Assessing the landscape potential to deliver ecosystem services in modeling scenarios of land use change

Anton Nazarenko (nazarenko.iwep@gmail.com)
Institute for Water and Environmental Problems of Siberian Branch of the Russian Academy of Sciences (IWEP SB RAS)

Research Article

Keywords: Ecosystem services, pecuniary valuation, agriculture, spatial planning, sustainable development

Posted Date: May 11th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1500616/v3

Abstract

The article presents an algorithm for assessing the scenarios of land use change in terms of the landscape potential to deliver ecosystem services (ES). The developed algorithm was applied to the model area in Altai Krai (Russia) to assess scenarios for using fallow lands.

The assessment was performed for local natural landscapes with consideration of their land use structure and based on productivity of forest ecosystems and agricultural lands (including pastures, hayfields and arable lands). For assessing the landscape potential to deliver ES, we used and mapped the economic value (US $ / ha / year) of seven ecosystem services.

For spatial planning of land use structure and developing scenarios, we employed expert assessments and evaluation of permissible agricultural impact**.** These tools were successfully tested under designing scenarios for fallow lands use in the Zarinsky region. To check the effectiveness of the developed scenarios, ES were re-assessed and the obtained results compared with the original scenario.

Our findings suggest that though economic indicators do not fully reflect the ES value, they can be used as the basis for decision-making in land use planning at the regional and sub-regional scales.

Highlights

• Nowadays, a dual problem of sustainable development of agricultural areas does exist. For instance, prevention of ecosystem degradation requires a reduction in agricultural impact that is hardly feasible under current market conditions.

• Complex expert assessments as well as evaluation of permissible agricultural impact and ecosystem services (ES) in land use planning may contribute to this problem solution.

• Scenarios for modifying the land use structure of the Zarinsky region (Altai Krai, Russia) have been developed and evaluated based on this approach.

Introduction

Spatial planning of land use is carried out for solving a wide range of challenging problems in agriculture, water resources and climate change management. It is designed to mitigate global warming, to increase carbon sequestration from the atmosphere and reduce its industrial emissions in order to smooth out the greenhouse effect (Liu et al., 1999). In water management, land use planning can reduce the harm from pollution of water bodies and facilitate their sharing (Kelly and Aris, 2007). Anyway, land use planning often has environmental focus to a more rational use of land resources in the framework of sustainable development. In agricultural management, land use planning is primarily designed to increase its productivity using different models for analyzing the future effect (Verburg et al., 2004). Some of these models assume optimization of agricultural loads on the territory through reforestation and reduction of arable areas in favor of natural forage lands. This increases not only agricultural productivity, but also the amount of carbon sequestration thus reducing the effect of global warming(Orlova and Sharabarina, 2015). Therefore, we need to search for new tools ensuring both the increased agriculture efficiency with consideration of life-supporting functions of ecosystems and the reduction in growing agricultural loads.

The assessment of the landscape potential to deliver ES is a promising tool for a long-term environmental planning (Bastian et al., 2012; Bolliger and Kienast, 2010; Müller et al., 2010). In addition, the ES assessment helps regional planning authorities to find consensus between multiple societal needs and demands, which provoke conflicts in exploitation of the same piece of land for different purposes. The sub-regional and regional scales of land use organization are suitable for making such assessments (Costanza et al., 2014). Assessing and applying of ES in land use planning at the regional scale is often hampered by a particular focus made on single ES without any comprehensive analysis. Sometimes modern assessment approaches have no feedback to land use changes (Koschke et al., 2012). Besides, the ES assessments are usually made at the national scale being further inapplicable to evaluation in the regional projects.

One way to solve these problems is to use multi-criteria and expert-driven approaches (Koschke et al., 2012). It is well known that at times planners and stakeholders can not apply assessment results to a specific territory because they are expressed in different relative indices. Often, the outcome is not clear to the users of natural resources, who can hardly see an obvious link between changes in the ES potential and material benefits they derive from economic activities. Planning authorities occasionally experience the lack of the data required for assessing ES (Seppelt et al., 2011; Zerger et al., 2011). In this case, it is reasonable either to involve these authorities in developing assessment methods or to use their data.

Integrated pecuniary valuations at the regional and sub-regional scales involve the ES assessment for land use planning. The monetary form makes the result understandable for stakeholders and allows them to compare the value of provisioning ES of a landscape under different conditions and the benefits derived from various economic activities. Meanwhile, at present, there is no common understanding of the relationship between the ES value and their funding. Moreover, pecuniary valuation does not fully consider the social and cultural value of ecosystem services (Jax et al., 2013), however, in combination with expert estimates they can serve as a basis for choosing sustainable land use structure. An important point is that only the landscape potential to deliver ES in sustainable way can be assessed.

The implementation of such evaluations in decision-making calls for appropriate tools (Daily and Matson, 2008; Koschke et al., 2012)

1) to ensure the integrated assessment of ES;

2) to be applicable to another territory (at the national level);

3) to operate on the basis of available statistics provided by regional planning bodies;

4) to reflect landscape potential to deliver ES in comprehensible units;

5) to simulate model scenarios of land use changes.

Such a toolkit is being currently developed for solving various practical problems. The study by Albert et al. presents the ES indicators for soil fertilization practices, climate regulation, landscape attractiveness and biodiversity conservation in Northern Germany. These indicators served as the environmental criteria and were employed in forecasts (Albert et al., 2016).

V. Garsia-Diez et al. dealt with mapping the recreational ES to preserve the areas intended for recreation (García-Díez et al., 2020).

The integrated assessments of ES for Barcelona suburbs made by C. Basnou et al. are also of interest. Based on these evaluations, the researchers developed scenarios for human-modified land use structure of the territory in order to increase the ES potential while conserving biodiversity. The study involved an assessment of ES for ensuring soil fertility, climate regulation, landscape attractiveness and biodiversity conservation (Basnou et al., 2020).

Such tools are also being developed for agricultural areas. A research by A. Holt et al. (Holt et al., 2016) is devoted to the trade-offs between agriculture, ecosystem services and biodiversity as well as multifunctionality on the landscape scale. Interrelationships of economic value of ES of animal husbandry, crop production, carbon deposition and wood growth are studied in France (Accatino et al., 2019). In China, researchers deal with studying the possibilities and ways to achieve the trade-offs between agricultural efficiency and sustainability of ecosystem services (Zhang et al., 2022).

With this study, I aimed to develop the algorithm for modeling scenarios of land use modification in terms of economic values of five ES of the administrative region of Altai Krai (Russia) using the statistical data. Apparently, it is an important step in realization of the idea on discussed tools development.

Materials And Methods

Territory

Altai Krai is located within 51–54° N and 78–86° E at the junction of two physical-geographical countries, i.e. the West Siberian plain and the Altai-Sayan mountain country distinguished by various natural conditions and landscapes.

The region has a pronounced agricultural specialization due to soil diversity, sufficient amount of active air temperatures and large waterways. Altai Krai plays a significant role in food supply to other regions of Siberia and Russia as a whole. In this connection, assessing the Altai ecosystem services potential is of particular importance because it largely determines the performance of natural industries (including agriculture), and, therefore, its optimization may contribute to food security at the national scale.

The Zarinsky region located on the territory of three landscape provinces, i.e. Upper Ob province (the West Siberian plain), Presalair province (the West Siberian plain) and Salair province (the Altai-Sayan mountain country) was selected as a key study area (Fig. 1).

