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Application of Ecology-Geomorphology Cognition Approach in Land Type Classification: A Case Study in the Altay Region

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Abstract: Land types play an important guiding role in human survival and production. Clarifying the division of land types is the basis for ensuring the sustainable and coordinated development of social-economic-natural complex ecosystems. To date, the land type classification system has not formed a unified standard, and the existing classification fails to highlight the natural background elements of land. Therefore, it is important to construct a classification system that can reflect natural background elements. Additionally, land type classification is often based on land resource surveys. Updating the land type is generally difficult and slow, mainly due to a lack of appropriate information. Hence, it is necessary to develop an automatic land type renewal method using multisource information. This study proposes the ecology-geomorphology cognition (Eco-geoC) approach for land type classification. The approach is realized by the segmentation of land units using remote sensing images, geographic information, vegetation, soil, DEM, and geoscience knowledge. This approach is an extension of the object-based image analysis method. The spatial objects segmented from different attribute data are integrated, and finally, a comprehensive land mapping unit representing a certain degree of geographical homogeneity and land use potential is generated. The results show that the Eco-geoC approach is an integrated approach with objectification cognition on remote sensing images and multisource information using geo-knowledge. The Eco-geoC approach is tested in the Altay region. From coarse to fine scales, the study area is divided into two kinds of natural belts, 27 land systems and 78 land units, and a 1:500,000 land-type map, which shows a good coupling relationship between the physiognomy, vegetation, and soil in the Altay region, is compiled. The results of this study show that the use of the Eco-geoC approach for land type classification is significant and has potential for land assessment and planning. This approach can provide a scientific basis for the restoration of the regional ecology and the comprehensive management and adjustment of land resources and the environment.

Keywords: ecology-geomorphology cognition approach; land type classification; land unit; three-level classification

1. Introduction

Land is the foundation of human existence. In recent years, the contradiction between the increasing material needs of humankind and the limited resources of the environment has become increasingly prominent, leading to human conflicts and posing serious threats...
to the living environment and the quality of life of humans [1]. Therefore, land must be understood based on its natural attributes to shift from the disorderly utilization of resources to a harmonious relationship between humans and land [2–6]. Land is formed by the interaction of the endogenic and exogenic forces of the Earth. It has natural characteristics, such as a structural origin, surface configuration, and material composition. Research on the distribution pattern and interaction process of natural elements such as the physiognomy, vegetation, and soil of a region is an important prerequisite for land type classification [7,8]. The land type is one of the most basic methods used to understand the land structure and distribution law of natural resources [9–11]. The law of the spatial distribution pattern of different land type patches reveals the relationship between various natural elements and provides a deep understanding of land resources.

Land types can reflect the differentiation law of medium- and small-scale sections and the overall comprehensive characteristics of the environment. The main research feature is to divide the types according to the law of lot differentiation. The divided unit type (i.e., land unit) is the land type mapping unit, which is usually the smallest unit in land type classification. The land characteristics within a land unit are the same or similar. It should be noted that land type classification and land use/cover classification are two completely different concepts. The former is landscape research focusing on geomorphic ecological characteristics, while the latter is land system research focusing on human use. Combined with remote sensing interpretation maps and field investigation data, GIS software can be used to integrate different layers, covering the main environmental components (climate, lithology, geomorphology, soil, vegetation, geology and other information), resulting in a number of hierarchically arranged land units, homogeneous in terms of biotic potential and ecological processes [5,12,13]. In the 1980s, China introduced a national standard land type classification system that integrates climate, physiognomy, soil, and vegetation information and provides a framework for land feature surveys [14]. However, due to the different research directions, the classification results of this classification system cannot be applied to medium- and small-scale land use planning. In addition, this classification system considers only natural geographical factors and ignores the impact of human activities. Humans, as an important part of the ecosystem, have an increasingly complex impact on the natural environment, and it is difficult to fully reflect the complex relationship between humans and land from a single perspective [15,16]. The environmental structure of land is controlled by the more stable physical features (e.g., climatic conditions, geological substrates, and landforms), which determine the distribution of species, habitats, and potential natural vegetation types and affect the use of the territory [17,18]. However, the geology in the natural characteristics mainly reflects the material composition, structure, and development history of the Earth. This study aims to provide monitoring, management, and sustainable development for medium- and small-scale land resources. Therefore, the land is classified without considering the geological characteristics; only the vegetation, physiognomy, soil, and land use type indicators can be directly observed. To sum up, combined with the actual situation of the study area, we use the land type classification system based on ecology-geomorphology cognition proposed in this study to divide the land types of the study area based on natural geographical elements (climate, geomorphic types, soil types, and vegetation types) and human factors (land use types).

As an emerging interdisciplinary concept, ecological geomorphology is closely related to the natural environment and human factors affecting land type classification. Geomorphology and ecosystem ecology are closely related to human beings. Geomorphology plays a fundamental role in controlling many ecosystems, and ecosystems can have a far-reaching impact on many geomorphic forms and geomorphic processes [19]. Ecological geomorphology includes the most natural background elements involved in land type classification, such as landforms, vegetation, and hydrothermal and human factors, and studies the relationship between any level of a geomorphic system and the human ecosystem, that is, the relationship between human existence and the environment [20]. In other words, ecological geomorphology is a science that studies the relationship between ecology
and geomorphology by taking the natural and human entities in an area as the research object [21]. Therefore, to carry out land type classification research from the perspective of ecological geomorphology, the most natural background elements of the land, land use types, and other factors are used to comprehensively explore the status of regional land types, which is the basis and premise of reasonably adjusting measures to local conditions, planning and utilizing land resources, maintaining ecological balance, and enhancing ecosystem management and restoration. Additionally, this approach promotes the orderly and sustainable development of land type research and ecological geomorphology and can be used to expand the research scale of land types and promote the development of disciplinary systems.

Most land type classification studies are based on land resource investigations [22,23]. In recent years, with the development of GIS and RS technology, remote sensing images have been widely used as the main data source for land resource monitoring and evaluation. Comprehensive remote sensing images and other multisource data have been increasingly studied based on land use/land cover types and land functions, and a classification system reflecting various attributes of land has been formed [24,25]. In China, the idea of geographic image analysis was proposed in the book Remote Sensing Geosience Analysis as early as 1990 [26]. On the basis of Chen’s idea, Luo proposed the concept of a remote sensing intelligent geo-interpretation model related to geographic image analysis [27]. In reference to studies of spatial cognition behavior and cognition, the modes of spatial cognition on images and multisource information related to ecology and geomorphology, including three levels (ecology-geomorphology spatial feature perception, ecology-geomorphology spatial object cognition, and ecology-geomorphology spatial pattern cognition), were studied by researchers [28]. With the development of Earth observation (EO) technologies, the object-based image analysis (OBIA) method emerged [29,30]. Recently, several studies used the OBIA method to conduct geographic image analysis [31,32]. Geographic image analysis methodologies were used to extract thematic information, with a focus on land use and land cover and vegetation information. Studies using the object-oriented analysis method have focused on land cover/land use classification and forest classification [28,33–38]. These studies can reflect the surface vegetation cover and land carrying capacity well. However, the geomorphic type, soil type, vegetation type, and other natural factors, as well as artificial factors such as the land use type and utilization intensity, have not been comprehensively considered.

