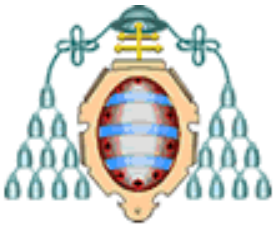


UNIVERSIDAD DE OVIEDO

**ESCUELA POLITÉCNICA DE MIERES**

**GRADO EN INGENIERÍA FORESTAL Y DEL MEDIO NATURAL**

**DEPARTAMENTO DE BIOLOGÍA DE ORGANISMOS Y SISTEMAS**

**ÁREA DE ECOLOGÍA**


**TRABAJO FIN DE GRADO**

# THE REWILDING OF THE CANTABRIAN LANDSCAPES IN A CONTEXT OF GLOBAL CHANGE


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## ABSTRACT

Climate and socio-economic changes have led to human depopulation and the loss of traditional farming systems in Cantabrian Mountains landscapes. These has resulted in important landscape changes, including the expansion of woody vegetation in semi-natural open areas. In this context, rewilding has become an opportunity for biodiversity conservation in rural abandoned landscapes. This ecological process restores functioning ecosystems by reducing human pressure and makes them self-regulated. Variations in the quantity and quality of ecosystem services as well as in biodiversity due to the spread of vegetation were determined. Furthermore, it has been analysed the three factors that make ecosystems being self-sustainable and their implication in Cantabrian Mountains landscape. Rewilding implies challenges that often end up with human-wildlife conflicts due to the recolonization of large carnivores. Moreover, rewilding is associated with an increased fire risk due to the presence more flammable landscapes and the reduction of open areas. Both cases as well as their consequences were studied by reviewing a total of 29 literature and investigation articles. Rewilding initiatives with a minimal human management in order to maintain semi natural open areas has been describe as the best option to reduce ecological risks and maintain local population.



Keywords: traditional farming systems, rewilding, ecosystem services, biodiversity, abandoned landscapes, large carnivores, fire risk.



## RESUMEN

Los cambios climáticos y socioeconómicos han llevado a una despoblación y una pérdida de los sistemas ganaderos tradicionales en los paisajes de la Cordillera Cantábrica. Esto ha resultado en importantes cambios en el paisaje, incluyendo la expansión de la vegetación leñosa en áreas abiertas seminaturales. En este contexto, la renaturalización se ha convertido en una oportunidad para la conservación de la biodiversidad en paisajes rurales abandonados. Este proceso ecológico restaura ecosistemas funcionales reduciendo la presión humana en el paisaje y los hace autorregulados. Las variaciones en la cantidad y calidad de los servicios ecosistémicos además de en la biodiversidad han sido determinadas. Asimismo, se han analizado los tres factores que hacen a los ecosistemas ser autosuficientes y su implicación en el paisaje de la Cordillera Cantábrica. La renaturalización implica retos que muchas veces desencadenan conflictos entre humano y fauna debido a la recolonización de los grandes carnívoros. Igualmente, la renaturalización está asociada a un incremento del riesgo de incendios debido a la presencia de paisajes más inflamables y a la reducción de las áreas abiertas. Ambos casos se estudiarán y se determinarán sus consecuencias mediante la revisión de 29 artículos de investigación y de revisión bibliográfica. La renaturalización con una mínima intervención humana para mantener las áreas abiertas seminaturales se describe como la mejor opción para reducir riesgos ecológicos y mantener a la población local.



Palabras clave: sistemas ganaderos tradicionales, renaturalización, servicios ecosistémicos, biodiversidad, paisajes abandonados, grandes carnívoros, riesgo de incendio.

# INDEX

# 1. INTRODUCTION

## 1.1. Global change: climate change and land use change

The Planet Earth is experiencing continuous climate and environmental changes on a global scale due to the transformations that humans have been doing over the last millennia. These changes have become particularly relevant over the last centuries: reduction of polar ice caps, rise of the sea level, increasing flood risk, water shortage, modifications in ecosystems and species distributions patterns, invasive species, pests, and catastrophic events as wildfires, floods or extreme heat events. These environmental changes have negative impacts on human and natural systems, for instance, affecting water availability and food supply in rural areas. Climate change also influences population and demography, shifting land uses and covers (IPCC, 2014; Aguiar et al., 2018).

Of special relevance are these huge processes of land use change that are occurring all across the world. On the one hand, in continents like Asia, Africa and South America natural areas are massively turning into agricultural lands. On the other hand, in high income continents like Europe, North America, and Oceania, the trend is the opposite with forests seizing agricultural land (Schröter et al., 2005). The most visible changes are taking place in Europe, where the general trends are either the reduction of the land use intensity, land abandonment to the fullest, or the agricultural intensification (Blanco-Fontao et al., 2011; Navarro and Pereira, 2015).

In their review, Queiroz et al. (2004) evaluated the global impacts of farm abandonment across all continents. They found out that the continent affected by more negative impacts (65%) and, at the same time, the one with fewer positive impacts (6%) is Europe (Queiroz et al., 2004). This is related to the fact that European landscapes have always been influenced by human factors and have co-existed with them. In fact, humans must be recognised as an integral part, which, despite all the negative effects that can be brought with them, also guarantee the protection of traditional agricultural landscapes (Molina, 2003; Schröter et al., 2005). This interaction have been shaping forest and agricultural landscapes over centuries, turning into what we know as cultural landscapes (Queiroz et al., 2004; Blanco-Fontao et al., 2011). These socioecological agricultural systems link nature and people, who have been an integral part of landscapes for two million years in Africa and Asia and for millennia in other continents like Europe (Pettorelli et al., 2018). In the Cantabrian Mountains, this interaction started with the first settlements were established in the Bronze age (García-Ruiz et al., 2020); for example, in Monte Areo, Asturias, where the first evidence of human landscape transformation dates back to 7300 years (Carracedo et al., 2018).

The current loss of agricultural landscapes, generated by either abandonment or intensification of land use, is driving to a biodiversity loss that is linked to the homogenization and simplification of land (Blanco-Fontao et al., 2011). In fact, extensive land management, is responsible for organizing cultural landscapes, reducing wildfire risk and increasing the diversity of species benefited from a slight human management

(García-Ruiz et al., 2020). On the one hand, the abandonment of such management practises have been occurring over the last 20 centuries, when mountain ecosystems of southern Europe went through a socioeconomic marginalization due to the migration to cities or rural exodus and the ageing of the population, but also resulting from industrialization and land abandonment (García Llamas et al., 2018). On the other hand, the opposite process, the intensification of farming systems is eventually turning into a big issue. Agricultural intensification has the aim of increasing the production yield by technological advances (pesticides, fertilizers, machinery). It is a major cause of biodiversity loss that is related to crop and livestock specialization occurring on a heterogeneous, semi-natural landscape mosaic with an extensive agricultural management. Therefore, it generates a loss of important ecological processes and complexity, which make ecological systems more vulnerable to perturbations and damage their capacity to recover from environmental changes (Perino et al., 2019). Consequently, for many authors, agricultural intensification is considered as the main driver of diversity decline in agricultural landscapes, way more than farmland abandonment, and it affects the benefits that humans gain from ecosystems (Emmerson et al., 2016).

## 1.2. Rewilding processes

It is expected that, during the period 2000-2030, 20 million of hectares will have changed their use in Europe from farmlands to forests and heathlands (Navarro and Pereira, 2015), due to land use change and farmland abandonment related to rural exodus and ageing of rural population. Consequently, rewilding processes will be at the heart of national and regional political agendas (Jones et al., 2020). This concept emerged in the 80's in North America but it was originally named as recovery of wilderness (areas where natural processes occur without human intervention). In the beginning, it emphasized the importance of three key features: keystone species, large, protected cores, and connectivity (Carver et al., 2021). The first articles that mentioned the word "rewilding" were published in 1999 and talked about vast protected and connected areas with presence of large predators (Pettorelli et al., 2018; Perino et al., 2019).

