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SPECIAL FEATURE: ORIGINAL ARTICLE

Valuation of Nature and Nature's Contributions to People

Memory over matter?—a conceptual framework to integrate social–ecological l legacies in agricultural NCP co-production

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Abstract

To better account for how social–ecological legacies of social and ecological systems jointly shape the current composition, the quality and quantity of nature's contribution to people (NCPs), we integrate the concept of NCP co-production into social–ecological system thinking. Our expanded framework highlights how NCP co-production is frequently entangled within its social–ecological context, such as legacies, current resources and social activities. Additionally, we underline the relevance of non-material and material dimensions of resources in NCP co-production. To illustrate the potential of this expanded framework, we explore its application to an agricultural system of the French Northern Alps. We conclude that this framework (1) facilitates the understanding of society–ecosystem interactions in a specific regional social–ecological context; (2) helps to better conceptualise the interdependencies between resources and social activities; (3) demonstrates how current rule sets to organise social–ecological legacies affect the entire NCP co-production chain. The framework's further implementation requires more research to better understand the complex interlinkages between the social and the ecological subsystems that underpin socioeconomic activities.

Keywords Social–ecological legacies · Nature's contributions to people (NCP) · Social–ecological systems · Co-production

Introduction

Societies and surrounding ecosystems have co-evolved over a long period in their various interdependent material and non-material aspects. To support pathways to sustainability, there is a critical need to understand how this interplay of resources and social dynamics underpins current socioeconomic activities in their specific social–ecological context (Ostrom 2009; Meyfroidt et al. 2018; Mastrángelo et al. 2019). To explain these dynamic interrelationships, we use the multidimensional concept of "co-production" of "nature's contributions to people" (NCP). Broadly defined, NCP encompass "all contributions, beneficial or harmful, that individuals, communities, societies, nations or humanity as a whole derive from nature" (Díaz et al. 2018). Expanding on the ecosystem service concept, the NCP concept explicitly acknowledges that flows from nature can have not only different qualities (material, non-material and regulating), but also offer different aspects of appreciation to people (MEA 2005; Díaz et al. 2018; Pascual et al. 2021 Mar 25). In addition, the NCP approach acknowledges that the material and non-material categories are fluid, thus, e.g. a material

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NCP such as milk can also have a non-material aspect such as the maintenance of identities (Díaz et al. 2015). The co-production concept as applied to NCP describes how people use different resources in diverse ways to generate with ecological systems outcomes that people consider as meaningful (Barnaud et al. 2018; Muhar et al. 2018). Palomo et al. (2016) and Jones et al. (2016) initiated the formalisation of NCP co-production (CP); they defined NCP co-production as the process by which societies and individuals organise and manage resources to mobilise material and non-material flows from nature to contributions to people's good quality of life. The hyphen in 'co-production' stresses that these social activities for the production of NCP can vary to different extents (Palomo et al. 2016). For example, some NCP can benefit society without social intervention, such as some regulating NCP such as soil erosion reduction, regulation of hydrological flows and nutrient cycling. However material NCP (e.g. food production) require in most cases some minimum human intervention (Bruley et al. 2021a).

Research has yet to fully integrate NCP co-production in its social–ecological context. This means considering the diverse surrounding material and non-material resources and the associated social activities (Díaz et al. 2015). Research that has targeted the society–ecosystem interface has often analysed NCP co-production using a capital-based approach (Guerry et al. 2015; Jones et al. 2016). This approach distinguishes between social capital and manufactured capital, but neglects that non-material and material resources are mutually dependent (Chaigneau et al. 2019). For example, a material resource, such as a farm or other physical infrastructure, can also be the carrier of non-material aspects such as knowledge, habits or the feeling of belonging for different people (Winner 1980).The integration of social activities can facilitate understanding these multiple dimensions. As an example, co-production was used to evaluate the impact of varying degrees of human input (technology, infrastructure, etc.) in different Portuguese small-scale fisheries on one material NCP (Outeiro et al. 2017). In the French Alps, research suggests that material NCP require potentially more human intervention than non-material or regulating NCP (Bruley et al. 2021a). (Fedele et al. 2017) applied the concept of co-production along the different mechanisms of the ecosystem service cascade framework (Haines-Young and Potschin 2010). What unites these various approaches is the explicit or implicit acknowledgement of non-material aspects such as traditional knowledge (Outeiro et al. 2017), identities (Fischer and Eastwood 2016), shared values (Bruley et al. 2021a), value articulation (Ernstson 2013) or other cognitive dimensions (Palomo et al. 2016) to co-produce NCP. A systematic interpretation of co-production that accounts how societies apply these non-material and material dimensions in NCP co-production has yet to come (Bennett et al. 2015; Mastrángelo et al. 2019). We assert that the perspective of regional coupled social–ecological systems (SES) provides a means to contextualise and explain NCP co-production (Reyers et al. 2013).

The SES approach considers social (e.g. institutions) and ecological (ecosystems) factors as deeply interlinked (Berkes et al. 2000; McGinnis and Ostrom 2014; Colding and Barthel 2019). They are composed of multiple subsystems with overlapping processes (such as farms, municipalities or pasture land) that interact across scales (Folke 2006; Ostrom 2009). From a spatial and organisational perspective, they are nested in or are linked to other political, socioeconomic, technological, cultural and biophysical structures (Folke 2006; Plieninger et al. 2015). The drawing of system boundaries can be challenging (Walker et al. 2002). Frequently, research designs them based on political or administrative units (Dearing et al. 2014; Hanspach et al. 2016), biophysical measures (Martín-López et al. 2017), institutional management divisions (Ostrom 2009), or broad concepts such as resilience (Alessa et al. 2009). Social–ecological system studies often do not appropriately address the definition of system boundaries (Colding and Barthel 2019).

