

Hyrceanian forests conservation based on ecosystem services approach

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Abstract Lush Hyrcanian mixed temperate forests are globally important ecosystems with considerable ecological and economic values and high variety of ecosystem services (ES). In this study, an ES-based approach is adopted to develop a spatial conservation framework for Gorganrood Watershed, northeastern Iran. In doing so, the integrated valuation of ecosystem services and trade-offs modeling tool was implemented to spatially quantify a collection of five ES including soil retention, habitat quality (as a proxy for biodiversity), water yield, food supply and carbon storage. These services were integrated into a single layer based on the Total Ecosystem Services (TES) index. By performing correlation analyses, the type and the strength of relationships between ES, TES index values and different land features were analyzed to reveal which land-use categories at what locations are more capable to provide bundles of ES. Accordingly, Hyrcanian mixed temperate forests in the southern sub-watersheds of the area were detected to have higher potential for simultaneous provisioning of multiple ES. In addition, we show that biodiversity hotspots and provision of other ES are

highly correlated and thus that conservation of one group can be beneficial for the other. Our findings are particularly applicable in areas where complex network of land-uses and limited resources are major barriers against effective conservation of Hyrcanian mixed temperate forests.

Keywords Lush Hyrcanian mixed temperate forests · Ecosystem services · Biodiversity · Total Ecosystem Services index · InVEST · Iran

Introduction

Ecosystem services (ES) are benefit that humans receive from ecosystems (Millennium Ecosystem Assessment 2005). The connotation of ES refers to several benefits of ecosystems to human communities (Haines-Young and Potschin 2010). Different ES are inherently interrelated, and ecosystem conservation efforts seek to satisfy the growing demands of human communities for provisioning of various ES such as food, timber and fiber (Foley et al. 2005). In this regard, addressing the contribution of environment and coupled human–nature systems into land-use/land-cover (LULC) planning practices is being increasingly considered to inform strategy and policy making (Carpenter et al. 2009; Larigauderie et al. 2012). As an important approach toward informed LULC planning, spatial modeling of ES has been considered as an innovative and sustainable perspective to address the effect of ecosystems and their functioning on policy-making attempts (Nemec and Raudsepp-Hearne 2013). Mapping and quantifying spatial distribution of ES can assist in revealing which services should be managed and protected and where resources and investments should be allocated to enhance synergies and decrease trade-offs among bundles

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of ES (Schröter and Remme 2016). Spatial ES evaluations could provide valuable insights for systematic LULC planning and conservation practices. The main advantage of such an approach is to guarantee the long-term potential of ecosystems to supply multiple ES (Egoh et al. 2007, 2008). However, integration of ES into LULC planning efforts is relatively a new approach, which yet needs to be studied and analyzed for practical purposes.

Spatial variation of each ES across the landscape can be different (Egoh et al. 2008; Bai et al. 2011). In addition, different levels of spatial co-occurrence among multiple ES can increase the complexity of planning practices. Therefore, it is important to detect hotspot locations, where the highest degree of congruence between several ES does exist and to determine which LULC categories are more effective to provide bundles of ES.

The term *ES hotspot* indicates which locations in a landscape are of higher priority for ES conservation since they supply a greater load of different ES (Cimon-Morin et al. 2013). Spatial analysis of ES bundles provides valuable insights into spatial congruence and divergence of biodiversity conservation hotspots and protection of multiple ES. Such attempts finally result in optimized planning efforts for multiple ES conservation (Zarandian et al. 2017).

There is a series of recent studies in the literature based on spatial analysis of ES bundles that attempted to address the effect of ES on hotspots detection and informed LULC planning. In this regard, Bai et al. (2011) investigated the spatial congruence between biodiversity and multiple ES using correlation, overlap and principal component analyses. They showed that biodiversity is positively correlated with soil retention, water yield and carbon sequestration services and negatively linked with N/P retention and pollination. In a further attempt, Pan et al. (2013) formulated two spatial indices of Total Ecosystem Service (TES) and trade-offs (TO) to study the spatial variation of supply of four ES and to analyze the relationships between environmental factors with provisioning of multiple ES. Wu et al. (2013) implemented overlap and correlation analyses to identify multiple hotspots and the relationships between landscape services. The results showed that ES have spatial heterogeneity and various locations have different levels of potential to supply one or multiple ES. In addition, they reported that ES could be divided into two trade-off groups of natural (carbon storage, soil retention and habitat conservation) and artificial (material production and population support) categories. In a review study, Schröter and Remme (2016) classified different methods to spatially detect hotspots locations providing multiple ES. They demonstrated how spatial arrangement of hotspots for a collection of ES varies based on the implemented method. In addition, it has been highlighted that different hotspot

detection methods can also differ in terms of estimating the total amount of ES provided in a given location. Bagstad et al. (2016) mapped ES hotspots for six national forests in Colorado and Wyoming, USA, applying different methods. They indicated delineation of ES hotspots can inform landscape scale planning and also support past finding on public attitudes toward wilderness areas. Studying the linkage between socioeconomic characteristics and supply of multiple ES is also an active research agenda. In this regard, Ai et al. (2015) studied associations between the provisioning of ES and socioeconomic development. The results implied there is a meaningful negative linkage between crop production and tourism income and a positive relationship between crop production and nutrient retention as well as carbon sequestration. In addition, the negative effect of urban growth process on provisioning and regulating services was also detected.

Considering the above-mentioned studies, it could be elicited that the innovative concept of ES can effectively improve LULC practices from a structure-based analysis of the environment (biophysical environment) into function-based efforts (i.e., ecosystem functions in this context correspond to services provided by the ecosystem). Such efforts not only inform spatial policies, but also provide a basis for optimized resource allocation and informed decision making. Applications of ES-based LULC planning attempts in Iran are very limited. Zarandian et al. (2017) conducted a scenario-based study in Hyrcanian mixed temperate forests in northern Iran. Their results indicated that collaborative planning strategy can contribute to informed decision making by establishing a landscape whose configuration is associated with maintenance of supply for multiple ES, reduced environmental impacts and less conflict between authorities and local stockholders.

Lush Hyrcanian (Caspian) mixed temperate forests are globally important ecosystems in northern Iran with high endemism as well as ecological and economic values (Amirnejad et al. 2006). These forests cover nearly 55,000 km² in the southern coast of the Caspian Sea, and they are named after the ancient era of Hyrcania (*wolf land*). In addition, these forests provide a multitude of services in terms of climate regulation, human health, tourism and recreation, wildlife refuges and habitats, fresh water supply, erosion control, nutrient cycling, biodiversity protection, disturbance regulation and many others. ES obtained from Hyrcanian mixed temperate forests are strongly interrelated. For example, on the one hand, biodiversity is dependent on the large extent and connected network of healthy forest ecosystems, and on the other hand, decline in forest biodiversity will result in decreasing forest productivity and sustainability. Therefore, sustainable forest conservation practices are oriented to support

simultaneous supply of multiple ES such as soil retention, water yield, carbon storage and sequestration and biodiversity enrichment.

Nowadays, the integrity, resilience and functioning of these ecosystems for long-term supply of ES are threatened by a variety of natural and anthropogenic threats such as forest fires, unplanned expansion of farmlands, uncontrolled urbanization, heavy industrialization, broad spatial extent and lack of effective regional planning strategies. The complexity of the problem which arises from interactions between different ES and their spatial variation is also another barrier for effective conservation of these valuable ecosystems. In this regard, majority of studies in the literature (Bai et al. 2011; Ai et al. 2015; Schröter and Remme 2016; Bagstad et al. 2016) mainly considered detection of biodiversity hotspots or analyzed various ES without considering the trade-off and synergy effects. There are also a series of studies in the literature, which highlight that investigating the linkages between different LULC categories and their corresponding ES (trade-offs and synergies between ES) is active research topics and challenging issues in developing spatial planning efforts. Besides, consideration of several LULC categories and their linkage with multiple ES is also a less noted attempt in the literature. In this matter, Qin et al. (2015) focused on the evaluation of ecosystem services under different LULC schemes applying correlation rate model and distribution mapping. In addition, Landuyt et al. (2016) analyzed interaction among several ecosystem services together with their driving forces using Bayesian belief network models.

Therefore, by adopting a holistic consideration of different LULC categories and multiple ES as well as addressing the trade-offs and synergies between different ES (i.e., regulating and provisioning), this study goes beyond the mentioned limitations to more practically and realistically optimize management options and more logically address the complexity of the landscape and the decision problem. Accordingly, a grounded and scientific basis for ES-based conservation of Hyrcanian forests along with other land resources would be of considerable interest since it is potential to decrease conflicts among different stockholders by creating compromised solutions and synergy between various ES. Such an approach is of interest particularly in areas where insufficient acreage of land resources for farmland expansion and urban growth is leading to drastic conversion of ecologically valuable lands and natural forests into human-made surfaces. Therefore, based on such criticism, the current study attempts to answer the following questions:

Is there any spatial variation in congruence of ES bundles provided by lush Hyrcanian forests and other LULC categories in northern Iran?

In case of any spatial variation, which locations and what LULC categories have more significant contribution for simultaneous supply of multiple ES in northern Iran?

Can the concept of ES hotspots improve conservation of Hyrcanian mixed temperate forests, while reducing LULC conflicts and enhancing biodiversity levels?

