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Should abandoned land be redeveloped? A transdisciplinary approach applied to a Mediterranean groundwater catchment

Philippe Le Coent, Nicolas Surdyk, Cécile Hérivaux, Ines Martel

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Abstract:

Land abandonment is a significant challenge in Europe, reshaping ecosystems and socio-economic landscapes. This study investigates its impacts and potential management pathways in a Mediterranean groundwater watershed, facing land use transitions from intensive agriculture to abandonment and grasslands. Using a transdisciplinary approach, we integrate biophysical modelling, stakeholder engagement, qualitative and quantitative surveys to assess the social, economic and hydrogeologic dimensions of abandoned land management. Stakeholder interviews reveal negative perceptions of abandoned land, including increased fire risk and diminished agricultural productivity, alongside some recognition of biodiversity benefits. A survey of 334 residents confirms these views and identifies preferences for repurposing abandoned land, with strong support for extensive pastures but a tendency to favour vegetable cultivation on irrigated lands. Hydrogeological modelling of future scenarios nevertheless highlights significant trade-offs. While abandoned land and extensive grasslands improve groundwater quality, intensive agricultural uses on abandoned land lead to heightened nitrate contamination, conflicting with water management goals. This research demonstrates the contribution of transdisciplinary approaches for the design of land management strategies but also highlights some remaining challenges.

Keywords:

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1 Introduction

Land abandonment has become a prevalent phenomenon in Europe, with an estimated 120 million hectares across Europe since the 1990s (Levers *et al.*, 2018). The Mediterranean region is undergoing two contrasting and interconnected processes of change: on one hand, the abandonment of rural, mountainous, and less economically developed areas, and on the other hand , the intensification of agriculture, urbanization, and escalating human pressures (García-Ruiz *et al.*, 2020; Serra *et al.*, 2008). The main destinations of abandoned agricultural land in Europe, defined here as the cessation of agricultural activities, including of crop production and grazing, with no evidence of management for a minimum duration of 4 years (Prishchepov *et al.*, 2021; Queiroz *et al.*, 2014), are either urban transformation or spontaneous revegetation (Fayet, 2022). Alternative pathways such as the development of managed forests or the return to alternative agriculture uses, require active management actions, such as land management policies for agriculture dynamization and afforestation of abandoned agricultural lands.

Spontaneous revegetation modifies the type and intensity of ecosystem services initially provided by agricultural land. In a meta-analysis of studies carried out in a Mediterranean context, Quintas Soriano et al (2022) highlights the impacts of this phenomenon on a diversity of ecosystem services. Although some research highlights positive impact on biodiversity, soil formation and protection and the improvement of recreational activities, many studies highlight negative outcomes beyond the obvious loss of food production and economic opportunities, such as the loss of biodiversity related to agriculture and open environments and the increase of fire risks, and mixed impact (neither positive nor negative). In terms of disciplines, research on the impact of abandoned land tend to privilege biophysical approaches and include a limited number of results from social sciences on the perception of stakeholders of ecosystem services (Quintas-Soriano *et al.*, 2022). Existing studies of perception and representation of abandoned land overwhelmingly reveal negative views, whether from land owners and people with direct involvement in land management policies (Benjamin *et al.*, 2007; Frei *et al.*, 2020; Kuntz *et al.*, 2018; Moreau, 2019; Weissgerber *et al.*, 2023), local residents (Höchtl *et al.*, 2005; Hunziker, 1995; Ruskule *et al.*, 2013) or tourists (Höchtl *et al.*, 2005; Hunziker, 1995; van der Zanden *et al.*, 2018). These studies largely focus on the aesthetic impact of abandoned land in landscapes, generally perceived negatively (Höchtl *et al.*, 2005; Hunziker, 1995; Ruskule *et al.*, 2013). They also reveal negative emotions towards abandoned land such as sadness or nostalgia or desolation (Hunziker, 1995; Ruskule *et al.*, 2013; van der Zanden *et al.*, 2018) and other perceived effects such as the loss of tradition and cultural heritage (Höchtl *et al.*, 2005; Hunziker, 1995; van der Zanden *et al.*, 2018), the loss of economic opportunity (Hunziker, 1995; van der Zanden *et al.*, 2018) and mixed perception on the impact on biodiversity (van der Zanden *et al.*, 2018). Some positive impacts are perceived mainly on regulating services related to soils (Weissgerber *et al.*, 2023) although other regulating services are considered disturbed, such as increased fire risks (van der Zanden *et al.*, 2018)

Research on abandoned land is mostly focused on disciplinary approaches with almost no studies combining social science and biophysical studies to evaluate the impact of abandoned land and potential pathways for their management, with the exception of Höchtl et al. (2005) that combined the evaluation of the impact on plant biodiversity with perception of locals and tourists. This lack of interdisciplinarity may create limitations in the capacity to formulate land management plans that incorporate societal views of the effect of land abandonment with information on their actual impact (Krueger *et al.*, 2016; Mann *et al.*, 2018; Zscheischler *et al.*, 2015). In addition, we did not identify any studies on the impact of land abandonment on groundwater quality, despite the importance of this issue in Europe and its straight ties with land management. Indeed, agriculture is one of the main contributors to groundwater pollution and the extensification of agriculture and land use change is one of the strategies to reconquer water quality (Neverre *et al.*, 2022).

Our research therefore brings novel insights in the study of land abandonment and their (perceived) impact on ecosystem services. We implement a transdisciplinary approach bringing together

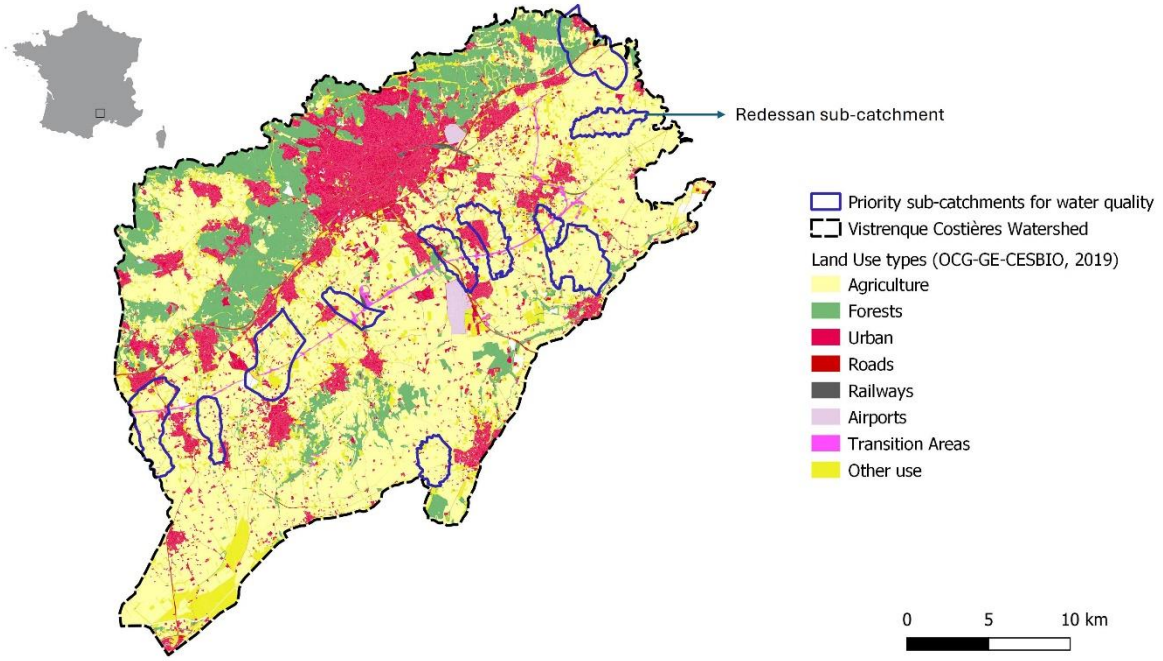
stakeholder participation, biophysical modelling, qualitative and quantitative surveys. We conduct a combination of qualitative interviews, with land-related stakeholders, with and a quantitative survey, with a sample of residents of a territory, on the perception of ecosystem services and disservices generated by abandoned land. We also explore preferred land use changes using the choice experiment method, which examines how the characteristics of abandoned land influence preferred land use pathways. We finally integrate these various social science approaches with stakeholder consultations to develop scenarios, which are then evaluated using our biophysical hydrogeological model. This biophysical model is focused on quantifying one of the unaccounted impacts of land abandonment: their effects on groundwater quality. This methodological sequence is implemented in a case study in the South of France combining high rates of land abandonment, groundwater quality issues and issues related to biodiversity protection. This context is defined by high agricultural potential due to access to irrigation, in contrast to most other studies, which are conducted in mountainous or hilly regions with low agricultural potential (Bauer *et al.*, 2009; Frei *et al.*, 2020; Höchtl *et al.*, 2005; Hunziker, 1995; van der Zanden *et al.*, 2018; Weissgerber *et al.*, 2023).

2 Method

2.1 Case study description

Our case study is the Vistrenque and Costières watershed, which is located in the South of France near the city of Nimes (Figure 1).

Figure 1 : Study Area Map



This watershed, covering a surface of 786 km^2 includes an aquifer used for the supply of drinking water to 182,000 residents. The Vistrenque and Costières aquifers are highly sensitive to surface activities in areas where they are not, or are only minimally, protected geologically by silt layers. The development of urbanization and of intensive agriculture in the 1950s resulted in groundwater pollution from nitrates and pesticides, which has led to the identification of 11 priority sub-catchments to restore the quality of groundwater (Figure 1)This area includes ecologically sensitive territories with a Special Protection Zone primarily established to safeguard the largest population of the endangered Little Bustard (*Tetrax tetrax*) in France.

Over recent decades, the Vistrenque and Costières watershed has undergone significant land use (LU) changes. Historically, this area was predominantly rural, with wine production as the primary activity, supplemented by small-scale livestock farming and itinerant sheep grazing. In the 1950s, the development of the Rhône irrigation network (*Bas Rhône Languedoc*) enabled the introduction of water-intensive crops such as orchards and vegetables. From 1970 to 2020, the region experienced a 30% reduction in agricultural land, mainly due to urbanization around Nîmes, agricultural land abandonment, and infrastructure development, such as the high-speed rail line (LGV) [1].