In this day and age, the concept of rewilding has evolved and involves a lot of complex elements that make this word even more difficult to define. Rewilding is considered as an ecological process that restore functioning ecosystems by reducing human pressure, and let ecosystems be self-regulated (Carver et al., 2021). We can make a distinction between three or four types of rewilding, depending on the author: (i) trophic rewilding is the one which gets closer to the first concept of rewilding, being its aim the restoration of top-down trophic interactions; (ii) Pleistocene rewilding can be defined as a subtype inside trophic rewilding, whose aim is to restore the ecological processes lost in the late Pleistocene; and, (iii) passive, or ecological rewilding which highlights the passive management of abandoned landscapes (Pettorelli et al., 2018; Perino et al., 2019). Some examples of passive rewilding actions are the implementation of areas without game, with low forestry activities (Perino et al., 2019) or the expansion of woody vegetation generated by passive rewilding that benefits regulation services such as runoff, erosion, wildfire dynamics and, water and air quality (García-Llamas et al., 2018).

Due to this complexity, rewilding draws criticisms among some authors who state that this is a "plastic word" that means "many things" and, what is more, that always changes its meaning (Jorguensen, 2015). Eventually, this is a problem because there is not a specific definition (Jones et al., 2020). This problem can be solved by building more specific definitions and setting common objectives. Some interesting meanings are: (i) 'rewilding is a process of (re)introducing or restoring wild organisms and/or ecological processes to ecosystems where such organisms and processes are either missing or are 'dysfunctional' (Prior and Ward, 2016): (ii) 'rewilding is the process of rebuilding, following major human disturbance, a natural ecosystem by restoring natural processes and the complete or near complete food web at al trophic levels as a self-sustaining and resilient ecosystem with biota that would have been present had the disturbance not occurred' (Carver et al., 2021). These definitions of rewilding have a common element, which is the passive management. As it is shown in *Figure 1*, rewilding (passive management, low agricultural use) represents the opposite process of agricultural intensification (active management, high agricultural use). In the middle of them, we can place agricultural extensification.

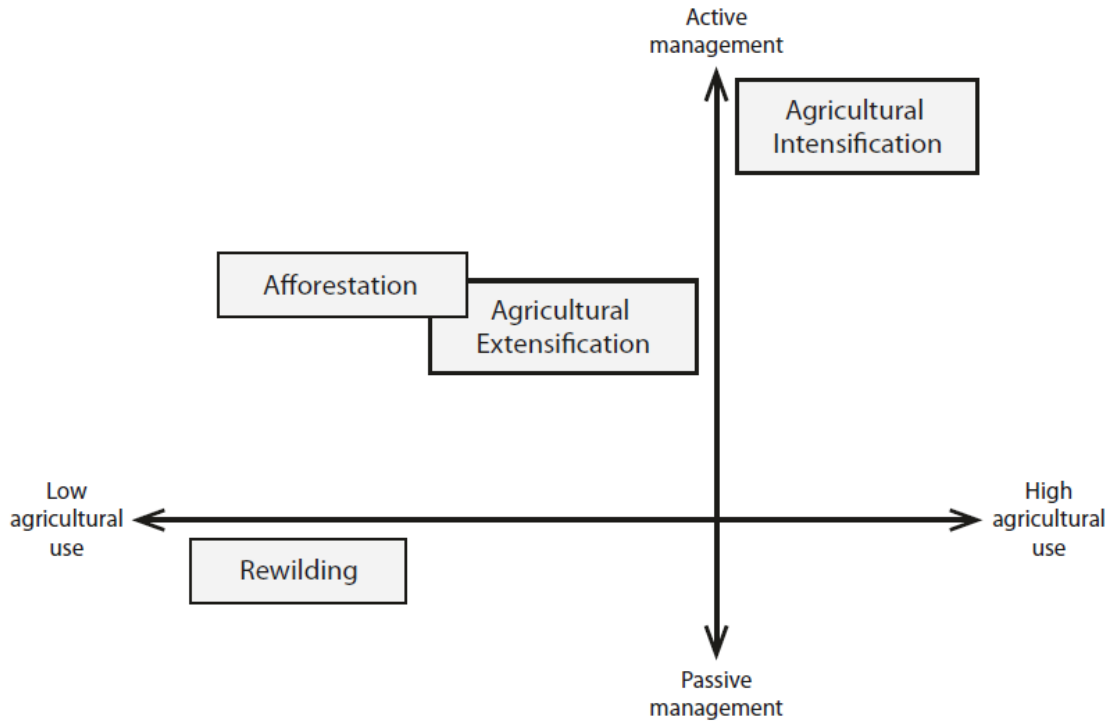


***Figure 1***: Extract from paper [18]: Diagram which shows different types of management plotted based on their agricultural use and level of management

A common aspect in all definitions is the target of rewilding: the self-sustaining of ecosystems, achieved by reducing human pressure on them with minimal interventions. Yet, in cultural landscapes, experts consider that some level of intervention is necessary to maintain these type of ecosystems due to prolongated human presence. This goal is achieved by restoring ecological dynamics, but also disturbances and trophic complexity. The effects of rewilding are specific to the ecosystem where it take place (Perino et al., 2019). It is important to stress the relevance of passive management because, in many

European landscapes, rewilding is happening over the last decades without intervention, spontaneously, due to the decline of human influence and land abandonment (Navarro and Pereira, 2015; Jones et al., 2020; Carver et al., 2021). In addition, authors and stakeholders highlight the fact that rewilding leaves humans out of land management, by creating "wild without people" and by "excluding human in time and age from nature" (Jorguensen, 2015). This criticism is currently gaining importance in many rural landscapes, such as the Cantabrian Mountains, where local people and stakeholders organize protests due to the fact that forests and heathlands are invading traditional pastures are left out of the rural activity. To be successful, rewilding actions should not leave humans out in the cold, because we are an integral part of these landscapes. Additionally, they would need the support of local population and should be inclusive with the stakeholders and consider their necessities and expectations (Navarro and Pereira, 2015; Perino et al., 2019; Carver et al., 2021).

Another challenge and key factor for rewilding actions is their practical implementation and, in consequence, the monitoring they imply (Jones et al., 2018). In many cases, rewilding is associated with clear goals as restoring the previous heterogenous mosaic and promoting native species. However, the outcomes of rewilding are highly unpredictable and it is not easy to balance the benefits and the costs. These unpredictable benefits may be seen as negative impacts by local population and stakeholders, who can only see the costs (crop and cattle predation). Moreover, current legislation is not letting rewilding projects start the way they want. In this context, the Common Agricultural Policy (CAP) plays a fundamental legal role. It encourages the maintenance of the less productive agricultural lands with payments, which makes rewilding turn into a challenge for the EU legislation (Pettorelli et al., 2018; Perino et al., 2019). That is why having clear objectives, monitoring at different scales the ecological consequences of rewilding and informing the stakeholders about clear benefits obtained from wildlife (ecosystem services, ecotourism) is fundamental for the success of a rewilding project. Besides, it is essential to revise current EU legislation on land use and conservation to facilitate the implementation of new rewilding projects (Pettorelli et al., 2018).

## 1.3. Structural and functional implications of land use changes and rewilding on ecosystem services

Spatial heterogeneity is a fundamental topic in landscape ecology, and it conditions the structural part of landscapes and ecosystems. When talking about heterogeneous landscapes, we are considering land mosaics made of ecosystems of different type, shape and configuration. In these landscapes, different crops are combined with natural and semi-natural land cover types into a fined grain mosaic characteristic from traditional or cultural farming systems with an extensive management. In natural land cover types, the biggest part of the primary production is not consumed by humans, and the frequency and intensity of human interventions is relatively low. Heterogeneity can be increased by transforming landscapes with agricultural intensification into more natural lands where, despite having a lower production, the ecosystem services they generate suppose a benefit to the owner and the society (provisioning, cultural and regulating services) (Schröter et

al., 2005; Fahrig et al., 2015). Nevertheless, it must be kept in mind the fact that a diversification of the cover types in the landscape mosaic also produces a decrease of the amount of some specialist species and its dispersal, for example, the brown bear, who needs large continuous extensions of territory (Fahrig et al., 2011). In this context, landscape connectedness is another concept that is influenced by landscape structure. It guarantees the viability of populations by means of well-connected landscapes which promote movement and migration between different core areas (Carver et al., 2021). Human activities and intensive land use practices produce land fragmentation and habitat degradation, which threatens the viability of species in need of large extensions. Capercaillie, whose population is in constant decline, also needs huge extensions of mature forests. For these kind of species, connectivity among different populations and patches is vital to enhance the dispersal of individuals and to preserve populations, avoiding isolation (Velázquez et al., 2017).

