Towards Managing Biodiversity of European Marginal Agricultural Land for Biodiversity-Friendly Biomass Production

Anna Burland † and Moritz von Cossel *,†,‡

Abstract: The use of marginal land, especially that which has already been used for agricultural purposes in the past two decades, for biomass cultivation is seen as an important approach for the transition to a sustainable bioeconomy. Marginal land can provide many other important ecosystem services than biomass provisioning for bioenergy and biobased products such as erosion mitigation, groundwater protection and nursery services to promote biodiversity. However, marginal land is also often subject to dynamic processes, mostly soil degradation and climate change, which make its fauna and flora particularly vulnerable to land-use changes. This study provides insights into marginal land’s potential biodiversity characterization and critically discusses further steps towards applicable management approaches. Not all commonly used indicators apply to all types of marginal land, especially regarding the site-specific biophysical constraints and the landscape heterogeneity. This is because both the biodiversity and biophysical constraints are sensitive to disturbances. Therefore, when marginal lands are used for biomass production, all available measures should be taken to allow for predominantly positive impacts on local biodiversity, such as a survey of the status quo using camera traps, area mapping, or caterpillar mimics and a forecast of potential biophysical and agrobiological impacts of management.

Keywords: agroecosystem; beneficial land-use change; biodiversity; biomass production; biorefinery; environmental protection; land degradation; land-use management; resilience; sustainable intensification

1. Introduction

The protection of species diversity is deeply implemented in current European agricultural policy frameworks [1]. This process is responsible for what we now refer to as biodiversity, a contraction of the words “biological” and “diversity” that denotes the variety of all life on Earth [2]. The Convention on Biological Diversity (CBD, Rio de Janeiro, Brazil) defined biological diversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” [3]. However, the definition of the term “biodiversity” has been a subject of scientific discussion for decades, skirting a universally applicable interpretation since its introduction in the 1980s [4]. Even now, a broadly suitable definition of the term “biodiversity” does not exist. Instead, biodiversity is generally redefined according to the individual author’s purpose and the context of the work where it is used [5]. Species richness is often used as a measure of diversity, but it is a simple metric and may not be well suited for all purposes [6]. Definitions of biodiversity also did not always necessarily include cultural modifications to diversity, either local or global, such as domesticated species, but expanding the concept beyond only native biodiversity is considered by some to weaken biodiversity’s utility as a biological concept [7]. However, invasive, or nonnative species, whether they are caused by human-facilitated introduction or ranges expanding because of climate change, continue to
be a reality of wildlife populations globally. Nonetheless, the lack of clarity in relation to this term does not mean that the conservation of the diversity of life on Earth should not be protected or conserved [8].

In some ways, the effort to define biodiversity can be seen as a way to underscore its significance as a concept to environmental science and discussions concerning it. It is easier to understand the concept of biodiversity if it is seen not as absolute but as context-dependent and a product of human thought [9]. Even if biodiversity as a concept is not perfectly defined, it is evident that the ideas of biodiversity and ecosystem services are inextricably linked [8,10–12]. Given the coupling of this study with potential examples of biodiversity-conscious biomass crop cultivation which will be delineated in later sections, biodiversity that has been modified by humans (such as non-native and crop species) will also be considered.

1.1. The Role of Biodiversity for Biomass Production on Marginal Land

The potential environmental, social, and economic benefits of a transition towards a bioeconomy are often mentioned in the pertinent literature [13–17]. Among these ideas, the current and future utilization of marginal land (MAL) to grow biomass crops (also known as “non-edible crops” or “industrial crops”) is a popular one (Figure 1) [18–27].

![Figure 1. Schematic overview of environmental challenges regarding marginal land (MAL) management, with above- and belowground biodiversity being an amalgamated key component (adapted from [25–27]). Biodiversity of MAL has the potential to be both a threat to and a victim of agricultural use.](image)

In order to avoid competition between biomass crops, food crops, and feed crops on productive agricultural land, shifting biomass cropping systems to MAL now seems
to be an obvious decision in terms of achieving food security [25]. It can also make sense in view of climate protection through carbon sequestration on infertile MAL [28,29]. In this course, MAL has garnered attention for its potential to host biomass cropping systems [18,22,30]. Identifying MAL is linked to being able to make strategic decisions regarding landscape planning, environmental protection, and sustainability, among other potential benefits [31,32]. However, such areas are generally seen as environmentally fragile and may have a number of biophysical challenges [27,33].

Over time, the term “marginal land” has had different definitions depending on the region, organizations, current type of land use, and management goals of those areas [33]. These differences in the definitions of MAL can make it difficult to clearly delineate what areas are specifically being referenced when talking about MAL. The concept of marginality does not always hinge only on the biophysical or environmental dimensions of an area, but can be influenced by socio-economic factors, location, and utilization history. It follows that given this unclear concept of “MAL”, there are other terms that refer to land types that are also marginal in some way (Table 1). Therefore, this study mainly focuses on MAL available for agricultural production, thus excluding most other, non-agricultural land-type uses such as protected areas and forests. Interdisciplinary analysis can generate confusion about definitions [34], so clear definitions are an important facet of this study.

Table 1. Definitions for various land types that can overlap with the definition of marginal land (MAL) or are often mentioned in research that concerns MAL.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unproductive land</td>
<td>Land that is unproductive in terms of agricultural production.</td>
<td>[18]</td>
</tr>
<tr>
<td>Marginal land</td>
<td>“Lands having limitations which in aggregate are severe for sustained application of a given use and/or are sensitive to land degradation, as a result of inappropriate human intervention, and/or have lost already part or all of their productive capacity as a result of inappropriate human intervention and also include contaminated and potentially contaminated sites that form a potential risk to humans, water, ecosystems, or other receptors”.</td>
<td>[35]</td>
</tr>
<tr>
<td>Less favored areas</td>
<td>Classified as areas where conditions are present that make farming more difficult due to natural constraints, which increase the costs of production or reduce opportunities for agricultural ventures.</td>
<td>[26]</td>
</tr>
<tr>
<td>Fallow land</td>
<td>Arable land that is used in a crop rotation system or is otherwise well maintained and is in good agricultural and environmental condition. Fallow land must be left to recover from the processes of agricultural production, usually for at least one entire crop year. This definition includes bare land that maintains no crops at all, land with natural growth that can be used as feed or ploughed, and green fallow areas intended for the production of green manure.</td>
<td>[36]</td>
</tr>
<tr>
<td>Mountainous areas</td>
<td>Classified as areas in Nordic areas that experience temperatures similar to or lower than the highest peaks of the Alps, non-mountainous areas that form part of mountain ranges, municipalities that are 50% mountainous, but excluding isolated mountain areas that are comprised of less than 5 km².</td>
<td>[37]</td>
</tr>
<tr>
<td>Abandoned land</td>
<td>Abandoned land was once used for a particular purpose, such as industrial, silvicultural, or agricultural activities but has since been abandoned. Abandoned land is not the same as fallow land, since there is no intention to eventually resume activities. This land type is difficult to map.</td>
<td>[38]</td>
</tr>
<tr>
<td>Wasteland</td>
<td>Previous management, natural processes, or other events have rendered this land type unused, unstable, and without agricultural potential. This type includes active dunes, salt flats, rock outcrops, deserts, ice caps, and arid mountain areas.</td>
<td>[39]</td>
</tr>
<tr>
<td>Brownfields</td>
<td>Land that may be affected by contamination or pollution issues; may be seen as a subset of degraded land.</td>
<td>[23]</td>
</tr>
</tbody>
</table>
Table 1. Cont.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degraded land</td>
<td>Land where productive use has been limited by anthropogenic activities. Generally, at least some degraded lands are seen as marginal.</td>
<td>[23]</td>
</tr>
<tr>
<td>Buffer strips</td>
<td>Small marginal areas near rivers, roadways, or other urban places.</td>
<td>[40]</td>
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</table>

The Sustainable Exploitation of Biomass for Bioenergy from Marginal Lands (SEEMLA) definition considers MAL to be “land with clearly reduced soil fertility that does not however exclude profitable biomass production” [21], which is also centered on anthropogenically degraded lands and excludes natural badlands and more productive fallow land. Marginal land tends to be dynamic because of changes in land use, socio-economic conditions, management techniques [18,19,33], and climate change [30,41,42]. Strijker (2005) defines MAL as “characterized by land uses that are at the margin of economic viability”, where economic viability is established by available alternatives for different types of production (Figure 2). There are three categories of MAL according to the current literature: biophysical limitations, low production potential, and economical limitations [21]. Biomass yield and/or biomass quality will be lower on MAL than on favorable land, and MAL is typically farther from markets which increases its associated production costs [43].

![Figure 2](image-url)  
An overview of how biomass crops’ cultivation could fit into available agricultural areas. The term “marginal” here denotes biomass yield and quality levels below average; the term “food crops” here refers to both food and fodder crops. The terms “ILUC” and “DLUC” refer to indirect and direct land-use change effects, respectively. Thus, it must be decided on a case by case approach whether cultivation makes sense under both social-ecological and economical aspects. For instance, in some cases, the integration of non-edible (biomass) crops into crop rotations on favorable (non-marginal) land could help control weed populations or improve the soil fertility by reducing food crop-related pests and diseases in the soil and thereby lead to beneficial land-use change effects [32] (A). Moreover, on some types of agricultural land not suitable for food crop cultivation, non-edible crop cultivation is considered feasible and could help, in the best case, to reclaim suitability for food crop cultivation in the future or at least reduce degradation processes (B).

In this study, MAL has been chosen because biodiversity values should still be considered even in areas that are unproductive, degraded, or otherwise less economically or agriculturally viable. Therefore, this study intends to help minimize negative impacts on ecosystem services and biodiversity [44] and thus improve the social and ecological sustainability of marginal agriculture land low input systems (MALLIS) [30], especially because
MAL is a natural resource and may already provide active societal benefits by supporting biodiversity [21,44]. Hence, MAL may not be unproductive in an economic sense, but may still provide ecosystem services such as preserving biodiversity, mitigating erosion, and sequestering soil carbon. Thus, low-input land-use systems may create synergies between biomass production, biodiversity, and ecosystem service provisioning [45]. An apparent lack of direct benefits to society in an area does not mean that those areas are not providing indirect benefits or supporting other more productive areas nearby [16]. Consideration of these indirect benefits (and costs) is imperative in order to generate a more realistic picture of the true costs and benefits of alternative land-use systems, which was recently shown for the example of miscanthus (Miscanthus ANDERSSON) cultivation [16].