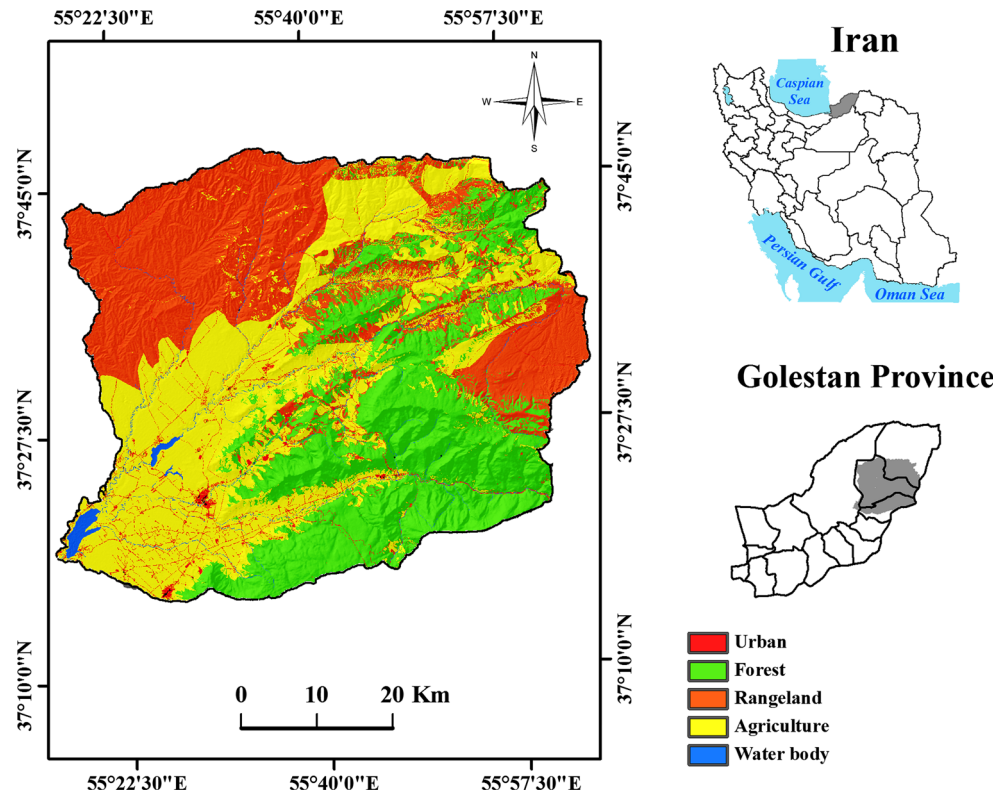
Materials and methods

Study area

The area of study (Gorganrood Watershed) is located in Golestan Province, northeastern Iran, and its spatial extent covers latitudes 37°19'N and 37°49'N, and longitudes 55°4'E and 55°16'E (Fig. 1). The study area is also part of southeastern coast of the Caspian Sea, and in the south, Hyrcanian mixed temperate forests and Alborz Mountain Range characterize the main environmental and topographical properties of the study area. The areal extent of the research location is approximately 3178 km², and average elevation is 634 m above the sea level (range 0–2167 m). The major collection of tree species in the area with ecological and economic values includes *Fagus orientalis* (beech), *Ficus religiosa* (sacred fig), *Quercus castaneifolia* (chestnut-leaved oak), *Parrotia persica* (Persian ironwood), *Quercus castaneifolia* (oak), *Platycladus orientalis* (Chinese arborvitae), *Acer cappadocicum* (cappadocian maple), *Tilia platyphyllos* (linden), *Carpinus betulus* (common hornbeam), *Alnus glutinosa* (alder), *Acer velutinum* (Persian maple), *Zelkova carpinifolia* (Caucasian zelkova), *Diospyros lotus* (Caucasian persimmon), *Pterocarya fraxinifolia* (Caucasian wingnut), *Ulmus minor* (elm) and *Juniperus polycarpos* (Persian juniper). In case of forest vegetation types, Persian ironwood-common hornbeam-oak, Persian ironwood-oak, Persian ironwood-common hornbeam-beech, Caucasian zelkova-common hornbeam-oak and beech-common hornbeam-linden indicate some important native species in the area (the detailed list of tree species and forest vegetation types can be found in Golestan Province Land-use Planning Report 2013).

Agricultural fields, vast plains, urban areas and rangelands dominate the landscape of the area in the northern and western directions. Central and eastern parts of the study area are primarily mixed ecosystems located in transition and ecotone areas between different ecosystems. Golestan is historically one of the most active provinces of Iran for its agricultural and environmental protection utilities. In this regard, the area is characterized by its high potential for agricultural activities and high acreage of farmlands, orchards and rangelands that supply food products for the growing population in the region. In the south, part of Golestan National Park is located in dense

Fig. 1 Geographical location of the Gorganrood Watershed in Golestan Province, northeastern Iran



Hyrcanian mixed temperate forests that are home to many species of migratory and native birds, large mammals, fishes, amphibians and several species of native and endemic plants (Sakieh et al. 2015). The area also possesses high aesthetics and ecological values (Sakieh et al. 2016) that attract thousands of tourists and scholars each year for recreational and scientific purposes.

ES selection

Due to following reasons, a collection of five ES including water yield, food production, habitat quality, soil retention and carbon storage was considered in this study:

Food production service is greatly correlated with socioeconomic status of the study area, and therefore, variation in production of such valuable service can greatly influence the stability, life conditions and sustainability of human communities;

- Previous ES-based studies in the area (Mahiny and Clarke 2012, 2013; Sakieh et al. 2015, 2016; Golestan Province Land-use Planning Report 2013) indicated the potential of Golestan Province for a series of important ES including food production, biodiversity, hydrological ecosystem services (e.g., water yield) and soil stabilization is significantly linked with LULC change processes;

- These ecosystem benefits belong to three important categories of regulating (soil retention, carbon sequestration), supporting (habitat for species) and provisioning (food production, water yield) services that are reported to be critically important for their economic benefits and their contribution to environmental sustainability (Bennett et al. 2009); and
- These services (especially soil retention and habitat quality) in the targeted landscape are also reported to be correlated with cultural ES such as landscape aesthetics and tourism (Sakieh et al. 2016).

ES mapping

The InVEST (integrated valuation of ecosystem services and trade-offs) model (Sharp et al. 2014) has been employed for ES mapping in this study. InVEST is a geo-computation modeling tool that quantifies production of different ES in a targeted landscape with a particular emphasis on LULC categories of the area (Polasky et al. 2011; Leh et al. 2013; Zarandian et al. 2017). Accordingly, the LULC layer of the area (2010) was obtained from Gorgan University of Agricultural Sciences and Natural Resources, which is the leading institute for conducting LULC planning studies in Golestan Province. The LULC layer is derived from Landsat satellite images (TM sensor)

with 30 m × 30 m spatial resolution. The layer includes five categories of urban, forest, rangeland, agriculture and water body. In addition, digital elevation model (DEM) of the study area with 10-m spatial resolution was acquired from National Cartographic Center (NCC) of Iran and used to delineate hydrological units.

Delineation of sub-watersheds

The watershed and sub-watershed delineation was undertaken using DEM data and employing a physically based watershed model (SWAT2009). The DEM layer was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. The watershed delineation process includes five major steps of DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-watershed parameters (Winchell et al. 2010). For the stream definition, the threshold-based stream definition method was used to define the minimum size of the sub-watershed. The ArcSWAT interface allows the user to fix the number of sub-watersheds by specifying the initial threshold area. The threshold area defines the minimum drainage area required to form the origin of a stream. In this research, watershed was divided into 26 sub-watersheds using the default threshold area (7182.28 ha) that is the minimum drainage area required to support a permanent headwater stream.

Based on InVEST model algorithms, water yield and soil retention are directly calculated at sub-watershed scale, whereas other ecosystem services are generated at pixel scale (30 m × 30 m). To overcome the scale mismatch, pixel values were averaged across each sub-watershed as suggested by Su and Fu (2013).

Water yield

Water yield is referred to as the amount of water that a watershed discharges out of its boundaries (i.e., rainfall minus the amount of water infiltration and evapotranspiration). The InVEST model implements average annual rainfall, soil depth, available water storage to plants, annual reference evapotranspiration, the depth of the plant root and LULC information to compute the average annual water yield (Y_{xj}) for each raster pixel (adopted from Sharp et al. 2014):

$$Y_{xj} = \left(1 - \frac{AET_{xj}}{P_x}\right) P_x \tag{1}$$

where AET_{xj} stands for the annual actual evapotranspiration for pixel x with LULC category j , P_x indicates the annual rainfall on pixel x , and AET_{xj}/P_x is an estimation of the Budyko curve suggested by Zhang et al. (2004):

$$\frac{AET_{xj}}{P_x} = 1 + \frac{PET_x}{P_x} - \left[1 + \left(\frac{PET_x}{P_x}\right)^w\right]^{1/w} \tag{2}$$

where PET_x is the potential evapotranspiration and w_x is a non-physical variable that evaluates the climatic-soil characteristics both given below:

$$PET_x = K_c(\ell_x) \cdot ET_{0(x)} \tag{3}$$

$$w_x = Z \frac{AWC_x}{P_x} + 1.25 \tag{4}$$

where $ET_{0(x)}$ is the observed evapotranspiration for raster pixel x and $K_c(\ell_x)$ is the coefficient of the vegetation evapotranspiration related to the LULC ℓ_x on raster pixel x (Sharp et al. 2014). The parameter of $ET_{0(x)}$ indicates the climatic characteristics of the area according to the evapotranspiration of a reference plant such as grass or alfalfa grown at that geographical location. The parameter of $K_c(\ell_x)$ is mainly determined according to the vegetative conditions of the LULC type in a given raster pixel (Allen et al. 1998). The K_c variable regulates the ET_0 values according to the crop or vegetation cover of each pixel. The element of w_x is an empirical variable that could be formulated as a linear function ($\frac{AWC \cdot N}{P}$), where N is the annual number of events and AWC indicates the volumetric (mm) available water to vegetation cover that is defined by soil texture and effective rooting depth. The Z parameter is an empirical constant, which is referred to as seasonality factor and illustrates the local rainfall pattern and additional hydrological properties. The 1.25 term represents the minimum value of w_x parameter, which could be regarded as a value for bare soil (i.e., root depth = 0) (for more descriptions, readers are referred to Yang et al. 2008; Donohue et al. 2012; Sharp et al. 2014).

