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Integrating actual land cover data and landscape zone map to assess terrestrial ecosystems in Armenia

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Abstract

Ecosystem mapping and accounting are essential for biodiversity conservation and ecosystem services maintenance. In this study, we tested a simple geographic information system approach by overlaying Armenia's landscape zones with land cover data from the Environmental Systems Research Institute and the European Space Agency. This analysis resulted in maps of 20 combinations of woody and non-woody land cover classes across 10 landscape zones, which we term landscape-land cover classes (LLCCs) and use as proxies for natural ecosystems. The LLCC-based method employed in this study accounts for the landscape and geographic specificity of terrestrial ecosystems, providing data on the extent of LLCCs within ecosystem accounting areas (EAAs), identifying rare LLCCs, and tracking changes in their extent following updates to land cover data. We found this approach applicable for assessing the extent and changes of LLCCs whose area exceeds the margin of error in land cover identification. In addition, it provides a useful framework for developing a prototype of ecosystem accounting in EAAs lacking regularly updated ecosystem maps.

Keywords: Ecosystem mapping; Ecosystem extent accounting; Rare ecosystems

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1. Introduction

In the context of the global environmental crisis, biodiversity conservation is recognized as a crucial pre-requisite to ensure the survival and sustainable development of humanity.[1,2] All hierarchical levels of biodiversity are important for human well-being, including intraspecific genetic diversity, species and functional diversity within ecosystems, and the diversity of ecosystems within landscapes.[3-5] The task of preserving ecosystem diversity is critically important; however, it often receives less public attention than the conservation of species and genetic diversity.

In addition to its direct goal of conserving biodiversity, ecosystem diversity is essential for the delivery of ecosystem services that support human well-being. The importance of species diversity for ecosystem functions and services has been well demonstrated through numerous experiments and surveys of real-world systems.[3,5] Although the role of ecosystem and habitat diversity has been less studied, recent research indicates its importance in maintaining what are known as landscape ecosystem services.[6-12] The same applies to β-diversity.[13,14] Ecosystem diversity directly enhances cultural ecosystem services,[15] supports landscape multifunctionality,[13,16] and stabilizes landscape services.[12,17,18]

Conserving biodiversity cannot be accomplished without effective accounting and monitoring. Ecosystem accounting has rapidly developed in recent years, following the United Nation's recommendations.[19] It includes accounts of ecosystem extent and condition, as well as accounts of ecosystem services and assets. Therefore, ecosystem mapping and monitoring of changes in their extent are necessary components of ecosystem accounting.

Ecosystem mapping is a complex task that remains incomplete in many countries. While present available land cover maps provide a tool for monitoring changes in ecosystem extent, they define only a small number of broad land cover classes without reflecting the biological specifics of ecosystems. Scientific geobotanical and landscape zoning, as well as national and international classifications of ecosystems, such as the International Union for Conservation of Nature (IUCN) Global Ecosystem Typology,[20] reflect the specifics of biodiversity and ecosystems. However, they do not account for ongoing changes in the actual extent of ecosystems.

The European initiative of mapping and assessing ecosystems and their services[21] is an example of large-scale progress along this path. The European map of ecosystems[22] is based on a combination of spatially explicit land cover data and the habitat classification of the European Nature Information System (EUNIS) (https://eunis.eea.europa.eu/habitats.jsp), which includes numerous types of ecosystems, taking into account natural conditions and geographical features of biodiversity.[23,24] At the same time, the European Ecosystem Extent Accounts.[25-27] continue to rely on data from the coordination of information on the environment (CORINE) detailed land cover, which was updated every 6 years from 2000 to 2018 by the Copernicus Land Monitoring Service.

The most direct form of ecosystem diversity protection comes through national and international red lists of ecosystems. The IUCN red list of ecosystems (RLE)[28,29] includes eight categories similar to those used for the Red List of Species, along with five criteria that provide a consistent method for assessing the risk of ecosystem collapse. Two of these criteria are based on the area of ecosystems and their changes: (i) declining distribution and (ii) restricted distribution. The European Red List of Habitats is based on modifications of the IUCN methodology. It assesses 233 natural and semi-natural terrestrial and freshwater habitat types, of which 36% are classified as critically endangered, endangered, or vulnerable.[30] In the post-Soviet space, an attempt to prioritize ecosystems based on their rarity[31] was made within the framework of The Economics of Ecosystems and Biodiversity-Russia project (2013 – 2021).[32] This experience showed that ecosystem mapping is a key pre-requisite for such assessments.

Armenia's diverse ecosystems and species richness make all these tasks crucial for the country. Due to its mountainous terrain, Armenia has a great diversity of ecosystems and species in a relatively small area.[33-36] It is part of the Caucasus biodiversity hotspot, as identified by Conservation International.[37] However, Armenia's ecosystems face significant negative impacts from climate change and unsustainable use of natural resources by humans.[36]

This study serves as a preparatory step for the project, Ecosystem Accounting in Armenia: Setting the Scene,[38] which is being implemented in collaboration with the Leibniz Institute of Ecological Urban and Regional Development (IOER), with the participation of experts from leading scientific organizations in Armenia, and the support of the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety. The Biodiversity Conservation Centre in Armenia conducted a preliminary analysis of open data on the state of Armenia's ecosystems and biodiversity,[39] which highlighted that the available data provides a solid foundation for developing national ecosystem accounting. The assessment of ecosystem diversity and further development of ecosystem extent accounts can be based on available scientific maps of landscape zones and vegetation, as well as available land cover and satellite images.

