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Review

Rendzinas of the Russian Northwest: Diversity, Genesis, and Ecosystem Functions: A Review

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Abstract: Rendzinas in the taiga zone are intrazonal soils; moreover, all of their processes occur in ways that are different from podzolic soil formation, which is typical for the zonal taiga boreal ecosystem. At the same time, the habitats of carbonate soils are known as places in which there is a concentration of biodiversity in the more southern regions, as they are drier, are insolated, and have a higher trophic state than zonal podzols. The biotopes on carbonate soils are becoming more southern and are dominated by nemoralis species of flora, including abundant calciphilous plant species. Carbonate soils regulate biogeochemical processes within their distribution and in the geochemically subordinate landscapes of Northwest Russia. They are associated with the existence of a number of specially protected natural areas, as well as the implementation of a number of important ecosystem services. Carbonate soils of the southern taiga are endangered and require special protection. The belt of the carbonate soils in the northwestern Russian and Baltic regions extends to Poland and is the basis for the formation of a special landscape–ecological framework with specific biodiverse, biogeochemical, and geographical characteristics. The intensive extraction of limestone from quarries leads to the destruction of rendzinas, which makes them increasingly rare and extremely vulnerable. The rate of recovery of rendzina soils after technogenic impacts is much slower than the regeneration of zonal podzols; therefore, they are an almost non-renewable resource. Thus, rendzinas are an important component of the Northwest Russian soil cover, where all factors of soil formation “refract” and acquire specificity, leading to radical changes not only in the soil-forming potential of the environment but in all of the components of terrestrial ecosystems. In other words, the island of alkaline rocks inherited from the ancient seas is currently pedogeochemically actualized in the soil cover of vast taiga areas.

Keywords: rendzinas; sod carbonate soils; limestones; intrazonal soils; alvares; Russian northwest; Baltic region

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1. Introduction

Shallow Hyperskeletic fertile soils with a high content of carbonate inherited from parent materials are known as rendzinas. For the first time, officially, rendzinas were mentioned by a famous follower of Dokuchaev, N.M. Sibirtsev, in his soil taxonomy system [1,2] as kind of intrazonal soil found in all natural zones confined to the carbonate soil-forming rocks of different geneses and composition [2]. N.M. Sibirtsev wrote: “Such humus carbonate soils have intrazonal character, i.e., they are caused by one dominant formation—parent material. Type of such soils is “rendzina” (rendzina) or “borowina” of Polish kingdom. They always appear where there are outcrops of chalk, limestone, dolomite, or marl (no matter the type of geological system)” [2] (p. 387). N.V. Sibirtsev noted an increase in the content of humus in these soils (from 2 to 7%), as well as in clay matter and in their suitability for wheat. It is noted in Sibirtsev’s textbook that “similar humus-carbonate soils are also known abroad, for example in Germany and Austria on lime and dolomite rocks” [2] (p. 388). When describing humus–carbonate soils in the text, N.V. Sibirtsev used the terms “rendzina” and “soils of semi-rendzina character”. Vilensky [3] clarified the genesis of the word rendzina: "In 1903 the work of Y. Mazanowski on the humus-carbonate soils of Poland, in which he wrote that the Polish word "rendzina" includes the following meaning—clay soil, viscous soil, clay soil. It appears to be derived from the word—rzendzie, rzezie—to shudder, and is related to the behavior of the plow when plowing such lime-rich crushed lime-rich soils". Duchaufour [4] conducted a deep and detailed investigation of rendzinas under forests and other types of vegetation cover, with a special emphasis on soil evolution [4]. Reintam [5] generalized information about the development and evolution of rendzinas, mainly in Estonia; at the same time, and for many years, he collaborated with the Department of Soil Science of Leningrad University in his investigation of rendzinas. Thus, Gagarina [6–8] has published many papers on rendzinas of the Leningrad region, which are quite similar to the Estonian types; meanwhile, the most recent of these are similar in their genesis to Polish carbonate soils. Rendzinas have also been investigated in various conditions and types of climates in Eurasia [9,10], Africa [11], and other continents. They may be found both on plains and mountains, as well as in flat and sloped positions [12]. The rendzinas of all climatic belts were characterized by their increased gravimetric concentrations of organic matter in superficial soil horizons. Thus, Pestryakov [13] declared these soils to be the most productive for the Leningrad region, and the botanist Nitsenko [14] remarked that the vegetation cover of rendzinas is characterized by southern features in comparison with the zonal south taiga of the Leningrad region. The presence of rendzinas in the soil cover of the central part of the Leningrad region was due to the fact that the carbonate soils were the first to be involved in agricultural development [12]; this was also the reason that the first large settlements appeared on the Izhora Uplands, also known as the Ordovician Plateau, since the lands were owned by Sweden. Thus, although native and uncommon in the southern taiga, these soils play a significant role in the biodiversity of taiga forests, as well as in the history of the agricultural development of the region and the formation of the geochemical features of the macro-landscape. Moreover, they are very informative in terms of understanding the theory of soil formation and soil evolution. Northwest Russia is the youngest area in the post-glacial Holocene history of the East European Plain. This territory is a very interesting model of primary soil formation and weathering. In view of the above, the aim of this review was to analyze the main patterns of rendzinas' formation and evolution in northwestern Russia. The objectives were formulated as follows: (1) to analyze the soil genesis and taxonomy based on various parent materials; (2) to understand the soils' role in the transformation of landscapes and ecosystems; (3) to investigate anthropogenic rendzinas formation and (4) to highlight the peculiarities of rendzinas formation in the southern taiga in comparison to similar soils of other natural zones in Eurasia.

