Stakeholder visions for trajectories of adaptation to climate change in the Drôme catchment (French Alps)

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ORIGINAL ARTICLE

Stakeholder visions for trajectories of adaptation to climate change in the Drôme catchment (French Alps)

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Abstract

Analyzing actions of climate change adaptation as envisaged by stakeholders enables to draw a shared vision or, conversely, alternative pathways imagined for a territory; and to question their inclusion in governance. This article focuses on the adaptation levers devised by 170 local stakeholders (state services, elected officials, agriculture, forest and river technicians, farmers, inhabitants) in the French Drôme Valley. Data was collected through a visioning process combining interviews and workshops designed around three collectively identified structuring issues: quality of life, agricultural production and tourist attractiveness. We characterized the 300 proposed actions according to: (1) stage of implementation, (2) the degree of socio-ecological transformation they imply, (3) the type of strategy for co-production of associated Nature's Contributions to Adaptation through: ecosystem management, mobilization, social appreciation, and associated social dynamics (socio-economic demand, governance, knowledge systems), (4) proponents' roles in governance of the socio-ecological system, (5) the repertoire of values to which they participate as part of collective visions for a desirable future. We identified three typical visions and associated normative goals: sustainable development, ecological and social transition, and ecosystem wealth and self-sufficiency. Each vision was characterized by the set of actions proposed by stakeholders as a pathway to the vision. We compare these three typical pathways with actions already implemented (the current trajectory), and with actions proposed according to the social roles of participants to discuss the cross-cutting nature of desired actions, and convergences or divergences across stakeholders according to their involvement and capacity to influence ecosystem management.

Keywords Co-production · Nature's Contributions to Adaptation · Transformation · Governance · Values rules knowledge (VRK) · Normative scenario

Introduction

Resolving the current environmental and social crisis requires an urgent change in societies (Allen et al. 2018; Díaz et al. 2019). Transformation will require deep changes in dominant values, economic models, finance and higher-level institutions (Abson et al. 2017; Fazey et al. 2017). It is however likely to arise from a combination of incremental adaptation through coping and adjustment and qualitative transformation, rather than just radical transformation (Colloff et al. in revision; Termeer et al. 2017). For this to happen in local places and ultimately to scale up, it is important to co-design adaptation pathways with people (Campos et al. 2016; Cradock-Henry et al. 2020).

Nature's Contributions to Adaptation (NCA) are properties of ecosystems that provide options for future livelihoods and adaptation to reconfiguration of ecosystems by climate change (Lavorel et al. 2015; Colloff et al. 2020). NCA consider ecosystems, their biodiversity and contributions to people as resources for developing solutions to environmental change. Such a functional perspective on nature focuses on how people living in a territory can respond and act during socio-ecological transformation by modifying their behaviours and decisions (Barreteau et al. 2016; Locatelli et al. 2017). Thus, the integration of NCA into the place-based co-design of adaptation pathways identifies how local social processes of nature's value attribution, mobilization, appropriation and exchange play out in socio-ecological

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transformation (Spangenberg et al. 2014; Ellis et al. 2019). In so doing, stakeholders and decision-makers are empowered to harness natural capital in their pathways to transformation (Lavorel et al. 2019; Colloff et al. 2020).

The French Drôme Valley has been portrayed as a pioneer and transformative territory, supporting co-management arrangements, and integrated and inclusive processes of urban planning and regional projects (Adger et al. 2005). Its exemplarity has been recognized nationally through institutional support (Biovallée-TIGA 2019), and multiple research projects have focused on its development trajectory. The *Biovallée* catchment has based its development on organic agriculture (Ollivier et al. 2018), river restoration and a process of territorial co-design (Girard 2012). The region is currently experiencing strong impacts of climate variability, which align with expected longer-term trends of climate change for France (Ouzeau et al. 2014). In this research, we aimed to understand the visions and associated NCA desired by stakeholders facing climate change challenges, according to their role in governance. We asked: (1) Which visions do stakeholders desire for their future and how transformative are they? (2) What is the place of NCA in proposed pathways and through which actions? How does this compare with the current trajectory of change through actions of local governance bodies? (3) How do proposed pathways vary according to stakeholders' roles in governance and are their intentions congruent with their actual roles?

We addressed these questions by analyzing the relationships between (1) desired collective visions and their associated values, rules and knowledge integrated in models for the local socio-ecosystem and (2) actions for activating Nature's Contributions to Adaptation devised by stakeholders according to their governance roles. For this, we used adaptation actions proposed by stakeholders during a participatory process as elementary units of information. In the following, we outline our framing for: (1) constructing visions from proposed adaptation actions; (2) characterizing actions as NCA, their decision context and their level of transformation; (3) analyzing how actions differ across stakeholders according to their governance roles.

Constructing visions and models from proposed adaptation actions

Deliberative processes with broad participation, where knowledge objectives are embedded in the collective production of solutions, are considered most appropriate to address wicked problems such as transformative adaptation to climate change (Meadow et al. 2015; van Kerkhoff and Pilbeam 2017). A variety of methods have been developed for participatory production of scenarios and transformation pathways (Oteros-Rozas et al. 2015; Norström et al. 2020). Among these, projects have experimented with co-design between researchers and stakeholders following three steps: (1) shared socio-ecosystem conceptualisation, (2) producing visions for a desirable future (Wiek and Iwaniec 2014); (3) identifying pathways of actions towards these desired outcomes by backcasting (Falardeau et al. 2019; Cradock-Henry et al. 2020).

Through their discourses on their visions, stakeholders propose actions reflecting their decision contexts and their underpinning interplay of values, rules, and knowledge (VRK) (Gorddard et al. 2016). We define here values in a pragmatic way as a collective process of valuation, "the result of whole set of operations by which a quality is assigned to an object (things, persons, actions, states of the world), with varying degree of consensus and stability". (Heinich 2020). In this approach, valuation is underpinned by the axiological grammar of justification sequences (Boltanski and Thévenot 2006) or "repertoires of values", which co-exist and are permanently re-shaped (Heinich 2020).

Visioning methods associates the vision of a desirable future (expressing values) to coherent and systemic models of social-ecosystems (Wiek and Iwaniec 2014). Plumecocq et al. (2018) proposed inspiring models for western sustainable agriculture: the biotech model, based on biological inputs and a global food market; the circular model of industrial ecology with farmers inorganized as productive clusters; the diversified-globalized, relocalized and integrated landscape models based on increasing agroecological practices that integrate benefits from local NCP, integrated local food-energy systems and territorial embeddedness.

Our process aimed to capture contrasting models for adaptation among stakeholders, through the values, visions and sets of adaptation actions they proposed. By action, we mean "doing something that has physical or behavioural repercussions. Actions include purposefully changing practices and environments as well as implementing or changing regulations, policies, and institutions" (van Kerkhoff and Lebel 2006). Practices or actions can be legitimate or disqualified in different models (Plumecocq et al. 2018), depending on their compatibility with values (here the repertoires of values), rules (modes of regulation and organization, space and time horizons for actions) and knowledge (Gorddard et al. 2016; Plumecocq et al. 2018 — note that these authors followed the terminology by Boltanski and Thévenot (2006)).

