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Community-Based Institutions Shape Cheese Co-Production in a French Alpine Valley

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Livestock systems are vital to socioeconomic livelihoods in mountain territories, yet quantitative analyses of their diverse modes of production beyond farm level are missing. We used the concept of nature's contributions to people to account for these various society–ecosystem interactions. We investigated the role of biophysical constraints, resources, and community-based institutions (CBIs) for agricultural production at municipal scale. We asked: What are the driving variables that govern the agricultural system at municipal scale in a mountain territory, and what is the role of CBIs? Based on qualitative research with local informants, we identified the most relevant resources for agricultural production in 53 municipalities that are part of a cheese-producing CBI in Maurienne Valley (French Alps). Correlation analyses showed how biophysical constraints and external drivers from tourism shape the agricultural management of ecosystems. The inductive clustering to 3 production typologies suggested that the CBIs could buffer resulting differences in economic outcomes. Our results display how such mixed-method analyses can inform policymaking in heterogeneous mountain territories.

Keywords: *French Alps; mountain territories; nature's contributions to people (NCP); agriculture; community-based institutions; local governance.*

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Introduction

Agricultural livelihoods in mountain areas are deeply embedded in specific geographical and historical contexts. In the European Alps, these local systems enact different society–ecosystem interactions against diverse biophysical and resource backgrounds (Altaweel et al 2015; Martín-López et al 2019). These heterogeneous settings coupled with a variety of institutions at different scales and thematic entry points complicate understanding of the functioning of agricultural systems at territorial scale. Comparative, bottom-up typologies offer solutions to facilitate territorial-level understanding beyond their social–ecological heterogeneities.

Socioeconomic activities involve multiple, frequently interlinked societal (eg infrastructure, knowledge) and ecological (eg biomass, livestock) components within a specific local context (Ostrom 2009). In line with research on natural resource management, we broadly term these components "resources" (Anderies et al 2004; McGinnis 2011). Their use depends on social preferences and is frequently governed by formal or informal institutions with differing rule sets and management practices across spatial (eg local, regional, national) scales (Ostrom 1990; Spangenberg et al 2014). We consider the intermediate scale of "territories" (eg a mountain valley) to be a suitable scale for considering these deep interlinkages (Ostrom 1990; Barreteau et al 2016).

The concept of nature's contributions to people (NCP), defined as "all the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life" (Díaz et al 2018: 270), emphasizes the social dynamics that underlie society–ecosystem interactions (Fedele et al 2017; Chan et al 2018). NCP can have a material dimension (eg biomass), but they frequently encompass multiple, subjective dimensions that contribute to a good quality of life (Díaz et al 2015; Schröter et al 2020). For example, in all societies, food is a primary material contribution, but its production and consumption are deeply embedded in cultural dimensions. Social structures determine NCP desired by a society and are actively involved in coordinating resources to manage ecosystems for NCP production (Spangenberg et al 2014). This process is defined as NCP co-production. It describes the ways societies organize and implement social resources to mobilize different types of flows from nature to deliver NCP (Lele et al 2013; Palomo et al 2016; Bruley, Locatelli, Vendel, et al 2021; Grosinger, Potts, et al 2021). Previous research has shown how the ecosystem service cascade framework (Haines-Young and Potschin 2010; Fedele et al 2017) can be implemented to structure the different resources and actors (eg institutions) into 4 successive steps of human intervention along an NCP co-production chain (Bruley, Locatelli, Vendel, et al 2021; Grosinger, Potts, et al 2021). Co-production step 0 (CP0; organizing) describes how society organizes a rule set for the following steps (Ostrom 1990). Co-production step 1 (CP1; management) describes ecosystem management, such as grazing livestock, and, in agriculture, this step mainly takes place at farm level. Co-production step 2 (CP2; mobilization) refers to the mobilization of outputs from the agricultural system, such as milking or haymaking. Co-production step 3 (CP3; appreciation) underpins the translation to a final NCP benefit, for example, milk and transformed dairy products. NCP co-production takes place in a specific local context. Apart from biophysical conditions (eg elevation, climate), the social–ecological context (eg infrastructure, summer pastures) influences current types and forms of NCP co-production (Martín-López et al 2019; Grosinger, Potts, et al 2021). This context defines resources that result from past interactions between and within social and ecological processes (Cook et al 2012; Grosinger, Potts, et al 2021). In this article, we focus on the role of collective structures in NCP co-production.

Collective structures are key factors in the organization of resources along the steps of NCP co-production (Anderies et al 2004; Cumming et al 2020). Institutions are defined as "the ways in which people and societies organize themselves and their interactions with nature at different scales" (Díaz et al 2015: 6). Following previous research on natural resource management, we define community-based institutions (CBIs) as local voluntary associations that decide and follow a formalized rule set that considers local specificities when interacting with their surrounding ecosystem (Ostrom 1990; Leach et al 2012). CBIs frequently play a crucial role by streamlining and simplifying production processes in agricultural systems (Ostrom 1990; McGinnis 2011; Bennett et al 2015). Thus, they can buffer different endowments across members, for example, by providing infrastructure or trading opportunities (Ostrom 1990). While CBIs are crucial in NCP co-production activities at different steps of co-production, higher-scale institutions (eg [supra] national, regional, local governments) are usually indirect drivers at CP0, for instance, through regulations, subsidies, or technical support (Vatn 2005). Qualitative analyses have demonstrated their importance within agricultural territories (Schermer et al 2016; Pachoud et al 2020). However, they have so far been poorly included in quantitative social–ecological analyses (Muhar et al 2018; Martín-López et al 2019). One of the reasons why CBIs have remained underexplored might be their context dependency (Ostrom 1990). A comparative analysis of CBIs across a heterogeneous geographical area can discount effects of local biophysical constraints within regional agricultural systems.