The choice of the key area is due to a variety of natural conditions affecting different economic activities in nature-dependent industries (agriculture, forestry, tourism and nature conservation).

In Upper Ob province, flat landscapes of mid steppe with leached chernozem and gray forest soils prevail. Favorable soil and climatic conditions provide stable grain and industrial crops making this province one of the most developed in West Siberia.

Presalair province is a transitional zone situated on the border of the West Siberian plain and the Altai-Sayan mountains with natural conditions typical both of foothill and flat landscapes. Here, the landscapes of mid and northern forest-steppe with dark gray forest soils dominate.

Salair province is low mountain and covered almost everywhere with forests. This province has numerous black taiga landscapes with mountain-forest and gray forest soils.

Note that some sites of the Salair National Park with its protected rare species of plants and animals are situated here. The total of 12 landscape areas are presented within the Zarinsky region boundaries (Table 1).

Table 1
Description of local natural landscapes in Zarinsky region

Landscape provinces	Local natural landscape number	Description
Upper Ob province	131	Hilly-ridged dissected surfaces with grass-forb meadow steppes and steppe meadows on leached and podzolized chernozems in combination with birch and aspen-birch steppe forests and wood patches on gray and dark gray forest soils.
	134	First above-floodplain terraces of large and medium rivers are swampy, flat, in places hilly-ridged with birch, pine-birch and herb-shrub forests on sod-slightly podzolic soils.
	135	Gently sloping valleys and gullies with flat bottoms occupied on slopes by steppe and true meadows and feather grass steppes with chernozem-meadow, meadow and, less often, meadow-bog soils.
	136	Floodplains of large and medium-sized rivers dissected by oxbows, with forb-cereal bushy and halophytic meadows on alluvial meadow and bog-meadow soils in combination with willow-poplar-shrub forests on alluvial layered soils.
Presalair province	203	Hilly-ridged interfluvial dissected surfaces with legume-forb-cereal steppe meadows on leached chernozems in combination with small woods on gray and dark gray forest soils (220–330 m).
	205	Ridged dissected and hilly-ridged surfaces with aspen-birch tall-grass forests in combination with grass-forb meadows on dark gray forest soils (240–300 m)
	206	Riverside gently sloping dissected surfaces with birch grass forests on dark gray forest soils
	207	Terraced valleys with forb-cereal and sedge-cereal meadows on meadow and bog-meadow soils.
	208	Terraced valleys with aspen-birch sedge and sedge-reed swamp forests on peat-gley and humus-gley soils.
Salair province	210	Ridged surfaces with wide flattened peaks with aspen and fir-aspen (with an admixture of birch) tall-grass shrubby forests on mountain-forest sod-deeply podzolized soils (350–400 m)
	212	Gently sloping slightly dissected surfaces with aspen-fir tall-grass shrubby forests on mountain-forest deeply podzolized soils (360–560 m).
	215	Flat valleys with mixed-herb-gramineous and sedge-gramineous boggy meadows in combination with tree-shrub thickets on meadow and meadow-boggy alluvial soils

In the study region, landscape areas differ significantly in relief, moisture, vegetation, soil cover and ES potentials as well. In this regard, local natural landscapes serve as major territorial units for assessing ecosystem services, which do not arise directly from the natural capital, but exist in the context of interactions of natural, social and infrastructural capitals (Costanza et al., 2014).

As natural conditions, the economic features play an important role for the ES potential. To consider these drivers, mapping of land use structure of the region was implemented.

To analyze the structure of land use, we employed cadastral and field data. The study was conducted in August 2020 and consisted of 4 stages:

1) search for and processing of LANDSAT8 satellite data;

2) selection of a key area for identifying agricultural lands;

3) field research;

4) mapping of agricultural land based on classification of LANDSAT8 satellite data in accordance with the maximum similarity method.

The LANDSAT8 satellite data (July 17, 2020) were obtained from the US Geological Survey (USGS) website. To identify agricultural lands, a RGB combination of spectral channels of images (6-5-2) was used, i.e. near infrared channel (1.56–1.66 microns), near infrared channel (0.845–0.885 microns), and blue channel (0.45–0.515 microns). The correspondence of different color combinations of LANDSAT8 images to types of agricultural lands was determined by the example of a key site near the Zagonny station characterized by most diverse land use structure.

Based on the field findings, the album of correspondence of color combinations of LANDSAT images to land types was created.

The ravine net mapped in 1980 was compared with modern areas mapped by the author with the use of LANDSAT data. Due to obtained correspondences, the image data classification was performed based on the maximum similarity method. Identification of fallow lands was challenging because of a similar reflection of deposits and pastures on the image as well as errors induced by weeds spread in the plowed fields.

For results clarification:

1) the data on distribution of forest areas, hayfields and pastures were compared with similar information obtained by “Altaigiprozem” to distinguish disputed pastures from fallow lands;

2) the classification adjustment was made due to reconciliation results with the use of the maximum similarity method;

3) generalization of sites (less than 1 ha) was implemented to eliminate errors and avoid fallow "islands" occurrence in the plowed fields.

Note that various landscapes provide land use diversity of the region (Fig. 2).

Forests and agricultural lands (i.e. arable lands, hayfields and pastures) occupy a vast territory of the region. When moving from west to east, a gradual transition from agricultural to forestry land use due to gradual change in landscapes (from flat to foothill ones) is marked.

Also the region is rich in a fairly high proportion of fallow lands (4.16% of the total area) referred to agricultural but unused for a year or even more.

When assessing ES, the territory features affecting their value (ecosystem disservices) were considered as well. In the Zarinsky region it is gully erosion. For mapping and assessing dynamics of a ravine network development, the Atlas of Altai Krai (published in 1980), open maps of Roskartography at a scale of 1: 50000, multi-seasonal (spring and autumn) high-resolution satellite images of 2020 were used.

The ravine net mapped in 1980 was compared with modern areas mapped by the author with the use of LANDSAT data. In the Zarinsky region, the areas prone to gully erosion are located along riverbeds and near settlements. Figure 3 shows the largest ravines on the schematic map.

Due to performed assessment, eight areas – most susceptible to the development of gully erosion, were revealed. The comparison of the obtained updated data on ravine location with those from the Atlas of Altai Krai showed significant enhancement of the ravine area starting from 1980.

In the modern structure of land use, the growth of the ravine network over the past 40 years has brought to agricultural land alienation (Table 2):

Table 2
Land alienation induced by ravine network growth in Zarinsky region (1980–2020)

Types of land use	Lands alienated in 1980–2020, km^2
Cropland	25.23
Fallow	5.49
Pasture	14.31
Hayland	10.02
Others	23.37

In the Zarinsky region, arable lands with the area exceeding 25 km^2 are most affected by this process. Noteworthy that 5.49 km^2 of eroded lands are not in agricultural use over the past few years.

The obtained data allowed us to determine the range of provisioning ES in the region under study.

Spectrum of ES

To identify ES, we used the modified classification proposed in the Millenium Ecosystem Assessment project (MA, 2005). The choice fell on provisioning ES affecting major nature-dependent sectors of the Zarinsky region, i.e. agriculture and forestry. The biomass ES were differentiated by types of produced goods (wood, non-wood and food resources of forests, grass on hayfields and pastures, food).

In the Zarinsky region, it is extremely important to preserve biodiversity, which ensures sustainability of landscapes – genetic resources of rare species of plants and animals (including hunting ones).