Characterizing nature-based adaptation pathways

We propose that potential contributions of nature to people (NCP) become NCA through a co-production process mobilizing human-derived capitals. Therein, following Bruley et al. (2021), we situate steps of co-production (CP) along the cascade from ecosystems to contributions to people (Fedele et al. 2017) (Fig. 1). Ecosystem management actions (CP1) aim to modify ecosystem structure (including biodiversity) and functioning to increase supply potential of desired functions. In a rural landscape, they comprise nature conservation, agricultural and forestry practices, or watercourse hydro-ecological interventions. Physical mobilization of desired ecosystem functions (e.g. communication infrastructure, water storage and distribution networks) and its regulation (e.g. public-restricted protected areas) (CP2) are often necessary for supply potential to be converted to contributions to people. CP3 includes actions of socio-economic transformation, allocation, appropriation and commercialization (Spangenberg et al. 2014), for example through the food and timber sectors, water uses or tourism. To support these three co-production steps and their changes, activation through new capabilities and anthropogenic capitals (CP0) may be necessary. Contributing processes include changing legislation, land allocation, promotion of new economic activities, or social solidarity. Within CP0, actions aimed at modifying a governance institution, its stakeholders and its prerogatives (GOV) represent leverage points to transformation (Abson et al. 2017). Actions aiming to change societal demand for local NCP (Dd), by changing benefits' values (Fedele et al. 2017) or by integrating multiple nature's values (Pascual et al. 2017), include increasing stakeholders' knowledge of biodiversity or water consumption, changing diets, and farmer training.

Following this identification of actions for NCA co-production, the level of adjustment (Aj) or transformation (Tr) is characterized by depth (altering means and current practices vs. change of values and worldviews), scope (individual to system-wide) and persistence of change (linear trajectory vs. bifurcation) (Termeer et al. 2017; Fedele et al. 2019). Coping actions are reactive to climate impacts and maintain current socio-ecological structures and processes. Among them, we distinguish substitution (SUB) at varying steps of co-production of impacted NCP by resources from other socio-ecosystems or by anthropogenic processes; from protection (PRO), whereby grey infrastructure is built to counter the impacts of extreme events.

Roles in governance of different types of stakeholders

Decision contexts of managers and users, and how they perceive their roles in the management and governance of nature and its contributions to people (Felipe-Lucia et al. 2015; Vallet et al. 2019) shape their different adaptation responses (Gorddard et al. 2016). Considering impacts of climate change on nature and nature's contributions to people (NCP, Díaz et al., 2019) enables envisioning futures where decision contexts either persist or are reconfigured (Colloff et al. in revision; Stafford Smith et al. 2011; Chhetri et al. 2019).

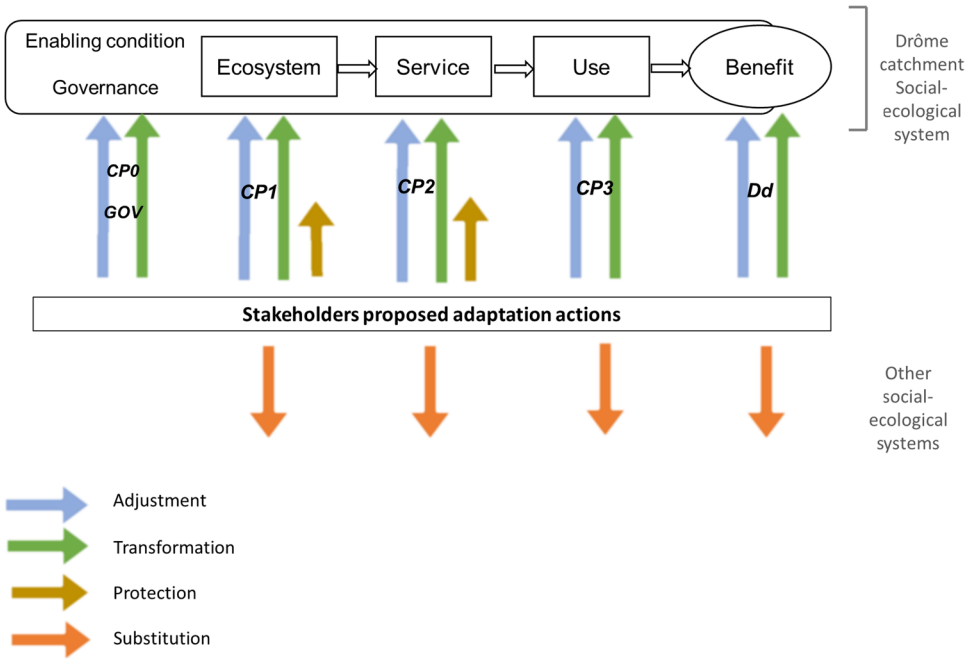

Fig. 1 Analytical framework for characterizing the co-production of Nature's Contributions to Adaptation. Coping (substitution and protection), transformative and adjustment actions are assigned along the Nature's contributions to people (NCP) co-production cascade, from co-production (CP) enabling conditions (CP0) and modifications of governance entities (GOV), ecosystem management (CP1), mobilization (CP2), allocation and appropriation (CP3) to benefits valued by society (Demand—Dd)

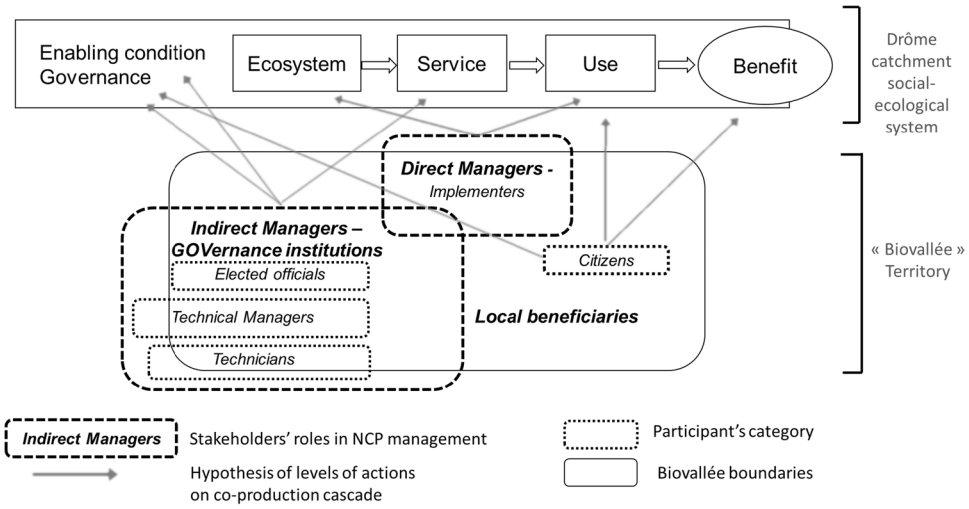

Fig. 2 Participants' categories according to their role in Nature's Contributions to People (NCP) management, and hypotheses about their levels of action in co-production cascade