Therefore, to strengthen the role of remote sensing, geographic, and other multisource information and the use of geoscience knowledge for the extraction of land thematic information, the Eco-geoC classification approach was proposed based on the idea of ecological geomorphology and the object-oriented analysis approach. In simple terms, Eco-geoC is the objectification cognition of remote sensing images and multisource information using geo-knowledge. This approach purposefully integrates a variety of natural and cultural elements to study land types. In addition, it integrates remote sensing, land, and geographic information and knowledge on the basis of the OBIA method to synthesize and extend more information sources and geographic information. In detail, Eco-geoC can be used to develop automated methods to partition remote sensing imagery, digital elevation models (DEMs), soil, and multisource information into meaningful spatial objects. Using the concept “top-bottom, coarse-fine”, multiple spatial objects are superimposed and combined into meaningful image objects, namely, land units, and thematic information maps are generated to analyze their spatial distribution laws and combination characteristics. Finally, the Altay region, a typical area consisting of mountains, plains, and other geomorphic types and various ecological elements is chosen to test the developed method for land type classification.

2. Materials and Methods

2.1. Study Area

The Altay region is located in the hinterland of Eurasia and north of Xinjiang, China, with a geographic scope of 85°31′~91°01′ E, 45°00′~49°10′ N (Figure 1). The region borders Mongolia, Kazakhstan, and Russia and stretches 402 km from east to west and 464 km
from north to south, with a total area of $1.18 \times 10^5$ km$^2$, accounting for 7.1% of the total area of Xinjiang. The region includes six counties and one city, all of which are border counties (cities), and it is a multi-ethnic area composed of 39 nationalities. By the end of 2020, the total population of the region was 668,587. The region has a high latitude, great vertical climate differences, and a significant local microclimate. It belongs to the temperate continental climate. The land cover in this area is diverse. Glacier, forest, grassland, wetland, desert, farmland, and other ecosystem types form a complete “mountain-river-forest-field-lake-grass life community” [39]. The study area includes the Altai Mountains in the north, the Shawu Mountains in the west, and the Junggar Basin in the south. The terrain is high in the west and low in the east, showing an obvious ladder shape. It is one of the focus areas of cross-border water security issues of international concern, with three major surface runoff sources: the Irtysh River, the Wulungu River, and small rivers in Jimunai County. There are various types of soil, such as gray forest soil, meadow soil, brown desert soil, and so on. However, under the influence of human factors such as long-term development of mineral resources, grassland overgrazing, and oasis agricultural overdevelopment, coupled with the superposition of natural factors such as fragile ecosystems, climate change, and the decline in groundwater levels in arid areas, the ecosystem health and ecological security in the study area are facing great challenges.

Figure 1. Location and topography of the study area.

2.2. Data Sources and Preprocessing

DEM data: the physiognomy represents the surface fluctuation state and can redistribute surface hydrothermal conditions. Therefore, physiognomy has an important impact on the differentiation of land types [40]. In this study, SRTM-DEM data with a resolution of 30 m were selected. With reference to the achievement data of 1:1 million geomorphic types in China (https://www.resdc.cn/Default.aspx, accessed on 13 July 2021), the basic geomorphic types of the Altay region were divided. The physiognomy directly affects the distribution of vegetation and land use based on the altitude, fluctuation, and denudation degree, so geomorphic characteristics were regarded as one of the elements of the land type division. Research on geomorphic type classification based on topographic factors is gradually developing [41–43]. Reliable results were achieved in the application of DEM segmentation based on a multiscale segmentation algorithm [43,44]. In this study, the altitude, surface fluctuation, and slope change rate reflecting the geomorphic boundaries were selected as the division indexes of the geomorphic types based on DEM data. The multiscale segmentation algorithm and the mean change point method were used to determine the best statistical unit of fluctuation in the study area to divide the geomorphic types [43,45–47]. Finally, the best statistical unit for calculating the surface relief in the Altay region was $12 \times 12$ (0.1296 km$^2$) pixels. To make the land type classification system more scalable, this study followed the “China land 1:1 million digital geomorphic classification system” [48,49]. On this basis, the classification standards of the geomorphic types were
adjusted in combination with the actual geomorphic characteristics of the study area, and the classification system (Table 1) was obtained.

Table 1. The classification system of geomorphological type data.

| Relief Amplitude          | Altitude (Low Altitude) | Medium Altitude | High Altitude |
|---------------------------|-------------------------|-----------------|--------------|
|                           | (<1000 m)               | (1000–2400 m)   | (>2400 m)    |
| Plain (generally, <30 m)  | Low altitude plain      | Medium altitude plain | High altitude plain |
| Platform (generally, >30 m) | Low altitude platform | Medium altitude platform | High altitude platform |
| Hill (<200 m)             | Low altitude hills      | Medium altitude hills | High altitude hills |
| Small undulating mountain (200–400 m) | Small undulating middle mountain | Medium undulating middle mountain | Large undulating high mountain |
| Medium undulating mountain (400–600 m) | Medium undulating low mountain | Large undulating middle mountain | High altitude platform |
| Large undulating mountain (>600 m) | —                      | —               | —            |

Soil data: The soil type reflects the availability of land resources to a certain extent [50]. Soil is also an important factor affecting vegetation growth, so the soil type is an important indicator of land type division. Soil type vector databases were provided by the China Soil Database (http://vdb3.soil.csdb.cn/, accessed on 25 November 2021) and National Soil Information Service Platform (http://www.soilinfo.cn/map/index.aspx, accessed on 25 November 2021). Combined with the field sampling data, according to the Chinese soil classification standard, we divided the soil into soil categories and subcategories, which were included in the land type classification system.