Maintaining valuable biodiversity in unproductive landscapes can improve their quality and conserve important habitats. Cereal steppes and Montado systems can host high levels of biodiversity and support animal production systems [46]. Low input agricultural systems can be valuable to increasing biodiversity, while abandonment can positively or negatively impact biodiversity [34]. There is consequently a strong influence of the MAL and the regional context on whether land sparing is better for biodiversity conservation or land sharing. In this regard, Siggia et al. (2020) found that the "research on the effect on unused, fallow and polluted land for energy crop production, however, is minimal". Thus, there are gaps in the literature when it comes to the impact of biomass crop cultivation on farmland species, particularly mammals, on MAL [44].

1.2. Aim of This Study

Against this background, the aim of this study is to critically discuss whether it would be possible to characterize and manage biodiversity on MAL. This discussion aims to better understand the potential of low-input biomass cultivation in these areas, while supporting the conservation or restoration of biodiversity there. Thus, this study is not intended to measure biodiversity everywhere but narrows its scope to include only biodiversity on MAL which needs to be considered for more biodiversity-friendly biomass crop cultivation in the future bioeconomy.

2. Methods

2.1. Literature Search

The literature search was based on Scopus (https://www.scopus.com/, accessed on 10 June 2023, Elsevier B.V., Amsterdam, The Netherlands) and Wiley Online Library (https://onlinelibrary.wiley.com/, accessed on 10 June 2023, John Wiley & Sons, Hoboken, NJ, USA). Relevant papers were found using combinations of identified search terms (see below). The accumulated literature contained documents that referred to projects put into place by the European Union such as Natura 2000, Mapping and Assessment of Ecosystems and Their Services (MAES, https://biodiversity.europa.eu/maes, accessed on 10 June 2023), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) which were then also investigated on their own respective home pages or websites for identifying potential biodiversity indicators for use in this study. Documents found within reference lists of the accumulated literature were also taken into consideration.

The following 15 search terms were combined using Boolean operators (“AND”, “OR”, etc.) so that results could be relevant to biodiversity across MAL in the European context:

- Assessment;
- Biodiversity;
- Biodiversity assessment;
- Biomass production;
- Categorization/categorize;
- Characterization/characterize;
- Conservation;
- Ecosystem services;
- Europe;
- Evaluation/evaluate;
- Functional diversity;
- Marginal land;
- Resilience;
- Response diversity;
- Unproductive land.

The terms “marginal land” /“unproductive land”, “Europe”, and “biodiversity” were always included so that the accumulated literature could be used for the hypothetical case studies. “Unproductive land” was included as a search term since not all relevant research refers to the idea of MAL as used in this study as “marginal land” specifically (agricultural context). MAL is present globally, but the search range of the literature review was limited to Europe to better suit the scope of this study. Other terms, such as “response diversity”, “biomass production”, “resilience”, and so on were each combined with the first three terms to locate the relevant literature on strategies for assessing biodiversity, biodiversity literature, biodiversity indicator lists, and so on. Additionally, the potential biophysical challenges (e.g., climate change and degradation) of the MAL’s ecosystems were taken into account.

By reviewing available biodiversity monitoring schemes and their respective indicators, it became clear that, first, there does not appear to currently be such a project that is specifically geared towards MAL. However, other notable biodiversity assessment projects that currently exist were nevertheless reviewed. Indicators for the biodiversity assessment utilized in some EU biodiversity monitoring schemes were also considered. Another consideration of this study was that biodiversity is asymmetrically distributed across the globe, so assessments of biodiversity must be specific to the biome, site, and context [44], while still being useful for tracking changes of biodiversity across large regions and future data integration. Indicators of biodiversity cannot be tested for reliability if they cannot be captured in numbers, so it makes sense to combine indicators with quantifiable features of biodiversity [9]. However, the biodiversity characterization itself is not the only concern of this study. Existing land assessments and mapping efforts are also important when considering parameters for a biodiversity-friendly biomass production management on MAL. For example, the SEEMLA algorithm was the starting point for the development of a map of MAL for identifying areas suitable to produce specific energy crops [21]. In contrast, Streamlining European Biodiversity Indicators (SEBI) 2010 was not intended to be comprehensive, and most of its selected indicators do not specifically assess biodiversity [47]. Thus, the range of indicators used in other projects is also not always intended to be comprehensive, given the sheer complexity of the topic. The issue of complexity, as well as the presence of knowledge gaps in the available data can limit the development of effective indicators [48].

A large body of work concerning the study and evaluation of biodiversity and ecosystem services has been produced by the scientific community, particularly in the last few decades. From the literature, the opportunity for a MAL-specific approach to biodiversity classification presents itself. However, first, some definitions of key terms such as ‘biodiversity’ and ‘ecosystem services’ as well as the types of marginal land are needed.

2.2. Definitions

To maintain clarity throughout this study, a number of important terms have been selected to be listed here to ensure that the intent behind their use for this study is clear (Table 2). The biodiversity characteristics will be referred to as “parameters”.

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Table 2. Definitions pertinent to this study.

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</tr>
</thead>
<tbody>
<tr>
<td><strong>Biodiversity</strong></td>
<td>“Biodiversity is a state of attribute of a site or area and specifically refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be measured in terms of genetic diversity and the identity and number of different types of species, assemblages of species, biotic communities, and biotic processes, and the amount (e.g., abundance, biomass, cover, rate) and structure of each. It can be observed and measured at any spatial scale ranging from microsites and habitat patches to the entire biosphere”.</td>
<td>[7]</td>
</tr>
<tr>
<td><strong>Biodiversity parameters</strong></td>
<td>Features of biodiversity that will be used within the characterization matrix produced in this study. Similar to “indicators” used within biodiversity monitoring schemes.</td>
<td></td>
</tr>
<tr>
<td><strong>Ecosystem processes</strong></td>
<td>Intrinsic ecosystem characteristics that maintain the ecosystem’s integrity. These processes include, for example, decomposition, production, nutrient and energy cycles or fluxes.</td>
<td>[8]</td>
</tr>
<tr>
<td><strong>Ecosystem services</strong></td>
<td>Benefits that humans obtain from ecosystems. Includes provisioning services (such as food or water), regulating services (such as flood or disease control), cultural services (such as spiritual, cultural, or recreational services), and supporting services (such as nutrient cycling).</td>
<td>[8]</td>
</tr>
<tr>
<td><strong>Ecological resilience</strong></td>
<td>The measure of the ability of an ecosystem to absorb changes and continue to persist. In addition, the level of disturbance an ecosystem can experience, without shifting to a different structure with different outputs, depends on ecological dynamics and the organizational/institutional capacity to understand, manage, and respond to those dynamics.</td>
<td>[8]</td>
</tr>
<tr>
<td><strong>Response diversity</strong></td>
<td>The variety of species that can provision different ecosystem functions, that also have different capacities to respond to disturbance which makes the entire ecosystem more resilient.</td>
<td>[50]</td>
</tr>
<tr>
<td><strong>Ecological stability</strong></td>
<td>The ability of an ecosystem to quickly return to a state of equilibrium after temporary disturbances.</td>
<td>[49]</td>
</tr>
<tr>
<td><strong>Biodiversity surrogates</strong></td>
<td>Can be used to indirectly capture biodiversity changes. However, changes must be inferred instead of directly observed.</td>
<td>[51]</td>
</tr>
<tr>
<td><strong>Species richness</strong></td>
<td>The number of species in an area (in total or at a specific organizational level) but does not reflect abundance or distribution.</td>
<td>[9]</td>
</tr>
<tr>
<td><strong>Alpha/beta/gamma diversity</strong></td>
<td>Alpha diversity is the diversity in an ecosystem expressed in species richness, beta diversity compares communities using habitat gradients, and gamma diversity is the sum of the alpha values of all the communities in a landscape as well as the differentiation of their beta values.</td>
<td>[52]</td>
</tr>
<tr>
<td><strong>Functional diversity</strong></td>
<td>Functional diversity is the variety of physiological, morphological, and ecological species traits of an area. In addition, the range, value, and relative abundance of traits present in organisms within a community.</td>
<td>[8,53]</td>
</tr>
<tr>
<td><strong>Transition zones/overlap zones</strong></td>
<td>Areas of transitions between two biomes or other abiotic differences (elevation, for example).</td>
<td></td>
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<tr>
<td><strong>Ecotones</strong></td>
<td>Areas of transitions between ecological communities.</td>
<td>[54]</td>
</tr>
<tr>
<td><strong>Temporal turnover</strong></td>
<td>The rate of temporal changes in ecological communities, which occurs as a consequence of shifting community composition and changes in species abundance.</td>
<td>[55]</td>
</tr>
</tbody>
</table>

3. Results and Discussion
3.1. The Evaluation of Biodiversity in Europe

To set the scene, Europe has experienced significant agricultural development and landscape changes over its long history of human habitation [56]. Before the industrial revolution in the 20th century, agricultural usage was extensive and maintained high nature values [34]. The increasing modernization of agriculture and dependence on fossil fuels have shifted this trend over time. Biodiversity in Europe is experiencing a continuous
strong decline. Both landscapes and seascapes have become more uniform in terms of species composition and less diverse overall, driven by land-use change, urbanization, and the intensification of agriculture [57]. The first comprehensive global agreement to address biodiversity at different organization levels was the CBD in 1992 [2]. More recently, biodiversity has also become a major topic for legislative and policy developments specifically in the European Union. The European Commission’s Biodiversity Strategy to 2020 called for EU member states to participate in MAES in 2014 and provided guidance on how to assess the condition of Europe’s ecosystems [58]. At the moment, all EU member states are actively involved in MAES and the Biodiversity Strategy has since been updated for 2030. Robust biodiversity monitoring schemes have the potential to provide consistent ecosystem data for the whole of the EU, including ecosystem quality.