We identified through our participative process, in the specific social-political context (Appendix 1) five roles in governance to which stakeholders are assigned (Fig. 2). We hypothesize that considering stakeholders' roles in NCP management and governance (Felipe-Lucia et al. 2015; Vallet et al. 2019) and their place in the co-production cascade (Sarkki 2017) is essential for understanding their choices of incremental vs. transformation pathways, and for analyzing differences between the actions they are currently implementing and their desired actions. *Implementers*, referred to as *appropriators* and *producers* by Ostrom (1990), *direct managers* by Vallet (2019), or *providers* by Barnaud et al. (2018) are professionals acting directly on ecosystems and simultaneously managing and benefiting from NCP. We hypothesize that they act on CP1 (ecosystem management) and CP3 (appropriation) through rules-in-use and technical knowledge. *Indirect managers*, also referred to as *intermediaries* (Barnaud et al. 2018), or *providers* (Ostrom 1990), manage rules-in-form, and thus act on CP0. They benefit little, but actively manage NCP, by providing support, rules and constraints to direct managers, in particular for access to NCP (CP2). Among indirect managers, studies of participatory processes (Wamsler et al. 2020) and of changes in public action (Bryson et al. 2014) highlight different roles along decision-making processes (Idt et al. 2012). *Elected officials*, including representatives of municipalities or farmers elected in the chamber of agriculture, make collective decisions, define projects and rules, and thus act on CP0. Support *technicians* in agriculture, forestry and river management support professionals and citizens and act as intermediaries with governance entities. Between elected officials and technicians, *technical managers* — heads of districts and state services — guide elected officials to implement projects, ensure that rules-in-form and appropriate procedures are followed and facilitate deliberation, thereby enhancing the effectiveness and accountability of institutions (Bryson et al. 2014). *Citizens* are other inhabitants benefiting from NCP, but who do not hold management, regulating or decision roles. We hypothesize they act on use (CP3) and demand (Dd); they support value changes by taking part in participatory processes and citizen associations, and their role as voters allows them to indirectly influence enabling conditions (CP0) and governance (GOV).

Methods

Study site

The Drôme catchment in southeastern France spans from the Jocou mountain (2051 m) in Diois to the confluence with Rhône River (88 m), ranging from an alpine climate in the North/East to a Mediterranean climate in the South/West. 56,000 inhabitants are distributed across three districts (Fig. 3; details in Appendix 1). The downstream area is strongly dependent on employment in the Valence conurbation, whereas the upstream area largely depends on tourism.

Forest covers 56% of the area, including legacy *Pinus nigra* stands from the nineteenth century state mountain restoration policy and extensive *Pinus sylvestris* colonisation on abandoned agricultural lands. The Drôme river and its groundwater are an irrigation resource downstream. It supports horticulture, cereal cropping and market gardening in lowlands, while lavender and other aromatic plants, livestock farming and viticulture dominate agriculture in uplands. Agriculture supports a significant share of employment but has been steadily declining (2012–2015: – 11% upstream, – 14% downstream; INSEE 2017).

Organic farming, based on social and technological innovation, is a significant component of agriculture (38% farms; RPG 2016), contributing to creating a territorial agrifood system. However, the organic sector is split across two

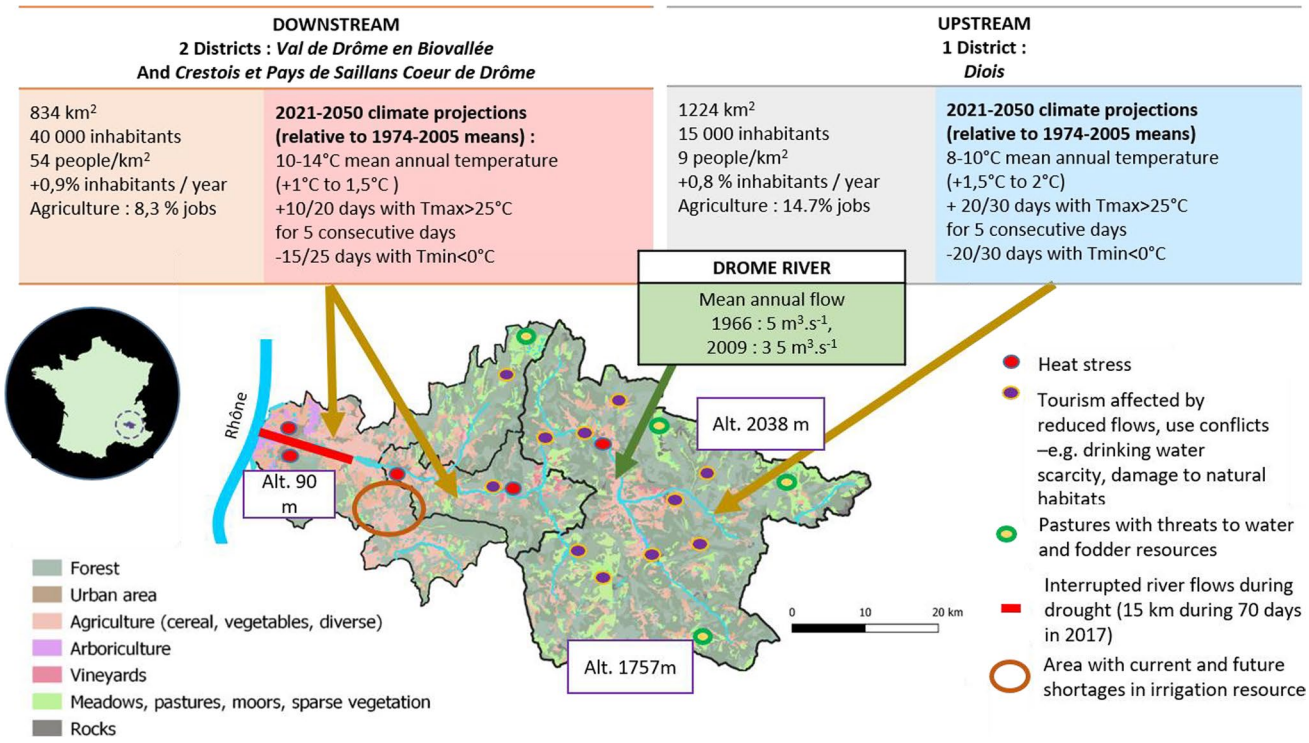

Fig. 3 Drôme Valley. Socio-demographic elements, climate projections and principal impacts devised by participants. (Corin Land Cover 2018; INSEE 2017, MeteoFrance 2018: RCP 8.5 downscaled climate projections to 2021–2050)

models: radical ecologization vs. ecological modernization within the productive regime, endorsed by conventional economic stakeholders (Ollivier et al. 2018).