For the remaining LULC types, actual evapotranspiration is directly calculated from the observed evapotranspiration $ET_{0(x)}$ and possesses an upper limit explained by the rainfall:

$$AET_{xj} = \text{Min}(K_c(\ell_x) \cdot ET_{0(x)}, P_{(x)}) \tag{5}$$

For mapping water yield service, the input data including average annual rainfall P_x and annual potential evapotranspiration $ET_{0(x)}$ were obtained from Iranian Meteorological Organization database (<http://irimo.ir>). For calculating the average annual evapotranspiration, the modified Hargreaves method was implemented (Droogers and Allen 2002; Samani 2000). This method is used to calculate the reference evapotranspiration applying minimum climatological information. The modified Hargreaves equation uses the average value of the mean daily maximum in addition to daily maximums and extraterrestrial radiation. Due to data unavailability in our study area, soil-related parameters including soil depth (as a surrogate layer

for root restricting depth) (Sharp et al. 2014) and plant available water content (AWC) were obtained from Harmonized World Soil Database provided by FAO (Nachtergaele et al. 2008).

Soil retention

The potential of each watershed for soil retention was determined by assessing the interaction between soil retention potential of each LULC category, precipitation, soil characteristics and topographical conditions. Applying the USLE (universal soil loss equation) method (Wischmeier and Smith 1978), internalized in the sedimentation module of the InVEST model, the potential soil loss of each raster pixel was estimated as the following:

$$\text{USLE} = R \times K \times L \times S \times C \times P \quad (6)$$

where USLE represents the potential average soil loss per year, R mirrors the rainfall aggressivity (erosivity) parameter ($\text{MJ mm ha}^{-1} \text{h}^{-1} \text{y}^{-1}$), K stands for the soil erodibility variable ($\text{t ha h ha}^{-1} \text{MJ}^{-1} \text{mm}^{-1}$), L and S factors are slope length and steepness (directly computed from DEM of the study area), respectively, C is the LULC-type management parameter, and P indicates the supporting practice parameter. Soil retention is measured by calculating the difference between potential soil loss (ULSE) and the maximum potential soil loss of the watershed, which considers the study area as a bare landscape:

$$\text{Soil retention potential} = \text{ULSE} - (R \times K \times L \times S) \quad (7)$$

There are different methods to determine the rain erosivity parameter or R . One appropriate method is computing the Fournier index, which requires rainfall data at the scale of monthly average values. It is also acknowledged that there is an association between F and R values (Loureiro and de Azevedo Coutinho 2001; Diodato and Bellocchi 2007), and therefore, such parameter can be implemented in development of regional models (Gregori et al. 2006).

Referring to Renard and Freimund (1994), the average annual and monthly precipitation data are used to calculate the R parameter. In this case, annual and monthly precipitation data from hydrological stations in the study area were compiled for a 25-year time period and the F parameter is computed for the hydrological stations. Accordingly, using F values acquired from the following formula, the R parameter was calculated for hydrological stations:

$$F = \frac{\sum_{i=1}^{12} p_i^2}{\sum_{i=1}^{12} p} \quad (8)$$

where p_i indicates the average precipitation (mm) in month i and p stands for the average annual precipitation (mm).

Having F values calculated, the following formulas were employed to ultimately compute the rainfall erosivity layer based on the ordinary kriging interpolation method (Renard and Freimund 1994):

$$\text{If } F < 55 \text{ mm, then } R = (0.07397 \times F^{1.847}) \quad (9)$$

$$\text{If } F \geq 55 \text{ mm, then } R = (95.77 - 6.081 \times F + 0.477 \times F^2) \quad (10)$$

The K or the parameter of soil erodibility mirrors sensitivity of soil particles to detachment and transferring by precipitation and runoff. According to Roose (1996), the sensitivity of different soil compositions in our study area to erosion is determined based on organic material content and textural class characteristics.

The C parameter (i.e., crop and management factor) mirrors the reducing effect of vegetative covers on the process of soil erosion. The C factor could be produced using experimental equations (Wischmeier and Smith 1978); however, the NDVI (normalized difference vegetation index) is the most common method to calculate the C layer (Kouli et al. 2009). The following equation is employed for reverse linear transformation of NDVI values into their respective scores of the C factor (Kouli et al. 2009):

$$C = ((1 - \text{NDVI})/2) \quad (11)$$

The P (i.e., supporting practice) factor is the ratio of soil loss with a support practice (e.g., terracing, contouring or strip-cropping) to that with straight-row farming up and down the slope (Renard et al. 1997). According to similar studies in the literature (Deore 2005; Leh et al. 2013), each land feature was given a value representing the support practice factor.

Habitat quality

The habitat quality service was modeled as a surrogate layer for biodiversity. The capacity of an ecosystem to provide habitat for different species of wildlife is a major function to support biodiversity. Using a habitat-based approach, variables such as habitat quality and rarity are implemented as proxies for biodiversity. In other words, according to the InVEST modeling approach, the habitat suitability is defined as the capability of an ecosystem to effectively maintain persistence of an organism (Sharp et al. 2014). Therefore, habitats with suitable conditions can support their fundamental functions for wildlife. The collection of input data for habitat quality mapping includes threat's relative impact, the relative susceptibility of each habitat type to each threat, the distance between habitats and the sources of the threat, and finally the legal degree of land protection. In this regard, a linear decay

function is employed to measure the influence of i_{rxy} of threat r from pixel y on habitat in raster pixel x (distance between the source of the threat and habitat):

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{rmax}} \right) \tag{12}$$

where d_{xy} refers to the linear distance between raster cell x and cell y and d_{rmax} represents maximum influential distance of the threat. The net degree of the threat or D_{xj} in raster cell x with land feature j is estimated with the following formula:

$$D_{xj} = \sum_{r=1}^R \sum_{y=1}^Y \left(\frac{W_r}{\sum_{r=1}^R W_r} \right) r_y i_{rxy} \beta_x S_{jr} \tag{13}$$

where y indexes total number of grid cells on r 's raster layer and Y_r mirrors the collection of raster cells on r 's data layer. The β_x variable indicates the degree of accessibility (i.e., the impact of the threat that can reach that pixel) in grid cell x , where 1 stands for the absolute accessibility (i.e., physical, social, institutional and legal protections often do diminish the impact of extractive activities). The S_{jr} factor refers to the vulnerability of LULC (habitat type) j to threat r , and closer scores to 1 represent greater habitat vulnerability. In this regard, if S_{jr} equals 0, then D_{xj} is not considered as a function of the threat r . It is noteworthy that threat weights (W_r) are normalized so that the sum of all threats weights equals 1. Thus, D_{xj} is the result of the weighted average of all threat levels in raster pixel x . At the next step, each cell's degradation score is transformed into habitat quality score using a half-saturation equation,

where the user should assign the half-saturation value. With the increase in pixel degradation value, habitat quality score declines. Ultimately, the value of habitat quality (Q_{xj}) in parcel x which is within the LULC j is computed according to the following formula:

$$Q_{xj} = H_j \left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z} \right) \right) \tag{14}$$

where z (2.5) and k are referred to as scaling constants. According to Sharp et al. (2014), z equals 2.5 and k as the half-saturation constant and a user-defined variable was specified with the value of 0.1 (according to the guideline explained in Sharp et al. 2014). H_j represents habitat suitability of land feature j . There is a positive association between Q_{xj} and H_j , and Q_{xj} is equal to 0 if $H_j = 0$. In contrast, the Q_{xj} decreases as D_{xj} increases.

Tables 1 and 2 indicate scoring schemes of different parameters used for habitat suitability mapping, which are determined based on our local knowledge of the study area, InVEST tutorial guidelines and similar studies in the literature (Leh et al. 2013; Sharp et al. 2014).

Carbon storage

The InVEST Tier 1 carbon storage model has been employed, and this model disaggregates terrestrial carbon storage into five main pools including (1) aboveground biomass, (2) belowground biomass, (3) soil, (4) other organic matter and (5) harvested wood products (HWPs) (Sharp et al. 2014). The amount of carbon storage on a particular parcel at time t , indicated by C_{xt} and quantified in metric tons of C, corresponds to the sum of the carbon storage in each pool in a particular parcel at time point t :

$$C_{xt} = C_{pxt} + \sum_{j=1}^J A_{xjt} (C_{aj} + C_{bj} + C_{sj} + C_{oj}) \tag{15}$$

where C_{aj} , C_{bj} , C_{sj} and C_{oj} represent the metric tons of carbon storage per hectare (Mg of $C\ ha^{-1}$), in aboveground, belowground, soil and other organic matter pools of LULC $_j$, respectively. In this equation, $j = 1, 2, \dots, j$ indexes the categories of LULC that form the landscape of

Table 1 Scoring scheme of the threats in Gorganrood Watershed

Threat (LULC type)	Maximum effective distance of the threat d_{rmax} (km)	Threat weight (W_r)
Agriculture	4.0	0.8
Urban	5.0	1.0
Primary roads	3.0	0.8
Secondary roads	2.0	0.7

Table 2 Scoring scheme of different LULC type for their habitat suitability and relative sensitivity to threats

LULC type	Habitat suitability based on LULC type (H_j)	The relative sensitivity of each LULC (habitat) type to each threat (S_{jr})			
		Agriculture	Urban	Primary roads	Secondary roads
Urban	0.1	0.1	0.0	0.0	0.0
Forest	1.0	0.8	0.5	0.6	0.4
Rangeland	0.8	0.8	0.5	0.5	0.4
Agriculture	0.2	0.0	0.6	0.5	0.4
Water body	0.5	0.7	0.5	0.3	0.2

the area. In addition, C_{pxt} refers to parcel x 's HWP's pool storage level at time point t and A_{xjt} stands for the area of LULC $_j$ occupying parcel x at time t . The A_x could be calculated through the following formula:

$$A_x = \sum_{j=1}^J A_{xjt} \text{ (parcel area does not change over time)} \quad (16)$$

If carbon data in some pools are lacking, the model can still be implemented with any subset of the remaining five pools of carbon storage. To measure the metric tons of C stored across the entire area at time t (i.e., C_t), the total value of the parcel-level carbon storage is calculated through the following equation (Kareiva et al. 2011):

$$C_t = \sum_{x=1}^X C_{xt} \quad (17)$$

In many situations, as with our study, data availability on carbon pool storages are highly limited, and this matter indicates that practical LULC planning attempts should employ more general information sources (e.g., Intergovernmental Panel on Climate Change guidelines or IPCC). Referring to IPCC (2006) methodology, values of different carbon pools have been estimated for each LULC category. In addition, in case of HWPs data in our study area (e.g., forest harvest rates and degradation rates of harvested products), we used forest management reports provided by Forests, Ranges and Watershed Management Organization of the Golestan Province (Comprehensive Forest Management Report of Gorganrood Watershed 2015). The InVEST model aggregates the amount of stored carbon in these pools based on LULC layer and classification scheme adopted by the modeler. According to the IPCC (2006) methodology, values for the carbon stored in each carbon pool have been estimated for each LULC category.