SES are embedded in social–ecological legacies that continue to influence current types and forms of NCP co-production. These social and ecological memories are the result of numerous interactions between and within social and ecological processes for centuries to millennia (Cook et al. 2012). We consider social–ecological legacies as resources that contain social and ecological elements that co-evolved in time and space, resulting in integrated entities. These can be places like alpine pastures (Quétier et al. 2010; Egarter Vigl et al. 2016), cultural landscapes (Tengberg et al. 2012; Plieninger et al. 2015) or resources for management, such as local livestock breeds (Vilá and Arzamendia 2020 Oct 26) or agricultural knowledge (Berkes et al. 2000; Kim et al. 2017). Legacy effects of past society–ecosystem interactions such as modified ecosystems, altered ecosystem functions or social path dependencies have shaped and will continue to shape the type and modes of NCP co-production (Renard et al. 2015; Wu et al. 2020; Bruley et al. 2021b). Current resources may become legacies if their material or non-material forms and functions continue to influence future processes (Foster et al. 2003). For example, pasture fertility is a current material, ecological resource supporting fodder production, which will carry over to future soil nutrient status due to slow biogeochemical dynamics (Spiegelberger et al. 2006; Quétier et al. 2007). The same holds true for social resources such as cultural specificities or attachments to places that can transform into common value sets, institutional settings and routinised behaviour (Upton 2008). Non-material dimensions such as knowledge (Hernández-Morcillo et al. 2014) or collective identities (Pachoud 2019) depend on the type of social activities. They are frequently linked to visible social–ecological legacies such genetic diversity (Essl et al. 2015) and regional cultural landscapes (Oppermann et al. 2012; Plieninger et al. 2015). Policies related to agricultural land use have recognised these historically evolved co-production processes in more or less explicit ways. A notable example in Europe is the classification of farmland as High Nature Value (HNV) (Feranec et al. 2016) or regulations for protected areas that require sustained human intervention (Europarc 2018). The European food quality label "Protected Designation of Origin" (PDO) promotes distinct regional agricultural products and can be regarded as an attempt to preserve social–ecological legacies through economic mechanisms (Quiñones Ruiz et al. 2018). Still, the role of social–ecological legacies for NCP co-production remains underexplored in conceptual and empirical research (Herrero-Jáuregui et al. 2018; Mastrángelo et al. 2019). To fill this knowledge gap, we propose a conceptual framework that links NCP co-production to the SES approach. This allows us to effectively integrate social–ecological legacies and more robustly distinguish between social (infrastructure, knowledge, etc.) and ecological (biomass, livestock, etc.) resources (Anderies et al. 2004; McGinnis 2011).

The rest of the paper is organised as follows: first, we present an expanded SES framework to fully account for the role of social–ecological legacies and social activities in the NCP co-production. In particular, we discuss the challenges regarding the delineation of system boundaries within these frameworks between the organisational (social, ecological), temporal (legacies, current resources) and spatial (biophysical, economic) dimensions. In the subsequent section, we apply this framework to a regional SES. In Europe, agricultural mountain production systems rely on social–ecological legacies to ensure the maintenance of regional rural economies. The integration of social–ecological legacies and interlinked social activities can explain varying transformation strategies of the same products (Madelrieux et al. 2018) or entirely different agricultural production systems in adjacent regions with similar physical endowments (Bruley et al. 2021b). It allows us to show how different trajectories are based on the previous experiences of a system and how they are linked to different appreciations and values of NCP co-production. Specifically, we illustrate the applicability of our framework for a regional mountain SES and its cheese production.

An expanded SES Framework for NCP co-production in agricultural systems

We present a framework to embed NCP co-production in its social–ecological context. We defined the social–ecological context as social–ecological legacies, current resources and social activities. We separated the social from the ecological subsystem (Fig. 1, boxes) following previous epistemological and analytical considerations on NCP co-production (Díaz et al. 2015; Palomo et al. 2016; Bruley et al. 2021a) and the current IPBES framework (Díaz et al. 2015). We decided on this delineation because social activities are widely considered as dominant drivers of change in SES (Folke 2006; Kofinas and Chapin 2009; Spangenberg et al. 2014). Further, the two systems exhibit their own processes that can (1) act independently (Anderies et al. 2004; Colding and Barthel 2019), (2) have different rates of change, (Ostrom 2000; Foster et al. 2003; Walker et al. 2006) and (3) imply different understandings of scale (Winkler et al. 2021 Mar 16). We link these two subsystems with four subsequent steps (Fig. 1, black arrows) that describe social activities.

We used an economic delineation of the boundaries based on material NCP, which are frequently agricultural or forestry products. This permits the identification of social activities and their actors. It allows for the possible modifications of social activities for future adaptation. More broadly, agricultural activities frequently present an "umbrella" for other non-monetarised NCP (such as pest control, pollination) (Lescourret et al. 2015). However, economic boundaries are more diffuse than biophysical boundaries and not spatially explicit. Our top-down approach is in contrast to other (bottom-up) NCP studies based on biophysical boundaries that subsequently identify NCP in a given spatial area (Reyers et al. 2013). Economic boundaries are non-spatial, and actors involved in different NCP may share the same resources (Eakin et al. 2017). In the context of an Alpine region, for example, tourism shares the same pastureland as the agricultural system, but each of these socioeconomic activities represents different, yet linked, types of NCP co-production. To accentuate social activities interacting with their surrounding ecosystem, we limit this framework to the regional scale. To consider demand (see Fig. 1, white box), we integrate monetary flows (such as subsidies, tourist spending, etc.) that can influence the resource use in NCP co-production (Carrasco et al. 2017). For example, increased profits may lead to increased technology use (e.g. investments in new time saving machinery that leads to increases in farm size). Non-monetary, exogenous factors such as climate change (e.g. droughts), water pollution, higher-scale governance decisions or the externalised production of energy intensive products highlight the porosity of these human boundary constructs (Martín-López et al. 2017). Lastly, we assume there are unidentified flows (Fig. 1, grey arrows) between the social and the ecological system that cannot be analysed with our conceptual framework.