Climate change is affecting the socio-ecosystem by increasingly frequent and longer droughts, increased average temperature and heat waves, reduced winter frost, snow cover and snow time, early springs and late frosts (Fig. 3, Meteo France 2018).

Research process and data collection

The study took place from April 2018 to March 2020 and was initiated by the researchers at the request of the Ministry for Environment, to co-produce "Biovallée" climate adaptation pathways. First exploratory interviews showed that land planning, agriculture, forestry, water, tourism, nature protection were indispensable elements of the local socio-ecosystem functioning. We thus constituted a steering committee in consultation with the local government (Drôme sous-préfecture) comprising seven members representing these sectors (see details in Appendix 1). At this time, the territory was involved in several climate, water, and land use planning processes, with diverse perimeters. Climate change was an important issue in each of these processes, but districts had quite different statutory competence to act directly on its impacts through current plans (see Appendix 1). Stakeholders therefore expressed interest in incorporating climate at least in their respective diagnoses and support information for deliberation. Consequently, we initiated collaborations with districts and the river syndicate to observe some meetings, to present the study (climate projections, reported impacts, local issues) and to co-facilitate some workshops (details in Appendix 1).

The research was structured in three phases, with 45 semi-structured interviews and 8 workshops, for a total of 177 participants. Our goal was to mix professionals (82%) and inhabitants (18%), people with (63%) and without (37%) expertise on local climate adaptation to foster dialog and diversify contributing knowledges and values. To obtain a large representation of expert knowledge, interests and visions for Drôme Valley climate adaptation pathways, we involved key sector representatives who did not attend workshops through complementary interviews (detailed research process in Appendix 1, and participants' sociology in Table 1).

We collected currently felt and anticipated impacts of climate change. Participants located projected changes on maps (Fig. 3) and listed current and desired adaptation actions to address impacts. Backcasting in visioning workshops consisted of: (1) participants' prioritization and debate about desired values for the territory in 2040, combining values from civic, domestic, economic-market, ethics, functional,

Table 1 Participants according to their categories, by gender, age, residence location and duration, and expertise

		Elected officials	Technical Managers	Technicians	Implementers	Citizens	*Total*
Participants	Number	*29*	*11*	*77*	*29*	*31*	*177*
	%	16	6	44	16	18	
Gender	F (%)	25	18	40	32	57	*37*
	M (%)	75	82	60	68	43	*63*
Age	20–29 (%)	0	0	4	7	7	*4*
	30–39 (%)	0	0	30	17	19	*19*
	40–49 (%)	25	18	38	28	15	*29*
	50–59 (%)	29	73	21	31	22	*28*
	60–69 (%)	32	9	5	14	33	*17*
	70–79 (%)	14	0	3	3	4	*3*
Residence	Downstream (%)	79	36	27	48	37	*41*
	Upstream (%)	14	18	11	45	63	*26*
	Whole/ext (%)	7	46	62	7	0	*33*
Residence *	< 10 years (%)	5	33	60	30	37	*33*
	> 10 years (%)	95	67	40	70	63	67
Expertise**	Forest (%)	0	18	16	14	6	*10*
	Agriculture (%)	28	9	43	69	3	*36*
	River (%)	3	36	9	0	3	*8*
	Tourism (%)	0	0	3	17	0	*5*
	Biodiversity (%)	3	0	8	0	6	*4*
	Non-specific (%)	66	37	21	0	82	*37*
Citations of actions (by co-productions mobilized and with redundancies)		132	68	315	115	162	*792*

Upstream (vs. Downstream) refers to citizens living in Diois or participants from institutions with a Diois (vs. Val de Drôme, Crestois and Saillans) jurisdiction. Whole/ext.: participants acting across the territory, vs. in a larger perimeter or in a neighbouring territory. * for 117 local stakeholders with known data. **for citizens, expertise is defined by a particular practice or skills with engagement in an association

technical-industrial, and fame frameworks (Heinich 2020; Boltanksi and Thévenot 2006), (2) collectively describing their visions — a desirable future state — for different themes and subsystems, comprising forest, water resources, nature protection, farming, tourism, local quality of life; (3) individually identifying actions needed for reaching these visions by 2040.

Data analysis

From all the utterances collected during the recording and transcription of interviews and the workshop recording, transcripts and productions (maps, tables), we extracted each impact and adaptation cited, which were the basic units coded for our analysis. We grouped similar suggestions into one class of impact and one unit of action but counted citations for each unit. We obtained 75 impact classes and 327 action units (Appendix 1). We related each action to climate impacts and NCP cited by stakeholders and qualified the associated type of co-production (Fig. 1; CP0, GOV, CP1, CP2, CP3, Dd — one action can mobilize multiple co-production type) and the degree of change (Aj for incremental or Tr for transformative action). For example, "changing farming practices using agro-meteorological information" was scored as CP1Aj, whereas "adopting agroforestry systems" was scored as CP1Tr.

We linked adaptation actions to the stakeholders who formulated them according to their role in NCP governance (Fig. 2). We then analysed sets of actions and associated preferences in co-production types according to stakeholder roles, to define the adaptation profiles associated with each of the five roles.

Prioritization and formulations of desired values for the territory, visions and actions were analysed using an inductive method to identify different visions and associated models, following the method for heuristic model construction and generic models proposed by Plumecocq et al. (2018). We consolidated statements into three qualitatively contrasted and internally consistent visions, characterizing each model according to its major strategy responding to

climate change, knowledge systems to develop, values and rules. Then, each cited action was scored according to its consistency, compatibility, or incompatibility with each of the three visions, and each vision was associated with a set of actions. Incompatibilities, oppositions and alternatives in proposed actions, like "maintaining current crops by irrigation" and "creating new water storages" vs. "giving up maladapted crops", were used to separate visions. Some actions were compatible with several visions, as in Plumecocq et al. (2018). For example, "use cover crops" was consistent with the three visions.

We then analysed using χ^2 tests differences in numbers of actions between each of the visions and current actions, and differences in numbers of actions among visions for level of change (adjustment vs. transformation) across co-production components, considered as the visions' adaptation profiles. Differences in adaptation profiles across NCP governance roles were also tested using χ^2 tests (R Core Team 2017). Lastly, a co-inertia analysis using R package *ade4* (Dray and Dufour 2007) tested for associations between governance roles and visions through their associated actions.

We presented the three visions and their profiles during five meetings (steering committee, district, agricultural technicians, river syndicate and citizen association). Participants' feedback and discussions contributed to fine-tune and check the validity, legitimacy and interest of the three visions.

