci.2019.07.016

Geels FW, Schot J (2007) Typology of sociotechnical transition pathways. Res Policy 36:399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geneletti D, Dawa D (2009) Environmental impact assessment of mountain tourism in developing regions: a study in Ladakh, Indian Himalaya. Environ Impact Assess Rev 29:229–242. https://doi.org/10.1016/j.eiar.2009.01.003

Girel J, Quetier F, Bignon A, Aubert S (2010) Histoire de l'agriculture en Oisans. Hautes Romanche et pays Faranchin - Villar d'Arène, Hautes Alpes

Gorddard R, Colloff MJ, Wise RM, Ware D, Dunlop M, et al (2016) Values, rules and knowledge: adaptation as change in the decision context. Environ Sci Pol 57:60–69. https://doi.org/10.1016/j.envsci.2015.12.004

Grêt-Regamey A, Brunner SH, Kienast F (2012) Mountain ecosystem services: who cares? Mt Res Dev 32:S23–S34. https://doi.org/10.1659/MRD-JOURNAL-D-10-00115.S1

Gretter A, Ciolli M, Scolozzi R (2018) Governing mountain landscapes collectively: local responses to emerging challenges within a systems thinking perspective. Landsc Res 43:1117–1130. https://doi.org/10.1080/01426397.2018.1503239

Grier C, Alessa L, Kliskey A (2017) Looking to the past to shape the future: addressing social-ecological change and adaptive trade-offs. Reg Environ Chang 17:1205–1215. https://doi.org/10.1007/s10113-016-1096-y

Grigulis K, Lavorel S, Krainer U, Legay N, Baxendale C, et al (2013) Relative contributions of plant traits and soil microbial properties to