Social–ecological legacies and current resources

Disentangling social–ecological legacies (landscape, livestock breeds, farm infrastructure, etc.) into social and ecological components is complex and often not straightforward

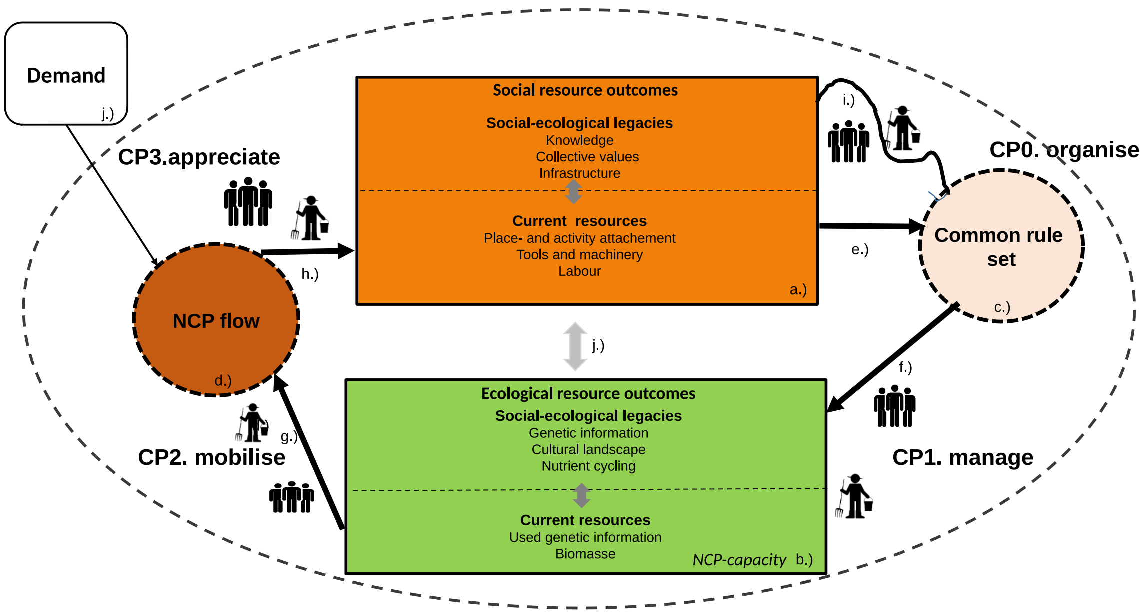

Fig. 1 Social (**a**, orange box) and ecological system (**b**, green box) as two subsystems along with their associated social–ecological legacies and current resources. The dashed lines within the two subsystems show the porous boundaries between legacies and current resources. The terms NCP capacity (ecological system) and NCP flow refer to the cascade framework (Haines-Young and Potschin 2010). The two circles (**c**, **d**) describe the intermediate steps of NCP co-production. The different positions of the common rule set (**c**) and NCP flow (**j**) indicate that the steps of co-production can happen at different points of time. External demand (**i**, white box) affects NCP flow. The four straight arrows (**e**–**h**) mark the social activities that link the successive steps of NCP co-production. We illustrate the organisation of the resource system with the crooked arrow (**i**), to underline the negotiation process between diverging interests. The text in the boxes is illustrative. The grey arrows (**j**) between the social and the ecological subsystems emphasise there can be unnoticed flows between them. We emphasize the circularity and the interdepencies of the four steps of co-production

(Remme et al. 2014; Jones et al. 2016). Based on Remme et al. (2014), we assign social–ecological legacies to the ecological or the social subsystem by identifying those for which ecological processes play a significant role. This allocation also acknowledges that current ecological processes cannot be substituted by technological or social innovations (Edens and Hein 2013). We incorporated this consideration into our framework. For example, we consider farm infrastructure as a social–ecological legacy in the social subsystem, which contains ecological resources (timber) previously mobilised by human intervention. Biomass is an ecological resource and if not extracted will become a social–ecological legacy (potentially leading to an increase in soil carbon) in the ecological subsystem. We easily identify these boundaries for common material resources (milk, biomass, etc.) utilised for later NCP co-production processes. In contrast, these distinctions are less evident for ongoing livestock husbandry. We regard mobilised resources of livestock husbandry (e.g. wool, milk, meat) as leaving the ecological subsystem, while grazing livestock (and its manure) remain in the ecological subsystem. When livestock is sold (and serves than as an NCP for various aspects of appreciation), we consider it as leaving the ecological subsystem. However, the non-material dimension, such as genetic diversity, remains in the subsystem. The knowledge and values to maintain this breed is a social–ecological legacy in the social subsystem and exhibits its own processes. While the notion of social–ecological legacy strongly emphasises the intimate interlinkages between the social and the ecological system, we opted for didactic purposes for an analytical (and accordingly graphical) presentation of two separate spheres. In doing so, we also align with Riechers et al.'s (2020) reasoning that most resource types (e.g. infrastructure, genetic diversity) are best measured in social, respective ecological indicators.

Legacies and current resources can influence each other and are linked. For example, current practices such as irrigation and fertilisation along with the legacies of former land use and social values affect the amount of the current resource of biomass (Quétier et al. 2007). In addition, society can agree on maintaining extensive, labour intensive management practices based on previous experience coupled with current resources. For example, Alpine agricultural systems maintain traditional haymaking for winter livestock feed, but they have considerably reduced manual labour by increasing mechanisation. Aspects of appreciation from NCP co-production can thus feedback into the social subsystem and influence how and which social–ecological legacies and current resources are used. In Table 1, we present an illustrative overview about possible variables for the analysis for co-production of a regional agricultural NCP (more information on indicators is provided in SM1).

Activities along the NCP co-production chain

Social activities make use of social–ecological legacies and current resources along the different steps of co-production. They define and affect the types of co-production (Spangenberg et al. 2014; Plieninger et al. 2015). Following the ecosystem service cascade framework (Potschin-Young et al. 2018) and its refinement for accounting explicitly for human agency in the delivery of benefits from ecosystems to people (Fedele et al. 2017; Bruley et al. 2021a), we structured NCP co-production as a four-step process (illustrated by the four arrows in Fig. 1). This disaggregation enables the more precise identification of the various actors (e.g. individual or collective) and eventually assessing their role along the entire NCP co-production process.