Food production

As an ES, food production is referred to as planted vegetation cover for human and animal use. In this study, the spatial extent of farmlands in each sub-watershed was regarded as a measure of food production potential (Raudsepp-Hearne et al. 2010).

Analyzing spatial variation of supplies of multiple ES

The TES index (Pan et al. 2013) was employed as a measure to quantify and analyze the spatial variation of the supplies of multiple ES. The TES measure was computed for each sub-watershed applying the following formula (Laterra et al. 2012):

$$TES = \frac{\sum_{i=1}^n \text{Relative ES}_i}{n} \quad (18)$$

where TES is the total relative value for all types of ES under study and n refers to the total number of ES types. The *Relative ES $_i$* indicates the relative amount of ES with category i , which is computed through the following equation:

$$\text{Relative ES}_i = \frac{ES_i - ES_{i-\min}}{ES_{i-\max} - ES_{i-\min}} \quad (19)$$

where ES_i is the actual value of ES type i in a particular sub-watershed, $ES_{i-\min}$ stands for the minimum actual value of ES type i in total collection of sub-watersheds in the study area, and $ES_{i-\max}$ refers to the maximum value. When $0 \leq TES \leq 1$, it is expected that higher values of the TES measure indicate greater level of supply for multiple ES in a given sub-watershed. The absolute and relative values of each ES at sub-watershed level are given in Table 3, and the InVEST-derived ES layers are depicted in Fig. 2.

Correlation analysis between ES, LULC categories and TES index

The area of each LULC category in Gorganrood Watershed was calculated, and bivariate associations between TES index values, multiple ES and percent of each LULC category in each sub-watershed (Table 4) were computed to analyze which land features at what locations (sub-watersheds) are more potential to simultaneously provide bundles of ES. In this regard, Spearman rank correlation coefficient and coefficient of determination (R^2 linear) were used for correlation analysis. A positive Spearman rank coefficient indicates there is a positive feedback between a pair of ES and one service increases with the increase in another one (synergy). In contrast, a negative coefficient implies that increase in one service could be achieved by decreasing another service (trade-off). From the environmental conservation perspective, those locations and land categories that effectively provide multiple ES are of higher priority for conservation.

The results of such analyses can assist in identification of hotspot locations and LULC categories that are of higher priority for conservation efforts. In addition, for each sub-watershed, the amount of each service was plotted using radar charts. A radar chart is an illustration for different levels of relative ES values (based on TES index calculation) in each sub-watershed and provides a holistic insight regarding the amounts of different ES at a particular sub-watershed. Radar charts were plotted for the total set of

Table 3 Absolute and relative value (ES_i) of different ecosystem services in each sub-watershed used to calculate the Total Ecosystem Services (TES) index at sub-watershed level

Sub-watershed no.	Water yield	Relative ES _i	Soil retention	Relative ES _i	Habitat quality	Relative ES _i	Food supply	Relative ES _i	Carbon storage	Relative ES _i	TES index
1	443.821	0.810	26.647	0.139	0.55	0.470	36.70	0.384	2.68	0.340	0.429
2	438.970	0.826	32.763	0.173	0.59	0.520	23.80	0.249	2.75	0.350	0.418
3	319.891	0.548	5.113	0.022	0.78	0.760	0.10	0.001	0.35	0.030	0.272
4	451.085	0.845	9.185	0.044	0.78	0.760	1.20	0.013	0.36	0.030	0.334
5	516.996	0.985	11.282	0.055	0.57	0.490	33.50	0.350	0.43	0.040	0.380
6	506.892	0.975	16.226	0.082	0.68	0.630	17.10	0.179	3.35	0.430	0.453
7	533.022	1.000	33.915	0.179	0.81	0.800	0.00	0.000	0.97	0.110	0.418
8	481.547	0.905	9.805	0.047	0.73	0.700	8.00	0.084	0.36	0.030	0.350
9	442.650	0.834	7.869	0.037	0.43	0.320	55.60	0.582	0.99	0.110	0.371
10	414.343	0.727	47.688	0.254	0.66	0.610	18.70	0.196	3.28	0.420	0.445
11	421.949	0.769	56.598	0.303	0.78	0.760	2.30	0.024	3.53	0.460	0.462
12	496.732	0.952	82.191	0.443	0.72	0.680	24.50	0.256	5.18	0.680	0.596
13	306.554	0.537	2.539	0.008	0.20	0.030	95.60	1.000	0.43	0.040	0.319
14	443.035	0.834	23.517	0.122	0.34	0.200	71.60	0.749	1.61	0.200	0.416
15	274.746	0.466	22.505	0.117	0.36	0.230	70.40	0.736	2.26	0.280	0.362
16	201.355	0.303	3.846	0.015	0.51	0.420	45.60	0.477	0.39	0.030	0.247
17	126.243	0.143	9.698	0.047	0.18	0.000	86.50	0.905	0.38	0.030	0.223
18	145.914	0.185	3.887	0.015	0.22	0.050	88.70	0.928	0.61	0.060	0.245
19	127.239	0.137	2.334	0.007	0.19	0.010	92.20	0.964	0.41	0.030	0.229
20	428.160	0.803	48.666	0.260	0.59	0.520	34.90	0.365	3.96	0.510	0.486
21	311.155	0.525	184.245	1.000	0.97	1.000	1.90	0.020	7.57	1.000	0.709
22	185.989	0.271	4.817	0.020	0.20	0.030	92.40	0.967	0.55	0.050	0.265
23	64.181	0.000	1.127	0.000	0.37	0.240	34.60	0.362	0.15	0.000	0.120
24	397.786	0.735	95.765	0.517	0.74	0.710	27.40	0.287	5.59	0.730	0.591
25	402.853	0.744	19.105	0.098	0.30	0.150	76.90	0.804	1.51	0.180	0.391
26	334.164	0.553	1.327	0.001	0.23	0.060	77.80	0.814	0.35	0.030	0.296

Unit: water yield (mm/ha/year), habitat quality (unitless), carbon storage (ton/ha/year), food supply (% of farmlands) and soil retention (ton/ha/year)

sub-watersheds to serve as a planning tool at the sub-watershed scale.

Results

Bivariate associations between each pair of ES were measured, and the results are given in Table 5. Accordingly, majority of ES were found to be positively or negatively correlated. Specifically, habitat quality, water yield and soil retention are found to be positively correlated, while food production is negatively linked to the total set of ES. In addition, there are positive linkages between carbon storage, soil retention and habitat quality services, while no meaningful relationship between carbon storage and water yield was identified.

The quantitative and graphical results for TES index calculations are shown in Table 3 and Fig. 3. Accordingly, such set of the data indicates which sub-watersheds are more potential to simultaneously supply multiple services in Gorganrood Watershed. In this regard, southern sub-watersheds (nos. 12, 20, 21 and 24) depict higher TES values, while eastern, northern and western sub-watersheds portray lower values for the TES index, respectively. In this matter, based on Figs. 4 and 5, spatial pattern of forest, agriculture and water body and spatial distribution of all ES values depict strong linkages ($p < 0.01$) with the distribution of TES index values. Lush Hyrcanian mixed temperate forests in the southern part of the study area are more potential to simultaneously supply multiple ES. Except for the food production service, the remaining collection of ES indicated positive correlation with the TES index values.