Here, regulating ES primarily depend on natural climate regulation expressed by atmospheric carbon sequestration by plants.

Among most valuable cultural ES are picturesque landscapes of black taiga in Salair province as well as a relief of the Upper Ob province with its hills suitable for paragliding and hang gliding, which ensure tourism development.

Since objectivity and unambiguity of pecuniary valuation results to be further applied in land use optimization are of great importance, only ES potentials with the defined cost equivalent were assessed (Table 3).

Table 3
Ecosystem services of landscapes in Zarinsky region

Categories of ES	Ecosystem services
Provisioning ES	forest ES (timber, non-timber and food resources)
	hayland ES (grass)
	pasture ES(grass)
	Food provision
	Genetic resources ES (rare species of plants and animals, hunting animals)
Regulating ES	Climate regulation
Cultural ES	Tourism attractiveness

The ES spectrum makes it possible to predict some changes in their value in case of land type conversion (forests, arable land, hayfields and pastures).

Assessment methods

In the Zarinsky region, assessing local natural landscapes (with prevailed relief types) was made in terms of land use structure. Within the boundaries of each landscape, the areas with different land types and their contribution to land use structure were defined.

For pecuniary valuation of provisioning services, we used the indicators of land productivity expressed in monetary units (Table 4).

Productivity of forest ecosystems, haylands and pastures determines their economic value in agricultural and forestry sectors. Integral characteristics of soil fertilization practices, their technological properties and location influence on the performance of arable farming. In Russia, they are used for parcel assessment of agricultural lands.

Climate regulation services were assessed through expressing atmospheric carbon sequestration by ecosystems in monetary units. For forest ecosystems, we considered such indicators as the forest area, forest stands composition, age distribution and specific rates of carbon sequestration by different species and age groups (ton/ha/year), while for non-forest ecosystems – the area and different types of lands, including their ability to carbon sequestration (ton/ha/year). Weighted average price per ton of carbon emitted to the atmosphere served as the monetary expressed value of ES on global carbon markets.

The genetic resources of rare species of plants and animals (including hunting animals) provide biodiversity and resilience of landscapes. For their evaluation, we applied a costly approach in accordance with approved by RF Ministry of Natural Resources methods for assessing harm made to biodiversity.

The indicators of the average annual income of tourism enterprises were employed in assessing tourist attractiveness of landscapes due to infrastructure and recipients of ES.

The estimation results for each local natural landscape were expressed in specific values (US $/ha/year) according to the Jenks natural breaks classification method and further presented as schematic maps.

Applied data

To facilitate practical implementation of planning, we employed consistently updated official statistics on land use patterns and productivity.The forest statistics for Altai Krai (2018) served as the major data source for estimation of timber, non-timber and food resources of forests as well as regulating ES. The established in the Kemerovo-Altai forest-tax region payment rates for logging of different species as well as purchasing prices of non-wood and food resources of forests (2018) were used for pecuniary valuation.

ES of haylands and pastures (yield grass) were assessed based on the data of sectoral statistics of the Zarinsky region for 2012–2020. Hay prices established in Altai Krai in 2020 were used for estimation of these ES.

The previous parcel evaluation of lands in the Zarinsky region provided the data on land use structure of the region, including the integrated characteristics of soil fertility and their technological properties (2016).

To calculate a weighted average price per ton of emitted carbon, we used emission prices and sales volumes of carbon quotas on global markets (USA, Canada, EU, China, Korea, New Zealand). In the study, we draw on weighted averages because the carbon trading mechanism has not been introduced in Russia yet. With regard to specific values characterizing the ability of different ecosystems to sequestrate carbon from the atmosphere, we availed of the data from (Isayev et al., 1993) and for non-forest ecosystems from (Dolman et al., 2012).

As mentioned above, ES of aesthetic attractiveness of landscapes were assessed for the areas suitable for tourism development. Nowadays, only two tourist companies, i.e. IE Kondratyev A.V. (village Golubtsovo) and LLC «Frize» (st. Tyagun) operate in the region.

The ES assessment of rare species of plants and animals (including hunting animals) was made for three local natural landscapes of Salair province incorporating some sites of the Salair National Park, which provides protection of rare species of plants, animals and their habitats. Here, rare species of animals (Ciconia nigra, Falco peregrinus, Pernis ptilorhynchus, Lutra lutra), hunting animals and rare plant species (Erythronium sibiricum, Tilia sibirica) were assessed.

Results And Discussion

Economic value of ES

The obtained results for the economic values of the ecosystem services are presented as schematic maps in Fig. 4–5. The eastern part of the Zarinsky region in Salair province of the Altai-Sayan mountain country almost completely (95%) occupied by forests is most valuable in forest ES (timber, non-timber and food resources) (Fig. 4a). On the contrary, meadow areas of Presalair province in the central part of the region are the least valuable ones.

Maximum grass provision on haylands in the region (Fig. 4b) is observed in meadow landscapes of Presalair province distinguished by the largest hayfields acreage (12.4–15.2%). Forest landscapes of Salair Province (with lands unsuitable for mowing) are least valuable in this respect. Valleys of small rivers and the R. Chumysh in Upper Ob province are rich and most valuable in vast pastures (14.9–26.9%), overuse of which can lead to small rivers pollution (Fig. 4c). To the contrary, the least valuable pastures are located in Salair and in the north of Presalair provinces, which are rich in forests.

The highest ES value of food (Fig. 4d) is recorded in the meadow areas of Upper Ob and Presalair provinces, whereas the least – in the Chumysh river valley and the territory of Salair province unfit for plowing. The specific ES value of arable lands is basically much higher than that of others since food provision is among primary needs of the society.

The highest ES value of genetic resources of rare plant and animal species (including hunting ones) is noted in Salair province due to the Salair National Park, which protects rare plant and animal species as well as their habitats (Fig. 4e). On the contrary, this indicator is the lowest in the valleys of rivers Chumysh and Alambay because of transport routes (a regional road, a railway) and more than 20 settlements built there.

From Fig. 5a it follows that forest ecosystems produce 68% of total value of climate regulation services in the area. Hayfields (17%), arable and fallow lands (11%) play an important role in shaping the discussed value. In the region, a share of forests and hayfields in land use structure shows increase as well.

The areas distinguished by picturesque slopes suitable for extreme sports, including picturesque landscapes of black taiga in the east of the region, are valuable in terms of tourism development (Fig. 5b). Other sites of the region are also aesthetically attractive, but in the absence of the organized economic activities and recipients of services their value is zero since ecosystem services are the interaction of natural, social and infrastructural capitals.

Among the considered ES, the most valuable are genetic resources of rare species of plants and animals (including hunting animals). It is associated both with the use of a costly assessment approach based on the methods approved by the Ministry of Natural Resources of the Russian Federation and with the fact that restoration of valuable commercial and rare species of animals and plants is extremely expensive.

The croplands ES are also valuable because of food production that is one of the primary societal needs.

Distribution of the ES value within landscape provinces is represented in Table 5.

Table 5
Landscape potential to deliver ES in provinces, US $ /ha/yea

Landscape provinces	Provision of timber, non-timber and food resources of forests	Grass provision on haylands	Grass provision on pastures	Provision of food	Climate regulation	Tourist attractiveness	Genetic resources of rare species of plants and animals, hunting animals
Upper Ob province	3.34	3.76	3.72	91.36	3.83	0.51	20.13
Presalair province	3.38	7.55	2.81	92.48	4.81	0.00	20.69
Salair province	10.08	0.19	0.06	1.15	5.35	0.56	349.54
Regional average	6.36	3.23	1.84	51.48	4.78	0.39	167.07
In Table 5, the cells with maximum ES value are highlighted in green, and exceeding the average – in light green.							