2. Materials and Methods

We analyzed numerous literary sources on the genesis of soils from carbonate rocks in Northwest Russia. In this study, the northwest was understood not in terms of the Federal region, but in a geomorphological sense, as designated by D.B. Malakhovsky [15], i.e., the Leningrad, Novgorod, and Pskov regions. In addition, this region borders on the Baltic States where limestone rocks of similar geneses are also widely distributed. We also analyzed data from our own long-term studies of soil formation on calcareous rocks in the region: morphology, chemistry, soil processes, the spatial distribution of soils, and the specificity of their ecological functions.

3. Results and Discussion

3.1. Geography, Morphology, and Taxonomy

The total area of rendzina soils (in the broad meaning of this term) in Russia is estimated to be 3%, or about 500,000 km^2 [16]. The carbonate-containing soils of Northwest Russia are presented in two categories. The first is thin soils with a thin soil profile that is formed upon hyperskeletic parent materials, which, in some cases, are covered by local carbonate moraines [17]. These soils are mostly concentrated on the Izhora Upland.

Some areas of rendzina soils are described for the Pskov and Novgorod regions [7,18,19]. Rendzinas and highly fertile luvic rendzinas are present in the territory of the Dnovsky and Pechorsky districts of the Pskov region [19], where they are located on expositions of Hyperskeletic limestones. Another type of soil cover, deep-leached umbric Albeluvisols (retisols), originate from rendzina soils during a long-term history of weathering of local carbonate moraines located in the Pskov and Novgorod regions and are represented on the following map (Figure 1) by a green color. These soils are not really rendzinas; however, they are their closest relatives and are also characterized by high fertility.

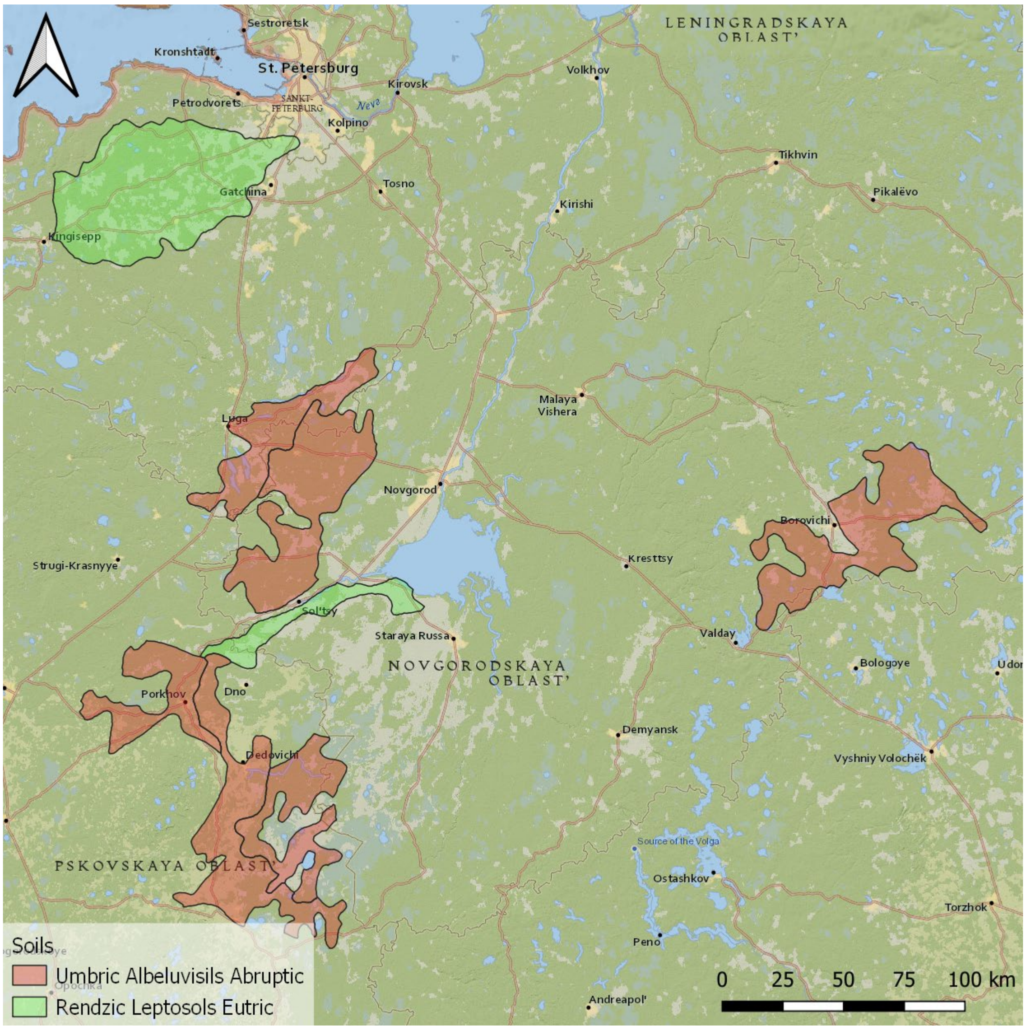


Figure 1. Schematic carbonate soils distribution in the Russian Northwest (according to [17]).