The purpose of this study was to evaluate the applicability of an approach based on the intersection of land cover data and a landscape map for accounting for terrestrial ecosystems in Armenia. It is important to clarify that our objective was not to assess Armenia's ecosystems but to test the suitability of this methodological approach for ecosystem accounting. To achieve this, maps of landscape-land cover classes (LLCCs) – combinations between landscape zones and land cover classes (Environmental Systems Research Institute [ESRI] 2023, 2017, and European Space Agency [ESA] 2021) – were created as proxies for terrestrial ecosystems. We then estimated the area of natural landscapes and LLCCs within the administrative provinces of Armenia and ranked the LLCCs by rarity. Using the obtained data, we evaluated the importance of Armenia's administrative provinces in conserving natural landscapes and LLCCs. Subsequently, we assessed changes in the extent of landscapes and LLCCs, as well as shifts in provincial importance, over the period from 2017 to 2023. Finally, we discuss the primary challenges associated with this approach for ecosystem accounting in Armenia.

2. Materials and methods

2.1. Study area

The analysis covers the entire territory of the Republic of Armenia, which has an area of 29,743 km^2 and is located in the northeastern part of the Armenian Highlands within the southern Caucasus. Geographically, Armenia lies between a latitude of 38°50' and 41°18' N and a longitude of 43°27' and 46°37' E (Figure 1A). The terrain is predominantly mountainous, with elevations ranging from 375 to 4,095 m above sea level (m.a.s.l.). The average elevation is 1,850 m.a.s.l. Due to significant altitudinal variations, Armenia has a highly diverse climate, ranging from arid subtropical to cold high-mountain climates. The average annual air temperature in the country is 5.5°C. In low-altitude regions, temperature reaches 12 – 14°C, while at elevations above 2,500 m, they drop below zero. Summers are very warm, with an average July temperature of 16.7°C. Winters are generally cold, with an average January temperature of −6.7°C. The average annual precipitation is 592 mm, varying from 200 to 1,000 mm across different regions.[34] Armenia consists of 11 administrative provinces (Figure 1B), excluding the capital Yerevan from this analysis.

The mountainous terrain creates a wide variety of natural conditions over a relatively small area. Armenia represents all major ecosystem types of the Caucasus (except for the humid subtropics) and nearly half of the Caucasus vascular flora (approximately 3,800 species).[34,36] There are up to 10 landscape zones in Armenia,[36] located at different altitudes, ranging from high-altitude snowfields to semi-deserts (Figure 2A).

All landscapes face climate and anthropogenic threats, including unsustainable agriculture and forestry practices, such as overgrazing, irrational irrigation, insufficient reforestation, weak regulation of construction in natural areas, and the overuse of biological resources (firewood, medicinal, edible, and ornamental plants) by local populations. Most of the semi-desert zone is used for irrigated agriculture, which causes soil erosion, secondary salinization, and desertification, contributing to the expansion of degraded semi-desert areas. Steppes have been significantly converted into croplands and are used as pastures. Only isolated patches of mountainous steppe remain as undisturbed natural ecosystems, with a reduction in the lower part of the steppe belt due to the expansion of semi-desert areas. The subalpine and alpine landscapes are used for haymaking and summer pastures. Unsustainable grazing has degraded large pasture areas, causing erosion, trampling, and soil decomposition. Armenia's forests suffered two major waves of degradation in the 20th century – first due to excessive logging from 1930 to 1950 and then during the economic crisis from 1992 to 1995.[36]

2.2. Data sources

Our analysis is based on the following publicly available statistics, cartographic data, and scientific publications:

(i) The map of landscape zones was created by Armenian scientists in past decades based on classical academic research.[36] The digitized contours of landscape zones were obtained from the Interactive Forest Atlas of Armenia website.[40] and used after correcting minor technical errors (Figure 2A).

(ii) Land cover data with a resolution of 10 m covering the territory of Armenia were sourced from ESRI, 2017, 2023 (https://livingatlas.arcgis.com/en/home/) and ESA, 2021 (https://esa-worldcover.org/en) (Figure 2B and C). The ESRI and ESA datasets were selected for testing as a component of the ecosystem accounting of Armenia, following a preliminary analysis of several land cover datasets, which indicated

Figure 1. Study area. (A) The location of Armenia. Image made with Natural Earth (naturalearthdata.com). (B) Administrative provinces of Armenia.

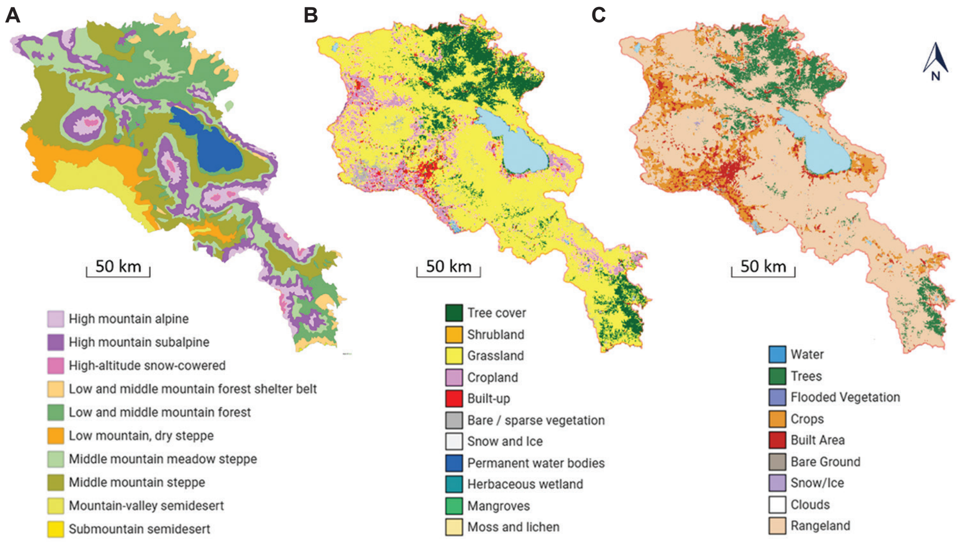

Figure 2. Digital maps and land cover datasets used. (A) The map of landscape zones of Armenia. (B) Environmental Systems Research Institute land cover dataset. (C) European Space Agency land cover dataset.