Remote sensing data: We used remote sensing data to interpret the vegetation types and land use/cover types. As a natural background element, vegetation is an essential attribute of land type classification. Land use types can reflect the impact of human activities on land type differentiation. Therefore, the land use type is regarded as a reference for land type classification to coordinate the needs of land type classification, mapping, and application research. This study used remote sensing images with a resolution of 2 m from the Gaofen-1 satellite (GF-1) in 2019 (http://36.112.130.153:7777/DSSPlatform/productSearch.html, accessed on 21 March 2019). To improve the accuracy of visual interpretation, the image selection was mainly based on remote sensing data from June to September (during the vegetation growing period) of the current year or adjacent years, and the cloud cover of images was less than 10%. To eliminate the influence of the atmosphere, temperature, Earth rotation, sensors, and other factors on image deformation in the imaging process, cloud shadow detection and geometric and radiometric correction were carried out for all images [51]. Then, remote sensing images of the study area were obtained by orthophoto correction fusion, image registration, stitching, and mask cutting. The Envi 5.3 (Product of Exelis Visual Information Solutions inc. in the United States.), Locspace viewer (LSV) (Product of Beijing 3D Vision Technology Co., Ltd) and ArcGIS 10.2 (Product of ESRI inc, RedLands, California) software were used. Combined with supervised classification and manual visual interpretation, various land use data and vegetation type data were extracted. Among them, the land use type classification was based on the Chinese land use classification system issued by the Chinese Academy of Sciences (http://www.resdc.cn, accessed on 13 July 2021). According to the land cover characteristics and land use optimization, the grid database of the land use types in the study area was obtained. The results of supervised classification contained some sporadic points that were inconsistent with the actual situation. To improve the interpretation accuracy, Google images were used for manual visual interpretation of the land use classification. In total, 175 sampling points were selected for verification, and the accuracy was 0.9678. Therefore, the land use in 2019 was revised again (Table 2) and used as a benchmark. The remaining
images were interpreted and corrected by superimposing remote sensing images and Google images.

Table 2. Land use status classification system.

| First Class       | Second Class               |
|-------------------|-----------------------------|
| 1-Cultivated land | 1-1 Paddy land              |
| 2-Forestland      | 1-2 Dryland                 |
| 3-Grassland       | 1-3 Natural grazing land    |
| 4-Water area      | 1-4 Bare gravel land        |
| 5-Developed land  | 2-1 Woodland                |
| 6-Unused land     | 2-2 Shrub wood              |
|                   | 2-3 Sparse wood             |
|                   | 2-4 Other woodland          |
|                   | 3-1 Artificial grazing land |
|                   | 3-2 other grassland         |
|                   | 4-1 Canal                   |
|                   | 4-2 Lake                    |
|                   | 4-3 Pit-pond                |
|                   | 4-4 Shoaly land             |
|                   | 5-1 Urban land              |
|                   | 5-2 Rural residential area  |
|                   | 5-3 Industrial and mining land |
|                   | 6-1 Sand land               |
|                   | 6-2 Saline-alkaline land    |
|                   | 6-3 Marsh land              |
|                   | 6-4 Bare gravel land        |
|                   | 6-5 Permanent glacier and snowfield |

Other data: The species distribution data used in this study were obtained from the Altay regional statistical yearbook, local chronicles, and other documents.

2.3. Ecology-Geomorphology Cognition (Eco-geoC) Approach for Land Type Classification

The land type classification approach of Eco-geoC connects the characteristics of remote sensing images and multisource information with vision, experience, knowledge, and memory of various land types to form symbolic expressions of spatial information [52,53]. The land type classification approach of Eco-geoC includes three levels: ecology-geomorphology spatial feature perception, ecology-geomorphology spatial object cognition, and ecology-geomorphology spatial pattern cognition. In other words, this method transitions from spatial feature perception to spatial object cognition and then to spatial pattern cognition under the cognitive mode of the feature-object mode. The main goal of the Eco-geoC method is to segment remote sensing images, DEMs, and other multisource information related to land attributes that affect land type classification into meaningful spatial objects. Then, the functions and processes of visual interpretation are simulated by geoscientists and ecologists to make meaningful combinations of these spatial objects. In this way, land types covering a variety of attributes were obtained, and their spatial characteristics, spatial objects, and spatial patterns were analyzed. This approach was realized by segmenting land attribute images to meaningful image units based on geoscience knowledge and geographic information and on the premise of supporting the integration of different variables and indicators. This approach provides a unified framework for land use decision making. Thus, various other variables related to the land type can also be integrated (Figure 2).

![Figure 2. Conceptual framework of Eco-geoC on land type classification.](image-url)
2.4. Determining Land Units

The land unit is an ecologically and geographically homogeneous area on a given resolution level with similar physiognomy, vegetation, and soil characteristics. It is a range without obvious boundaries that divides attribute data into spatial objects with boundaries through certain rules and then superimposes and combines these spatial objects according to the boundaries. In this way, land units are formed. This bounded region is to some degree indeterminate and calculated by scientific research. The segmentation of land units using remote sensing images and multisource information is based on the spatial patterns of physiognomy, soil, vegetation, and land use as well as geoscience knowledge and cognition of remote sensing image information.

The basic element of the Eco-geoC approach is spatial objects, that is, the segmented continuous regions in attribute data. In this study, physiognomy, vegetation, soil, land use type, and image information related to land type differentiation were divided into different types, namely, vegetation type, geomorphic type, soil type, and land use type. In eCognition Professional 7.0 (Product of American Trmible company), a bottom-up region merging method was used to segment spatial objects, starting from a pixel object. The image objects of land units were segmented by variables related to land type classification. Thus, physiognomy, vegetation and soil layers, and image information were used to segment land units. ArcGIS 10.2 (Product of ESRI inc, RedLands, California) was used to convert the segmentation results to vector layers. GF-1 data fusion transformations (panchromatic-multispectral data) were used as layers of spectral information. The combination of these layers was used as the input variable to segment land units. Under the principle of the land type classification level, vector layers were integrated using the overlay function. The overlay function creates a new layer by crossing the input layers, which is the integrated land type classification layer. The new layer integrates all attributes of the input layers.

Figure 3 shows the framework of the application of the Eco-geoC approach for the land type classification in this study. Under the cognition mode of feature-object patterns, starting from natural geographical elements and combined with the impact of human activities on land type differentiation, and based on the registration of remote sensing image interpretation maps, DEM, land use maps, soil maps, field survey data, and multisource images, different attribute maps were segmented into meaningful object units according to certain rules. Based on geoscience knowledge and rule databases, the Eco-geoC approach was used for land type classification to integrate object units and geoscience knowledge in the study area. Finally, a thematic land-type map of 1:500,000 was drawn.

Figure 3. Approach framework of Eco-geoC on land type classification.
2.4.1. Classification of Geomorphic Types

According to the above classification system and calculation results, the geomorphic types of the Altay area were finally divided into 6 categories (namely, medium-scale geomorphic types) and 14 subcategories (namely, small-scale geomorphic types) (Figure 4) using eCognition Professional 7.0 (Product of American Trimble company). The 6 categories were used to divide level 2 land types, and the 14 subcategories were used to divide level 3 land types.