Rendzina soils were named and classified in various soil taxonomy systems. In the USSR's soil taxonomy system [20] was type of sod–carbonate soil ("dernovo–carbonatnye" in Russian) with three subtypes—typical, leached and podzolized. These subtypes are close to each other in terms of their geneses and evolution in time and space. The new Russian soil taxonomy [21,22] divided this type on the basis of various trenches of soils—primary soils (lithozems) and postlithogenic soils (organo-accumulative clay-illuviated carbonate soils). Thus, a previously single type of soil formation became divided by the new Russian classification [16]. Also, agrocarbonate soils were separated on the basis of type. The key classification parameter is the presence of primary carbonates inherited from parent materials. The presence of a skeletal fraction is typical for normal rendzinas, while pararendzinas are known as soils formed on friable unconsolidated materials (marl, tuff). The profile of typical rendzina soils consists of A-ACα-Cα (AU-ACca-Cca) horizons, where index "α" ("ca") in lowercase letters indicates lithogenic (primary) carbonates inherited from parent material and A (AU) is a humus layer with neutral or alkaline pH values. The profile of illuviated rendzina includes the following horizons: A-Abt-Cα(AU-ABt-Cca), where a middle soil horizon of leaching and illuviation appears; the total thickness of such a profile is essentially higher than the solum of normal rendzina. In some cases, we can also find profiles with such in situ soil weathering; thus, these soils could be named as cambic rendzina, with a profile of A-Bw-Cα (AU-ABm-Cca), where browning (cambification) is designated by "m". The existence of a brown version of rendzinas was mentioned by Ponomareva and Myasnikova [23], resulting from various types of soil weathering; thus, this suggestion also may be taken into account for the elaboration of more detailed soil naming in subtype frames. The type of parent material, namely the amount of non-carbonate components (residue that is insoluble in hydrochloric acid) affects the color of weathering products and could determine the soil type—illuviated or cambic [6]. As for the WRB taxonomy [24], rendzinas are known as rendzic leptosols. According to the field handbook for Russian soil taxonomy [21,22], it is possible to define a special type of red-profile genera of rendzinas with the designation "ro" for the case where the soil's red color is inherited from red-colored parent materials. Goryachkin et al. [25] proposed specific types of sulfate rendzinas formed on gypsum. Another of the closest relatives of rendzinas is produced from the deep weathering of limestones in a Mediterranean climate [9], the so-called "terra rossa" and "terra fusca" soils. This formation could be added to the field description of the cinnamic soils of Crimea and Dagestan. Thus, despite being an intrazonal type, these soils may be typical for all natural bioclimatic zones.

