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Spatial assessment of ecosystem services provisioning changes in a forest-dominated protected area in NE Turkey

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Abstract Forested landscapes offer high provisioning capacities for many ecosystem services (ES), yet their capabilities may change in time due to multifaceted ES drivers. Therefore, assessing the changes in individual ES is critical for ecosystem-based management. This study analyzes the spatio-temporal changes in ES provided by a forest-dominated protected area in NE, Turkey. To this end, 18 ES were quantified and mapped using the ES matrix approach for 1985 and 2021. Then, the status of the ES and potential drivers of landscape changes were revealed through the assessment of demographic and management structure changes. The results showed that the multiple ES provisioning capacity of the landscape increased by 7% over 35 years. The capacities for "crops" and "livestock" ES decreased for the same period. The most prominent ES were "wild foods," "erosion regulation," and "knowledge systems." Spatially, ES hotspots accumulated in the northern parts and the core zone of the protected area. The most significant changes occurred in the lowlands, mostly composed of degraded forests and coppices as of 1985 after their transformation into productive forests. The spatio-temporal changes in many ES can be attributed to the declaration of the landscape as a protected area in 1994. The removal of anthropogenic pressure and the impact of conservation management can be evaluated as the main drivers for the positive changes in the total ES capacity. Thus, sound policy structures and effective conservation strategies should be further encouraged for increasing protected areas' capacities to provide the large array of ES.

Keywords Ecosystem services (ESs) · ES drivers · ES matrix · Protected area management · Hatila Valley National Park

Introduction

The *Millennium Ecosystem Assessment* (MA, 2005) briefly defines ecosystem services (ES) as the benefits people derive from nature. They can be classified under three main categories: (i) Provisioning, (ii) Regulating & maintenance, and (iii) Cultural ES (Haines-Young & Potschin, 2018), such as timber production, climate regulation, and recreation, respectively. The ES concept is seen as a useful instrument for sustainable and equitable management of "natural capital" since it provides valuable information to decision-making processes in natural resource management through understanding complex ecosystem dynamics and ES drivers (Baral et al., 2013; Baskent, 2020; Jacobs et al., 2015; Rounsevell & Harrison, 2016).

The ES drivers cause changes in the status of ecosystems at different periods across multiple geographical scales (Rounsevell & Harrison, 2016). Anthropogenic

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pressures and biotic disturbances, for instance, directly affect ecosystem dynamics, result in multidirectional changes in the composition and structure of ecosystem types. Such changes may increase or decrease the ecosystem capacity to provide multiple ES (Burkhard et al., 2012). Specifically, human-induced land use/land cover (LULC) changes, and overharvesting generally undermine Regulating ES of forests. Likewise, fertilization, human power, and energy inputs can underpin Provisioning ES offered by agricultural systems to a limited extent. Therefore, a clear understanding of the nature and magnitude of the ES drivers and how these affect specific ecosystems is a must in sound ES assessment studies (Rounsevell & Harrison, 2016). In this context, monitoring and assessing the spatio-temporal changes in ES are critical for developing sustainable ES management and land-use strategies since people's dependence on ES gains further importance day by day.

To this end, many tools and models have been developed by researchers worldwide. The matrix model, developed by Burkhard et al. (2009, 2014), is one of the most practical tools widely used in ES monitoring and assessments. The model is mainly based on expert estimation of ES capacity for each LULC unit in a given map. Thanks to the model, any landscape's capacity to provide ES can be modeled and mapped separately for single ES or ES bundles. Thus, decision makers can compare different landscape units by quantifying their ES provisioning capacities with a uniform Likert scale. Jiang et al. (2022), for instance, used this tool to assess the supply–demand balance of ES in southwestern China between 1980 and 2015. They concluded that land fragmentation and population growth were the main ES drivers in their study area, resulting in imbalances between the supply and demand for selected ES. In another study, Poikolainen et al. (2020) used the matrix model for assessing ES in eastern Finland using GIS techniques. They found that old-growth forests and undrained mires had significant potential to provide multiple ES, while water bodies and settlements were prominent in terms of Cultural ES provisioning. The results also compatible with the "ground truth": the ES hotspots in their maps spatially overlapped with the "high biodiversity areas" defined by the local experts.

The strength of the matrix approach mainly comes from the model's ease of application, accessibility, and adaptability. It also has limitations due to its simplistic nature, subjectivity, and lack of confidence reporting (Hou et al., 2013; Jacobs et al., 2015). However, using such pragmatic tools is sometimes inevitable due to the global biodiversity and ES crisis. In such an age, elaborating sustainable and ecosystem-based management strategies are urgently needed to balance people's increased needs and nature's limited capacity to provide the large array of ES (Baskent, 2020; Jacobs et al., 2015).

In fact, the ES matrix has previously been used in many studies conducted in different ecoregions of the world (i.e., Burkhard et al., 2009; Jiang et al., 2022; Jurmalis et al., 2017; Poikolainen et al., 2020). Likewise, the long-term effects of management strategies on selected ecosystems can be broadly identified based on modeling and/or decision support systems (i.e., Baskent, 2020; Jurmalis et al., 2017; Lodin et al., 2020; Zengin et al., 2015). However, there are knowledge gaps in analyzing the effects of protected area management (e.g., active or passive management) on ES provisioning capacity of a formerly managed ecosystem. Since ecosystems are unique and most ecological studies are site-specific, creating a knowledge base using empirical data is important, especially for ecologically important but understudied regions.

In this context, the present study aims to (i) analyze the spatio-temporal changes of single ES and ES bundles in Hatila Valley National Park for the period 1985–2021 and (ii) reveal the main ES drivers that led to the potential changes in selected ES. Hatila Valley, a mixed forest-dominated landscape located in NE Turkey, was chosen as the case because it was declared as a protected area in 1994 based on the IUCN-II conservation criteria (Eroğlu et al., 2010). The study area is within the globally important biodiversity hotspots (i.e., Caucasus hotspot area) due to its high endemism rate and distinct environmental features (CI, 2004). Anthropogenic pressures have been limited in Hatila Valley since its declaration as a national park. Thus, an increased capacity for multiple ES potential is expected in the case study area.

Materials and methods

Characterization of the study area

Hatila Valley National Park is located in Artvin Province of Turkey (Fig. 1). Its total area coverage is 16888 ha. The main LULC classes in the study area are natural

