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Review

The Decline and Possible Return of Silvipastoral Agroforestry in Sweden

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Abstract: Silvipastoral agroforestry in the form of forest grazing and wooded semi-natural pastures has historically been very important for the Swedish supply of food and wood products for local use. Since the end of the 1800s, this form of combined production system has greatly decreased and now covers only 1% of Sweden's land area. However, in recent decades it has gained increased relevance for reasons of landscape, biodiversity and climate. Agroforestry's decline and possible future increase are described through reviews of statistics and the literature read by farmers and politicians whose decisions are behind the development. Especially when it comes to biodiversity and climate, this review also includes the scientific literature. Surveys on Swedish citizens' valuation of silvipastoral agroforestry landscapes compared to treeless pasture and closed forest are also reviewed. It is possible that efforts to increase Sweden's low self-sufficiency in beef and lamb meat, the coming requirements according to the EU's nature restoration law and the need to limit climate change through carbon sequestration in trees may again increase the area of silvipastoral agroforestry. For this to be economically feasible, large grazing areas can be created out of remaining small scattered wooded semi-natural pastures and intervening forestland, which historically may have been grazed forests.

Keywords: semi-natural pasture; wooded pasture; forest grazing; cattle; sheep; abandonment; afforestation; landscape; biodiversity; climate

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1. Introduction

Agroforestry is defined as "deliberate growing of woody perennials on the same unit of land as agricultural crops and/or animals, either in some form of spatial mixture or in sequence, and there must be a significant interaction (positive and/or negative) between the woody and non-woody components of the system, either ecological and/or economical" [1]. In silvipastoral agroforestry, trees are combined with forage and livestock production including high- (forest or woodland grazing) and low-density (open forest trees) stands [2].

Silvipastoral agroforestry in Sweden now occurs sparsely, but was very common until the 19th century in the form of forest grazing and grazing in wooded semi-natural pastures [3–6]. Almost all the previously grazed forests and a large part of the semi-natural pastures have now become dense forests for specialized timber production for the growing export-oriented forest industry [7]. Other parts of semi-natural pastures have been cultivated into agricultural land for specialized food and feed production (Table S1). In recent decades, new establishment of agroforestry has been brought up-to-date due to landscape, biodiversity and climate reasons, but still only to an insignificant extent.

The aim of this review is to describe how the occurrence of silvipastoral agroforestry has developed in Sweden to the present time, and to discuss how the future development might occur. In doing so, we analyze how its development has been affected, and can conceivably be affected in the future, by technical and economic development, public

opinions and various societal goals. Hereby, it is assumed that secure food supply, carbon storage in growing trees to limit climate change, as well as maintaining attractive landscapes and biodiversity will become increasingly important societal goals. It is also assumed that future farmers will demand at least a farm laborer's hourly rate for their work and a market rate of return on their investments in order to maintain the current area of silvipastoral agroforestry in the long term and to sustainably increase the future area of silvipastoral agroforestry in Sweden.

2. Materials and Methods

Information on Swedish forest grazing and grazing in wooded semi-natural pastures, up to the beginning of the 1900s, is taken from historical overviews. Information on the development thereafter, up to the 1960s, is mainly sourced from advisory materials aimed at farmers and foresters whose decisions determined whether forest grazing and semi-natural pastures were to remain or not. By the 1970s and 1980s, the main area of forest grazing and a large part of the wooded semi-natural pastures were already gone, and a continued rapid reduction of the arable land was also predicted. The preservation of open agricultural landscapes became an important issue for nature conservation organisations, the public and politicians. From this time on, investigations made by governmental agencies such as the Ministry of Agriculture, Swedish Board of Agriculture and Environmental Protection Agency as well as environmental literature are therefore important sources in this review. These investigations were the basis on which political and administrative decisions were made, in order to possibly support the preservation of attractive agricultural landscapes including agroforestry.

During the 1990s, conservation of remaining high-nature-value semi-natural pastures, including EU support to preserve them, became an important issue. Somewhat later, climate issues involved with grazing animals, trees and forests also became important questions. From the 1990s onwards, not only investigations by Swedish authorities but also international scientific literature are therefore included in this review. In recent years, the number of trees allowed in semi-natural pastures in order for them to be eligible for EU support and environmental payments has been a hotly debated issue in Sweden. Therefore, opinion polls about Swedes' preferences for pastures with or without trees are referenced.

Calculations of the future economic conditions for preserving and expanding the area of silvipastoral agroforestry, in the form of wooded semi-natural pastures and forest grazing, are included in this literature review. Based on this economic analysis and the preceding literature review, the future of Swedish silvipastoral agroforestry is discussed in the conclusion.

Below is a description of the references in the following sections:

3.1. Forest Grazing, the Oldest Form of Silvipastoral Agroforestry: Historical overviews: 2–6.

3.2. From Forest Grazing to Wooded Semi-natural Pastures: Historical overviews: 6, 7, 13, 14. Advisory materials: 8–12, 15.

3.3. From Wooded Semi-natural Pastures to Cultivated Pastures, Arable Grazing and Concentrate Feed: Historical overviews: 7, 13, 18, Table S1. Advisory materials: 16. Public investigations and statistics: 17, 21. Environmental literature: 19, 20.

3.4. From Farmland to Spruce Plantation and Slow Natural Afforestation: Historical overviews: 22, Table S1. Advisory materials: 23–26. Public investigations and statistics: 17, 21, 28, 29. Environmental literature: 20, 27.

3.5. Silvipastoral Agroforestry for the Landscape: Historical overviews: 30, 44, Table S1.

Advisory materials: 32, 36, 39. Public investigations and statistics: 17, 21, 29, 31, 45. Environmental literature: 33, 35, 40–43. Opinion polls: 34, 37, 38, Figures S1 and S2

3.6. Agroforestry for the Climate: Advisory materials: 39. Public investigations and statistics: 48, 49. Environmental literature: 47. International scientific literature: 46.

3.7. Silvipastoral Agroforestry for Biodiversity, Food Security and Economic Sustainability.

Advisory materials: 8, 23, 24, 39, 56–60. Public investigations and statistics: 21, 50–53, 55. Environmental literature: 47, 54.