3.2. The Role of Parent Materials in Soil Genesis

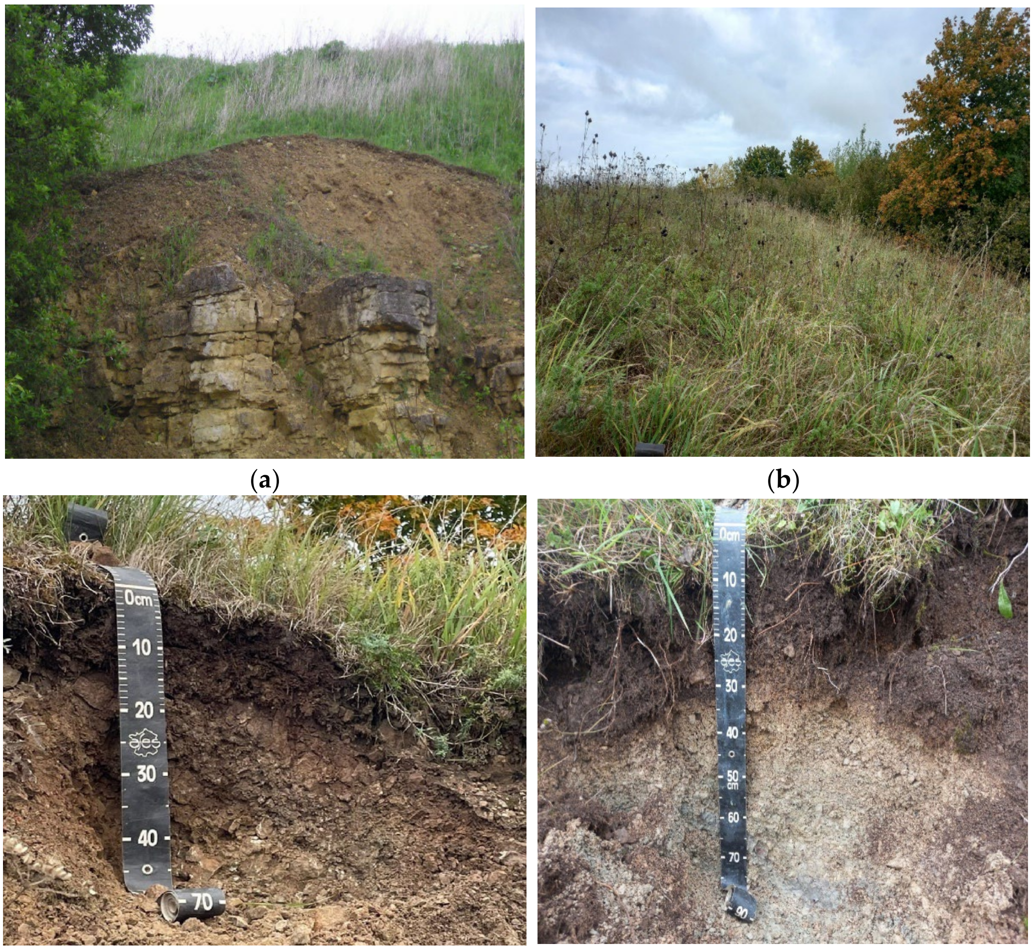
As a result of the stage-by-stage glacial retreat in the territory of the northwest, different parts have different absolute surface ages; hence, the duration of soil-forming processes on each is different [7]. The formation of soil parent material can be conventionally considered as the initial state of the soil system and the zero moments of soil formation. Meanwhile, in the periglacial zone, the consolidation of soil-forming features was often limited to the deposition of new material or other processes [15]. Soils formed on moraine deposits are most common in the northwest. On carbonate moraines, the soil-forming process deviated from the zonal one. The gradual leaching of carbonates was accompanied by weathering, browning of the upper horizons, and loessivage. Two types of soil chronologies formed on carbonate moraines were found within the northwest. The first chronology is very traditional—sod–carbonate typical→sod–carbonate leached→sod–carbonate podzolized soil. These soils are typical for low carbonate-containing moraines of poor mineralogical composition. In some cases, especially in the marginal parts of the cliff (Baltic–Ladoga escarpment), a different variant of soil chronoseries developed on high-carbonate and polymictic moraines: sod–carbonate-typic rednzina→cambic–rendzina→cambisol, which indicates the essential role of soil-forming rocks in determining the trend of soil evolution. In this sense, the soil formation on carbonate moraines is most divergent. The highest diversity of rendzinas morphology is typical for the proximal part of the Izhora Upland. The reason for high pedodiversity is due to the increased diversity of parent materials in zones of glacial dislocations [15]. The pressure of marginal parts of glaciers resulted in the mixing of various sediments with limestone-containing parent materials and moraines. Limestone rock expositions are typical for mountainous landforms, in connection with rendzinas forming at their outcrops; in particular, in the Subpolar Urals [26] and Samarskaya Luka [27], they can also be observed on the banks of rivers that cut into limestones (for example, the Msta River in the Novgorod region) [28].

3.3. The Development of Soil Profile in Time

There is a question as to whether rendzinas are an independent though intrazonal soil type, or if they represent an initial stage of soil evolution, developing further into zonal soils. The first case is true for rendzinas formed on dense rocks, for example, on dense limestones of the Izhora Upland (Leningrad region) or on the upper slopes of the

Zhigulevsky mountains (Samara region). The second case is more suitable for pararendzinas, which contain fewer stones and more loose material. Here, the decarbonatization and then leaching of cations proceeds relatively quickly; calcareous material is dissolved intensively and insoluble residue remains, which is the mineral base for the subsequent soil type. This is well described in the studies of Gararina [6–8], Ergina [28], Reintam [29], Sukhanov [11], and Valkov [9]. Russia's soil taxonomy [21] has various subtypes of humus horizons designated as such for their dependence on the soil organic matter content and pH range. These subtypes are the following: dark humus AU horizon with a neutral or alkaline pH and a humus content of more than 4–5%; gray humus AY horizon with a low humus content and an acidic pH range and light humus AJ horizon with a low humus content and alkaline pH values [16]. All of these types can be revealed in different natural zones; however, for the south taiga, only AU and AY are possible in its soil profiles. The following horizon sequences and soil profile formulas, in terms of the WRB and Russian soil taxonomy, are the most common after generalizing the published data of Reintam [29], Gagarina [6–8], and Pestryakov [13] for the south taiga regions, on the basis of an example from the Baltic region. The formula of the soil profile before brackets is according to the WRB system; the horizon sequence in brackets is given according to Russian soil taxonomy: Aα—ACα-Cα-Rα (AUca-ACca-Cca-R)—typical rendzina formed on Rα (Rca)—dense limestone, covered by the products of its weathering—Cα (Cca), where Acα (ACca) is a transitional horizon of low humus accumulation and intensive decarbonatization of skeletal parts; thus stony lime materials become fine earth. The whole thickness of these soils is about 20–30 cm. The Aα (AUca) horizon fizzes from hydrochloric acids from the superficial part of the soil. This is a typical rendzina in the sense suggested by Sibirtsev [2]. The next stage of this soil evolution is A-ACα-Cα (AU-ACca-Cca-R), where A (AU) is leached from carbonates; this is why it is not Aα (AUca), but A. This is still a typical rendzina, while the next stage is presented by AE-AC-Cα-Rα (AUe-AC-Cca-Rca)—leached rendzina that features the eluviation of fine particles from the top horizon to the middle part of the soil profile. In this case, the whole thickness of the solum increases and reaches 40–50 cm; thus, the soil cannot be named as a primary soil [21] or leptosol [24]; this is the next step to zonal soils. And, from this stage, soil formation diverges towards the zonal soils of the respective natural zones, which was proven earlier by Valkov [9] and Sukhanov [11]. In case of the south taiga, two zonal ways of further pedodevelopment are possible: (1) podzolization AE-Bt-C-Cα -Rα (AYe-AB-C-Cca-Rca)—gray humus-leached rendzina and A-E-Bt-C-Cα -Rα (AY-EL-BI-C-Cca-Rca)—podzolized ("retisolized") rendzina and (2) in situ soil weathering with further cambification—A-Cw-C-Cα-Rα (AU-ACw-C-Cca-R) and A-Bw-Cw-Cα-Rα (AU-ABm-Cm-Cca-Rca)—causing cambisols that are also typical for the very eastern part of the Izhora Upland in Leningrad region, and for the limestone uplands of Estonia [30]. These rendzinas are similar with the rendzic leptosols brunic, described for western Ukraine [31]. A similar transformation of rendzinas into zonal types has been described for forest-steppes [26], steppes [9,28], and subtropic [11] environments, and indicates that intrazonal redzinas are exclusively caused by carbonate parent materials, which modify the so-called soil-forming potential of the environment as a set of soil-forming factors. Thus, at a certain stage in redzinas evolution when they have not yet developed into zonal soils, there is latitudinal zonality of the redzinas as an independent soil type. The most interesting question of rendzina development concerns the speed of their development regulated by the initial content of calcium carbonate in dense parent material and the precipitation/evaporation rate. The classical time scaling of soil development of Alexandrovskiy [32] should be amended from the data on rendzinas for the evaluation of stages of this type of soil onthogenesis.