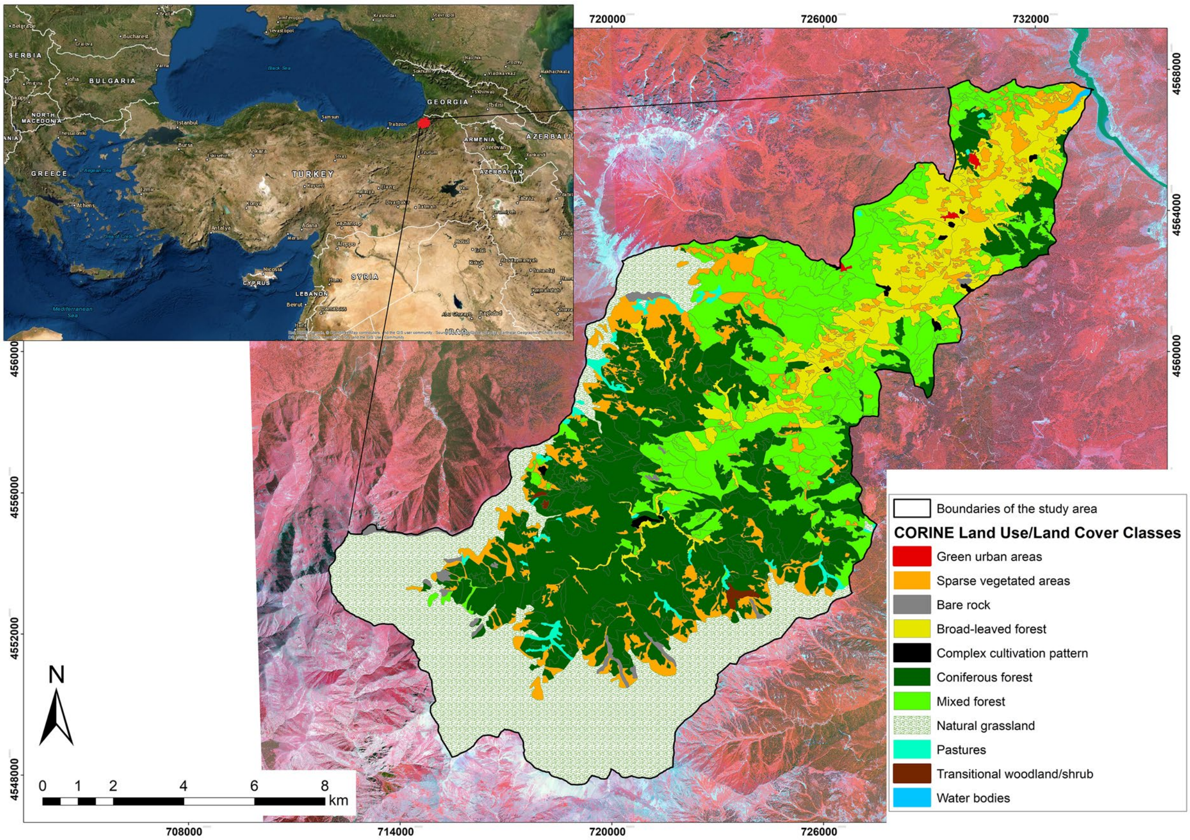

Fig. 1 Location of Hatila Valley National Park with the actual LULCs in 2021

forests and grassland. Table 1 shows the current shares and the temporal changes in the area coverages of each LULC class from 1985 to 2021. The dominant forest tree species in Hatila Valley are *Picea orientalis* L., *Pinus sylvestris* L., *Fagus orientalis* Lipsky, *Abies nordmanniana* ssp. *nordmanniana, Carpinus betulus* L., *Quercus petraea*, and *Ostrya carpinifolia*. These species establish pure or mixed natural stands with different combinations. The study area has a harsh topography with rocky terrain and steep slopes. The altitude of the V-shaped valley ranges from 250 m in the NE lowlands to 3200 m in the SW grasslands. The average slope is more than 60%. Many canyons, waterfalls, and straits exist particularly in the middle parts of the valley due to the rugged topography (GDF, 2022).

The climate is semi-humid in the case study area. It is characterized by mild and wet winters while the summer season is cool and dry. The annual average air temperature and precipitation totals are 12 °C and 720 mm, respectively (Eroğlu et al., 2010). That is why some Mediterranean plant communities, e.g., *P. pinea*, *Arbutus andrachne*, *Laurus nobilis*, and *Olea* sp., can locally survive from the last ice age although the study area is located in the Caucasus Region. Moreover, Hatila Valley hosts many endemic herbaceous species, old-growth forest stands, and some large carnivores. It is also one of the 21 priority protected areas of the world, i.e., Caucasus' temperate forests (CI, 2004). Thus, the valley was designated as a national park in Turkey (Eroğlu et al., 2010). Since then, its previously managed forests have been strictly protected against silvicultural interventions. Nevertheless, pure *P. orientalis* stands in the area are occasionally subjected to the *Ips typographus* (spruce bark beetle) attacks. In such cases, salvage cuttings are allowed to foresters for extracting infected trees from these forest stands (Akkuzu et al., 2009; GDF, 2022).

Table 1 The area, share, and the temporal change of each LULC class in the study area (GDF, 1985, 2022)

	Land use land cover (LULC) classes		Area coverage (ha)		Share (%)		Change direction
	Turkish stand-types nomenclature	CORINE nomenclature	1985	2021	1985	2021	
Forest	Broad-leaved stand	Broad-leaved forest	543.3	1809.7	3.2	10.7	+
	Coniferous stand	Coniferous forest	4750.6	5399.5	28.1	32.0	+
	Broad-leaved + conifer mixed stand	Mixed forest	4010.0	3482.4	23.7	20.6	−
	Degraded stand	Sparsely vegetated areas	2816.4	1616.7	16.7	9.6	−
	Regeneration site	Transitional woodland/shrub	214.8	25.2	1.3	0.1	−
		Total forest area	12,335.1	12,333.5	73.0	73.0	=
Non-forest	Grassland	Natural grassland	4306.0	4308.9	25.5	25.5	=
	Small meadows within the forest	Pastures	113.0	125.4	0.7	0.7	=
	Agricultural land	Complex cultivation patterns	132.5	26.6	0.8	0.2	−
	Settlement	Green urban areas	0.0	18.3	0.0	0.1	+
	Stony and rocky areas	Bare rock	0.0	67.2	0.0	0.4	+
	Water	Water bodies	1.4	8.1	0.0	0.1	+
		Total non-forest area	4552.9	4554.5	27.0	27.0	=
		Grand total	**16,888**	**16,888**	**100**	**100**	=

Methods

The flowchart of the study can be seen in Fig. 2. The methodology of each step is described in the next subsections with procedural details.

Geodatabase development

A comprehensive database was developed in GIS environment (ESRI, 2012). The forest management plans, belonging to the years 1985 and 2022, and their forest cover maps (aka stand-types maps) were used as the main data source in compiling the database (GDF, 1985, 2022). However, the map of the 2022 plan was based on the previous year's satellite data and field surveys conducted during the 2021 summer. Thus, we took the examination period as 1985–2021.

Since the historical forest cover maps of the Turkish General Directorate of Forestry (GDF) were in hardcopy form, the map of Hatila Valley was first transferred to the digital environment in three steps: (i) scanning hardcopy maps into digital format, (ii) adapting to the 1/25,000 topo-maps based on UTM projection and digitalization, (iii) generating attribute table of the 1985's map with stand-type codes. Thus, the historical forest cover map was made ready to use and comparable to the digital map of 2021.

In a next step, the ES provisioning capacity of each stand type was manually entered into the maps' attribute tables at the stand (aka sub-compartment) level. To this end, new fields were added to the attribute tables of the 1985 and 2021 maps. Then, detailed stand-type codes, including tree species, developmental stage, and canopy closure, were generalized and matched to the CORINE's land cover classes. The matched LULCs of the two classification systems are shown in Table 1.

ES assessment and other spatial analyses

The CORINE classification system was used to associate stand types with 18 ES in the matrix (Table 2). Thus, the landscape's capacity to provide individual ES could be assessed spatially. The ES matrix approach was first developed by Burkhard et al. (2009) and then improved again by Burkhard et al. (2014), and Jacobs et al. (2015). It allows to conduct a rapid assessment and produce a map of the relative value of individual ES in a given spatial unit, such as LULCs and stand types. Here, the ES values are determined based on various resources, such as expert judgment, statistics, interview results, on-site assessment, and computer-based modeling. Then, they are scaled using proper class breaks. In the matrix, a