3.8. Discussion: Historical overviews: 4, 6, 22, 30, 44, Table S1. Advisory materials: 8, 39, 61, 66. Public investigations and statistics: 17, 31, 48–51, 53, 62–64. Environmental literature: 10, 20, 33, 41–43, 47, 65, 70. International scientific literature: 67–69, 71.

3. Results

3.1. Forest Grazing, the Oldest Form of Silvipastoral Agroforestry

From the beginning of stationary Swedish farming with permanent fields, around 2500 BP (before present) until the late 1800s, the country´s agriculture area consisted of small arable fields, large open or wooded hay-meadows and extensive outlands of grazed semi-open forests [3]. Thereafter, the combined production of livestock feed and wood products for subsistence use in meadows and semi-open forests decreased. By the 1940s, land use had been almost completely separated into either arable land and pasture or forest exclusively for the production of timber and pulp-wood [3].

The outlands in the old agricultural landscape were managed not only to provide sufficient grazing, but also to ensure farm and village access to wood products. It was more open than today's forests but far from treeless. It is unknown how the trees were distributed, but they were probably not evenly spread. Most likely, the outlands were mosaics of open spaces and naturally regenerated wooded areas, according to both landscape researchers [4] and Swedish landscape painters such as Carl Larsson (1853–1919) and Bruno Liljefors (1860–1939). Such grazed outland forests were the oldest form of silvipastoral agroforestry in Sweden [3].

In forest-dominated districts in central and northern Sweden, since the 1600s it was also common to have forest grazing around summer farms (shacks) far from the villages where agricultural land was scarce. As the animals grazed at the summer farms, the agricultural land near the villages could solely be used to produce human food and winter feed for the livestock [5,6].

3.2. From Forest Grazing to Wooded Semi-Natural Pastures

During the late 1800s and early 1900s, forest grazing became more and more in question, due to its negative impact on timber production, which had begun to gain greater value as a result of the development of sawmills and the paper pulp industry [7]. The grazed forest was often kept sparsely covered by thinning and burning trees to favor grass growth, which reduced timber production [6]. The livestock grazing also killed deciduous seedlings and damaged coniferous plantings by trampling and gnawing, resulting in lower growth and defective tree stem shape. Even older spruce was damaged by trampling and gnawing of the roots and bark, which can result in future rot damage and thus lower timber value [8]. Another reason for the decline of forest grazing in the 1900s was the breeding work progress, resulting in high-yielding dairy cows for which forest grazing was nutritionally insufficient [9]. The conclusion was that grazing damages forestry and forestry damages grazing, hence they should not be conducted on the same land [8].

The solution to the problems of forest grazing, according to both foresters and agronomists, was to remove livestock from forests and keep them in fenced semi-natural pastures [7]. Such wooded semi-natural pastures, where the majority of the trees had been removed, could give 10 times higher grazing yield per hectare (ha) than forest grazing [10]. The wooded pastures thus required less acreage, and the majority of the forest could be used for specialized timber production.

Forest grazing declined from the late 1800s and early 1900s onwards but continued to a significant extent until World War II [7]. In 1927, 752,000 ha of forest grazing remained [11]. The proportion of livestock that grazed fully or partially in forests in 1937 was estimated to be 40% in northern Sweden, 20% in large parts of central Sweden and 10–15% in southern Sweden's forested areas [12]. Today 29,000 ha remain, of which 16,000 ha receive

environmental compensation [6]. Forest grazing has transitioned from being important for the food supply to becoming a concern for nature conservation [6].

The semi-natural pastures that replaced forest grazing generally contained many deciduous trees. At a meeting with the Royal Swedish Academy of Agriculture and Forestry in 1960, it was stated, "In the older pasture management, the pastures were cleared but not clear-cut" [13]. They wanted deciduous trees and therefore removed the conifers in the first place. The deciduous trees were used as handicraft timber and firewood, as well as producing leaves for winter feed. The leaves that fell on the ground gave rise to decay and mulch, which, in contrast to the coniferous waste, promoted grass growth" [13]. The value of forest production in wooded semi-natural pasture of olden times could be between 35% and 45% of the value of forest production when forestry production only was performed on land of the same fertility [14]. In *The Book of Swedish Agriculture* (1927) it was stated that "The task of semi-natural pastures is to produce quality timber and pasture plants and the main tree species is and will always be naturally regenerated birch" [15]. What is now called silvipastoral agroforestry was thus still common in Sweden 100 years ago.

3.3. From Wooded Semi-Natural Pastures to Cultivated Pastures, Arable Grazing and Concentrate Feed

Already at the beginning of the 1900s, wooded pastures began to be questioned by forestry representatives due to their low yield and thus large need for land that could alternatively be used for specialized forestry [7]. The advisory services therefore suggested developing high-yielding cultivated pasture that could be created on a smaller part of semi-natural pastures. The area of semi-natural pasture was halved during the first three decades of the 1900s (Table S1: *Areas of agricultural land and forest grazing, number of cattle and number of herds with cattle in Sweden 1901–2022*).

According to *The Farmers Book* (1945) [16], in addition to the felling of trees, the pasture cultivation included ditching, soil preparation with a pasture culture harrow, liming, basic fertilization, sowing of grazing plants and finally continuous maintenance fertilization. Trees were saved only to the extent that it was justified by the well-being of grazing animals [16]. Especially after World War II, also grazing on arable land began to gain widespread use [13] and an investigation by the National Board of Agriculture in 1967 [17] predicted that the majority of all Swedish semi-natural pastures would be abandoned and replaced by cultivated pasture and grazing on arable land by 1980.

However, the introduction of suckler-based beef production using pastures [18] and an increased conservation interest in keeping semi-natural pastures open for landscape and recreation reasons [19,20] meant that the decrease in semi-natural pastures was kept to only 22% from 1966 to 1980 [21]. In 2022, there were more suckler cows, sheep and horses, and a larger area of semi-natural pasture, than in the 1960s. Meanwhile, the number of dairy cows and total number of cattle as well as the area of arable land have decreased sharply (Table S1).