The morphological organization of natural rendzinas of the Northwest Russian Federation is presented in Figure 2. Figure 2a shows two soil-forming rocks simultaneously—limestone and the local carbonate moraine overlaying it. In this case (Leningrad region), the thickness of the local carbonate moraine is tens of centimeters to the first and second meters; the moraine is very strongly enriched in carbonates and is characterized by the weak leaching of carbonates. Figure 2b shows typical plant communities—alvares, which Nitsenko [14] characterized as steppe meadows, i.e., a peculiar intrazonal vegetation type. To the south, in the Pskov and Novgorod regions, carbonate moraines are more leached and thicker, which contributes to the formation of more differentiated soil profiles (Figure 2e). Thus, the degree of development of the soil profile and its vertical differentiation is closely related to the degree of decarbonatization and leaching of the initial parent materials. The area differentiation of soil types shown in Figure 1 is also related to this. The more northern soils of the northwestern region contain more carbonate, except for those confined to the Shelon and Msta rivers in places of erosion in their watersheds of hard calcareous rocks. Loamy sediments of older, southern marginal moraines of the early Valdai age contribute to residual carbonate umbric albeluvisols (retisols) rather than rendzinas formation.



(**a**) (**b**)

(**c**) (**d**)

Figure 2. *Cont.*

(**e**) (**f**)

Figure 2. (**a**) Ordovician limestones overlapped by local carbonate moraine, central part of Izhora Upland (Ordivician Plateau); (**b**) alvares (dry herbaceous vegetation communities) of Izhora Upland; (**c**) rendzic leptosols on hyperskeletic debris of limestones, Izhora Upland, (**d**) rendzic leptosols, Izhora Upland; (**e**) leached rendzina on deep weathered carbonate debris, Izhora Upland; (**f**) umbric albeluvisol on deep leached and weathered carbonate moraine, Borovitchy, Novgorod region.

3.4. Soil Organic Matter in Presence of Carbonates

Generally, superficial soil horizons of rendzinas are more enriched with total organic carbon than zonal podzolic or retic soils. It is well known that the presence of carbonate in fine earth stimulates soil organic matter stabilization and accumulation in topsoils [5,31–33]. The leaching of carbonates in rendzinas with illuviation features normally results in decreasing humus content in topsoils, and the reaccumulation of organic matter in deeper horizons. There is a kind of dilution of humus in increasing amounts of fine-grained deposits; the latter occurs due to the destruction of carbonate rubble and a general increase in the fine-grained layer of soils, including through deepening the profile [34]. It is well known that the system of soil organic matter in rendzinas is completely different from that of zonal podzolics. The reason is that the presence of calcium results in the formation of so-called "dark" fractions of humic acids, strongly bound with calcium cations, with increased humin fraction content than in acidic soils [23]. Also, the Cha/Cfa ratio is higher in carbonate soils than in podzolized ones. Thus, the chemical composition of parent materials plays the most important role in the formation of such intrazonal soils as rendzinas. Thus, the key feature of rendzinas humus is the essential portion of humic acids bound with calcium [35,36]; it is the so-called "second" fraction of the humus. In post-Soviet times in northwest Russia, there was a conversion of large areas to a fallow state, which led to intensive leaching of cations and carbonates not only from acidic but also from weakly alkaline carbonate soils [37]. All of this can lead to the regrouping of humic acid fractions; in particular, the second fraction of humic acids bound to calcium can enrich the first fraction bound to iron hydroxides and exist in a partially water-soluble form. The opposite has also been proven—liming of agricultural soils leads to a significant increase in the content of humic acids [38]. Thus, carbonates are not only a passive factor in the formation of intrazonal soils on the basis of the presence of calcareous parent materials, but carbonates can also be an active driver that regulates the lability of organic matter. The same was revealed for rendzinas in Serbia [39]. Recently, it was suggested to define a specific morphological–chemical form of humus—"calci-mull"—typical for soils enriched with calcium carbonates [40].