Results

In the following, we first describe the raw data consisting of impacts on NCP mentioned by study participants along with ongoing or proposed actions to address them. We then present the visions produced by consolidating the adaptation actions and characterize them regarding their nature (protection, substitution, adjustment, transformation) and the elements of co-production they address. We end by describing how action profiles differed across NCP governance roles of their proponents.

Perceived impacts and adaptation actions in the Drôme Valley

On the basis of climate projections and expected ecological impacts, participants anticipated strong effects on the watershed and land uses, with an inversion of the catchment's attractiveness towards a more pleasant climate upstream, contrasting with heat stress in the towns and plains downstream (Fig. 3).

Overall impacts on material NCP were mostly cited (60%, Supplementary Information 2), and concerns about regulating NCP were significant (40%, Supplementary Information 2). Concern about ecological functioning was also significant in cited actions, with 12% of actions targeting restoration of ecological functions, nature conservation, forestry practices or river restoration for regulating NCP, and 54% targeting a combination of regulating and material contributions.

Agriculture was strongly prominent in discussions (27% impacts, 34% actions), reflecting the strong participation of agricultural experts (36%), and the interest from other stakeholders. Adaptations of farming practices (10% actions) were proposed to face water scarcity, enable the preservation of soils and biodiversity and sustain production. Beside these, participants debated relative merits of novel NCP from crop conversions (e.g. pistachio, almonds, legumes; 5% actions) vs. maintaining and adapting historical crops (3%). Common Agricultural Policy subsidies and agri-environment-climate measures were little mentioned (1%), due to a sense of inability to influence, although, when cited, they were recognized for enabling a wide variety of impacts. Dietary changes, local food systems and new forms of territorial governance for natural resources reached 3% citations.

Heat and heat waves were a highly cited impact (25% quotes), for their positive as well as negative repercussions on living conditions, health and land use conflicts. Although stakeholders were uncertain about the effects of increasing heat on physical experiences NCP and tourism demand, multiple actions were proposed to adapt urban planning (6%) and regulate tourism (10%).

Although water experts were only 8%, participants identified water scarcity as a major concern (34% impacts). They cited effects of seasonally interrupted river flows and droughts on agricultural production (food, feed and medicinal products), landscape aesthetics, summer aquatic activities and drinking water. These effects concentrated on downstream areas and some upstream valleys. Proposed actions focused mainly on the regulation of water demand (26% about irrigation and clean water, currently not aligning with abstraction targets set in 2013). The few actions for restoring the natural functioning of the river (2%) reflect the conflicting nature of the plans currently under discussion.

Climate change could foster both forest expansion and dieback. Concerns of citizens and forestry technicians focused on dieback from pests, and the induced erosion and flooding risks (10% impacts). River experts emphasized decreased river flows from forest expansion (1%). In spite of the objective risk (Dupire et al. 2019), fire received limited spontaneous mentions, due to fewer recent fires, partly attributed to fewer ignitions from pasture management than in adjacent territories. Proposed responses to these impacts favoured ecological processes of regeneration, planting adapted species and selection forestry (8% actions) and organization of wood energy and timber sectors (3% actions).

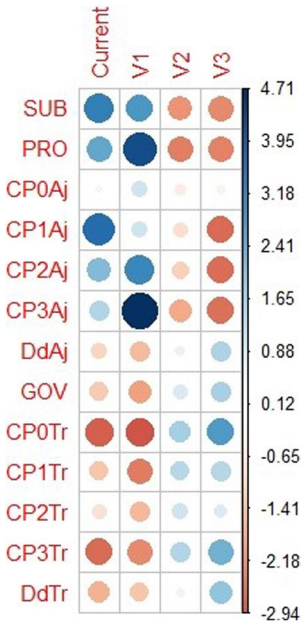

Fig. 4 Difference between current actions and the three visions by co-production type and level of transformation. 327 collected actions were qualified consistent with visions 1,2, and/or 3 (94 actions in V1, 218 actions for V2, 169 actions for V1). In each vision, actions are qualified in function of the co-productions they are activating (104 in V1, 249 in V2, 197 in V3). They are compared to the 111 current actions (128 CP). Pearson standardized residuals across current actions and the three visions for criteria of transformation and co-production as defined by the conceptual framework. Standardized residuals describe the difference between expected (if there was no pattern of association between visions and action types) and observed frequencies in contingency tables. The size of the dots represents the magnitude of residuals with blue dots for positive associations and red dots for negative associations

Lastly, biodiversity was a significant concern (7% impacts), which was addressed by nature protection actions (2%), and many actions around restricting access, urban revegetation and agroecological practices.

Overall many climate change impacts could feedback on identities supported by different components of the landscape. In particular, participants' discourses revealed values of a little appreciated "backdrop" forest, above all for estover benefits and for municipalities income from harvesting, and by very few for learning and inspiration. Forest novel and latent contributions to adaptation could change forest appreciation and concern. Conversely, the sense of place provided by the highly valued river for its beauty, qualified as 'the territory's spinal cord', is deeply changed by interrupted flows and tensions around economic and ecological issues from aquatic activities.

Current actions and the three visions

The analysis of the current response to climate change revealed an incremental trajectory with some coping elements. Overall the 111 actions (Supplementary Information 1 and Supplementary Information 2) are characterized by substitution (e.g. irrigation canal), protection (e.g. hail nets), incremental ecosystem management (e.g. agro-ecological practices, grazing practices) and adjustments in mobilization (mainly water reservoirs). Very few current actions address demand. Local stakeholders had different interpretations of the current climate response trajectory and of actions to implement. For example, some participants pictured the territory as proactive by anticipation since the 1990s, whereas environmental activists denounced maladaptation and procrastination, in particular in the reduction of water extraction targets.

The inductive analysis of discourses and actions therein identified three paradigmatic visions and associated models, which we labelled "sustainable development" (V1), "socio-ecological transition" (V2), and "ecosystem wealth and self-sufficiency" (V3), described in Supplementary Information 1. Their action profiles are presented in Fig. 4 and Supplementary Information 3, where they can be compared with current actions. Action profiles differed significantly across the three visions and from the current response ($\chi^2(36) = 221.6$; $p < 0.001$)).

Vision 1 (94 actions) described climate responses through market-oriented technological and organizational innovations, with sustainability conceived as an instrumental relationship with nature. This vision was supported by minority individual (but powerful) stakeholders. They challenged projected future water scarcity and argued for sufficient

hydrological flows and supporting storage. Vision 1 was close to current actions, with prominent protection (PRO) and substitution (SUB), like the canal from the Rhône River for irrigation. It aimed to preserve current NCP, current market values like profitability (Supplementary Information 1) and current farming systems and crops mainly through adjustment of agroecological practices, for example developing biocontrol, genetic engineering, and precision irrigation for specialized crops. Novel actions focused on adjusting mobilization (e.g. exploiting karstic groundwater) and changing appropriation (e.g. extending tourism for longer summers). Stakeholders requested support from climate services for adaptation to agro-meteorological changes and medium-term climate projections for assessing the viability of current uses. Governance was not questioned, nor was demand. This vision can be related to a mix of *biotech* and *circular* models (Plumecocq et al. 2018): biological input-based farming, embedded in globalized food systems and a local circular economy for biological inputs and selling byproducts or organic matter.