![Geomorphological maps of the study area](image)

**Figure 4.** Geomorphic maps of the study area: (a) 6 medium-scale geomorphic types and (b) 14 small-scale geomorphic types.

2.4.2. Classification of Soil Types

Using the soil type data provided by the geographic information monitoring cloud platform and the field sampling and soil attribute analysis data, and referring to the digital soil mapping research based on spatial analysis technology [54,55], the soil group and soil subgroup were used to express the soil attributes of level 2 and level 3 land types, respectively (Figure 5).

![Distribution map of soil types in the study area](image)

**Figure 5.** Distribution map of soil types in the study area.
2.4.3. Classification of Vegetation Types

Vegetation type data were mainly from remote sensing image interpretation, 175 field sampling data points, and the 2019 statistical yearbook of the Altay region. Additionally, to ensure the accuracy of the data and update the dataset, we collected data on vegetation formations and their distributions from the literature (1950–present). To meet the expandibility principle of land type division, the division principle and classification standard of the Vegetation Map of the People’s Republic of China (1:1,000,000) were used. By adopting the phytocoenology-ecology principle, formations with the same dominant species were classified as the same formation [56]. The vegetation was divided into three levels: vegetation category, vegetation subclass, and vegetation name. The first two categories were used to divide the level 2 land type, and the vegetation name was used for the level 3 land type. See Appendix B, Table A2 for detailed classification of vegetation types.

2.4.4. Classification of Land Use

The classification of the land use type was carried out by choosing training samples of different classes in eCognition Professional 7.0 (Products of American Trimble company). Remote sensing images were used to interpret the current situation of land use types in 2019, and the secondary classification of land use types (Figure 6) was used as the reference basis for the land type classification.

![Figure 6](image)

**Figure 6.** Land use types in the study area.

3. Results

Land is complex and formed by the interaction of natural geographical components and human activities. From the perspective of ecological geomorphology, based on multsource land spatial information data and geographical science cognition, this study constructed a land type classification approach of ecological geomorphology cognition, completed the division of land types on the basis of “geomorphic types, soil types, vegetation types and land use types”, and drew a 1:500,000 land type map. The proposed method provides a new idea for land type classification systems and ecological geomorphology research. In addition, the application of land type classification results was expanded from small-scale to large- and medium-scale.

Due to the differences in research systems, the naming rules of land classification results are not unified. To fully express the land attributes contained in each land type, research results are typically named “geomorphology + vegetation + soil + geology + climate” [13,57]. In this study, due to the complex geomorphic types, diverse vegetation, soil types, and land use types, the main characteristics of different regional land types varied. For mountainous and hilly areas, the characteristics of geomorphic types were more prominent, so we used the name “geomorphology + vegetation + soil + land use”. For plain areas with less obvious geomorphic characteristics, vegetation, soil types, and land use types were highlighted, so we used the name “vegetation + land use + soil + geomorphology”. For areas without vegetation cover, we directly used the name of the
land use types or the soil characteristics. The final results are shown in Figure 7 and Table A1 in Appendix A.

**Figure 7.** Classification maps of land types under different levels: (a) level 2–27 are kinds of land systems and (b) level 3–78 are kinds of land units. The legend corresponds to Table A1 in Appendix A.

*Note: This map refers to the 1_500,000 land type map of Altay Region prepared by ‘Xinjiang Wasteland Resources Comprehensive Investigation Team’ in October 1980. Mapping: Zili Fan. Drawing: Defa Li.*
4. Discussion

According to the zonality of climate and vegetation, land was first divided into two land types of level 1, namely, natural belts. They were temperate desert steppe and temperate desert. On the basis of level 1, land was further refined according to six medium-scale geomorphic types, vegetation categories, vegetation subclasses, and great soil groups and finally divided into 27 land types of level 2, namely, land systems. Based on level 2, land was further refined according to 14 small-scale geomorphic types, soil subgroups, and vegetation names and finally divided into 78 land types of level 3, namely, land units.

4.1. Distribution Characteristics of Land Types

According to the spatial distribution map of land type classification (Figure 7), the study area presented obvious spatial distribution laws and combination characteristics. Land types were mainly distributed along elevation gradients and spatial combinations.

4.1.1. Land Types Were Distributed along the Elevation Gradient

Affected by the factors of physical geography and the difference in material and energy exchanges, land types showed certain spatial distribution characteristics [58]. The spatial distribution characteristics of land types refer to the spatial distribution law and combination form of land types. The Altay region presented a stepped distribution form with increasing terrain that could be roughly divided into three geomorphic units: the northern mountainous area; the central hilly, valley, and plain area; and the southern (Gobi) desert area, accounting for 32%, 22%, and 46% of the total area, respectively. Due to the low latitude and longitude span in the study area, the whole region is located in a temperate continental climate. The land type is less affected by climatic conditions (the zonality of latitude is not obvious), so the hydrothermal conditions in the territory were basically similar. However, the relative elevation difference was 4057 m, with large fluctuations in the terrain. The law of vertical zonal differentiation was obvious. Therefore, geomorphic characteristics were the main classification basis for dividing the land types.

According to the classification basis of the above geomorphic types, the study area included six medium-scale geomorphic types: plains, platforms, hills, low mountains, middle mountains, and high mountains. Because of the great difference in altitude and topographic relief, medium-scale geomorphic types were further divided. Hills were divided into medium-altitude hills and low-altitude hills. Plains were divided into low-altitude plains, medium-altitude plains, and high-altitude plains. The platform was divided into low-altitude platforms and medium-altitude platforms. Low mountains were divided into small undulating low mountains. The middle mountain was divided into small undulating middle mountains, medium undulating middle mountains, and large undulating middle mountains. High mountains were divided into small undulating high mountains, medium undulating high mountains, and large undulating high mountains. As the altitude increased from low to high, the distribution of soil and vegetation began to change significantly [59,60]. As an important indicator of land, soil affects the quality and productivity of land, the growth of vegetation, and the quality of human living standards. As one of the main factors reflecting land differentiation, vegetation can reflect the vegetation growth status and suitability in different areas.