We define a pre-conditioning step zero of co-production (CP0; organising) that describes how different actors, either collectively or individually, agree on a rule set over the types and modes of co-production (Bergeret and Lavorel in press). CP0 may stem from former NCP co-production, and then be considered as a mix of social–ecological legacies (such as already established rule sets that predominate a landscape) and represent actors' network and dynamics. This step is biophysically and spatially separate from the local ecological subsystem, but social–ecological legacies affect and frame this rule set. In democratic structures, this organisation of resources requires collective agreement on common values and knowledge (Ostrom 2000). It depends on the social–ecological context, and tereby the social–ecological legacies, current resources and the involved actors. The crooked arrow indicates these rule sets are the consolidated result of often long negotiations among local stakeholders and government or regulatory authorities. Empirical research analyses formalised relationships to capture the non-material collective values of a given social subsystem (Ostrom 1990). However, we suggest that these formalised collective values can only present a compromise between the different actors and do not capture the totality of collective values.

Co-production at step one (CP1) is the stage of biophysical ecosystem management, such as fertilisation of agricultural fields. For example, actors apply different management practices based on the agreed rule set, their current resources (available labour, technology and/or knowledge about management practices, etc.) and their personal considerations on the management of the cultural landscape as shaped by social–ecological legacies. Thus, the combination of CP0 and individual perceptions of the involved actor underpin the management of the social–ecological legacy landscape.

Co-production at step 2 (CP2) is where activities of extraction of current resources (e.g. biomass) from the social–ecological legacies (livestock breed, landscape) occur, such as milking or haymaking. Mobilisation does not necessarily depend on the current biophysical management at CP1, but on social–ecological legacies such as the amount of pastureland, infrastructure or knowledge. Picking berries in a forest does not require targeted management for the production of these fruits, but this activity necessitates access in physical (e.g. a path) and more intangible (e.g. knowledge about the edibility or location) terms. However, current resources can modify the type and quality of current ecological resources (e.g. fertilisation increases biomass yields). CP2 usually requires some social resources, such as permanent infrastructure, e.g. a form of physical access to mobilise ecological outputs (Bruley et al. 2021a).

Co-production at step 3 (CP3) relates to the translation to a final NCP benefit, e.g. the sale or transformation of milk and other aspects of appreciation (happiness to be in nature, place of belonging, etc.) that co-producing actors consider as relevant. It requires multiple, frequently subtle cognitive factors e.g. feeling of attachment (Fedele et al. 2017). These appreciations feedback into the social subsystem as current resources.

NCP co-production is dynamic and not linear. The entire process is based on and will produce future social–ecological legacies. Each of the following steps is an outcome of the previous steps. Here, we chose the chronological numbering to align with previous conceptualisations of NCP co-production (Bergeret and Lavorel in press; Bruley et al. 2021a) and reasoning on society–ecosystem interactions (Haines-Young and Potschin 2010; Fedele et al. 2017). Nevertheless, we emphasise the interdependent, frequently concurrent (accumulating) circular processes of NCP co-production.

The Maurienne Beaufort cheese production system

Beaufort cheese production takes place in three adjacent valleys (Beaufortain, Tarentaise and Maurienne) of the Northern French Alps. Since 1968, the EU label "Protected designation of origin" (PDO) entails binding product specifications. This commonly agreed rule set guarantees the characteristics of the final product and the maintenance of associated management and production techniques (INAO 2015; Lynch and Harvois 2016). In the following, we exclusively discuss the Beaufort production system in the Maurienne valley; however, the rule set applies to the whole production area. The Maurienne valley with its three cooperatives representing about 80 producers (900 t of cheese/yr) has been an integral part of the Beaufort PDO since its inception in 1968. All 14 cooperatives in the three valleys are associated

Table 1 Illustrative overview of indicators and respective sources for the conceptual framework application to Maurienne Beaufort cheese production (MBP)

Resource categories	Definition	Social subsystem	Examples of variables	Data for study area*	Main CP	Ecosystem	Example of variables	Data for study area**	Main CP
Social–ecological legacies	Experiences from past society–ecosystem	**Common Values**[a] Views and preferences that influence how ecological resources are governed over time (Chan et al. 2012; van Riper et al. 2018)	Regional breeds of total livestock % local fodder of total fodder Mean farm size	100% 75% 31 ha	CP0	**Genetic information** Persisting impact of human activities (e.g. agriculture) on the abiotic or biotic characteristics of ecosystems (Cuddington 2011)	Taxon richness of grassland (in nr.)	432 Vanpeene-Bruhier, Moyne, and Bru(Vanpeene-Bruhier et al. 1998)	CP1
		Traditional ecological knowledge[a] The evolving body of local knowledge, practice and belief, handed down through generations by cultural transmission (Berkes et al. 2000)	Grazing or harvest dates and duration (days) adjusted to interannual climate variability	Annual changes	CP0/CP1	**Agricultural landscape** Ancestral landscapes can be the foundation of current agricultural production (Koohafkan and Altieri 2011)	Grassland cover	26% (RGD SMB 2014)	CP1
	Biophysical or physical memory from the past	**Physical infrastructure** Geographical proximity to production facilities can play a relevant role for social dynamics in regional production chains (Madelrieux et al. 2018; Pachoud et al. 2020)	Travel time to transformation facility	30 min	CP2	**Amount of carbon stored in above- and below-ground biomass** Agricultural practices (e.g. grazing) can be beneficial or detrimental for soil organic carbon (Garcia-Pausas et al. 2017)	Carbon stock	70–120 Mg/ha (Poulenard 2020, in prep.)	CP1

Table 1 (continued)