During this period, vineyard areas, which comprised 30% of agricultural land in 2020, were halved, primarily due to recurring viticulture crises and challenges in improving wine quality. Cereal cultivation also declined by half, representing 12% of agricultural land in 2020. In contrast, there was a significant increase in grassland areas, expanding from 10% to 29% of agricultural land between 1970 and 2020, driven by the revival of sheep farming largely supported by a very large biodiversity offsetting program (associated with the construction of the LGV infrastructure development) that converted abandoned vineyards into grassland systems.

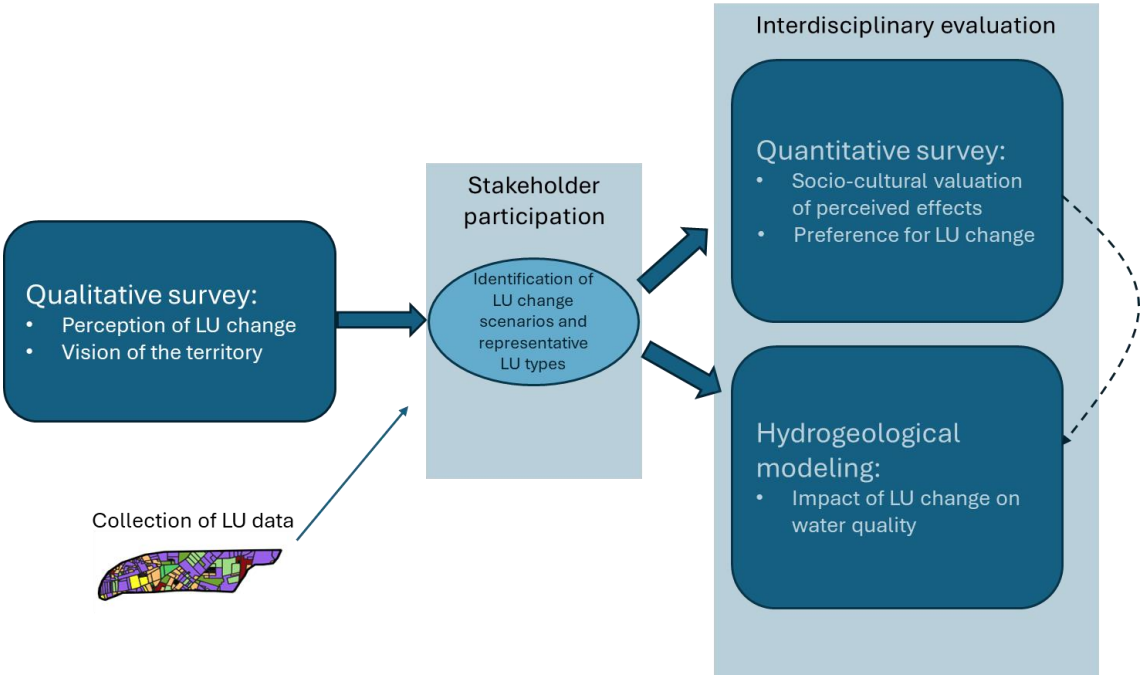
The widespread occurrence of abandoned land and the recent surge of extensive grassland is prompting stakeholders to question the future evolution of land use in the territory. Some stakeholders argue for the redevelopment of agriculture, either as an economic sector or to enhance local food production systems to supply the neighbouring city of Nimes, while others advocate for preserving the mosaic of habitats created by the recent changes in agricultural practices. Our study aims to address the following research questions:

- RQ1: How do stakeholders perceive land use changes, and what are their alternative visions for managing abandoned land?
- RQ2: How do residents perceive land use and its impacts on ecosystem services and disservices, and what are their preferences for the future use of abandoned land?
- RQ3: What would be the potential impact of future scenarios, aligned with these visions and preferences, on groundwater quality?

[1] Land use figures are extracted from the French Agricultural Census from 1970 to 2020 (INSEE)

2.2 Interdisciplinary evaluation of Land Use Change

Figure 2 : Overall methodological approach



In order to assess these research questions, we developed in interdisciplinary research method described in Figure 2. The first step consisted in a qualitative survey aiming at describing the perceptions of land abandonment of local stakeholders and more generally land use change in the territory and the perception of ecosystem services and disservices generated by this change. This approach was instrumental in 1) understanding qualitatively the perception of land use change, 2) constructing the quantitative survey with prior information on the local perception of ecosystem services and disservices, and 3) highlighting alternative visions for the future of the territory that could be used to identify scenarios.

The second step involved the participation of stakeholders for the identification of scenarios. In this step, we also identified types of land use representative of different visions of future LU change to be evaluated in the following steps of the study.

The final step involved the interdisciplinary evaluation of the impact of scenarios through 1) the hydrogeological modelling of LU change scenarios to estimate their impact on groundwater quality and 2) the socio-cultural evaluation of the effects of land use change through a quantitative survey with 334 residents of the territory, as well as the evaluation of the preference of residents of the watershed for the use of abandoned land. This evaluation led to the design of an alternative scenario to be evaluated with the hydrogeological model based on public preferences.

2.2.1 Qualitative survey on the perception of land use.

The study employed semi-structured interviews for their ability to capture the detailed, subjective perspectives of participants.

An interview guide was developed to gather information on the main themes of interest. These themes included:

1) Life experiences in the territory and their relation to land use,

2) description of their reference state, which is the state considered as “normal” in the history before “disturbances” occurred (Moreau, 2019). This subjective reference state may reveal the desire of respondents for the future of the territory,

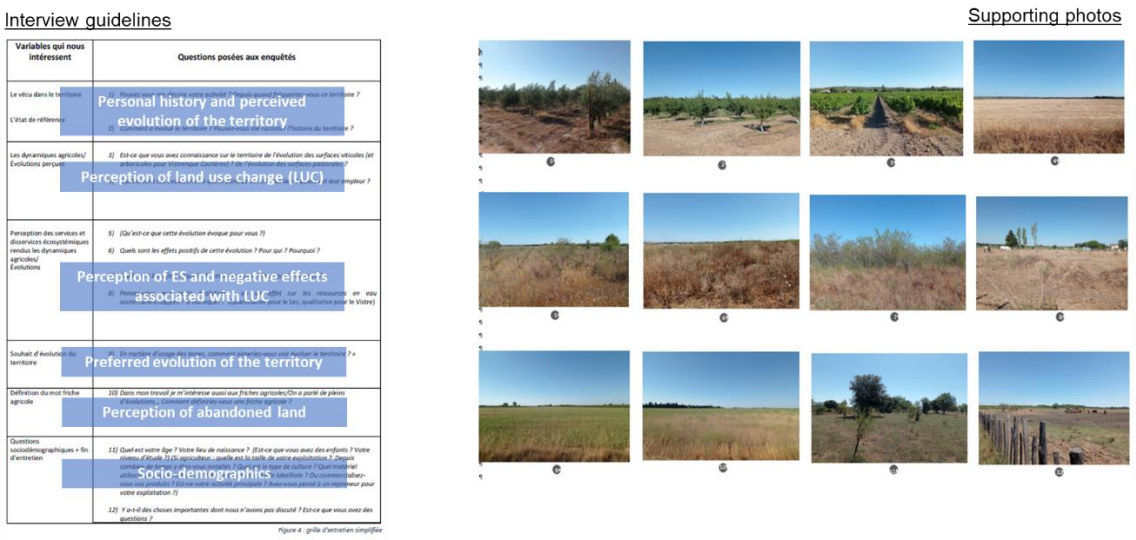
3) perceived land use dynamics since the state of reference,

4) perceptions of ecosystem services and disservices were discussed based on the prevailing land use identified in point 3. The idea in this section was to let respondents spontaneously identify the main services and disservices associated with land use instead of imposing specific lists of services and disservices (de Oliveira *et al.*, 2014; Klain *et al.*, 2014; Moreau, 2019). Although we did not carry out a photo elicitation survey (e.g. Zoderer *et al.*, 2019), photos of the different types of land use present in the territory were used as an accompanying tool in order to clarify the land use under discussion. The questions were carefully phrased to avoid influencing responses by using neutral terms like "evolutions" and "positive or negative effects" instead of more specific terms such as ecosystem services or disservices.

5) perception of abandoned land

6) socio-demographic variables

Figure 3 : Qualitative interview guidelines and sample pictures.



The study involved interviewing individuals connected to land management. A total of 12 interviews were conducted with 5 wine growers, 1 orchard farmer, 2 animal farmers, 2 elected officials and 2 environmental associations.

The interviews were analysed using the thematic analysis methodology, a method that identifies recurring themes within the data using the software QDA Miner lite. The analysis included both pre-defined themes (ecosystem services and disservices) and new themes that emerged during the interviews. The analysis also aimed at identifying alternative visions of the territory based on responses on preferred evolution of the territory.

2.2.2 Stakeholder participation

Stakeholders involved in institutions for the management of LU and water quality were involved at distinct stages of the process. They were especially involved through three different workshops focused on: i) the elaboration of land use scenarios to be evaluated in the hydrogeological model and the choice of representative land use types to be evaluated in the survey; ii) the discussion and validation of the

hypotheses of the hydrogeological model and iii) the construction and validation of the quantitative survey.

In addition to scenarios, these discussions led to the identification of four land use types representative of different future of the territories which are subsequently used in the interdisciplinary evaluation:

- Abandoned agricultural land
- Pasture and forage represent a more extensive vision of agriculture development
- Vineyards is the main historical land use in the area
- Vegetable production is associated with food security but also a more intensive form of agriculture

Reasons for choosing these land use types are described in the results section.

2.2.3 Quantitative survey of effects of land use, including land abandonment

2.2.3.1 Socio-cultural evaluation

In this research, our aim was to evaluate the effects, including ecosystem services and disservices associated with the four representative land uses.