Affected by physiognomy, many soil types were identified in the Altay region, and the distribution characteristics were complex. The soil distribution at high altitudes and low altitudes varied and was roughly distributed in steps. The mountain soil series from the high mountains to the foothills included alpine cold desert soil, alpine meadow steppe soil, subalpine meadow steppe soil, mountain brown coniferous forest soil, mountain greyish brown forest soil, mountain chernozem soil, mountain chestnut soil, and mountain brown calcium soil. The plain soil series from the front of the mountain from north to south were brown calcium soil, light brown calcium soil, grey–brown desert soil, and aeolian sand soil. In addition, saline soil, swamp soil, and cracked soil were scattered.
From the land-type classification results, in the northern mountainous area of the study area, forest resources were mainly distributed at altitudes of 1500–2400 m. At an altitude of approximately 2000 m, there were obvious vertical vegetation band spectra, mainly composed of trees, shrubs, and herbs. At an altitude of 900–1500 m, in places with good habitats, there was bush fallow, thick grass growth, and miscellaneous wood forest. In the middle hilly valley plain area, the pasture was fertile, and there were dense river valley natural forests on both banks. In the southern Gobi Desert area, drought-tolerant forage and Haloxylon ammodendron were scattered in the depression between hills. Overall, the spatial structure of this area was very obvious due to the significant altitude difference. Land systems from high altitude to low altitude included glaciers and snow, alpine ice marsh, peat swamp, alpine meadow, subalpine meadow, meadow steppe, middle mountain forest and forest steppe, low mountain steppe, low mountain shrub steppe, dry steppe, low mountain and hilly desert steppe, Piedmont desert steppe, steppe desert, high river-terrace desert, low terrace-floodplain forest, low beach-meadow steppe, farmland, rivers, lakes, reservoirs and ponds.

4.1.2. Characteristics of the Spatial Combination form of Land Type

There were obvious mosaic composite structures in the study area. A mosaic refers to a major land type with several other land types embedded in it [61]. The mosaic composite structure was widely distributed, mainly in the central hilly valley plain area and the southern desert (Gobi) area. For example, agricultural land was distributed in intermountain valley basin steppe, low mountain shrub steppe, and meadow low flat ground. Saline alkali land and Populus euphratica_Haloxylon ammodendron_desert forestland were distributed in low mountains and hills desert land. Adobe soil land and saline-alkali soil land were distributed in salt firewood desert-brown desert calcic soil_fat ground.

For the northern mountainous area, the most prominent spatial distribution feature was the dendritic structure. In the northern area, several dendritic structures were formed due to the influence of gullies and the interspersed influence of alpine ice/snow meltwater. For example, dendritic alpine meadows were interspersed in alpine tundra. Subalpine meadow, meadow steppe, and middle mountain forest-forest steppe were interspersed with each other, showing a dendritic distribution. In addition, dendritic alpine tundra was interspersed in alpine meadow, subalpine meadow, and meadow steppe.

The classification results of the Eco-geoC approach were verified by 175 field sampling points in the study area. Additionally, the classification results were compared with previous field investigation-related studies [62–65], and the results were consistent. Therefore, it is feasible for the Eco-geoC approach to divide land attributes by appropriate methods and then superimpose and combine them into land types. This method saves manpower and material resources for the field investigation of land resource management and saves time for land type updating. These results show the advantages and capabilities of the Eco-geoC approach in land-type mapping. In addition, the Eco-geoC approach can eliminate the “salt” and “pepper” effects in pixel-by-pixel classification images. Land-type mapping based on the Eco-geoC approach depends on the accurate division of various land attributes.

The application of the Eco-geoC approach is conducive to the classification of land types because this method can simulate the image interpretation ability of human interpreters. It also benefits from the integration of remote sensing images, multisource information, and geoscience knowledge. However, the rationality and accuracy of dividing each land attribute into spatial objects have an important impact on the classification accuracy of the final merged land units. In the Eco-geoC approach, it is very important and challenging to determine the division scale in the process of dividing land attributes into meaningful spatial objects. In addition, although this method has potential in land type classification and extrapolation, the input layer in the classification process and the application of appropriate functional models in other regions may be different.
4.2. Land Type and Landscape

Land, as used here, is synonymous with landscape in its meaning as “the total character of a part of the Earth’s surface” (von Humboldt) or the tangible ecosystems including all biotic and abiotic aspects as they can be recognized visually at the Earth’s surface.

A landscape is a part of the space on the Earth’s surface consisting of a complex of systems, formed by the activity of rock, water, air, plants, animals, and man and that by its physiognomy forms a recognizable entity [66]. Landscape definitions differ according to the context or type of application. In the present study, landscapes are considered to form recognizable, although often heterogeneous, parts of the Earth’s surface, which show a characteristic ordering of elements. Landscapes are ecological meaningful units where many processes and components interact. As such, landscapes themselves have resulted from the long-term interactions of natural abiotic, biotic, and anthropogenic processes and are complex systems in which many components are interdependent [67].

Landscapes are complex, spatially heterogeneous systems with many properties and values. This makes classification and mapping difficult, especially at continental scales. The conceptual framework used [68–70], is based upon a hierarchical approach of various landscape components: abiotic, biotic, and cultural factors.

Land and landscape in this study are synonymous. The thought and theory of land type research originated from landscape science. Land type is also a comprehensive scientific concept. Land type refers to the natural category divided according to the difference and similarity of regional natural conditions, reflecting the combination of regional natural elements. Through the study of land types, we can reveal the distribution law and interaction of various natural elements in a geographical area and reveal the formation, characteristics, structure, function, regional differentiation, and dynamic succession law of natural complex. “Land comprises the physical environments including climate, relief, soils, hydrology and vegetation to the extent that these influence the potential for land use” (FAO 1976). For example, John et al. [6] used soil, landform, and vegetation as indicators to divide the land types of forests and guide the management of forest resources. Alireza [71], Robert [72], and Kasper [10] classified land types and made great contributions to land regulation by using the research results. Since the 21st century, more mature applications such as informatization and digitization have been gradually applied to the research of land types and have become the focus of geography research. For example, Kussul et al. [73] used the scenes of 19 periods obtained by the landsat-8 and sentinel-1a RS satellites to deeply classify the land types of Ukraine. Kienast et al. [74] took Switzerland as the research area by using GIS technology and studied its land use landscape by using the method of quantitative analysis. The research results provide an important reference for the land remediation work in Switzerland in the later stage. Cabral et al. [75] obtained the land cover map of West African countries from 1990 to 2015 by using remote sensing data (Landsat TM, ETM + OLI) and analyzed the change of landscape pattern. Finally, he found that the main reason for the change was related to the outflow of rural population.

In this study, land types are treated as a series of spatial units whose morphological characteristics of landscape are relatively consistent with the natural, social, and economic attributes of land. That is, land types can be understood as spatial objects with different landscape morphological units [76]. A landscape can be regarded as a system, while land types can be used as ecologic expressions of a landscape. A land unit, as an expression of a landscape as a system, is a fundamental concept in landscape ecology, and it is an ecologically homogeneous tract of land [12,77]. Therefore, the landscape can be divided into many ecologically and geographically identical areas with similar physiognomy, vegetation, and soil characteristics, and land units can be repeated on the surface.