that ESRI and ESA most closely align with the available data from the state statistics of agricultural areas in Armenia.[41]

(iii) Digitized borders of administrative provinces of Armenia were sourced from the Interactive Forest Atlas of Armenia website.[40]

(iv) Regional statistics from the Statistical Committee of the Republic of Armenia (Armstat) were used to compare the land cover data with statistical data on agricultural areas.[42]

2.3. Creation of the LLCCs map

We intersected land cover classes with the 10 landscape zones from the landscape map of Armenia to align the land cover data more closely with the diversity of natural ecosystems, enabling updates on the natural-anthropogenic mosaic within these landscape zones.

We analyzed terrestrial natural land cover classes, excluding water bodies and wetlands from the analysis. The exclusion was made because the factors determining their condition and dynamics differ significantly from those affecting terrestrial ecosystems. In addition, anthropogenic territories, such as croplands and built-up areas, were also excluded from the analysis.

The ESRI land cover dataset includes four terrestrial natural classes (trees, rangelands, bare ground, and snow/ice). In comparison, the ESA dataset includes six terrestrial natural classes (tree cover, shrubland, grassland, moss and lichen, bare and sparse vegetation, and snow and ice). The intersection of ten landscape zones with land cover classes resulted in 60 and 40 combinations, respectively. We termed these combinations as LLCCs since they serve as proxies for ecosystems at this stage of analysis without precisely defining the ecosystems they represent. For simplicity of analysis, they were grouped into 20 combinations, woody (W) and non-woody (N-W) LLCCs in each landscape zone. We found it appropriate to combine all N-W natural classes (shrubland, grassland, moss and lichen, bare and sparse vegetation, and snow and ice) into one category named N-W LLCCs for several reasons: (i) to reduce the number of analyzed LLCCs for a clearer interpretation of the results, (ii) due to relative imprecision in distinguishing between different non-tree land cover classes, (iii) because of the very small area covered by shrubland, moss and lichen, and snow and ice, and (iv) because the IUCN and EUNIS ecosystem and habitat classifications,[20,22,26] including the EUNIS version adapted for Armenia,[34] group shrub vegetation with heathlands and tundra rather than woody vegetation. Thus, the resulting map includes 20 LLCCs obtained by intersecting woody and non-woody areas with 10 landscape zones.

2.4. Methods of analysis

The general workflow for processing input data and analyzing results is shown in Figure 3.

Both source land cover maps were provided as raster data in GeoTIFF format, while the province layer was delivered as vector data in GeoPackage format. We used the open-source desktop application Quantum Geographic Information System (QGIS)[43] to prepare and process the data. First, the vector landscape map was rasterized in QGIS to match the coordinate reference system, spatial

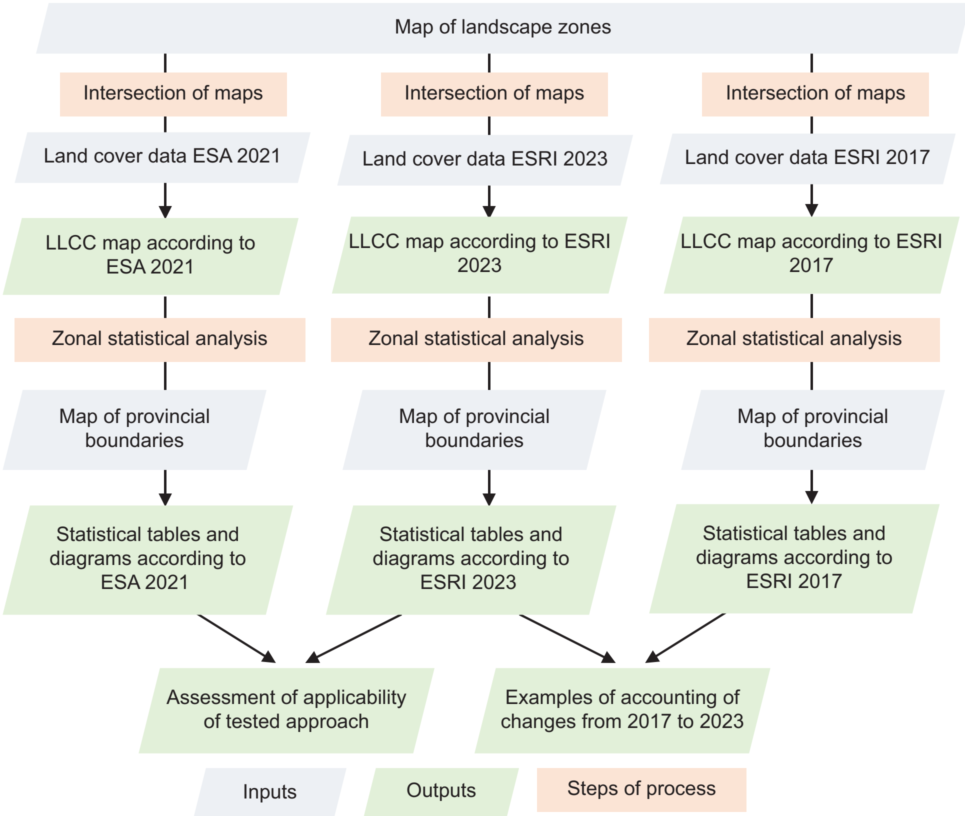

Figure 3. A diagram of the procedure algorithm
Abbreviations: ESA: European Space Agency; ESRI: Environmental Systems Research Institute; LLCC: Landscape-land cover classes.

extent, and resolution of the land cover rasters, ensuring all maps shared the same pixel-wise structure. Next, the resulting landscape raster map was combined with the land cover raster maps through two steps: (i) the pixel values of the land cover map were multiplied by 100, and (ii) these adjusted values were added to the corresponding pixel values of the landscape map, resulting in a unified raster. For example, a final pixel value of 204 indicates that the pixel has a land cover value of two (e.g., trees) and a landscape value of four (e.g., low and middle mountain forest).