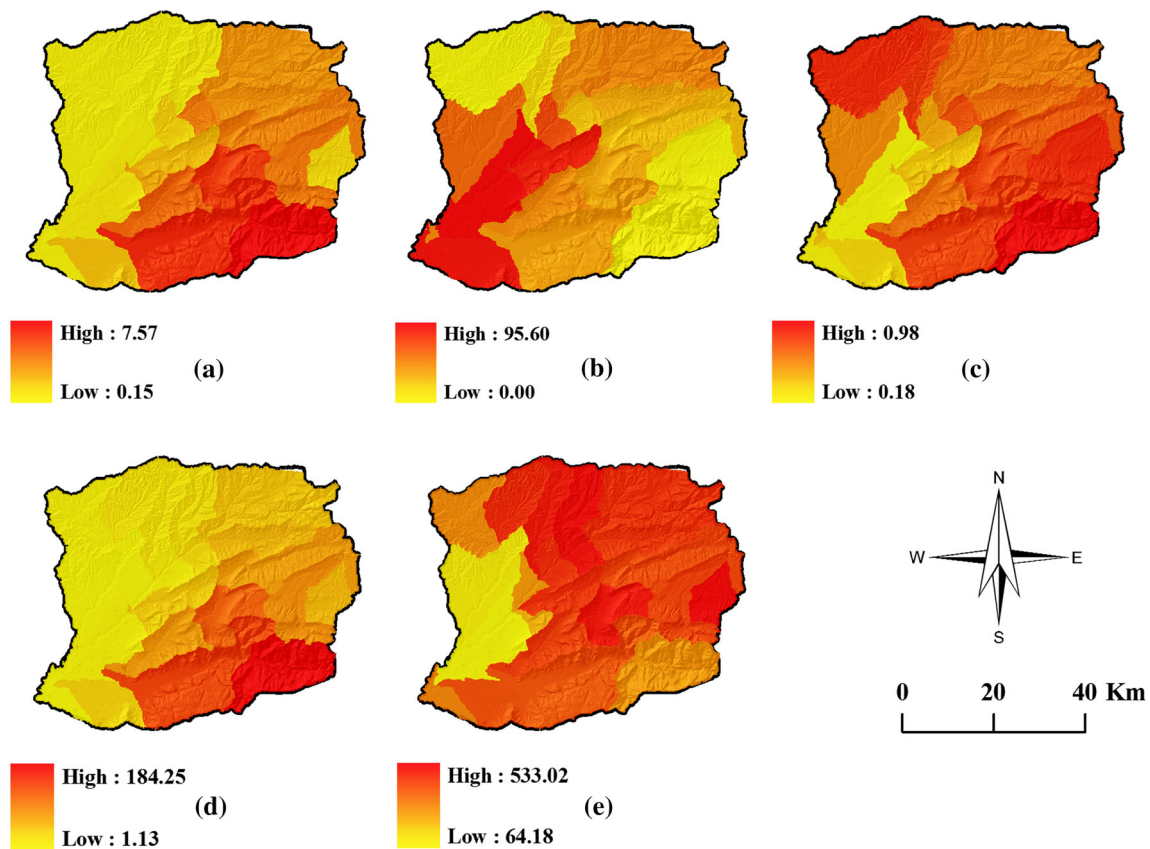


Fig. 2 Ecosystem service layers derived from InVEST modeling tool at sub-watershed level: **a** carbon storage: ton/ha/year, **b** food supply: percent of farmlands, **c** habitat quality: unitless, **d** soil retention: ton/ha/year and **e** water yield: mm/ha/year

Similarly, agriculture category illustrated negative correlation with TES values. Such results mirror the fact that expansion of farmlands for more production of food resources can reduce potential of the area for provisioning of ES bundles. In contrast, forest category can increase services such as water yield, habitat quality, soil retention and carbon storage, while it reduces the potential of the area for food production. Urban and rangeland categories depicted no meaningful relationship with TES index values, which indicates that these categories are less important for simultaneous conservation of multiple ES. Regardless of its low areal extent, water body category depicted strong negative relationship with TES index values.

Figure S1 (see Supplementary Materials) provides valuable information regarding potential of each sub-watershed for providing bundles of ES in different locations of the study area (relative ES values for each service in each sub-watershed are demonstrated as radar charts). For example, in sub-watersheds where Hyrcanian temperate forest dominates landscape of the area, it is clearly depicted that there are higher levels of increase in water yield, soil retention, carbon storage and habitat quality services. In contrast, sub-watershed nos. 18, 22, 23 and 26 illustrate higher potential for food production, and this capability is

linked with decreased potential of these sub-watersheds for provisioning of other ES. These sub-watersheds are located in western part of the Gorganrood Watershed, where agricultural fields form the main matrix of the landscape. Sub-watershed nos. 3, 4 and 8 demonstrate similar behavior in which increased potential for water yield and habitat quality is associated with decreased potential for the remaining services. These sub-watersheds are located in northern part of the study area, where rangeland is the dominant land feature. The rest of sub-watersheds (e.g., nos. 1, 2, 6, 7, 9 and 10) demonstrate heterogenous combinations of different of LULC categories, and at these locations, some services are increased at the cost of decreased potential for other services. These sub-watersheds are primarily located in central part of the study area, where transition areas from a human-dominated landscape (e.g., urban and farmlands) to natural ecosystems (e.g., forest and rangeland) form the main matrix of the region. In these locations, combinations of different LULC categories demonstrate a variety of mixed ecosystems, and therefore, there are higher levels of interactivity between different land features, which might ultimately affect the potential of the ecosystem to provide different ES.

Table 4 Percent area of different LULC types at sub-watershed level

Sub-watershed no.	Urban	Forest	Rangeland	Agriculture	Water body
1	2.7	31.1	19.6	46.3	0.3
2	3.5	31.6	26.1	38.5	0.3
3	1.5	0	97.4	0.8	0.3
4	1	0	98	1	0
5	1.5	0.5	63.2	34.5	0.4
6	3	38.5	30.2	27.5	0.8
7	0.5	9	90.5	0	0
8	0.8	0	90.2	8	1
9	2.3	7.8	32.3	57.1	0.5
10	3	42.3	24.6	29.3	0.8
11	0.7	42.2	40.8	15.7	0.6
12	3.2	64.5	6.3	25.4	0.7
13	2.3	0	1.6	95.2	0.9
14	5	16.1	5.7	72.2	1
15	1	24.7	1.1	72.2	1
16	1.6	0	52.3	45.3	0.8
17	6.6	0	0	84.3	9.2
18	3.7	2.7	0	88.3	5.3
19	5.5	0	0	90.8	3.7
20	5.9	48.2	6.7	38.2	1
21	0.8	93.5	0.7	4.3	0.7
22	5	0	1.8	91.5	1.7
23	3.6	0	0	33.8	62.6
24	3	70	0.1	26.2	0.7
25	7.6	14.9	0	76	1.5
26	6.3	0	0	74.3	19.4
Total area and percent of LULC categories (317,831.1 ha, 100%)	Urban (8667.4 ha, 2.70%)	Forest (97,266.1 ha, 30.70%)	Rangeland (96,145.3 ha, 30.20%)	Agriculture (111,967.6 ha, 35.20%)	Water body (3784.7, 1.20%)

Table 5 Spearman rank correlation coefficient between spatial correlation of different ecosystem services at sub-watershed level ($n = 26$)

	Water yield	Soil retention	Habitat quality	Food supply	Carbon storage
Water yield	1				
Soil retention	0.506**	1			
Habitat quality	0.559**	0.718**	1		
Food supply	-0.547**	-0.593**	-0.961**	1	
Carbon storage	0.341	0.786**	0.421*	-0.270	1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Discussion

Spatial variation in congruence of multiple ES

As an important premise to this study, spatial variation for the congruence of multiple ES was studied and hotspot

locations in addition to LULC categories that supply bundles of ES were identified (Bennett et al. 2009; Holland et al. 2011; Pan et al. 2013). Similar to our study, Wu et al. (2013) identified meaningful correlations between different pairs of ES, which finally assisted detection of important hotspots. They outlined that improved understanding

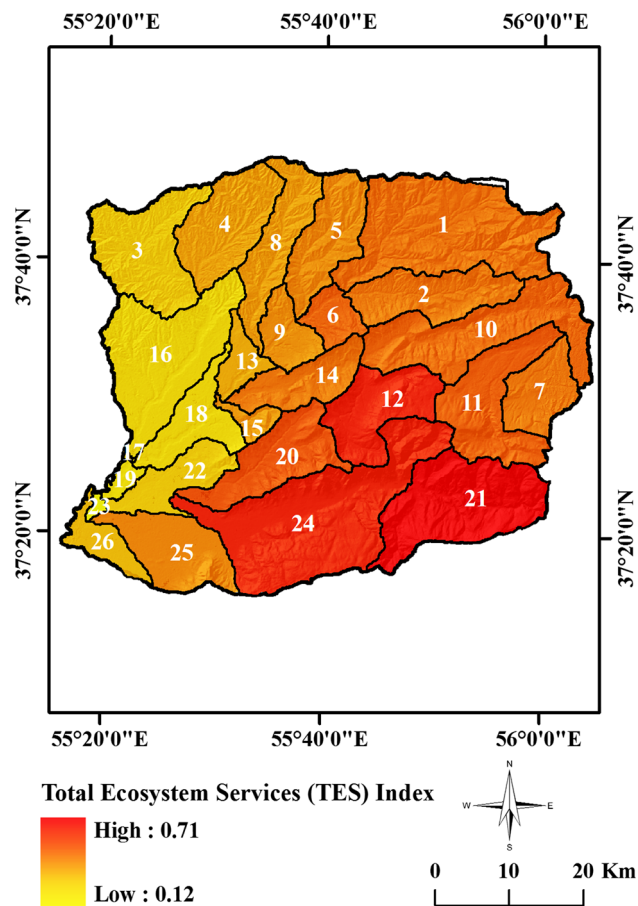


Fig. 3 The resultant layer of the Total Ecosystem Services (TES) index at sub-watershed level

between services is important for major stockholders and decision makers. In addition, Ai et al. (2015) emphasized that socioeconomic factors are also important parameters that affect the synergy and the trade-off between different ES and their dynamics. Schröter and Remme (2016) indicated that regardless of the implemented ES mapping method, spatial congruence is existent among multiple ES and spatial co-occurrences (hotspot) are greatly important for decision making and conservation efforts. In particular, Bagstad et al. (2016) highlighted that hotspots are more common in wilderness areas within natural forests and these ecosystems simultaneously provide several ES and also inform landscape scale planning efforts. In addition, in a recent study in Hyrcanian forest environments, Zarandian et al. (2017) indicated the concept of ES can optimize management options and conservation zones, which finally establishes a rational landscape that supports functioning of the ecosystems and assures long-term supply of multiple ES. Such studies in different parts of the world and their relevant results prove that ES-based conservation efforts have general planning implications and could be used in various research locations. Factors such as high spatial

extent, limited resources and data availability restrictions are considered as major barriers against development of regional LULC planning efforts. Therefore, the innovative approach of the ES-based conservation could practically address the effect of natural ecosystems and their respective services on planning practices, and by optimizing conservation priorities, it can guarantee the long-term functioning and ES provisioning of ecosystems.