Vision 2 (218 actions) proposed strong territorial and inter-territorial regulation to organize a social-ecological transition, combining increased ecosystem services and multifunctional landscape management to preserve natural capital and local social and economic viability as common goods. It relates to *integrated-landscape* models (Plumecocq et al. 2018), with a large panel of biodiversity-based farming systems, capacity to manage individual and collective levels, to analyse trade-offs and associated compromises, where nature is understood as a living system, recognized for intrinsic and productive values. It envisions gradual change, building on past successes. Actions aimed to maintain and adapt existing, valued and locally anchored tourism and agriculture, and to safeguard endangered forests and rivers. They targeted incremental and transformative ecosystem management (CP1Aj and CP1Tr) and the implementation of novel rules and social organization (CP0Tr), with new or adapted institutions to deliberate between multiple values and uses, on what constitutes the common good (GOV), along with changing lifestyles and consumption patterns (DdTr). This vision supported quantitative and qualitative knowledge systems for reinforcing institutions' capacity to assess public and private actions' social and environmental sustainability, like assessing tourism environmental impacts, monitoring river temperature and flows, or experimental agroecological research.

Vision 3 (169 actions) related to a biocentric view focusing on the work of nature and ecosystem wealth, and on local autonomy for farming practices and product distribution. It resembled Vision 2 in its co-production profile, but with fewer actions overall, a higher share of transformative actions and a very low share of adjustment actions. In response to an expected systemic collapse, it proposed a radical reconfiguration of the economic model prioritizing environmental vs. economic values. Key components included a local food-energy integrated system, local solidarity, renouncing certain economic activities (reducing tourism, second homes, emblematic sectors like viticulture, water-demanding maize) and strong natural areas protection. It combines the *relocalized* and *diversified* models, based on stringent biodiversity-based farming systems (Plumecocq et al. 2018) where new norms appear around "good" practices ("good" state of the field and acceptable level of production), new social forms, peer groups and community knowledge exchanges.

Action profiles according to Nature's contributions to people governance roles

Adaptation profiles (Supplementary Information 4) compare co-production actions according to the place and skills of study participants in NCP governance (Fig. 2). First, 30% of proposed actions targeted ecosystem management, and especially transformative management, even for indirect managers without relevant skills, suggesting a major public concern and lever for adaptation. Secondly, the large share of activating actions and governance (CP0 + GOV, 27%), and especially of transformative activation, across participant roles shows that social, legal and political re-organization is a common priority. Mobilization (18%) and appropriation (16%) were less represented, while very few actions targeted demand (6%). Thirdly, all participants favoured transformative rather than adjusting activation and ecosystem management and shared a very limited focus on substitution and protection (Fig. 5, Supplementary Information 5). As such, all adaptation profiles aligned most with visions 2 and 3, and to an extent with current actions (Supplementary Information 6).

Nevertheless, as we hypothesized when conceptualizing the role of co-production in adaptation (Fig. 1), detailed profiles differed significantly across the five groups ($\chi^2(48) = 66.1$; $p = 0.0425$) and were congruent with stakeholders' roles in NCP governance. Adjustment in ecosystem management and mobilization were most distinctive across governance roles and visions (Fig. 5). For example, differing suggestions for water mobilization revealed incompatibilities and conflicted values about protecting resources vs. mobilization and storage; opponents considered the latter as supporting continued productivism and high resource extraction. In the following, we detail key differences across roles.

Technicians had the most distinctive profile, with the greatest balance between adjustment and transformation. They favoured coping and adjustment interventions (PRO, e.g. hail nets; CP1Aj, e.g. cover crops), along with promoting ecological sustainability and transforming ecosystem management (e.g. agroecology, abandoning water-intensive crops, river restoration),

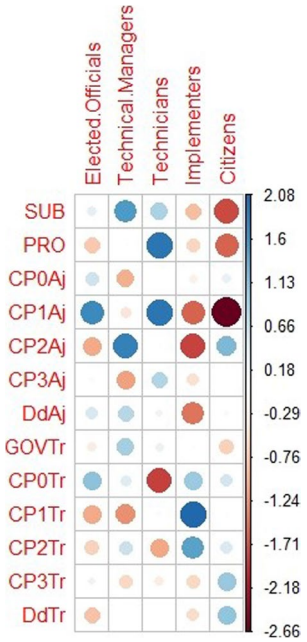

Fig. 5 Difference between adaptation profiles of stakeholder categories by co-production (CP) type and level of transformation. An action is taken into account as many times as it has been cited. Some actions involved more than one CP and were qualified as such. As a result, we collected 677 citations of actions, which represent 792 CP mobilized. Pearson standardized residuals across Nature's Contributions to People governance roles for criteria of transformation and co-production as defined by the conceptual framework. Standardized residuals describe the difference between expected (if there was no pattern of association between actor groups and actions) and observed frequencies in contingency tables. The size of the dots represents the magnitude of residuals with blue dots for positive associations and red dots for negative associations

mobilization (e.g. forest understory grazing) and appropriation (e.g. prohibiting leisure activities for protected habitats).

Their profile contrasted most with that of citizens and implementers which, in line with V3, strongly favoured more transformation of either CP1 and CP2 (implementers), or CP3 and demand (citizens). Citizens and implementers rejected substitution and adjustments for their risks of maladaptation or for transferring vulnerabilities to neighbouring territories. This result is best understood knowing that participating citizens mostly belonged to "transition" associations or alternative election lists, and that participating farmers mostly represented the "radical ecologization" model. As hypothesized, implementers were most proactive for ecosystem management (e.g. new crops, farm and forestry systems). They also favoured transformative activation (revising water sharing rules, public control of crop choices) and mobilization (e.g. wilderness reserves, re-opening encroached pastures). Citizens favoured actions on demand (e.g. progressive water pricing and reduction of consumption) and appropriation (e.g. local food chains; sustained by CP0Tr actions like land allocation for food autonomy), reflecting their agency through consumption choices. Conversely, they proposed fewer changes in the composition of governance entities than other groups.

Elected officials who, consistent with their governance role, favoured rules-in-form and organization (CP0) had an intermediate adaptation profile. They preferred adjusting activation (e.g. urban development in cooler areas) and ecosystem management. These preferences matched their priorities for economic profitability, population increase (consistent with V1). Consistent with V2, they also favoured transformation with strengthened urban planning to preserve NCP, public control of crop choices and stronger territorial forest governance. They shared with citizens and V3 suggestions for transforming value chains.