This combined raster was then analyzed using a vector layer containing provincial borders. The Zonal Histogram tool in QGIS was employed to count the occurrences of each unique raster value within the polygonal zones of the provinces. The output layer, which contained statistics on the number of pixels for each combined LLCC within each Armenian province, was exported in tabular format for further statistical analysis.

We used LLCCs as a proxy for ecosystems to assess ecosystem rarity and diversity. We estimated the rarity of LLCCs based on their area – LLCCs with the smallest area were considered rare. To assess the importance of provinces for conserving LLCC diversity in Armenia, we calculated the total share of each LLCC area located within each province. Unlike the rarity ranking, which used the share of an LLCC area relative to its total area in Armenia, this method focused on the proportion of an LLCC area within a province compared to its total area in Armenia. This approach was applied to ensure that the value of rare LLCCs is not diminished.

Changes in the extent of natural landscapes and LLCCs were identified by comparing results from the ESRI 2023 and 2017 datasets. The linguistic accuracy was polished using the artificial intelligence tool ChatGPT.

3. Results

3.1. Accounting for the extent of natural landscapes

The 10 landscape zones are extremely unevenly represented in the country. Sub-mountain semi-desert and high-altitude snow-covered landscapes have the smallest total areas. The largest zone, the middle mountain steppe, occupies 23% of the country's territory. Other landscapes have areas between these extremes (Figure 4A). Grasslands predominate in all landscape zones. Tree cover occupies significant areas (from 17% to 55%) only in the low and middle mountain forest and forest shelter belt zones. ESRI dataset generally

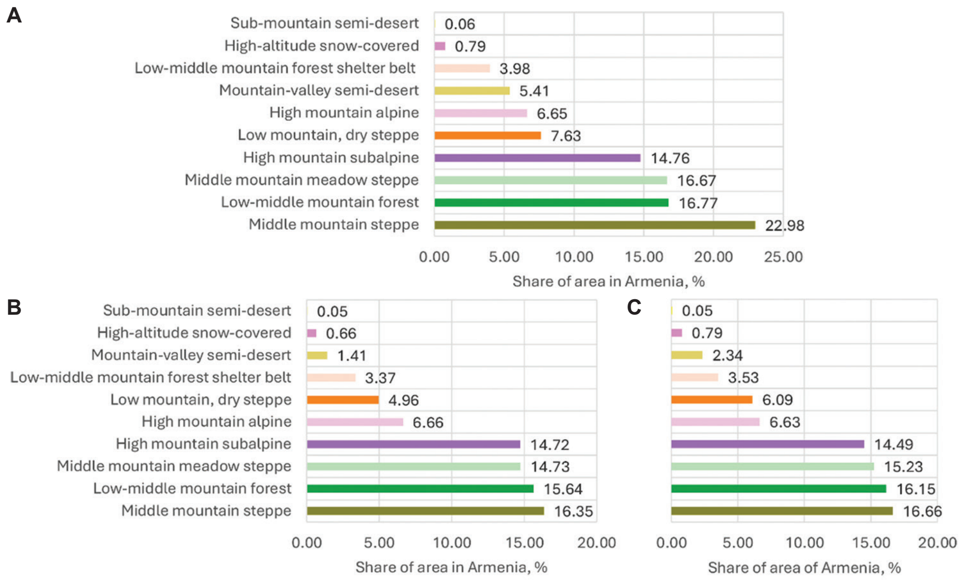

Figure 4. Extent of landscapes in Armenia. (A) Share of the total area of landscape zones, including both anthropogenic and natural areas. (B) Share of natural landscapes according to the Environmental Systems Research Institute 2023 data. (C) Share of natural landscapes according to the European Space Agency 2021 data.

identifies less tree cover and more anthropogenic areas (croplands and built-up areas) compared to ESA. Humans have transformed the mountain-valley semi-desert zone to the greatest extent, with more than half occupied by cropland and built-up areas. Low- and middle-mountain steppes are also significantly transformed by humans. High-altitude, alpine, subalpine, and mountain forest landscapes are the least transformed.[44]

To account for the area of natural landscapes, we excluded the areas of croplands and built-up zones from the calculations. This adjustment affected the ranking of the most human-transformed zones. The areas of mountain-valley semi-desert, low-mountain dry steppe, and middle-mountain steppe were significantly reduced (Figure 4B and C). The area of natural landscapes within the mountain-valley semi-desert and the low-mountain dry steppe is smaller according to ESRI data than the ESA data. This is because ESRI identifies a larger area of croplands and built-up areas compared to ESA.[44]

The landscape area is extremely unevenly distributed across the provinces. The smallest landscape zone by area, the submountain semi-desert, is located only in the extreme south of the country, in the Syunik province. Mountain-valley semi-deserts are located mainly in Armavir and Ararat provinces, low-mountain dry steppes in Aragatsotn, forests in Tavush, Syunik, and Lori, and snowy highlands and alpine zones in Syunik, Aragatsotn, Gegharkunik, and Vayots Dzor. Other landscapes are more evenly distributed across the provinces.[44]