The process of rewilding is based on three basic components that must be taken into account for any project, which guarantees the self-organization of ecosystems: trophic complexity, disturbances, and dispersal. These three ecological processes maintain the complexity and resilience of ecosystems. *Figure 2* gives a general outline of the state of ecosystems in a schematic three-dimension way, where each dimension represents one ecological process. The orange colour stands for a degraded ecosystem and the yellow one a restored self-sustaining ecosystem. The dashed line between them represents how far ecological processes can go, due to human restrictions. However, they can be pushed further (orange line) thanks to rewilding actions, always supported by the stakeholders. An increase of one ecological process may influence the other ones, for example, dispersal and perturbations affect trophic complexity (Perino et al., 2019).

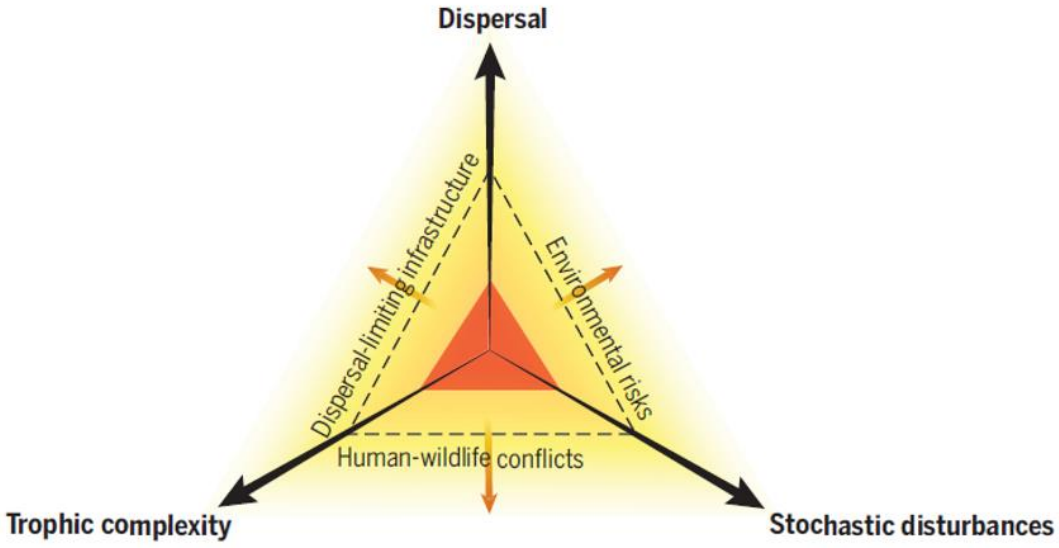


***Figure 2***: Extract from paper [20]: Representation of the ecological state in a three-dimension way

Trophic complexity is determined by the trophic interactions of species, whose populations are regulated by predation and competition. As a matter of fact, species in higher levels of the trophic chain (large predators and herbivores) are incredibly important for ecosystem dynamics, even becoming keystone species (without them an ecosystem will dramatically change of even disappear) and ecosystem engineers (they can change, directly or indirectly, the resources of the ecosystem). Trophic complexity can be easily altered by humans by hunting, forest management and agriculture, and it is usually detrimental to the most complex species (larger reproductive cycles, higher spatial needs, larger body size), which represent large herbivores and predators. Consequently, restoring actions like reintroductions or establishment of non-hunting areas are proposed to benefit keystone species. On top of that, coexistence between humans and wildlife must be ensured in order to reduce human-wildlife conflicts (Perino et al., 2019; Carver et al., 2021). Stochastic disturbances often occur in an unpredictable way, spatially and temporary. They determine the complexity of a system, influencing its composition and organization and making ecosystems be dynamic and in constant change. They are fundamental for succession and competition processes. Nowadays, cultural landscapes and more-natural areas with an important human influence often reduce or even supress disturbances to maintain constant productions and incomes (fire suppression policies instead of prevention policies, flood protection). This general tendency in this kind of landscapes reduces the frequency of disturbances; yet still, it increases its magnitude and makes them more dangerous. Furthermore, some actions carried out after serious disturbances, like the removal of damaged trees, can also affect the ecosystems dynamics, owing to the fact that they do not benefit the regeneration of certain species (Perino et al., 2019; Carver et al., 2021). Dispersal is another concept that makes ecosystems resilient and complex. It benefits the exchange of different populations and its competition, also improving genetic diversity. Dispersal gets better by developing connectivity and reducing barriers, setting up corridors. Experts support that corridors are great conservation mechanisms, especially in fragmented landscapes (Beier and Noss, 1998; Perino et al., 2019).

These three ecological processes have consequences in the quality and the amount of ecosystem services humans benefit from. The concept of ecosystem services establish a link between ecosystems and humans, its definition implies a strong anthropological character. They can be defined as ecosystem functions and processes which benefit directly or indirectly human welfare with goods and services. Ecosystem services are classified in three groups: regulation, provisioning and cultural services. Regulation services are the benefits humans obtain thanks to the capability of ecosystems to regulate fundamental ecologic processes. Provision services provide direct and indirect benefits and goods for human consumption such as raw material and food. Cultural services involve all the non-material services humans obtain from ecosystems, for example, recreation and tourism (Camacho et al., 2012).

Semi-natural, traditionally managed landscapes provide important ecosystem services of all types that improve human welfare (Camacho et al., 2012; García-Llamas et al., 2018). Matter-of-factly, the loss of these ecosystems and the homogenization of the landscape even provokes the loss of multiple ecosystem services and biodiversity, which are essential for local populations (Blanco-Fontao et al., 2011). On the one hand, land abandonment reduces the amount of services linked to open areas such as livestock. On

the other hand, it increases provisioning (wood fuel, timber) and regulating services related to forest and heathlands, including runoff and erosion protection and the improvement of water and air quality.

Simplification of agricultural landscapes due to agricultural intensification reduces the amount and quality of important regulations services such as control of pests and pollination. Reduction of regulating services due to biodiversity loss generates an increase in the amount and severity of pests. Agricultural intensification and yield incrementation has negative effects on biodiversity from local to landscape scales, also induced by the use of fertilizers and pesticides, and generates a decrease of the ecosystem services. The figure below shows some important regulating ecosystem services affected by an agricultural intensified use and how these regulating services influence each other (Emmerson et al., 2016).

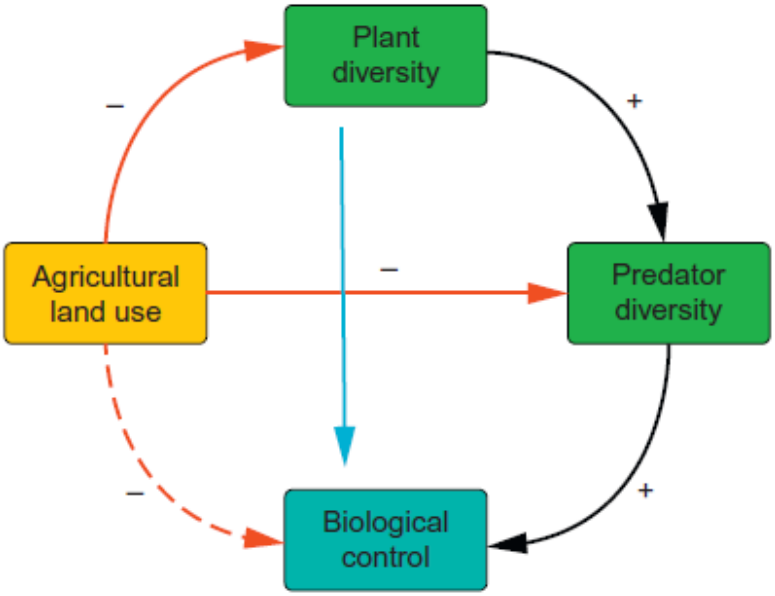


***Figure 3***: Extract from the paper [9]: Diagram which predicts the influence of agricultural land use in plant and predator diversity as well as in biological control

## 2. JUSTIFICATION OF THE CASE OF STUDY

The Cantabrian Mountains are a mountain range of 480 km that are located at the NW of Spain. They go from Galicia to País Vasco and cover a total of 31494 $km^2$. This mountain range lies at the limit between two well-known climate zones in Spain, the north region, Atlantic, and the south region, sub-Mediterranean – sub-Atlantic climate. Cantabrian Mountains have such a big altitude range from the sea level; they reach 2650 m.a.s.l. (Ortega et al., 2015).