Resource categories	Definition	Social subsystem	Examples of variables	Data for study area*	Main CP	Ecosystem	Example of variables	Data for study area**	Main CP
Current resources	The results of current society–ecosystem interactions influenced by external drivers	**Activity attachment** Motivation of individuals to pursue an activity despite purely economic objectives (Hinojosa et al. 2016; Madelrieux et al. 2018)	Change in producer between 2012 and 2019	− 3%	CP3	**Ecosystem productivity** Biophysical and social factors influence the net amount of carbon (Haberl et al. 2007)	Biomass production in grassland areas	Mean average for European Alps: 9.8 (± 3.8) (Jäger et al. 2020)	CP2
		Place attachment The feeling of relatedness to a place is a relevant factor in mountain farming (Hinojosa et al. 2016)	Change in utilised agricultural area between 1988–2010	− 15%[b]	CP3	**Biomass production**	Fodder harvest	0.6–9 t DM/ha	CP1
		Labour Labour is an input for agricultural production (Erb et al. 2013; Lescourret et al. 2015)	Labour force unit/holding	2.06 Labour force Units/ha	CP1	**Livestock density**	Livestock unit (LSU)/ha	0.39 LSU/ha)	CP1
		Technology Factor of production for agricultural products (Erb et al. 2013)	Irrigated surface of total agricultural surface	4%	CP1				

Key concepts in column "social subsystem" and "ecosystem" are emphasized in bold font

[a]Sources if not otherwise indicated (Schoch 2013, 2014; Clavel 2014; INAO 2015)

[b]Sources for the entire Maurienne valley

to a consortium. The consortium offers and regulates legal and technical assistance and control of the product specifications. The Maurienne valley shaped by the Arc River spans almost 120 km and is the longest Alpine valley in France. Its 40,000 inhabitants live in predominantly rural settings with only 3 of the 56 municipalities exceeding 2000 inhabitants (SPM 2020). The climate ranges from a humid pre-Alpine climate in the west to a continental alpine climate in the east. Representing one-third of the whole area, grasslands are a characteristic feature of landscape (Fig. 2). Today, the local economy largely reflects the general picture of European mountainous areas with a large part of the work force (25%) linked to the service sector, 19% to the industrial sector and 2% to the primary sector (EC 2009; SPM 2020).

To apply our framework to the Maurienne Beaufort production system, we conducted 20 semi-structured interviews with actors associated with the system. We first identified 100 actors directly economically affiliated with Beaufort production and selected interviewees based on Internet searches and subsequent purposive snowballing (Bryman 2016). Seventeen of them were active in the Maurienne Beaufort production system during the research period, among which 4 actors in managing positions of the three cooperatives, 1 of the consortium and 12 Beaufort producers. In addition, we included three actors as “time witnesses” who were actively involved in the establishment of the Beaufort production system from the 1960s onwards. The interviews were conducted between February and September 2019 (see SM2). The interviews focused on the role and background of respective actors and their views on and relations to the Beaufort production system (interview guide is provided in SM3).

Using qualitative manual coding with NVivo, we identified the main activities and associated resources used along NCP co-production by a predefined typology (Clarke and Braun 2014; QSR International 2020). This typology was built on previous studies of agricultural NCP co-production and iteratively improved during coding (Palomo et al. 2016; Vallet et al. 2019; Bruley et al. 2021a). We drew the economic system boundaries as encompassing all resources, e.g. livestock, biomass or carbon storage and actors associated with the Beaufort production system in the valley.

Organising resources (CP0)

In our framework, we defined CP0, the organisation of a regional collective rule set, depending on social–ecological legacies and current resources of the social subsystem with its actors. The Beaufort consortium oversees the rule set of product specifications for the entire production area. It regularly consults its board composed of representatives of the cooperatives and producers (INAO 2015; Lynch and Harvois 2016). This rule set has not been externally