3.2. Extent and rarity of LLCCs

The area of the 20 analyzed W and N-W LLCCs ranges from 0.005 km^2 to 4,700 km^2. Half of these LLCCs occupy <1% of the country's area and can thus be formally classified as rare (Figure 5A). This group includes nearly all woody LLCCs, except those in the low and middle mountain forest, forest shelter belt, and middle mountain meadow steppe. Among N-W LLCCs, only two, located in the sub-mountain semi-desert and high-altitude zones, were classified as rare. Three LLCCs, N-W ecosystems in subalpine, middle-mountain, and meadow steppe zones, are widespread, each covering between 14% and 16% of the country's territory. The remaining LLCCs fall between these extremes. Notably, most of the rare LLCCs do not align with the dominant vegetation types of their respective landscape (e.g., trees in high-altitude zones or semi-deserts). These anomalies require careful verification, as they may result from land cover interpretation errors or may belong to anthropogenic areas. Despite the differences in ESA and ESRI land cover data, the rarity rankings of LLCCs derived from both sources are very similar.[45]

Maps of LLCC rarity, based on these rankings, show a similar distribution pattern[45] (Figure 5B). The rarest LLCCs, covering <1% of the country's area, are distributed in small areas throughout the country, especially in the south, notably in the province of Syunik. Relatively rare LLCCs, occupying 1 – 5% of the country's area, are primarily found in the Ararat Valley and its surroundings. These include mountain-valley semi-desert and low-mountain

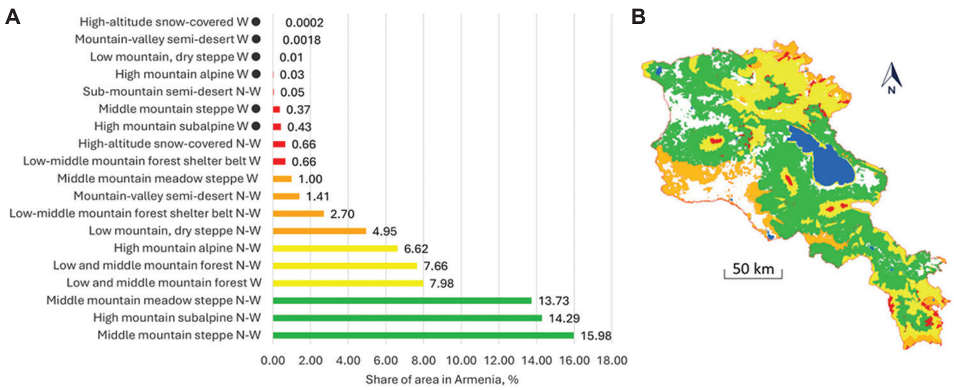

Figure 5. Assessment of landscape-land cover class rarity according to the Environmental Systems Research Institute 2023 data. (A) Ranking landscape-land cover class (LLCC) types by their area. LLCCs occupying no more than 5% of the zone's area are marked with a "●" symbol. (B) The map of LLCCs rarity. Colors correspond to those in the diagram.
Abbreviations: N-W: Non-woody; W: Woody.

dry steppe LLCCs. Although these LLCCs formally cover a large area, natural vegetation occupies only a small area due to significant anthropogenic transformation. The most widespread LLCCs are located in the central part of the country.

The pattern of distribution of N-W LLCCs across provinces generally mirrors the distribution of landscape zones, while the distribution of woody LLCCs in some provinces differs significantly. Syunik and Vayots Dzor contain a larger proportion of woody LLCCs than expected based on landscape distribution. In contrast, Shirak, Gegharkunik, and Aragatsotn have a smaller area of woody LLCCs.[45]

3.3. Assessment of the role of administrative provinces in preserving landscape-land covers class diversity in Armenia

To assess the importance of provinces for conserving natural landscapes and LLCCs in Armenia, we used an indicator based on the total share of landscape and LLCC areas located within each province. Unlike the LLCC rarity ranking (Figure 5), which considers the share of LLCC areas relative to their total area in Armenia, this approach calculated the share of landscape and LLCC areas within each province relative to their total area in Armenia. This method was adopted to ensure that the value of rare landscapes and LLCCs is not diminished.

The rankings of provincial importance for conserving natural landscapes based on ESRI and ESA data are very similar, differing only in the positions of certain provinces with similar values in the middle of the list (Figure 6).

Based on the rankings of provincial importance for conserving LLCCs derived from the ESRI and ESA data, only the first-ranked province (Syunik) and the last-ranked province (Shirak) remain consistent. The positions of other provinces vary within the rankings. Syunik is significantly ahead of other provinces, as it contains many rare LLCCs and retains a large share of their area in Armenia. In contrast, Shirak province has the smallest area of rare LLCCs (Figure 7). Notably, according to ESA data, the total share of LLCCs in Syunik is 1.5 times larger than that calculated using ESRI data.

When using the indicator of the total share of landscape and LLCC areas within each province, the rankings are largely influenced by the rarest LLCCs, which may be errors in the land cover datasets. For example, Syunik province ranks exceptionally high based on ESA data because almost all pixels of three rare LLCCs (woody areas in high-altitude snowy and alpine zones and sub-mountain semi-desert) are concentrated there. This pattern is not observed in ESRI data (Figure 7B). Conversely, Gegharkunik province ranks second in the ESRI-based ranking because almost all woody pixels in the high-altitude snowy zone are concentrated there (Figure 7A). These discrepancies suggest that ultra-rare LLCCs may represent land cover interpretation errors. If the rarest LLCCs, occupying no more than 5% of the landscape zone's area (marked with a "●" symbol in Figure 5), are excluded from the calculations, the province rankings based on ESRI and ESA data become more similar. However, some provinces with similar indicators occupy different positions in the middle of the list (Figure 7C and D). Despite this alignment, these rankings differ from the provincial rankings for landscapes (Figure 6).