On this basis, the Eco-geoC approach was used for land type classification, in order to provide reference for the rational utilization of local land resources. It should be noted that geology, as one of the important natural attributes of land, is not considered in this study. Incomplete geological data is an important reason. In addition, the purpose of this study is to use the easily obtained multisource data to quickly realize the division of land types.
Therefore, this study only selects four directly observable indicators of vegetation, terrain, soil, and land use type to verify the Eco-geoC approach. In future research work, geology and other indicators will be considered to make the results more convincing and meaningful.

5. Conclusions

The Eco-geoC method is an approach for developing automated methods to partition remote sensing imagery and multisource information into meaningful spatial objects on different attribute layers of land using geoscience knowledge; then, based on the geoscience knowledge and rule database, the spatial objects of multiple layers are meaningfully combined to form the primary land type classification unit. On this basis, geoscientists and ecologists can simulate the function and process of remote sensing image visual interpretation and overlay geoscience knowledge with primary land type classification units to obtain the land types covering a variety of natural attributes and generate thematic information. The proposed method is an extension of the image analysis approach. The ultimate goal of Eco-geoC is to simulate the visual interpretation of ecological-geomorphology experts and extract the spatial features, spatial objects, and spatial patterns of land types from remote sensing images on the basis of integrating geoscience knowledge and multisource information supported by different cognitive models. The Eco-geoC approach is divided into three levels: ecology-geomorphology spatial feature perception, ecology-geomorphology spatial object cognition, and ecology-geomorphology spatial pattern cognition.

Under the approach framework of Eco-geoC on land type classification, the approach was applied in land type classification and tested in the Altay region, Xinjiang Province, China, with a complex physical geographical situation. Combined with geoscience knowledge, remote sensing images and multisource data were used to segment land units, and land type classification was realized. The results show that the application of Eco-geoC to classify land types using remote sensing and multisource information was effective.

The Eco-geoC method provides an opportunity to study and characterize land attribute states using remote sensing images. This study was an attempt to classify land types by using remote sensing images, multisource information, and geoscience knowledge. This method can also be used in land use classification, land degradation assessment, and other land-related studies. The Eco-geoC method is of great significance for land resource monitoring and evaluation using remote sensing images. However, the Eco-geoC method involves more content and methods. The above methodological framework and application examples in land type classification are not complete. It is of great significance to further develop and improve the Eco-geoC method.

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**Conflicts of Interest:** The authors declare no conflict of interest.

**Appendix A**

**Table A1.** Land-type structure of the study area.

| Natural Belts          | Land Systems                                                                                   | Land Units                                                                                       |
|------------------------|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| I-1 Alpine tundra      | I-1-1 Alpine glaciers and permanent snow land                                                 | I-1-1 Alpine glaciers and permanent snow land                                                   |
|                        | I-1-2 Alpine bare rock land                                                                   | I-1-2 Alpine bare rock land                                                                     |
|                        | I-1-3 Alpine moss lichen ice marsh land                                                       | I-1-3 Alpine moss lichen ice marsh land                                                         |
|                        | I-1-4 Alpine garden Betula platyphylla shrub ice marsh alpine gleyic podzol soil land         | I-1-4 Alpine garden Betula platyphylla shrub ice marsh alpine gleyic podzol soil land           |
| I-2 Alpine meadow      | I-2-1 Alpine Artemisia barren meadow litosols land                                             | I-2-1 Alpine Artemisia barren meadow litosols land                                              |
|                        | I-2-2 Alpine miscellaneous grass_Carex and miscellaneous meadow alpine podzol soil land      | I-2-2 Alpine miscellaneous grass_Carex and miscellaneous meadow alpine podzol soil land         |
| I-3 Subalpine meadow   | I-3-1 Subalpine miscellaneous grass_Dogstail meadow alpine podzol soil land                   | I-3-1 Subalpine miscellaneous grass_Dogstail meadow alpine podzol soil land                     |
| and meadow steppe      | I-3-2 Subalpine Dogstail Meadow steppe land                                                    | I-3-2 Subalpine Dogstail Meadow steppe land                                                     |
| I-4 Middle-mountains   | I-4-1 Middle mountains_Pinus sibirica Abies sibirica_Brown coniferous forestland              | I-4-1 Middle mountains_Pinus sibirica Abies sibirica_Brown coniferous forestland               |
| forest and forest      | I-4-2 Middle mountains_Siberian larch_podzol soil land                                        | I-4-2 Middle mountains_Siberian larch_podzol soil land                                         |
| steppe                 | I-4-3 Middle mountains_Shrub Meadow steppe_Leached Chernozem land                             | I-4-3 Middle mountains_Shrub Meadow steppe_Leached Chernozem land                              |
|                        | I-4-4 Middle mountains_Miscellaneous grass-Dogstail_Meadow steppe Chernozem land            | I-4-4 Middle mountains_Miscellaneous grass-Dogstail_Meadow steppe Chernozem land              |
| I-5 Low-mountain       | I-5-1 Low mountains_Shrub Dogstail steppe_Chenozem land                                       | I-5-1 Low mountains_Shrub Dogstail steppe_Chenozem land                                        |
| Bushveld               | I-5-2 Low mountains_Spiraea salicifolia Solitary thatch steppe_thin layer Dark Chestnut soil land | I-5-2 Low mountains_Spiraea salicifolia Solitary thatch steppe_thin layer Dark Chestnut soil land |
|                        | I-5-3 Low mountains_Spiraea salicifolia Solitary thatch steppe_thin layer Dark Chestnut soil land | I-5-3 Low mountains_Spiraea salicifolia Solitary thatch steppe_thin layer Dark Chestnut soil land |
|                        | I-5-4 Low mountains_Solitary thatch steppe_thin layer Dark Chestnut soil                      | I-5-4 Low mountains_Solitary thatch steppe_thin layer Dark Chestnut soil                      |
|                        | I-5-5 Low mountains_Spiraea salicifolia Stipa capillata steppe_thin layer light Chestnut soil | I-5-5 Low mountains_Spiraea salicifolia Stipa capillata steppe_thin layer light Chestnut soil |
|                        | I-5-6 Low mountains_Spiraea salicifolia Stipa capillata steppe_light Chestnut soil           | I-5-6 Low mountains_Spiraea salicifolia Stipa capillata steppe_light Chestnut soil           |
|                        | I-5-7 Low mountains_Stipa capillata steppe_thin layer light Chestnut soil                    | I-5-7 Low mountains_Stipa capillata steppe_thin layer light Chestnut soil                    |
| I-6 Low mountains and   | I-6-1 Low mountains and hills_Artemisia Solitary thatch and Stipa capillata Desert steppe_thin layer brown calcic soil land | I-6-1 Low mountains and hills_Artemisia Solitary thatch and Stipa capillata Desert steppe_thin layer brown calcic soil land |
| hills-desert steppe    | I-6-2 Low mountains and hills_Artemisia Salt firewood Stipa capillata Desert steppe_thin layer Brown calcic soil land | I-6-2 Low mountains and hills_Artemisia Salt firewood Stipa capillata Desert steppe_thin layer Brown calcic soil land |
|                        | I-6-3 Low mountains and hills_Artemisia Salt firewood Stipa capillata Desert steppe_Brown calcic soil land | I-6-3 Low mountains and hills_Artemisia Salt firewood Stipa capillata Desert steppe_Brown calcic soil land |
|                        | I-6-4 Low mountains and hills_Artemisia_Salt firewood Steppe desert_light Brown calcic soil land | I-6-4 Low mountains and hills_Artemisia_Salt firewood Steppe desert_light Brown calcic soil land |
| I-7 Intermountain valley basin steppe_desert steppe | I-7-1 Intermountain valley basin_Solitary thatch steppe_Dark Chestnut soil land | I-7-1 Intermountain valley basin_Solitary thatch steppe_Dark Chestnut soil land |
|                        | I-7-2 Intermountain valley basin_Artemisia Dogstail_Brown calcic soil land                   | I-7-2 Intermountain valley basin_Artemisia Dogstail_Brown calcic soil land                     |
| Natural Belts            | Land Systems                                      | Land Units                                                                 |
|-------------------------|---------------------------------------------------|----------------------------------------------------------------------------|
| I-8 Mountain swamp      | I-8-1 Alpine valley tower head, Carex species, Swamp low wetland |                                                                            |
| I-9 Steppe-Chestnut     | I-9-1 *Stipa capillata* steppe, light Chestnut soil, Sloping flat ground |
| soil-flat ground        |                                                   |                                                                            |
| I-10 Desert steppe-Brown calcic soil-flat ground | I-10-1 Artemisia, Salt firewood, *Stipa capillata* Desert steppe, Brown calcic soil, Sloping flat ground I-10-2 Ephemeral plant, Artemisia, Brown calcic soil, Sloping flat ground I-10-3 Artemisia, Salt firewood, *Stipa capillata* Desert steppe, Brown calcic soil, Flat ground I-10-4 Artemisia, Salt firewood, *Stipa capillata* Stipa glareosa, Desert steppe, Brown calcic soil, High flat ground I-10-5 Artemisia, Salt firewood, *Stipa capillata* Desert steppe, thin layer, Brown calcic soil, Denuded flat ground I-10-6 Artemisia, Salt firewood, *Stipa capillata* Desert steppe, Brown calcic soil, Denuded flat ground |
| I-11 Steppe desert-light Brown calcic soil-flat ground | I-11-1 Salt firewood, Artemisia, Steppe desert, light Brown calcic soil, Sloping flat ground I-11-2 Salt firewood, Artemisia, Steppe desert, light Brown calcic soil, Flat ground I-11-3 Salt firewood, Artemisia, Steppe desert, Basification light Brown calcic soil, Flat ground I-11-4 Salt firewood, Artemisia, Steppe desert, thin layer, light Brown calcic soil, High flat ground I-11-5 Salt firewood, Artemisia, Steppe desert, light Brown calcic soil, High flat ground I-11-6 Salt firewood, Artemisia, Steppe desert, thin layer, light Brown calcic soil, Denuded flat ground |
| I-12 Meadow_low flat ground | I-12-1 River valley poplar forest, Shrub meadow, soil, Low flat ground I-12-2 Miscellaneous grass, Gleyic Chernozems, Low flat ground I-12-3 *Achnatherum splendens*, *Phragmites australis*, Salinization meadow, soil, Low flat ground |
| I-13 Swamp_low wetland  | I-13-1 *Phragmites australis*, *Typha orientalis* Presl, Fernwort, Peat boggy soil land I-13-2 Miscellaneous grass, Carex species, Dogstail Meadow, Boggy soil land I-13-3 Everglade |
| I-14 Saline-alkali soil | I-14-1 Dogstail, Miscellaneous grass, Saline meadow, Solonchak land I-14-2 Succulent salt firewood, Typical Solonchak land I-14-3 Residual Solonchak land I-14-4 Mineral Solonchak land |
| I-15 Adobe soil         | I-15-1 Bare adobe soil                            |                                                                            |
| I-16 Agricultural land  | I-16-1 Irrigated Chestnut soil, Agricultural land I-16-2 Irrigated Brown calcic soil, Agricultural land I-16-3 Irrigated Meadow soil, Agricultural land I-16-4 Salinization, Paludification, Agricultural land I-16-5 Dry Cultivated land |
Table A1. Cont.