Mapping multiple ES and application of the TES index could effectively reveal spatial congruence for provisioning of multiple ES. In this regard, Hyrcanian mixed temperate forests in the southern part of the study area are more potential to simultaneously provide bundles of provisioning and regulating services. In contrast, agricultural fields and urban areas in western part are less capable to provide multiple ecosystem benefits. In addition, rangeland is moderately potential to supply bundles of ES and this category dominates the northern landscape of the area. The correlation analysis between spatial distribution of the TES index values and spatial variation of individual ES and land features (Figs. 4, 5) indicated that Hyrcanian forests in southern sub-watersheds are more suitable for congruence of several ES. Analysis of the TES index values indicates that there is a trade-off between provisioning and regulating services in the study area and improvement in the supply of one group is achieved by declining the supply of another one. Sustainable and informed LULC planning practices could enhance regulating services, while also improving provisioning services such as food production.

Lush Hyrcanian mixed temperate forest conservation based on ES approach

Spatial associations between pairs of ES and TES index values versus bundles of ES and majority of land features were very strong (Table 5; Figs. 4, 5). Similar to the studies by Turner et al. (2007) and Bai et al. (2011), Spearman rank correlation coefficients and R^2 values depicted highly significant results for such relationships; habitat quality indicated a positive linkage with soil retention, water yield and carbon storage and a negative correlation with food supply (-0.961), with the highest positive relationship being with soil retention (0.718). Such relationships between bundles of ES, land features and TES index values mirror the fact that biodiversity hotspots considerably overlap with regulating and supporting ES such as soil retention, water yield and carbon storage, but there is no overlap with provisioning services such as food production. This finding highlights that in lush Hyrcanian mixed temperate forests, biodiversity conservation priorities are highly correlated with conservation of other ecosystem benefits.

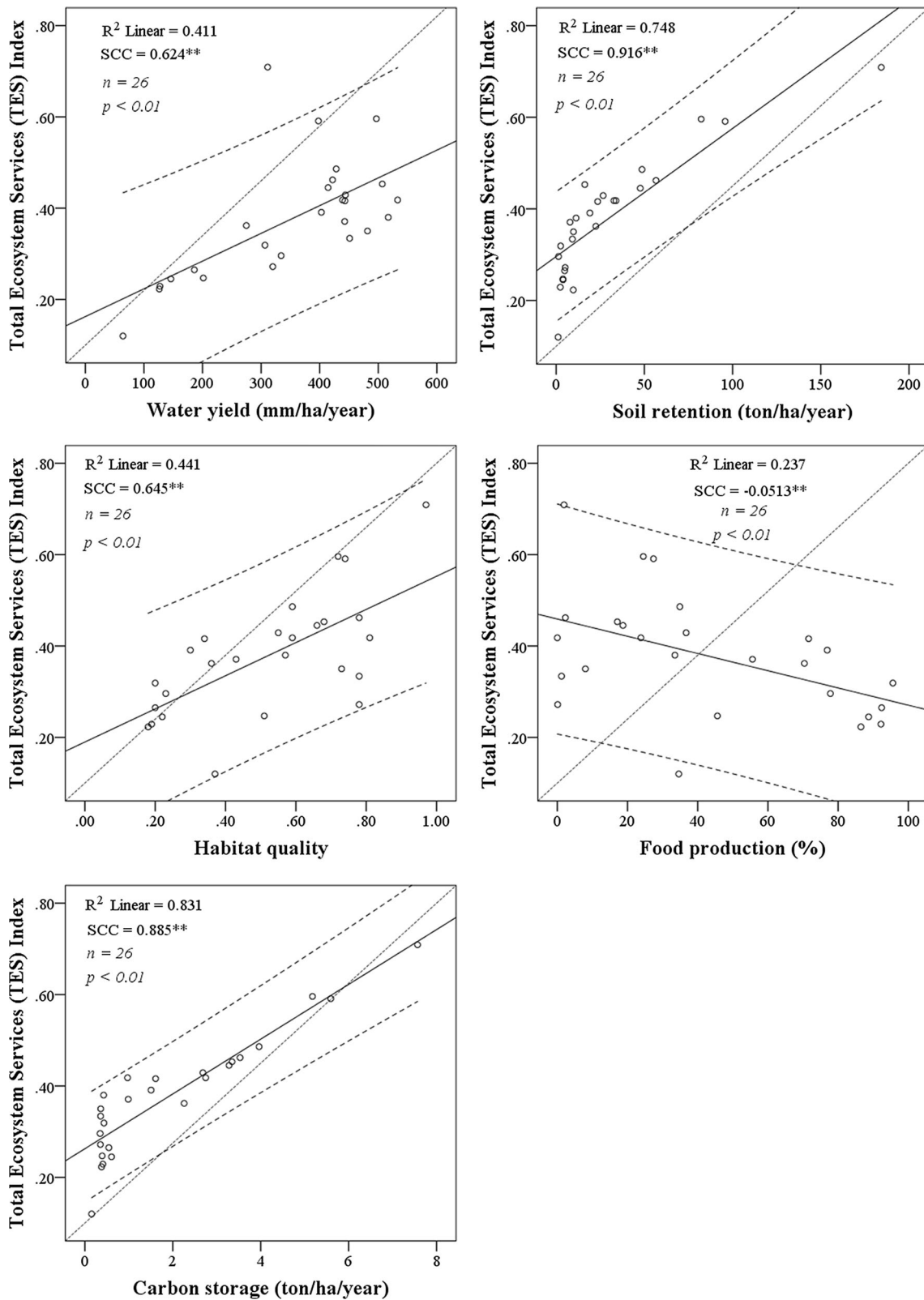


Fig. 4 Scatterplots depicting the type and the strength of bivariate associations between spatial distribution of different ecosystem services and Total Ecosystem Services (TES) index (in this figure,

SCC indicates Spearman rank correlation coefficient and the dotted lines represent 95% confidence interval)

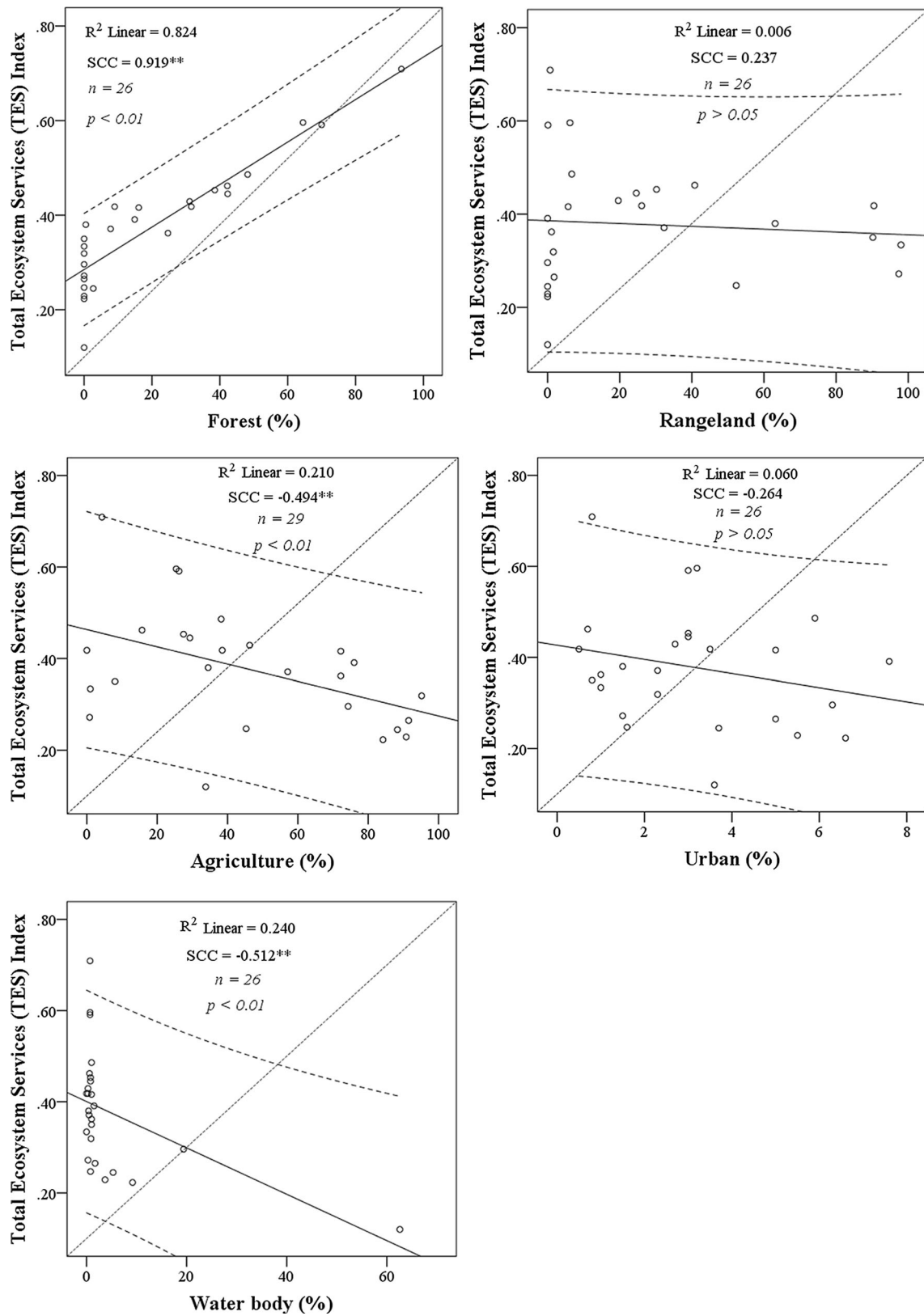


Fig. 5 Scatterplots depicting the type and the strength of bivariate associations between spatial distribution of different LULC categories and Total Ecosystem Services (TES) index (in this figure, SCC

indicates Spearman rank correlation coefficient and the dotted lines represent 95% confidence interval)