mountain grassland ecosystem services. J Ecol 101:47–57. https://doi.org/10.1111/1365-2745.12014
Gunderson LH, Holling CS (2002) Panarchy: understanding trans- formations in human and natural systems. Island Pre, Washington, DC
Hinojosa L, Napoléone C, Moulery M, Lambin EF (2016) The "mountain effect" in the abandonment of grasslands: insights from the French southern Alps. Agric Ecosyst Environ 221:115–124. https://doi.org/10.1016/j.agee.2016.01.032
Hinojosa L, Tasser E, Rüdisser J, Leitinger G, Schermer M, et al (2019) Geographical heterogeneity in mountain grasslands dynamics in the Austrian-Italian Tyrol region. Appl Geogr 106:50–59. https://doi.org/10.1016/j.apgeog.2019.03.006
Ianni E, Geneletti D, Ciolli M (2015) Revitalizing traditional ecological knowledge: a study in an Alpine rural community. Environ Manag 56:144–156. https://doi.org/10.1007/s00267-015-0479-z
INSEE (2016) Institut national de la statistique et des études économiques (INSEE). https://www.insee.fr/fr/accueil
IPBES (2018) The regional assessment report on biodiversity and ecosystem services for Africa of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. ISBN no: 978-3-947851-05-8
Jaligot R, Chenal J, Bosch M, Hasler S (2019) Historical dynamics of ecosystem services and land management policies in Switzerland. Ecol Indic 101:81–90. https://doi.org/10.1016/j.ecolind.2019.01.007
Jepsen MR, Kuemmerle T, Müller D, Erb K, Verburg PH, et al (2015) Transitions in European land-management regimes between 1800 and 2010. Land Use Policy 49:53–64. https://doi.org/10.1016/j.landusepol.2015.07.003
Kariel H, Kariel P (1982) Socio-cultural impacts of tourism: an example from the Austrian Alps. Swedish Society for Anthropology and Geography Wiley 64:1–16. https://doi.org/10.1080/04353684.1982.11879467
Klein JA, Tucker CM, Nolin AW, Hopping KA, Reid RS, et al (2019) Catalyzing transformations to sustainability in the world's mountains. Earth's Future:547–557. https://doi.org/10.1029/2018EF001024
Körner C, Ohsawa M, Spehn E (2005) Mountain systems. In: Island press WD (ed) in: Millennium ecosystem assessment. Current state and trends: findings of the condition and trends working group. pp 681–716
Krausmann F (2004) Milk, manure, and muscle power. Livestock and the transformation of preindustrial agriculture in Central Europe. Hum Ecol 32:735–772. https://doi.org/10.1007/s10745-004-6834-y
Lamarque P, Artaux A, Barnaud C, Dobremez L, Nettier B, et al (2013) Taking into account farmers' decision making to map fine-scale land management adaptation to climate and socio-economic scenarios. Landsc Urban Plan 119:147–157. https://doi.org/10.1016/j.landurbplan.2013.07.012
Lamarque P, Meyfroidt P, Nettier B, Lavorel S (2014) How ecosystem services knowledge and values influence farmers' decision-making. PLoS One 9. https://doi.org/10.1371/journal.pone.0107572
Lavorel S, Colloff MJ, Locatelli B, Gorddard R, Prober SM, et al (2019) Mustering the power of ecosystems for adaptation to climate change. Environ Sci Pol 92:87–97. https://doi.org/10.1016/j.envsci.2018.11.010
Lavorel S, Grigulis K, Leitinger G, Kohler M, Schirpke U, et al (2017) Historical trajectories in land use pattern and grassland ecosystem services in two European alpine landscapes. Reg Environ Chang 17:2251–2264. https://doi.org/10.1007/s10113-017-1207-4
Lavorel S, Locatelli B, Colloff MJ, Bruley E (2020) Co-producing ecosystem services for adapting to climate change. Philos Trans R Soc 375. https://doi.org/10.1098/rstb.2019.0119
Levers C, Erb K, Haberl H, Mu D, Rudbeck M, et al (2015) Archetypical patterns and trajectories of land systems in Europe. Reg Environ Chang 18:715–732. https://doi.org/10.1007/s10113-015-0907-x
Locatelli B, Lavorel S, Sloan S, Tappeiner U, Geneletti D, et al (2017) Characteristic trajectories of ecosystem services in mountains. Front Ecol Environ 15:150–159. https://doi.org/10.1002/fee.1470
Martín-López B, Leister I, Cruz PL, Palomo I, Grêt-Regamey A, et al (2019) Nature's contributions to people in mountains: a review. PLoS One 14:1–24. https://doi.org/10.1371/journal.pone.0217847
Martin-Noel J (1962) Une grande Coopérative laitière alpine : « Dauphilait ». Revue de géographie alpine 50:659–664. https://doi.org/10.3406/rga.1962.1008
Martin N (2014) Les migrations d ' agrément , marqueur d ' une dynamique d ' après tourisme dans les territoires de montagne
Mcdowell JZ, Hess JJ (2012) Accessing adaptation : multiple stressors on livelihoods in the Bolivian highlands under a changing climate. Glob Environ Chang 22:342–352. https://doi.org/10.1016/j.gloenvcha.2011.11.002
Meyfroidt P, Chowdhury RR, De Bremond A, Ellis EC, Erb K, et al (2018) Middle-range theories of land system change. Glob Environ Chang 53:52–67. https://doi.org/10.1016/j.gloenvcha.2018.08.006
Morán-Ordóñez A, Bugter R, Suárez-Seoane S, de Luis E, Calvo L, et al (2013) Temporal changes in socio-ecological systems and their impact on ecosystem services at different governance scales: a case study of heathlands. Ecosystems 16:765–782. https://doi.org/10.1007/s10021-013-9649-0
Munteanu C, Kuemmerle T, Boltiziar M, Butsic V, Gimmi U, et al (2014) Forest and agricultural land change in the Carpathian region-a meta-analysis of long-term patterns and drivers of change. Land Use Policy 38:685–697. https://doi.org/10.1016/j.landusepol.2014.01.012
Muscella C (2004) Les enjeux de la construction d'un territoire de Haute Montagne : Etude du canton de la Grave (Hautes Alpes). Université Lumières Lyon II, Faculté d'Anthropologie et de Sociologie
Nelson DR, de Souza Filho F d A, Finan TJ, Ferreira S (2014) Trajectories of adaptation: a retrospectus for future dynamics. Social-Ecological Systems in Transition:121–136. https://doi.org/10.1007/978-4-431-54910-9_7
Nelson GC, Bennett E, Berhe AA, Cassman K, DeFries R, et al (2006) Anthropogenic drivers of ecosystem change: an overview. Ecol Soc 11. https://doi.org/10.5751/ES-01826-110229
Nettier B, Dobremez L, Lavorel S, Brunschwig G (2017) Resilience as a framework for analyzing the adaptation of mountain summer. Ecology 22. https://doi.org/10.5751/ES-09625-220425
Palomo I (2017) Climate change impacts on ecosystem services in high mountain areas: a literature review. Mt Res Dev 37:179–187. https://doi.org/10.1659/MRD-JOURNAL-D-16-00110.1
Palomo I, Felipe-Lucia MR, Bennett EM, Martín-López B, Pascual U, et al (2016) Disentangling the pathways and effects of ecosystem service co-production. Adv Ecol Res 54:245–283. https://doi.org/10.1016/bs.aecr.2015.09.003
Perlik M (2006) The specifics of amenity migration in the European Alps. In: Moss L (ed) The amenity migrants: seeking and sustaining mountains and their cultures. CABI Publi, Cambridge, pp 215–231
Plieninger T, Draux H, Fagerholm N, Bieling C, Bürgi M, et al (2016) The driving forces of landscape change in Europe: a systematic review of the evidence. Land Use Policy 57:204–214. https://doi.org/10.1016/j.landusepol.2016.04.040
Plieninger T, Kizos T, Bieling C, Le Dû-Blayo L, Budniok MA, et al (2015) Exploring ecosystem-change and society through a landscape lens: recent progress in European landscape research. Ecol Soc 20. https://doi.org/10.5751/ES-07443-200205
Prokopová M, Cudlín O, Včeláková R, Lengyel S, Salvati L, et al (2018) Latent drivers of landscape transformation in eastern Europe: past, present and future. Sustainability (Switzerland) 10:1–17. https://doi.org/10.3390/su10082918
Quétier F, Rivoal F, Marty P, de Chazal J, Thuiller W, et al (2010) Social representations of an alpine grassland landscape and socio-political