Information regarding ecosystem quality is vital for guiding policy and management decisions [8,58]. Tracking changes in biodiversity requires datasets collected over long time periods to which new information can be compared. The objective of habitat monitoring is to describe the current state of habitat-relevant facets of biodiversity to be able to compare the current state to any changes that occur [59]. Several methods of categorizing or assessing biodiversity and ecosystem services exist, notably the Millennium Ecosystem Assessment [8] and The Economics of Ecosystems and Biodiversity, which were used in part to build the Common International Classification of Ecosystem Services, and the assessments of the IPBES, which were both considered when creating MAES [57,60]. There is also SEBI, which endeavors to standardize the monitoring data, and the strategies used for assessing biodiversity improvements under the Common Agricultural Policy (CAP). Beyond that, the Coordination of Information on the Environment Biotopes project was the first European project to describe habitat types using a unified typology [59]. This is not a complete list of all European biodiversity monitoring schemes, but it provides an impression of the activities/available building-up datasets that may be relevant toward the characterization of biodiversity on European MAL.

Despite commonality among their goals, there can be significant differences between designs and indicators among long-term biodiversity monitoring datasets [61]. A current challenge for biodiversity monitoring over large regions or multiple countries is the need for data integration. Data integration is an important aspect of being able to more broadly understand biodiversity changes both globally and in regions as large and differentiated as the European Union. Biodiversity monitoring schemes can focus on different species or habitats and their relevant selected indicators, focusing on what biodiversity parameters have been selected as important for those areas. Biodiversity is not distributed equally across countries, so it follows that different areas would have different goals. Biodiversity, in all of its complexity, cannot be fully captured through the use of simple or practical indicators, since these may fail to capture particular aspects that may be vital to certain communities, contexts, or conservation goals [48]. Therefore, some contextual indicator selection approaches are outlined below.

EU-wide monitoring methods and systems of surveillance for species and habitats of community interest identified five biological parameters for use in their monitoring project: distribution of species, abundance, demographic processes, species assemblage, and environmental parameters [62]. In addition, in 2005, the European Academies Science Advisory Council (EASAC) identified several biodiversity indicators for assessing the current state of the situation that could be implemented at that time: measures of population trends (such as the Wild Bird Indicator, among others), measures of habitat extent (such as the Coordination of Information on the Environment habitat classification database), measures of changes in threatened species (such as the IUCN Red List), measures of fishing impacts on marine fishes (such as the Marine Trophic Index), as well as the Living Planet Index and the Natural Capital Index [48]. Other monitoring systems may recommend focusing on simplicity by selecting indicators concerned only with species richness at different spatial scales (local, landscape, and macro-scale) [63], while projects such as the Aichi Biodiversity Targets have 20 targets that each have a large variety of nested indicators, as well as having
had indicators crossmapped to these targets from the Biodiversity Indicators Partnership, often dependent on country or other parameters [64]. The Biodiversity Indicators Partnership’s indicators include some dimensions that might be considered as not directly relevant to natural biodiversity because they instead measure the progress of implementation of pro-biodiversity policies, level of public awareness, or drivers of biodiversity change [65]; such indicators are also present in SEBI 2010’s (Table 3) and EASAC’s indicator lists, among others. Biodiversity indicators may be a general concept, such as species richness, or exist in an index or database such as the Marine Trophic Index.

**Table 3.** SEBI’s 2010 indicators, showing CBD focal areas and their respective EU headline indicators adapted from [47].

<table>
<thead>
<tr>
<th>CBD Focal Area</th>
<th>Headline Indicator</th>
<th>SEBI 2010 Specific Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Status and trends of the components of biological diversity</strong></td>
<td>Trends in the abundance and distribution of selected species</td>
<td>Abundance and distribution of selected species</td>
</tr>
<tr>
<td></td>
<td>Change in status of threatened and/or protected species</td>
<td>Red List index for European species</td>
</tr>
<tr>
<td></td>
<td>Trends in extent of selected biomes, ecosystems, and habitats</td>
<td>Ecosystem coverage</td>
</tr>
<tr>
<td></td>
<td>Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance</td>
<td>Livestock genetic diversity</td>
</tr>
<tr>
<td></td>
<td>Coverage of protected areas</td>
<td>Nationally designated protected areas</td>
</tr>
<tr>
<td><strong>Threats to biodiversity</strong></td>
<td>Nitrogen deposition</td>
<td>Critical load exceedance for nitrogen</td>
</tr>
<tr>
<td></td>
<td>Trends in invasive alien species (numbers and costs of invasive alien species)</td>
<td>Invasive alien species in Europe</td>
</tr>
<tr>
<td></td>
<td>Impact of climate change on biodiversity</td>
<td>Impact of climatic change on bird populations</td>
</tr>
<tr>
<td><strong>Ecosystem integrity and ecosystem goods and services</strong></td>
<td>Marine Trophic Index</td>
<td>Marine Trophic Index of European seas</td>
</tr>
<tr>
<td></td>
<td>Connectivity/fragmentation of ecosystems</td>
<td>Fragmentation of natural and semi-natural areas</td>
</tr>
<tr>
<td></td>
<td>Water quality in aquatic ecosystems</td>
<td>Fragmentation of river systems</td>
</tr>
<tr>
<td><strong>Sustainable use</strong></td>
<td>Area of forest, agricultural, fishery, and aquaculture ecosystems under sustainable management</td>
<td>Forest: growing stock, increment, and felling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forest: deadwood</td>
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<tr>
<td></td>
<td></td>
<td>Agriculture: nitrogen balance</td>
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<td></td>
<td></td>
<td>Fisheries: European commercial fish stocks</td>
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<tr>
<td></td>
<td></td>
<td>Aquaculture: effluent water quality from finfish farms</td>
</tr>
<tr>
<td><strong>Status of access and benefits sharing</strong></td>
<td>Percentage of European patent applications for inventions based on genetic resources</td>
<td>Patent applications based on genetic resources</td>
</tr>
<tr>
<td><strong>Status of resource transfers</strong></td>
<td>Funding to biodiversity</td>
<td>Financing biodiversity management</td>
</tr>
<tr>
<td><strong>Public opinion (additional EU focal area)</strong></td>
<td>Public awareness and participation</td>
<td>Public awareness</td>
</tr>
</tbody>
</table>
In 2005, a start was made in the SEBI process of contributing to the creation of streamlined and workable biodiversity indicators to complement ongoing biodiversity research and to prevent duplicated efforts in biodiversity monitoring (Table 3) [47]. In comparison, the framework for assessing biodiversity as presented for MAES considers six roles that biodiversity has in supporting ecosystem function, which are: ecological processes, functional traits, biophysical structures, genetic diversity, species richness, and biotic interactions [58]. Between 2011 and 2020, member states of the EU performed national ecosystem assessments using the frameworks of either the Economics of Ecosystems and Biodiversity or the Millennium Ecosystem Assessment 2005 [57].

3.2. Current Biodiversity Monitoring Schemes

Current biodiversity monitoring schemes do not always deal directly with biodiversity that is present on marginal land used for agricultural production [44]. To be able to characterize biodiversity in a specific context, biodiversity characterizations in general must first be considered. It was integral to this study to consider the interface between biodiversity, agricultural land use, marginality, and dynamical processes over time. An issue with policies such as the CAP, which are not explicitly about biodiversity but do list biodiversity maintenance or improvement as a goal, can be that they produce limited results and can be too broad to usefully apply at a farm-level or landscape-context, which is vital for predicting impacts to local biodiversity and ecosystem services [66]. Beyond that, indicators used in biodiversity assessments can be selected for reasons other than scientific criteria, and may be influenced by stakeholder interests, lack of data availability, or solutions chosen only for specific contexts [65]. MAL may present ecological challenges because of (i) a degraded, contaminated, or abandoned state, (ii) the proximity to urban areas, or (iii) the presence of agriculture or other anthropogenic activity.

There are a number of ways to measure biodiversity, and this study did not capture them all. However, some common methods were reviewed that are often referred to in the literature. Most notably, species richness measures the number of species in a given area (this can be in total or narrowed to one organizational level) but does not provide information about species abundance or distribution [9]. An issue with species richness can be that sometimes measures of species richness are instead effectively measures of species density, where species density is the measure of units of species in a specified area and depends critically on the specific amount of area sampled [67]. Another common measure, species abundance, is “the total number of individuals of a taxon or taxa in an area, population, or community” [8] while relative abundance is “the total number of individuals of one taxon compared to the total number of individuals of all other taxa in an area, volume, or community” [8].

Related to the concept of species richness is alpha, beta, and gamma diversity. Alpha diversity is the diversity in an ecosystem expressed in species richness, beta diversity compares communities using habitat gradients, and gamma diversity is the sum of the alpha values of all the communities in a landscape as well as the differentiation of their beta values [52]. More recently, functional diversity, which is the variety of physiological, morphological, and ecological species traits of an area [53], has started to be seen as a measure that may more accurately capture ecosystem functioning [50]. In part, this is because trait-based approaches to characterizing communities may offer better ways of understanding the effects of landscape structure on the composition of assemblages [68].

Overall, there is not one true measure of biodiversity that can capture the situation of an area with a single number [9]. Different measures of biodiversity are context-dependent, which can make it difficult to determine which measure is the most appropriate for any given context [50]. However, biodiversity is not only affected by species diversity at the various organizational levels.

3.3. The Role of Genetic Diversity and Landscape Structure

Biodiversity encompasses the idea of not just the number of different species, but also the diversity of genes within a single species group. However, phylogeny is generally not
included in conservation or management decisions on MAL, likely because of a lack of empirical support. However, protecting species richness may in turn protect phylogenic diversity [53]. Genetic diversity can play a role in the resilience and adaptability of a group, as genetic bottlenecks may limit natural evolutionary processes that would otherwise allow a group to survive changing conditions. In particular, shared evolutionary history between species can be used to capture functional similarities [53].

Genetic diversity is not limited to wildlife, the CBD focal area “status and trends of the components of biological diversity” [69] includes the SEBI 2010 indicator that targets livestock genetic diversity. This indicator is connected to the EU headline indicator “trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance” [69]. Genetically diverse groups of switchgrass (Panicum virgatum L.) from lowland ecotypes, for example, showed more tolerance to salt stress, a significant biophysical issue on MAL [70]. Some wildlife species tolerate agricultural intensification and land-use change in agricultural areas while some decline in abundance [71]. Therefore, there should be a balance between selecting appropriate biomass crops for the area and ensuring that biodiversity can be maintained by understanding local wildlife responses to land management decisions [25,30].