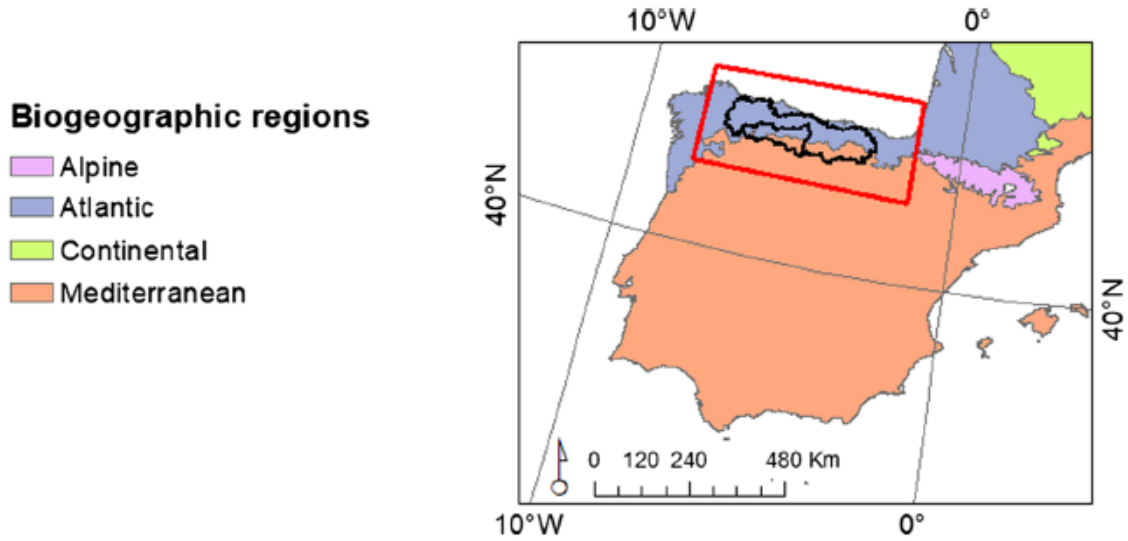


***Figure 4**:* Extract from paper [11]: Location of the Cantabrian Mountains and their different biogeographic regions

The cultural landscapes of the Cantabrian Mountains are influenced by a combination of traditional and extensive farming practices which has been determined by human presence over the last centuries (Blanco-Fontao et al., 2011). They represent a good example of low intensity farming systems with low productivity of seminatural grassland (*Photography 1*) (Navarro and Pereira, 2015). The landscape mosaic is highly heterogeneous, holding a good array of land cover types, as forests, heathlands, and pastures, maintained by cattle (Blanco-Fontao et al., 2011; Navarro and Pereira, 2015; García-Llamas et al., 2018). Cantabrian landscapes are a hot spot of biodiversity and produce an important supply of ecosystem services for the local population (García-Llamas et al, 2018). As other mountainous landscapes of southern Europe, Cantabrian landscapes are being affected by the current context of global change. On the one hand, important processes land abandonment are occurring in marginal areas (*Photography 2*) (Regos et al., 2016; García-Llamas et al., 2018) and, on the other hand, agricultural intensification is happening in the most productive and accessible lands (Blanco-Fontao et al., 2011; Navarro and Pereira, 2015; García-Llamas et al., 2018). Changes in management produce the marginalization of less productive areas leading to the intensification of the most productive and accessible ones, by grouping these agricultural lands (García-Llamas et al., 2018; Perpiña et al., 2020).

***Photography 1****:* Cultural landscape with different land cover types. Celón, Allande, Asturias. Sergio Rodríguez-Almoño Frade.

***Photography 2****:* Abandoned landscape of shrublands in marginal mountainous areas. Puerto del Palo, Allande, Asturias. Sergio Rodríguez-Almoño Frade.

Land abandonment affects mountainous regions and marginal areas more severely, where economic and social events have produced big changes in demography (Perpiña et al., 2020). During de 20$^{th}$ century, socioeconomic marginalization of these mountainous areas generated rural depopulation and exodus, leading to a decrease of traditional management: transhumance and extensive practises (García-Llamas et al., 2018). The marginalization of these landscapes was induced by a loss of profitability and competitiveness due to industrial and technological improvements and because of accessibility: poor communications that did not improve regional development (García-Llamas et al., 2018; Perpiña et al., 2020). However, despite the decrease of population of this region, a study made from 1986 to 2007 showed a significant increase in the cattle numbers in this mountainous region, almost a 30% in just 20 years. This leads to intensification, putting aside the traditional extensive farming management, characteristic for low intensity production, which alters important ecological processes such as succession and nutrient cycling. By increasing the number of cattle heads in these open areas, cattle may act even as an ecosystem engineer. Nowadays, cattle requirements are

not just the resources available on the pastures where they stay, they also need food from other pastures, leaving out the traditional management of these pastures and trashumance.

Either land abandonment or farming intensification in Cantabrian Mountains is driving to landscape homogenization at both regional and local scales. These processes reduce the functionality of landscapes, by decreasing the amount of ecosystem services generated, especially with agriculture intensification. Nonetheless, this dominant context of land abandonment opens the way for new strategies which are benefited from this land use changes. Passive rewilding has been discussed and evaluated recently as an opportunity for abandoned mountainous landscapes to restore the original ones and native ecosystems (García-Llamas et al., 2018).

# 3. QUESTIONS AND OBJECTIVES

In these context, the main general questions driving this work are:

- *How is rewilding taking place in Cantabrian Mountains?*
- *Does rewilding benefit biodiversity and ecosystem services?*

Based on these initial questions, other more specific have been proposed, all of them focused on the study area, the Cantabrian Mountains. These new questions are related to the three ecological processes that transform an ordinary system into a self-sustaining (trophic complexity, stochastic disturbances and dispersal (*Figure 2*)). Some of them involve local populations and stakeholders, essential for any rewilding project, and likewise important nowadays because of criticism and protest emerged due to land abandonment, afforestation and return of large predators.

