Bundles and hotspots of multiple ecosystem services for optimized land management in Kentucky, United States

Supplementary Information

Supplementary Table S1. Data requirement for the InVEST model (Water yield model=WY; Nutrient delivery ratio model=NDR; Sediment delivery ratio model=SDR; Carbon sequestration model=CS; Timber production model=TP)

Data	Type	Data source	Note	Related model
Digital Elevation Model	Raster	http://kyraster.ky.gov/arcgis/rest/services/ElevationServices	Resolution is 30m×30m	NDR, SDR
Annual average precipitation	Raster	http://www.prism.oregonstate.edu	Resolution is 30m×30m	WY, NDR, SDR
Reference evapotranspiration	Raster	http://www.cgiar-csi.org/data/global-aridity-and-pet-database	Resolution is 30m×30m	WY
Net primary productivity	Raster	http://files.ntsg.umt.edu	Resolution is 30m×30m	CS
Forest biomass map	Raster	https://www.wur.nl	Resolution is 30m×30m	TP
Plant available water content	Raster	https://websoilsurvey.nrcs.usda.gov	Resolution is 30m×30m	WY
Land use / land cover	Raster	https://www.mrlc.gov/index.php	LULC of year 1992 and 2011, including water, forest, construction land, pasture, cultivated land, bare land and wetlands resolution is 30m×30m	WY, NDR, SDR
Depth to root restricting layer	Raster	https://websoilsurvey.nrcs.usda.gov	Resolution is 30m×30m	WY
Watersheds	Shapefile	http://kyraster.ky.gov/arcgis/rest/services	A shapefile determined by DEM raster using ArcGIS tool	WY, NDR, SDR
Rainfall erosivity index	Raster	https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity	Resolution is 30m×30m	SDR
Soil erodibility	Raster	https://websoilsurvey.nrcs.usda.gov	Resolution is 30m×30m	SDR
Biophysical table	.CSV file	-	Including attributes of each LULC, Kc (the plant evapotranspiration coefficient), load of nutrients, efficiency of nutrient retention, etc.	WY, NDR, SDR

Supplementary Table S2. Key parameters used in the current study

Parameters	Description	Computation
k_{ij}	Evapotranspiration coefficient for each pixel	Defined according to the literature and InVEST user's guide
$load\_n$ $load\_p$	Load of nitrogen and phosphorus for each LULC	Defined according to the literature data [1,2]
eff_n eff_p	The maximum retention efficiency of nitrogen and phosphorus for each LULC, varying between 0 and 1.	Defined according to the literature data [1,2]
$SDR\_\max$	The maximum theoretical *SDR*	Defined as 0.8 according to the InVEST user's guide

Supplementary Table S3. Critical parameter settings in the biophysical table

LULC_desc	Kc	root_depth	usle_c	usle_p	sedret_eff	load_n	eff_n	load_p	eff_p
Water	1	1000	0.001	0.001	0.8	0.01	0.01	0.01	0.01
Developed	0.3	500	0.001	0.001	0.05	30.5	0.01	19.1	0.01
Barren	0.2	10	0.25	0.01	0.2	12.4	0.01	1.18	0.01
Forest	1	7000	0.003	0.2	0.6	11.4	0.6	2.36	0.6
Shrubland	0.85	4750	0.003	0.2	0.5	11.4	0.6	2.36	0.6
Grassland	0.65	2000	0.02	0.25	0.4	15.21	0.5	10.5	0.5
Pasture	0.75	1000	0.02	0.25	0.4	36.05	0.5	27.55	0.5
Cultivated	0.6	700	0.5	0.4	0.25	53.5	0.4	44.6	0.4
Wetland	0.8	4500	0.01	0.2	0.5	3.8	0.6	0.01	0.8

1. Supplementary 1 InVEST models

The InVEST (Version.3.3.3) suite of tools has been developed to enable decision makers to assess trade-offs within and among ecosystem services and to compare the consequences of different future change scenarios, for example those related to land use or climate [3]. This study selects the Water Yield model (for water retention and water provision service), the Sediment Delivery Ratio model (for sediment retention service), and the Nutrient Delivery Ratio model (for water purification service) to evaluate the corresponding ecosystem services in Kentucky.

1.1. Water yield (WY) model

The annual water yield for pixel i on LULC j, Y_{ij} (mm/yr), is estimated based on average annual precipitation and the Budyko curve as follows:

$$Y_{ij} = (1 - \frac{AET_i}{P_i}) \cdot P_i$$

where AET_{ij} (mm/yr) is the actual annual evapotranspiration for pixel i on LULC j, and P_i (mm/yr) is the annual precipitation for pixel i.

For vegetated LULC, the evapotranspiration portion of the water balance, $\frac{AET_i}{P_i}$, is based on an expression of the Budyko curve proposed by [4] and [5].

$$\frac{AET_i}{P_i} = 1 + \frac{PET_i}{P_i} - [1 + (\frac{PET_i}{P_i})^{\omega}]^{\frac{1}{\omega}}$$

where PET_{ij} is the potential evapotranspiration and ω_i is a non-physical parameter that characterizes the natural climatic-soil properties.
Potential evapotranspiration, PET_{ij}, is defined as:

$$PET_i = K_{c,j} \cdot ET_{0,i}$$

where $ET_{0,i}$ is the reference evapotranspiration from pixel i and k_{ij} is the vegetation evapotranspiration coefficient associated with the pixel i on LULC j