3.4. Changes in landscapes and LLCCs extents and their provincial conservation importance in Armenia

Land cover changes recorded by ESRI data from 2017 to 2023 have resulted in changes in the area of natural landscapes and LLCCs (Figure 8). The data on LLCC

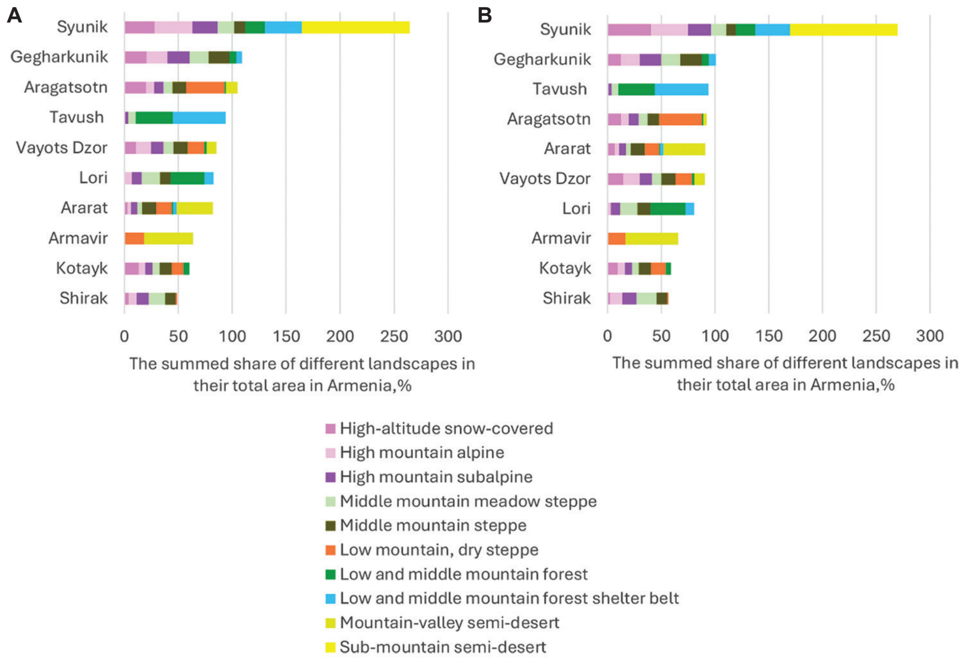

Figure 6. The rankings of the importance of provinces for conserving natural landscapes in Armenia. Rankings based on (A) Environmental Systems Research Institute 2023 data and (B) the European Space Agency 2021 data. The total percentage for provinces can exceed 100%.

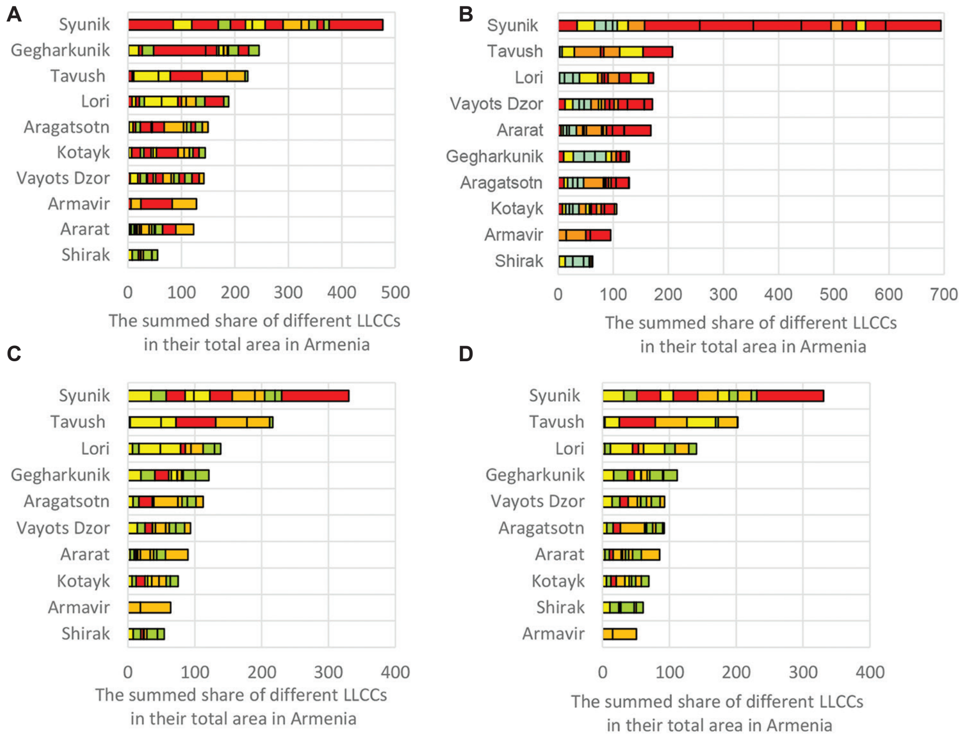

Figure 7. The rankings of provincial importance for conserving landscape-land cover class in Armenia. Rankings that include all LLCCs for (A) ESRI 2023 and (B) ESA 2021 data. Rankings that exclude LLCCs that occupy no more than 5% of the landscape zone's area using (C) ESRI 2023 and (D) ESA 2021 data. The LLCCs are shown in red, the less rare ones in orange, the relatively common in yellow, and the most common in green. The total percentage for provinces can exceed 100%.
Abbreviations: ESA: European Space Agency; ESRI: Environmental Systems Research Institute; LLCC: Landscape-land cover classes.

changes provides the following additional information compared to the data on landscape changes.