| Natural Belts | Land Systems | Land Units |
|---------------|--------------|------------|
| I-17 Desert   | I-17-1 Calligonum mongolicum_Fixed and semi fixed dunes  |
|               | I-17-2 Haloxylon ammodendron_Fixed and semi fixed dunes  |
|               | I-17-3 Fluid dune  |
| II-1 Upland meadow | II-1-1 Low mountains-shrub_Stipa capillata steppe_thin layer light Chestnut soil land |
| II-2 Low mountains and hills_desert steppe | II-2-1 Low mountains and hills_Artemisia_Salt firewood_Stipa capillata Desert steppe_thin layer Brown calcic soil land |
| II-3 Low mountains and hills_desert | II-3-1 Low mountains and hills-Salt firewood desert gypsum grey brown desert soil land |
| II-4 Salt firewood desert_brown desert calcic soil_flat ground | II-4-1 Anabasis salsa desert_thin layer brown desert calcic soil_high flat ground |
|               | II-4-2 Anabasis salsa desert_Basification thin layer brown desert calcic soil_high flat ground |
|               | II-4-3 Anabasis salsa desert_Basification brown desert calcic soil_high flat ground |
|               | II-4-4 Anabasis salsa desert_sandy brown desert calcic soil_Denuded flat ground |
|               | II-4-5 Anabasis salsa desert_thin layer brown calcic soil_Denuded flat ground |
|               | II-4-6 Salt firewood desert_thin layer brown calcic soil_Erosion Pits and valleys land |
|               | II-4-7 Anabasis salsa desert_thin layer brown desert calcic soil_Undulating hilly land |
| II-5 Haloxylon ammodendron_Salt firewood desert_gypsum grey brown desert soil_flat ground | II-5-1 Haloxylon ammodendron-desert gypsum grey brown desert soil_high flat ground |
|               | II-5-2 Anabasis brevifolia gypsum grey brown desert soil_high flat ground |
|               | II-5-3 Anabasis brevifolia-gypsum grey brown desert soil_Denuded flat ground |
| II-6 Populus euphratica_Haloxylon ammodendron_Desert forestland | II-6-1 Haloxylon ammodendron_shrubbery land |
| II-7 Saline-alkali soil | II-7-1 Residual Solonchak land |
|               | II-7-2 Mineral Solonchak land |
| II-8 Residual marshland | II-8-1 Residual Peat marshland |
| II-9 Adobe soil land | II-9-1 Bare adobe soil land |
| II-10 Desert   | II-10-1 Haloxylon ammodendron_Fixed and semi fixed dunes  |
|               | II-10-2 Fluid dune  |
## Appendix B