For a few decades at the beginning of the 1900s, grazing on arable land increased. However, during the post-World War II period, the arable grazing decreased due to fewer dairy cows, less grazing and more intensive feeding with more concentrated feed. In 1950, grazing accounted for about 37% of the dairy cows' total annual feed intake. By 1980 it had fallen to 14% [18].

3.4. From Farmland to Spruce Plantation and Slow Natural Afforestation

The abandonment of semi-natural pasture and arable land was very fast during the first post-World War II decades (Table S1). It was especially fast in forest districts where there was already not so much agricultural land [21]. These areas were associated with small farms and movement of farmers and farm workers to better-paid jobs in the fast-growing industry [22]. Forest planting, mainly with spruce, was seen by the authorities as the main alternative for the disused agricultural land [17], and tree planting was stimulated by grants [23]. However, during the 1950s and 60s, only 25% of the abandoned agricultural

land was planted despite these grants, while 15% was used for built-up areas and other purposes [17]. More than half of the land was left without active use. During this time much land left agriculture because it was just not profitable to cultivate, while in the 1800s and early 1900s, land was actively taken from agriculture because it was needed for timber production (Sections 3.2 and 3.3).

The abandonment of agricultural land was predicted to continue until 1980 when only half of the 1951 area of arable land and virtually no semi-natural pasture were estimated to remain [17]. However, the continued abandonment did not become as extensive as anticipated (Table S1). The area of forest plantation also had a much smaller spread than anticipated. Statistics suggest that the majority of agricultural land that was abandoned after 1970 has been left without plantation, and has slowly become, or is becoming, self-seeded forest [24]. This occurs despite the fact that spruce planting on abandoned agricultural land can be profitable, at least in southern and central Sweden where spruce grows fast [25]. Natural afforestation of abandoned agricultural land generally takes a long time, and in many cases results in low-producing forest with little economic value (see Figure S1: Example suggesting that natural afforestation of abandoned agricultural land can take a long time and produce patchy low-producing low-quality forest).

Important reasons for the slow abandonment of and negligible forest plantation activities on agricultural land after 1970 are probably the reluctance of landowners to afforest land that their ancestors cultivated with great hardship [26], as well as the public's preference for open landscapes and aversion to spruce planting on agricultural land [20,27]. The public's desire to preserve open farmland led to the introduction of environmental payments for grazing in the 1980s [28], and it was expanded in connection with Sweden's entry into the EU in 1995 also to include grass cultivation on arable land [29].

3.5. Silvopastoral Agroforestry for the Landscape

The slow abandonment of arable land in combination with rapidly increasing yields per ha thanks to plant breeding progress and commercial fertilizer [30] led to troublesome and price-depressing overproduction of grain on the Swedish market in the 1980s. Resumed afforestation was seen as the main option to deal with this problem by the agricultural and forestry authorities, but landscape-dependent opposition to afforestation implied that agroforestry was seen as an appealing alternative [31]. Preliminary calculations also showed that silvipastoral agroforestry with birch planting and grazing animals could be profitable on arable land that lacks profitable alternative use [32].

However, when Sweden joined the EU in 1995, with its larger market, the overproduction problem disappeared. This membership also meant a range of various economic supports for agriculture, but not for agroforestry [29]. Agroforestry without support could not compete with, e.g., supported pasture-based meat production without tree planting. Interest in agroforestry therefore disappeared. Requirements in the support rules in the years around 2010 also meant that many farmers were forced, for economic reasons, to reduce the number of trees in their existing old wooded semi-natural pastures [33].

According to studies during the 1980s, the Swedish population had a high willingness to pay for preserving open agricultural landscape if the alternative was spruce planting. This willingness to pay was higher for wooded semi-natural pastures than for tree-free pastures and arable land [34,35]. In a series of studies during the years 1995–2021, the Swedish population's ranking of landscapes, including silvipastoral agroforestry in the form of wooded semi-natural pastures, treeless pastures, arable land and afforestation with spruce and birch has been investigated.

In the first of these preference studies, real estate agents were asked to estimate the likely market value of residential buildings surrounded by various land use alternatives [36]. The latter studies have been web-based surveys with 1000 respondents each from TNS Sifo's online panel consisting of randomly selected Swedes aged 18–75 [37]. The respondents were shown drawings or photos of different land use options. Through manipulation, the photos depicted the same kind of grazing animals so that the respondents would rank the

alternatives entirely based on the landscapes without being influenced by whether the grazing animals were more or less appealing. The respondents were asked the question "Suppose that you live or often travel overlooking these landscapes. Rank the landscapes from the best to the worst based on your preferences". In one case, the respondents were instead asked to evaluate the options on a five-point scale from low value = 1 to high value = 5 based on their preferences [37,38].

Figure 1 shows examples of the options that respondents were asked to rank in sub-studies based on drawings and partially manipulated photos. In the latter study, half of the respondents received the following climate-related additional information: "When the trees in the pasture grow, they absorb carbon dioxide, which climate compensates for parts of the livestock's greenhouse gas emissions". The results of all the valuation studies from 1995–2021 are summarized in Table 1 and reported in detail with drawings and photos in Figure S2: Valuation of landscapes by eight surveys with online panels consisting of randomly selected Swedes.