One question was proposed in relation to the last topic and the role local population would play in a rewilded landscape where human intervention in passive rewilding would be minimal. As a result, the objective proposed was:

a) *Is the return of large predators viable for local populations?*

The next topic raised was related to perturbations, precisely wildfires, on account of their important interaction with rewilding and the shifts on fire regime (increased severity and extent) in the NW of Spain associated to global change. Therefore, the next question has been aimed:

b) *Is fire risk associated with rewilding processes?*

Finally, concerning dispersal as a key to achieve self-sustainability, the next topic has been put forward:

c) *Which patterns of connectedness and connectivity may be found in rewilded Cantabrian landscapes?*

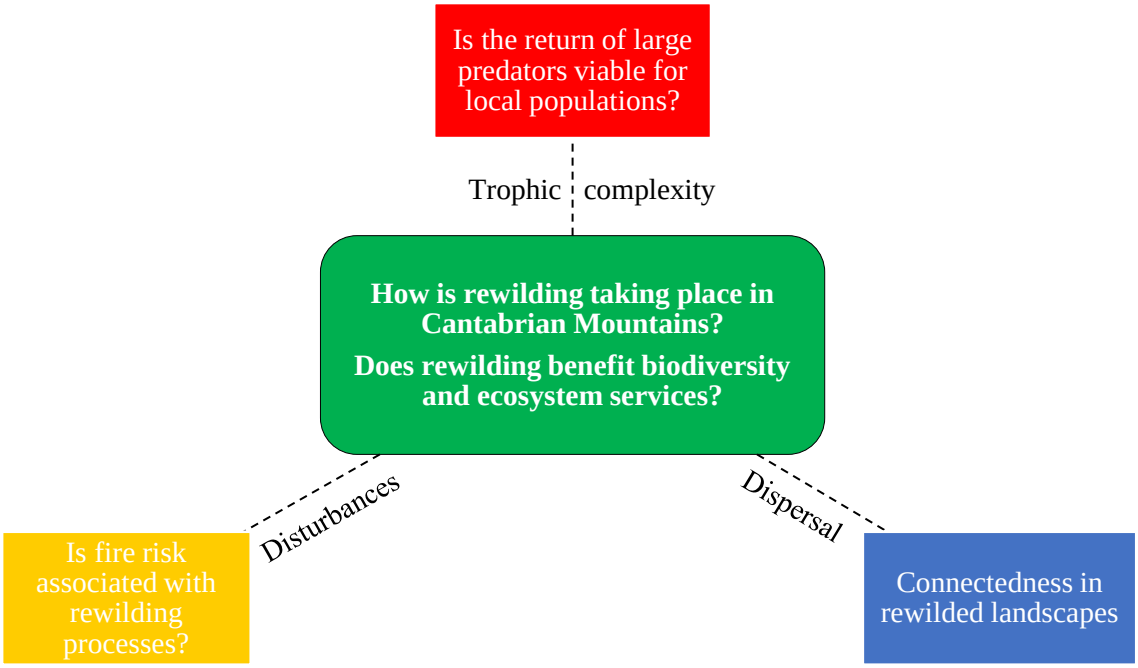


***Figure 5:*** Diagram of the questions and topic posed

# 4. METHODOLOGY

The lines of research were done consulting *Google Scholar* data-base. In the beginning, the terms looked up were:

*Rewilding*, *landscape heterogeneity*, *land use change*, *land abandonment*, *landscape intensification* and *ecosystem services*, all focused on Europe and on the Cantabrian Mountains.

After searching for key words, I combined the terms mentioned to find more specific articles and to find new key words. The term rewilding is a recent concept, so I tried to find papers written in the last 5 years. In the beginning of the research, I looked for papers from Europe, focusing then on more specific articles about the Cantabrian Mountains. Then, I grouped the articles in different categories depending on their content (*Table 1*):

a) *Rewilding* → Characteristics, problems and examples.
b) *Global Change* → Climate, landscape and land use change (abandonment and intensification).
c) *Ecosystem services*.

On top of that, I weight up if it was a literature review or an investigation article.

| Researching criteria | |
|---|---|
| *Publication of the article* | • Year of publication |
| *Content of the article* | • Location<br>• Key words used<br>• Topic |
| *Type of article* | • Literature rewiew<br>• Investigation/Monitoring |

***Table 1**:* Researching criteria

## 5. RESULTS

A total of 29 articles from 22 different journals were selected using the criteria above mentioned. Almost a third part of them (31%) were published in four journals: *Regional Environmental Change*, *Science*, *Science of Total Environment* and *Investigaciones Geográficas*. From them, nearly the 60% of the articles were published over the last five years.

Most of the articles addressed issues about rewilding and land use changes in Europe and Spain and some of them even in the Cantabrian Mountains. The main ideas obtained from the most important articles studied are outlined in *Table 3*. Furthermore, five studies were done in Europe and four in Spain. Nine papers were specifically focused on the Cantabrian Mountain. *Table 2* shows the number of articles found for each key word searched for in the data base. From the total, 13 papers were literature review papers while 16 addressed investigation and monitoring examples of different cases of rewilding, land use change, structural and functional implications and ecosystem services.

| References for each key word | |
|---|---|
| *1. Rewilding Europe* | • [6, 8, 12, 14, 15, 18, 20, 22, 23] |
| *2. Land abandonment* | • [11, 21, 24, 26] |
| *3. Agricultural intensification* | • [3, 9, 10, 11] |
| *4. Ecosystem services* | • [5, 11, 16, 17, 27] |
| *5. Fire regime* | • [4, 6, 19] |
| *6. Landscape heterogeneity* | • [9, 10, 11, 26, 28] |
| *7. Trophic rewilding* | • [18, 25] |
| *8. Landscape connectivity* | • [2, 10, 25, 26, 28, 29] |

***Table 2**:* References for each key word

| TITLE OF THE ARTICLE | YEAR | RESULTS |
|---|---|---|
| • *Carver et al. (2021)* | 2021 | Introduction to rewilding and expose 10 key principles that define any rewilding project. |
| • *García-Ruiz et al. (2020)* | 2020 | Importance of humans in cultural and traditional managed landscapes. |
| • *Jones et al. (2020)* | 2019 | Definitions of rewilding vs what people thinks. |
| • *Jorguensen (2015)* | 2015 | Most important problems of rewilding: definition, rewilding does not consider humans. |
| • *Navarro et al. (2015)* | 2015 | Importance of creating a sustainable relation between large carnivores and humans, accepting human influence in al trophic levels. |
| • *Perino et al. (2019)* | 2019 | Identifies the three interacting ecological processes that promote rewilding: Dispersal, trophic complexity and stochastic disturbances |
| • *Pettorelli et al. (2018)* | 2018 | Importance of integrating rewilding in the current policy context. |
| • *Prior and Ward (2016)* | 2016 | Response to rewilding criticism, giving more precise definitions. |
| • *García-Llamas et al. (2018)* | 2019 | Loss of the traditional farming systems and land abandonment control the landscape. Landscape homogenization affects ecosystem services supply. |
| • *Perpiña et al. (2020)* | 2020 | Northwest region of Spain has important land abandonment processes, specially mountainous and marginal areas. |
| • *Queiroz et al. (2004)* | 2014 | Review of 276 papers of farmland abandonment all around the world, being Europe the most affected continent. |
| • *Regos et al. (2016)* | 2014 | Biodiversity of different bird species before and after farmland abandonment in Galicia. Overall, biodiversity increased after land abandonment. |
| • *Emmerson et al. (2016)* | 2016 | CAP promotes intensification and difficult rewilding initiatives, simplifying agricultural landscapes. |
| • *Blanco-Fontao et al. (2011)* | 2011 | Significant increase of cattle densities over the past 20 years which suppose negative consequences in Cantabrian Mountains landscape. |

| | | |
|---|---|---|
| • *Fahrig et al. (2011)* | 2011 | The most heterogeneous landscapes contain large areas of more-natural cover types which improve regulating ecosystem services. |
| • *Camacho et al. (2014)* | 2012 | Three types of ecosystem services (provisioning, regulating and cultural) which benefit human welfare direct or indirectly. |
| • *Keesstra et al. (2018)* | 2018 | Nature based solutions are able to restore ecosystems and improve the quality and quantity of regulating ecosystem services. |
| • *Schröter et al. (2005)* | 2005 | Net increase of European forest area, decreases in agricultural land and afforestation. |
| • *Calvo et al. (2002)* | 2002 | In the past, heathlands were removed to obtain pastures, but this trend changed in the 70 due to the absence of low-intensity fires and grazing. |
| • *Campos et al. (2021)* | 2021 | Studies of Galicia and Portugal which pose two possible scenarios associated with the increased fire risk: High Nature Value Farms and rewilding. |
| • *Carracedo et al. (2018)* | 2018 | Human influence in landscapes and fire regime since Neolithic. |
| • *Velázquez et al. (2017)* | 2016 | Main reasons of the decline of cantabrian capercaillie: climate change and landscape fragmentation and degradation, low connectivity. |
| • *Recio et al. (2020)* | 2020 | Rewilding suppose the return of large carnivores, which affects local population: crops and livestock damaged. |
| • *Beier and Noss (1998)* | 1998 | Corridors as fundamental connectedness features in landscape. |
| • *Zarzo-Arias et al. (2019)* | 2019 | Identifies areas with the presence of bears and future areas of expansion and the biggest problems which affect its expansion (low connectivity between west and east populations). |