Non-monetary ecosystem service assessment method are receiving increasing interest for their capacity to evaluate the whole spectrum of ecosystem services, and to assess the values not well captured by monetary methods (Cheng et al., 2019; Peck et al., 2021) such as non-self-interested values (Scholte et al., 2015) or also because people make decisions over nature based on both cognitive and experiential processes (e.g. emotions, experiences, attachments and not necessarily on rational decision (assumed in monetary valuation) (Markanday *et al.*, 2024). Assessment methods for ecosystem services aim to understand and measure the value that communities and individuals assign to the services provided by ecosystems. While there is no standardized methodological approach for non-monetary assessment methods, survey-based methods are dominant (Cheng *et al.*, 2019; Jacobs *et al.*, 2018; Scholte *et al.*, 2015).

Survey methods generally involve individual rankings where ecosystem services (ES) are assigned a value, for example, based on the proportion of respondents who perceive them, using a Likert scale (Jadin *et al.*, 2022; Villanueva *et al.*, 2023; Viti *et al.*, 2023), and/or ranking them by importance (Jadin *et al.*, 2022; Oteros-Rozas *et al.*, 2014).

In this survey, we first addressed the importance respondents place on different possible effects of land use (rated from 1-Not at all important to 5-Very important). Next, after providing definitions of the different land-use categories and presenting a representative picture of this land use, respondents were asked the following question: "In your opinion, how do these land uses contribute to the following objectives?" (rated from -2 Very negatively to +2 Very positively).

The list of effects is derived from the results of the qualitative survey (See section 3.1) and consultations with stakeholders. It includes both classic ecosystem services as well as other negative effects identified by stakeholders. The effects are presented in the questionnaire as contribution to territorial objectives and are framed positively:

Figure 4 : List of effects of land use types used in the questionnaire.

TERRITORIAL PLANNING OBJECTIVES	CONTRIBUTION FROM LAND USE
Maintenance of farming activities	Promotes the farming activities in the territory
Food production	Enables local production of plant- or animal-based food
Climate regulation	Fights climate change by fixing CO2 and makes the local climate milder (temperature reduction, etc.)
Flood protection	Limits flooding, especially by retaining water in the soil and vegetation
Fire protection	Limits the start and spread of fires
Improvement of groundwater recharge	Promotes water infiltration to aquifers
Improvement of water quality	Promotes infiltration of good-quality water into aquifers
Soil conservation	Prevents soil erosion and enhances soil capacity for plant production
Improvement of air quality	Captures air pollutants or prevents the emission of harmful substances
Landscape preservation	Contributes to pleasant landscapes
Preservation of cultural identity of the territory	Helps maintain local know-how and traditions
Accessibility of spaces for outdoor activities	Improves access for nature sports and recreational activities (hiking, cycling, hunting, fishing, etc.)
Biodiversity protection	Provides habitats for a variety of plant and animal species
Reduction of nuisances for neighboring residents	Reduces nuisances (noise, odors, etc.) for neighbors
Control of damage from wild animals	Unfavorable for the development of harmful animals for agricultural production (wild boars, rabbits)

In the following, we group these effects for presentation according to the Millenium Ecosystem Service Assessment classification (MEA, 2005) to which we add disservices. This classification was however not used in the questionnaire.

2.2.3.2 Preference for land use change

The evaluation of the preference for land use change is based on the choice experiment method (Lancaster, 1966) but with two specific features. First, our aim was not to evaluate the willingness to pay but rather to evaluate the influence of certain land characteristics on the preferences of residents for different land use. In addition, there was no credible vehicle of payment to be used in the evaluation. We therefore conduct a choice experiment without vehicle of payment. Second, in choice experiments the main aim is to study the influence of attributes on the probability to choose alternative. In this case, we ask respondents to choose the land use that they would like local authorities to promote on different types of abandoned land which is characterized by only one attribute: the future land use picked from the list of land use types described in section 2.2.2; vineyard, vegetable production, pasture/fodder production or no action (leading to the development of shrubs and trees). The rest of the attributes are constant among the alternatives since they characterize the type of abandoned land under consideration and therefore are rather characteristics of the status quo.

We therefore estimate the impact of various characteristics of the abandoned land on the probability to choose future land use types, with the following hypotheses:

- Vegetation development (Herbaceous or trees). The vegetation development on abandoned land varies depending on the time since abandonment, reflecting different stages of rewilding. Our assumption is that for abandoned land which has reached the development of trees, residents may view these areas as being closer to a natural state and prefer them to remain unchanged (Hand *et al.*, 2008; Hoshino *et al.*, 2010; Mansfield *et al.*, 2005; Tu *et al.*, 2016) or managed extensively with animal farming (compatible with the maintenance of trees).
- Access to irrigation (Yes/ no). This characteristic prompts to the agronomic potential of the land and therefore the loss of agricultural production associated the abandonment of land. In addition, certain land uses, particularly vegetable production and, to a lesser extent, vineyards require irrigation. Our hypothesis is that respondents will favour vegetable production and, to a lesser extent, vineyards on this type of land.
- Location (Sub-urban, agricultural area, natural area). We aim to determine whether the location of the abandoned land may influence preferences. Intuitively, respondents may prefer abandoned land to remain unmanaged or managed through animal farming close to natural areas and prefer agricultural uses in agricultural areas. We had no specific hypotheses for sub-urban areas since many factors may influence preferences: willingness of proximity of food production but concerns about negative externalities associated with nuisance of agriculture (pesticides, noise…), fears for fire risk leading to preference for managing abandoned land.
- Past state: agriculture or abandoned land. Our hypothesis here is that respondents may have a preference for status quo (Anderson, 2003; Barreiro-Hurle et al., 2018; Meyerhoff & Liebe, 2009; Samuelson & Zeckhauser, 1988), and therefore have a preference for the return to agricultural use for lands that were farmed in the past, and preference for maintaining as abandoned land already abandoned ten years ago.

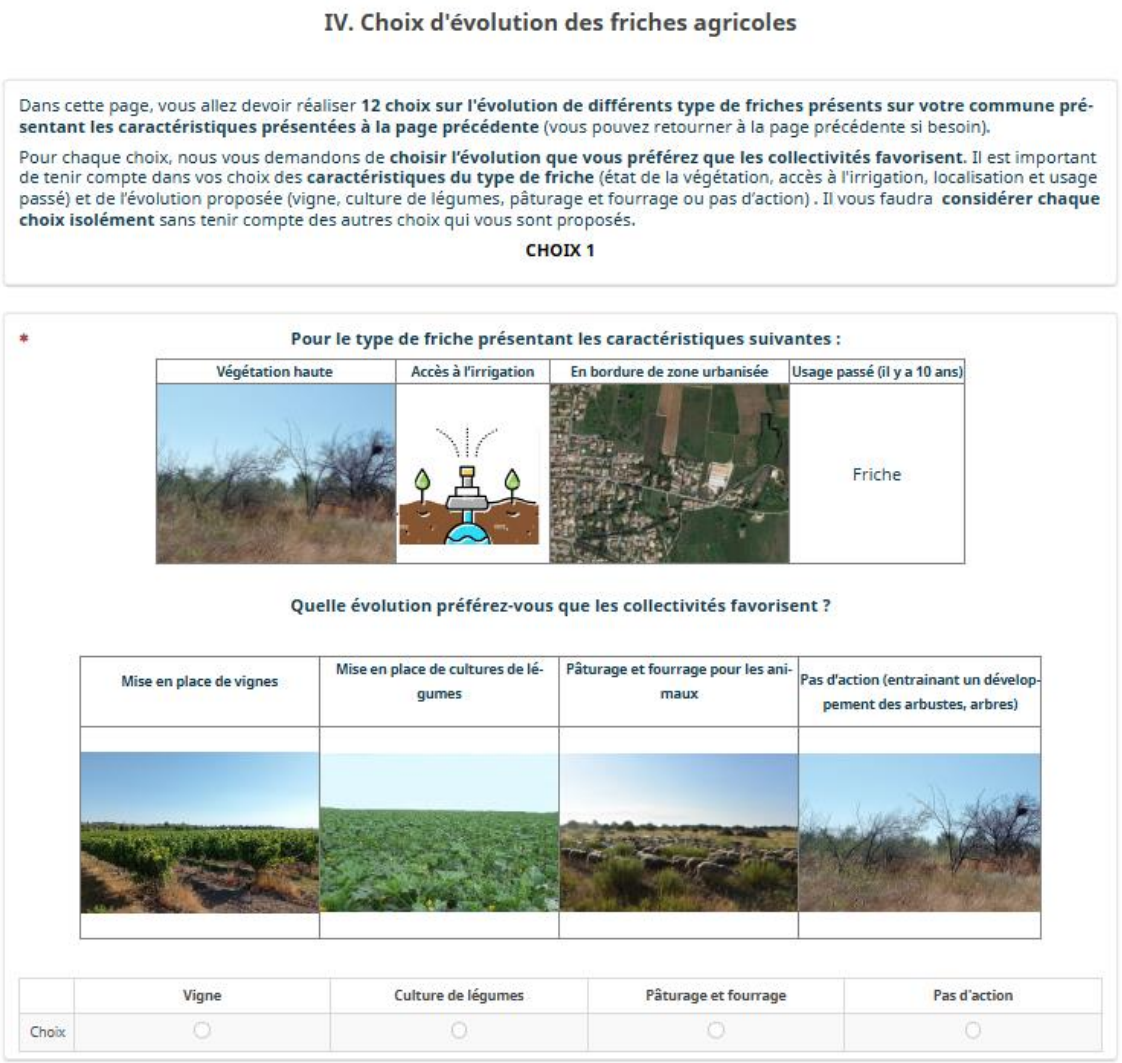
A full factorial design includes 24 possible combinations of these characteristics of abandoned land. To avoid cognitive fatigue, each respondent chose their preferred land use for a subset of 12 random combinations of these characteristics of abandoned lands. A sample of choice card is presented in Figure 5.

The econometric modelling relies on classic choice modelling approaches, but our main interest does not lie in the main effect of the attributes; rather, it is in the interaction of the effect of the sole attribute (land use) with characteristics of the abandoned land. We test two different approaches: the classic multinomial logit approach (McFadden, 1974) and the mixed logit model (mixlogit model in Stata (Hole, 2007); 500 Halton draws) with main effects of the land use types and interaction with land use characteristics as normally distributed parameters.