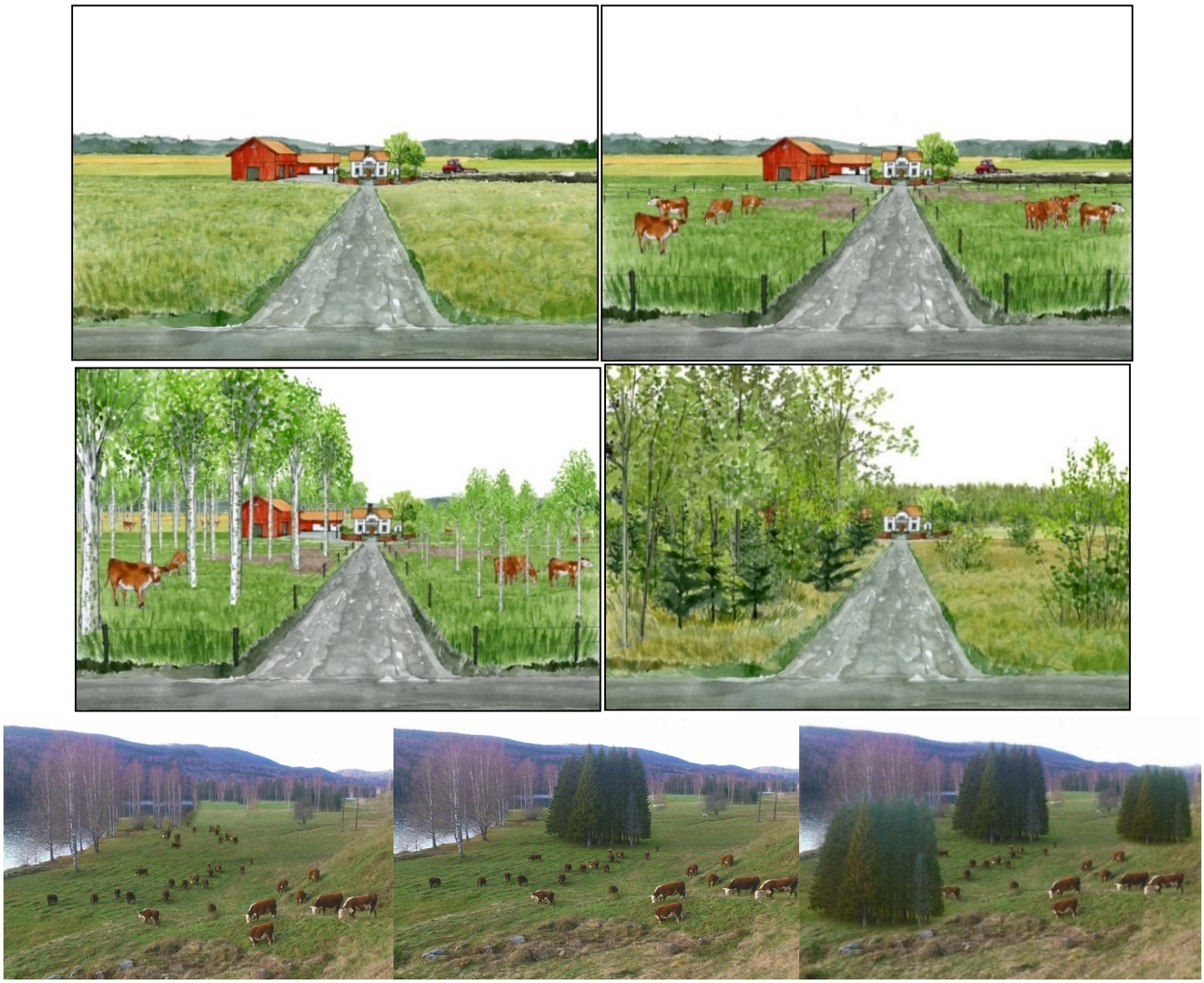

Figure 1. Alternatives that respondents were asked to rank in two sub-studies. In the first study, the alternatives were arable land, treeless pasture, silvipastoral agroforestry and natural afforestation. In the latter study, the options were treeless pasture, silvipastoral agroforestry with one spruce grove and silvipastoral agroforestry with three spruce groves.

Table 1. Valuation of landscapes with silvipastoral agroforestry in the form of wooded semi-natural pasture, treeless pasture, arable land and afforestation according to a survey on the value of residential buildings in 1995 [36] and eight surveys in the years 2014–2021 with online panels consisting of randomly selected Swedes aged 18–75 [37]. Score 1 means best option, 2 second best, etc. The trees in silvipastoral agroforestry can stand individually scattered over the entire pasture or stand in dense groves on a smaller part of the pasture. In the latter case, "groves" are indicated in the table. "Climate information" in the 2021 study means that the respondents received information about the climate benefit of the trees through carbon sequestration and storage.

Investigation Year	Silvipastoral Agroforestry (Wooded Semi-Natural Pasture)	Treeless Pasture	Arable Land	Afforestation
1995	1 (birch)	2		3 (spruce plantation)
2014	1 (birch) 1 (old oaks)	3	4	2 (natural afforestation)
2016	2 (old birches) 4 (young trees) 1 (old birches)		3	
2019:1	2 (young birch groves) 4 (young planted birches)	3		
2019:2	1 (birch)	2		3 (natural afforestation) 4 (birch plantation) 5 (spruce plantation)
2021:1 without climate information	2 (spruce groves)	1		
2021:1 with climate information	1 (spruce groves)	2		
2021:2 without climate information	1 (birch groves)	2		
2021:2 with climate information	1 (birch groves)	2		

Source: Figure S1.

Table 1 shows that silvipastoral agroforestry was valued highest in all cases except in one case where silvipastoral agroforestry consisted of spruce groves and the alternative was treeless pasture (2021:1 without climate information). However, respondents who received information about the climate benefit of the spruce groves through carbon uptake and storage rated the spruce-agroforestry alternative the highest (2021:1 with climate information). Treeless pasture or arable land came in second place in the valuation after silvipastoral agroforestry in most cases.

One of the studies (2019:1) indicates that Swedes would rather have naturally regenerated trees than planted trees in wooded pastures. Treeless pasture was even preferred over wooded pasture with planted trees in this study.

Afforestation was ranked as the worst alternative from a landscape point of view in all but one case, in which natural afforestation was valued higher than treeless pasture and arable land (2014). In this case, treeless pasture and arable land constituted large monotonous plain landscapes and are thus not representative of forest regions with abandoned and risk-of-being-abandoned agricultural land. Spruce plantation was rated as the worst alternative in all cases when it was included in the comparisons.

Agroforestry with older trees was rated higher than agroforestry with younger trees. The old trees were standing in traditional oak and birch wooded semi-natural pastures (2016 and 2019:1), which generally have high biodiversity and cultural-historical value [4,39]. Birches, however, usually do not grow older than about 100 years. Without rejuvenation, the birch wooded pastures will therefore disappear in the longer term and become "a very characteristic feature of a just-gone era in a changing agricultural landscape" [40]. In order to have valuable birch wooded pastures also in the future, new ones must therefore be created through planting or thinning in young naturally regenerated birch groves in

pastures [41]. Oak lives a long time, but in the very long run regeneration of oak is also needed to preserve its biological and cultural-historical values [42].