Typologies of NCP co-production at municipal scale can enable comparisons, reduce complexity, and help to aggregate seemingly unique systems (Rocha et al 2020). These classifications can help to explain recurrent patterns that shape the dynamics of local types of NCP co-production (Oberlack et al 2019), and they can help to distinguish effects of social–ecological context from generic social–ecological processes (Rocha et al 2020). At regional scale, these classifications can facilitate understanding of the roles of different actors and their associated production systems within a given CBI. Thereby, they could advance generic understanding of CBIs and agricultural systems at a territorial scale (Ostrom 1990; Rocha et al 2020). Previous inductive typologies, such as for irrigation systems in Spain (Villamayor-Tomas et al 2020) or for mountain communities (Altaweel et al 2015), have described constellations of collective structures in local agricultural systems. However, knowledge of how CBIs play out across a heterogeneous region is missing (Altaweel et al 2015; Rocha et al 2020). Furthermore, the impact of the same CBI across heterogeneous local entities, such as municipalities, has not yet been studied.

We analyzed a cooperative system of Alpine cheese production. We aimed to analyze how the production of Beaufort cheese and its multiple material and nonmaterial facets in different geographical settings function within a common, homogeneous CBI rule set, and to identify types of NCP co-production that coexist regionally. We asked:

- Which societal and ecological resources are involved in the NCP co-production of Beaufort cheese?
- How do these resources define types of NCP co-production at municipal scale?
- What is the role of CBIs in NCP co-production?

Methodology

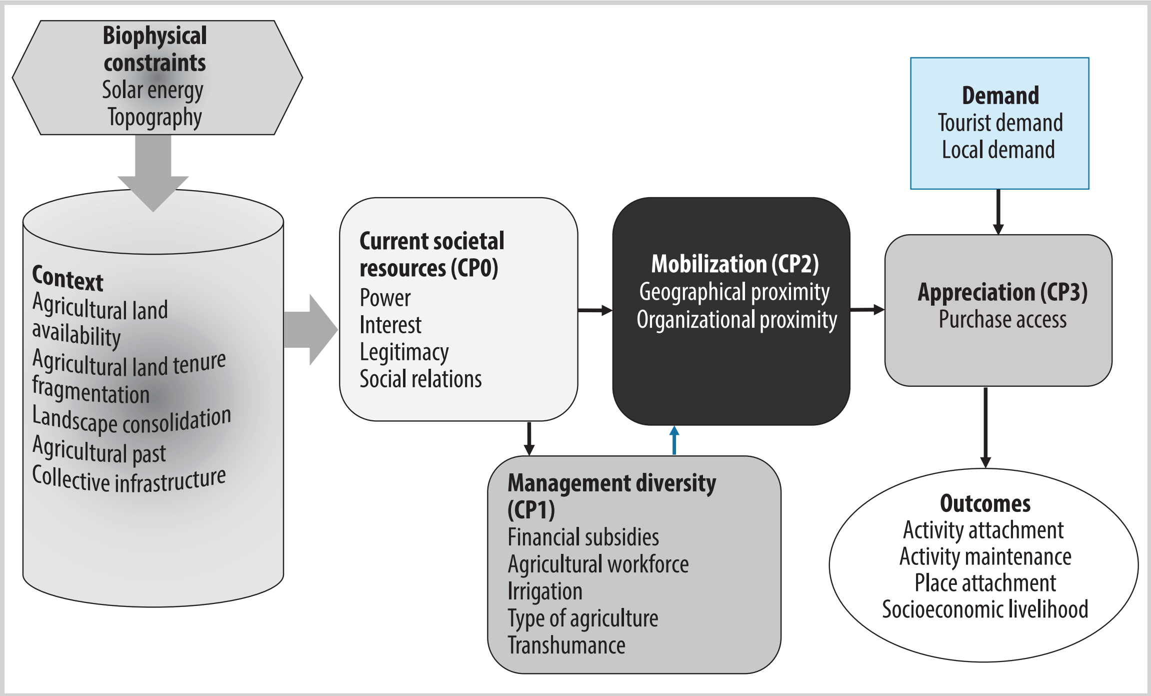
Study site

Maurienne Valley is located in the northern French Alps (6°08′09.7″E–7°11′02.3″E; 45°34′22.0″N–45°04′22.4″N). The valley spans almost 120 km and hosts ~40,000 people in 53 mainly rural municipalities (SPM 2020). Municipalities differ in size (50–1640 km^2), median elevation (500–2700 m), population density (3–85 inhabitants/km^2), wealth (gross domestic product/capita: US$ 55,200–73,000), and unemployment rate (2.7–27.5%). The territory's economy largely reflects the general picture of European mountain areas, with strong winter tourism, some industry, and to a far lesser extent agriculture (EC 2009; SPM 2020). A map of land use of the research area is shown in Appendix S1 (see *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1).