(i) The area of woody LLCCs has decreased more significantly than that of N-W LLCCs within the middle-mountain meadow steppe.
(ii) The total reduction in the area of mountain forest landscapes is driven by opposing changes in woody and N-W LLCCs, specifically, a decrease in woody LLCCs and an increase in N-W LLCCs.
(iii) The total area of the forest shelter belt has remained unchanged, although the wooded LLCCs within it have decreased.

For the assessment of changes in provincial importance (Figure 9), the data on LLCCs provides the following additional information: (i) the importance of the Syunik province for conserving LLCCs has decreased, even though it has remained unchanged with respect to landscapes and (ii) the importance of the Tavush province for conserving LLCCs has grown significantly more than it has for landscapes.

4. Discussion

4.1. Ecosystem mapping and accounting for ecosystem extent

The European ecosystem map is developed using a combination of land cover data (CORINE Land Cover [CLC], specific high-resolution layers, and data from OpenStreetMap) and the EUNIS habitat classification.[46-48] The present EUNIS hierarchical habitat classification contains four categories of natural terrestrial habitats at Level 1,[49,50] while the latest version (3.1) of the European

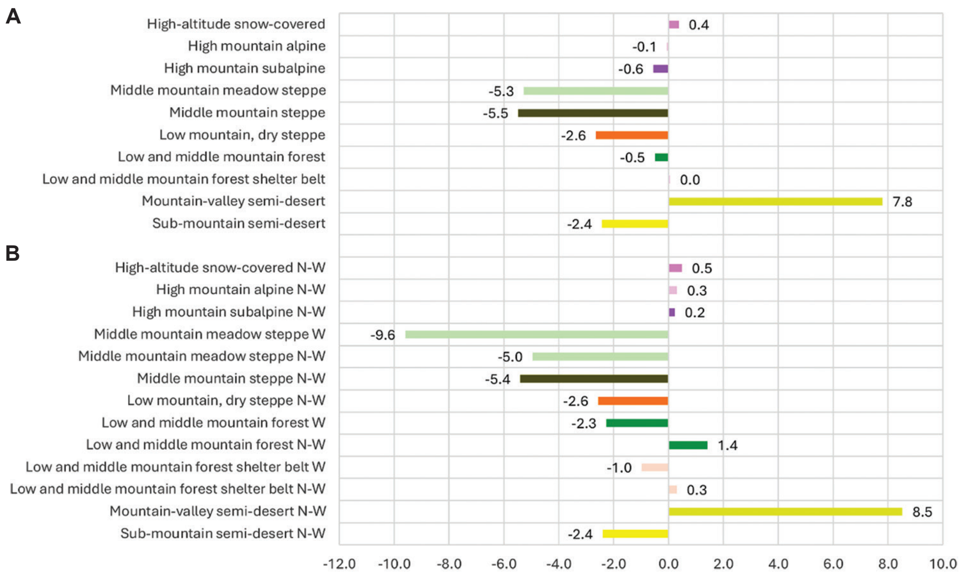

Figure 8. Changes in the extent of natural landscapes and landscape-land cover classes from 2017 to 2023. Changes in the area of (A) landscapes and (B) landscape-land cover classes.
Abbreviations: N-W: Non-woody; W: Woody.

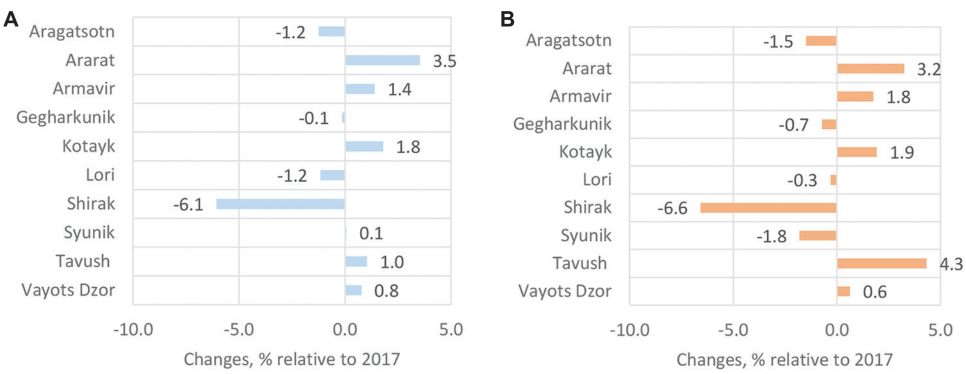

Figure 9. Changes in provincial importance for conserving natural landscapes and landscape-land cover classes in Armenia from 2017 to 2023. Changes observed in the (A) landscapes and (B) landscape-land cover classes.

ecosystem map expands this to seven categories.[48] At more detailed levels, the classification encompasses hundreds of ecosystem types, taking into account natural conditions and geographical features of biodiversity.[26,27,48,49] In European ecosystem extent accounts, a three-tier approach is used to track the changes in ecosystem areas. The Tier I account calculates the area of broad land cover classes, and the Tier II and III accounts subdivide the broad land cover classes into 23 and 30 ecosystem types, respectively.[23-25] In general, Level 1 and Tier 1 correspond to the general land cover classes, and more detailed levels reflect the biological and geographic specificity of ecosystems.