In addition to studying the determinants of land use choice, we predict the probability of each land use to be chosen by respondents based on these characteristics using the predicted probabilities of choice (predict for clogit and mixlpred for mixlogit in Stata). Based on these estimations, we can determine the preferred land use for each combination of characteristics (the land use with the highest probability of choice). This approach enables the design of scenarios based on preferred land use of residents in areas where the abandoned land use characteristics are known.

The questionnaire was administered on-line and diffused via several communication channels: a polling company, announcement in the medias and diffusion through the network of local stakeholders.

Figure 5 : Example of choice card.



IV. Choix d'évolution des friches agricoles

Dans cette page, vous allez devoir réaliser **12 choix sur l'évolution de différents type de friches présents sur votre commune présentant les caractéristiques présentées à la page précédente** (vous pouvez retourner à la page précédente si besoin).

Pour chaque choix, nous vous demandons de **choisir l'évolution que vous préférez que les collectivités favorisent**. Il est important de tenir compte dans vos choix des **caractéristiques du type de friche** (état de la végétation, accès à l'irrigation, localisation et usage passé) et de l'évolution proposée (vigne, culture de légumes, pâturage et fourrage ou pas d'action) . Il vous faudra **considérer chaque choix isolément** sans tenir compte des autres choix qui vous sont proposés.

CHOIX 1

* **Pour le type de friche présentant les caractéristiques suivantes :**

Végétation haute	Accès à l'irrigation	En bordure de zone urbanisée	Usage passé (il y a 10 ans)
			Friche

Quelle évolution préférez-vous que les collectivités favorisent ?

Mise en place de vignes	Mise en place de cultures de légumes	Pâturage et fourrage pour les animaux	Pas d'action (entrainant un développement des arbustes, arbres)

	Vigne	Culture de légumes	Pâturage et fourrage	Pas d'action
Choix	○	○	○	○

2.2.4 Modelling of the impact of land use change on groundwater

The evaluation of the impact of land use change on groundwater required a change of scale. While studies on the perception of land use change were carried out at the overall case study scale, evaluating the impact required focusing on a sub-catchment where land use dynamics were precisely known, where long time series of groundwater quality and piezometric data were available, and where significant land abandonment had occurred. On this basis, the sub-catchment of Redessan was selected (Figure 1).

To assess the impact of land use scenarios on the evolution of groundwater nitrate concentrations, the co-constructed scenarios were simulated with the nitrate transfer model BICHE (Thiery et al., 1985). BICHE is a lumped model, representing the watershed as a cascade of surface, intermediate and deep compartments. Processes are represented by simple laws, which parameters are specific to each compartment. BICHE simulates the evolution of groundwater nitrate concentration at the drinking water well by considering the catchment, without spatial discretization. It does not require a comprehensive hydrogeological survey of the study area. Through a calibration phase, model parameters are adjusted to fit the observed time-series (piezometric levels and nitrate concentrations). As a hydrological lumped model, it is designed to evaluate long term trends (not to reproduce short-term variations). The BICHE model was selected for its ease of use and its low input data requirement.

There are numerous modelling studies that highlight the impact of changes in agricultural practices and land use on nitrate concentrations (Kersebaum *et al.*, 2003; Neverre *et al.*, 2022; Olesen *et al.*, 2019). One of the challenges here was to simulate the impact of abandoned land. Abandoned land is characterized by spontaneous vegetation successions that facilitate the transition from cropland to an arboreal stage (Xiao et al., 2018). The impact of this succession on nitrate transfer remains difficult to determine, depending on the vegetation age (stage in succession) and the species composition (Prévosto *et al.*, 2006; Xiao *et al.*, 2018). In these simulations, abandoned land was treated as unfertilized grass covers. No changes in vegetation type were considered. A realistic and representative abandoned land type was simulated for a Mediterranean environment, even though there is no single "typical" abandoned land. The evolution of land use in the past was constructed based on data provided by the local institution in charge of implementing programs to restore water quality (see Figure 11 to Figure 16 in supplementary material). Fertilization practices were first based on existing references and amended and validated during a specific stakeholder workshop.

3 Results

3.1 Perception of land use change and vision of the territory

In this section, we present the results of the qualitative survey; we highlight the main land use trends identified by respondents, the main effects associated with the different land use and the different visions of the territory that came out of respondent's discourse.

The abandonment of vineyards and orchards resulting in the development of abandoned land, is the main land use trend identified by stakeholders, resulting in the contraction of agricultural land. This trend is perceived to be due to the wine and fruit crisis of the 90s. The resulting abandoned land encompasses a diversity of type of land use in which a high herbaceous stratum dominates with some shrubs and trees. Respondents include in this category: land where no activity is undertaken, land with a few horses for leisure activities or land where the grass is irregularly harvested or grazed. When these lands are used for regular pasture, they are considered newly as agriculture land. Respondent, indeed, identify a recent surge of animal farming in the last 5 years in the area. Different drivers are identified to explain these dynamics. First, the wine market crisis and resulting policies has encouraged the abandonment of vineyards and the uprooting of wine plants. Second, the ageing of farmers and the lack of young generation farmer wishing to take over farming activities is leading to farm abandonment. Finally, the large biodiversity programme implemented to offset the destruction of habitats associated with the construction of the TGV railway line is also considered to have perpetuated the abandonment of historical agricultural land use, by acquiring land and passing contract with farmers to maintain an herbaceous cover on abandoned vineyards and orchards. This programme is also responsible for the redevelopment of animal farming in the territory.

Figure 6 illustrates the main ecosystem services and disservices associated with abandoned land, grassland and vineyards. Only the spontaneously mentioned effects are included and only for land use that were considered to have changed significantly in the recent past. For the same service, the impact may be perceived as positive (in green) or negative (in red) depending on respondents. For abandoned land, the main disservices perceived are the increase of fire risk, the damages on crops generated by wild animals that live and reproduce in abandoned land (rabbits, wild boars), the reduction of food production and the degradation of landscape. Positive effects are limited to biodiversity and soil conservation. Grassland is perceived to have limited negative effects but to have a positive effect mainly on the improvement of water quality and fire risk reduction. The main positive effect of vineyards are the increase of agricultural production and the reduction of fire risk.

Figure 6 : Ecosystem services and disservices associated with Abandoned land, grassland and vineyards in the qualitative survey.

Overall, we interpreted the results of the qualitative survey along three alternative visions of the future of land use, each underpinned by a distinct perspective on abandoned land supported by a distinctive group of stakeholders.

- Back to the past: This group only perceives negative effects of abandoned land and an increase of this phenomenon over the years. They associate negative emotions to abandoned land: « an abandoned vineyard is like an abandoned house: it hurts » and are nostalgic about the past. This group, composed solely of farmers, wants a return to the land use mix of the past.
- Pro-diversity. The members of this group have a more balanced perception of abandoned land with a perception of ecosystem services, and ecosystem disservices associated with abandoned land. This group is more neutral about the past and aims at a future that maintains a diversified territory with landscape, food autonomy, agriculture and environment. The members of this group belong to distinct categories including elected people.
- Pro-nature. Finally, this group, composed of members that are not directly involved in agriculture, consider that there is a general decrease of natural land and do not perceive negative effects associated with abandoned land. They want to see overall more space dedicated to natural areas.

The results of the qualitative survey were presented to stakeholders and were use used as a basis to identify three scenarios that they wished to be simulated in the hydrogeological model for the sub-catchment of Redessan:

- Back to past scenario: land use is back to land use from 1994, i.e. with no abandoned land and pasture and dominated in this order by vineyards, orchards, wheat and vegetable production (in agreement with the back to past vision)
- Status quo scenario: maintaining the balance of 2020 between vineyards, orchards, pastures and abandoned land and is in agreement with the pro-diversity scenario.

- 100% grassland: this scenario is an extreme benchmark which is a caricature of the pro-nature vision. It aims at understanding the effects of the disappearance of agriculture activities on water quality.

Details of the land use composition of each scenario are provided in Figure 11 to Figure 14 in supplementary material.

Overall, the visions highlighted during the qualitative survey and the scenarios formulated during the stakeholders consultation also led to the identification of the 4 representative land use mentioned in the methodology section:

- Vineyard, which is the main representative of the "back to past" scenario.
- Vegetable production which matches one of the aims of the "pro-diversity" vision of the territory, in its food autonomy component, as well as one of the elements of the "back to past" land use.
- Grassland which represents an extensive vision of agriculture and a better compromise with the environment, also coherent with the "pro-diversity" scenario.
- Maintaining land abandonment, with eventually a return to a natural state, which represent the "pro-nature" vision of the territory.

3.2 Quantitative survey of resident perception and preferences

3.2.1 Sample description

Our sample gathers 334 respondents. The characteristics of respondents are presented in Table 3 in supplementary material. The sample is comparable to the general population of the area with two limitations: i) a slight overrepresentation of women ii) a limited presence of unemployed and workers. The sample is evenly distributed across the area, with 30% of respondents residing in the main city of Nimes and the remainder spread throughout the territory (see Figure 9 in supplementary material). Only 15% of the sample considered the information provided insufficient or largely insufficient (2%). We decided to keep these respondents in the sample.

3.2.2 Socio-cultural evaluation of services of land uses

For this analysis, we first focus on the importance given to the different services and then on the perceived contribution of different land uses to these services.

The results of the quantitative survey show a fairly high level of homogeneity in the importance of the different objectives (cf. Table 1). However, it is noteworthy that the services related to flood regulation, fire prevention, water recharge, and water quality are considered the most important by the respondents, even more so than provisioning services. Among these, only the service related to fire regulation is statistically more important than the others (ANOVA, Tukey's test). The strong emphasis on fire risk, therefore, is confirmed from the qualitative survey. Disservices, such as nuisances caused by wild animals and neighbours, as well as accessibility of spaces, are considered significantly less important than other effects.