Lush Hyrcanian mixed temperate forests are globally important ecosystems with considerable ecological and economic values and high variety of ecosystem benefits. In this study, we considered the relationships between different LULC categories and their regulating, provisioning and supporting ES in addition to their trade-off and synergy. It should be noted that there are some other critically important ES in the area (e.g., tourism, landscape aesthetics, pollination and nutrient retention) and inclusion of such services is also important to support the efficacy of conservation efforts. In case of tourism and landscape aesthetics services, previous studies in the research area (Sakieh et al. 2015, 2016) highlighted that high values of tourism and landscape aesthetics suitability are significantly distributed across Hyrcanian forests. Therefore, conservation plans should also acknowledge the potential of the area for such activities to ensure their sustainability. In this regard, Sakieh et al. (2016) reported that mixed ecosystems at the edge of Hyrcanian forests (central part of the study area) are of higher potential for tourism, which is an environmentally friendly activity. In addition, due to low levels of ecological footprints associated with tourism-related activities, this utility can serve as a buffer for conservation of natural lands with high degrees of wilderness. Therefore, such considerations might provide complementary perspectives, when developing practical and realistic LULC planning strategies. More specifically, multi-objective optimization of different LULC categories could be undertaken in which ES of different types (i.e., provisioning, supporting, regulating and cultural services) can serve as spatial objectives for optimizing the configuration of land features. In this regard, the concept of ES can explicitly include the contribution of ecologically valuable lands and natural ecosystems such as Hyrcanian mixed temperate forests in spatial planning attempts. The concept of ES for Hyrcanian forests management is also highly influential to detect those locations that simultaneously provide the above-mentioned services. Under such characteristics, the decision maker is faced with a less challenging situation and a less complex spatial problem and such benefits facilitate informed decision making and effective management. Such implications are extremely important since Hyrcanian forests extend over vast areas and existence of various and often-conflicting stockholders prevent devising comprehensive forest conservation plans.

Based on research questions, it could be concluded that ES bundles have important planning implications for effective conservation of lush Hyrcanian forests. Regardless of variability in spatial patterns of different ES, biodiversity and other ES can generally be divided into two groups (based on correlation analysis). In addition, 26 sub-watersheds can be prioritized in terms of TES index values through which sub-watershed nos. 21, 24 and 12 with forest

LULC type receive higher conservation priorities since they mainly provide a higher load of ecosystem benefits. Therefore, biodiversity conservation could also benefit other services specially soil retention (Bai et al. 2011). This matter highlights that bundling of multiple ES could assist in informed decision making and practical optimization of conservation zones.

Policy implications for LULC planning

Previous conservation attempts in the lush Hyrcanian temperate forests mainly concerned with biodiversity and largely ignored the protection of different and valuable ES in these ecosystems. According to the findings of the present study, there are highly meaningful spatial correlations with biodiversity hotspots and other ES conservation priorities, which are considered as important implications to optimize future conservation strategies.

The results of this study could all be considered as priorities for the purpose of ES-based conservation and LULC planning. In this regard, the ES-based approach can provide additional level of knowledge on the complexity and functioning of coupled human–nature systems especially in northern Iran, where interactions between human-made structures and natural lush Hyrcanian forests establish a challenging situation to manage. It should be noted that based on systematic conservation of natural resources (Margules and Pressey 2000), site prioritization should consider both biodiversity and ES, for which methodologies have been evaluated in recent studies (Bai et al. 2011; Cimon-Morin et al. 2013; Schröter and Remme 2016). Specifically, in case of forest conservation practices, the ES-based planning approach has some major important implications. In these regions, protection of forest structure and prevention of farmland encroachment are of higher priority since part of Golestan National Park is located in this area. In other words, multiple land-use planning for forested sub-watersheds is not possible since any modification in these regions is associated with decreased potential for the majority of services and increased capability for few ones (Bennett et al. 2009). In contrast, sub-watersheds located in central and eastern parts of the study location are of higher potential for multiple land-use planning. Namely, these areas are located in transition lands between agriculture, rangeland and forest ecosystems and each category is associated with its own collection of ES. The planning of these sub-watersheds is more challenging since an accurate and detailed trade-off analysis is necessary to support supply of provisioning services, while maintaining their capacity to generate long-term regulating services. According to Sakieh et al. (2016), such ecosystems in Golestan Province are reported to possess considerable topographic variability, vegetation diversity,

aesthetics values and cultural ES. Such characteristics make these areas highly potential for a variety multiple land-use planning practices among which agroforestry, afforestation and ecotourism are of higher priority. These activities can bring both ecological and economic benefits to the society, while maintaining the major structure and integrity of natural and seminatural ecosystems and therefore supporting their functioning (Benayas and Bullock 2012; Sakieh et al. 2016). It should be noted that these sub-watersheds are more sensitive to any drastic LULC transformation. For example, increased food potential service in these regions is associated with increased soil erosion, declined biodiversity and loss of cultural services. This matter is clearly demonstrated in Fig. S1 (see Supplementary Materials). In this regard, those homogenous sub-watersheds with agriculture as the dominant LULC category (nos. 13, 17–19, 22, 23, 25 and 26) portray less variable net of multiple ES such that one (food production) or two services (food production and water yield or food production and habitat quality) are increased at the cost of dramatic decrease for other services. Similarly, those locations with rangeland as the dominant land feature (no. 3, 4, 7 and 8) indicate a simplified net of ES provisioning in which water yield and habitat quality are increased at the cost of high decreased levels for other services. In contrast, sub-watersheds dominated by forest category or a mixture of different land features (e.g., nos. 1, 2, 6, 15, 20, 21 and 24) demonstrate more variable net of supply for multiple ES. Such characteristic is the result of more variability in topographic and biophysical attributes in these locations, diversity in microclimate conditions, variety of plant species, the existence of different LULC categories that form mixed ecosystems and therefore higher rates of mutual exchange between different land features and higher intensities of landscape dynamics. In this regard, these sub-watersheds necessitate detailed and synoptic consideration of their associated ES and LULC planning efforts in these locations should adopt optimized and informed strategies to ensure and maximize simultaneous provisioning of multiple ES and future sustainability of the environment.

As shown in Fig. S1 (see Supplementary Materials), it is indicated that increased food production service could be achieved at the cost of declining regulating services such as soil retention, habitat quality, carbon storage and water yield. Therefore, expansion of agricultural fields could be considered as a barrier against enhancing other regulating ES. As a suggested available option, technological management of agricultural utilities such as conservation tillage, afforestation, fertilization and land consolidation could contribute to increased functionality of farmlands, and therefore, less acreage of agricultural fields is needed to support the growing population in the area (Pan et al. 2013). In this regard, it has been stated that a collection of

technologies for of farmland resource conservation could considerably influence improved functioning of agricultural fields for providing crop products and also for water conservation and carbon sequestration in 57 countries (Pretty et al. 2006).

Planning practices for large national forests such as lush Hyrcanian ecosystems that span over thousands of square kilometers is a highly challenging task since conservation units are more likely to be assigned over areas of large spatial extent. Thus, planning a large number and probably fragmented hotspots might be even more problematic and less biologically significant than for fewer and more concentrated hotspots (Bagstad et al. 2016). This is an important implication since data availability constraints and conservation resource limitations necessitate optimized solutions for effective conservation and informed decision making for forest and ES conservation.

Conclusions

The spatial congruence of multiple ES was studied using the TES index and correlation analyses. Significant differences between different sub-watersheds and various land features were identified in terms of simultaneous provisioning of ES bundles (soil retention, habitat quality, carbon storage, food production and water yield) in Gorganrood Watershed. At sub-watershed level, the largest difference for the TES index values was detected between Hyrcanian temperate forests in the south with largest TES values, which was approximately seven times higher than that for farmlands in the western part of the study area with the lowest TES values. Therefore, based on an ES-based LULC planning perspective, southern sub-watersheds with Hyrcanian forest cover are of higher priority for conservation efforts. In addition, transition areas in central and eastern parts of the study area not only offer high ecological values, but also they are suitable for conducting mixed activities such as agroforestry and afforestation as well as ecologically friendly utilities such as ecotourism that can bring economic benefits to the region.

Increasing the extent of farmlands and encroachment of agricultural fields into natural lands can cause decreased supply of regulating services in the study area, while application of technological packages for improved functionality of croplands can increase supply of provisioning services. Therefore, sustainable LULC planning efforts should adopt a holistic approach that takes the complexity of different components of a coupled human–nature system into account to finally ensure the resilience and integrity of its environmental structures and effective functioning of its ecosystems. As a topic of further research, future studies can dynamically measure and compare the relationships