The ecological history of land can be an important consideration when making management or conservation decisions. Temporal turnover occurs in both stable ecological communities, as well as those experiencing directional change, as community composition may be influenced by environmental factors or disturbance events [61]. In one example, after implementing strategies for the control of bracken (Pteridium aquilinum L. Kuhn), often seen as a weed species and of little importance to biodiversity because of its potential to invade other habitats and support disease-spreading ticks, land managers expected that vegetation would return to its previous state on its own after the bracken was removed. However, the returning vegetation was usually dominated by grasses instead and generally did not develop into the desired heathland/moorland vegetation type [72]. Studies concerning the ecological consequences of land abandonment are less common in the literature than those focused on the effects on intensification, but under-use of land or abandonment is still seen as a potential threat to local biodiversity [73].

Land abandonment that represents the intensification of land elsewhere can lead to higher contrast between landscapes, such as densely wooded forest versus intensively farmed cropland [74]. Transition zones may host high levels of biodiversity because of edge effects, which concern patterns of species turnover which occur between biomes or because of elevation gradients [75]. Ecotones, where ecological changes, shifts, and variability occur naturally over space and time, may be useful for biodiversity monitoring and modeling, particularly as climate change influences more extreme changes to natural communities [54]. However, species do appear to avoid certain habitats in agricultural landscapes and are influenced by landscape matrix composition that may increase or decrease the exchange of individuals between populations in different habitat patches [76].

Habitat loss and habitat fragmentation are sometimes used to refer to the same concept, but actually refer to two different processes that often happen in conjunction with each other; thus, a habitat may become smaller via habitat loss, but without the division of that habitat into smaller patches it does not become fragmented [77]. Fragmented landscapes instead produce “habitat patches”. Habitat fragmentation involves more than simply changing the size and composition of habitat patches, and can change the entire landscape matrix and regulate the movement of some animals such as amphibians [76]. The concept of “habitat fragmentation per se” was developed to refer to the idea of habitat fragmentation independent of habitat loss, in cases where the habitat area is not lost but spatial habitat configuration of separate habitat patches is changed [78]. Anthropogenic habitat fragmentation is a driver of population decline in insectivorous European birds, particularly specialist species, since fragmentation or disturbance changes the resource availability in a landscape [79].
While it is understood that the physical structure of a habitat influences the ecosystem productivity and biodiversity, the mechanisms that determine this physical structure are still uncertain [80]. The landscape structure has an effect on functional traits, particularly those related to reproduction and life cycle, which are not always due to changes in species richness [68]. The presence of ecological corridors may help maintain the abundance of some species that would otherwise be isolated to habitat patches and the potential for dispersal may increase the persistence of those species (for example, microarthropods) [81]. This could eventually be provided by the integration of MALLIS—especially those based on perennial biomass crops. Even scattered trees in modified landscapes can contribute to providing habitat to species that prefer tree cover and can maintain relatively high habitat connectivity for some species [82,83]. Some species may have preferences for specific types of microhabitats, and a lack of consideration for these preferences may produce bias when trapping animals for biodiversity sampling or monitoring purposes [84]. The maintenance of habitats dependent on disturbance, for example in Europe, where human activities have replaced natural disturbances such as herbivory or wildfire, can present a challenge for conservation [85]. There may also be direct or indirect effects from transition zones that border MAL or the management of surrounding land areas.

The idea of resilience is a measure of the ability of an ecosystem to absorb changes and continue to persist, while stability is the ability of an ecosystem to quickly return to a state of equilibrium after temporary disturbances [49]. However, similarly to the concept of biodiversity, resilience does not have a singular definition. Resilience can be seen as “ecological resilience” or that amount of disturbance an ecosystem can withstand before it will change, or as “engineering resilience” which refers to the time an ecosystem takes after a disturbance to return to equilibrium [86]. With this concept comes the idea of “resilient ecosystem functions” for conservation decisions that include consideration that essential ecosystem services will still be provided under a variety of potential ecosystem disturbances [87].

3.4. Temporal Changes of Biodiversity

Abiotic factors play a significant role in the community or ecosystem structure, but individual species, or functionally similar species groups, can alter abiotic components such as energy or material flows and impact the diversity or abundance of other species [80]. Climate change continues to displace growing zones and change historic ranges of flora and fauna. Shifting ranges are a necessary consideration for biodiversity classification, as the introduction of new species may change ecological interactions and climate-influenced adaptations in populations may evolve quickly [88]. On the other side, the ecosystem structure also has a significant influence on species. Species specialized for specific abiotic components are vulnerable to a changing ecosystem structure, while generalists may thrive regardless of changing conditions or habitats. There are different components of specialization. For example, the five indices of avian specialization used in Morelli, Benedetti, and Callaghan (2020) were diet, foraging behavior, foraging substrate, habitat selection, and nesting site selection, so a bird might be narrowly specialized for a specific diet but may be more general when selecting suitable nesting areas, and so on.

Some common examples of European generalists are easy to spot even when working from home. Carrion crows (*Corvus corone*), Eurasian magpies (*Pica pica*), and feral pigeons (*Columbia livia*) live in parallel to human society in city centers and neighborhoods. In contrast to the abundance of the generalist feral pigeon, a fellow bird of the family Columbidae, the European turtle dove *Streptopelia turtur* is characterized by a high level of specialization and is declining in nearly all European countries [79]. Local assemblages of birds in European cities have become more and more homogenized, biased towards generalists, while specialists and beta diversity are in decline, likely driven by changes in land use and climate [89].

Birds are heavily impacted by anthropogenic activities and structures, in both positive and negative ways. As a class, birds have shown a great plasticity of lifestyle and adapta-
tion to anthropogenic changes but are still very vulnerable to things such as wind turbines, unobstructed windows, habitat loss or fragmentation, agricultural land-use change, predation by domestic or feral cats, and other human–avian conflicts. Birds also represent, to the average person, the majority of wildlife seen on a daily basis. Raptors in particular have, in the last few decades, become more popular as the subjects of research and in the identification as an umbrella species [74]. However, it has become clear that birds perform somewhat poorly as single taxon surrogates when monitoring total biodiversity [90].

Because of the ubiquity of birds, there are biases against birds in research. Broadly, many biodiversity indicators are biased towards certain taxonomic, geographical, or temporal variables, likely in part because most biodiversity data originate from less biodiverse areas such as North America and Europe [65]. Distribution data about birds are more available than that of other species because birds are easy to survey and are well-known taxonomically, and support for bird conservation is easier to receive because of the general awareness and appeal of birds and birding activities [90]. Drivers of bird extinctions are well documented, while the general pattern emerging from the International Union for Conservation of Nature’s (IUCN) Red List of threatened species indicates that birds are the least threatened group when it comes to taxon extinction risk [91].

Despite their role in the provisioning of ecosystem services, African, European, and South American vulture populations have declined because of intentional poisoning [92]. However, birds are not the only species impacted by extermination efforts. A notable European example, wolves (Canis lupus Linnaeus, 1758), are often seen as a controversial species, because of the potential for predation on livestock and domestic pets, competition with game hunters, and the wolf’s status as a symbol of fear and social conflicts. This means that human acceptance of wolves could become a major problem in much of Europe, particularly areas where they have recently been reintroduced [93]. Further, European landscapes are often dominated by humans, where even natural landscapes often try to satisfy production, recreation, conservation, and residential goals, which complicates the conservation of large predators such as the wolf [94]. Despite these challenges, the wolf population in Europe has grown significantly since the ratification of the Bern Convention [95].

Even species seen as undesirable or dangerous have their own positions in natural communities. The concept of ecosystem multifunctionality recognizes that ecosystems are able to provide multiple ecosystem functions, and because this is driven by functional traits of present species, a certain degree of multifunctional redundancy may exist between species with similar traits in the same area [96]. Functional redundancy is the characteristic of ecosystems where more than one species can carry out the same ecosystem process; this redundancy may be partial or total, where a species may or may not be able to replace another species because of the processes it is involved in [8]. One conceptual model of multifunctionality is centered on the idea that different species perform different ecosystem functions, but it is unlikely that a singular species only performs one ecosystem function, so ecosystems are more likely to lose functioning if functional traits between species do not covary and each species is only performing one function [97]. This concept is not limited to living things, for example, agricultural landscapes can be multifunctional, then leaving remnants of native vegetation in such areas may serve as a way to increase landscape diversity, increasing matrix permeability and habitat quality [98]. However, the mechanism that directly links biodiversity and ecosystem multifunctionality is not yet well understood and makes it difficult to understand which ecosystem functions are driven by biodiversity and how those functions impact other functions [6]. Certain other abiotic ecosystem elements such as water balance have a better understood influence on biodiversity.

Water balance or quality is an abiotic parameter of biodiversity, but may be impacted by biotic processes, species interactions, and the management of other nearby areas. Upstream ecosystems may provide regulatory services in the dilution of point source pollutants entering downstream areas while terrestrial ecosystems regulate the diffusion and retention of contaminants into soils and their transport to surface waters [99] (Figure 3).
Investigating the functional characteristics and the influence of different morphologies of plants, which may be drivers of water balance differences between communities, as well as local meteorological and climatic conditions, is essential to understanding the relationship between plant diversity and water balance [100]. Freshwater ponds in non-urban landscapes support local biodiversity and may facilitate species dispersal, but urban ponds also support relatively high levels of biodiversity and both types of ponds should be considered in conservation decisions [101].

On the other hand, there is uncertainty concerning the condition of freshwater and groundwater ecosystems because of a lack of data [101,102], which may in part be because of a lack of monitoring of freshwaters not covered by the EU Water Framework Directive, such as urban ponds [101]. However, water dynamics are essential to healthy ecosystem function and can have effects that often reach through entire regions.

Another important ecosystem function is the role of vegetation in serving as both a source of air pollutants as well as playing a role in the interception, deposition, and removal of air pollutants, but very high rates of pollutant deposition may impact the provisioning of ecosystem services [99]. There is some evidence that species diversity changes and community level interactions in forest tree assemblages may influence the volatile organic compound emissions of the ecosystem and thus also influence atmospheric chemical processes [103].