Table 1 : Average importance score for ecosystem services and disservices in the sample (N=334)

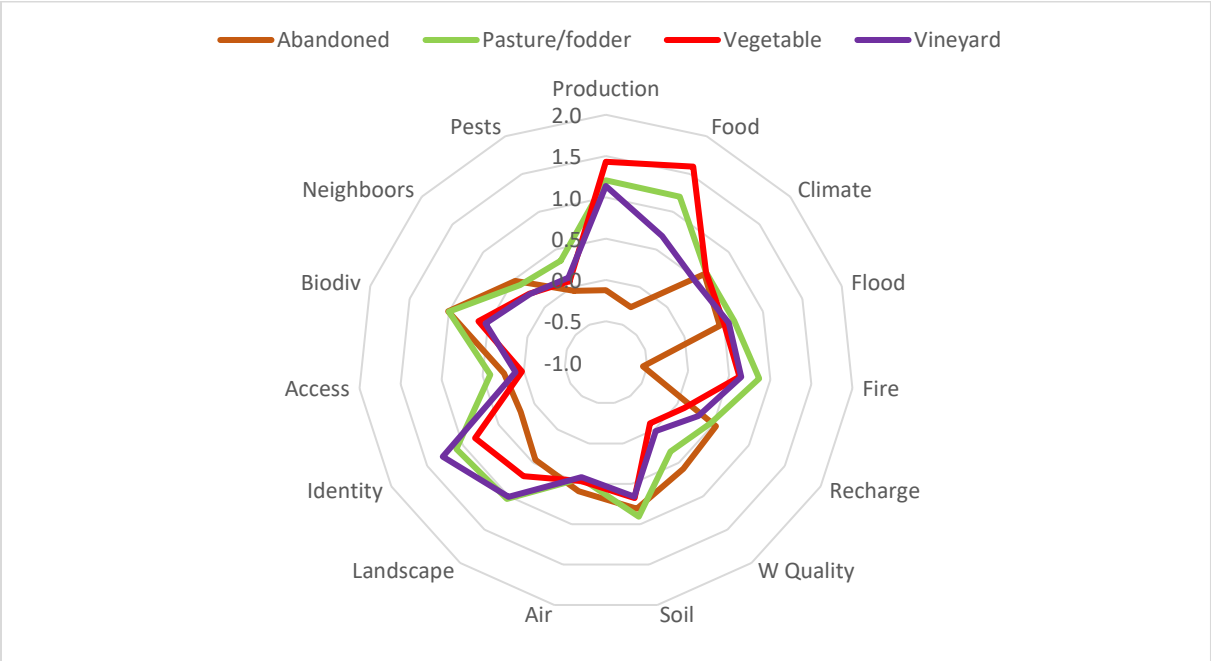
		IMPORTANCE
PROVISIONNING	Production	4.3
	Food	4.3
REGULATION	Climate	4.2
	Flood	4.4
	Fire	4.5
	Recharge	4.5
	Water Quality	4.5
	Soil	4.2
	Air	4.2
CULTURAL	Landscape	4.3
	Identity	3.9
	Access	3.7
SUPPORT	Biodiversity	4.3
DISSERVICES	Neighbours	3.7
	Pests	3.3

The perception of the contributions of different land uses to services described in Figure 7, shows that pastures are regarded as the land use providing the highest level of perceived services: provisioning services (though slightly lower than vegetable crops), regulating services (notably fire risk), cultural services (with the highest levels for landscape and just after vineyards for the cultural identity of the territory), and biodiversity. Thus, although during the qualitative interviews, some stakeholders questioned the redevelopment of livestock farming, it is ultimately perceived as having the most positive effects by the inhabitants of the territory.

Although abandoned land use is sometimes seen as contributing to biodiversity, it is regarded as the most unfavourable land use due to its negative impact on fire risk, provisioning services, the landscape, and the identity of the territory. We therefore also observe that perceived salient effects of abandoned land are consistent with the results of the qualitative survey.

Vineyards are perceived to fall behind pastures mainly on regulating services but is considered as the land use that promotes the most the local cultural identity. Vegetable production shares similarities with vineyards, exhibiting a stronger emphasis on food provisioning services but a weaker connection to cultural identity.

Figure 7 : Ecosystem services and disservices associated with Abandoned land, grassland, vegetable and vineyards in the qualitative survey (The value is equal to the average of the perceived effect from -2 very negative to +2 negative)



3.2.3 Preference for land use change

The econometric analysis of the choice experiment presented in Table 2 confirms two hypotheses formulated on preferences. First, the interaction between "high vegetation" and the three land use effects is negative and significant. This reveals that if abandoned land bears secondary vegetation with a tree stratum, residents tend to prefer to keep land evolve naturally rather than re-developing an agricultural land use. This is consistent across future land use types. Second, the interaction between "irrigation" and "vegetable" and "irrigation" and "vineyard" is significant and positive, whereas it is negative for grassland. Residents therefore prefer that abandoned land with access to irrigation be converted to vegetable production and to a lesser extent to vineyard (lower value of the coefficient). On the contrary, they are less likely to prefer the conversion of abandoned land to pasture when land has access to irrigation. A third results is a general preference for the conversion of abandoned land to pasture/fodder production, all other things being equal. This is consistent with the results of the socio-cultural evaluation that revealed that pastures are perceived to have on average the land use with the most positive effect. There is finally a negative preference for the conversion of abandoned land to vineyards, which however only appears on the mixed logit model. Results are less clear regarding the influence of location on land use preference. Quite unexpectedly, residents prefer the conversion of land to the vineyard or vegetable production in suburban areas.

Table 2 : econometric modelling of the choice experiment. Land use are main effects whereas effects listed under the main effects are interactions with land use characteristics (Abandoned land is the reference modality)

	Conditional logit	MXL (WTP space)	
	Coeff	Coeff	SD
Vineyard	-0.18	-0.44***	1.19***
High vegetation	-0.30***	-0.41***	-0.50**
Irrigation	0.32***	0.36***	0.62***
Natural area	0.06	0.05	0.50**
Sub-urban area	0.33**	0.35**	0.42
Past agriculture	0.18*	0.22*	0.28
Vegetable	0.17	-0.02	1.05***
High vegetation	-0.36***	-0.46***	0.49***
Irrigation	0.79***	1.01***	0.84***
Natural area	0.14	0.21	0.44**
Sub-urban area	0.35**	0.46***	-0.55***
Past agriculture	0.14	0.17	-0.39**
Pasture/fodder	0.67***	0.65***	0.85***
High vegetation	-0.24**	-0.28***	0.45***
Irrigation	-0.13	-0.15	0.42**
Natural area	0.05	0.06	-0.27
Sub-urban area	0.04	0.02	0.48**
Past agriculture	0.05	0.06	-0.21
Obs.	16032	16032	
Log-likelihood	-5304	-5043	
LR chi² (11)	503.56	522	
Prob chi2	0.00	0.00	
AIC	10644	10158	
BIC	10783	10434	

The prediction of probabilities to accept the alternatives for the 24 possible combinations of abandoned land use characteristics are presented in the supplementary material (Table 4). The interactive effect of access to irrigation with the preference for vegetable production and the main effect for pasture and fodder production appear to be the main determinants of land use preferences. In fact, resident prefer that local authorities support the conversion of abandoned land to vegetable production when irrigation facilities are available and to pastures and fodders if not. The rest of land use characteristics does influence the probability of choice but not sufficiently to affect preferred land use change.

Based on information about abandoned land use characteristics in a specific area, we could therefore predict the preferred land use by residents of the watershed. For example, in the Redessan sub-catchment, which is studied in the hydrogeological model, all abandoned land has access to irrigation. We can therefore estimate that the preferred scenario for residents would be the conversion of all

abandoned land to vegetable production in the future. This scenario is therefore added to the scenarios formulated by stakeholders in the hydrogeological modelling section.

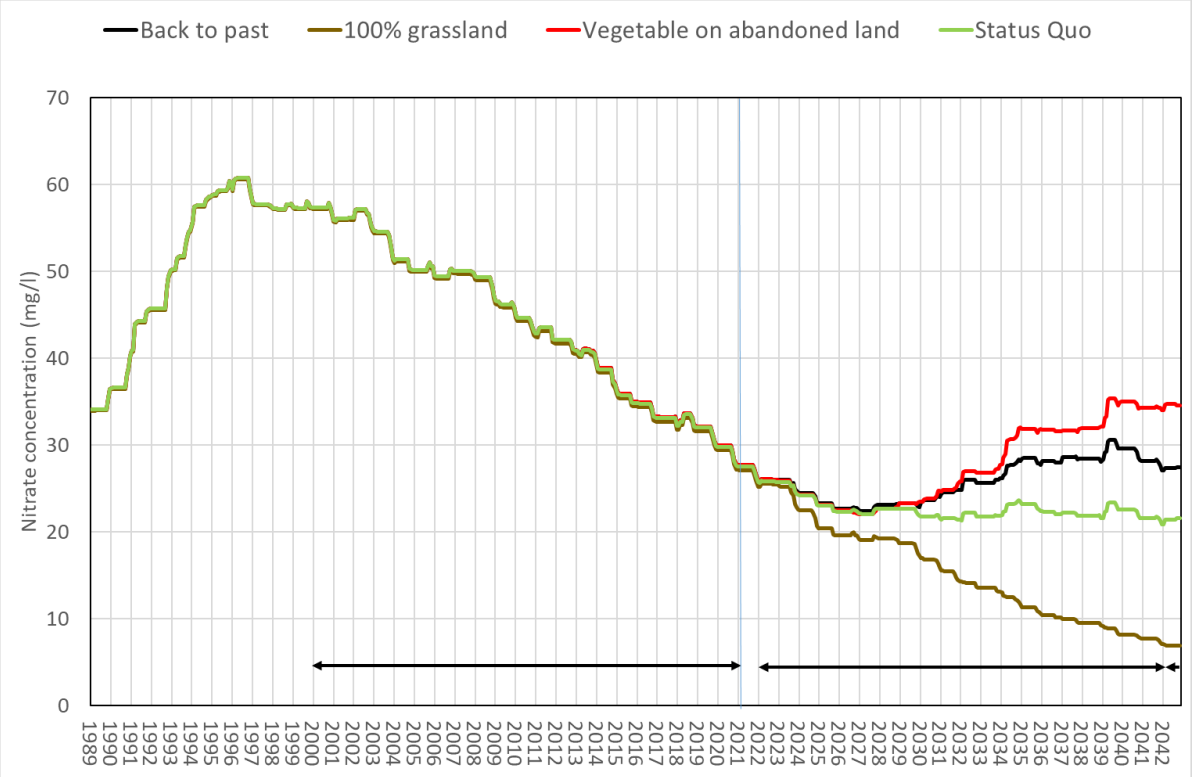
3.3 Impact of land use change scenarios on water quality

Based on the surveys and the stakeholders process, we therefore decided to estimate the impact of four scenarios requiring evaluation for their impact on water quality: back to past, status-quo, 100% grassland and the final scenario based on resident preferences- the vegetable on abandoned land scenario.