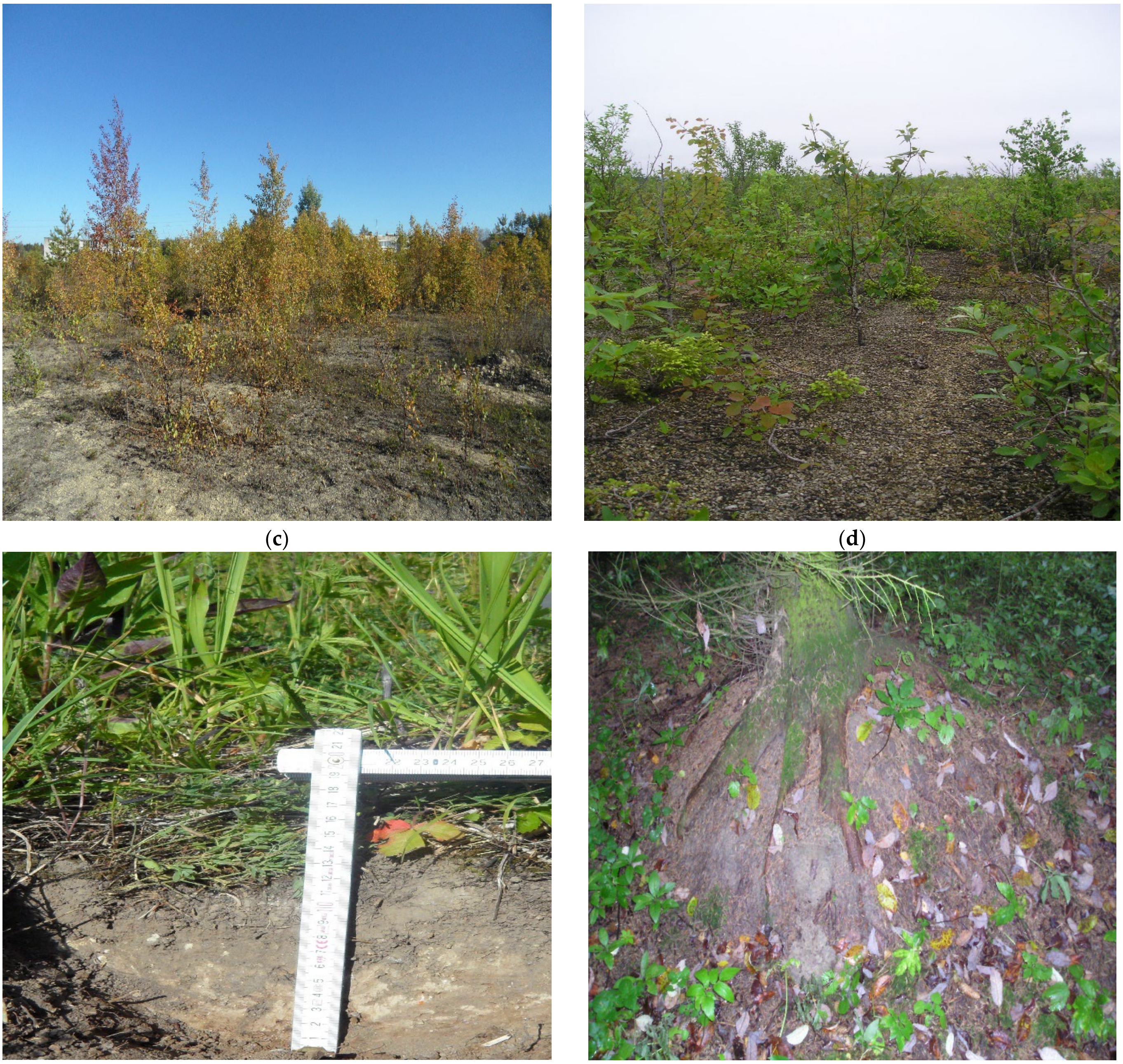
3.5. Agricultural and Thechnogenic Soil Transformation