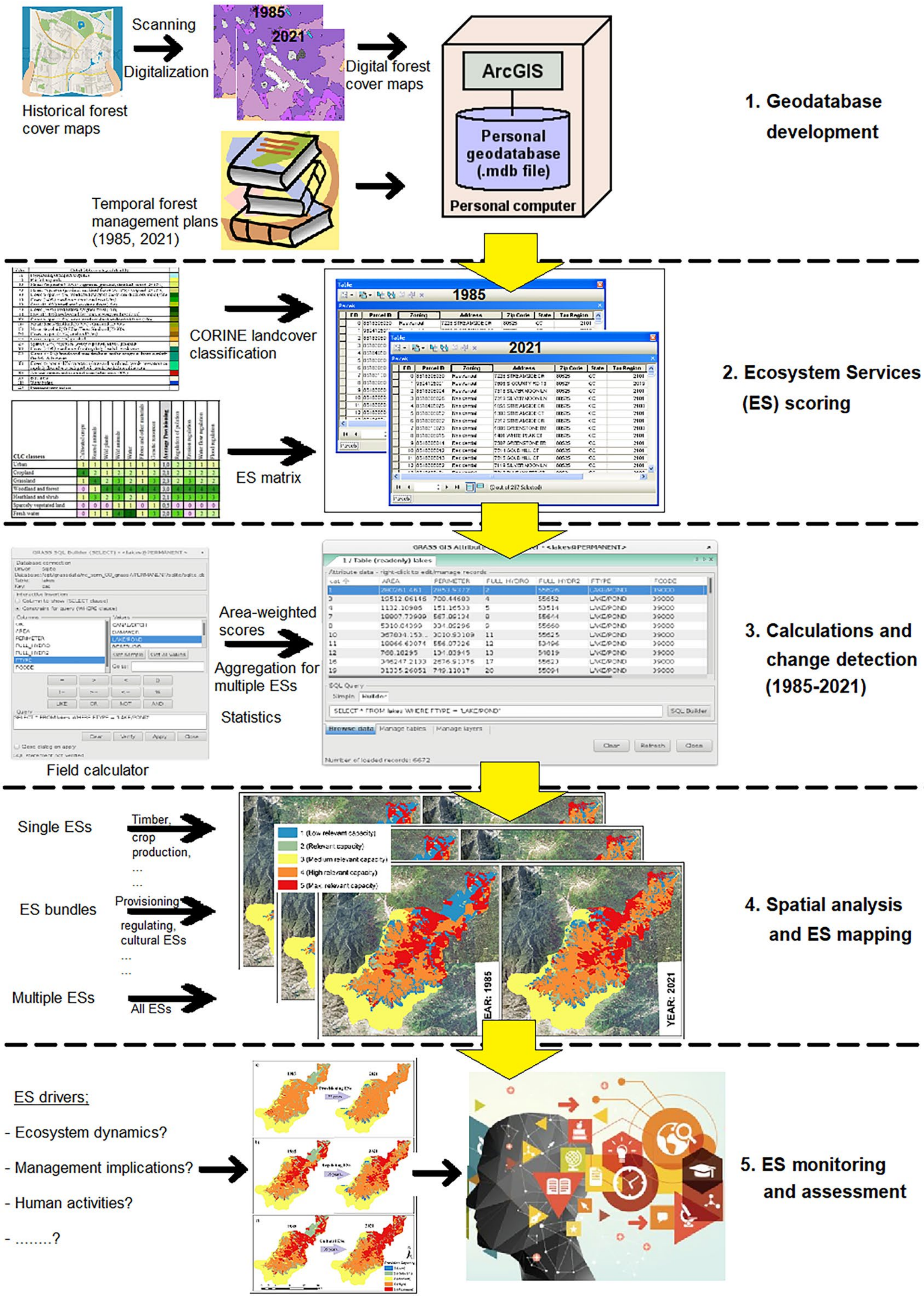

Fig. 2 Workflow and main procedural steps used in the study

Table 2 The matrix to assess the landscapes' ES provisioning capacities (adapted from Burkhard et al., 2009, 2014)

Land use land cover class	Provisioning ES score*						Provisioning ES bundle (Σ_1)	Regulating ES score					
	Crops	Fodder	Livestock (domestic)	Timber	Fish, seafood & edible algae	Wild foods & resources		Biodiversity	Global climate regulation	Water flow regulation	Erosion regulation	Pollination	Pest and disease control
Broad-leaved forest	0	1	0	5	0	5	**11**	4	5	3	5	4	4
Coniferous forest	0	1	0	5	0	5	**11**	4	5	3	5	4	4
Mixed forest	0	1	0	5	0	5	**11**	5	5	3	5	4	5
Sparsely vegetated areas	0	0	1	0	0	1	**2**	3	0	1	1	0	1
Transitional woodland/shrub	0	1	1	1	0	1	**4**	4	2	1	1	2	2
Natural grassland	0	2	3	0	0	5	**10**	5	5	1	5	1	1
Pastures	0	5	5	0	0	2	**12**	2	2	1	1	0	2
Complex cultivation patterns	4	2	1	0	0	1	**8**	3	1	1	1	2	3
Green urban areas	0	0	0	0	0	0	**0**	3	2	2	2	2	2
Bare rock	0	0	0	0	0	0	**0**	3	0	0	2	0	0
Water bodies	0	0	0	0	4	4	**8**	4	1	5	0	0	3

Regulating ES bundle (Σ_2)	Cultural ES score						Cultural ES bundle (Σ_3)	Multiple (all) ES score ($\Sigma_1+\Sigma_2+\Sigma_3$)
	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & diversity	Natural heritage & diversity		
25	5	5	5	3	4	5	**27**	**63**
25	5	5	5	3	4	4	**26**	**62**
27	5	5	5	3	4	5	**27**	**65**
6	1	1	3	0	2	1	**8**	**16**
12	2	3	4	1	2	2	**14**	**30**
18	3	4	5	1	3	3	**19**	**47**
8	2	2	2	0	3	1	**10**	**30**

Table 2 (continued)

Regulating ES bundle (Σ_2)	Cultural ES score						Cultural ES bundle (Σ_3)	Multiple (all) ES score ($\Sigma_1+\Sigma_2+\Sigma_3$)
	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & diversity	Natural heritage & diversity		
11	2	2	2	0	3	0	**9**	**28**
13	3	3	1	0	2	1	**10**	**23**
5	2	3	3	2	2	1	**13**	**18**
13	5	4	4	2	3	3	**21**	**42**

*Scale for assessing the ES scores (0 – 5): 0 = no relevant capacity, 1 = low relevant capacity, 2 = relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity, 5 = Maximum relevant capacity

uniform scale (from 0 to 5) is used where zero is for spatial units where the selected ES is not delivered at all and five is for spatial units with a maximum capacity value of the selected ES (Table 2). Thus, it is possible to make different ES comparable, as stated by Jurmalis et al. (2017). Based on this approach, ES scores were separately assigned to 643 and 778 sub-compartments in the 1985 and 2021 maps, respectively. We used original scores suggested by Burkhard et al. (2009, 2014) for "normal" landscapes at one time point in summer before harvest.

The area coverage of each stand differed in the temporal forest cover maps. During the spatial analyses, the effect of the area coverage (i.e., contribution of each ES) was taken into account by using Eq. 1. Then, ES bundle scores were calculated for the Provisioning, regulating, and cultural ES as shown in Eqs. 2–4. Finally, the ES bundle scores were summed up for calculating the multiple (total) ES capacity provided at the stand level (Eq. 5).

$$\mathrm{AWESS} = \frac{\mathrm{ESS} \times \mathrm{Shape\_area}}{10\,000} \tag{1}$$

$$\begin{aligned}\mathrm{AWS(P)} = {} & \mathrm{AWESS(Crops)} + \mathrm{AWESS(Fodder)} \\ & + \mathrm{AWESS(Livestock)} + \mathrm{AWESS(Timber)} \\ & + \mathrm{AWESS(Fish)} + \mathrm{AWESS(Wildfoods)}\end{aligned} \tag{2}$$

$$\begin{aligned}\mathrm{AWS(R)} = {} & \mathrm{AWESS(Biodiversity)} + \mathrm{AWESS(Climate)} \\ & + \mathrm{AWESS(Water)} + \mathrm{AWESS(Erosion)} \\ & + \mathrm{AWESS(Pollination)} + \mathrm{AWESS(Pest)}\end{aligned} \tag{3}$$

$$\begin{aligned}\mathrm{AWS(C)} = {} & \mathrm{AWESS(Recreation)} + \mathrm{AWESS(Aesthetics)} \\ & + \mathrm{AWESS(Knowledge)} + \mathrm{AWESS(Religious)} \\ & + \mathrm{AWESS(C.heritage)} + \mathrm{AWESS(N.heritage)}\end{aligned} \tag{4}$$

$$\mathrm{AWS(Multiple)} = \mathrm{AWS(P)} + \mathrm{AWS(R)} + \mathrm{AWS(C)} \tag{5}$$

In Eqs. 1–5, AWESS is the area-weighted ES score for a given stand (sub-compartment) in the forest cover maps, ESS is the ES score for each ES in the matrix (Table 2), the Shape_area is the area coverage for a given stand (m^2), 10,000 is the conversion coefficient from m^2 to ha, AWS(P) is the area-weighted score for the Provisioning ES bundle, AWS(R) is the area-weighted score for the Regulating ES bundle, AWS(C) is the area-weighted score for the Cultural

ES bundle, and AWS(Multiple) is the area-weighted score for the total capacity of all ES provided by each stand.

Since the total ES capacity is generally reported at the landscape level (Burkhard et al., 2009), stand-level ES scores were aggregated to the entire study area through the Sum function of the ArcGIS Statistics tool. The landscape-level scores might also be presented as per unit area (i.e., 1 ha in the Turkish forestry) for the two temporal maps by dividing them by the total size of the study area (each 16,888 ha in our case). As a last step, the original per unit area scores (0–5) were rescaled to a scale of 0 to 100.

As for mapping, the landscape's current and historical ES provisioning capacities were visualized in ArcMap 10.2 (ESRI, 2012). The visualization was performed by classifying the ES scores based on the quantiles at the stand level. The final maps were generated for selected ES (timber and crop production), ES bundles (provisioning, regulating, and cultural bundles), and multiple ES (total ES capacity) provided by the entire study area.

Results and discussion

The current state of ecosystem services

The current capacities of Hatila Valley for provisioning ES can be seen in Fig. 3a. The radar graphic revealed wild foods & resources, and timber production as the two prominent ES in the valley. Their provisioning capacities were about 90% and 60%, respectively. The harvesting of wild foods & resources (e.g., mushrooms, wild berries, and wild goats) by the local people is limited and timber production activities are forbidden since the study area is strictly protected under the national park statute in Turkey. The high capacities for those ES can be associated with the high share of the forest LULC class. Indeed, forestlands cover almost ¾ of the entire study area.

The ES provisioning capacities of fodder and domestic livestock were low (Fig. 3a) due to the limited agricultural land. Although vast natural grasslands dominate the SW parts of the study area (Fig. 1), the elevation is quite high (~2500 m) for animal husbandry. (Sub-) Alpine conditions characterize these areas during most of the year. In addition, the road network is insufficient to access those highlands by the villagers. Therefore, local people and shepherds generally use small openings within forest stands for the pastoral needs of livestock (GDF, 2022).