Nature conservation actors have deeply regretted the loss of wooded semi-natural pastures, i.e., silvipastoral agroforestry, over the last 100 years and have particularly opposed spruce planting [4]. One of them wrote: "Now, since the farmers have turned more and more to indoor-feeding of the cattle all year round or feeding them in clover seeded or artificially fertilized pastures on arable land, the wooded pastures are doomed. They are completely inadequate as pasture for today's high-milking cows. In other cases, the pastures are allowed to grow back into forest, if it is not directly planted with spruce. When the darkness of the spruce forest suffocates the pastures, it feels as if some of one's finest memories would also die the death of suffocation" [43].

One reason for the resistance of Swedish residents to afforestation of agricultural land is that the area of agricultural land in Sweden already has decreased from 5 million ha in the 1920s to 3 million ha (Table S1). Sweden is a forest-dominated country, with 69% of the contry's total land area being forest. Heath land, meadows, open mires and bare rock, etc., occupy 20%, and built-up land 3%. Arable land and semi-natural pasture (agricultural land) make up only 8% of the area as a result of the last century's planting and natural afforestation [44]. Between districts with a high proportion of agricultural land in southern Sweden and the mountainous areas in northwestern Sweden, the proportion of forest is over 80% in large areas of the country [44]. It is in these forest-dominated areas that the abandonment of agricultural land has been the greatest [21] and where there is a particularly high proportion of agricultural land at risk of being abandoned [17]. In such areas, silvipastoral agroforestry can be particularly important for preserving landscape values.

Figure 2 shows an example of silvipastoral agroforestry in a forest-dominated area with much abandoned agricultural land. On the land that is now silvipastoral agroforestry with a grove of birches, it was arable land until 1960. After abandonment, it became a dense self-seeded forest that was converted to silvipastoral agroforestry during the 1980s in connection with the farm's resumption of animal husbandry. When the birches are felled or die in the future, it may become treeless pasture, agroforestry through tree planting or only forest if the farm's animal husbandry ceases again. Silvipastoral agroforestry can thus be deliberate growing of trees on the same unit of land as pasture in spatial mixture as in the picture, or in sequence [1] as it has been and can be again in the current example. In both cases, it is a good alternative with regard to landscape to total permanent afforestation in already forest-dominated areas.

Figure 2. Silvipastoral agroforestry with birch grove in pasture in a forest-dominated area with much abandoned agricultural land.

3.6. Agroforestry for the Climate

Trees that are growing can limit climate change through carbon dioxide absorption and carbon storage in the wood as long as they grow, and after they are felled, through wood that is substituted for climate-affecting materials such as concrete and steel in building construction [45]. In a report from the Swedish Agricultural Agency in 2011, trees in pastures were therefore brought to attention as a way to offset the greenhouse gas emissions of pasture-based meat production [46]. A governmental inquiry in 2022 [47] also proposed tree planting in, e.g., pastures and on abandoned agricultural land in order to, through carbon sequestration (negative emission) of the trees, contribute to achieving Sweden's climate goal of net zero emissions of greenhouse gases by 2045. However, agroforestry accounted for only a very small part of the negative greenhouse gas emissions in the inquiry's proposal [47,48]. The main proposals were instead for capture and storage of biogenic carbon dioxide (bio-CCS) from the pulp and paper industry, re-wetting drained peatland, the use of catch crops in arable farming and traditional afforestation of abandoned farmland. However, the inquiry [47] calculated the cost of bio-CCS at SEK 0.70–1.05/kg carbon dioxide (EUR 0.07–0.105). With compensation for carbon sequestration in growing trees corresponding to this cost, birch and oak planting in pastures would be profitable [41].

3.7. Silvipastoral Agroforestry for Biodiversity, Food Security and Economic Sustainability

The European Commission has proposed a nature restoration law aimed at, e.g., increasing biodiversity, limiting global warming and reducing risks to food security [49]. The Swedish Board of Agriculture has analyzed the possible consequences of this proposal for Swedish agriculture in general and Swedish semi-natural pastures in particular. The agency admits that the level of biodiversity in the Swedish agricultural landscape is poor, due to abandonment of agriculture with subsequent afforestation or overgrowth of previously open land. It therefore concludes that over one million ha of hay-meadows and semi-natural pastures need to be restored or recreated in order to achieve the proposal's requirements for a favorable conservation status. This would increase food production, while the forest production that currently takes place on the land would be pushed back. Another complicating aspect highlighted by the agency is that the EU's proposed defores.tation regulation does not allow the sale of meat from animals that have been grazing on land recently converted from forest to pasture [50].

Beef and lamb production based on pasture and silage or hay for winter feed would be the only economically realistic options on now forested former semi-natural pastures and hay-meadows [23], to achieve the requirements according to EU´s nature restoration law. Increased pasture-based meat production would also improve Sweden's food security, as domestic production now only covers 60 and 30%, respectively, of the country's consumption of beef and lamb, while the self-sufficiency levels for pig and poultry production is almost 100% and for grain production over 100% [51]. The production of beef and lamb, corrected for changes in the meat stock in live animals, has also decreased since 2017 [21], despite the fact that the Swedish Parliament the same year decided on a food strategy aimed at increasing the country's food production [52].

In order to minimize the conflict between, on the one hand, resuming pasture-based meat production on overgrown lands and, on the other hand, limiting global warming, some of the trees on the forested lands should remain and continue to store carbon (Section 3.6). Trees in pastures also provide a landscape that is appreciated by the public (Section 3.5). Trees in pastures also provide grazing animals with sun, wind and precipitation protection [41]. Naturally generated trees in pastures can also be beneficial from a biodiversity point of view [4]. Silvipastoral agroforestry thus has a number of advantages. However, this production system must become profitable if it is to become widespread again.