Before, evaluating the scenarios, the model was first calibrated based on past piezometric levels and nitrate content, past land use and information on the evolution of fertilisation practices in the sub-catchment of Redessan. The quality adjustment criteria (square root of the Nash coefficient) during the calibration phase were considered satisfactory. The value is high for hydrological modelling (value > 0.71), and the simulation accurately reproduces seasonal fluctuations as well as interannual variations. The adjustment criterion value for the water quality aspect is also high (value > 0.91). The calibration curves are provided in the supplementing material.

The result of nitrate concentration simulations for the four scenarios are presented in Figure 8.

Figure 8 : Simulation of nitrate concentrations in the Redessan sub-catchment with the Biche model for 4 future land use scenarios.



The results of the Biche simulations indicate contrasting results for the evolution of nitrate concentrations at the water abstraction point of the Redessan sub-catchment. As expected, the extreme benchmark of a full conversion to grassland would lead to a constant reduction of nitrate concentrations. The concentrations measured here are low and even approach the thresholds often estimated for uncultivated land (Limbrick, 2003), which is quite rare in existing research. The status-quo also expectedly leads to a stabilization of nitrate concentrations at acceptable levels around 20mg/L of nitrates (the drinking water standard is 50mg/L). The “back to past” scenario leads to a moderate increase of nitrates of about 7 mg/L. Surprisingly results do not come back to past levels of nitrates

observed at the beginning of the calibration phase. This is due to the evolution of agricultural practices, such as for example the reduction of nitrate fertilisation on vineyards from 100kg/ha of nitrate at the beginning of the period to 50kg/ha presently. These evolutions are accounted in the simulation, since we maintained agricultural practices constant at the present levels in the simulations.

Finally, the increase of nitrates associated with the conversion of abandoned land is quite significant (+15mg/L after 20 years). This evolution was expected considering the high levels of nitrates used for these crops. Interestingly, this scenario which results from resident preferences leads to a significant and preoccupying increase of nitrate pollution in groundwater, considered as a strong policy priority by decision makers of the area.

4 Discussion

The results of the qualitative survey revealed that the perception of abandoned land is largely negative among stakeholders, primarily due to its association with increased fire risk, the increase of damages to crops by wild animals, reduced agricultural production, and detrimental impacts on landscapes. Stakeholders nevertheless perceive the ecosystem services generated by abandoned land, especially on biodiversity and water and soil. Interestingly, the socio-cultural evaluation of services of abandoned land, evaluated in our quantitative survey with a sample of residents, is coherent with these results, except for the damages generated by wild animals. Non-experts seem to share similar views on the effects of abandoned land, considering it the least beneficial land use compared to other major land use types, such as vineyards, vegetable production, and pasture/fodder production. These results are consistent with previous findings in different contexts, that highlight a negative perceptions of abandoned land (e.g Benjamin *et al.*, 2007; Höchtl *et al.*, 2005; Hunziker, 1995; Ruskule *et al.*, 2013). The coherence of perception between lay people and experts is also similar with the other study that compares the perceptions of these two categories of people (Ruskule *et al.*, 2013).

The quantitative survey indicates that pasture and fodder production is seen as providing the best balance among the various ecosystem services and disservices. This positive perception is confirmed by the general preference to convert abandoned land into pasture/fodder production, estimated in the choice experiment. We nevertheless identify characteristics that alter this general preference. Indeed, people prefer the development of more intensive agricultural use (vegetable production and to a lesser extent vineyard) on abandoned lands with high agricultural potential, due to access to irrigation infrastructure. Preferences are also significantly affected by the presence of a high vegetation strata in abandoned land, with a higher probability to select the “laissez faire” strategy (maintain abandoned land). These findings tend to reveal that people rather adhere to a “land sparing” vision of territorial management whereby intensive agriculture should be concentrated in high potential areas and nature conservation or extensive farming on areas with less agricultural potential (Green *et al.*, 2005).

In the case of the Redessan sub-catchment, the hydrogeological model reveals that the two co-constructed scenarios of reuse of abandoned land (that include some form of intensive agriculture) lead to a degradation of water quality, through nitrate concentration increase. Consistent with other research, modelling shows a lag time between actions and their effects on groundwater (Kim et al., 2020), and crops with a low nitrogen balance (such as grasslands or abandoned land) result in less nitrate contamination (Eulenstein et al., 2008) and their replacement with crops with a high nitrogen balance yields the opposite results. The most severe degradation is generated by the scenario built on resident preferences, i.e. to convert all abandoned land with access to irrigation to the production of vegetables. This outcome therefore raises questions about the direct use of resident preferences for environmental decision making. However, the involvement of citizens in the decision process should integrate a more thorough process than the one initiated here (Reed *et al.*, 2009). Providing additional information to citizens although considered sometimes with limited impact potential could in this case alter preferences. For example, we did not examine the impact of the location of abandoned land in

sensitive areas for water quality, which could influence resident preferences for future use. This presents an opportunity for future research.

We adopted a transdisciplinary approach that combined insights from sociology, economics, and hydrogeology, along with active stakeholder participation. These approaches cross-fertilized each other throughout the process. Firstly, the integration of sociologic qualitative approaches and economic quantitative surveys methods enriched our understanding of stakeholder perception and preferences. The narrative method initially used in the qualitative survey facilitated an understanding of the perceived effects of land use change without imposing a pre-established framework such as the ecosystem service approach. The results of this analysis *inter alia* supported the development of a socio-cultural quantitative survey tailored to local perceptions of land use change. Secondly, the complementarity between social sciences and natural sciences also proved crucial. By incorporating stakeholder visions through workshops and the results of surveys, we were able to design land use scenarios that reflected local preferences, to be evaluated with physical modelling. Thirdly, the participation of stakeholders was also instrumental in the validation of modelling hypotheses and results. Finally, the presentation of results to local stakeholders will facilitate the incorporation of the research findings into local management plans. An initial plan to remobilize abandoned land for local food supply was for example questioned by the results of the "vegetables on abandoned land" scenario.

The approach we have developed is an initial step towards an integrated assessment of future land use policies in line with recent recommendations from the IPBES nexus assessment published in 2024, urging to tackle together the five interlinked challenges of Biodiversity, Water, Food, Health and Climate Change[2]. Interestingly it revealed that a programme initially aimed at restoring biodiversity, through a biodiversity offsetting programme for the construction of a railway line that led to the redevelopment of extensive pastures, had other unintended benefits on another element of the nexus, namely water quality. Our transdisciplinary approach nevertheless requires further development for the design and evaluation of future land use scenarios. Some difficulties were experienced, related to the different scales required for the different studies, at the large watershed level for the survey and at a tractable sub-catchment level for the hydrogeological model, leading to difficulties in extrapolating conclusions at the right scale for stakeholder decision-making. Finally, the breadth of disciplines included in this framework needs to be expanded. For example, evaluating the impact of land use scenarios on biodiversity through modelling approaches would be crucial, considering the biodiversity challenges at stake in this territory.

5 Conclusion

This study highlights the importance of adopting a transdisciplinary approach to address the complex issue of land abandonment, combining social, economic, and environmental insights with stakeholder participation. By integrating qualitative interviews, quantitative surveys, and biophysical modelling, we revealed that residents' preferences for land use change aligns with perceptions of ecosystem services but can conflict with environmental priorities, such as groundwater quality. Specifically, resident preferences for intensive agriculture on irrigated abandoned land were shown to significantly increase nitrate concentrations in groundwater. This conclusion strengthens the need to follow nexus approaches -integrating food, health, climate change, water and biodiversity – including in communication messages targeting the general population.

[2] https://www.ipbes.net/node/85582

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7 Supplementary material

Table 3 : Sample description of the quantitative survey

	Population INSEE	Sample
18-29	18%	10%
30-44	22%	27%
45-59	22%	30%
60-74	25%	26%
+75	12%	6%
Male	48%	41%
Female	52%	58%
Farmers	1%	1%
Craftsmen, shopkeepers, business owner	5%	4%
Superior categories	7%	17%
Intermediate categories	31%	34%
Workers	11%	1%
Retired	28%	27%
Unemployed	21%	9%

Figure 9 : Map of the distribution of respondents in the municipalities of the study area