Keystone species may impact multiple trophic or non-trophic interactions through their disproportionately large role in structuring communities and ability to modify habitats, despite their relatively low abundance or biomass [80]. However, keystone species are not the only species capable of significant trophic interactions. As a species approaches extinction and its population numbers drop, its contributions to ecosystem functioning will drop below measurable levels before the species itself fully disappears [104]. The complementarity of different functional characteristics and niche differentiation is a common explanation for the positive relationship between planet species diversity and productivity, since plants are able to acquire many different resources in an environment, such as water,
light, and nutrients [100]. However, as will also be covered again later in this section, higher levels of biodiversity do not always directly correlate with more ecosystem productivity or the provision of more ecosystem services. Similarly, highly redundant functional groups may be more vulnerable to environmental fluctuations and do not always ensure high response diversity, as highly vulnerable species within these groups may still be eliminated even at low levels of environmental pressure [50]. However, it may also be true that when an ecosystem is stable, it will require lower levels of biodiversity to provision ecosystem services than it would when the ecosystem is in a state of disturbance or change [87]. While the mechanisms of response diversity are not well understood, biodiversity plays a significant role in ecosystem resilience, and this is related to functional diversity and the maintenance of ecosystem services [105].

Soil fauna represents a significant amount of global biodiversity just by themselves. Soil can harbor significant levels of biodiversity that represents numerous different varieties of bacteria, and wide ranges of fungi, arthropods, mites, nematodes, and invertebrates, and is closely linked to biodiversity of above-ground communities [96]. Soil organisms and biogeochemistry are an essential part of nutrient and carbon cycling in ecosystems [106,107]. The study of soil diversity is still relatively new and soil biodiversity itself has proven difficult to measure [108,109], but this type of diversity quite literally lays the groundwork for healthy ecosystems and biodiversity. The unrecognized influence of soil diversity can result in it being disregarded when making management decisions and limit the ability of soils to provide ecosystem services if they are not properly conserved.

Methods of categorizing biodiversity on MAL can be limited by the intended management goals or conditions of the area that is under review [33]. In the case of controlling bracken, several points should be considered when making management decisions: the impacts of control on current biodiversity and land use, the non-target effects of control (for example, herbicide sensitivity of local non-target species), what vegetation and land use is desired at the site, the practicality of different control methods, what resources are available for follow-up management, and the costs of establishing/managing vegetation [72]. Understanding of ecological changes over time may be limited due to lack of data, because temporal biodiversity patterns have not received as much attention as spatial patterns [61].

Intensive agricultural activity was found to consistently impact European soil biodiversity in negative ways in all areas reviewed by [110]. However, the link between soil biodiversity and ecosystem function is not as direct as it may appear. Soil functions are likely regulated not only by abiotic processes but are also balanced by biotic interactions that help determine ecosystem processes at regional levels [108]. Soil biodiversity appears to be characterized by some level of redundancy among the functional characteristics of the microorganisms that represent it, which can explain why microbial diversity has not been observed to have a relationship to soil functions [109]. The presence of soil organisms with a variety of different functional characteristics is more important for the function of ecosystem processes than simply increasing biodiversity, if essential functional characteristics would still be missing [106,111]. As long as microorganisms with the required functional characteristics still exist after a loss of soil species, soil functions can continue on as before.

The final parameter for characterizing biodiversity will consider land at the environmental management level. Some MAL in Europe may benefit from low/moderate levels of management instead of being fully abandoned, since agricultural maintenance can prevent landslides, wildfires, or erosion [112]. In environments where natural resources and technology are abundant, agricultural production (including MALLIS) may cause soil overexploitation and other environmental threats [113]. However, in economically marginal areas, land abandonment may result in greater environmental and landscape degradation, depending on site conditions and the long-term effects of previous use [114,115]. Traditional agricultural knowledge is location-specific and develops from the coevolution of specific social and ecological systems [116]. However, traditional agricultural knowledge is often not considered in landscape planning even though traditional agricultural practices tend to cultivate sustainable landscapes with high biodiversity [114]. Beyond that, while
the maintenance or reimplementation of past land management systems can often be appropriate in many contexts, that should not discourage novel management practices that mimic the essential characteristics of these areas and focuses on their ecological processes [117].

Species assemblages may change over time, sometimes due to human influence, and invasive species often prove to be a difficult management challenge. The biggest threats to biodiversity, as defined by the Joint Norwegian Scientific Committee for Food and Environment (VKM) and the European Food Safety Authority (EFSA) Symposium in 2018, are: alien organisms, climate change, land-use change, overexploitation, and pollution [10]. Invasive species are a reality in many ecosystems globally and often need to be considered during management planning. The loss of a key species or the invasion of a new one can cause non-random sequences of local extinction based on these species body sizes, trophic positions, specializations, physiologies, morphologies, or life history [105]. Further, the climate niche distributions of invasive species that have originated from agriculture are generally very similar to the niches of biomass crops since broad climatic tolerance is a desirable characteristic of crop plants but is also positively correlated with invasiveness [118]. However, it is not only the current above-ground factors that impact biodiversity.

A vital element of all other parameters is the concept of temporal change (Figure 4, Table 4). Many ecosystems experience disturbances that operate across both spatial and temporal scales, but biodiversity provides the capacity for renewal or reorganization [105,119]. Biodiversity, by the nature of evolution, is influenced by the history of the community it represents. For this study, the consideration of the history of the MAL areas in question and an understanding of the drivers of its marginality are crucial. Understanding the relationship between the current landscape structure and its historical structure, and how that impacts the traits of species assemblages may help make it possible to detect delayed ecosystem responses to changes in agricultural landscapes [68].

Table 4. Exemplary factors for biotic/abiotic factor categories seen as relevant for biodiversity characterization on marginal and non-marginal land.

<table>
<thead>
<tr>
<th>Factor Category</th>
<th>Factor Group within Category</th>
<th>Factors (Where Applicable)</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>Ecological factors</td>
<td>Local biodiversity</td>
<td>Abundance/distribution of species</td>
<td>[120]</td>
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<td></td>
<td></td>
<td>Alpha/beta/gamma diversity</td>
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<td></td>
<td></td>
<td>Functional diversity (at all organizational levels)</td>
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<td></td>
<td></td>
<td>Genetic diversity</td>
<td>[58]</td>
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<td></td>
<td></td>
<td>Species density</td>
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<td></td>
<td>Species utilization</td>
<td>Biotic interactions</td>
<td>[58]</td>
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<td></td>
<td></td>
<td>Compatibility with crop</td>
<td>[122]</td>
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<td></td>
<td></td>
<td>Dispersal</td>
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<td></td>
<td></td>
<td>Ecological corridors</td>
<td>[123]</td>
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<td>Food/material availability</td>
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<td>Invasive/non-native species influences</td>
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<td>Migration routes</td>
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<td>Nest sites</td>
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<td></td>
<td></td>
<td>Species dispersal potential/response to climate change</td>
<td>[124]</td>
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<td></td>
<td>Habitat types</td>
<td>Habitat structure/microhabitats</td>
<td>[58,125]</td>
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<td></td>
<td></td>
<td>Fragmentation</td>
<td>[78]</td>
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<td></td>
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<td>Habitat loss</td>
<td>[126]</td>
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<td>Patch sizes</td>
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<td></td>
<td></td>
<td>Transition zones</td>
<td>[75]</td>
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</tbody>
</table>

Temporal turnover
Table 4. Cont.

<table>
<thead>
<tr>
<th>Factor Category</th>
<th>Factor Group within Category</th>
<th>Factors (Where Applicable)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogeochemistry factors</td>
<td>Soil microbes/rhizomes</td>
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<td>[107]</td>
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<tr>
<td>Soil quality</td>
<td></td>
<td>Structure/texture</td>
<td>[123]</td>
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<td>Nutrient availability</td>
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<td>pH</td>
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<td>Productivity</td>
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<td>Level of degradation or compaction</td>
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<td></td>
<td>Vulnerability to erosion</td>
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<td>Water-holding capacity</td>
<td>Soil type</td>
<td>Pasture</td>
<td>[127]</td>
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<td>Slope</td>
<td>Meadow</td>
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<td>Salinity</td>
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<td>Abandoned</td>
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<td>Management factors</td>
<td>Current land use</td>
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<td>Pasture</td>
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<td>Abandoned</td>
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<td>Inputs (type and level)/intensity level</td>
<td>Fertilizer (mineral/organic)</td>
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<td>[128]</td>
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<td></td>
<td>Chemical–synthetical plant protection measures</td>
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<td>Bio-based plant protection measures</td>
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<td>Biocontrol agents</td>
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<td>Tillage intensity</td>
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<td>Number and type of area traffic</td>
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<td>Crop type</td>
<td>Annual/perennial crop</td>
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<td>Mono-, inter-, mixed-cropping</td>
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<td>Cover cropping</td>
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<td>Types and numbers of flowers</td>
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<tr>
<td>Conservation management goals</td>
<td>Land sharing</td>
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<td>[132,133]</td>
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<td>Land sparing</td>
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<td></td>
<td>Habitat networking</td>
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<td>Agricultural history</td>
<td>Severity of habitat fragmentation (if present)</td>
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<td>[134]</td>
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<td></td>
<td>Level of degradation/abandonment (if present)</td>
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<td></td>
<td>Farming system</td>
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<td>[128]</td>
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Figure 4. General presentation of the biodiversity parameters of this study with their subheadings to show the importance of the temporal dimension. As on all other land types, changes in, and interactions between these parameters can occur on marginal land (MAL). These interactions can be either management-related (e.g., land-use changes) or environmental (e.g., climate change effects). Learning from the history of the current biodiversity situation may help improving the future biodiversity situation on MAL when using it for biomass production.

3.5. Cropping Systems

Agriculture is a driver and a victim of climate change, because of its position as both a major driver of land-use change and habitat degradation via intensification or misuse and as a practice that is dependent on the natural environment for success. It is well understood that intensification and expansion of industrial agriculture leads to a rather non-biodiversity-friendly agricultural intensification [135] due to the homogenization of crops, the use of chemical–synthetic pesticides [128], degradation of traditional agriculture [136], and habitat loss or fragmentation [114,134]. The evidence of agriculture’s propensity to negatively influence the environment is evident the world over. However, agriculture is also struck by the repercussions of climate change [42], biodiversity loss, nutrient depletion or eutrophication, and habitat degradation, among many effects of agricultural intensification [8,137]. One problem with the current state of modern agriculture is the need to align the goals of agricultural production with those of biodiversity conservation [44,128].
In traditional and low-intensity agricultural landscapes, farming systems are still integrated with natural ecological functions and yields, and land use is mostly determined by the environment and low-input management [25,56,138]. Europe hosts a diversity of such farming practices. A few examples are: traditional agriculture landscapes (TALs) [114], low-intensity livestock, arable, permanent crop, or mixed systems [56,139], and integrated farming, organic farming, precision farming, and conservation farming (Table 5) [128,140]. These low-input systems may have value for nature conservation, particularly for farmland species or species with large ranges that cannot be protected in small nature areas [139]. Increasing farmer awareness of the CAP measures may again help land degradation in vulnerable or marginal areas [112]. Nature conservation agreements with farmers can help to conserve high nature value farmland in mountainous areas [127]. In fact, farming systems-specific approaches are relevant to answering the question of how and where biomass crops should be cultivated to maintain or improve biodiversity in agricultural landscapes whilst providing economically acceptable performance [141,142].