Swedish semi-natural pastures with high biodiversity and other conservation values typically have an average area of about 4 ha and a median area of about only 2 ha [53]. In forest districts with much abandoned and at-risk-of-being-abandoned agricultural

land, these pastures are generally even smaller and are scattered around in the forest-dominated landscapes [54]. Economically sustainable pasture-based meat production requires larger areas of pasture to be managed sustainably and efficiently. It may require at least 50 suckler cows + 100 calves and followers on 130 ha of pasture [24] or 500 ewes + close to 1000 lambs on 150 ha of pasture [55]. In order for beef and lamb production to be able to compete economically with spruce plantations, significantly larger herds and areas of pasture may be required, especially in southern Sweden where the spruce grows quickly and is especially profitable [24]. Profitable pasture-based meat production also requires large contiguous pastures to limit the costs of fencing, water supply and animal management [24].

These conditions for economic sustainability can be accomplished by creating large cohesive pasture-forest mosaics of small scattered existing and abandoned semi-natural pastures and hay-meadows, together with abandoned and at-risk-of-being-abandoned fields and intervening forestland, which may have been agricultural land or grazed forest in the past. The main task of the forestland in the mosaics is to tie together the small scattered pastures and fields in order to enable profitable pasture-based meat production. The forest also provides some grazing, e.g., 100–300 kg of dry matter (DM)/ha [56–58] which can be compared with 1000–1500 kg of DM on semi-natural pastures [59].

Climate considerations mean that some of the trees in the restored pastures should be allowed to remain as in the examples in Figure S3 *(a) Silvopastoral agroforestry with birch grove that was left behind when overgrown farmland was restored;* and *(b) Silvopastoral agroforestry with self-seeded birch groves on land that was grazed forest until the 1950s and was finally felled in the 1990s, after which it became self-sown dense birch-dominated young forest*. The restored landscapes in the figures have become mosaics of wooded semi-natural pastures and grazed forests, i.e., silvipastoral agroforestry landscapes that were common 100–150 years ago but then disappeared as a result of competition from forestry and the rationalization of agriculture (Sections 3.1–3.3).

In the grazing areas within the mosaics, animals have access to nutritious cultivated pasture that provides the majority of their herbage intake while damage to the forest is insignificant [60]; meanwhile, heavy grazing in forest alone, which was common in the past, can cause very serious forest damage [8]. Such damage was an important reason why forest grazing was abandoned in Sweden in the period of 1850–1950 (Section 3.2). Beef or lamb production in the outlined large pasture–forest mosaic is silvipastoral agroforestry with historical roots, having possibilities of combining rational meat production with rational wood production.

In the example in Table 2, the profitability of pasture-based beef production is calculated in small 2 ha scattered pastures and in large pasture–forest mosaics consisting of 40% small scattered semi-natural pastures and 60% grazed intervening forest. The larger silvipastoral paddocks mean that the costs per animal for fencing, water supply and supervision will be lower than in the small scattered pastures. It is also assumed that creating the large mosaics, including restored abandoned farmland, makes larger pasture areas available for beef production, which allows the herd to increase from 20 to 50 cows including finishing the calves to slaughter as young cattle (cows+). Through this growth the costs per cow+ for feed including pasture, building, labor and sundries are reduced thanks to economies of scale [24].

The result of creating large pasture–forest mosaics and simultaneously increasing the herd size from 20 to 50 cows+ is that beef production's contribution to land, management and risk (CLM&R) increases from – SEK 37,000 (≈ – EUR 3700) to + SEK 208,000 (≈ + EUR 20,800) (Table 2). Production in small scattered pastures is thus unprofitable, while production in large pasture–forest mosaics is profitable and thus economically sustainable, at least if governmental supports and payments remain at the current level.

Table 2. Number of suckler cows including their calves and young cattle (cows+), land requirements for feed production, revenues, costs and contribution to land, management and risk (CLM & R = revenues - costs) when grazing in small scattered pastures and large pasture–forest mosaics in central Sweden. Swedish kronor SEK (1 SEK≈ 0.1 Euro).

	Small Scattered Pastures	**Large Pasture–Forest Mosaics**
Number of cows + their calves and young cattle to slaughter	20 cows+	50 cows+
Land for feed production, ha		
Arable land for grass/clover silage and grazing	20	50
Small scattered pastures	53	
Pasture in large pasture–forest mosaics		133
Forest in large pasture–forest mosaics		200
Revenues and costs (-)		
Beef	258,000	645,000
Governmental supports and payments from EU and Sweden [1]	377,000	942,000
Feed excl. cost of land	−307,000	−642,000
Building	−156,000	−351,000
Labor	−136,000	−211,000
Sundry costs [2]	−73,000	−175,000
Contribution to land, management and risk CLM&R, SEK/herd [3]	**−37,000**	**208,000**
CLM&R, SEK/ha agricultural land [3]	**−510**	**1140**

Source: [24]. [1] Headage support to cattle, support to less favored area, environmental payments to semi-natural pasture and single farm payment, enterprise support and payment to organic production. [2] Bull, electricity, insurance, vet, feed analyses, interest, etc. [3] Agricultural land includes arable land and semi-natural pastures (not forest). Management includes planning, labor management, administration and accounting. Risk includes biological and physical risks (e.g., feed-crop failure and abnormally high calf mortality), economical risks (e.g., reduced beef price), and political risks (e.g., reduced or abolished supports and payments).

Table 2 refers to beef production in central Sweden. In northern Sweden, the grazing period is shorter and production costs are higher, while the grazing period is longer and the costs are lower in southern Sweden. Higher support to less favored areas in the north and lower such support in the south means that CLM&R is roughly the same throughout the country [24]. The conclusion is therefore that beef production in small scattered pastures is unprofitable in the whole country and thus economically unsustainable, while it can be profitable and economically sustainable if it is possible to create large pasture–forest mosaics from the small scattered pastures and intermediate forest.

This production can also be climatically sustainable if the pastures are wooded and the forest grazing does not damage tree growth [23,46]. Silvipastoral agroforestry with wooded pastures and well-managed forest grazing can thus become economically and climatically sustainable and enable the restoration of semi-natural pastures that satisfy the EU´s nature restoration law. Restoration of abandoned pastures and other disused agricultural land would also improve Sweden's food security.

4. Discussion

During most of Sweden's history, the food supply has been based on animals grazing in forests and wooded semi-natural pastures, the winter feed for animals produced on wooded hay-meadows and the grain for direct human consumption coming from small arable fields. What is now called agroforestry has therefore historically been very important (Sections 3.1 and 3.2). This importance decreased rapidly during the 19th and 20th centuries when large areas of hay-meadows were cultivated into arable land, and crop rotation including grass replaced the former one-sided grain cultivation. The animals received better fodder and the harvests increased.