Regarding Regulating ES, the valley provides the near-full capacities for biodiversity, climate regulation, and erosion control ES (Fig. 3b). It is mostly attributable to the existence of fully-covered and multi-species stands in the unmanaged forests of Hatila. Indeed, more than half of the forested area is fully stocked, which is a favorable ecosystem structure for climate regulation. Many forestry studies showed that fully stocked, productive forests could store a high amount of carbon in their above- and below-ground biomass (Bulut & Günlü, 2019; Felipe-Lucia et al., 2018; Sauti, 2019; Seki & Atar, 2021). These forests are also recognized as superior for the erosion control ES to protect soil against the erosive effects of rainfall (Vatandaşlar et al., 2020). In a recent study by Sauti and Karahalil (2022), the 43-year change in soil loss amount was explored in the Yuvacık Forest Planning Unit located in NW, Turkey. The researchers found a decrease in soil loss by up to 90% for the study period (1972–2015). The sharp decrease was attributed to the increase in stand basal area & standing volume, as well as effective forest conservation practices, such as preventing illegal logging, and grazing within the forest.

Nevertheless, capacities for water flow regulation, pollination, and pest & disease control ES are low or medium levels in Hatila Valley (Fig. 3b). The low capacity for the water production ES can be expected because the leaf area index is generally high in densely forested watersheds. Eventually, a huge amount of rainfall is intercepted from the canopy surface directly to the atmosphere (Yurtseven et al., 2018). In addition, dense forests uptake more water from the soil through transpiration. Thus, the runoff coefficients are often low in fully covered watersheds, resulting in decreased surface water provision. However, the water quality may be high in such watersheds (Yurtseven et al., 2018; Zengin et al., 2015). Water production ES can also be associated with the mean diameter at breast height (DBH) of forest stands. Sauti and Karahalil (2022) showed that the amount of water significantly decreases in a forested catchment as the mean DBH increases over time. This is also true for our study area since the unmanaged forests of Hatila Valley continued to grow up for almost 30 years based on natural forest development.

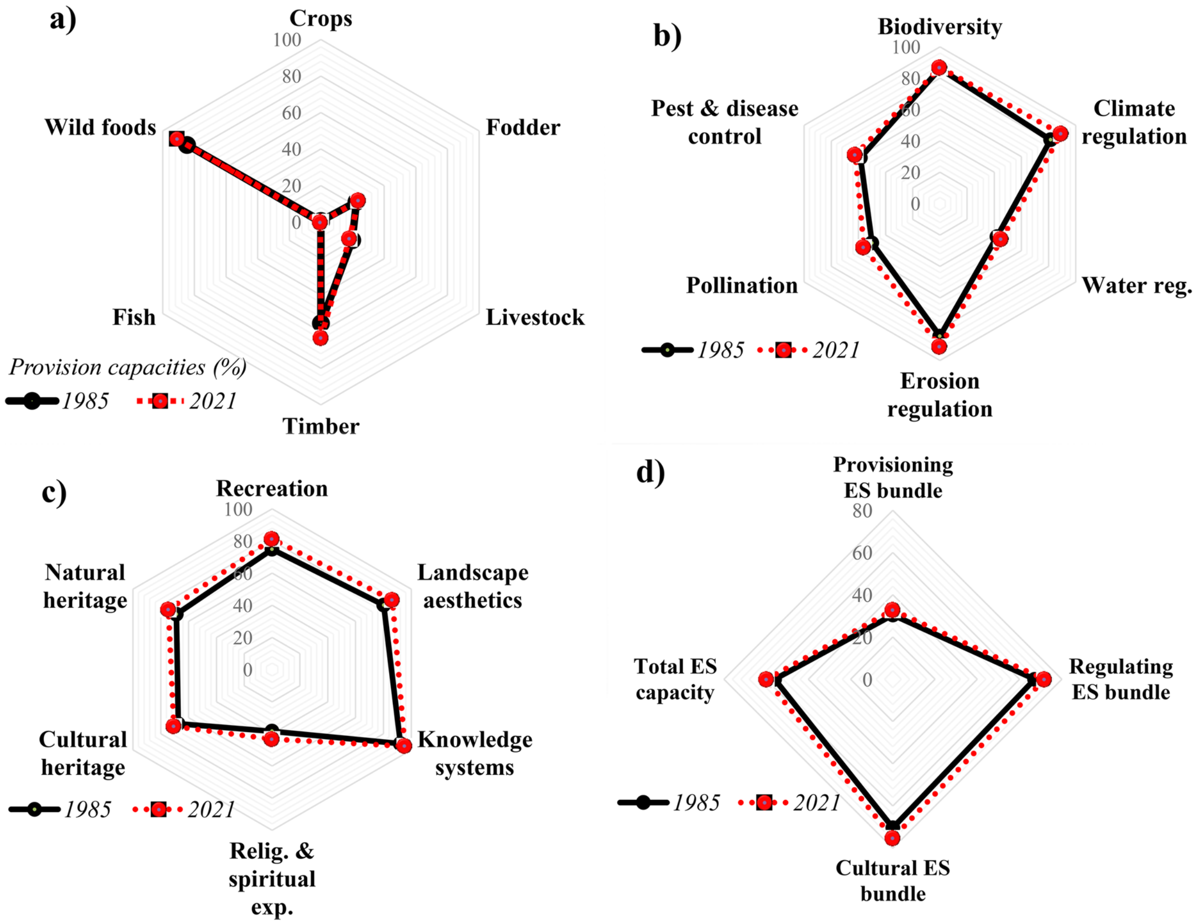

Fig. 3 The capacities of Hatila Valley to provide **a** provisioning, **b** regulating, **c** cultural ES, and **d** ES bundles & multiple (total) ES in 1985 and 2021

As for the pest & disease control ES, the provisioning capacity of the landscape is about 60% (Fig. 3b). The reason for this medium capacity may be the large portion of fully covered *Picea* stands in the study area. Felipe-Lucia et al. (2018) stated that fully covered coniferous forests tended to offer a lower provisional capacity for controlling pests and disease. Indeed, some forest compartments in the Hatila forest are currently suffering from significant pest attacks by the *I. typographus*. In particular, it affected pure *Picea* stands in SE parts of the forestland, causing tree mortality in a short period (GDF, 2022).

The provisioning capacities for Cultural ES are shown in Fig. 3c. The knowledge systems ES is remarkable owing to the diverse ecosystems and rich environmental settings in the study area. In this sense, many relict species, geomorphological formations, research setups, and multiple viewpoints are some of the values of Hatila Valley (Fig. 4a, b). As for relict tree species, the isolated stands of *P. pinea* and *A. andrachne* can be given as examples (Fig. 4c, d). These species originally grow in the Mediterranean region but can also survive only on Hatila's lowlands in the Black Sea region of Turkey. That is why a 188 ha *P. pinea* stand, located at an altitude of 600 m, was set aside as an "in situ gene conservation forest" by the GDF in 1996. A monumental tree, *P. orientalis*, was registered in Hatila Valley, whose age, DBH, and height were about 200 years old, 100 cm, and 35 m (GDF, 2022). These elements offer great opportunities to conduct in situ research to scientists and respective students. They also improve other Cultural ES, such as recreation & ecotourism, natural & cultural heritage, landscape aesthetics, and spiritual experiences & inspiration. In this sense, the glass-made