between biodiversity hotspots and spatial patterns of potential areas for ES bundles under different scenarios of LULC change. The results of such study can provide valuable insights into the dynamics of conservation priority areas, and decision maker can evaluate and compare the possible outcomes of decisions that they might take. Application of spatio-statistical modeling algorithms could also be useful to analyze trade-offs and synergies between ES and their relationships with LULC. Such efforts finally provide an objective basis for automatic optimization of different LULC categories under various environmental circumstances.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Ai J, Sun X, Feng L, Li Y, Zhu X (2015) Analyzing the spatial patterns and drivers of ecosystem services in rapidly urbanizing Taihu Lake Basin of China. *Front Earth Sci* 9(3):531–545
- Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration. Guidelines for computing crop water requirements. FAO irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations, Rome, Italy
- Amirnejad H, Khalilian S, Assareh MH, Ahmadian M (2006) Estimating the existence value of north forests of Iran by using a contingent valuation method. *Ecol Econ* 58(4):665–675
- Bagstad KJ, Semmens DJ, Ancona ZH, Sherrouse BC (2016) Evaluating alternative methods for biophysical and cultural ecosystem services hotspot mapping in natural resource planning. *Landscape Ecol*. doi:10.1007/s10980-016-0430-6
- Bai Y, Zhuang C, Ouyang Z, Zheng H, Bo J (2011) Spatial characteristics between biodiversity and ecosystem services in a human-oriented watershed. *Ecol Complex* 8(2):177–183
- Benayas JMR, Bullock JM (2012) Restoration of biodiversity and ecosystem services on agricultural land. *Ecosystems* 15(6):883–899
- Bennett EM, Peterson GD, Gordon LJ (2009) Understanding relationships among multiple ecosystem services. *Ecol Lett* 12(12):1394–1404
- Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries RS, Díaz S, Dietz T, Duraiappah AK, Oteng-Yeboah A, Pereira HM, Perring C, Reid WV, Sarukhan J, Scholes RJ, Whyte A (2009) Science for managing ecosystem services: beyond the millennium ecosystem assessment. *Proc Natl Acad Sci USA* 106(5):1305–1312
- Cimon-Morin J, Darveau M, Poulin M (2013) Fostering synergies between ecosystem services and biodiversity in conservation planning: a review. *Biol Conserv* 166:144–154
- Comprehensive Forest Management Report of Gorganrood Watershed. 2015. Published by Forests, Ranges and Watershed Management Organization of the Golestan Province. Gorgan City, Iran
- Deore MSJ (2005) Prioritization of micro-watersheds of upper Bhama Basin on the basis of soil erosion risk using remote sensing and GIS technology. Doctoral dissertation, University of Pune Pune
- Diodato N, Bellocchi G (2007) Estimating monthly (R) USLE climate input in a Mediterranean region using limited data. *J Hydrol* 345(3):224–236
- Donohue RJ, Roderick ML, McVicar TR (2012) Roots, storms and soil pores: incorporating key ecohydrological processes into Budyko's hydrological model. *J Hydrol* 436–437:35–50
- Droogers P, Allen RG (2002) Estimating reference evapotranspiration under inaccurate data conditions. *Irrigat Drain Syst* 16(1):33–45
- Egoh B, Rouget M, Reyers B, Knight AT, Cowling RM, van Jaarsveld AS, Welz A (2007) Integrating ecosystem services into conservation assessments: a review. *Ecol Econ* 63(4):714–721
- Egoh B, Reyers B, Rouget M, Richardson DM, Le Maitre DC, van Jaarsveld AS (2008) Mapping ecosystem services for planning and management. *Agric Ecosyst Environ* 127(1–2):135–140
- Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. *Science* 309:570–574
- Golestan Province Land-use Planning Report (2013) Published by Gorgan University of Agriculture and Natural Resources, edited by Abdolrassoul Salmanmahiny. Gorgan City, Iran
- Gregori E, Andrenelli MC, Zorn G (2006) Assessment and classification of climatic aggressiveness with regard to slope instability phenomena connected to hydrological and morphological processes. *J Hydrol* 329(3):489–499
- Haines-Young R, Potschin M (2010) Proposal for a common international classification of ecosystem goods and services (CICES) for integrated environmental and economic accounting. European Environment Agency, New York
- Holland RA, Eigenbrod F, Armsworth PR, Anderson BJ, Thomas CD, Heinemeyer A, Gillings S, Roy DB, Gaston KJ (2011) Spatial covariation between freshwater and terrestrial ecosystem services. *Ecol Appl* 21(6):2034–2048
- Intergovernmental Panel on Climate Change (IPCC) (2006) IPCC guidelines for national greenhouse gas inventories, volume 4: agriculture, forestry and other land use. In: Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds) Prepared by the national greenhouse gas inventories programme. Institute for Global Environmental Strategies (IGES), Hayama. <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>
- Kareiva P, Tallis H, Ricketts TH, Daily GC, Polasky S (2011) Natural capital: theory and practice of mapping ecosystem services. Oxford University Press, Oxford
- Kouli M, Soupios P, Vallianatos F (2009) Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ Geol* 57(3):483–497
- Landuyt D, Broeckx S, Goethals PL (2016) Bayesian belief networks to analyse trade-offs among ecosystem services at the regional scale. *Ecol Ind* 71:327–335
- Larigauderie A, Prieur-Richard A-H, Mace GM, Lonsdale M, Mooney HA, Brussaard L, Cooper D, Cramer W, Daszak P, Díaz S, Duraiappah A, Elmqvist T, Faith DP, Jackson LE, Krug C, Leadley PW, Le Prestre P, Matsuda H, Palmer M, Perring C, Pulleman M, Reyers B, Rosa EA, Scholes RJ, Spehn E, Turner Ii B, Yahara T (2012) Biodiversity and ecosystem services science for a sustainable planet: the DIVERSITAS vision for 2012–20. *Curr Opin Environ Sustain* 4(1):101–105
- Laterra P, Ordie ME, Booman GC (2012) Spatial complexity and ecosystem services in rural landscapes. *Agric Ecosyst Environ* 154:56–67
- Leh MD, Matlock MD, Cummings EC, Nalley LL (2013) Quantifying and mapping multiple ecosystem services change in West Africa. *Agric Ecosyst Environ* 165:6–18

- Loureiro N, de Azevedo Coutinho M (2001) A new procedure to estimate the RUSLE EI 30 index, based on monthly rainfall data and applied to the Algarve region, Portugal. *J Hydrol* 250(1):12–18
- Mahiny AS, Clarke KC (2012) Guiding SLEUTH land-use/land-cover change modeling using multicriteria evaluation: towards dynamic sustainable land-use planning. *Environ Plan* 39(5):925–944
- Mahiny AS, Clarke KC (2013) Simulating hydrologic impacts of urban growth using SLEUTH, multi Criteria evaluation and runoff modeling. *J Environ Inform* 22(1):27–38
- Margules CR, Pressey RL (2000) Systematic conservation planning. *Nature* 405(6783):243–253
- Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: scenarios: findings of the Scenarios Working Group, vol 2. Island Press, Washington
- Nachtergaele FO, van Velthuisen H, Verelst L, Batjes NH, Dijkshoorn JA, van Engelen VWP, Fischer G, Jones A, Montanarella L, Petri M, Prieler S (2008) Harmonized world soil database (version 1.0). Food and Agriculture Organization of the United Nations, Rome
- Nemec K, Raudsepp-Hearne C (2013) The use of geographic information systems to map and assess ecosystem services. *Biodivers Conserv* 22(1):1–15
- Pan Y, Xu Z, Wu J (2013) Spatial differences of the supply of multiple ecosystem services and the environmental and land use factors affecting them. *Ecosyst Serv* 5:4–10
- Polasky S, Nelson E, Pennington D, Johnson KA (2011) The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the State of Minnesota. *Environ Resource Econ* 48(2):219–242
- Pretty JN, Noble AD, Bossio D, Dixon J, Hine RE, Penning de Vries FW, Morison JI (2006) Resource-conserving agriculture increases yields in developing countries. *Environ Sci Technol* 40(4):1114–1119
- Qin K, Li J, Yang X (2015) Trade-off and synergy among ecosystem services in the Guanzhong-Tianshui Economic Region of China. *Int J Environ Res Publ Health* 12(11):14094–14113
- Raudsepp-Hearne C, Peterson GD, Bennett EM (2010) Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proc Natl Acad Sci* 107(11):5242–5247
- Renard KG, Freimund JR (1994) Using monthly precipitation data to estimate the R-factor in the revised USLE. *J Hydrol* 157(1):287–306
- Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE), vol 703. US Department of Agriculture, Agricultural Research Service, Washington
- Roose E (1996) Land husbandry: components and strategy, vol 70. FAO, Rome
- Sakieh Y, Salmanmahiny A, Jafarnejad J, Mehri A, Kamyab H, Galdavi S (2015) Evaluating the strategy of decentralized urban land-use planning in a developing region. *Land Use Policy* 48:534–551
- Sakieh Y, Salmanmahiny A, Mirkarimi SH, Saeidi S (2016) Measuring the relationships between landscape aesthetics suitability and spatial patterns of urbanized lands: an informed modelling framework for developing urban growth scenarios. *Geocarto Int*. doi:[10.1080/10106049.2016.1178817](https://doi.org/10.1080/10106049.2016.1178817)
- Samani Z (2000) Estimating solar radiation and evapotranspiration using minimum climatological data. *J Irrig Drain Eng* 126(4):265–267
- Schröter M, Remme RP (2016) Spatial prioritization for conserving ecosystem services: comparing hotspots with heuristic optimization. *Landscape Ecol* 31(2):431–450
- Sharp R, Chaplin-Kramer R, Wood S, Guerry A, Tallis H, Taylor R (2014) InVEST user's guide: integrated valuation of environmental services and tradeoffs. The Natural Capital Project, Stanford
- Su C, Fu B (2013) Evolution of ecosystem services in the Chinese Loess Plateau under climatic and land use changes. *Global Planet Change* 101:119–128
- Turner WR, Brandon K, Brooks TM, Costanza R, da Fonseca GAB, Portela R (2007) Global conservation of biodiversity and ecosystem services. *Bioscience* 57(10):868–873
- Winchell M, Srinivasan R, Di Luzio M, Arnold J (2010) ArcSWAT interface for SWAT 2009 user's guide. Texas Agricultural Experiment Station and United States Department of Agriculture, Temple
- Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses - A guide to conservation planning. In: Predicting rainfall erosion losses - A guide to conservation planning. Department of Agriculture, USA, pp 1–69
- Wu J, Feng Z, Gao Y, Peng J (2013) Hotspot and relationship identification in multiple landscape services: a case study on an area with intensive human activities. *Ecol Ind* 29:529–537
- Yang H, Yang D, Lei Z, Sun F (2008) New analytical derivation of the mean annual water-energy balance equation. *Water Resour Res* 44(3):W03410. doi:[10.1029/2007WR006135](https://doi.org/10.1029/2007WR006135)
- Zarandian A, Baral H, Stork NE, Ling MA, Yavari AR, Jafari HR, Amirnejad H (2017) Modeling ecosystem services informs spatial planning in lands adjacent to Sarvelat and Javaherdasht protected area in northern Iran. *Land Use Policy* 61:487–500
- Zhang L, Hickel K, Dawes WR, Chiew FHS, Western AW, Briggs PR (2004) A rational function approach for estimating mean annual evapotranspiration. *Water Resour Res* 40(1):W02502. doi:[10.1029/2003WR002710](https://doi.org/10.1029/2003WR002710)