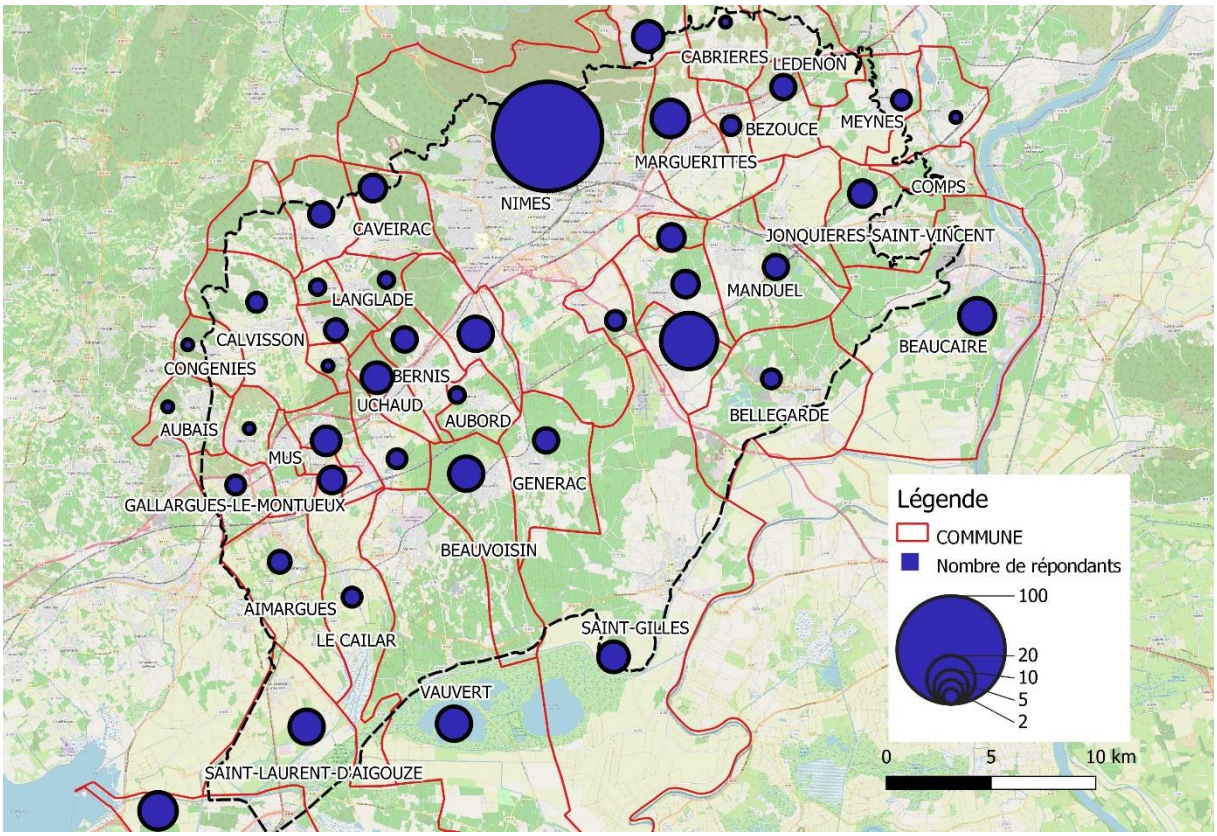
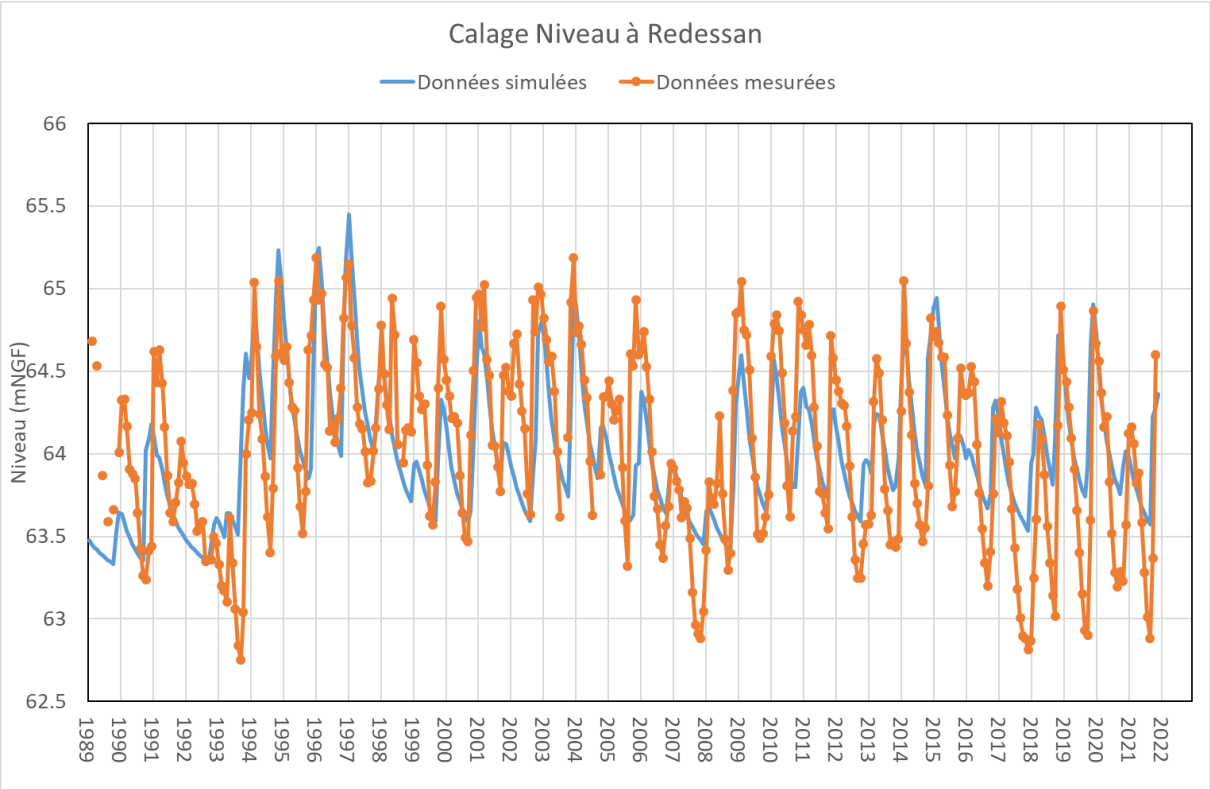


Table 4 : Predicted probabilities for residents to prefer different land use types.

High vegetation	Irrigation	Natural area	Sub-urban area	Past agriculture	P(Vineyard)	P(vegetable)	P(Pasture)	P(Abandoned)	Max	Preferred LU
0	0	0	0	0	0.18	0.23	0.39	0.20	0.39	Pasture
0	0	0	0	1	0.20	0.24	0.37	0.18	0.37	Pasture
0	0	0	1	0	0.21	0.28	0.34	0.17	0.34	Pasture
0	0	0	1	1	0.23	0.30	0.32	0.15	0.32	Pasture
0	0	1	0	0	0.18	0.25	0.38	0.19	0.38	Pasture
0	0	1	0	1	0.20	0.27	0.36	0.17	0.36	Pasture
0	1	0	0	0	0.20	0.39	0.26	0.15	0.39	Vegetable
0	1	0	0	1	0.21	0.41	0.25	0.13	0.41	Vegetable
0	1	0	1	0	0.21	0.45	0.22	0.11	0.45	Vegetable
0	1	0	1	1	0.23	0.46	0.21	0.10	0.46	Vegetable
0	1	1	0	0	0.20	0.42	0.26	0.13	0.42	Vegetable
0	1	1	0	1	0.21	0.43	0.24	0.12	0.43	Vegetable
1	0	0	0	0	0.16	0.20	0.39	0.25	0.39	Pasture
1	0	0	0	1	0.18	0.22	0.37	0.23	0.37	Pasture
1	0	0	1	0	0.19	0.26	0.35	0.21	0.35	Pasture
1	0	0	1	1	0.21	0.27	0.33	0.19	0.33	Pasture
1	0	1	0	0	0.16	0.23	0.38	0.23	0.38	Pasture
1	0	1	0	1	0.19	0.24	0.37	0.20	0.37	Pasture
1	1	0	0	0	0.18	0.36	0.28	0.19	0.36	Vegetable
1	1	0	0	1	0.20	0.37	0.27	0.16	0.37	Vegetable
1	1	0	1	0	0.20	0.41	0.24	0.15	0.41	Vegetable
1	1	0	1	1	0.21	0.43	0.23	0.13	0.43	Vegetable
1	1	1	0	0	0.18	0.38	0.27	0.17	0.38	Vegetable
1	1	1	0	1	0.20	0.40	0.26	0.15	0.40	Vegetable

Figure 10 : Calibration curves of the Biche model for piezometric levels and nitrate concentration.