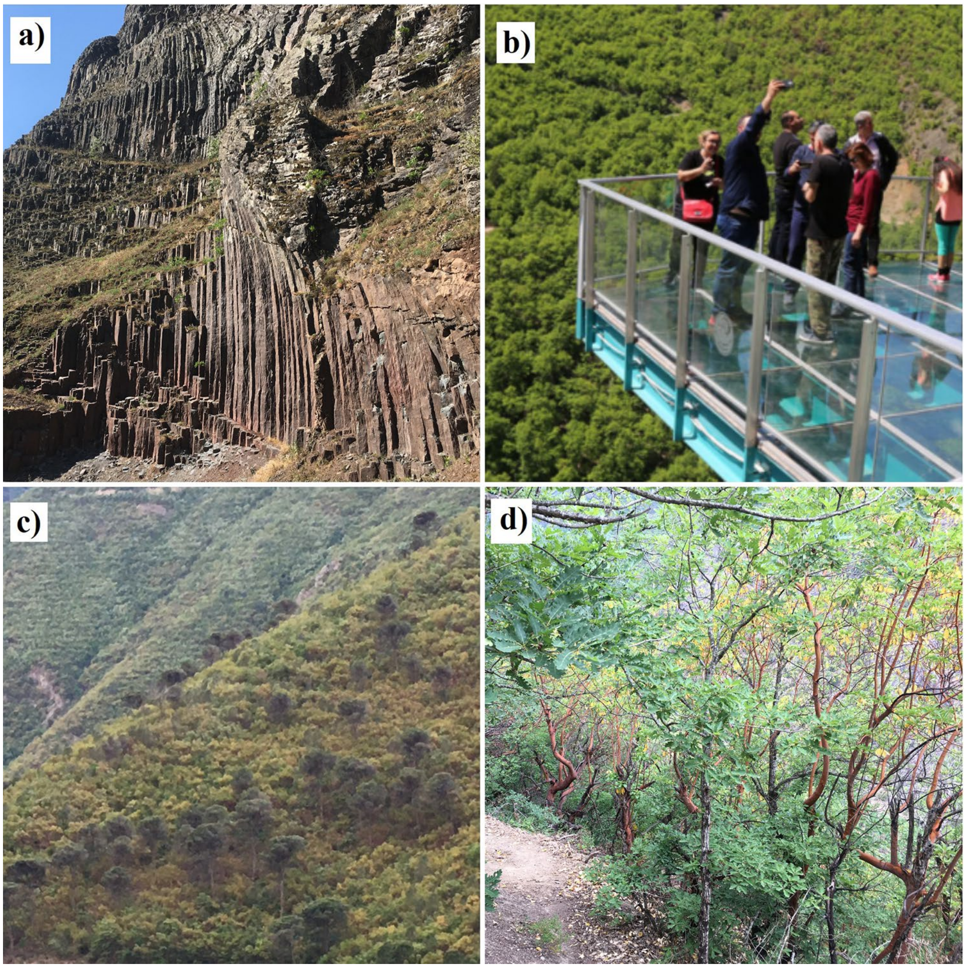

Fig. 4 Some characteristics depicting Hatila Valley: **a** the basaltic rocks viewpoint, **b** glass-made observation terrace, **c** the in situ gene conservation stand of *P. pinea*, and **d** an ecological trail passing through the mixed stand of *A. andrachne* and *Q. petraea* (Photos: **a**, **c**, **d** by Can Vatandaşlar; **b** from Taka Newspaper, 2017)

observation terrace, basaltic rocks, and picnic areas near Hatila Creek are some of the popular facilities for domestic and foreign tourists (Fig. 4).

Overall, the regulating and cultural ES supplies are higher than the provisioning ES (Fig. 3d). It may be stemming from the low potential of individual Provisioning ES in the study area. Specifically, there are almost no crops and fish, and seafood & edible algae ES categories in the landscape in 2021 (Fig. 3a). Fodder and domestic livestock ES are also offered at low capacities (24%, and 18%, respectively). Although wild foods & resources and timber production ES are supplied at reasonable levels, the lower levels of other individual Provisioning ES adversely affect the aggregated value of this ES bundle. In contrast, almost all ES for the regulating and cultural bundles were provided at more than 50% (Fig. 3b, c). The domination of Regulating and Cultural ES can be explained in this way. These findings are partly in line with other published studies focused on ES assessment. For example, Yuan et al. (2019) analyzed the impact of LULC change on ES value in Shangzhou district, China. Accordingly, the total ES value of Shangzhou was mostly composed of the regulating and supporting ES bundles both in 2000 and 2015. Since they used a different classification system separating regulating and supporting ES, the results were not completely comparable for the bundles of the present study. However, in their study, these two bundles were followed by the provisioning ES bundle, like us.

Aggregating all ES bundles, the total capacity of the landscape for multiple ES provisioning was calculated as 60% (Fig. 3d). The lower flows of Provisioning ES (33%) caused the multiple ES capacity to remain at this level. Depending on ecosystem dynamics and other external drivers, such as human activities and protected area management, it may change in time. Indeed, the structure of LULC classes and their distribution pattern in the landscape can strongly affect the ES scores in the matrix. Given a study focusing on forest ES, Jurmalis et al. (2017) stated that stand age, and species mix determined the supply quality of most ES. For example, clear-cut forest areas in central Latvia could provide no noise reduction ES in their case study. These kinds of forest patches should be taken into account in ES assessment studies, especially for managed forests.

The temporal changes in ecosystem services

Table 3 shows the temporal changes of ES provided by Hatila Valley for the studied period. Accordingly, the multiple ES provision capacity increased by 7% over 35 years. Likewise, the increases in the provisioning, regulating, and cultural ES bundles were slight and almost equal to each other (Table 3). Excluding the unexpected rise in the fish, seafood & algae ES category, the most significant positive change was observed in the timber production ES in the valley. The increase rate of 14.3% can be attributed to the difference between the forest's growing stocks (aka timber volume) in two temporal points. While there was no change in the total area coverage of the Hatila forest (Table 1), the composition and configuration of the forest changed between 1985 and 2021. In addition, Hatila Valley has declared as a national park in 1994 (Eroğlu et al., 2010). Since then, the valley has been strictly protected by the Turkish General Directorate of Nature Conservation and National Parks (DKMP). Therefore, no timber harvesting activity is allowed in the area, except for limited salvage loggings for deadwood. Thus, the unmanaged stands of Hatila have continued to grow uninterruptedly (without any planned

Table 3 The temporal changes in ES provisioning capacity of Hatila Valley

ES type	Standardized (0–100) ES score in 1985	Standardized (0–100) ES score in 2021	Periodical change in the ES capacity (%)
Crops	0.6	0.1	−83.3
Fodder	22.5	23.7	+5.3
Livestock (domestic)	19.7	18.0	−8.6
Timber	55.4	63.3	+14.3
Fish, seafood, & edible algae	0.1	0.4	+400.0
Wild foods & resources	84.6	91.1	+7.7
Provisioning ES bundle	30.5	32.7	+7.2
Biodiversity	86.1	86.9	+0.9
Global climate regulation	81.5	89.3	+9.6
Water flow regulation	42.0	45.3	+7.9
Erosion regulation	84.5	91.2	+7.9
Pollination	50.0	55.9	+11.8
Pest and disease control	58.5	62.3	+6.5
Regulating ES bundle	67.1	71.8	+7.0
Recreation & tourism	74.8	81.2	+8.6
Landscape aesthetics & inspiration	80.2	86.4	+7.7
Knowledge systems	92.2	95.3	+3.4
Religious & spiritual experience	38.4	43.3	+12.8
Cultural heritage & diversity	67.4	70.6	+4.7
Natural heritage &diversity	68.8	74.5	+8.3
Cultural ES bundle	70.3	75.2	+7.0
Total capacity for multiple (all) ES	**56.0**	**59.9**	**+7.0**

management action such as clear-cutting, regeneration, and thinning) for the period 1994–2021 based on natural forest development. Eventually, growing stock, and canopy cover increased and the species mix changed in the forest (GDF, 1985, 2022). Yuan et al. (2019) experienced similar changes in Shangzhou district, as the total ES value of the case study area increased significantly between the years 2000 and 2015. They attributed this change to forest expansion owing to local policies of returning farmland to woodland. Thus, the contribution of forests to the total ES value increased to 61% in Shangzhou, although forestlands cover only 33% of the entire landscape.

A significant decrease was observed in the crop production ES. Its capacity decreased by 83.3% from 1985 to 2021 (Table 3). It can be explained by the decline in the area coverage of agricultural lands in Hatila Valley (Table 1). The main driver for this ES change might be reducing the human population in the study area during the same period. The people inhabiting the villages almost halved over 35 years, parallel to Turkey's rural population and rural abandonment dynamics (Fig. 5).

The most drastic change was observed in fish, seafood & edible algae ES category as much as 400% in a positive direction (Table 3). This was due to increased area coverage of water bodies in the study area. However, there was no actual change in the area of water bodies. It was all about the advancement of remote sensing technologies and the changes in the modern mapping techniques, i.e., GIS. Until the early 2000s, LULC classes were being separated with coarse delineations because of several limitations embedded into the low-resolution-based analog