After World War II, hectare yields increased further at a rapid rate thanks to plant breeding, artificial fertilizers and pesticides. At the same time, cattle breeding progress, better fodder from the cultivated grass from arable land and an increased use of feed grain

meant that the milk yield per cow increased from 800 kg in 1850 to 2900 kg/year in 1950 and 4900 kg/year in 1976 [30]. This increase in yield, which continued at an accelerated pace to reach 10,200 kg in 2020 [61] and limited market space, has caused the number of cattle to decrease rapidly. During the 20th century, horses were also replaced by tractors and the number of sheep decreased as a result of wool being replaced by other textile materials. The technical development in agriculture combined with a rapidly growing forest industry's need for more wood (Sections 3.2 and 3.3) has meant that the reduction in forest grazing, semi-natural pastures and hay-meadows that began in the 19th century continued in the 20th century (Table S1). Silvipastoral agroforestry was about to disappear.

Unlike the forestry sector, Swedish agriculture could not compete on the world market. Therefore, the increased harvests per hectare and more efficient animal production led to price-depressing overproduction of agricultural products from the 1950s onwards. At the same time, the rapidly growing Swedish industry demanded more labor, which caused wages to rise rapidly. Depressed prices and opportunities for well-paid industrial work caused many farmers to leave agriculture [22], and small labor-intensive fields were abandoned [17]. Of 4.4 million ha of arable land and semi-natural pasture in 1951, only 3.4 million ha remained in 1968 (Table S1). The abandonment was predicted to continue until 1980 when only 1.9 million ha arable land and virtually no semi-natural pasture was predicted to remain [17].

The majority of abandoned agricultural land was assumed to be afforested [17] mainly by spruce planting or naturally regrown with deciduous thicket [20]. However, keeping parts of the abandoned agricultural land open became an important national goal with regard to landscape and recreational values during the 1970s. For this landscape conservation, i.e., grazing, mowing and herbicide spraying was considered. Deciduous tree planting was also suggested as an alternative to spruce planting [20]. Combining planted deciduous trees and pasture in the form of silvipastoral agroforestry to preserve and create attractive landscapes on abandoned and at-risk-of-being-abandoned agricultural land was also actualized during the 1980s [31].

In recent years, agroforestry has been noticed for its ability to combine climate and landscape goals. A report from the Swedish Board of Agriculture in 2011 found that carbon dioxide sequestration in trees planted in pastures can compensate for the grazing animals' emissions of greenhouse gases [46]. A governmental investigation from the year 2020 concluded that agroforestry can be a suitable compromise between, on the one hand, increased timber production with its climatic and industrial advantages, and on the other hand, the interest in maintaining a relatively open and varied landscape even in forest districts [47]. Another investigation carried out by the Swedish Board of Agriculture and the Swedish Forestry Agency in 2022 found that continuous renewal of the tree layer is needed in wooded semi-natural pastures so that carbon storage does not decrease when existing trees gradually die [48]. Opinion polls also show that Swedes would like to have trees in pastures, especially if people are informed about their climate benefits (Table 1; Figure 1; Figure S2).

With information about the trees' climate benefits, Swedes even prefer silvipastoral agroforestry with spruce groves (Figure 1, lower part; Table 1, 2021:1) over treeless pastures, despite the fact that spruce on agricultural land is otherwise frowned upon by both the public (Table 1) and conservationists [4,43]. A practical and economic advantage of spruce planting over deciduous tree planting in pastures is that spruce plants are not damaged by grazing animals nearly as much as deciduous plants. It is expensive to protect deciduous trees in pastures [24]. Cost-effective establishment of deciduous trees in pasture (Figure 1, upper part) can presuppose self-seeding during a period when the land is abandoned (Figure 2).

Despite climatic and landscape advantages, there are no environmental payments or other support measures to maintain or increase the number of trees in pastures or to establish new silvipastoral agroforestry in Sweden by planting trees in pastures. Instead, current support rules discourage agroforestry by cutting support and environmental compensation

if trees are planted in pastures [47,48]. There have even been cases where farmers have had to remove existing trees in pastures in order to keep the support [33]. If support is lost, the economic conditions for grazing in semi-natural pastures deteriorate drastically (Table 2).

Since the 1990s, conservation and restoration of semi-natural pastures, including wooded semi-natural pastures as well as forest grazing, has become an increasingly important social goal due to the biodiversity and cultural-historical values of these lands [4,62]. After Sweden's entry into the EU in 1995, there are therefore environmental payments for grazing semi-natural pastures and certain forests [63]. These payments, and not least the great interest of many farmers in keeping their land open [64], have contributed to the fact that the previous rapid reduction of semi-natural pasture has slowed down and that there is still some forest grazing left. Increased numbers of suckler cows, sheep and horses, which have compensated for the reduction in the number of dairy cows since the late 1960s, are important in this context (Table S1). However, a possible reduction in environmental payment and other agricultural support could make suckler cows and other grazing animals unprofitable (Table 2), which would worsen the conditions for the continued grazing of semi-natural pastures.

Interviews with farmers managing especially valuable semi-natural pastures show that idealism and tradition are important driving forces behind continued grazing [65]. "I will keep going despite economic losses" and "I will continue as long as I have the strength" were typical answers given by the interviewees. However, nearly half the interviewees also believed that their pastures would be ungrazed within 10 years despite environmental payments [64]. Statistics also show that much semi-natural pasture has been abandoned in recent decades and has become forest. This has been compensated by arable land and forest land that have been converted to pasture [10], which is why the semi-natural pasture area has decreased only slightly since 1995 (Table S1). However, the new pastures do not have the high biodiversity values that the ones that have been lost had.

An important reason why semi-natural pastures are abandoned is that they are small and scattered in the forest-dominated landscapes. For economically sustainable consuetude and reclaiming of such pastures, it is necessary to create large pasture–forest mosaics of these pastures together with intervening forest, which in many cases can be previously grazed forest or afforested semi-natural pasture and arable land (Section 3.7 incl. Table 2). Such mosaics should be able to meet the goals of the EU's proposed nature restoration law [49] by contributing to preserving biodiversity on land threatened with abandonment and recreating biodiversity on abandoned land.