Tracking changes in the total area of land cover classes at Tier I is not very informative for ecosystem accounting in Armenia, given its complex terrain and high diversity of landscapes. The same land cover class in different landscape zones reflects completely different ecosystems, such as grasslands in the semi-desert and alpine zones. Changes in the area of land cover classes throughout the country reveal only the most general processes, such as urbanization or big unidirectional changes in national agriculture or forestry. The total area of a particular land cover class can remain stable while significant changes in ecosystems occur. For example, in Europe, from 2000 to 2018, although the total forest area was stable, a significant structural change occurred within forest ecosystems, including a reduction in coniferous forests compensated by an increase in the area of transitional forests and woodland/shrubs.[23,24] This was a significant change in the structure of forest ecosystems that was not noticed by ecosystem accounting at Tier I.

Therefore, tracking changes at more detailed levels is likely more useful for ecosystem accounting in Armenia. In the tested approach, the land cover data correspond to Level 1 and Tier 1, providing an update to the ecosystem map, while the landscape zones reflect the geographic and landscape specificity of natural ecosystems.

Maps obtained by intersecting land cover data with landscape zones enable the accounting of natural landscapes and LLCCs, which serve as proxies for terrestrial ecosystems. These maps are applicable within different ecosystem accounting areas (EAAs), such as the whole of Armenia, administrative provinces, and landscape zones. The same analysis can be performed for protected areas and other EAAs.

The LLCC map makes it possible to identify rare LLCCs and assess two IUCN RLE criteria: (i) declining distribution and (ii) restricted distribution of ecosystems.

The LLCC maps represent only the initial step and require further verification and refinement. Rare LLCCs with a very small area must be carefully validated to exclude classification errors or anthropogenic areas from the list of natural ecosystems. The verified LLCC map should be further refined with floristic and geobotanical data for Armenia.[33-35,37] The prototype of the ecosystem map can also be produced using available maps of potential vegetation. A key step in accounting for rare ecosystems is mapping biodiversity hotspots[51] and rare and endangered plant formations[52] that are not reflected in the land cover data or the maps of landscapes and vegetation zones of Armenia.

At this stage of the research, LLCC-based analysis cannot be used to evaluate the rarest LLCCs, as they could potentially be classification errors. Nevertheless, it is suitable for assessing the extent and changes of relatively common ecosystem types, which are less affected by land cover errors. LLCC mapping provides additional information compared to the data on landscape extent (Section 3.4, Figure 8).

4.2. Land cover data accuracy

The key issue for ecosystem extent accounting is the accuracy of the land cover data used. The goal of the CLC 2000 product was to achieve at least 85% thematic accuracy, with a total reliability of 87% and significant variation between classes.[23] We lacked reliable reference sites or *in situ* observations to accurately estimate the quality of the land cover datasets. The only available source for assessing land cover quality was the ARMSTAT[42] statistical data on forest and agricultural areas. By comparing these areas with those in the land cover datasets, we obtained a general similarity rate. While this rate cannot be directly interpreted as a measure of land cover accuracy, it still serves as a useful metric for understanding the overall pattern.

Regarding the tree cover, we estimated the discrepancy between land cover data and state statistics at 19% for ESRI 2023 data and 6% for ESA 2021 data. In 2021, according to ARMSTAT, 289,200 ha of Forest Fund (FF) land was covered with forest. According to ESA 2021 land cover data, the total tree cover outside settlements was 407,807 ha, whereas the ESRI 2023 data reported 311,700 ha. However, a significant part of the tree cover lies outside FF land, and this area is not included in the open statistics, making it difficult to compare land cover data and statistics. In 2014, the ECOserve project[53] estimated that the difference between the total tree cover area and the FF tree cover area was 33% of the FF tree cover area. If this proportion remained the same in 2021 and 2023, then the total tree cover area should be 384,636 ha, which is 19% larger than the indicated ESRI data and 6% less than the indicated ESA data.

A significant challenge in defining N-W land cover classes arises from the difficulty of distinguishing between croplands and natural N-W classes. For ecosystem accounting, accurately identifying the location and area of croplands is critical, as their expansion is one of the main threats to natural ecosystems. According to ARMSTAT regional statistics, data are available for arable land (including all lands intended for plowing, even if not used annually) and annually plowed areas. The land cover data aligns better with the first indicator, exceeding arable area by 18% and 23%, according to ESRI and ESA, respectively. However, in different provinces, the discrepancies between land cover data and statistics range from −62% to 70%.[41]

In this study, we tested the ESRI and ESA land cover datasets, which, in the preliminary assessment, showed relatively smaller discrepancies with ARMSTAT statistics on agricultural areas.[41] However, discrepancies between land cover data and official statistics remain significant.

Open harmonized statistics on agricultural and forest areas at smaller administrative units than provinces, as well as within the boundaries of agricultural and forestry enterprises can help refine land cover data across different classes. For an adequate interpretation of the inaccuracy of some classes in land cover, a graduated scale of threshold reliability in the analysis of relative changes in the extent of ecosystems may be helpful.[23]

5. Conclusion

The tested approach of intersecting a map of landscape zones with land cover data to create maps of LLCCs offers a valuable tool for ecosystem accounting. It takes into account the landscape and geographical specificity of terrestrial ecosystems, tracking changes in their area if land cover data are updated. LLCCs serve as proxies for ecosystems, and the resulting LLCC map can be considered a prototype ecosystem map for ecosystem accounting.

However, the LLCC-based approach faces a significant challenge, particularly in evaluating rare LLCCs that may be classification errors, which could be due to the low accuracy of land cover data. Alternative mapping methods are required to assess rare and unique ecosystems. Nevertheless, the LLCC-based approach provides additional information compared to landscape extent data and enables the assessment of the extent and changes in relatively common ecosystem types, which are less affected by land cover errors.

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Conflict of interest

The authors declare they have no competing interests.

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Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Digital maps and statistical tables are available on the BCC-Armenia website under the section "Ecosystem Extent" https://biodiversity-armenia.am/en/extent

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