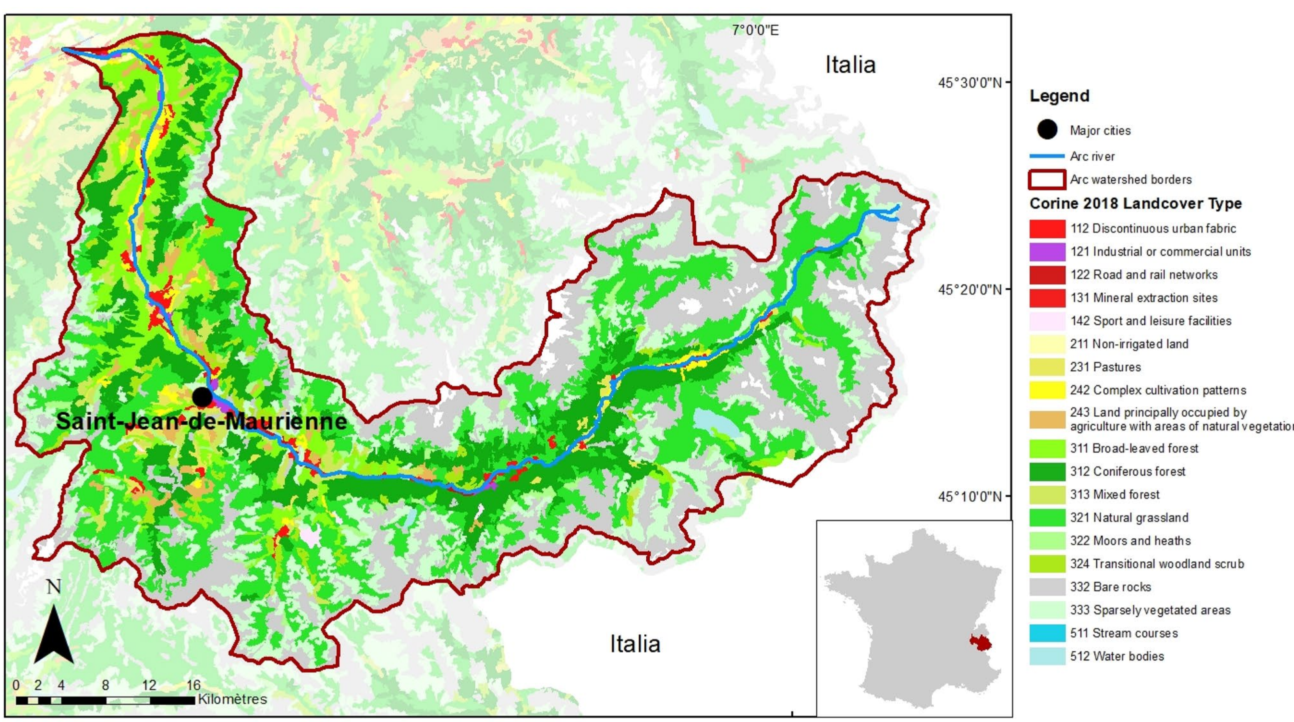

Fig. 2 Location of the study area

imposed, but actors have negotiated it over the years. An actor casually remarked: "*It's the history, which governs the conduct of the people*."

In the interviews, actors repeatedly referred to three main rules that shape the type of agriculture and the associated resource use along the NCP co-production steps (INAO 2015). The first rule links production quantity to the social–ecological legacy landscape (grassland covers 26% of total area) by requiring that 75% of fodder be regionally sourced. The second rule limits production through absolute milk quota at both the livestock unit, farm and cooperative level. This keeps farm size at a moderate level (average 32 ha). The third rule requires that low yielding, regional cattle breeds ('Abondance' and 'Tarine') constitute 100% of livestock. These rules couple production to the landscape's social–ecological legacies. This collectively agreed rule set maintains small-scale agriculture with extensive management embedded in a regional social–ecological context. While the rule set emerged from within the region, e.g. local actors defined the spatial boundaries of the PDO collection area and the rule set; today it depends on and corresponds to the standards of the PDO EU level.

We consider this rule set as the consolidated result of negotiations between differing interests over common values and knowledge and current resource use (activity attachment, technology, etc.) that has been evolving over time. The limited choice of cattle breeds is the result of a long negotiation process in the 1980s, where some farmers favoured high yielding cattle breeds over the local low yielding types in order to increase production quantity (Lynch and Harvois 2016). More recently, a debate focussed on the easing of the 75% local fodder requirement. While some actors prefer low production quantities, others would prefer more flexible fodder requirements to allow for higher production. Some actors question the third rule, which limits farm size. A fraction of farmers proposes stricter rules, such as a shift to organic labelling. Thus, the modification of these social social–ecological legacies could affect the NCP co-production steps and the ecological subsystem (landscape, genetic diversity). However, any modification prompts lengthy administrative processes at consortium level followed by a public enquiry and national approval by regulatory authorities. The results of the public enquiry are not binding, but as a leading actor on this level stated: "*In any case, for modifications to be accepted in the field there must be maximum consensus and a majority of producers who ask for them.*"

Producing fodder (CP1)

In the Beaufort production system, CP1 consists of the sum of available resources at farm level as limited by the commonly agreed rule set. Individual farmers manage the ecological subsystem by livestock grazing across different altitudes and by the management of meadows for haymaking in valley bottoms. These actors are represented in the management board of the consortium and can voice their opinion in an annual general assembly. The consortium controls the compliance to the rule set. Actors apply the currently formulated rule set (CP0) and use their current resources, labour and technology to manage (and maintain) the social–ecological legacies of the ecological subsystem. Individual perceptions of exogenous factors (recurrent droughts, urban spread) and financial flows (subsidy schemes) have led some actors to change how they use the resources available to them. They have increased technological input through irrigation since 2015. Still, the used amount of labour (2.06 LFU/h), irrigation (4% of agricultural surface) and livestock unit density (0.39 LSU/ha) of the Beaufort cooperative system are extensive management practices in a biophysically limited spatial area. But, even within a common rule set that regulates social–ecological legacies, management strategies are evolving, due to changing current resource use and possible individual preferences. Overall, farmers considered their agriculture as extensive and adjusted to the local conditions: "*The PDO Beaufort and our practices are reasonable. It's important to stay coherent in what you're doing*."

Mobilising ecological resources (CP2)

In our framework, mobilising ecological resources (CP2) is defined as a function of current resources and social–ecological legacies from the social and the ecological subsystems. In Maurienne, individual farmers mobilise the current resources of the ecological subsystem by milking cows. They must comply with high quality and hygienic standards. Cooperatives collect the milk once a day from individual farms. The nearby transformation facilities enable the mobilisation and subsequently easy access to markets. The relevance of physical infrastructure in farms proximity for mobilisation has been shown to be important in other Alpine regions (Bruley et al. 2021b). Actors were aware of the relevance of mobilisation: "*Here, no big player would come and get my milk. It just wouldn't pay off for him.*"

Appreciating NCP (CP3)

In the Beaufort production system CP3 (appreciating NCP) can be considered as the multiple outcomes of the entire production chain. These appreciations feedback as current resources into the social subsystem. Cooperatives transform the milk and sell the Beaufort cheese through whole or direct sale. Individual farmers use the remuneration for different aspects they consider as meaningful. The sale of the product supports households' socioeconomic livelihood and implies by its specific local production a certain lifestyle. Actors use (and reproduce) current social resources such as activity attachment and place attachment to appreciate the outcomes. The activity attachment of the Beaufort cooperative system appears to be only slightly declining; there was a reduction of −3% of Beaufort producers over the past 7 years (2012–2019). However, 15% of the Maurienne's grassland area was retired from agriculture from 1988 to 2010. In interviews, farmers expressed satisfaction with their socioeconomic livelihood (Grosinger et al. in review). The different steps of co-production interact. For example, the outcomes of CP3 such as place attachment and of the CP0 rule set reflect and shape each other. Place attachment affects how actors organise their rule set. For example, the compliance to the 75% local fodder requirement can be explained by the willingness of farmers to maintain certain landscape features (such as summer high pastures). Conversely, discussions about more flexible management rules may reflect the declining activity and place attachment of some farmers. Farmers might be less eager to pursue labour intensive, time-consuming activities in parcels difficult to access. In addition, a high appreciation of exclusive monetary benefits could motivate the desire for more flexible rule sets that favour greater production. The interdependency between place and activity attachment and rule sets is in particular evident when looking at the history of Beaufort. Actors with a strong activity and place attachment formalised and institutionalised their agricultural practices by the Beaufort cooperative in order to combat rural emigration and the decline of Alpine agriculture in the 1960s (Dubeuf 1996). It is yet unclear though how and if the Beaufort cooperative will be as effective to respond to ongoing and future challenges such as evolving life style expectations.