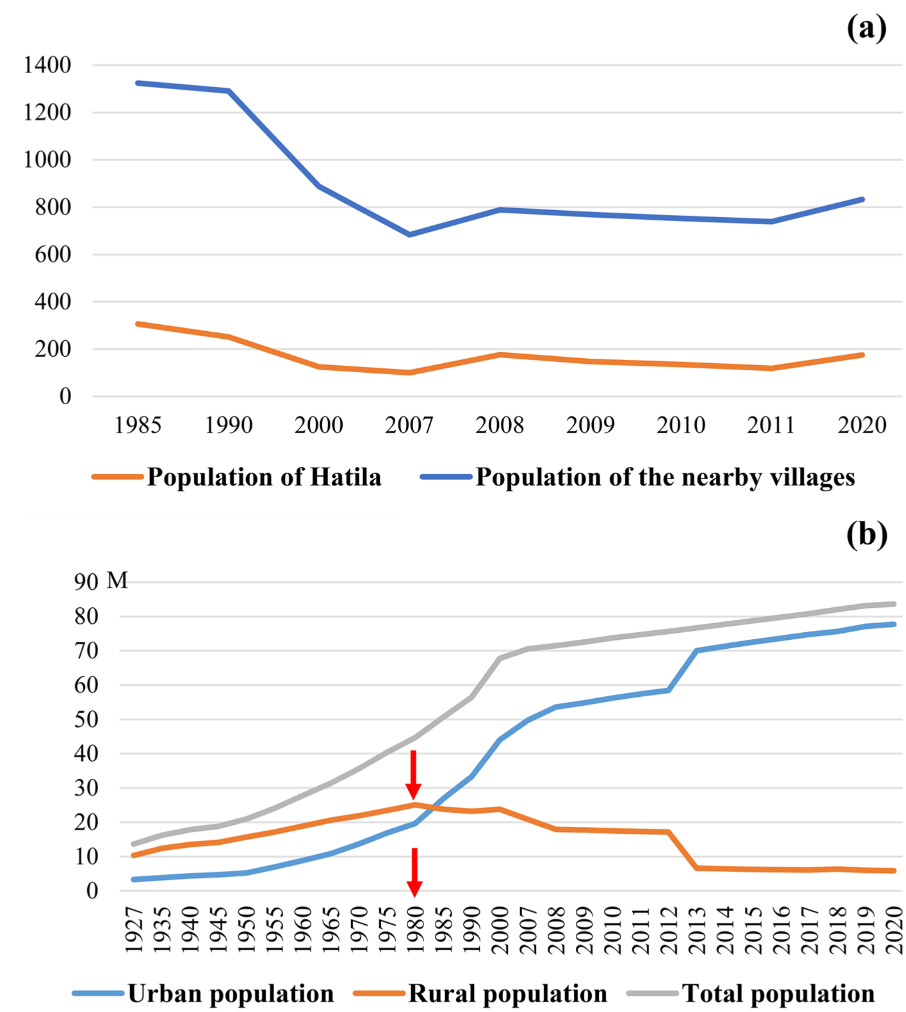

Fig. 5 Population dynamics of the investigation area for the studied period **a** and the long-term trends of the urban and rural populations in Turkey **b** (TSI, 2021)

aerial photos and traditional ground measurement techniques used in Turkey (Başkent et al., 2005; Kadiogullari et al., 2014). Towards the millennium, however, new tools and techniques such as GIS, GPS, and high-resolution-based remote sensing have been actively used for forest cover mapping. Thus, the large segments of the Hatila Creek and its actual alluvial plain could be separated from adjacent lands and classified as the water body in the current forest cover map. That was the main reason for the unexpected increase in the fish, seafood & algae ES category shown in Table 3. Nevertheless, the share of the water class is less than 0.05% in two temporal points. Thus, it is evaluated that its effect on the area-weight aggregated ES scores is negligible in the table.

The spatial changes in ecosystem services

The spatio-temporal changes in the timber production ES can be seen in Fig. 6 for the studied period. The ES map clearly shows the capacity increase, particularly in the NE parts of the study area (Fig. 6). Degraded coppices in these forestlands transformed into productive high forests of *Quercus* and *Fagus-Picea* species over 35 years (see Table 1 for areal transitions). The transformation may be stemming from the migration waves from rural areas to city centers in Turkey after 1980 (Fig. 5b). Since Artvin is a rural and remote province, emigration for employment opportunities is still common, particularly among young people (GDF, 2022). Turkish Statistical Institute reports an annual population growth rate of −34.1‰ for the Artvin city center (TSI, 2022). Eventually, the abandoned forest villages reduce the anthropogenic pressure on the forest. This leads to natural regeneration or self-rehabilitation of previously degraded stands, as reported for other forestlands of the Black Sea region (Bayramoglu & Kadiogullari, 2018). Moreover, the protection status of Hatila Valley must have shaped the landscape structure at least since 1994.

Another significant change in Fig. 6 was observed in blue-colored areas in the 1985 map. They were newly regenerated forest sites composed of *Picea* and *Abies* saplings (DBH < 8 cm) with low timber production capacity at that time. These sites transformed into advanced developmental stages (8 cm < DBH < 36 cm), providing high or maximum timber production capacities in the 2021 map (Fig. 6). This is a widely seen case in many other parts of the country. Sauti and Karahalil (2022), for example, explored the spatial changes in LULCs of another forest planning unit in Turkey based on temporal forest cover maps. They clearly showed the transition trend of forest stands from the juvenile stage (DBH < 8 cm) towards the large tree stage. Accordingly, the area

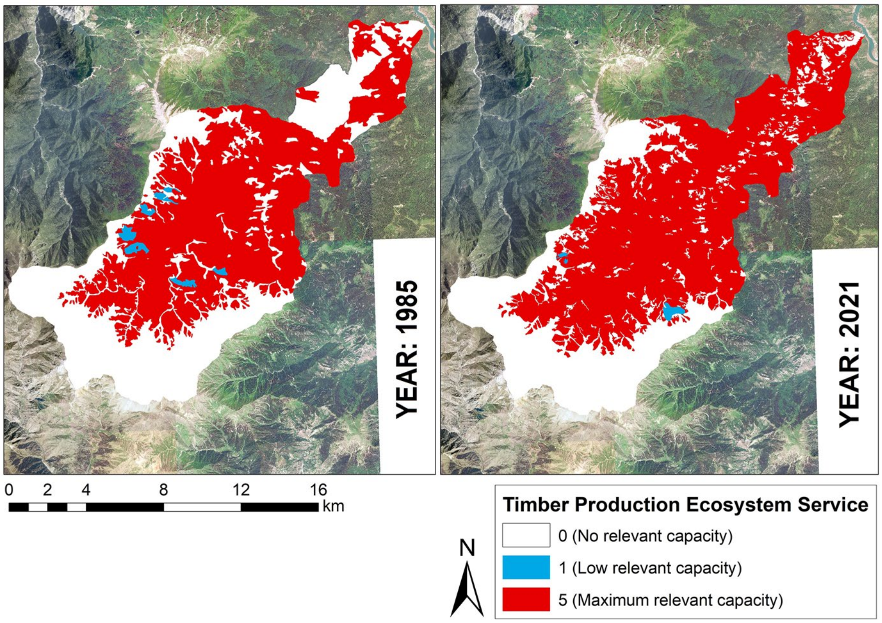

Fig. 6 The ES maps of timber production for the years 1985 and 2021

coverage of juvenile-stage stands decreased from 1354 to 27 ha over 43 years. We observed milder changes due to the 35-year study period and the differences in site quality & tree species between the case areas.

Figure 7 shows spatial changes in crop production ES between 1985 and 2021. The main ES driver for this change might be reducing agricultural land and rural population in the study area during the studied period. The total area of agricultural lands was 132.5 ha in 1985 and it significantly dropped to 26.6 ha in 2021 (Table 1). As a result, abandoned agrarian systems transformed into degraded or productive stands of *Quercus* and *Carpinus* sp., especially on the lowlands located at the NE parts of Hatila Valley (Fig. 7).

Although agricultural expansion is responsible for nearly 90% of deforestation in the world (EC, 2021), agricultural land abandonment is the general case in Turkey, particularly in the distant rural areas due to urbanization phenomenon accelerated in the 1980s (Egercioğlu, 2016). Figure 5 clearly shows the impact of urbanization on the country's population dynamics. Many scientific studies reported such findings, including forest expansion or other land-use conversion cases for Turkey. Covering the period 2005–2016, Bayramoglu and Kadiogullari (2018) analyzed the LULC changes of Torul State Forest Enterprise, located in the same region as the current case study area. The researchers reported similar findings documented in the present study. Accordingly, the forest area increased by 6% over 10 years, while the total area coverage of open spaces (including agriculture) decreased by 8% in Torul. They concluded that demographic movements and reduced forest crimes were responsible for forest expansion in the region. In our case, the declaration of the study area as a national park can be an additional factor for migration due to the limited utilization opportunities from natural resources in the valley. This may have also affected LULC changes in Hatila Valley over the last decades.