On a regional scale, the territory of each province is valuable in terms of provision of one or several ES:

Upper Ob province – pasture lands;

Presalair province – an increase in perennial grasses for hay, valuable arable lands;

Salair province – an increase in timber, non-timber and food resources of forest, carbon sequestration, attractiveness of landscapes, genetic resources of rare species of plants and animals (including commercial species).

The greatest ES value is noted in Salair province, the least affected by economical activities. Here, all valuable ES are provided by forests, including forest itself with its attractiveness for tourists, habitats of rare and hunting species of animals and plants, wood growth and atmospheric carbon sequestration.

In the buffer Presalair province, on the border of the lowland and mountainous physical-geographical countries, the value structure of ES differs greatly. In fact, it is a combination of value structure characteristic of Upper Ob and Salair provinces.

Scenarios of land use change

It is well-known that total development of the territory maximally reduces agricultural productivity. An excessive share of the developed lands makes a negative effect on stability and productivity of landscapes thus contributing to their further degradation. This is confirmed in practice by recent findings of X. Zhang et al. (Zhang et al., 2022).

Therefore, the shares of arable/fodder lands in the total area of agricultural lands and forest lands in the total area of the territory are referred to environmental parameters of agricultural impact.

In the Zarinsky region, agricultural activities are currently implemented within the boundaries of the forest-steppe Upper Ob and Presalair provinces. Methods for assessing the agricultural impact on natural systems in the steppe and forest-steppe zones (see Table 6) are presented in (Orlova and Sharabarina, 2015).

Table 6
Parameters of agricultural impact in the forest-steppe zone (Orlova and Sharabarina, 2015)

Parameters of agricultural impact	Optimal	Permissible	Critical
Percentage of natural landscapes	≥ 35%	25-34.99%	< 25%
Percentage of arable land	≤ 35–40%	40.01–49.99%	≥ 50%
Percentage of fodder land in farmland area	40–45%	39.99–35.01%	≤ 35%

The territory of Upper Ob and Presalair provinces belongs to the forest-steppe agricultural zone. The author assessed the structure of land use of this territory in the Zarinsky region based on the presented parameters (Table 7).

Table 7
Assessment of agricultural impact parameters in Upper Ob and Presalair landscape natural provinces, %

Landscape provinces	Number of local natural landscape	Percentage of natural landscapes	Percentage of arable land	Percentage of fodder land in farmland area	Percentage of forest area
Upper Ob	131	44.99	53.79	20.39	31.18
	134	56.89	14.85	55.66	37.18
	135	60.99	32.03	39.86	39.02
	136	59.74	11.49	72.32	23.03
Presalair	203	44.49	53.14	30.43	20.92
	205	71.69	28.28	35.46	55.92
	206	40.50	57.21	26.84	19.41
	207	58.08	30.73	54.14	19.81
	208	69.73	22.21	51.89	44.08
Upper Ob		**50.99**	**41.06**	**30.28**	**32.13**
Presalair		**55.50**	**41.03**	**34.91**	**32.86**
In this assessment, natural landscapes include forests and marshes as well as hayfields and pastures (not systematically used).					

The ratio of the developed and natural landscapes is the only optimal environmental parameter for all considered local natural landscapes and provinces. Note that plowing in the hilly-ridged meadow-steppe areas is excessive. To prevent their further degradation, it is necessary to increase the share of forage lands in the total area of farmlands.

Optimization of ecological parameters of agricultural impact in each area calls for

- reduction of the fallow land area by 18903.53 ha;
- reduction of the arable land area by 7416.55 ha;
- increase in the hayfield area by 19981.39 ha;
- increase in the pasture area by 2214.54 ha;
- increase in the forest area (Tyagunsk forestry) by 4124.15 ha.

This is Scenario № 1 for changing land-use structure.

The developed algorithm was used in assessing changes in the ES potential in case of achieving optimal parameters of agricultural impact compared to the existing structure of land use. (Table 8).

Table 8
Changes in ES value during modifying land use patterns (Scenario № 1)

Landscape provinces	**Number of local natural landscape**	**Change in ES value as compared with scenario № 1, $ / ha / year**							**Total, $ / ha/ year**
		Provision of timber, non-timber and food resources of forests	**Grass provision on haylands**	**Grass provision on pastures**	**Provision of food**	**Climate regulation**	**Tourist attraction**	**Genetic resources of rare species of plants and animals, hunting animals**	
Upper Ob	131	0.00	8.69	0.00	-8.80	1.89	0.00	0.00	147818.46
	134	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	135	0.00	2.44	0.00	0.00	0.58	0.00	0.00	84667.67
	136	0.20	0.00	-0.23	0.00	0.09	0.00	0.50	10325.67
Presalair	203	0.42	5.55	0.00	-16.17	1.33	0.00	0.81	-447759.00
	205	0.00	4.63	0.00	0.00	1.07	0.00	0.00	164033.93
	206	0.60	0.00	4.63	-18.41	0.14	0.00	1.06	-245674.81
	207	0.54	0.00	-0.18	0.00	0.16	0.00	1.06	8723.80
	208	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total, $ / ha / year									-277883.46

Thus, in case of decreasing the arable land area during the proposed transformations, the ES value throughout the region may drop by 277.88 th $ / year. It confirms the duality of the problem of achieving sustainable development, for instance, to avoid degradation of ecosystems is feasible through agricultural impact mitigation that in turn will lead to decreased provisioning services valued much higher on the market than climate regulation ones.

The Zarinsky region is distinguished by large areas of currently abandoned fallow lands developed in the second half of the XX century. According to our estimates, the area of fallow lands is 4.16% (2020) of the total region area. Nowadays, such lands do not deliver ES due to unprofitable plowing, disappearance of economic entities, etc. though they still have the potential for economic activities.

To assess the options of using fallow lands of local natural landscapes from the point of view of sustainability, it is necessary to apply:

1) the environmental parameters of agricultural impact;

2) the expert assessments;

3) the developed model for assessing ecosystem services.

For each local natural landscape, the proposals on fallow land use with regard for their specific location have been developed (Table 9).

Table 9
Proposals on fallow land use (Scenario №2)

Number of local natural landscape	***Fallow lands, ha***	**Proposals for organizing land use on fallow lands (Scenario №2)**
131	8793.36	Some restrictions on livestock grazing are associated with ravine area growth. Plots of fallow lands are almost everywhere adjacent to forests that creates conditions suitable for haymaking
134	262.34	Fallow lands are located near settlements with developed dairy and meat livestock, surrounded by pastures and suitable for grazing
135	1105.42	Fallow land plots are located near small rivers thus providing suitable conditions for haymaking
136	214.15	There is a need to limit livestock grazing on the territory in order to avoid an increase in the area of ravines and pollution of rivers. It is recommended to use plots of fallow lands in floodplains for selective mowing.
203	4074.86	Suggested for using as hayfields, fallow lands, as a rule, adjoin hayfields, the share of which in the total structure of the area is the highest.
205	2152.61	Fallow lands are almost everywhere adjacent to forests that makes haymaking suitable.
206	2308.59	In this area, there are optimal relief conditions for grazing livestock (the coefficient of eatability of pasture grass is 0.7). The area is adjacent to a large livestock enterprise “Altai LLC”. Due to little amount of forests, reforestation on 123 hectares of fallow lands adjacent to large ravines to limit their spread is proposed.
207	254.54	The area is adjacent to settlements with the developed dairy and meat cattle breeding in households of villages Mironovka and Zyryanovka. Due to poor forest cover, reforestation on 12 hectares of fallow lands adjacent to forest areas is proposed.
208	1876.55	Plots of fallow lands are located in the valley of R. Alambay with conditions suitable for haymaking

The proposed changes in fallow land use structure are expected to provide permissible environmental parameters in each local natural landscape and ensure economic activities without any threat of ecosystem degradation and decrease in the ES value (Table 10).