***Table 3**:* Results obtained for each paper, grouped as in *Table 2*

# 6. DISCUSSION

- *How is rewilding taking place in Cantabrian Mountains?*

Cantabrian Mountains are experiencing important global changes among which land use changes and, specially, land abandonment stand out. Mountainous landscapes are very vulnerable to economic and social changes due to their traditional low productive practices, which have been modifying landscapes over centuries. This management provided a heterogeneous landscape characterized for being a shifting mosaic. However, factors as the aging of the population, the rural exodus and a socioeconomic marginalization of mountainous landscapes (due to remoteness and low competitiveness), are generating land use changes and loss a of traditional extensive practices for livestock. Two important land use changes are occurring in Cantabrian Mountains: land abandonment (higher altitude and low fertile lands) and agricultural intensification (lower altitudes and fertile lands). Despite the political efforts made in the last decades to prevent abandonment, semi-natural grasslands have become progressively forest and heathlands, losing open areas, becoming homogeneous landscapes and decreasing the amount of functions of them, particularly as ecosystem services suppliers (Regos et al., 2016; García-Llamas et al., 2018).

Nevertheless, this forest and shrubland expansion encourage new conservation opportunities for Cantabrian mountainous landscapes. Farmland abandonment has been taken as a new chance rather than a threat to regenerate native ecosystems by applying preservation strategies, such as passive rewilding (Regos et al., 2016; García-Llamas et al., 2018). The study made by Regos et al. (2016) in a marginal mountainous landscape of NW Spain analysing changes in bird populations due to land use changes determines rewilding as an option of biodiversity in a context of land abandonment and fire-regime changes in these landscapes. Moreover, it encourages local populations to consider passive rewilding as a chance. Multiple benefits are recorded with passive rewilding in Cantabrian Mountains, for example, recolonization of heathlands; ecosystems considered to have an immense potential for nature conservation are well represented in Cantabrian Mountains by *Calluna vulgaris.* Yet, recent changes in land use and management are reducing their control, generating a fast expansion of shrublands. Traditional practices such as trashumance and grazing with sheep and goats have been replaced with livestock at lower altitudes making heathland expand rapidly (Calvo et al., 2002). Another ecological crucial factor in heathlands expansion is fire. The absence of small-medium size low intensity fires makes shrublands expand quickly, but it also generates denser vegetation and fuel accumulation, appearing bigger and more intense fires and transforming these areas into fire-prone shrublands (Calvo et al., 2002; Campos et al., 2021).

- *Does rewilding benefit biodiversity and ecosystem services?*

Traditional mountainous landscapes of the Cantabrian Mountains are particular for being an important source of ecosystem services. Thanks to their heterogeneity, brought by their dynamic mosaic, and biodiversity, these mountains can provide to the society

with a broad range of benefits of different types: ecological, cultural and socioeconomic. These multiple benefits are represented by ecological services of all types; provision, regulating and cultural services (Camacho et al., 2014; García-Llamas et al., 2018). However, the land cover changes previously mentioned are influencing the supply of multiple ecosystem services and producing discussion and criticism among stakeholders (Regos et al., 2016). As García-Llamas et al. (2018) mention, ecosystem services do not only change in time, but also in use and value. In the past, local communities who used to inhabit these traditional managed landscapes principally benefited from provisioning services, such as wood and grazing, which nowadays are experiencing a decline on its use. Nonetheless, other services not very valuable in the past for the locals, today represent important benefits, for example, cultural services as recreative, touristic, esthetical, educational or cultural identity. Regulating services represent another fundamental resource in Cantabrian Mountains and they have also changed their functionality over years. Rewilding and the expansion of forests and shrubland in marginal areas have improved regulating services such as air and water quality and have reduced the erosion due to the presence of forest cover and, consequently, runoff. Albeit land homogenization reduces important regulating services such as fire control, making ecosystems more vulnerable to wildfires owing to continuous flammable landscape generated (García-Llamas et al., 2016).

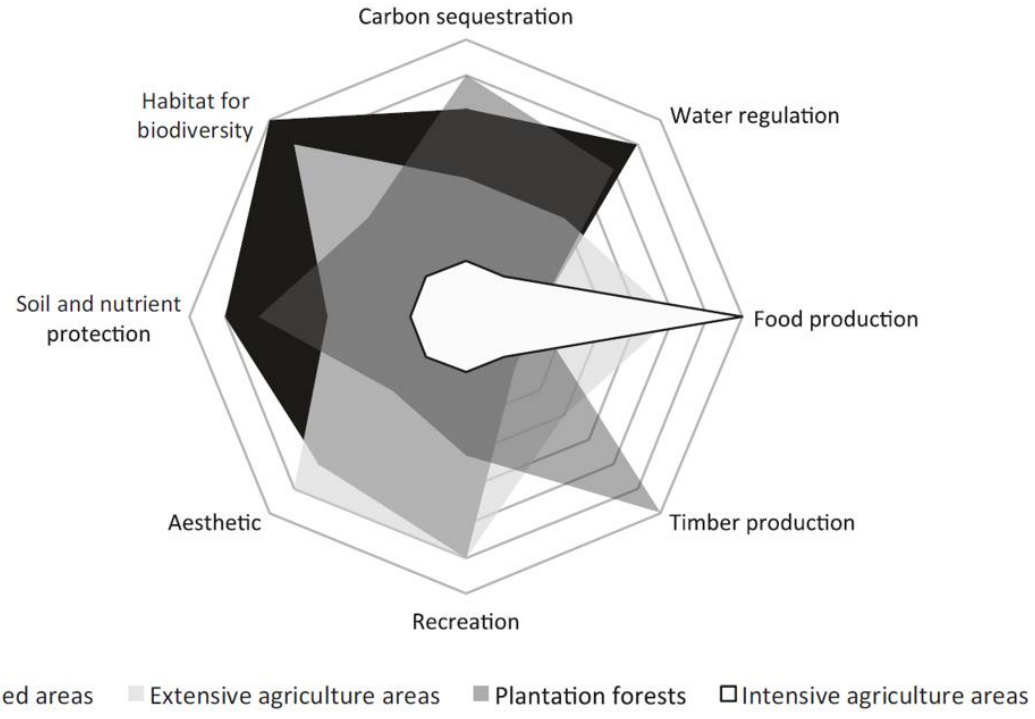


***Figure 5***: Extract from paper [18]: Ecosystem services provided by different landscape managements

However, establishing rewilding as a Nature Based Solution (NBS) with minimal intervention may reduce ecological risks while improving and producing new services. NBS are recognized for being a cost-effective way to solve ecological risks (fires, floods) as well as for restoring degraded ecosystems. Rewilding is an example of NBS, and it has

shown multiple landscape and ecosystem services benefits, particularly, and mentioned below, by regulating services (*Figure 6*).

Ecosystem services relevant for nature based solutions.

| Ecosystem services |
|---|
| Soil protection |
| Flood regulation |
| Water quality regulation |
| Carbon sequestration |
| Fire prevention |
| Biomass growth |
| Biodiversity |
| Ecosystem resilience |
| Nutrient regulation |

***Figure 6***: Extract from paper [16]: Regulating services improved by the use of NBS

For example, a rewilding project made in Slovenia registered an increase of regulating ecosystem services, even right after land abandonment. However, despite the positive effect of rewilding as a NBS in many ecosystem services, it also brought new problems never seen before. The presence of the new forest cover reduced flood risk and sediment loads, but the higher demand of water dried up the river in summer. This problem was solved with a minimal management which transformed some reforested lands with low erosion risk into grasslands. Apart from solving the previous problem, this measure has stimulated heterogeneity and biodiversity (protection of open areas species) and it has made an extensive farming in grasslands possible for local population. Moreover, it generated new income activities such as ecotourism and agrotourism (Keesstra et al., 2018).