discourses on rural development. Reg Environ Chang 10:119–130. https://doi.org/10.1007/s10113-009-0099-3

Quétier F, Thébault A, Lavorel S (2007) Plant traits in a state and transition framework as markers of ecosystem response to land-use change. Ecol Monogr 77:33–52. https://doi.org/10.1890/06-0054

Räsänen A, Sirkku J, Nygren A, Käkönen M, Kallio M, et al (2016) Climate change , multiple stressors and human vulnerability : a systematic review. Reg Environ Chang 16:2291–2302 . https://doi.org/10.1007/s10113-016-0974-7

Rau AL, von Wehrden H, Abson DJ (2018) Temporal dynamics of ecosystem services. Ecol Econ 151:122–130. https://doi.org/10.1016/j.ecolecon.2018.05.009

Renard D, Rhemtull JM, Bennett EM (2015) Historical dynamics in ecosystem service bundles. Proc Natl Acad Sci U S A 112:13411–13416. https://doi.org/10.1073/pnas.1502565112

Rousset PL (1992) Au pays de la Meije 3ème édition, Curandera

Schermer M, Darnhofer I, Daugstad K, Gabillet M, Lavorel S, et al (2016) Institutional impacts on the resilience of mountain grasslands: an analysis based on three European case studies. Land Use Policy 52:382–391. https://doi.org/10.1016/j.landusepol.2015.12.009

Schirpke U, Altzinger A, Leitinger G, Tasser E (2019) Change from agricultural to touristic use: effects on the aesthetic value of landscapes over the last 150 years. Landsc Urban Plan 187:23–35. https://doi.org/10.1016/j.landurbplan.2019.03.004

Siniscalchi V (2008) Économie Et Pouvoir Au Sein Du Parc National Des Écrins. Techniques & Culture:40–59. https://doi.org/10.4000/tc.3941

Spiegelberger T, Bergeret A, Crouzat É, Tschanz L, Piazza-Morel D, et al (2018) Interdisciplinary construction of a socio-ecological vulnerability trajectory based on the Quatre Montagnes (Isère, France) area from 1950 to 2016. Revue de géographie alpine 0–16 . https://doi.org/10.4000/rga.5046

Stürck J, Schulp CJE, Verburg PH (2015) Spatio-temporal dynamics of regulating ecosystem services in Europe- the role of past and future land use change. Appl Geogr 63:121–135. https://doi.org/10.1016/j.apgeog.2015.06.009

Tomscha SA, Gergel SE (2016) Ecosystem service trade-offs and synergies misunderstood without landscape history. Ecol Soc 21. https://doi.org/10.5751/ES-08345-210143

Vicente Serrano SM, Beguería S, López-Moreno JI (2010) A multiscalar drought index sensitive to global warming : the standardized precipitation evapotranspiration index. J Clim 23:1696–1718. https://doi.org/10.1175/2009JCLI2909.1

Zimmermann KF (1996) European migration : push and pull. Int Reg Sci Rev 128:95–128. https://doi.org/10.1177/016001769601900211