Table 10
Assessment of parameters of agricultural impact in Upper Ob and Presalair provinces (Scenario №2), %

Landscape provinces	**Number of local natural landscape**	**Percentage of natural landscapes**	**Percentage of arable land**	**Percentage of fodder lands in farmland area**	**Percentage of forest area**
Upper Ob	131	55.54	43.24	36.01	31.18
	134	59.43	12.30	63.26	37.18
	135	64.94	28.08	47.27	39.02
	136	60.92	10.31	75.08	23.03
Presalair	203	51.83	45.80	40.04	20.92
	205	79.17	20.81	52.51	55.92
	206	51.74	45.96	40.76	20.01
	207	62.70	26.11	60.91	20.03
	208	75.82	16.13	65.06	44.08
Upper Ob		**58.41**	**33.64**	**42.86**	**32.13**
Presalair		**63.06**	**33.47**	**46.81**	**32.95**

With the increasing share of fodder lands in the total structure of farmlands, the potential of hayfields ES will significantly grow. Due to high capacity of hayfields to carbon sequestration from the atmosphere, the value of climate regulation services will also increase.

Differences in the ES value before and after transformation in case of proposed use of fallow lands are presented in Table 11.

Table 11
Changes in ES value under modifying land use patterns (Scenario № 2)

Landscape provinces	**Number of local natural landscape**	**Change in ES value as compared with scenario № 2, $ / ha / year**							**Total, $ / ha / year**
		Provision of timber, non-timber and food resources of forests	**Grass provision on haylands**	**Grass provision on pastures**	**Provision of food**	**Climate regulation**	**Tourist attraction**	**Genetic resources of rare species of plants and animals, hunting animals**	
Upper Ob	131	0.00	6.53	0.00	0.00	1.36	0.00	0.00	658242.11
	134	0.00	0.00	0.72	0.00	-0.01	0.00	0.00	7273.82
	135	0.00	2.44	0.00	0.00	0.51	0.00	0.00	82789.60
	136	0.00	0.72	0.00	0.00	0.15	0.00	0.00	16049.79
Presalair	203	0.00	4.50	0.00	0.00	0.94	0.00	0.00	305032.50
	205	0.00	4.63	0.00	0.00	0.97	0.00	0.00	161192.64
	206	0.00	0.00	4.46	0.00	-0.07	0.00	0.08	91583.48
	207	0.00	0.00	1.30	0.00	-0.03	0.00	0.00	7043.13
	208	0.00	3.76	0.00	0.00	0.79	0.00	0.00	140517.84
Total, $ / ha / year									1466114.00

In some sites, an increase in pasture areas will slightly reduce the ability of ecosystems to carbon sequestration. However, such a decrease is insignificant as compared to the sites with larger hayfield areas. In general, the proposed option for changing land use structure in the region through involving fallow lands into circulation may increase the total ES value more than by $ 1.46 million a year.

At the same time, the proposed changes may prevent decline in agricultural production that is favorable for positive perception of the users of natural resources.

Let us compare the options of the proposed transformation with that where all environmental parameters of agricultural impact are optimal (Table 12).

Table 12
Comparison of scenarios for modifying land use structure in the Zarinsky regio

Land use structure change scenarios	**Level of parameters of agricultural impact**	**Change in ES value, th $ / year**
Existing land use structure	Critical	0
Land use structure with optimal parameters of agricultural impact (Scenario №1)	Optimal-green	-277.88
Land use structure change: production on fallow lands, taking into account their location and permissible agricultural impacts (Scenario №2).	Optimal-acceptable	1466.11

Hence, the developed optimal-acceptable scenario for changing the land use structure based on prevention of landscape degradation, achievement of optimal agricultural impact as well as on expert assessment is more preferable. This study also supports in practice one of the outcomes obtained by F. Accatino et al. (Accatino et al., 2019) For instance, there is a synergy effect between livestock production and other ES when multifunctional land use is implemented.

Conclusion

The analysis of two scenarios for sustainable development indicates that the use of optimal-green scenarios in land use does not always ensure sustainable development and may decrease economic value of ES. Our findings suggest that application of expert assessments, evaluation of permissible agricultural impacts and ES make it possible to solve a number of problems in land-use planning.

The employment of these tools excludes both ecosystem degradation and excessive ecologization of land use under land use planning. As a result it also allows to avoid a decline in agricultural production because our methodology is based not only on productivity, but also on sustainability of ecosystems.

Thus, growth of economic value of ES in agricultural areas can be achieved through changing the land use structure, including an increase in hayfields, pastures and reforestation areas (multifunctional land uses).

Although available regional data have limits in assessing provisioning and regulating services, the efforts to introduce such evaluations into planning practice may create the basis for further development of regional ES assessment for making a proper land use choice.

The developed algorithm for assessing scenarios of land use change opens wide opportunities for evaluation of expected changes in land use structure and decisions already made and affecting the performance. It is a rather simple procedure facilitating the implementation of assessment outcomes in land use planning. The introduction of such developments is of great importance for the regions with nature-dependent economies, including agriculture and forestry.

Declarations

1.Authors' contributions

Anton Nazarenko wrote the main manuscript text and prepared all figures and tables.

2. *Competing interests*

The author declares that he has no competing interests.

3. *Funding*

This study was carried out as a part of State Task of IWEP SB RAS (The project title «Modern challenges for natural and natural-economic systems of Siberia: diagnostics, adaptive capabilities and potential of ecosystem services» (№ 1021032422891-7).

4. Ethics Declaration statement

Not applicable.

5. Consent to Participate

Not applicable.

6. Consent for publication

Not applicable.

7. Data availability

The datasets generated during the current study are available from the author on reasonable request.