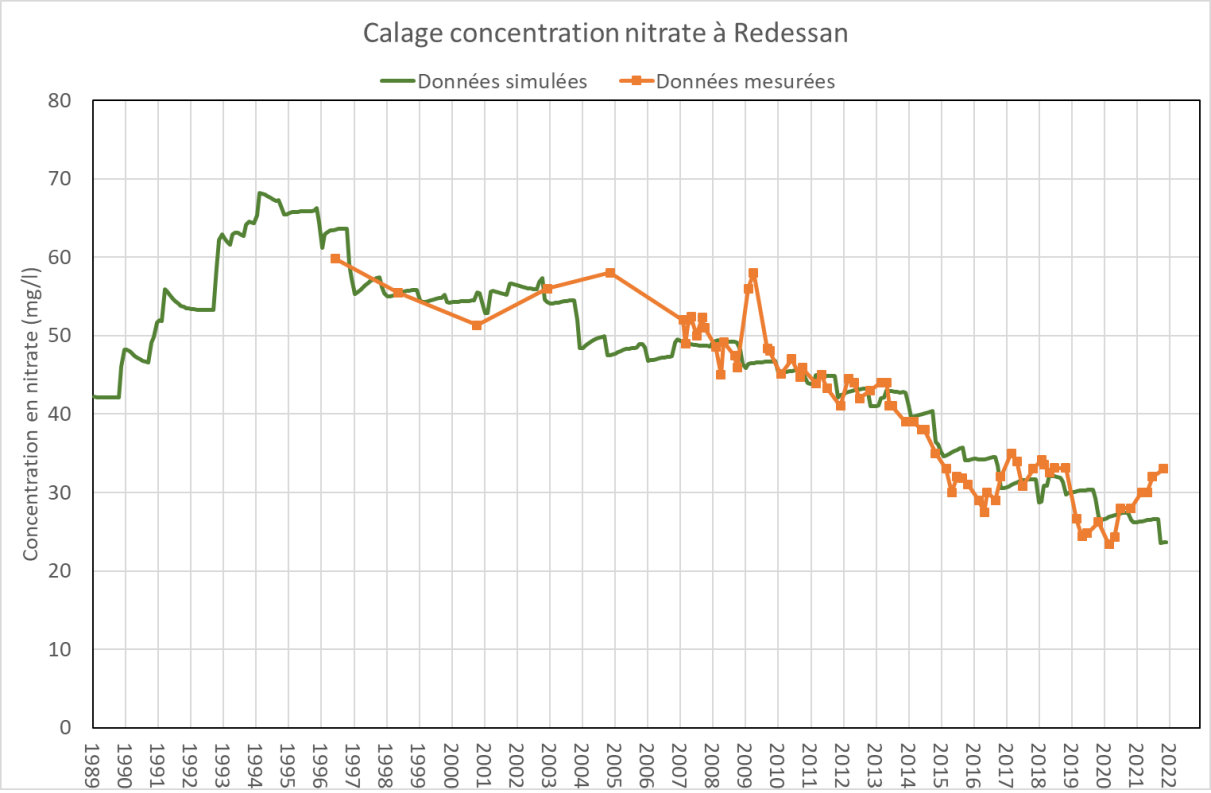


Figure 11 : Land use composition of the back to past scenario

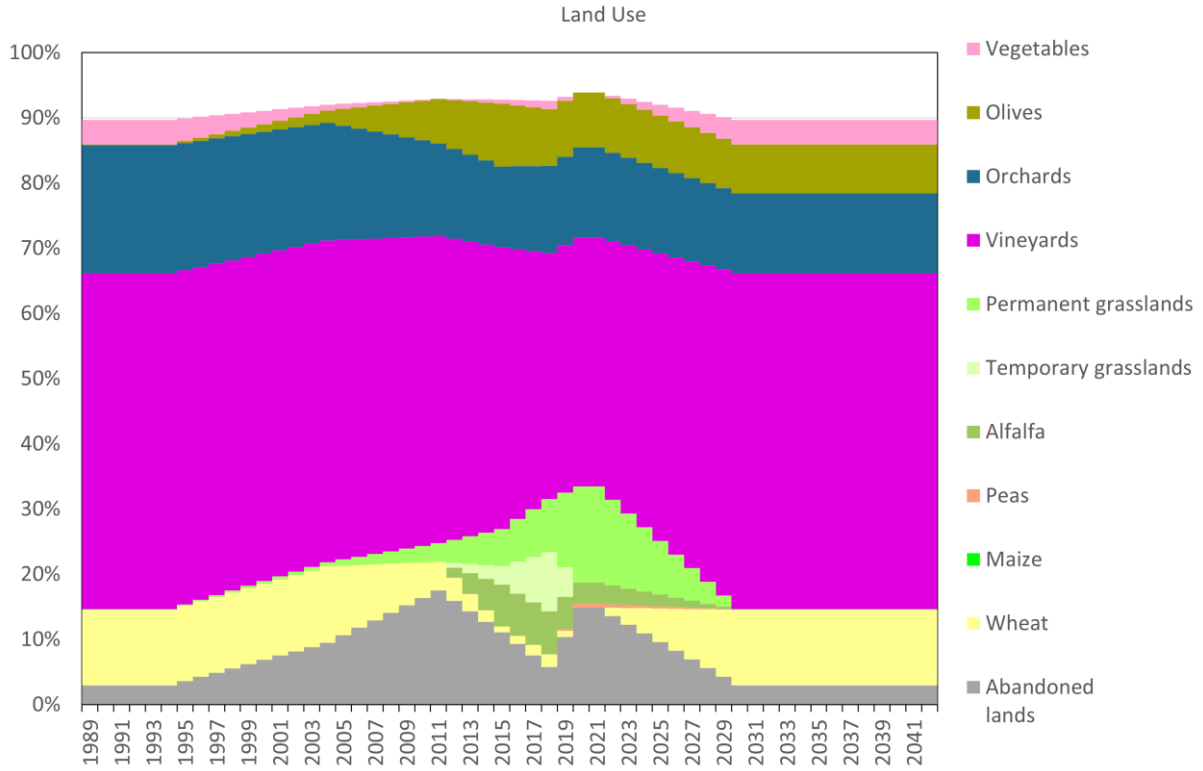


Figure 12 : Land use composition of the status quo scenario

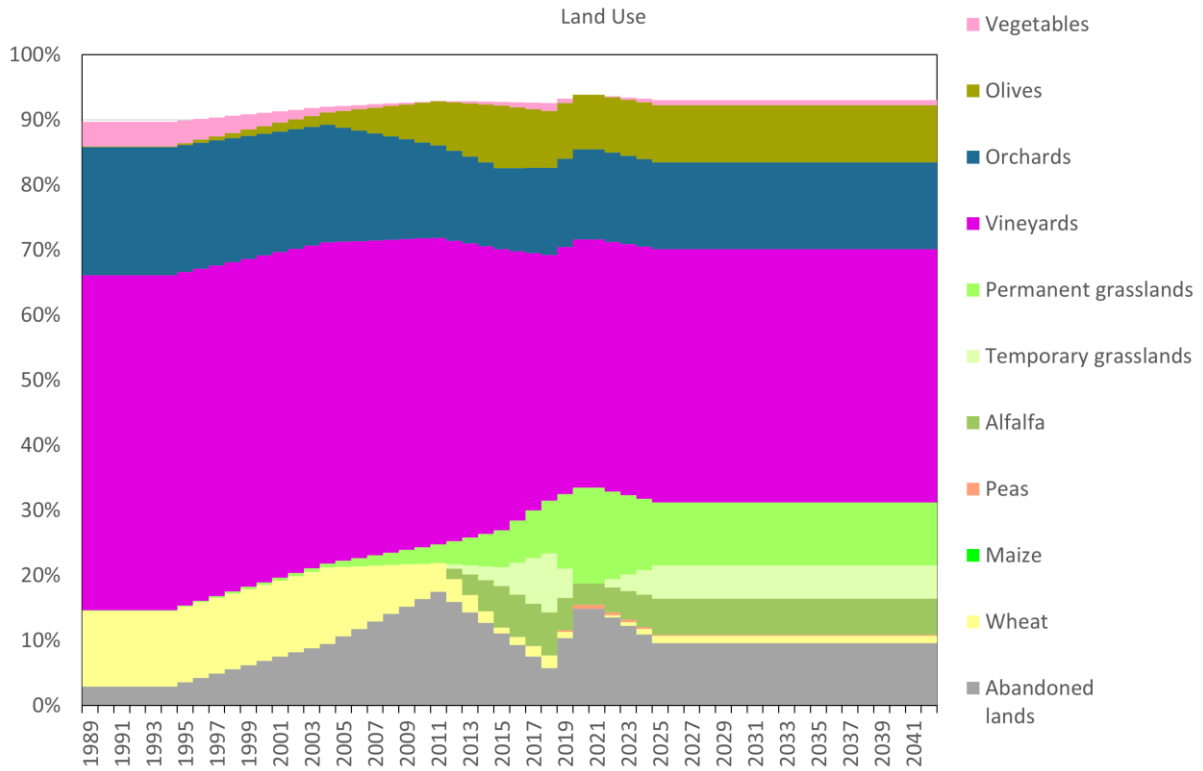


Figure 13 : Land use composition of the vegetable on abandoned land scenario

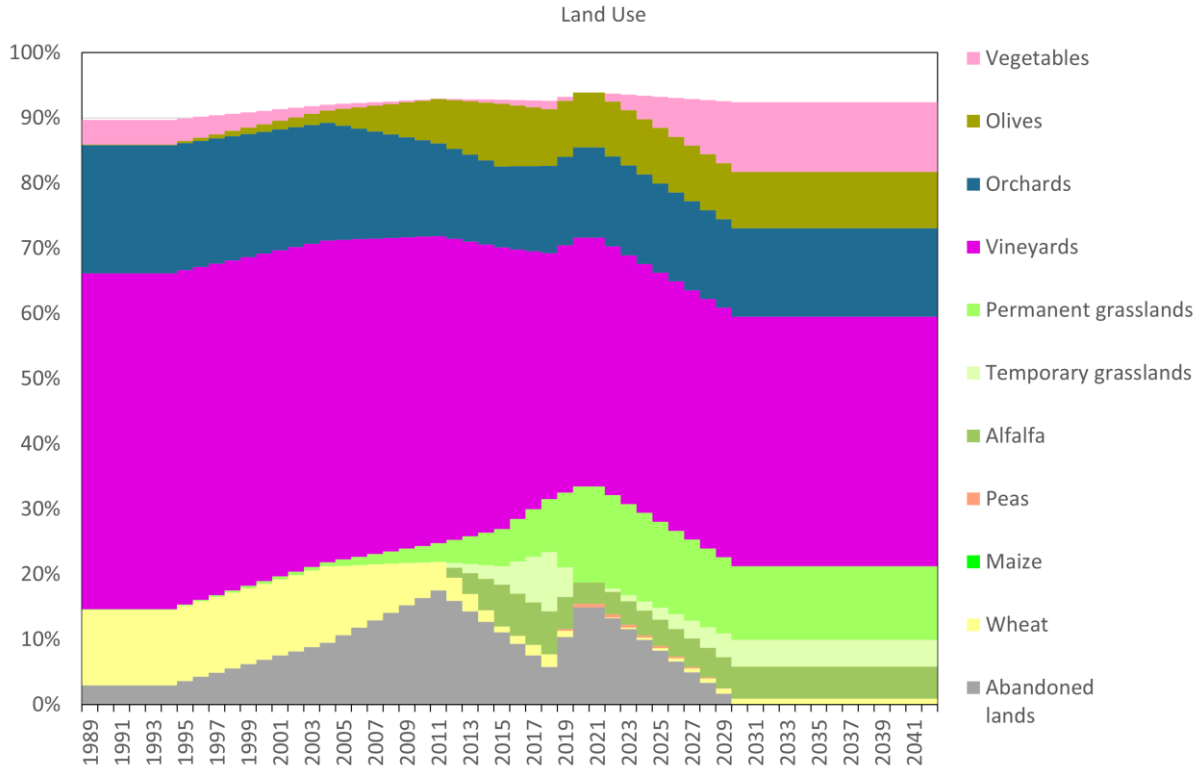


Figure 14 : Land use composition of the 100% grassland scenario