The main agricultural sector is the production of Beaufort raw cows' milk cheese by a cooperative system. Beef and small livestock (sheep, goats) are much less institutionalized (SPM 2020). Around 66% of small livestock grazing is based on transhumant herds from outside the valley (SPM 2020). Outside farmers have, despite the necessary land-use contracts, few socioeconomic ties to the local population.

Out of the 53 municipalities, 42 are part of the Beaufort cooperative (BC), a well-known CBI that stretches over 3 Alpine valleys. The BC is a consortium consisting of 14 autonomous cooperatives, 3 of which are located in Maurienne Valley, and producers. At CP0, the consortium formulates and maintains a collectively agreed-upon rule set. This encompasses management guidelines (CP1), sanitary conditions and quality criteria for mobilization (CP2), and transformation and sales (CP3) (INAO 2015). Each cooperative is responsible for the mobilization, processing, and sale of the product within its spatial collection area (Lynch and Harvois 2016). The product

FIGURE 1 Mental model of the Beaufort NCP co-production chain underpinning the quantitative analysis. The text in the boxes shows the indicators used for the subsequent quantitative analysis. Detailed information on the indicators is given in Appendix S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1.



carries the quality label "Protected Designation of Origin," which protects geographical indications of the European Union.

Materials

Based on the impact of CBIs in NCP co-production, we investigated the 42 municipalities that are part of the BC as a heterogeneous set composed of different types of NCP co-production at municipal scale (Hanspach et al 2016). We used qualitative methods to structure a quantitative analysis of municipality types (Meinzen-Dick et al 2004). Please see Appendices S2 and S3 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1) for the details of the interview partners and qualitative research.

First, we identified and coded the main activities and associated resources required for the production of Beaufort cheese based on a predefined typology of NCP co-production (Bruley, Locatelli, and Lavorel 2021; methods following Clarke and Braun 2014; QSR International 2020). Second, we formalized this understanding of the functioning of agriculture as a mental model of the different steps of co-production (Figure 1). Third, we identified and quantified social–ecological indicators of NCP co-production steps (see Appendix S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1). We selected indicators based on actor knowledge, their direct relations to agricultural production, their comprehensiveness, and their ability to inform long-term trends (Windhorst et al 2004). We prioritized indicators that had readily available data at municipal scale and were straightforward to replicate in comparable agricultural systems (Latruffe et al 2016). We included biophysical constraints as represented by mean elevation and solar power. We used indicators that reflected the role of institutions and, in particular, CBIs for context (collective infrastructure), CP0 (power interest, legitimacy, and social relations), CP2 (geographical and organizational proximity), and CP3 (purchase access). CP1 broadly encompasses agricultural practices. We included a variety of financial and other indicators to quantify demand and social and economic outcomes.