References

1. Accatino, F., Tonda, A., Dross, C., Léger, F., Tichit, M., 2019. Trade-offs and synergies between livestock production and other ecosystem services. Agricultural Systems 168, 58–72. https://doi.org/10.1016/J.AGSY.2018.08.002
2. Albert, C., Galler, C., Hermes, J., Neuendorf, F., Von Haaren, C., Lovett, A., 2016. Applying ecosystem services indicators in landscape planning and management: The ES-in-Planning framework. Ecological Indicators 61, 100–113. https://doi.org/10.1016/J.ECOLIND.2015.03.029
3. Basnou, C., Baró, F., Langemeyer, J., Castell, C., Dalmases, C., Pino, J., 2020. Advancing the green infrastructure approach in the Province of Barcelona: integrating biodiversity, ecosystem functions and services into landscape planning. Urban Forestry & Urban Greening 55, 126797. https://doi.org/10.1016/J.UFUG.2020.126797
4. Bastian, O., Haase, D., Grunewald, K., 2012. Ecosystem properties, potentials and services – The EPPS conceptual framework and an urban application example. Ecological Indicators 21, 7–16. https://doi.org/10.1016/J.ECOLIND.2011.03.014
5. Bolliger, J., Kienast, F., 2010. Landscape functions in a changing environment. Landscape Online 21, 1–5. https://doi.org/10.3097/LO.201021
6. Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Global Environmental Change 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002
7. Daily, G.C., Matson, P.A., 2008. Ecosystem services: From theory to implementation. Proceedings of the National Academy of Sciences 105, 9455 LP – 9456. https://doi.org/10.1073/pnas.0804960105
8. Dolman, A.J., Shvidenko, A., Schepaschenko, D., Ciais, P., Tchebakova, N., Chen, T., Van Der Molen, M.K., Belelli Marchesini, L., Maximov, T.C., Maksyutov, S., Schulze, E.D., 2012. An estimate of the terrestrial carbon budget of Russia using inventory-based, eddy covariance and inversion methods. Biogeosciences 9, 5323–5340. https://doi.org/10.5194/bg-9-5323-2012
9. García-Díez, V., García-Llorente, M., González, J.A., 2020. Participatory mapping of cultural ecosystem services in madrid: Insights for landscape planning. Land 9. https://doi.org/10.3390/LAND9080244
10. Holt, A.R., Alix, A., Thompson, A., Maltby, L., 2016. Food production, ecosystem services and biodiversity: We can't have it all everywhere. Science of The Total Environment 573, 1422–1429. https://doi.org/10.1016/J.SCITOTENV.2016.07.139
11. Isayev, A.S., Korovin, G.N., Utkin, A.I., Pryazhnikov, A.A., Zamolotchikov, D.G., 1993. Deposition in assessment of stores and annual sequestration of carbon in phytomass of forest ecosystems of Russia. Forestry 5, 3–10.
12. Jax, K., Barton, D.N., Chan, K.M.A., de Groot, R., Doyle, U., Eser, U., Görg, C., Gómez-Baggethun, E., Griewald, Y., Haber, W., Haines-Young, R., Heink, U., Jahn, T., Joosten, H., Kerschbaumer, L., Korn, H., Luck, G.W., Matzdorf, B., Muraca, B., Neßhöver, C., Norton, B., Ott, K., Potschin, M., Rauschmayer, F., von Haaren, C., Wichmann, S., 2013. Ecosystem services and ethics. Ecological Economics 93, 260–268. https://doi.org/10.1016/j.ecolecon.2013.06.008
13. Kelly, B., Aris, G., 2007. Optimization and Assessment of Agricultural Water-Sharing Scenarios under Multiple Socioeconomic Objectives. Journal of Water Resources Planning and Management 133, 264–274. https://doi.org/10.1061/(ASCE)0733-9496(2007)133:3(264)
14. Koschke, L., Fürst, C., Frank, S., Makeschin, F., 2012. A multi-criteria approach for an integrated land-cover-based assessment of ecosystem services provision to support landscape planning. Ecological Indicators 21, 54–66. https://doi.org/10.1016/j.ecolind.2011.12.010
15. Liu, A.J., Tong, S.T.Y., Goodrich, J.A., 1999. Land use as a mitigation strategy for the water-quality impacts of global warming: a scenario analysis on two watersheds in the Ohio River Basin. Environmental Engineering and Policy 2, 65–76. https://doi.org/10.1007/BF03500900
16. MA, 2005. Ecosystems and human well-being: synthesis. A report of the millenium ecosystem assessement. Island Press, Washington.
17. Müller, F., de Groot, R., Willemen, L., 2010. Ecosystem services at the landscape scale: The need for integrative approaches. Landscape Online 23, 1–11. https://doi.org/10.3097/LO.201023
18. Orlova, I. V., Sharabarina, S.N., 2015. Assessing agricultural impact on natural systems: Theoretical and methodological approaches. Geography and Natural Resources 36, 335–340. https://doi.org/10.1134/S1875372815040034

19. Seppelt, R., Dormann, C.F., Eppink, F. V., Lautenbach, S., Schmidt, S., 2011. A quantitative review of ecosystem service studies: Approaches, shortcomings and the road ahead. Journal of Applied Ecology 48, 630–636. https://doi.org/10.1111/j.1365-2664.2010.01952.x
20. Verburg, P.H., Schot, P.P., Dijst, M.J., Veldkamp, A., 2004. Land use change modelling: current practice and research priorities. GeoJournal 61, 309–324. https://doi.org/10.1007/s10708-004-4946-y
21. Zerger, A., Warren, G., Hill, P., Robertson, D., Weidemann, A., Lawton, K., 2011. Multi-criteria assessment for linking regional conservation planning and farm-scale actions. Environmental Modelling & Software 26, 103–110. https://doi.org/10.1016/J.ENVSOFT.2010.04.001
22. Zhang, X., Jin, X., Liang, X., Ren, J., Han, B., Liu, J., Fan, Y., Zhou, Y., 2022. Implications of land sparing and sharing for maintaining regional ecosystem services: An empirical study from a suitable area for agricultural production in China. Science of The Total Environment 820, 153330. https://doi.org/10.1016/J.SCITOTENV.2022.153330

Tables

Table 4 is available in the Supplemental Files section.