The negative perception of unproductive land such as that found in the Iberian Steppe can encourage industrial activities such as mining, wind farming, and waste dumps, and this trend is likely to continue into the future and can lead to habitat fragmentation or disruptions in species dispersal dynamics [143]. Significant biodiversity can be found on mountainous farmland in the Alps, but major losses of habitats important for biodiversity in these areas have been noticed [127]. Afforestation of traditionally steppe-type ecosystems for the purpose of supporting biodiversity can damage local avifauna populations instead of support them [145]. Further, in marginal landscapes, fragmentation of farmland can lead to abandonment [144]. It becomes clear that management decisions and their interaction with local species must be carefully considered for each situation. More research is needed, but evidence suggests that solutions designed to halt farmland biodiversity loss in Western Europe are not suitable as blanket solutions in Central or Eastern Europe and that regional specificity is needed for European actions or programs intended to halt biodiversity loss [145].

Table 5. List of some traditional or low input farming practices in Europe from which marginal land-use strategies are adapted.

<table>
<thead>
<tr>
<th>Name of Farming System</th>
<th>Key Characteristics</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-intensity farming systems</td>
<td>Farming systems that have a low level of external inputs, particularly fertilizers and agrochemicals. May involve both crop and livestock systems. These farming systems may take many different forms depending on where they are in Europe and may not fit neatly into one specific farming system.</td>
<td>[139]</td>
</tr>
<tr>
<td>Traditional agriculture landscapes</td>
<td>Productive, stable farm landscapes that develop slowly and may display high resilience. However, they are experiencing rapid transformation due to environmental pressures such as urban expansion, land abandonment, climate change, or agricultural intensification.</td>
<td>[114]</td>
</tr>
<tr>
<td>High nature value (HNV) farms</td>
<td>Combines biodiversity with the maintenance of certain land types and farming systems.</td>
<td>[146]</td>
</tr>
<tr>
<td>Livestock systems</td>
<td>Low-intensity livestock systems are common in mountain areas and are often characterized by transhumance; nearly all remaining HNV grasslands are associated with these systems.</td>
<td>[56]</td>
</tr>
<tr>
<td>Arable systems</td>
<td>Once common all over Europe but now mostly limited to the Mediterranean region, characterized by low yields and fallow periods that are important for conservation.</td>
<td>[56]</td>
</tr>
<tr>
<td>Permanent crop systems</td>
<td>Involve trees (olives, fruits, C4 grasses, short rotation coppice) or vines and are common, for example, in the Mediterranean region. Low intensity systems tend to be less specialized and integrate strip-intercropping or livestock grazing.</td>
<td>[25,56]</td>
</tr>
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</table>
Table 5. Cont.

<table>
<thead>
<tr>
<th>Name of Farming System</th>
<th>Key Characteristics</th>
<th>References</th>
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<tbody>
<tr>
<td>Mixed systems</td>
<td>Often subsistence farms in very isolated areas where farming is combined with other activities such as fishing or forestry.</td>
<td>[56,147]</td>
</tr>
<tr>
<td>Integrated farming</td>
<td>Aims to optimize agricultural management and inputs in a responsible way, by considering economic, ecological, and social aspects. This system seeks to minimize agrochemical inputs and include ecologically sound management practices when possible.</td>
<td>[128,140]</td>
</tr>
<tr>
<td>Precision farming</td>
<td>Management is targeted and spatially specific by taking advantage of modern technology. This system aims to take small-scale differences in management at the field level into account and often involves the monitoring of the nutritional status and health of crops or livestock.</td>
<td>[140]</td>
</tr>
<tr>
<td>Organic farming</td>
<td>Aims to sustain the health of soils, ecosystems, and people by relying on ecological processes, biodiversity, and cycles adapted to local conditions. This system combines tradition, innovation, and science and forbids the use of synthetic pesticides, fertilizers, or antibiotics.</td>
<td>[140,148–150]</td>
</tr>
<tr>
<td>Conservation farming</td>
<td>This system is characterized by three principles: minimizing mechanical soil disturbance, implementing permanent organic soil cover, and diversifying the sequence or associations of crop species.</td>
<td>[71,140,151]</td>
</tr>
<tr>
<td>Extensive small-scale, semi-subsistence farming</td>
<td>Characterized by low inputs or no external inputs at all and tend to be limited financially. This type represents 40% of all holdings in the EU-27, and a third of this farm type operates on less favored areas.</td>
<td>[152]</td>
</tr>
</tbody>
</table>

A characteristic of European agriculture is the variety of its agroecological conditions, economic potential, levels of production intensity, and social and cultural environments (Table 5) [152]. Further, the marginality of land is about perspective, as land may be marginal for one purpose but suitable for another (cropping vs. grazing) and both dimensions of marginality, biophysical and economic, may impact its definition as such [153]. Considering different European farming systems is important since small-scale farmers could participate in knowledge creation for the development of site-specific approaches [152]. The EU project MAGIC (GA ID 727698) focused, inter alia, on developing the abovementioned social–ecologically more sustainable biomass production strategy MALLIS, which incorporates four different low-input farming systems: integrated farming, organic farming, precision farming, and conservation farming [25]. The identification of suitable MAL for biomass crop cultivation along with the potential for biodiversity conservation via farming systems may provide important conservation opportunities [30].

It is understandable, given the diminished levels of natural habitat present in Europe, that farmland habitat has become important to many European species [139]. Sustainable biomass crop management offers the opportunity to create multipurpose ecosystems that produce goods as well as maintain other ecosystem services [44]. Such crop production has the potential for synergistic increases in biomass crop cultivation that couple with improved ecological function benefits [154]. However, a challenge of sustainable land management is coming to terms with the fact that knowledge of ecosystem dynamics is fragmented and is distributed among a variety of stakeholders with different interests and practices [155].

Clearing carbon-rich habitats for the cultivation of biomass crops may increase emissions because of their lower carbon storage potential, but the same cultivation on degraded land could minimize habitat destruction and carbon debts, which are usually associated with direct and indirect land-use change because of biomass crop production [156]. Marginal land has the potential to be enhanced or restored by improving land functions, which may increase productivity [33]. For example, unfertilized perennial legume–grass mixtures, which promote biodiversity, may provide resource-efficient biomass feedstocks.
for biogas production [45]. However, the value of local land varieties is strongly tied to the specific areas where they are used [114].

Pressure between expanding agriculture, preserving biodiversity, and limited physical room to grow exists in some countries. Marginal land offers an interesting opportunity for agricultural expansion without competing directly with food crops for land. Limited available land for agricultural production is a significant issue for the societal transition toward bio-based fuels and products. The question arises as to how the cultivation of biomass crops can be reconciled with biodiversity and nature conservation goals. From a study from the Midwestern USA, biomass crops may be grown on economically MAL with poor agronomic conditions during periods where prices for commodity crops are low or perennial biomass crops may be used to reduce the delivery of sediments and other agricultural pollutants by intercepting displaced soil before it is moved to water surfaces [157]. Cover crops may also be able to protect marginal soils from degradation [158].

Low-input systems have certain characteristics that create conditions that favor biodiversity which, as identified by [139], are: long-term and shorter-term management practices allow for wildlife diversity to co-exist alongside farming activity. It is generally observed that low-output farms have higher biodiversity on average than high-output ones, this is in part because low-output farms are more greatly molded by the constraints presented by the local environment in which they exist [56]. This can make production on MAL more difficult, since the land itself has a larger influence on farm activities. Understanding how biomass crops impact local farmland biodiversity is required to establish long-term sustainability of crop production [122].

Biomass crops can be used to restore degraded land and sequester soil carbon [43]. Biogeochemical benefits can be derived from appropriately managed biofuel production systems [107]. Certain characteristics of second-generation energy crops (long harvesting cycles, deep root systems, leaf litter production, and low maintenance requirements) noticeably improve soil quality and may help prevent flooding in vulnerable areas [159]. Targeted placement of perennial biomass crops may increase landscape stability and resiliency by increasing biodiversity [154]. Conversion of land from corn–soybean production to switchgrass resulted in more storage of soil carbon, as well as decreasing N\textsubscript{2}O emissions and negative greenhouse gas flux [107]. A risk management approach using Gentle Remediation Options can benefit areas looking to restore MAL for non-food crop production or avoid major land-use changes, as well as places where ecosystem services related to soil quality, such as biodiversity, are highly valued [160].

However, utilization of MAL is not necessarily always characterized by low input conditions [34], and high input conditions may impact the environment in a negative way [33]. Biomass crop cultivation on MAL has strengths in the large land supply potential and the adaptability of biomass crops, as well as potentially increasing farmer income and energy resource security, but has weaknesses in economic viability, environmental impacts, and low productivity [43]. In many cases, biomass crop cultivation on MAL was shown to result in lower profits than on favorable land [25,142]. Beyond that, the suitability of MAL for sustainable biomass crop cultivation depends on why the land is considered ‘marginal’ in the first place [161].

In areas with a long land management history, the abandonment of traditional farming systems may negatively affect some species that shelter inside old rural buildings, such as the lesser kestrel [74]. Low input farming systems can be applied to MAL to produce valuable products for the human economy while potentially benefiting biodiversity on MAL. One potential benefit of traditional agriculture practices and traditional crop use is that these systems can act as in situ conservation spaces [114].

Because of this, farmers require compensation when working land under adverse conditions [16,17,21,27]. Sustainable development should be balanced by economical, ecological, and social aspects, but the linkages between these can be tenuous and disconnected from the farm itself [56]. Agricultural abandonment is a complicated process, but design-
ing policies that are directed at alleviating common causes of abandonment may reduce unwanted land abandonment [162].