Aggregating 18 ES, multiple ES provided by Hatila Valley were mapped (Fig. 8). In Fig. 8, the ES hotspots can be seen in red color, meaning that these landscape units provide maximum ES capacities across the study area. The hotspots generally accumulated in the NE parts of the landscape in both maps. These parts are mostly composed of mixed forest stands (coniferous + broadleaved), located at the low (250 m) to medium (1500 m) elevation belts for this ecoregion. As ascending through this belt, the forest composition changes into pure stands of conifers, resulting in "high relevant capacity" areas, shown in orange color in Fig. 8. Afterward, the upper forest line is reached with an altitude of about 2000 m. The

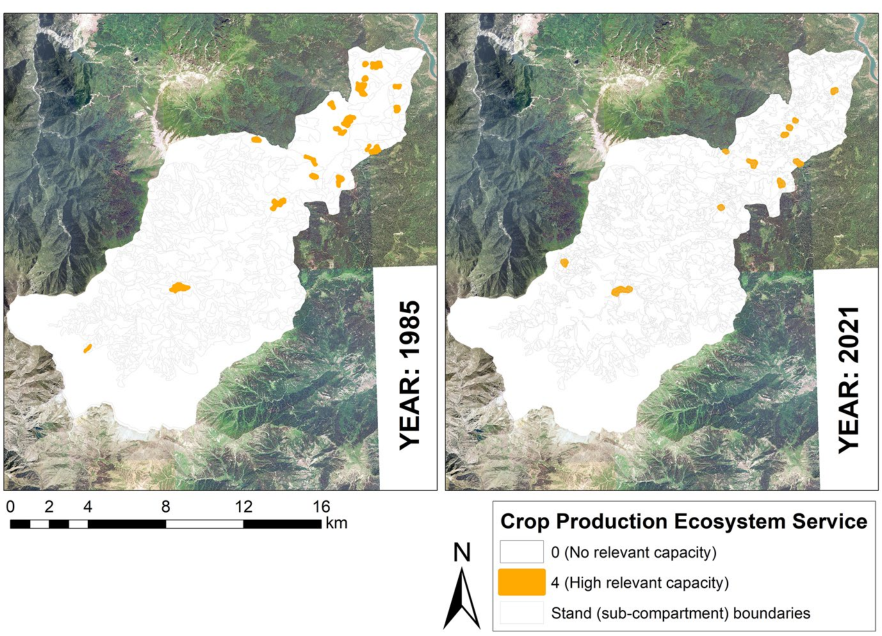

Fig. 7 The ES maps of crop production for the years 1985 and 2021

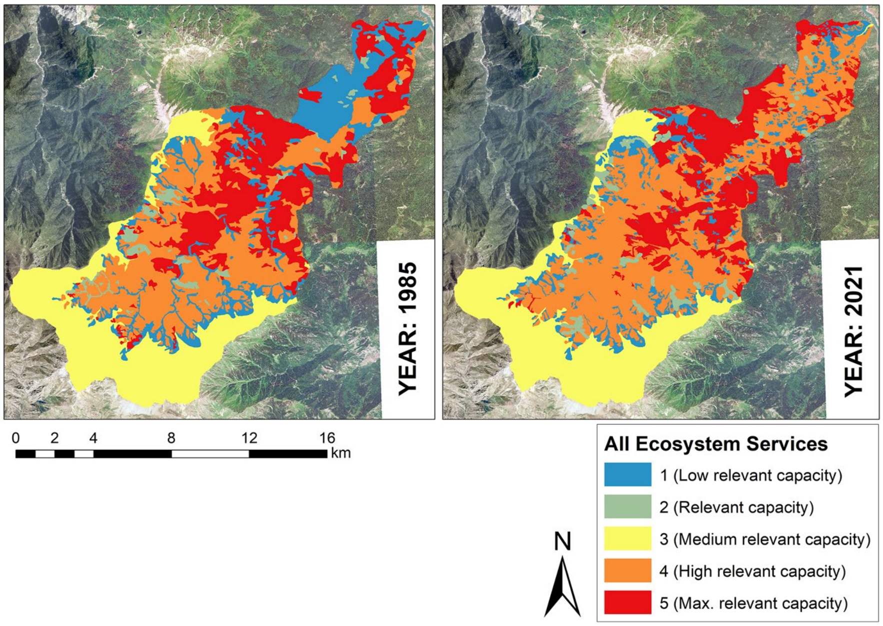

Fig. 8 The maps for multiple ES provisioning for the years 1985 and 2021

total ES capacity decreased here, but it still offered a "medium relevant capacity" (i.e., yellow-colored areas) due to the vast natural grasslands. Although the grassland cover delivers a limited capacity for multiple ES, its power for Regulating and Cultural ES is considerable.

The high elevation belt (> 2000 m) providing "medium relevant capacity" (i.e., yellow-colored areas) experienced no significant change in the study period (Fig. 8). This may be related to the absence of deforestation in the region (Bayramoglu & Kadiogullari, 2018). As seen in the maps and in Table 1, the outer boundaries and the total area coverages of grassland and forest LULC classes nearly unchanged over 35 years. By contrast, the change in the ES capacity of the bluish-colored N parts of the landscape are explicit in Fig. 8. These parts generally provided "low relevant capacity" in the 1985 map due to the degraded coppice composition (GDF, 1985) and the higher population in this rural region at that moment (Fig. 5a). Over the years, however, the rural population gradually decreased (Fig. 5) during which degraded stands of pure *Quercus* transformed into productive high forests composed of multi-species (GDF, 2022). Eventually, the total ES capacity provided by these stands increased nearly four times (Table 2), resulting in "high or max. relevant capacities" (i.e. orange- and reddish-colored areas) in the 2021 map (Fig. 8). In this regard, Sauti and Karahalil (2022) obtained similar results as coppice and degraded stands disappeared in their study area between 1972 and 2015. They also observed significant transitions from open lands to residential areas which conflicted with the present study's findings. The contradictory results can be explained by the distinct regional characteristics of the two study areas. More specifically, Yuvacık is located in an industrial region nearby metropolitan cities, like İstanbul. In contrast, Hatila is located in a remote and small province, Artvin. While the latter is a province of emigration (Fig. 5), the former is a city of immigration (Sauti & Karahalil, 2022). It is also evident that the protected area statute of the Hatila Valley National Park plays an important role in the absence of encroachment in this case.

The spatial distributions of the ES bundles (Fig. 9) differed substantially from the multiple ES map (Fig. 8). Regarding the provisioning ES bundle, the pastures, located in the SW parts, were the hotspots in 1985 (Fig. 9a). However, their ES provisioning capacity has decreased by almost 20% over 35 years. It is attributable to the LULC changes between the pasture and forest classes. Specifically, these pastures were, in fact, small-sized, treeless open lands utilized by local people for forage cutting, and husbandry. When anthropogenic pressure was reduced due to