Figures

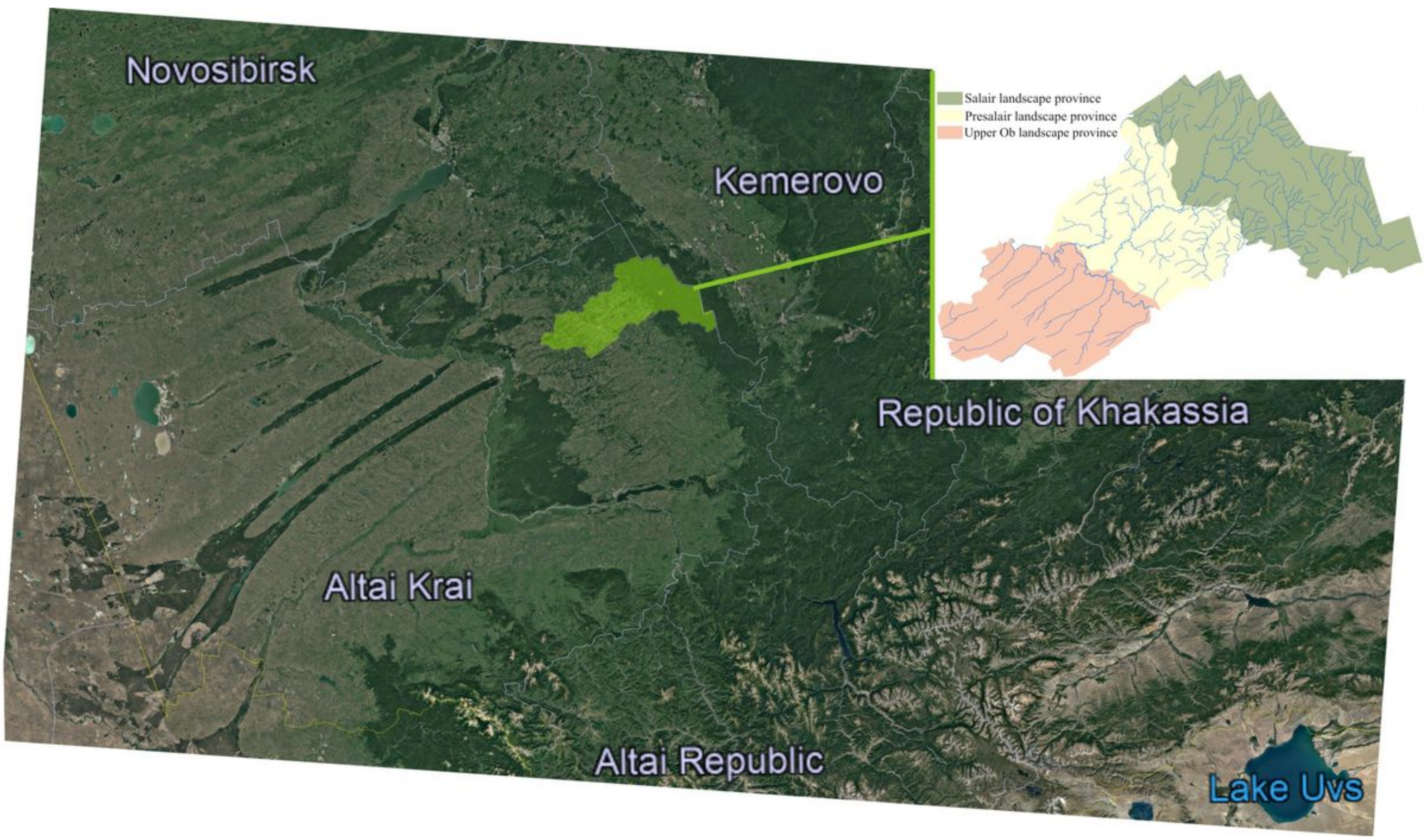


Figure 1

Geographical location and landscape structure of Zarinsky region

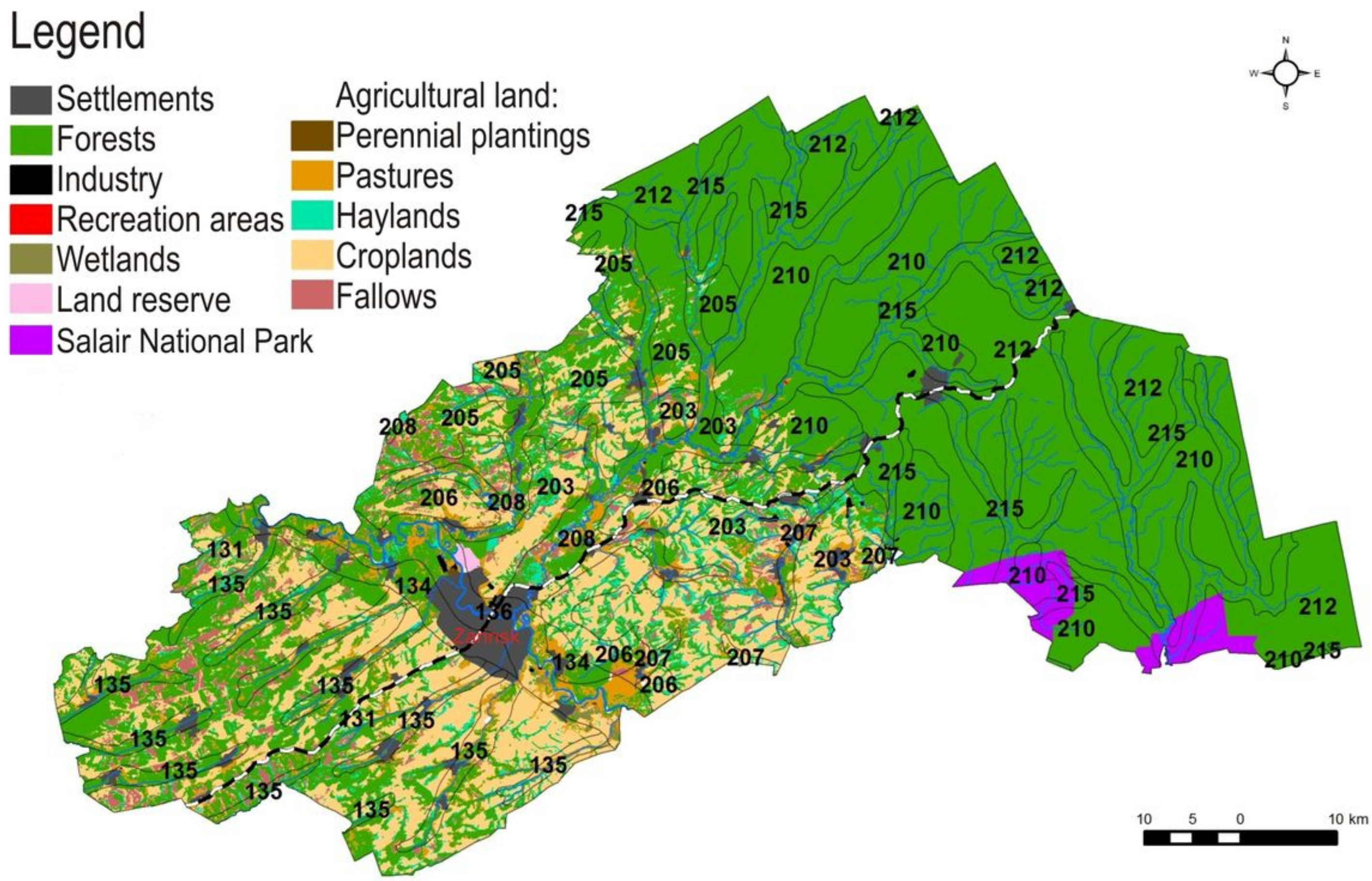


Figure 2

Land structure of Zarinsky region

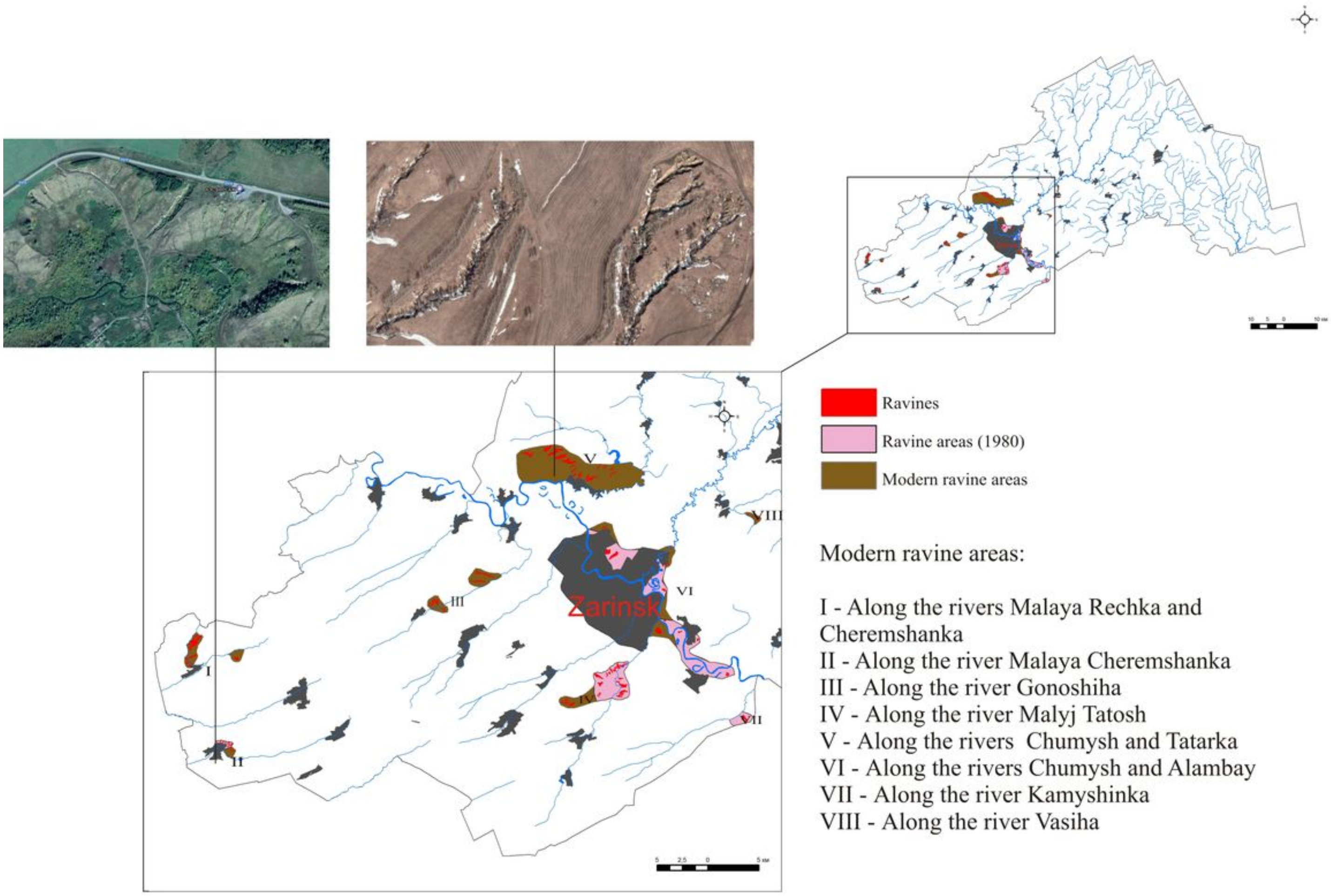


Figure 3

A ravine net in Zarinsky region (1980-2020)