Table A2. Vegetation type classification of the study area.

| Vegetation Category       | Vegetation Subclass                                | Vegetation Name                                                                 |
|---------------------------|---------------------------------------------------|--------------------------------------------------------------------------------|
| Coniferous Forest         | Cold-temperate and temperate mountains            | Larix sibirica forest                                                           |
|                           | coniferous forest                                 | Larix sibirica, Picea obovata forest                                            |
|                           |                                                   | Pinus sibirica forest                                                           |
| Broadleaf Forest          | Temperate microphyllous deciduous woodland        | Ulmus pumila woodland                                                            |
|                           | Temperate broadleaf deciduous forest              | Populus nigra forest                                                             |
|                           |                                                   | Populus tremula forest                                                           |
|                           |                                                   | Salix matsudana forest                                                           |
|                           |                                                   | Betula platyphylla, Populus davidiana forest                                     |
| Scrub                     | Subalpine broadleaf deciduous scrub               | Rosa sericea, Cotoneaster adpressus scrub                                        |
|                           |                                                   | Dasiphora fruticosa scrub                                                       |
|                           | Temperate dwarf semi-arboreal desert              | Haloxylon persicum desert                                                       |
|                           |                                                   | Haloxylon ammodendron gravelly desert                                            |
|                           |                                                   | Haloxylon ammodendron sandy desert                                               |
|                           |                                                   | Haloxylon ammodendron loamy desert                                              |
| Desert                    | Temperate shrubby desert                          | Calligonum rubicundum desert                                                     |
|                           |                                                   | Tamarix ramosissima desert                                                       |
|                           |                                                   | Calligonum leucocladum desert                                                    |
|                           |                                                   | Ephedra przewalskii desert                                                      |
|                           | Temperate semi-shrubby and dwarf semi-shrubby     | Artemisia arenaria desert                                                       |
|                           | desert                                            | Seriphidium terrae-albae desert                                                  |
|                           |                                                   | Seriphidium santolinum desert                                                   |
|                           |                                                   | Seriphidium gracilescens desert                                                 |
|                           |                                                   | Anabasis brevifolia desert                                                      |
|                           |                                                   | Ceratoides latens gravelly desert                                                |
|                           |                                                   | Ceratoides latens desert                                                        |
|                           |                                                   | Ceratoides latens sandy desert                                                   |
|                           |                                                   | Reaumuria soongorica sandy desert                                               |
|                           |                                                   | Anabasis salsa desert                                                           |
|                           |                                                   | Nanophyton erinaceum desert                                                     |
|                           |                                                   | Salsola arbuscula desert                                                        |
|                           | Temperate succulent holophytic dwarf semi-shrubby | Kalidium foliatum desert                                                        |
|                           | desert                                            | Carex liparocarpos, forb meadow steppe                                           |
|                           |                                                   | Festuca sulcata, forb meadow steppe                                              |
|                           |                                                   | Aneurolepidium angustum, forb, shrubby meadow steppe                             |
|                           |                                                   | Stipa kirghisorum, Stipa capillata, forb meadow steppe                           |
|                           |                                                   | Stipa capillata, forb meadow steppe                                              |
|                           |                                                   | Poa angustifolia, Festuca sulcata, Helictotrichon schelium                       |
|                           |                                                   | meadow steppe                                                                  |
|                           |                                                   | Festuca ovina steppe                                                            |
| Steppe                    | Temperate grass-forb meadow steppe                | Festuca sulcata steppe                                                          |
|                           |                                                   | Cleistogenes squarrosa steppe                                                    |
|                           |                                                   | Stipa capillata, Artemisia frigida steppe                                        |
|                           |                                                   | Stipa capillata, needlegrass steppe                                             |
|                           |                                                   | Artemisia frigida, dwarf needlegrass steppe                                      |
| Vegetation Category | Vegetation Subclass       | Vegetation Name                                                                 |
|---------------------|---------------------------|---------------------------------------------------------------------------------|
| Meadow              | Alpine *Kobresia* spp., forb meadow | *Kobresia* spp. alpine meadow  
|                     |                            | *Carex* oxyleuca alpine meadow  
|                     |                            | *Carex* atrofusca alpine meadow  
|                     |                            | *Kobresia* myosiroides alpine meadow  
|                     |                            | *Kobresia* smurnovii alpine meadow  
|                     |                            | *Carex* stenocarpa alpine meadow  
|                     |                            | *Kobresia* filifolia alpine meadow  
|                     |                            | *Festuca ovina*, forb alpine meadow  
|                     |                            | *Polygonum sphaerostachyum*, *P. viviparum* alpine meadow  
|                     |                            | *Poa* alpina, forb alpine meadow  
|                     |                            | *Poa* rossbergiana, *Littlealea racemosa* alpine meadow  
|                     |                            | *Festuca kurtschumica*, *Anthoxanthum alpinum* alpine meadow  
|                     |                            | *Poa* spp. alpine meadow  
|                     |                            | *Kobresia* stenocarpa alpine meadow  
|                     | Temperate grass and forb holophytic meadow | *Suaeda glauca* holophytic meadow  
|                     |                            | *Aneurolepidium dasystachys* holophytic meadow  
|                     |                            | *Phragmites communis* holophytic meadow  
|                     |                            | *Achnatherum splendens* holophytic meadow  
|                     |                            | *Calamagrostis epigejos* holophytic meadow with *Tamarix ramosissima*  
|                     |                            | *Phragmites communis* holophytic meadow with holophytic semi-shrubby  
|                     |                            | *Phragmites communis*, *Poacynum hendersonii* holophytic meadow with *Nitraria* spp., *Tamarix* spp.  
|                     |                            | *Sophora alopecuroides*, *Poacynum hendersonii*, *Glycyrrhiza inflata*, *Allagi pseudoalhagi*, *Karelinia caspica* holophytic meadow  
| Swamp               | Cold-temperate and temperate swamp | *Phragmites communis* swamp  
| Alpine Vegetation   | Alpine tundra              | *Cetraria nivalis* tundra  
|                     | Alpine sparse vegetation   | *Saussuora involucrata*, *Callianthemum alatavicum* sparse vegetation  
| Cultural Vegetation | One crop annually and cold-resistant economic crops | Spring wheat, gruel, potatoes; sugar beet, flux, rapeseed  
| Land Without Vegetation | Land without vegetation | Glaciers and snow limit  
|                     |                            | Bare sandy desert  

**Table A2. Cont.**
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