In analytical terms, the multiple individual cognitive dimensions of appreciations can render homogeneous, systemic quantification difficult. These deeply personal motivations might be difficult to upscale without losing the specific nature of such dimensions that contribute to a good quality of life. For example, an actor described her current activity as a realised desire from her childhood: "*Since I've been a child, I always wanted to have a farm. Me, the pasture land, I only see myself there.*"

Discussion

We conceptualised NCP co-production within the context of a coupled SES. This allowed us to analyse the intentional society-ecosystem interactions within the SES and to elucidate the importance of social–ecological legacies and social activities for NCP production. Below, we first discuss possible applications and empirical limits of this framework. We then explore the complexities of integrating social–ecological legacies into NCP research. We conclude by highlighting the interplay between social–ecological legacies and social dynamics.

Applications of the framework

We believe this conceptual framework may most easily be applied in systems where social and ecological boundaries are delineated by formal institutions, such as areas falling within geographical indications (Santini et al. 2015; Belletti et al. 2017). This enables detailed analysis of linkages between collective rule sets and landscape features. Nevertheless, the framework could also be applied in less strongly structured systems like cultural landscapes. Their boundaries are delineated by informal rule sets and only subsequently regularised by formal institutions such as official labelling bodies (e.g. high nature value landscapes) (Oppermann et al. 2012; Beaufoy and HNV Link Partners 2017; Benedetti 2017). In addition, the framework might not be able to adequately assess structures with a high inflow of external resources, such as industrialised agricultural systems with possible less social–ecologically evolved patterns. We suggest that the framework is best applicable where society is intrinsically linked to local ecosystems by physical and cultural interlinkages that are expressed by common norms and practices.

From an academic perspective, the framework can facilitate collaboration between different fields. First, it can raise awareness of natural scientists about the relevance of social–ecological legacies and social activities for NCP co-production at a regional scale (Hysing and Lidskog 2021). Secondly, the framework can accommodate a variety of interdisciplinary research questions, including the relations between collective values, ecosystems and regional governance rules (Ostrom 1990; Bodin 2017). From an analytical perspective, it integrates the economic dimensions of NCP co-production and associated actors with their surrounding ecosystem. In particular, the disaggregation of the steps of NCP co-production can highlight the multitude of actors and their social characteristics (and associated power in decision making) who are intimately linked by the resources used throughout co-production. Thus, it can facilitate a further integration of social sciences into assessments of society–ecosystem interactions (Stenseke and Larigauderie 2018).

Interdisciplinary approaches face the challenge of finding appropriate terms and underlying concepts that are intuitive and logical for multiple disciplines. For example, social sciences frequently use the term "capital" when referring to what we named social–ecological legacies (Guerry et al. 2015). On the other hand, natural sciences consider social–ecological legacies as memories from the past and not as a potential resource for NCP co-production (Essl et al. 2015). We believe that our framework can support meaningful exchanges for reconciling these diverging conceptualisations of available resources. We expect this will help further advancing research on value generation and associated modes of production in SES.

The framework deliberately emphasises the complementarity of resources from the social and ecological subsystems to co-produce different dimensions of appreciation. Thereby, it embodies the vision of strong sustainability (Daly 1997). The aim of analysing NCP co-production is not to quantify the relative share of co-production between the two subsystems (e.g. 1 tonne of maize is co-produced by 60% social and 40% ecological input.). The continuation of this thought would inevitably imply substitutability of ecological by social resources (Stiglitz 1997). Further, substitutability does neglect the impact of social–ecological legacies in NCP co-production processes. Nevertheless, we support suggestions from other research to investigate the effects of increasing levels of social resources in co-production on ecological degradation more thoroughly (Palomo et al. 2016; Outeiro et al. 2017). From a methodological perspective, the integration of social–ecological legacies like infrastructure might enable bridging the gap between research on NCP and other methods to analyse human–nature interactions, such as Material Flow Analysis or Life Cycle Analysis. The framework is relatively flexible. It does not assume to what extent NCP co-production is driven by social–ecological legacies or social activities. Some research suggests that NCP co-production is not based on natural resource endowments, but on human agency (Ballet et al. 2011; Spangenberg et al. 2014; Schröter et al. 2020). On the other hand, long-term studies on legacies suggest that biophysical drivers might have more explanatory power than socioeconomic variables for current land use patterns (Price et al. 2017). The application of our framework can incorporate both approaches.

Empirical application of the framework might encounter several challenges to account for external factors. Our case study describes a system whose boundaries were defined from the perspective of regional economic dynamics. The framework cannot capture the larger social structures that influence the regional SES. This is in particular evident for the different aspects of appreciation in the Beaufort production system in the Maurienne. The declining activity and place attachment reflect the general trend of decreasing farms in Europe. For that it cannot entirely be explained by the variables in our framework (EC 2009; Flury et al. 2013). In addition, the Beaufort production system depends on larger institutional structures, such as the European PDO label that ensures an above market prize and the persistence of the this regional production system (Quiñones Ruiz et al. 2018). Also changing consumer patterns, such as favouring high quality can support this low yielding extensive agricultural system (Lamarque and Lambin 2015). The framework incorporates these diverse drivers as one black box factor (demand). Thus, we suggest linking this framework with recent telecoupling approaches that consider such indirect external factors more explicitly (Hull and Liu 2018). We acknowledge that distinguishing social–ecological legacies in the social and ecological subsystems remains complex and requires further quantification and systematisation. This is in particular evident when comparing the framework with comparable conceptualisations that frequently consider livestock as anthropogenic assets and not, as in the reasoning of this framework, as a social–ecological resource within the ecological subsystem (Díaz et al. 2015; Lescourret et al. 2015).