Data analysis

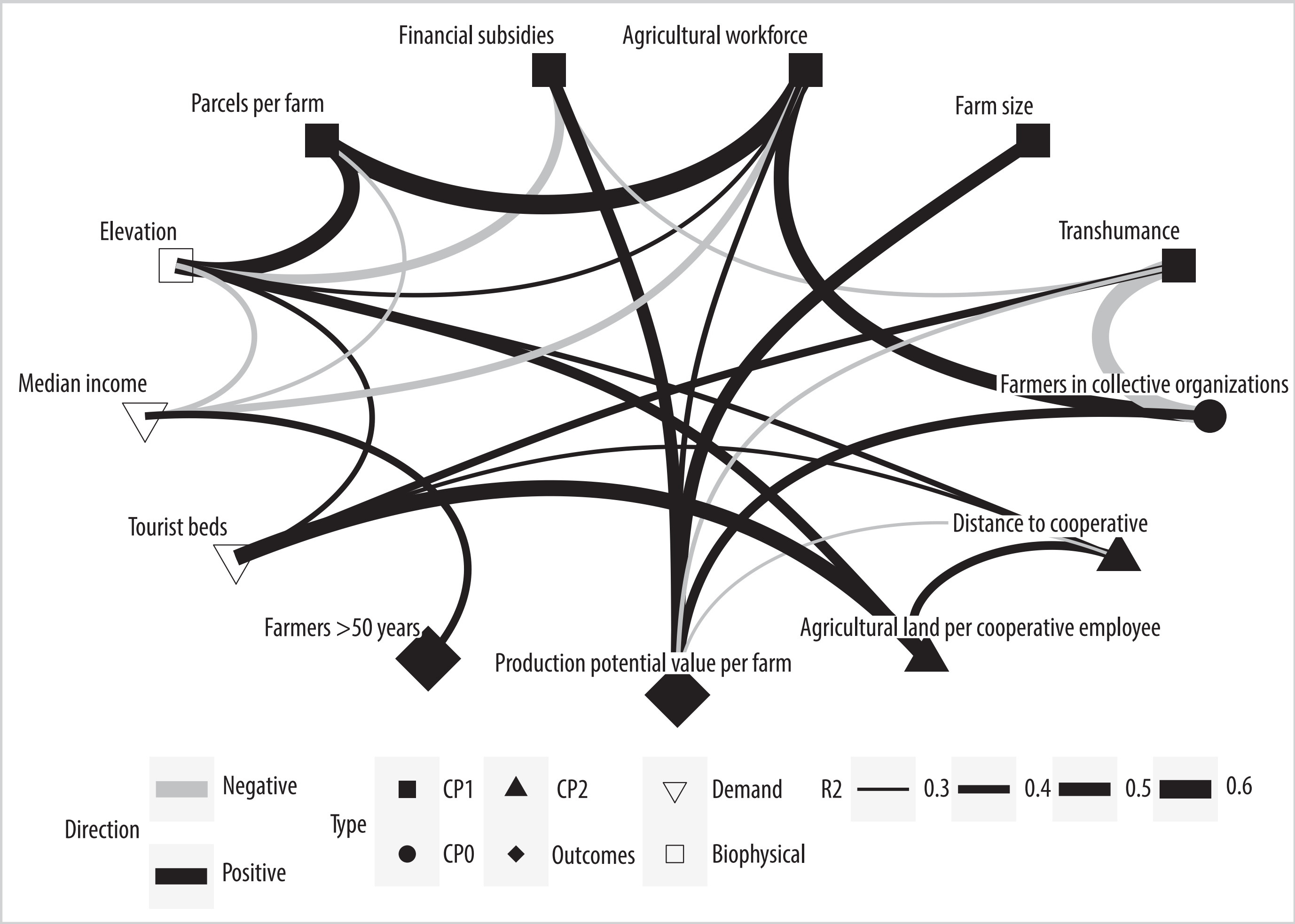
A preliminary exploration of value distributions and within-CP-group correlation structure across all indicators (Appendix S5, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1) gave a total of 15 parameters. These were further investigated for interrelationships along the co-production chain. We then examined pairwise Spearman correlations among these 15 indicators, that is a total of 105 potential correlations, and selected significant correlations at a threshold of $P = 0.05$. To build a typology of municipalities from these indicators, we applied hierarchical clustering with Euclidian distance to the matrix of municipality values for the 13 significant parameters. This allowed us to identify groups of municipalities, that is co-production types, with the closest values for the set of 13 parameters. All analyses were computed in R version 4.02 (R Core Team 2020).

Results

Key variables along the NCP co-production chain

Figure 2 summarizes significant relationships between selected variables (for detailed correspondence of indicators of Figure 1 and variables in Figure 2, refer to Appendix S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1). Thirteen of the 15 variables analyzed

FIGURE 2 Significant relationships between selected variables in the agricultural NCP co-production chain of Maurienne Valley. The different steps of co-production are represented by different shapes. CP1: ecosystem management; CP2: ecosystem mobilization. Dark arrows: positive correlation; light arrows: negative correlation; arrow thickness is proportional to the R^2 of the Spearman correlation. For detailed correspondence between indicators of Figure 1 and variables in Figure 2, see Appendix S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1.



showed significant correlations, while *number of farms* and *percentage of agricultural population in total working population* had no significant correlation with any other variable. Out of the 4 indicators for outcomes of agricultural production, *production potential value per farm*, and *farmers >50 years* were significantly and negatively correlated. The outcome *production potential value per farm*, which captures socioeconomic livelihood, was related to at least 1 variable along each step of the NCP co-production chain. The outcome *farmers >50 years* was correlated with *median income* (demand). Three of the 8 indicators for institutions (*percentage of farmers in collective organization*s at CP0; *distance to cooperative* and *agricultural land per cooperative employee* at CP2) showed significant relationships with other variables of the co-production chain.

Elevation was positively correlated with several steps of co-production (CP1: *agricultural parcels per farm*, *financial subsidies*, *agricultural workforce*; CP2: *distance to cooperative*) and demand (*median income*, *tourist beds*) variables. Overall, many actors seemed to be aware that the mountainous environment poses biophysical constraints to agricultural production. One quote from an actor underlines this:

> *Mountain agriculture is still complex. There are no large spaces, the space is limited, for that we must work more on less space.*
>
> (*interview 25, employee at a ski resort, March 2019*)

In CP0, the percentage of farmers in collective organizations, which was tightly correlated with indicators of higher-scale institutions (*farmers in municipal council*, *farmers as mayors*; see Appendix S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00035.1.S1), was positively correlated with *production potential value*. Multiple actors emphasized the importance of CBIs in local governance decisions over land use:

> *But if there is no collective which fights [for the maintenance of agricultural land], nobody can do agriculture here.*
>
> (*interview 36, farmer, August 2019*)

For CP1, 3 variables (*agricultural work force*, *financial subsidies*, *farm size*) were positively correlated with *production potential value*. *Number of agricultural parcels per farm* (CP1) and *agricultural work force* were positively correlated. Agricultural parcels in mountain areas are frequently dispersed across elevational belts to enable vegetation development to be tracked through the season. Consequently, manual labor is necessary to manage these fragmented parcels. In contrast to plains areas, options to increase technological input are limited and have reached their biophysical and energetic limits (Flury et al 2013; SPM 2020). The *share of irrigated surface* showed no correlation with other CP1 indicators (SM2) and hence was not retained in our final analyses, emphasizing this nonsubstitutability of human labor in mountains. *Financial subsidies* (CP1) and *farm size* (CP1) were each positively correlated with *production potential value*, but they were independent of each other. Some actors seemed to be preoccupied with the general tendency of farm growth. One farmer summed up his worries about the associated structural changes:

> *If I have more land, I will have more cows, more money, more milk, more, more, more. You cannot increase the available labor, people break down.*
>
> (*interview 37, farmer, October 2019*)

The negative correlation of *transhumance* with *percentage of farmers in collective organizations*, *financial subsidies*, and *farm production potential value* indicated that municipalities with a high share of transhumance overall hosted less intensive agricultural management, requiring fewer social and financial resources, but these efforts were less profitable. Transhumant actors manage and maintain the ecological system (eg by grazing; CP1), but they do not contribute to other steps of the NCP co-production chain. Transhumance compensates for the lack of municipal agricultural management activities at CP1, but it does not generate local production value. Interestingly, when asking actors to recommend relevant interview partners, none suggested people engaged in transhumant activities. This suggests limited social relations between local and external actors, in contrast to other mountain regions (Darnhofer et al 2016). The negative correlation of *transhumance* to *percentage of farmers in collective organizations* (CP0) and *financial subsidies* (CP1) suggests that CBIs (and public institutions) are relevant for agricultural production at a municipal level. Overall, some local actors expressed critical views on transhumance:

> *They come, they take, they go, but their involvement in the valley's agriculture is zero, really zero.*
>
> (*interview 36, farmer, August 2019*)

The CP2 variable *distance to cooperative* was positively correlated with *production potential value*. This suggests that the cooperative can mitigate geographical distances and associated biophysical constraints. The amount of *agricultural land per cooperative employee*, which denotes the efficiency of mobilization, was positively correlated with *distance to cooperative*. This may indicate that municipalities that are more peripheral might have more agricultural activities (eg more available area) than is feasible in more central, valley-based municipalities with greater land competition. Actors underlined the crucial role of the cooperative for the agricultural transformation:

> *The problem of this valley is that it is very long and you travel many kilometers. The trucks [of the cooperatives] do the work and get the milk every morning everywhere.*
>
> (*interview 19, farmer, August 2019*)

For demand, *tourist beds* and *median income* were correlated with selected steps of NCP co-production. Correlations with *tourist beds* revealed the mixed effects of tourism on agriculture. Tourist beds correlated with *distance to cooperative* and *area of agricultural land per cooperative employee* (CP2), indicating collocation between mobilization activities and tourism. Tourist beds were positively correlated with *transhumance* (CP1). Along with the negative association of the *median income* to *agricultural work force* with *agricultural parcels per farm*, this suggests that higher median income is obtained from activities other than agriculture, and that, where available, the municipal work force favors tourism over agriculture. The positive relation between *median income* (demand) and *farmer age* reinforces this hypothesis. Actors were fully aware of the relevance of tourism for agriculture; however, they mostly worried about aging:

> *If we don't do anything now, in 10 years there are no farmers here. We're all more than 50 years; the landscape will be completely reforested.*
>
> (*interview 19, farmer, August 2019*)

Typologies of NCP co-production at municipal scale

The hierarchical clustering analysis identified 3 types of agricultural systems at municipal scale (Figure 3). *Median income* was the first-order splitting variable, separating municipalities that were more affluent. The varying external demand determined the second split. This distinguished type 3 (16 municipalities) from type 1 (4 municipalities). Type 3 comprised numerous tourist beds at higher elevations and, given co-occurrence with more extensive farming systems, a higher level of transhumance than lower-elevation municipalities of type 1. Type 2 (22 municipalities) comprised lower-elevation municipalities with varying levels of co-production intensity and outcomes, but overall highly productive and active (including at cooperative level and other collectives) systems.