Lastly, technical managers had a relatively distinct profile, though careful inference is warranted given they represented only 68 actions from 11 participants, of which 4 river managers. They prioritized substitution, incremental mobilization and governance actions. These aligned with their roles in guiding public projects including infrastructures for resource mobilization, and of shaping rules-in-form. They shared with V1 preferences for complementing substitution (e.g. canal from the Rhône) by adjusting water mobilization (reservoirs, reducing leakage in water supply networks). Consistent with V2, they favoured some transformative activation and mobilization (e.g. nature protection, regulating individual bores, no-urbanization rules, agri-food territorial planning), and ecosystem management (e.g. climate-adapted forest plantings). They also promoted reforms of water and forest governance entities.

Discussion

Challenges and opportunities for transformation in an innovative territory

Participatory adaptation pathways often produce a majority of incremental options emphasizing flexibility and low-risk strategies within existing production systems, while establishing a basis for future potentially transformational actions (Cradock-Henry et al. 2020). In contrast in the Drôme watershed, participants proposed a majority of transformative actions. This reflects a combination of favourable preconditions: global increasing public climate awareness, an innovative territory (Girard 2012; Ollivier et al. 2018), self-selection of participants sensitive to climate change and transformation and local leaders who promote participation for shaping major social and environmental changes (Kates et al. 2012). Also several extreme events (droughts, heat waves, late frosts, snow storms, spring rains, forest dieback) were experienced in the Drôme Valley in 2018–2019. Sharing feelings about such events and multiple stresses are important in initiating transformative adaptation (Kates et al. 2012).

At the same time, the strong contrast between current actions and participants' strong support for transformation reflected in visions 2 and 3 (Fig. 4, Fig. 5) reveals the difficulty of implementing a transition. Visions combined adjustment and transformation actions, confirming that "intentional transformative adaptation" involves a sequential combination of incremental and radical adaptation (Colloff et al. 2020, Colloff et al. in revision): overall many participants supported continuous transformative change (Termeer et al. 2017). Climate change challenges stakeholders' assertions portraying Drôme Valley as an innovative "green" trajectory. Incremental increases in organic agriculture will not sufficiently address climate change (Feola 2015; Vermeulen et al. 2018).

Such a typology of contrasted visions and models is useful as long as these are acknowledged as archetypes of real co-existing and co-evolving systems in a same territory (Plumecocq et al. 2018). This is particularly true in Drôme Valley, where historical dynamics of organic farming has lead neither to the success of one model, nor to a hybrid model, but to reinforce and legitimate both the radical ecologization and ecological modernization paradigms (Ollivier et al. 2018). Our method highlighted actions and modes of organization, which lock into a given model or conversely bridge between them. (Dis)qualification mechanisms participate to internal dynamics of each model and can lead to its inflection towards a more or less radical transition.

Some incompatible practices between visions constitute bifurcations across pathways. As such, the contrast between actions for sustaining water supply in vision 1 and actions for changing water demand in visions 2 and 3 is representative of other French (Allain et al. 2018) and Global North regions (Abel et al. 2016; Frantzeskaki et al. 2019; Haasnoot et al. 2013). Vision 2 favours balanced human-nature relationships, whereas vision 3 favours ecological priorities through wilderness conservation, accepting to sacrifice the agropastoral heritage and its multiple NCP benefits (Klein et al. 2019). Visions 2 and 3 are also shaped by debates on territorial embeddedness and what "local" and autonomy mean (interdependencies vs. self-sufficiencies) for natural resources and value chains (Madelrieux et al. 2018). Without clear choice between these values and options, future projects could turn to weak stuck-in-the-middle strategies (Pertusa-Ortega et al. 2009).

Conversely, given actions match several visions, allowing "bridges" or compromises (Thévenot 1996) between models. Internal dynamics of requalification in one model can lead to its hybridization (Plumecocq et al. 2018). For example, water-smart crop diversification aligns with the three visions, though motivated by different values within each of them: vision 1 aims to reduce uncertainty and costs for farmers, vision 2 to regulate water abstraction, vision 3 to reduce water abstraction to favour local food system and develop biodiversity-based farming. This way, radical innovation can enhance sustainability of more established models (Plumecocq et al. 2018). Moreover, organizing a "local compatibility", i.e. an arrangement addressing a plurality of values (Thévenot 1996), into a hybrid strategy combining dimensions like profitability, territorial embeddedness, biodiversity-based farming, could be more effective than a "pure" strategy (Pertusa-Ortega et al. 2009). In that sense, Plumecocq et al. (2018) consider these as "a mode of transition that does not relate to intensity, as the distinction between incremental and radical change, but rather to a change in the nature of transition".

Hence, our participatory process allowed stakeholders supporting different visions to deliberate, thereby broadening understanding between stakeholders and creating options and compromises (Callon et al. 2011), as with conditionality for creating water storage. The visioning process mapped out the diversity of positions, enabling more informed negotiations (van Kerkhoff and Lebel 2006). This supported recognition of changes, reflexivity about practices and responses by re-framing stakeholders' aims, knowledge, values and practices (Schneider and Rist 2014; Dryzek and Pickering 2018).

Revealing Nature's Contributions to Adaptation

Nature's Contributions to Adaptation are co-produced by people through their actions on ecosystem management, mobilization of ecological functions and valuation and

appropriation of benefits (Lavorel et al. 2020). Our analyses showed a diversity of NCAs in the Drôme Valley for which we identified successive and interacting co-production mechanisms (Fedele et al. 2017; Lavorel et al. 2020). In the following, we highlight key original aspects of such NCAs and their co-production dynamics.

First, participants recognized the role of a diverse landscape for resilience of current NCP and transformation of ecosystems for supporting novel material and non-material NCP (Lavorel et al. 2015, 2020). Stakeholders emphasized the need to strengthen landscape heterogeneity and ecological connectivity, for example with agroforestry or climate-adapted plantings. Such landscape-integrated solutions for climate change adaptation are recognized as essential for nature and people (Kremen and Merenlender 2018).

Secondly, participants identified multiple novel NCA and values for latent regulating NCP. For example, historical concerns for swimming water quality (Girard 2012) shifted to valuing drinking water. The climate regulation, biodiversity habitat, energy and timber potentials of diversifying forest were expected to replace low appreciation of current monospecific stands given their low economic and biodiversity values. Multiple benefits were expected from preserving and extending crop and pastoral lands. As such the Drôme Valley illustrates how climate adaptation can be an opportunity for promoting multifunctionality (as demonstrated by the diverse NCP network portrayed in Supplementary Information 2) and for reshaping current structures and values (Lomba et al. 2020; Lavorel et al. 2020). In particular, proposed actions towards novel NCAs in multifunctional landscapes are likely to foster transformation ability and to limit trade-offs associated with specialized management (Lavorel et al. 2020).