The framework is in line with the IPBES framework that underlines the pervasiveness of non-material, cognitive elements in all components of NCP (Díaz et al. 2018). However, a structured assessment of these cognitive factors, such as values and aspects of appreciations, usually requires some level of simplification. For that, the framework might not be able to capture the various aspects of appreciation by different actors (Schröter et al. 2020). For example, the indicators we used for place and activity attachment measure its effects, but not its intrinsic underlying mechanisms. This weakness is shared across NCP research overall (Schulz and Martin-Ortega 2018), though recent developments help addressing multiple values of nature and their incorporation into analyses of SES (Schröter et al. 2020; Pascual et al. 2021 Mar 25). While we support the use of a simple range of qualitative and quantitative key indicators (e.g. Schröter et al. 2020), we believe that applying the framework starts with qualitative research.

Integrating social–ecological legacies for understanding NCP co-production

The regional rule set of a given landscape emerges as a complex integration of interacting norms and behaviours over a period of time. The illustrative example of Beaufort NCP co-production in the Maurienne valley indicates that the way in which social–ecological legacies are organised by a common agreement (such as a collective rule set) among actors can affect the entire production system. For example, compliance to regional livestock breeds and fodder sourcing influence farm size and presumably different aspects of appreciation. The organisation of resources by a rule set can only be understood by integrating social–ecological legacies such as common values as a key resource. In case of the Beaufort production system, the organisation of collective values allowed an otherwise not competitive product to ensure the maintenance of mountain agriculture (Lynch and Harvois 2016). This suggests that the (re)organisation of non-material social–ecological legacies can facilitate possible adaptation strategies to other challenges (e.g. climate change) for regional SES (Berkes et al. 2000; Oteros-Rozas et al. 2013; Lavorel et al. 2020). To advance agroecological transitions, collective institutions may (re)formulate or adjust collective rule sets in accordance with the anticipated aspects of appreciation (Lamine et al. 2019). Thus, collective rule sets can be relevant for the preservation of landscapes with a specific biodiversity and cultural values, such as High Nature Value (HNV) landscapes. Recent research explicitly studying these linkages in Slovenia has highlighted the relevance of collective rule sets and associated collective value sets for these landscapes (Rac et al. 2020). Some research suggests that collective rule sets can promote biodiversity conservation, but more numerous and standardised, or at least comparable, studies exploring these interlinkages are needed (Chappell et al. 2016). However, as can be seen in the case study, actors currently rather favour easing restrictions (e.g. 75% local fodder requirement) and only a fraction support stricter environmental measures. Social–ecological legacies can impede the introduction of new practices, for example the proposition of organic labelling for the Beaufort production is considered as controversial. This is in line with a recent meta-analysis on the modifications of PDO labels which suggests that ecological considerations only play a minor role in the amendment processes of the products (Marescotti et al. 2020). Thus, collective rule sets can either facilitate or hamper (e.g. by institutional inertia, path dependency or "stickiness") the continuation or change of NCP co-production (Waylen et al. 2015; Colloff et al. 2020; Lavorel et al. 2020).

Evolving current resources and types of appreciation

We showed that actors need to comply with a certain rule set, but are then relatively free to set their current resource use in their management activities. Changes in energy and material regimes, embodied as current resources, can profoundly impact current and future NCP co-production and subsequently modify these social–ecological legacies (Plutzar et al. 2016; Le Noë et al. 2020). In line with previous studies on natural resource management, our analysis of the Beaufort production system showed that the rule set could influence the use of current resources in management practices (Ostrom 1990). Social–ecological legacies coupled with evolving current resources and aspects of appreciation can lead to new management practices like increasing irrigation (Waylen et al. 2015). In our case study, new irrigation technology can lead to undesirable effects on the social–ecological legacies of the ecosystem (e.g. modifying soil carbon) (Mudge et al. 2021). Therefore, the rigidity of collective rule sets combined with changing current resources can lead to social–ecological traps, with the unintentional degradation of ecosystems (Boonstra and de Boer 2014). On the other hand, social–ecological legacies and evolving types of appreciations have also led to new forms of non-material NCP, such as landscape appreciation. In the case of the Beaufort production system, the cooperatives acknowledge this aspect and offer regular tourist visits to their transformation facilities or to grazing cattle on nearby pastures. On a larger scale, some European national or supranational subsidy schemes prioritise this non-material dimension of NCP co-production indirectly. The subsidies favour landscape management over production quantity to maintain a desired aesthetic appearance (von Glasenapp and Thornton 2011; Flury et al. 2013; Daugstad 2019). More research investigating the links between current resources, social–ecological legacies, individual management practices and types of appreciation are needed to better understand the role of social–ecological legacies in NCP co-production.

Conclusion

Our conceptual framework showed how regional societies make use of available resources for aspects they consider as relevant. We integrated social–ecological legacies and social activities to thoroughly analyse biophysical constraints and modifiable conditions SES are embedded in. The framework highlights the relevance of consensus among actors on the management of regional landscapes. We argued that a balanced recognition of social–ecological legacies of the social and the ecological subsystem is essential for describing agricultural systems. Further, the relations of outcomes with collective rule sets facilitate the understanding of actors' choices in their resource use. While the framework is conceptually complex and requires knowledge from multiple disciplines, we argue it will advance analyses of agricultural development, social–ecological legacies and regional governance systems because it decidedly focusses on the contextual specifics of these systems. Additionally, it allows rapidly identifying relevant key stakeholders. We believe that the explicit linking of society and ecosystems through social–ecological legacies provides a common ground for natural and social sciences in a regional context. This can nurture the discourse on value pluralism and foster research of non-material aspects that people consider as meaningful to their life.

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