These types of mountainous rural landscapes with low-intensity farming systems are considered to provide high levels of biodiversity. In fact, land use changes, both agricultural intensification and land abandonment, are judged as drivers of biodiversity loss. Many authors claim that the abandonment of these areas causes a reduction of heterogeneity and, as a consequence, biodiversity declines (Cibele Queiroz et al., 2014). Therefore, the abandonment of extensive farming practices of livestock in mountain areas is commonly contemplated as a conservation problem, so they are often protected. As a result, there is a widespread tendency to assume that livestock is decreasing in Cantabrian Mountains, generating a decline of biodiversity. However, and despite the significant decrease of population, the number of cattle in the north of the Cantabrian Mountains increased a 28% from 1986 to 2007. These trend may transform traditional extensive farming systems into intensive ones in the most accessible and productive areas (Blanco-Fontao et al., 2011). Agricultural intensification is the main process of decline of biodiversity, much more than farmland abandonment (Emmerson et al., 2016).

Land abandonment is also viewed as a unique opportunity to recover native ecosystems with high nature values (Regos et al., 2016). Moreover, the consequences of

this fact have shown complex results in biodiversity. Furthermore, biodiversity does not ensure the wilderness of an ecosystem (Blanco-Fontao et al., 2011). Land abandonment is stimulating mature forest species. Some of them named as winner species are increasing their abundance because they are well adapted to new conditions while loser species are declining. On the one hand, these ones are characterized for being open habitat and ecotone species, who are not favoured by abandonment and homogenization. On the other hand, forest-dwelling individuals benefit at a regional and local scale from abandonment.

Numerous studies made in the Mediterranean Region showed a positive influence of land abandonment and forest expansion in the abundance of forest birds but also negative effects in open habitat species. On the other hand, shrub expansion also boosted the colonization of shrubland species. A survey made in a marginal mountain landscape of the NW of Spain evaluated changes in bird diversity in a context of land cover changes. It determined bird diversity before and after land abandonment. Results showed that all the bird species that experience a decline were open habitat species related to human-influenced areas. Overall, land abandonment significantly increased the number of shrub and forest bird species, and the decrease of open habitat species was not alarming (Regos et al., 2016). In addition, the existence of low-intensity fires also enhances biodiversity. It is related to high heterogeneity landscapes where fire acts as an ecological factor which contributes to biodiversity conservation (Campos et al., 2021). In conclusion, the study showed that there are multiple potential benefits associated with land abandonment and rewilding, especially in areas with the presence of low-intensity perturbations such as small size fires which maintain open areas and avoid the loss of open habitat specialist and ecotone species (Regos et al., 2016).

a) *Is the return of large predators viable for local populations?*

Passive rewilding entails the restoration of natural and ecological processes by reducing the human impact on them (Recio et al., 2020). This recovery makes ecosystems be self-sustainable by restoring dispersal, stochastic disturbances and trophic-related processes (Perino et al., 2019). This last ecological process has been widely criticised due to the inevitable recolonization of large carnivores, often considered flagship and keystone species. The net increase of woody vegetation in Cantabrian Mountains is benefiting fundamental ecosystem services such as regulating ones and the dispersal of large carnivores (Navarro and Pereira, 2015; García-Llamas et al., 2018; Zarzo-Arias et al., 2019). It is one of the main conflicts generated by passive rewilding between human and wildlife. In the case of the Cantabrian Mountains, the most problematic large carnivore is the Iberian Wolf (*Canis lupus*). Brown Bear (*Ursus arctos*) also represents and iconic figure of Cantabrian Mountains landscapes.

Brown Bears used to have a low population during the 20$^{th}$ century because of hunting and landscape fragmentation. Changes in society opinions about biodiversity, and ecosystems and rewilding bring them an opportunity to return to normal by reducing land fragmentation and persecution. They live in inaccessible areas with low human activities and extent territories of hundreds of square kilometres. Nowadays, the main problem of Brown Bears in the Cantabrian Mountains is their isolation due to limited connectivity between the two subpopulations (western and eastern). Dispersal of the bears in western

Asturias is very low and the eastern population is increasing slowly. The main problems which reduce bears dispersal and specially the connectivity between the two subpopulations are human elements that act as barriers: transport infrastructures such as highways (Navarro and Pereira, 2015; Zarzo-Arias et al., 2019). Forest cover and human density are identified as the key factors which determine bear expansion (Zarzo-Arias et al., 2019). Bears are less tolerant to human activities than wolves, which can occupy cultural landscapes. Yet, they can coexist with low-intense human activities (Navarro and Pereira, 2015).

In the case of the wolf, it is recolonizing areas where it has been present in the last centuries, and not only in Spain, but also across Europe. This process clashes with the economic and cultural management that humans have been doing in traditional managed landscapes (Recio et al., 2020). Conflicts such as wolf attacks to wild and domestic species and livestock and competition with hunters for wildlife are hindering human-wolf coexistence (Navarro and Pereira, 2015; Recio et al., 2020). Wolf attacks are not randomly distributed, they appear in high cattle densities and in the highest elevations. Lower areas are not usually attacked due to the livestock stabling. Likewise, they also act in areas with depopulation and low density, but the main factor of wolf attacks is the accessibility they have to livestock. The number of wild ungulates is not so high, and livestock becomes an easy alternative due to its accessibility (Recio et al., 2020). The main problem of these human-wildlife conflict is that the wolf is recolonizing traditional cultural landscapes where humans were not used to it and now local communities are not familiar with the coexistence with them, as it happens with Brown Bear (Zarzo-Arias et al., 2019; Recio et al., 2020). This generates a deficit of protection measures, specially free-grazing livestock in higher altitudes, where livestock is accessible for wolves, much more than wild preys (Recio et al., 2020).

Due to wolf recolonization, the concept of shared landscapes (humans and large carnivores) might be reintroduced as well, readopting some traditional management (shepherding) but also new protection strategies such as electric fences, green bridges and enclosures of livestock (Navarro and Pereira, 2015). By reducing attacks, protections of these areas must be promoted if livestock farming activities continue in these mountainous places. Wolf attacks can be reduced with adequate protection measures and should be promoted by organisms like CAP, which is subsidizing theses marginal areas with low production and with constant fits. CAP should set common objectives with rewilding activities (Emmerson et al., 2016; Recio et al., 2020). Moreover, information campaigns to local communities with bear or wolf presence or with future presence due to its expansion may prevent human-wildlife conflicts (Zarzo-Arias et al., 2019). Protecting measures like enclosures of livestock in particular periods (lambing and calving seasons) and in the most vulnerable places, and the presence of dogs and shepherds results in a decrease of wolf attacks. New management strategies adapted to recent times and to large-scale rewilding where wolf is an important figure of landscapes must be promoted (Recio et al., 2020). For example, the implementation of new models based on the coexistence of humans and wildlife which respects both sides: the development of ecological processes of large carnivores such as predation and the presence of humans as necessary elements of landscapes (Navarro and Pereira, 2015). On top of that, subsides should be given to traditional managed areas with fertile lands in lower altitudes while fostering rewilding actions in the less productive ones, by adapting

them to the wolf and, in the same way, by introducing new economic activities (Recio et al., 2020).