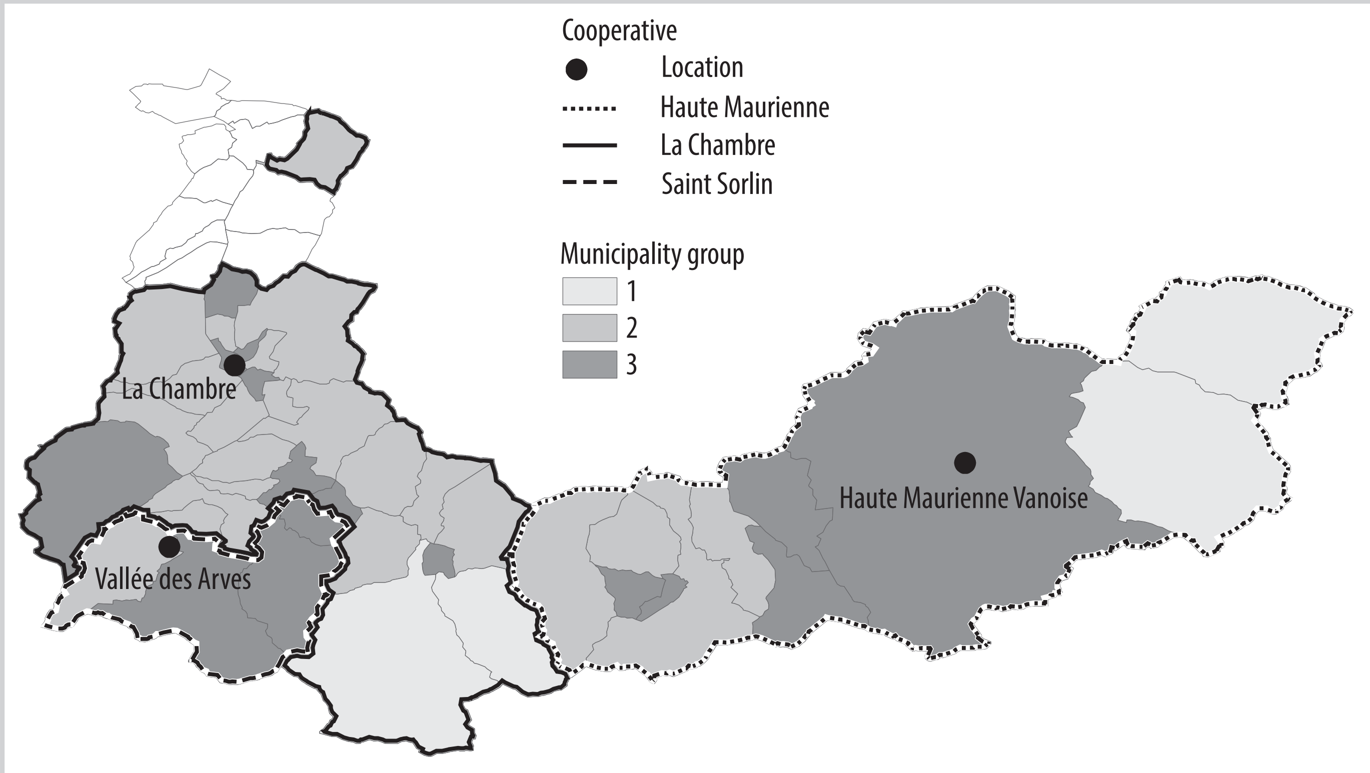
We overlaid the map of NCP co-production types on the collection area of each of the 3 cooperatives of Maurienne Valley (Figure 3). Each cooperative encompassed at least 2 of the 3 different types. Thus, each combined municipalities with differing biophysical constraints and varying economic foci on tourism. This indicates that the 3 types of municipal NCP co-production focus on different steps of CP. The productive type 2 focuses on activities surrounding CP1 and CP2, while types 1 and 3 are mainly engaged at CP3.

Farmers in municipalities faced with varying conditions and sale opportunities (eg being close to a ski resort) enjoyed the same access to collection, processing, and sales infrastructure (Figure 4) while significantly differing in their access to co-production resources (management, mobilization), demand, and outcomes. While further data collection and qualitative analyses are required to support this formally, this result suggests the division of roles across the 3 municipality types within the NCP co-production chain of a given cooperative.

Discussion

The analysis of the multiple variables of the NCP co-production chain in 42 municipalities of Maurienne

FIGURE 3 Map of Maurienne Valley showing the 3 municipal typologies (shades of gray) and the areas of the 3 cooperatives (boundaries). Shading is based on production types. Type 1: high elevation, less tourism intensive/CP3; type 2: lower elevation, intensive farming/CP1 and CP2; type 3: high elevation, tourism, extensive farming/CP3. The productive type 2 focuses on activities surrounding CP1 and CP2, while types 1 and 3 are mainly engaged at CP3.



Valley revealed that: (1) Biophysical constraints influence NCP co-production at the municipal level. (2) Variables that represent the CBI (CP0: *percentage of farmers in collective organizations*; CP2: *distance to cooperative*, *area of agricultural land per cooperative employee*) and external demand (*tourist beds*, *median income*) along the NCP co-production chain influence farm income. (3) The overall economic structure of municipalities is strongly influenced by external factors such as tourism through its effects on median income and on intensity of agriculture and financial subsidies. (4) Further, the cluster analysis and its mapping to cooperatives suggest that the CBI can buffer differences across production types at the municipal scale.