New pasture–forest mosaics can also contribute to achieving the goal in the Swedish national food strategy [52] by increasing Sweden's currently low level of self-sufficiency in beef and lamb. In order to also meet the goal of limited global warming [47], it is required that a large number of growing and carbon-storing trees are allowed to remain in the restored-to-pasture current forestland (Section 3.6). By planting trees in semi-natural pastures, the climate benefits can increase further [46]. Swedish residents would also rather have wooded pastures than treeless pastures (Table 1 and Figure S1). Establishment of new trees is also necessary in order for there to be birch- and oak-wooded semi-natural pastures far in the future [40,42]. There are thus a number of reasons for a return of silvipastoral agroforestry, in the form pasture_forest mosaics of wooded semi-natural pastures and forest grazing, after more than 100 years of decline.

Motivation for a return to silvipastoral agroforestry may increase if great simultaneous scarcity of both wood and meat will occur in the future. Agroforestry in particular can give a higher total production per hectare than pasture and forest grown separately on separate areas. One reason for the increased production is that tree roots grow deeper into the ground than grass roots and can therefore take up water and plant nutrients that grass roots do not reach [41]. Furthermore, in forest grazing, understory vegetation in the form of grass and leaf thicket is utilized, which would otherwise be of no use and even impede the growth of coniferous seedlings if it were not grazed down [65]. Forest grazing in the pasture–forest mosaics, where the animals also have access to more nutritious

cultivated pasture that provides the majority of their herbage intake, only damages the forest insignificantly [60]. Heavy grazing in forest alone, which was common in the past, can, however, cause very large amounts of forest damages [8]. These damages were an important reason why forest grazing became abandoned during the late 1800s and early 1900s (Section 3.2). The worst option in case of severe shortage of both food and wood is to leave fertile agricultural land unused (Figure S1).

Taking into account carbon sequestration in forests and the albedo effect (reflection of incoming solar energy which is high from bright surfaces such as snow-covered agricultural land and low from forest), deforestation has a net cooling effect in boreal regions while deforestation in the tropics has a net global warming effect. In temperate regions, forest has a near-zero effect on climate [66–68]. This suggests that afforestation for pasture-based meat production, especially in boreal northern Sweden, is climatically better than afforestation for such production in warmer countries where the ground is rarely, or never, snow-covered and forest growth is faster. These include countries from which Sweden at present imports beef and lamb; this meat could instead be produced in Swedish silvipastoral agroforestry on land that is now dense forest.

A Google search for *silvipastoral agroforestry photo* results largely in images of rows of planted trees and grazing livestock. Swedish silvipastoral agroforestry, on the other hand, has included and still includes almost exclusively naturally regenerated trees in wooded semi-natural pastures and grazed forests. However, small areas of agroforestry with planted trees do occur [69]. Naturally regenerated trees are better from a nature conservation point of view [4,6,43,48,50] and more popular with the public (Section 3.5; study 2019:1) than planted ones. If the trees' carbon dioxide sequestration is paid equivalent to what it costs to capture carbon dioxide with carbon capture and storage technology, it will, however, be profitable to plant trees in pastures [41]. Forest tree breeding that produces more fast-growing trees [70] will improve the profitability of such tree planting.

5. Conclusions

Until the late 1800s, forest grazing and wooded semi-natural pastures were very important for Sweden's food supply. Now almost all forest grazing is gone, and the area of semi-natural pasture decreased rapidly until the 1960s. Important reasons for the decline of these forms of silvipastoral agroforestry were the following:

1. Forest grazing in particular, but also semi-natural pastures, provided too poor fodder for ever-higher yielding dairy cows.
2. Small scattered semi-natural pastures were unsuitable for profitable pasture-based meat production.
3. The land was more needed for specialized timber production for Sweden's strongly growing export-oriented forest industry.

Further, especially in the 1950s and 1960s, many small fields were abandoned as farmers took better-paid jobs outside of farming. Much of the abandoned fields and semi-natural pastures were planted with spruce. Since the 1970s, the abandonment, and in particular the planting of spruce, has decreased mainly as a result of the following reasons:

1. Landowners do not want to afforest agricultural land that their ancestors had cultivated with great hardship.
2. The public and society want to keep open agricultural landscapes and dislike spruce planting.
3. Continued and resumed grazing in semi-natural pastures is important for biodiversity and the preservation of cultural and historical values. Environmental payments especially after Sweden's entry into the EU in 1995 facilitate grazing.

Future silvipastoral agroforestry may consist of large cohesive pasture–forest mosaics consisting of small scattered existing and abandoned wooded semi-natural pastures, abandoned and at-risk-of-being-abandoned fields and intervening forestland, which may have been grazed forest or agricultural land in the past. The main task of the forestland in the mosaics is to tie together small scattered pastures and fields in order to create large rational

pastures. Climate considerations mean that many of the trees in the restored pastures should be allowed to remain. The following reasons may mean that meat production in such large pasture–forest mosaics will become widespread in Sweden in the future:

1. It can be commercially viable if current agricultural supports and environmental payments remain.
2. Sweden's food security would be improved by increasing the currently low level of self-sufficiency in beef and lamb meat.
3. It may become necessary to meet the biodiversity and climate goals in the EU's proposed nature restoration law at a reasonable cost.
4. Swedes prefer wooded pastures to treeless pastures. This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12050940/s1, Figure S1: Example suggesting that natural afforestation of abandoned agricultural land can take a long time and produce patchy low-producing low-quality forest; Figure S2: Valuation of landscapes by eight surveys with online panels consisting of randomly selected Swedes; Figure S3: (a) Silvipastoral agroforestry with birch grove that was left behind when overgrown farmland was restored, (b) Silvipastoral agroforestry with self-seeded birch groves on land that was grazed forest until the 1950s and was finally felled in the 1990s, after which it became self-sown dense birch-dominated young forest; Table S1: Areas of agricultural land and forest grazing, number of cattle and number of herds with cattle in Sweden, 1901–2022.

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