The agrogenic transformation of rendzinas increases their bulk density, changes their porosity, and decreases their water-holding capacity [41]. How the resistance of sod–carbonate soils changes due to water erosion, which theoretically should be activated during the plowing of watersheds, where, as a rule, rendzinas are spread, is poorly studied. It is well known that the water-holding capacity of soils strongly depends on their stoniness [42]; therefore, taking into account the hyperskeletic features of many rendzinas, in the arable fields they occupy we should expect an increased depreciation of agricultural implements. Cultivated rendzinas represent one of the oldest cultivated soil types in Northwest Russia, although fewer publications have been devoted to them than to agropodzols or agropeatland soils. Limestone is a popular non-metallic mineral that is most often quarried in open pit mines. This is especially common in the Izhora Upland (Leningrad region) and Valday Upland (Novgorod region), where extensive areas of carbonate soils are consequently destroyed. Such operations lead to external dumping and dusting, as well as chemical contamination and alkalinization of adjacent ecosystems [43]. The dumps of lime-crushing siftings are a prospective ameliorator for acidic soils of the Russian northwest as a local and cheap fertilizer [44]. Cracked and carsted limestone in the center of the Leningrad region leads to an increased biogeochemical load on the rivers, and even on the Gulf of Finland, which is especially important and dangerous in connection with the problem of poultry manure disposal from developing poultry farms in the region [45]. Examples of soil restoration on mine surfaces are provided in Figure 3. Limestone mining is aimed at obtaining crushed stone for construction purposes; its siftings accumulate in large dumps and are subject to water and wind erosion (Figure 3b). These surfaces slowly overgrow during self-recultivation (Figure 3c) and are poorly amenable to reclamation in the case of planting poplar (Figure 3d). At the bottoms of the quarries where the geomorphological conditions are more stable, initial carbonate soil formation (Figure 3e) occurs. The presence of large coarse fragments of limestone in the reclaimed soils may have various effects on the soil, for example, disturbances to the integrity of the soil cover of the reclaimed lands due to the freezing of large stones, which leads to disturbances to the integrity of the root systems of woody plants (Figure 3f).

(a)

(b)

Figure 3. *Cont.*



(**c**) (**d**)

(**e**) (**f**)

Figure 3. Limestone mining and newly formed soils of open crust mining of Izhora Upland. (**a**) Abandoned mines, central part of Izhora Upland; (**b**) erosion of heaps, composed by remnants of limestone crushing sifting of the quarry; (**c**) self-revegetation of the quarry surface by birch; (**d**) biological reclamation of limestone heaps of the quarry by poplar plantations; (**e**) primary rendzic leptosol from reclaimed bottom of limestone quarry; (**f**) freezing of large fragments of limestone from the reclaimed soil of the quarry, and disturbance to the root system of planted Norway spruce.

3.6. Soil Transforms Local Biodiversity

The presence of carbonate soils leads to nemoralization (shift in plant species list from boreal to sub-boreal type) of taiga flora. This was noted by Nitsenko [14] for the central part of the Leningrad region. This is expressed through an increase in the proportion of broad-leaved trees and sub-boreal grass species. In the Izhorskaya Upland, there are widespread ecosystems of the alvares type [46,47], which are dry semi-xerophytic herbaceous communities with sparse juniper (*Juniperus communis*) forests. Thus, the presence of carbonates leads to changes in biodiversity, in particular to the appearance of calciphilous species such as *Cyprepedium calceoulus* and *Equisetum variegatum*. Some authors [48] compared alvares vegetation cover with steppe flora. Stable communities of ash (*Fráxinus excelsior*) are located in proximal parts of the Izhorskya Upland; they are located in carbonate cambisols enriched by alkaline cations [46] transported from upland to accumulative landscapes where the geochemical discharge takes place. Thus, carbonate soils affect not only their location but also adjacent landscapes, via geochemical regulation of the soil cover and biodiversity.

3.7. Soil Regulates Ecosystem Functions and Services

Ecosystem services are known as the benefits that humans receive from using or not using ecosystems [49]. Since carbonate soil sites are characterized by non-zonal ecosystems, with more southern species, such plant communities perform essential recreational ecosystem services. Thus, such regional natural monuments as Dudergof Heights and Pudost quarry are located on carbonate soils [50]. Another regional reserve, the Petrovshchinskaya larch grove, is located on the Putilovsky carbonate plateau in the Leningrad region. These sites attract numerous tourists. In addition, calciphilous plant species settle here (*Cyprepedium calceolus*, *Epipactis atrorubens*), which also attract nature lovers. Carbonate soils are also important in providing food ecosystem services, as it is believed that the best potatoes grow on the rubbly carbonate soils of the center of the Leningrad region. Carbonate soils of the northwest uplands regulate the chemical composition of water; for example, water flowing down from the Izhora Upland is carbonate and more neutral than the acidic water of podzolic and boggy soils [51]. The quality of drinking water is reduced due to the presence of carbonates [52]. On the other hand, in carbonate soils, heavy metals become less labile and hazardous, which is a self-remediating factor of carbonate soils. Thus, soils with an increased carbonate content transform both the biotope and the entire ecosystem, as well as the specificity of the human relationship with the environment; this should be evaluated and monetized in the future. A large number of carbonate soils are included in the Red Book of Soils of the Leningrad region [46], which indicates their important role in the formation of biodiverse, natural frameworks in the territories.