Thirdly, our results support the novel value of analyzing adaptation actions across the co-production chain for revealing co-benefits and feedbacks from different co-production components to natural capital and co-production steps (Fedele et al. 2017; Lavorel et al. 2020). Awareness of these interrelations varied across actor groups, as shown by differences in adaptation profiles across governance roles and confirmed through complementary interviews.

In V1, adjustive ecosystem management aimed to reduce impacts on natural capital from actions increasing natural resource use. Appropriation actions revealed resistance to change and preferences for coping and maintaining current ecosystem management, economic organization and social values including in demand. Such objectives are typical of maladaptive pathways that ignore long-term risks to natural capital (Seddon et al. 2020).

In contrast, transformative actions of ecological farming and forestry and of proactive nature protection (V2 and V3) imply a holistic and multifunctional approach to ecosystem functioning. This is combined with transformed appropriation and demand, with multiple co-benefits for regulating NCP (Supplementary Information 2). Moreover, establishment of markets and infrastructure for novel products develop anthropogenic capital for further transformation of ecosystem management and NCP mobilization (Lavorel et al. 2020). Such transformations were less cited, possibly reflecting (beyond the limited number of processing and commercialization professionals among participating implementers), a perceived inability to influence or disjointed knowledge between participants at the end of the value chain or those managing ecosystems. Analyzing possible feedbacks from demand and CP3 to other co-production steps enables understanding adaptive capacity. For example, the limited path-dependency for the wood provision NCP with a currently weak value chain is compatible with alternative visions focusing on woodland utility or conservation values (Burton et al. 2019). In agriculture, the development of local sales was highlighted as supporting diversification and crop changes, empowering consumers to overcome the traditional dependency among stakeholders of different co-production steps (Vallet et al. 2019). Possible negative feedbacks from increasing tourism to the condition of natural habitats were counterbalanced by the desire to be identified as a family, popular and nature-oriented destination. As in many other regions, climate change challenges visions for tourism, given its potential negative impacts on NCP (Klein et al. 2019).

How roles in Nature's Contributions to People governance shape adaptation profiles

Nature's Contributions to Adaptation are shaped by decision contexts and their enabling sets of values, rules and knowledge (Colloff et al. 2017, Colloff et al. 2020). As a result, we expected participants with different roles in NCP governance to produce different co-production profiles (Fig. 2). Results confirmed this hypothesis even if there were strongly shared visions for transformative ecosystem management and social, legal and political re-organization.

Prevalent actions targeted implementers' ecosystem management practices. Pathways to transformation combined multiple local practices by individual implementers and scaled them out to landscape level (Vos et al. 2018). By knowing their mutual interdependence for supporting coordinated actions at landscape level, implementers can thus create mutually beneficial solutions. Interestingly stakeholders differed in their views on levers to achieve this according to their governance roles and associated leverages on NCP co-production (Barnaud et al. 2018; Vallet et al. 2019). Transformative implementers highlighted their dependence on rules-in-form and coordination (CP0Tr). Technicians favoured combinations of adjustment and transformative management actions based on their knowledge about implementers' practices and of indirect managers' constraints. As

such they acted as intermediaries between rules-in-form and rules-in-use. In contrast, technical managers favoured combining adjustment and transformative mobilization in the short term with longer-term governance changes (e.g. for irrigating water allocation) (Pahl-Wostl et al. 2020). These differences between actor groups may reflect internal debates on means to manage NCP for adapting to climate change, as well as deeper values.

Limited ambitions among elected officials and technical managers for transformative management and appropriation, probably reflects short-term feasibility, questioning capacity to influence individual practices (e.g. irrigation and drinking water, crop choices, product processing, Allain et al. 2018)). Many elected officials and technical managers highlighted that their policy instruments were limited to feedbacks from activation (e.g. green practice designation, environmental legal obligations and subsidies) and mobilization (e.g. total withdrawal volume) to natural capital (as, for example, in Vallet et al. 2019). They felt the need for a novel integrated and effective polycentric governance (Pahl-Wostl et al. 2020), whereby integrating capacity to influence management and appropriation could avoid the "specialization trap" (Cumming 2018) and conflicting sectoral plans. Indeed, technical managers criticized silos between governance bodies; participating elected officials felt cognitive dissonances and contradictions. Cross-sectoral governance would address such limitations (Pahl-Wostl et al. 2020).

Participants suggested that coordination and re-structuring of governance and new environmental stewardship could achieve such articulation between rules to preserve/mobilize ecosystem resources, changing individual ecosystem management, well-being and socio-economic values (Abson et al. 2017; Bennett et al. 2018). These included incentives, conditionality, collective projects, increasing capacities for collective exchange of knowledge, practices and co-governance by multi-stakeholder entities (van Kerkhoff and Pilbeam 2017; Vos et al. 2018). In particular, citizens, by their desire to influence all co-production stages intended to fully integrate their roles as consumers and civil society members, with that of institutions, in the design and implementation of climate adaptation actions (Hegger et al. 2017; Wamsler et al. 2020). Such co-governance needs to be integrated at catchment scale, integrating various upstream and downstream issues, like tourism and agriculture (Rathwell and Peterson 2012), or food, energy and water (Pahl-Wostl et al. 2020). Climate change offers a new opportunity and legitimation for historical (Girard 2012; Ollivier et al. 2018) and current intents to construct a consistent perimeter of political action (unifying the three districts of the Drôme Valley) for achieving such integration, as in other French regions (Therville et al. 2019).

Conclusion

We identified with diverse stakeholders of the Drôme Valley climate change impacts on Nature's Contributions to People, and how nature can support adaptation to mitigate them. We showed how stakeholders imagined such Nature's Contributions to Adaptation and their implementation for reaching three future visions for the socio-ecosystem according to their roles in NCP governance. By using the NCP co-production framework, we were able to characterize each vision in terms of level of adjustment vs. transformation in ecosystem management, mobilization of ecosystem properties and functions and appropriation, and associated changes in activation and governance. In particular, we showed that participants largely rejected the *sustainable development* vision, which largely extends current actions of protection, substitution and incremental changes across co-production steps and perpetuates current governance or demand and their associated values. Rather, they suggested varying combinations of incremental and transformational change for reaching the *socio-ecological transition*, and *transformation in search of self-sufficiency* visions through combinations of interventions along the co-production cascade that reflected their governance roles, their values and their perceived agency. Overall, analyses showed how climate adaptation can be an opportunity for promoting multifunctionality through integrated landscape management and for reshaping current structures, institutions and values. The complementarity across stakeholders in leverage points identified along the co-production cascade strongly supports participatory and polycentric governance processes for reaching these goals. Negotiation among power groups and resources will undoubtedly constrain forthcoming implementation of stakeholders' visions for nature-based adaptation. Nevertheless, ideas and learnings from this exemplary territory are expected to be transferable to similar regions in European mountains and beyond, using the co-production framework for structuring analyses of Nature's Contributions to Adaptation.

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