3.6. Findings of the Evaluation of Biodiversity in Marginal Land

Biodiversity is very complex and land assessments and management decisions must, in general, be tailor-made for the areas under review. Any matrix or tool created to characterize biodiversity will, inevitably, not capture the true intricacy of a natural system. Biodiversity monitoring has expanded in Europe during the last few decades, thanks to projects such as SEBI and the CBD’s Aichi Biodiversity Targets, among others. Despite this, data that cover the ecological effects of biomass crops are still scarce, particularly when it comes to mammals, since current research tends to focus on birds, invertebrates, and plants [122]. Challenges of biodiversity monitoring do not solely exist on the external side, in the natural world where data are collected. Organizations, projects, and policies face their own internal challenges as well. Staff turnover, inconsistent terminology that may hinder future data integration, ambiguity of goals, and the loss of intellectual capital can create challenges for biodiversity monitoring schemes [51]. So, biodiversity monitoring faces at least two major challenges, which are (i) the need for maintaining monitoring efforts over several years to collect relevant data, and (ii) to ensure that the data collected are precise enough to detect changes to biodiversity over time and space [163].

Identifying MAL for biomass cropping systems can support decision makers in developing policies that encourage both environmental preservation and the rights of local people [31]. The strict segregation of edible and non-edible crops between MAL and productive land is unlikely to mitigate biodiversity losses caused by intensive agriculture in Europe [134,141]. As the impacts of energy production increase with the continued increase in energy demand, the sustainable production of energy in Europe must become a goal when creating new policies [44]. Further, because of an ecosystem’s ability to provision such services, social and cultural considerations should also be considered [40,113].

Therefore, as was also outlined by The Economics of Ecosystems and Biodiversity’s Guidance Manual, drivers of degradation, ecosystem dependencies, and vulnerability of sites to climate change need to be understood to categorize ecosystem services, which requires inputs from stakeholders and natural science experts [164]. In this regard, the perspectives of landowners can influence policy and help to expand biomass crop production into MAL [165,166]. Moreover, local stakeholders may identify different ecosystem services than those of published classification lists of ecosystem services [11,111,167], because their knowledge of local areas may be more specific than that of outsiders, so engaging with them can provide unique perspectives on local needs not available in the literature [111,164]. In this context, a common question is whether the supply of ecosystem services on farmland is higher on large, contiguous farms or on individual smaller farms that manage the same area [168].

The ownership of small, fragmented farming patches in Europe contrasts with modern, industrialized farming systems that require large tracts of land, and this can be associated with degradation of these land patches, which in turn discourages investment into them [144]. Thus, the degradation of landscapes in Europe is associated with a lack of long-term tenure because permanent arrangements that involve investments into natural capital are uncommon [169]. Small farms can be more vulnerable to fluctuations in the local environment and more dependent on ecosystem services than large properties. However, it was shown that more heterogeneous landscapes (through smaller field sizes) can support biodiversity even better than the transition from conventional to organic farming [134].

Accordingly, the cultivation of biomass crops such as miscanthus in MAL areas where high biodiversity already exists may have negative environmental impacts and aspects of biodiversity conservation [161]. Consequently, the interactions of potential biomass crop candidates and cropping systems with local biodiversity parameters should be carefully considered—not based on mere assumptions. For example, brown hares (Lepus europaeus, Pallas, 1778) were not found to feed on miscanthus in European bioenergy cropping
systems, but were nonetheless able to thrive in these areas [122]. Despite this one example, land-use change via the intensification of agriculture can still reduce suitable habitat and range for some species [124]. Measured extinction rates have inertia, gaining momentum from events in the past while choices made in the modern day have yet to enact their full ecological consequences [104].

According to [98,113], long-term biomass crop monitoring programs should include:

- Lifecycle sustainability assessments (LCSAs) of the biomass crops and their respective biobased value webs,
- Geographic information system (GIS) data and simulation models that validate LCSA results,
- Sampling procedures with methodological adaptations/innovations to reduce uncertainty,
- Connections of diversity patterns with complexity of processes in distinct biomass landscapes.

Habitat monitoring schemes in Europe tend to be fragmented and data collection methods are not standardized, are small in scope, and focus mostly on forest, marine, and grassland or coastal habitat, so the data are not easily accessible [39]. As previously mentioned, data integration will be an important next step for biodiversity monitoring schemes in Europe, of which habitat monitoring is a component [111]. Consideration for the impacts on biodiversity that occur through land-use change or habitat fragmentation on farmland, MAL, or lands otherwise impacted by anthropogenic activity may be useful for broadening understanding of this topic. Similarly, implementations of biomass crop monitoring programs could be important for projects that exist at the intersection of biomass crop cultivation and biodiversity or habitat conservation such as MIDAS (www.midas-bioeconomy.eu, accessed on 10 June 2023) or MarginUp (www.margin-up.eu, accessed on 10 June 2023).

Biodiversity surrogates can be useful for capturing biodiversity information that is difficult to measure directly [51]. Biodiversity surrogate groups comprised entirely of bird species (Figure 5) do capture about half of all rare species in an area, but supplementing these groups with species from non-bird taxa will allow them to better represent the real biodiversity conditions in an area [90]. Care should be taken when implementing biodiversity monitoring schemes so that research biases towards certain species are considered.

Biodiversity monitoring programs can benefit from the involvement of community volunteers [104], since it does not appear that volunteer-based monitoring data always produce imprecise results and sometimes may produce data that are more informative than that produced by professional monitoring networks [163]. Citizen science and volunteer engagement in biodiversity monitoring programs are not new ideas, as evidenced by the Christmas Bird Count hosted by the National Audubon Society, which began in 1900 [61]. A greater connection and feeling of responsibility for the local nature would also be beneficial for citizens in areas that aim to improve biodiversity and land quality, as public awareness is used as a progress indicator for Biodiversity Indicators Partnership, as previously mentioned.
Gentle Remediation Options are risk management or assessment strategies that aim to maintain or improve soil functionality on contaminated sites by using plant-, fungal-, or bacterial-based strategies [160]. “Greening” marginal or contaminated areas via the application of Gentle Remediation Options may allow these places to provide ecosystem services or sequester carbon, among other benefits, in conjunction with expert input and proper long-term management [170]. For instance, beneficial management practices according to Alternative Land Use Services (ALUS) in Canada include: riparian buffers, headland buffers, livestock exclusion, retirement of prod land/fallow, retirement of high-slopes (because of erosion), and modern woodlot plans [169] which may help conserve natural features such as wetlands, among other things. Another example is alternative methods of invasive species control that could combine bioenergy production and biodiversity conservation. The active control of invasive species such as tree of heaven (Ailanthus altissima Mill. Swingleis) in Romania or the Japanese knotweed (Reynoutria japonica Houtt.) in both Europe and North America is fundamental to restoring native biodiversity and ecosystem services, but utilization of these plant species as a bioenergy feedstock may not be possible for all bio-digester or combustion setups [171]. The desirable traits of biomass crops, that is, their high yield, minimal input requirements, tolerance for poor conditions, and carbon sequestration potential [25,29,172,173] also represent many traits of the invasive species ideotype [118]. The digestion or combustion of invasive plant matter during bioenergy conversion completely destroyed the viability of tested propagules so the danger of spreading invasives when using them as feedstock is from transporting, harvesting, and processing [171].

Large scale assessments of the invasive potential of species that cover large geographic areas [174] may sometimes overestimate invasion risk because the chance of at least one propagule finding success in a vulnerable community is high [118]. Crops that are high risk invaders in one area may be completely harmless in another. Invasiveness is not the only impact of introducing biomass crops into a landscape. For example, the perennial biomass crop miscanthus has shown some potential for disrupting pest–host relationships between maize and the Western corn rootworm [175]. This speaks further to the need for site-specific characterizations and a thorough understanding of local conditions before management decisions are made. The availability of ecological knowledge from the environmental sciences is vital to explaining the importance of certain management approaches to decision makers [176]. Invasive grasses have proven difficult to control worldwide and the costs...
and benefits of introducing or expanding the range of biofuel crops should be considered to better understand their ecological risks [177].

3.7. Hypothetical Case Studies on Biomass Production on Marginal Land

To illustrate the potential implementation scenarios of the above findings on biodiversity evaluation on MAL, this study will propose three hypothetical case studies on biomass crop cultivation in three different MAL situations.

3.7.1. Abandoned Agricultural Land

The first hypothetical production case study would be that of biomass crops on abandoned agricultural land. A consideration for this MAL type is the potential for conflict with other land conservation goals. The rewilding of abandoned European farmland may provide opportunities to produce novel ecosystems and new wilderness areas that are predominantly self-sustaining and require only a minimum of human management [178]. However, there is some evidence that field abandonment in Fukui Prefecture (Japan) affected pollination interaction networks and was mediated by changes in network size and species composition [73], which is in line with findings by [134]. Field abandonment will require some level of farm management since areas will not always simply return to a “natural” state. The amount of biomass removed from the site for bioenergy or bio-based products should be aligned with the required amount of biomass reincorporated to the soil in order to maintain humus content and overall soil fertility [179].

Short rotation woody crops such as poplar (Populus L.), aspen (Populus tremuloides Michx.), and willow (Salix L.) could provide energy feedstocks, improve carbon storage, and produce wood products in rural MAL with limited economic opportunities in North Carolina, USA, but choosing the right crop for the right application and site is important as different genotypes of poplar, aspen, or willow have different environmental interactions [180–183]. Large scale applications of short rotation coppice may have monoculture-related issues of lower biodiversity support compared with mixed deciduous forests [184]. However, well-integrated short rotation cropping to farming systems with annual (edible or non-edible) crops can help increase biodiversity support at regional scales by increasing structural heterogeneity and providing a variety of habitats such as undisturbed soil and a versatile weed flora [184–187].

3.7.2. Brownfield Sites

The second hypothetical case study would be the production of biomass crops on brownfield sites (Figure 6). The cultivation of miscanthus on land that is contaminated by heavy metals makes sense, since this crop can restore the land and increase soil organic matter content [161,188,189]. Miscanthus shows significant tolerance to environmental metal pollution and appears to partition most accumulated metals into its rhizomes and roots [190]. As another example, in marginal and contaminated areas in Sulcis, Italy, giant reed (Arundo donax L.), another perennial lignocellulosic crop, could have the potential to remediate contaminated areas, show relatively good performance in terms of yield and input levels, and have promise as potential biomass feedstocks due to their fermentable sugar content [191].