The relevance of institutions along the NCP co-production chain

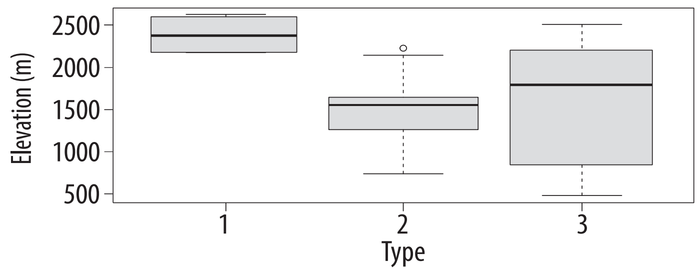
The structuring effects of the co-production chain on social relations through CBIs highlight the relevance of proximity for societal resources and related material (infrastructure) resources. Our analysis showed that biophysical constraints affected the type of farming (CP1), but that CBIs organized (CP0) and then provided equal access to infrastructure (CP2) and benefits (outcome). NCP co-production thus requires non-land-based societal resources (Meyfroidt et al 2018). CBIs can enable and support NCP co-production within territories by providing transformation and trading opportunities. Surprisingly, none of the contextual variables showed significant relationships within the co-production chain, while indicators capturing social relations represented 3 out of the 13 interacting variables. This confirms that social dynamics can buffer nonmodifiable conditions. Their relevance for agricultural mountain systems has been acknowledged, for instance, in a social network analysis of cheese cooperatives in the Italian Alps (Pachoud et al 2020) and in qualitative assessments of the role of social capital and transformation infrastructure (Madelrieux et al 2018; Bruley, Locatelli, Vendel, et al 2021). The specific territorial rule sets can support the introduction of stricter environmental regulations into already existing legal frameworks (Marescotti et al 2020). CBIs may induce social–ecological impacts beyond land-use effects, such as reinforcing collective structures, maintaining local economic activities, and easing rural depopulation trends. For instance, the Beaufort production system was an instrument to avoid rural outmigration in the 1960s (Lynch and Harvois 2016). Nevertheless, in our analyses, the impact of financial subsidies highlighted the economic dependence of Alpine agriculture on external support, confirming higher-scale institutional impacts on mountain farming (Schermer et al 2016). We still suggest that focusing agricultural policies on CP1 might not be sufficient and should further incorporate CBIs.

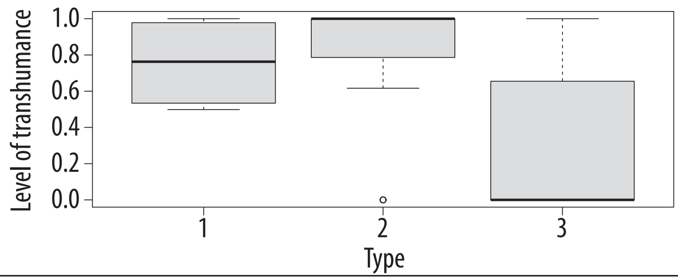
Production typologies

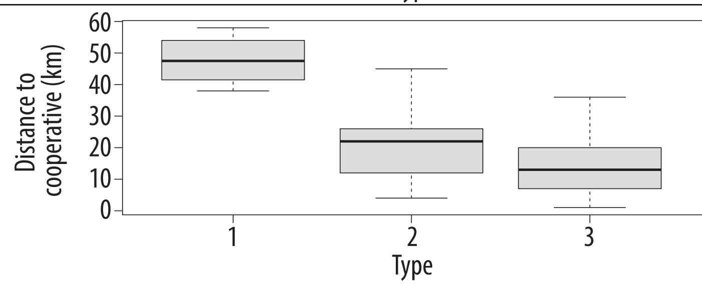
Inductive typological analysis by hierarchical clustering can empirically contribute to advancing middle-range theories of land-system change. These analyses are well suited for regional agricultural systems with specific contexts such as particular biophysical conditions, as in Alpine mountain territories (Meyfroidt et al 2018; Oberlack et al 2019). We suggest that the production of typologies of agricultural

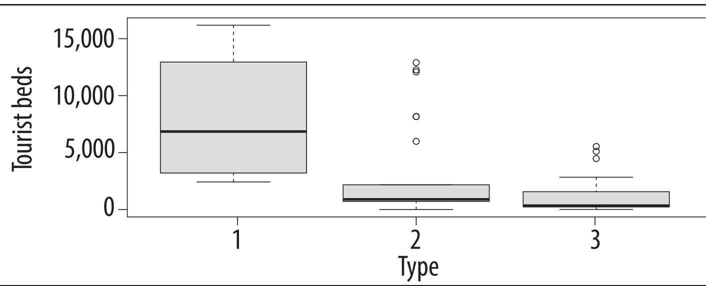
FIGURE 4 Key co-production, demand, and outcome variables for the 3 types.

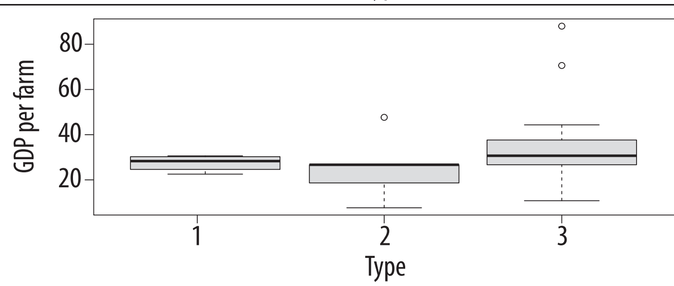
<table>
<tr><td>Biophysical constraints
Elevation (m):
$P = 0.013$

Type 1 vs 2: $P = 0.0095$
Type 1 vs 3: $P = 0.020$
Type 2 vs 3: $P = 0.090$</td><td colspan="3">
</td></tr>
<tr><td>CP0</td><td colspan="3">Same Beaufort rule set</td></tr>
<tr><td>CP1
Level of transhumance:
$P < 0.001$

Type 1 vs 2: $P = 0.91$
Type 1 vs 3: $P = 0.039$
Type 2 vs 3: $P < 0.001$</td><td colspan="3">
</td></tr>
<tr><td>CP2
Distance to cooperative (km):
$P < 0.001$