In the case of Central Apennines, Italy, the context of land use change was similar to the Cantabrian Mountains: rural exodus and ageing of the population developed a global tendency of land abandonment. Land use change has brought with it the return of large-carnivores and the remaining population is getting used to them by recovering traditional and sustainable extensive practices. Five large corridors were created (100000 ha), connecting national parks to guarantee dispersal, and new electric fences were installed replacing the old ones to avoid human-wildlife conflicts. Furthermore, despite the fact that provisioning ecosystem services are still the main economic activity, new cultural services such as tourism help local economy and provide new nature-based activities (Perino et al., 2019). These results were achieved by establishing dialogue with locals and stakeholders as well as with economic incentives to protect wildlife.

b) *Is fire risk associated with rewilding processes?*

Another important ecological process that must be kept in mind when talking about rewilding are perturbations. Currently, in Cantabrian Mountains, wildfires represent the most important disturbance due to its increasing magnitude and severity. As it happens with large carnivores, the fire risk associated with abandoned landscapes and rewilding is another big challenge which affects local populations. Abandonment processes in rural areas come with forest expansion open areas, as well as shrub encroachment, and consequently, fuel accumulations and continuity, which generate more flammable landscapes (Regos et al., 2016; Campos et al., 2021). In fact, wildfires have higher impacts on traditional managed landscapes related to a constant presence of human activities, where fire-regime changes because of the increase of vegetation and abandonment, which generate more dangerous wildfires (Campos et al., 2021). In addition, these changes are more noticeable on account of the increasing number of fires ignited by human cause (Regos et al., 2016).

The present measures taken against fires may not be the most effective ones and even counter-productive in some ecosystems. In this day and age, fire suppression techniques are a priority rather than prevention ones. This is generating an accumulation of fuel and denser vegetation which provokes more intense and bigger fires. These large fires, which are becoming more frequent, are creating fire-prone shrub covers, characteristic of homogeneous landscapes. Moreover, this reduces low-intensity wildfires that acts as an ecological factor and regulates succession, competition and nutrient cycle (Regos et al., 2016; Campos et al., 2021; Carver et al., 2021). Fire happening as a stochastic disturbance affects species diversity and regulates other important landscape characteristics such as connectedness (Campos et al., 2021). These low intensity wildfires may enhance heterogeneity in landscapes by maintaining a dynamic mosaic which changes after each perturbation and creates new habitats colonized after the disturbance. However, high frequency and large fires generate the opposite effect, making species dependent of these perturbations to generate open habitats that eventually become “ecological traps” (Regos et al., 2016).

With the recent scenario of land use change, abandonment and more flammable landscapes, new measures and opportunities have appeared, such as High Nature Value farming systems (HNVf). These scenarios represent an efficient and cheap way to reduce wildfire risks, as it was proved in many places of Spain. They highlight the importance of semi-natural open areas as the key to reduce the accumulation of dense vegetation. HNVf scenarios in combination with careful fire suppression strategies (avoiding total suppression strategies) is considered as optimal solution for today's land abandonment context, enhancing diversity as well as protecting ecosystems severe wildfires. Mentioned by Campos et al. (2021), the best alternative to reduce fire risks and benefit biodiversity, is to enhance rewilding by using fire and generate a "fire-mediated rewilding". In this context, the biggest issues associated to rewilding with fires can be solved with low suppression fire strategies (Campos et al., 2021). Modulation of fire suppression results in more heterogeneous mosaic landscapes where fire spread is reduced and limited due to the variety of vegetation (different ages and structures of fuel). Moreover, low pressure harvesting practices can also prevent the expansion of wildfires by reducing the availability of fuel and, at the same time, maintain certain open areas to enhance landscape heterogeneity. These measures will generate an optimal fire regime instead of a fire-prone ecosystem which benefits species from different ecosystems (Regos et al., 2016).

Furthermore, this sort of strategies boost rewilding initiatives in abandoned mountainous areas of the Cantabrian Mountains in the context of more flammable landscapes. However, and as it happens with large carnivores (Recio et al., 2020), new strategies and opportunities must be encouraged by renewed policies and legislation from the UE and CAP (subsides and economic incentives) which include rewilding as well as HNVf instead of flammable homogeneous landscapes (Campos et al., 2021).

c) *Which patterns of connectedness and connectivity may be found in rewilded Cantabrian landscapes?*

Connectedness is a basic property of landscapes which assists dispersal of individuals. It improves the resilience of ecosystems by encouraging movements and migrations over landscapes connecting core areas (Carver et al., 2021). Moreover, it guarantees sustainable populations by allowing them to compete and exchange individuals, improving their genetic diversity and obtaining healthier populations (Beier and Noss et, 1998; Navarro and Pereira, 2015; Perino et al., 2019).

One of the main objectives of rewilding is to increase connectivity, and consequently, dispersal to make more complex and resilient ecosystems. Dispersal is improved with connected landscapes with minimal barriers and corridors; it has been proved very useful in fragmented landscapes (Beier and Noss, 1998; Perino et al., 2019). The improvement of landscape connectedness brought by rewilding and the creation of large-scale corridors brings a new opportunity for large mammals (Navarro and Pereira, 2015; Perino et al., 2019). However, connectivity efforts should go further than focusing just on corridors. Identifying new opportunities such as hedgerows for birds and other species and other conservation measures such as the improvement of connectivity between patches is fundamental (Perino et al., 2019; Velázquez et al., 2019). Furthermore, habitat

degradation have fragmented landscapes and human barriers such as highways, fences or dams reduce dispersal ability (Perino et al., 2019). *Figure 7* is an example of a fragmented agricultural landscape were dispersal ability (colour and dashed lines) is reduced by a road which also decreases trophic complexity (circles with colour dots inside).

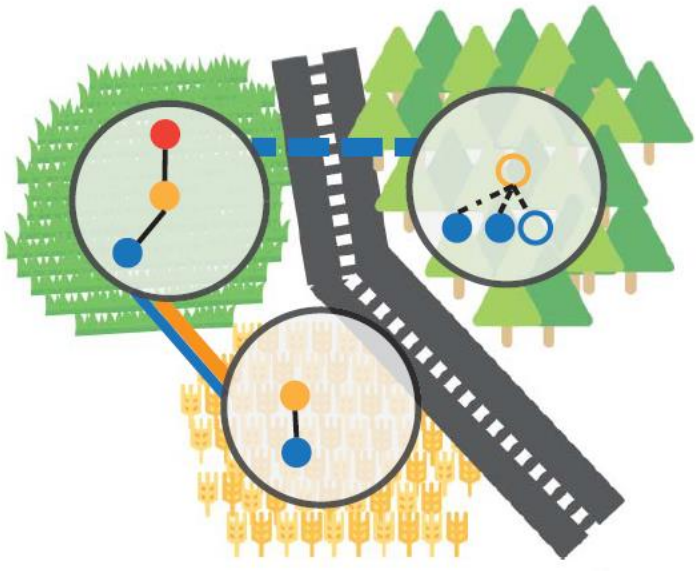

***Figure 7**:* Extract from paper [20]: Trophic complexity and dispersal ability in a fragmented agricultural landscape

For example, landscape degradation and fragmentation caused by human threats capercaillie populations in Cantabrian Mountains (Velázquez et al., 2019). On the one hand, in agricultural lands, homogeneity reduces the dispersal of certain species, but it can be solved with natural landscape elements which improve its permeability (Perino et al., 2019). Aside from that, landscape heterogeneity and the presence of open areas benefits capercaillie because it is a source of food and shelter that also increases connectivity between forest patches (Velázquez et al., 2019).

# 7. CONCLUSION

Land use changes in the Cantabrian Mountains are controlling land dynamics and landscape homogenization. The extension of woody vegetation and decline of semi-natural open areas is changing the way human benefits from ecosystem services. For instance, while some regulating services are increasing its supply, others, depending on traditional practices, are decreasing (e.g., cultural services related with traditional managed landscapes). Moreover, problems associated with land abandonment appear, as human-wildlife conflicts and increasing fire risks due to more flammable landscapes. However, land abandonment processes are an opportunity to establish Natural Based Solutions, such as rewilding. To mitigate ecological risks, in particular recent high-intensity fires, and to make a resilient landscape, admitting a minimal human intervention might by the best solution. In this case, human management can be limited to the maintenance of certain open areas, where traditional extensive practices would protect grasslands. The protection of forest and shrublands as well as open semi-natural areas, apart from increasing heterogeneity and biodiversity, will improve landscape connectedness of forest and open areas species.

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