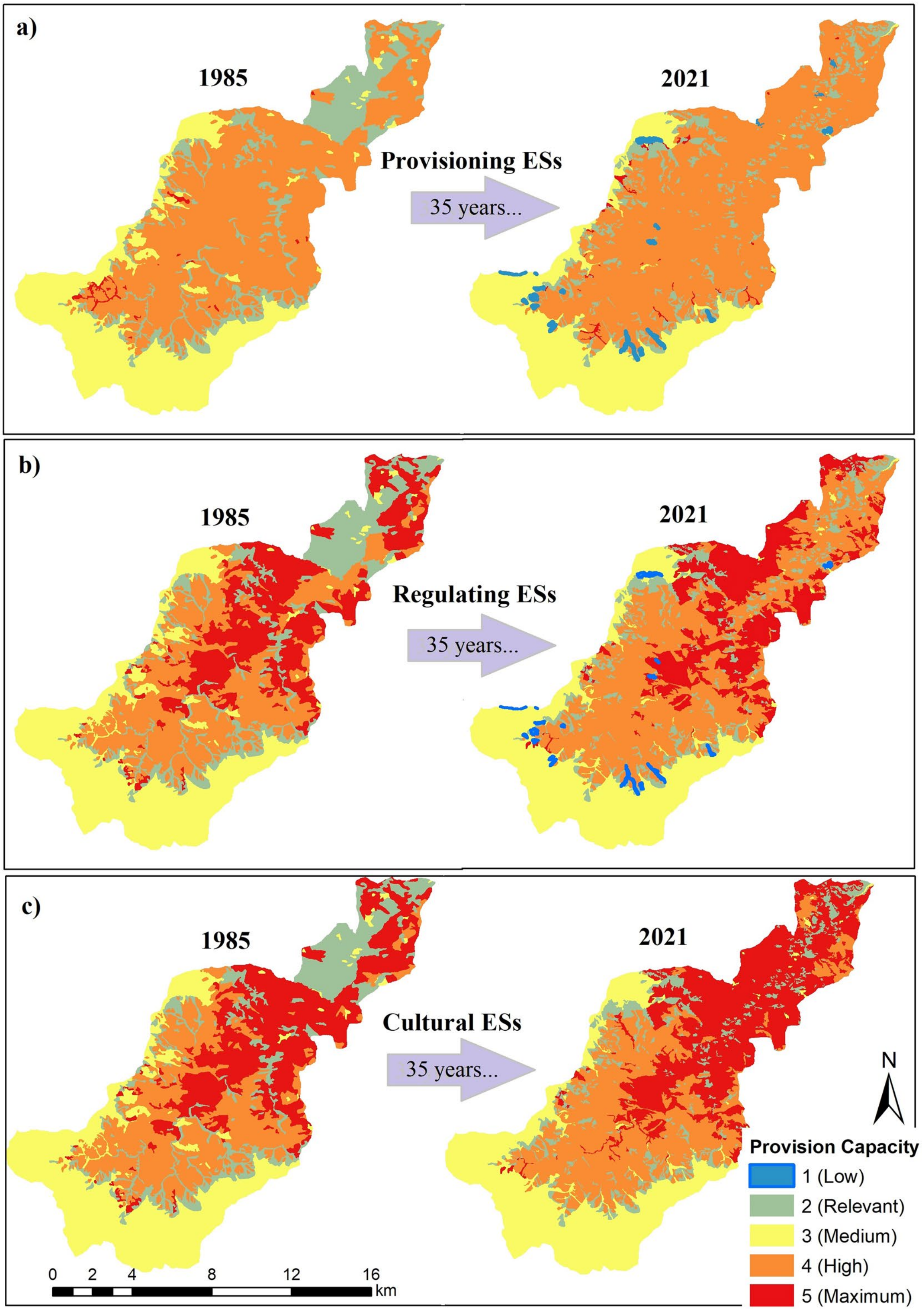

Fig. 9 The maps for three ES bundles for the years 1985 and 2021: **a** provisioning, **b** regulating, and **c** cultural ES bundles

migration (Fig. 5; TSI, 2022), some of those pastures naturally transformed into regenerated stands of conifers, supplying submaximal capacities for provisioning ES. This is a widely seen case in other parts of the world, too. Pinno and Wilson (2011), for example, found that the abandoned pastures in the Great Plains had been naturally regenerated by indigenous forest, resulting in increased carbon stock. However, the impact of this land conversion on biodiversity ES value is still unclear (Dymond et al., 2013; Pinno & Wilson, 2011).

In Fig. 9a, there was also a substantial change between the two maps in the N parts. As mentioned previously, the capacity increase in these parts was due to LULC changes from the pure coppice to multi-species high forest. The other landscape units generally provided similar ES capacities in 1985 and 2021.

As for the regulating ES bundle, the current hotspots generally accumulated in the N and E parts of Hatila Valley (Fig. 9b). These parts are composed of mixed forest stands with closed canopies. Thus, they provide many regulating ES at full capacity, including biodiversity, erosion regulation, and pest & disease control. The coldspots (blueish-colored), on the other hand, are generally composed of bare rocks. They occupy small and isolated areas (patches) across the landscape. Their regulating ES provisioning is also very limited if any. Significant changes were also experienced in the lowlands located at the NE parts. Both capacity increases and decreases occurred here (Fig. 9b). The transitions among forest types (i.e., coppice to high forest, broadleaved to conifers, and mixed to pure forest), particularly after the national park declaration, are thought to be the main drivers for the change in this ES bundle.

Like other ES bundles, a capacity increase was also observed for Cultural ES, particularly in the NE lowlands of the study area. In contrast to other ES bundles, the "maximum relevant capacity" was provided along the Hatila Creek, running through the middle of the valley and dividing it into two main slopes. Recreation & tourism, landscape aesthetics & inspiration, and natural heritage were the prominent Cultural ES in this buffer zone (Fig. 4). However, Yuxi et al. (2018) pointed out that recreational ES potential, in particular, may be deteriorated over time due to climatic extremes even in sparsely populated landscapes. Therefore, the authors recommend further ES analyses, considering the effect of climate change on spatiotemporal variations of recreation potential, as well as other ES capacities. Finally, the bare rocks were among coldspots for the regulating ES bundle, but they provided "medium relevant capacity" for cultural ES.

Overall, all landscape units somewhat offer a provisioning capacity when single ES are aggregated for mapping multiple ES provisioning. We observed no patch having "no relevant capacity" (i.e., white-colored areas) in either the 1985 or the 2021 maps (Figs. 8 and 9).

Limitations

Hatila Valley's capacity to provide a large array of ES was spatially assessed during the study, but some limitations were embedded into the analyses. First, the ES matrix, summarized in Table 2, simplifies the landscape and mainly uses expert judgments on scoring ES for each LULC class rather than measuring or modeling ecological indicators and/or processes underlying those ES (Jurmalis et al., 2017). For example, the score of erosion regulation ES is maximum (5) in Table 2 both for broad-leaved, coniferous, and mixed forests because the matrix only considers the growing season, i.e., full vegetation cover in early summer. However, the erosion control capacity of green vegetation varies throughout the year (Schmidt et al., 2018). Thus, a significant decrease in the score of erosion regulation ES should be expected for broad-leaved forests during wintertime (i.e., the leaf-off season), as stated by the works of Vatandaşlar et al. (2020) and Schmidt et al. (2018).

Similarly, LULC-based ES assessments are sometimes problematic due to the coarse delineations of the classes. In addition, there may be significant variations within the same category. For the sake of simplicity, treeless openings (< 1 ha) within some forest stands are not shown in forest cover maps in Turkey (GDF, 1985, 2022). While these openings generally provide high capacities for biodiversity and wild foods ES, their timber production ability is very low. Such uncertainties undermine the matrix approach in detailed ES assessment studies. In this sense, Jacobs et al. (2015) discussed other potential limitations embedded in the approach and provided important recommendations for overcoming them.

Another limitation could be the lack of monetary valuation of individual and multiple ES. The present study focused only on ES provision rates (via physical quantity) and their spatial changes over time. However, ES contribute considerably to human welfare and each ES has a unit price by definition (Burkhard et al., 2012). In this regard, many theoretical models and computation techniques exist in the literature for ES valuation (Li et al., 2017; Yuan et al., 2019). For example, Yuan et al. (2019) used modified equations considering socio-economic factors for Shangzhou district, China. They calculated the total ES value as 10.74×10^8 yuan and 20.32×10^8 yuan for the years 2000 and 2015, respectively. Interestingly, there were no dramatically changes in either LULC classes or ES provision capacity of the landscape for the study period. Thus, the results demonstrated that regional economic development, inflation rates, and "willingness to pay" are other important determinants of total ES value besides LULC shares of the landscape. Since unit prices for most ES are ambiguous for Turkey's biomes, we excluded the monetary valuation of the ES investigated.

Finally, we assessed only the "supply side" of ES provided by Hatila Valley. There are also the "actual flow" and the "demand sides" in the ES concept (Burkhard et al., 2012). For instance, Hatila Valley is strictly protected as a national park therefore the timber production ES capacity of the valley was found to be 63.3% in the present study. This rate should be taken as the "ES potential" and may not be used up by people, as in our case (i.e., currently protected area). If we had mapped the actual flow of this ES, it would be zero since timber harvesting activities are restricted in the area. Similarly, the demand side of ES is a completely different topic since there may be no or high demand on specific ES in some regions during different periods.

Conclusion

The present study assesses the status of ES provided by a forest-dominated landscape and analyzes its spatio-temporal change between 1985 and 2021. Given the ES matrix approach, the current state of the landscape's capacity to provide multiple (total) ES is about 60.0%. Regulating ES are more prominent than the cultural and provisioning ES bundles. While the wild foods & resources, erosion regulation, and knowledge systems are dominant ES, crops and fish, seafood, and edible algae ES are delivered at low capacities in the study area.

A slightly increasing trend (+7.0%) is observed in provisioning capacity for multiple ES from 1985 to 2021. The decreased trends are only observed for crops (−83.3%), and domestic livestock (−8.6%) ES for the same period. The main ES drivers seem to be the changes in the management structure and human population. Hatila Valley was declared as national park in 1994. Since then, no harvesting activities have been allowed for timber production in its forestlands. In addition, the population has started to decrease in the Hatila Valley in the 1980s parallel to the region (i.e., Artvin Province of Turkey). Thus, the ES provisioning capacity of the valley has gradually improved based on the natural ecosystem regeneration over time.

In conclusion, conservation management and human activities appear as key drivers for the case study area. They recognizably change the ecosystems' structures and their capacities to provide ES. The changes may occur in different spatial/temporal scales with positive or negative impacts on ES flows. Therefore, more detailed studies are needed to effectively assess the multidirectional effects of other drivers on ES provisioning. A clear knowledge of how multiple drivers interact across ecosystems will also improve ecosystem-based management by controlling potential synergies (win–win situation) and trade-offs (win-lose situation) among them. Since the drivers will continue to change over time, researchers should focus on scenario analyses by incorporating the combined effects of these driver sets into ES models and maps. Thus, resource managers can ensure the sustainable and equitable use of "natural capital" in the long term.

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Data availability The data and material can be shared by the author upon reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The author declares no competing interests.

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