Type 1 vs 2: $P < 0.001$
Type 1 vs 3: $P < 0.001$
Type 2 vs 3: $P = 0.137$</td><td colspan="3">
</td></tr>
<tr><td>Demand
Tourist beds:
$P = 0.00365$

Type 1 vs 2: $P = 0.026$
Type 1 vs 3: $P = 0.0028$
Type 2 vs 3: $P = 0.26$</td><td colspan="3">
</td></tr>
<tr><td>Outcomes
Production potential value per farm (€): $P = 0.019$

Type 1 vs 2: $P = 0.85$
Type 1 vs 3: $P = 0.50$
Type 2 vs 3: $P = 0.014$</td><td colspan="3">
</td></tr>
<tr><td>Example quotes describing agricultural activites for each type:</td><td>Labor is really expensive and tractors cannot work above a certain slope. For that, everybody wants flat land that we have here.
(Int. 39, Employee, August 2019)</td><td>Here, there are only 3 farms left. The herders are coming from the south with their sheep, the cows from Montmélian [100 km from Maurienne].
(Int. 10, Employee, May 2019)</td><td>There is a lot of irrigation at the bottom of the valley, but here, everything is steep. There are trees, there are the roads, it wouldn't work here. It takes too much time.
(Int. 20, Farmer, October 2019)</td></tr>
</table>

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systems coexisting under a homogeneous rule is relevant to institutional theories of local land-use change (Ostrom 1990; Meyfroidt et al 2018). This can offset the inherent weakness of inductive typologies, such as the lack of causal explanations and their character as a "territorial snapshot" (George and Bennett 2005; Meyfroidt et al 2018). The aggregation of production typologies at municipal level may facilitate higher-scale policymaking by targeting financial support (favoring less accessible, extensive agricultural systems) or urban planning (restricting construction on agricultural land) (Sietz et al 2019). Recent descriptive typologies produced at district level in France indicate the possible interest of public institutions to further operationalize these approaches (Agreste 2019).

Strengths and limitations of the study

This article outlined a complementary mixed-method, data-driven approach to better understand NCP co-production at local level. Our indicators relied almost entirely on easily accessible public data. Thus, these calculations are readily replicable in other agricultural systems (Rocha et al 2020). However, these datasets (eg production potential value, work force) do not describe the subtle benefits (eg personal satisfaction) that people derive from agricultural activities. The previous analysis of our qualitative interview data (Grosinger, Vallet, et al 2021) and previous research in the Alpine region (Hinojosa, Lambin, et al 2016) have shown the relevance of these subjective components.

However, our study has several methodological limitations. Our initial selection of indicators for outcomes did include indicators for cultural and intrinsic values, but these were not retained in the final statistical model due to the absence of significant relationships with any other variable in the co-production chain. Further, the lack of ecological variables at municipal scale limits in-depth analysis of relationships among management practices, biophysical constraints, and institutional influence. For future research, we suggest the integration of downscaled biodiversity indicators. The integration of ecological variables can pave the way toward a genuine adoption of social–ecological system thinking, emphasizing the (inter)dependence of local societies on their surroundings (Ostrom 2009; Vogt et al 2015; Filbee-Dexter et al 2018). It would be tempting to apply our approach to larger scales, but the high biophysical heterogeneity within relatively small spatial areas in mountain regions may lead to trivial or nonsignificant results. The influence of higher-scale institutions, for example, through financial subsidies and external factors such as tourism, limits the capacity of municipal production systems to influence their own functioning. For future research, we recommend a more thorough integration of cross-scale interactions, like the influence of higher-scale institutions and teleconnections at municipal scale (Pascual, Palomo, et al 2017; Meyfroidt et al 2018). Last, our simplified definition of equity may limit our analyses. We considered CBI members as economically equal regardless of their contextual constraints or preferences (Sen 2003). However, social–ecological research has recognized that the benefits of NCP co-production such as the sense of belonging go beyond purely economic criteria, particularly in mountain areas (Hinojosa, Napoléone, et al 2016; Pascual, Balvanera, et al 2017; Madelrieux et al 2018). We suggest that multidimensional approaches like the capability approach could enrich analyses by incorporating people's individual conditions (and objectives) into the analysis of mountain and other marginal regions (Sen 2000).

Conclusion

We demonstrated how the concept of NCP co-production facilitates the structured quantification and classification of agricultural systems across heterogeneous local contexts. Our analyses of the French Alpine Maurienne Valley underlined the crucial role of CBIs in buffering biophysical constraints across a territory. Further investigations of mountain territories could focus on local rule sets and associated governance systems. This research confirmed that the steps of NCP co-production can frame typologies at local scale. Such systematic approaches, which can be transferred to researchers and policymakers, contribute to developing a comprehensive understanding of how heterogeneous mountain agricultural systems provide socioeconomic livelihoods for local populations across specific historical and geographical contexts.

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Supplemental material

APPENDIX S1 Land-use map of the area.
APPENDIX S2 Profile of the interview partners.
APPENDIX S3 Qualitative research and interview guide.
APPENDIX S4 Materials and methods.
APPENDIX S5 Selection of indicators for correlation analysis.

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