3.8. Soil Chemical Properties

The key soil properties of typical representatives are shown in Table 1. The total organic carbon content (TOC) was higher in topsoils in comparison with zonal soils; this is a well-known phenomenon [23] because the presence of carbonates in the fine earth results in carbon compound stabilization in micro- and mezoaggregates, and it is due to the binding of humic materials with calcium cations. Umbric retisols contain a lower TOC than rendzinas; the reason for this is the dilution of humus in increasing proportions of fine earth formed from weathering processes [34]. As for rendzinas formed at the bottom of abandoned quarries, the humus accumulation rate is low in comparison with that in developed rendzinas. Thus, according to the suggestions of Konyshkov [15], we designated this horizon as AJ instead of AU, according to the Russian Soil Taxonomy [21]. As for the pH values and the calcium carbonate content, there is a tendency for the pH to decrease in retisols in comparison with rendzinas soils, due to the weathering of carbonates and leaching of alkaline cations. This is also accompanied by increasing skeletal fractions within the depth of the soil. The content of the skeletal fraction is lower in retisols while they form on parent materials with initially fewer stones (local carbonate moraines in the case of the Leningrad region and proximal carbonate moraines in the Novgorod region). As for the fractions of fine earth and clay particles, these values are higher in superficial soil layers due to weathering and lowest in the initial soil of the limestone quarry bottom, where the alteration of stones is at a very initial stage.

Table 1. Key soil chemical properties (personal data).

Horizon	Depth, cm	TOC, % to Fine Earth	pH	$CaCO_3$, %	Skeletal Fraction, %	Clay Fraction, %	Cha/Cfa
Rendzic Leptosol, Izhora Upland, Leningrad region							
A (AU)	0–10	8.09	7.20	27.09	55	19.1	1.50
Acα (ACca)	10–15	3.42	7.55	44.55	67	17.8	1.10
Cα (Cca)	15–22	0.20	7.90	58.70	80	12.1	0.90
Rendzic Technosol, bottom of quarry, Izhora Upland, Leningrad region							
A (AJ)	0–5	2.10	7.80	55.70	87	9.0	0.80
Acα (ACca)	5–12	0.53	8.10	69.80	93	6.0	0.70
Umbric Retisol, Izhora Upland, Leningrad region							
A (AU)	0–12	6.20	5.80	0.00	10	28	0.95
AE(AEL)	12–25	1.30	5.45	0.00	12	17	0.75
BCα (BCca)	25–35	0.50	5.70	2.30	15	23	0.79
Cα (Cca)	35–45	0.15	7.20	7.80	25	12	0.80
Umric Retisol, Novgorod region							
A (AY)	0–15	3.45	5.20	0.00	15	34	0.85
AE (AEL)	15–29	0.98	4.60	0.00	17	28	0.70
Bt (Bi)	29–45	0.25	5.80	1.20	19	33	0.60
CαCca	45–60	0.12	6.90	2.40	23	19	0.45

The degree of organic matter humification, expressed in terms of the Cha/Cfa (carbon of humic to fulvic acids) ratio (Table 1), is highest in rendzic soils (with the exception of rendzic technosol, where soil organic matter is humified little due to the young age of the soil). In the case of retisols formed in more leached and weathered substrata, the degree of humification is lower, and the percentages of fulvic acids are higher than those in rendzinas, enriched by calcium. Thus, it is evident that the carbonate content regulates the degree of soil organic matter stabilization.

4. Conclusions

The literature and personal data on rendzinas in the taiga zone was generalized for the territory of the Russian Northwest (Leningrad, Novgorod, and Pskov regions), located in the south taiga subzone of the boreal belt. Rendzinas are intrazonal soils—all of their processes occur in ways that are different from podzolic eluvial–illuvial soil formation that is typical for zonal taiga boreal ecosystems of coniferous forests. The locations with a predominance of carbonate soils are known as places of concentrated biodiversity in the more southern regions, as they are drier, are insolated, and have higher trophic states than zonal podzols. The geochemistry of rendzinas and their buffering capacity are completely different from those of podzol ecosystems. The biotopes on carbonate soils become more southern, dominated by nemoralis species (trees, shrubs, and herbaceous forms) of flora, including abundant calciphilous plant species, many of which are listed in regional and federal Red Data Books. Carbonate rendzic soils regulate biogeochemical processes within their distribution and in geochemically subordinate landscapes of the northwest (Neva lowland, ancient marine terraces of the southern part of the Gulf of Finland) and proximal parts of Valday (Vurm) glaciations in the Pskov and Novgorod regions. Rendzinas are associated with the existence of a number of specially protected natural areas, as well as the implementation of a number of important ecosystem services (provisional, aesthetic, etc.). The carbonate soils of the southern taiga are endangered and require special protection. The belt of carbonate soils in the Russian northwest and Baltic regions extending to Poland is the basis for the formation of a special landscape–ecological framework with a specific biodiversity, biogeochemistry, and soil geography. The intensive extraction of limestone from quarries leads to the destruction of rendzinas, which makes them increasingly rare and extremely vulnerable. The speed of self-regeneration in rendzinas soils after anthropogenic disturbances is much slower than the regeneration of zonal podzols. This is due to their different rates of weathering and mineral phase alteration; thus, they are an almost non-renewable resource. Thus, rendzinas are an important component of the soil cover in the Russian northwest, where all of the factors of soil formation "refract" and acquire specificity, leading to radical changes not only to the soil-forming potential of the environment but to all components of the terrestrial ecosystems. In other words, the island of alkaline rocks inherited from the ancient seas is currently being pedogeochemically actualized in the vast taiga areas.

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