As identified in [189], the sustainable production of miscanthus on contaminated lands has three main challenges: (i) maintaining growth and productivity on such soils, (ii) monitoring biomass quality so that it aligns with the requirements of local conversion chains, (iii) and mitigating production costs. Insights into the effects on biodiversity are relatively scarce [192]. Therefore, more research into the use of miscanthus for phytoremediation is recommended [193], particularly for its interaction with organic contaminants such as hydrocarbons [189]. Soil science exists at an intersection of soil physics, chemistry, biology, and social sciences, and the interactions of soil, biodiversity (microbiomes, plants, etc.), emerging contaminants such as pharmaceuticals, and management practices requires more interdisciplinary research [194].
3.7.3. Buffer Strips

The last hypothetical case study would be the production of biomass crops on buffer strips (Figure 6). Wild plant mixtures consisting of wild, flower-rich selections of annual, biennial, or perennial species, which have some potential as future biogas substrates, could be used in strip or buffer cultivation systems and in this way the agricultural system could provide benefits for both biodiversity conservation and groundwater protection [195,196]. Arrangements of buffer strips based on wild plant mixtures or miscanthus cultivation in...
farmlands should be designed with potential interactions with water surfaces as well as biotic and abiotic landscape elements [197,198].

Vegetated riparian buffer strips are often found in European river-basin management, but their effectiveness is still relatively poorly understood [199]. Bioenergy buffers, that is buffer strips comprised of perennial biomass crops such as miscanthus, willow, and poplar, do also have some potential benefits to environmental quality and biodiversity [141,198]. The impacts of bioenergy buffers on the provisioning of ecosystem services were found to be highly dependent on previous land use, where it is better to convert intensively managed croplands to bioenergy buffers, rather than areas such as grassland [197]. However, drivers of farm conservation management decisions may not be well understood and the current literature is lacking [169]. The opportunity costs of riparian buffer strips vary between German regions, which should be taken into account when implementing policy or management decisions [196,200].

3.8. Towards the Development of Biodiversity Indicators for Marginal Land

EASAC identified three stages for the development of biodiversity indicators: scoping (what facets of biodiversity should EU members care about), indicator design (choosing measures of biodiversity but also considering how, from what, when, and where the data supporting these indicators should be chosen), and implementation and reporting (testing outputs from indicators to ensure that they are meeting the needs of the project) [48]. Taking cues from efforts to create greater global data integration may also be helpful when making decisions on what indicators, indexes, or data sources to use. SEBI, for example, has performed well in streamlining the development of biodiversity indicators, which has reduced the workload of international indicator initiatives, and it aims to continue developing new indicators and link itself more closely with other EU environmental policies [47]. Available indicators and indexes already in place, such as the IUCN Red List, Project DAISE (Delivering Alien Invasive Species Inventories for Europe), PECBMS (Pan-European Common Bird Monitoring Project), Living Planet Index, and Natural Capital Index would be a possible starting place to begin the characterization of biodiversity [48], and some of these could potentially be useful for MAL-specific implementation.

An important consideration for the characterization of biodiversity on MAL based on the above-mentioned biodiversity indicator programs is taking biophysical constraints [26] into account. It seems that the role of biodiversity in soil formation and nutrient cycling was not adequately considered during the creation of the biodiversity monitoring schemes [48], while soil characteristics are an essential part of the characterization matrix produced for this study. The SEBI 2010 indicators and the EASAC available indicators list both have indicators that focus on nitrogen deposition, but none that focus explicitly on the soil quality in general. MAL is commonly defined by its low soil quality or lack of soil productivity, and soil problems on MAL comprise major biophysical identification criteria [43].

3.9. Benefits and Limitations of Biodiversity Evaluation on Marginal Land

The most obvious benefit of the evaluation of biodiversity on MAL would be expanding understanding of the state of current biodiversity and comparing that to how it changes in the future. Measuring long-term trends in biodiversity will be essential for monitoring the progress of biodiversity-centered policy and for understanding trends in species loss, but all biodiversity monitoring schemes face similar challenges in terms of needing to select appropriate indicators and having access to existing biodiversity data [65]. Biodiversity monitoring has expanded significantly in Europe over the past few decades and has already provided data that will be essential to future land management, conservation, and policy-making decisions [8]. As outlined by SEBI (Streamlining European Biodiversity Indicators), it is essential for biodiversity indicators to be consistent between different levels of scope (national, regional, global) to properly understand the extent of biodiversity loss [47].

Biodiversity policy in Europe is being led by several international organizations, including the European Union, the Council of Europe, and the United Nations Environ-
mental Programme (UNEP) that have pushed for synergy between biodiversity policies and integration of projects [48]. European biodiversity monitoring programs were found to be fragmented and requiring data integration [59]. While progress was made, it was identified that the capacity of the EU to monitor biodiversity and ecosystems still needs improvement and requires an updated data infrastructure and an international framework for organizing ecosystem data, both of which will be able to support existing and future legislation [57]. Biodiversity data may not always be available, which can be caused by barriers such as “data confidentiality, usage restrictions, limited accessibility of data sets, the remoteness of ecosystems, or data integration and quality issues” [65], but the utilization of extant data and new data collection could bridge current knowledge gaps. Regional or national scale collection of accurate, systematic biodiversity data and top-down targets (policy-driven approaches based what is possible in a socio-political context) can be useful for management at smaller scales [201]. In addition, at the field level, biodiversity data need to be collected, for example, by the non-lethal recording of the activity of individual animal species groups by motion-sensitive camera traps [202,203], territory mapping [204], or caterpillar mimics [205].

A better understanding of ecosystem services provided by MAL would also result from a thorough evaluation of biodiversity. A comprehensive understanding of the MAL requires an understanding of their ability to provision ecosystem services and their socio-economic situations [33,113,206,207]. The diversification of agroecosystems at landscape level through a purposeful implementation of perennial biomass crops with different growth cycles could increase the agroecosystems’ resilience—especially in the face of increasing climate change impacts [42]. In this regard, perennial biomass crops such as miscanthus could help improve both soil fertility and productivity on MALs [17,188,208,209]. Given Europe’s long history of agriculture and land-use change [34], considerations should be made for where and how to plan conservation via low input agricultural management on MAL [25] or instead dedicate an area to rewilding with minimum human engagement [210]. Historical ecological baselines or distributions should serve as guidelines for conservation, not as goals, as land-use change and climate change may change distributions and interactions with other community species [72,85]. Access to new information may make it possible to make more appropriate management decisions based on a site’s specific circumstances rather than to maintain traditional management practices, while other areas may continue to thrive under such practices [117].

Inevitably, evaluations of biodiversity as they exist on MAL today cannot capture the full extent of the situation. Knowledge gaps exist not only for the past and current state of biodiversity, but also because of the uncertainty surrounding future events. Environmental conditions are not fixed, and thus may be different in the future, which can become an issue in the future in monitoring schemes that do not take this into account [87]. Because there are so many more species than there are field scientists to study them or witness their extinctions, and not all species on Earth have been discovered, extrapolation to estimate the total number of extinctions yearly is not possible [104]. A challenge of biodiversity research is that, in order to be able to predict future situations, there must be ways to extrapolate information from well-known species data to gain a better understanding of more poorly known or undiscovered species [211]. The consideration of MAL adds another challenge, since the biophysical constraints of MAL are sensitive to natural processes and management styles, while the influences of market demands may impact the expansion of agricultural intensification into these areas that exist at the transition between productive and unproductive land [33]. This is because marginality is not always a permanent state, and instead a land’s current standing as marginal may be changed by natural processes, varied management, sensitivity to degradation, and climate change [153].

4. Conclusions and Outlook

Given the overlap of indicators between projects and policies reviewed for this study, it becomes clear that there are certain features of biodiversity that are widely agreed upon
and could be extrapolated to MAL. The maintenance of protected land via traditional European management and the extent of European agroecosystems shows that, at least for Europe, the conservation of biodiversity via farmland or farming activities could be employed there [212]. Some of the parameters for biodiversity characterization identified in the literature may not be useful for all land areas, but regional specificity could be beneficial to designing appropriate conservation management for European MAL [145]. Without having the opportunity to apply these biodiversity-tailored farm management strategies to real MAL situations, it cannot be fully tested for potential issues or blind spots. This is a weakness of this study, because of the level of complexity that needs to be captured, in addition to the unique features of MAL. However, it also lays the foundation for further research into this area of study. This study would recommend further research into the intersection of biodiversity values, MAL management, and biomass crop cultivation. There is also a lack of assessment of ecosystem function resilience [87], which may be important in dynamic landscapes or transitional landscapes such as MAL. Research biases towards certain species, habitats, and regions do exist [91]. There is also a need for the continued integration of biodiversity data collected over large scales and a unified approach to MAL-specific monitoring schemes could be beneficial to future research in this area.

Thus, MAL appears to be a key for tackling challenges surrounding the questions of where the biomass crop cultivation would be appropriate in terms of a sustainable bioeconomy. This is supported, for example, by a high number of suitable biomass crops and their use in both full-scale biogas production and combustion [30,45,173,213,214]. However, the study has shown that farm management decisions should be carefully tailored to the social and environmental context and situation in the regions concerned. Access to technology and suitability for certain biomass cropping systems differ greatly between areas. This would also be the case for choosing biomass crops that are (i) suited to the local area, both in terms of climate and local management goals, and (ii) fitting to the substrate mix and operating procedures of local biogas plants.

However, science seems a long way from providing specific recommendations for action to address the challenges posed by MAL in monitoring and conserving biodiversity. Soil, for instance, is an important biophysical component and carrier of biodiversity of MAL but is not always directly considered in biodiversity monitoring programs despite being strongly affected by external disturbances such as climate change and farm management decisions. Thus, one recommendation for future work in this area would be a more significant focus on marginal soils [22] and their potential impacts on biodiversity or ecosystem processes.

Overall, the need for data integration is also identified in the literature, and work is underway to integrate biodiversity data from MAL for the future when the technologies (e.g., precision farming coupled with AI) are ready [111]. Biodiversity is not limited by borders (e.g., marginal and non-marginal land) and clear, EU-wide understandings of the population dynamics of animals such as the wolf can be helpful when managing their conservation.

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