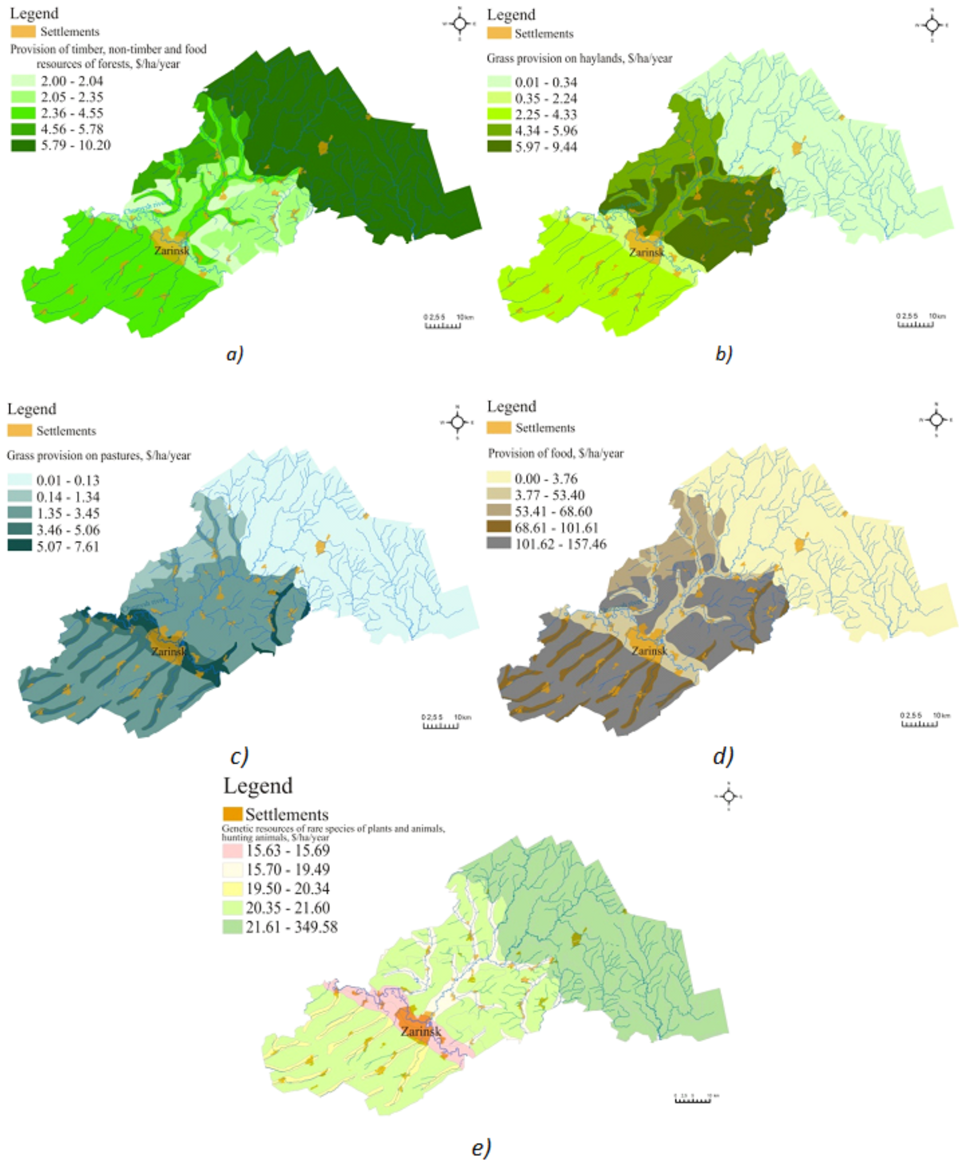
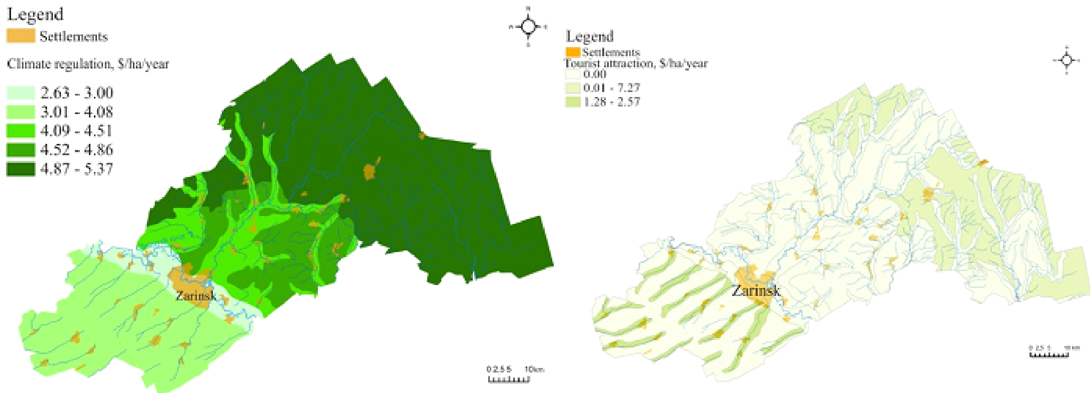


Figure 4

Economic value of provisioning ES in Zarinsky region, US $/ha/year



a) b)

Figure 5

Economic value of regulating and cultural ES in Zarinsky region, US $/ha/year

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table4AssessmentofESvalue.docx