$$\omega_i = Z \cdot \frac{AWC_i}{P_i} + 1.25$$

$$AWC_i = Min(Rest\_layer\_depth_i, Root\_depth_i) \cdot PAWC_i$$

where ω_i is a non-physical parameter that characterizes the natural climatic-soil properties; Z is a dimensionless constant, ranging from 1 to 30, that captures the local precipitation pattern and hydrogeological characteristics; AWC_i (mm) is the volumetric plant available water content; the 1.25 term is the minimum value of ω_i [2]; k_{ij} is the evapotranspiration coefficient for pixel i on LULC j; ET_{0_i} (mm/yr) is the reference evapotranspiration for pixel i; and $PAWC$ (mm) is the plant available water capacity.
For non-vegetated LULC (e.g., water, construction land), the actual annual evapotranspiration is computed directly from the reference evapotranspiration and has an upper limit defined by the precipitation:

$$AET_{ij} = Min(k_{ij} \times ET_{0_i}, P_i)$$

where k_{ij} is the evapotranspiration coefficient for pixel i on LULC j, ET_{0_i} (mm/yr) is the reference evapotranspiration for pixel i, and P_i (mm/yr) is the annual precipitation for pixel i.

1.2. Extension model for water retention

Since the InVEST water yield model cannot provide the amount of water that is retained by ecosystems, we used an extended model here to calculate water retention. Based on the water balance equation, the amount of water retention can be calculated by subtracting evapotranspiration and runoff from precipitation. Precipitation minus evapotranspiration, also called water yield, was modeled in InVEST. The amount of water retention (WR) is defined as:

$WR_{ij} = Y_{ij} - Runoff_{ij}$

where WR_{ij} (mm/yr) is the annual water retention for pixel i on LULC j, and $Runoff_{ij}$ (mm/yr) is the annual surface runoff for pixel i on LULC j.

The amount of runoff is defined as:

$$Runoff_{ij} = P_{ij} \cdot C_j$$

$$C_j = C_r + C_s + C_t$$

where C_j is the runoff coefficient for each LULC j. C_j is measured by determining the slope (C_r), soil infiltration (C_s), and land cover (C_t). Based on the SSURGO soil database, loamy, silty, and clayey are the main soil types in Kentucky. Loamy soil is classified as Group A; silty and clayey soil are classified as Group B. The slope values are shown in the table below based on the [6] and calibrated with [7-9]. The larger values correspond to higher runoff and lower infiltration rates.

Supplementary Table S4 Runoff Coefficients (C_j)

Land use types	Soil group					
	Group A			Group B		
	Slope					
	10%	30%	>30%	10%	30%	>30%
Forest	0.2	0.32	0.44	0.22	0.34	0.46
Shrubland	0.27	0.43	0.53	0.28	0.45	0.55
Grassland	0.35	0.54	0.62	0.37	0.56	0.64
Pasture	0.45	0.65	0.65	0.47	0.67	0.67
Cultivated	0.6	0.7	0.75	0.62	0.72	0.77
Water	0.9	0.9	0.9	0.9	0.9	0.9
Developed	0.85	0.85	0.85	0.85	0.85	0.85
Barren	0.8	0.9	0.95	0.8	0.9	0.95
Wetland	0.8	0.8	0.8	0.8	0.8	0.8

1.3. Sediment Delivery Ratio (SDR) model

The InVEST sediment delivery model maps overland sediment generation and delivery to the stream. The sediment export from a pixel i, $Export_i$ (ton·ha^{-1}·yr^{-1}), and the total sediment export of the evaluate area, $Export_{tot}$ (ton·ha^{-1}·yr^{-1}), are defined by the equations:

$$Export_i = usle_i \cdot SDR_i$$

$$Export_{tot} = \sum_i Export_i$$

The amount of annual soil loss on pixel i, $usle_i$, is determined by the revised universal soil loss equation:

$$usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i$$

where R_i (MJ·mm·(ha·hr)$^{-1}$) is the rainfall erosivity, K_i (ton·ha·hr·(MJ·ha·mm)$^{-1}$) is the soil erodibility, LS_i is the slope length-gradient factor, C_i is the crop-management

factor, and P_i is the support practice factor.
The soil retention is computed by the model as follows:

$$Soilretention = R_i \cdot K_i \cdot LS_i \cdot (1 - C_i \cdot P_i) SDR_i$$

It represents the avoided soil loss by the current land use compared to bare soil.
The connectivity index IC is defined as:

$$IC = \log_{10}\left(\frac{D_{up}}{D_{dn}}\right)$$

D_{up} is the upslope component defined as:

$$D_{up} = \overline{C}\overline{S}\sqrt{A}$$

Where $\overline{C}$ is the average C factor of the upslope contributing area, $\overline{S}$ (m/m) is the average slope gradient of the upslope contributing area, and A (m^2) is the upslope contributing area. D_{dn} is the downslope component, defined as:

$$D_{dn} = \sum_i \frac{d_i}{C_i S_i}$$

where C_i and S_i are the C factor and the slope gradient on pixel i and d_i (m) is the length of the flow path along the pixel i.
The SDR for a pixel i, SDR_i, is derived from the connectivity index IC as follows:

$$SDR_i = \frac{SDR_{\max}}{1 + \exp\left(\frac{IC_0 - IC_i}{k}\right)}$$

where $SDR_{\max}$ is the maximum theoretical SDR and IC_0 and k are calibration parameters that define the shape of the *SDR-IC* relationship.

1.4 Nutrient Delivery Ratio (NDR) model

The InVEST Nutrient Delivery Ratio model maps nutrient sources from watersheds and nutrient transport to streams. Nutrient export from each pixel is calculated based on the product of the load and the NDR :

$$X_{export_i} = load_{surf,i} \times NDR_{surf,i} + load_{subs,i} \times NDR_{subs,i}$$

$$X_{export_{tot}} = \sum_i X_{export_i}$$

Each pixel's load is modified to account for the local runoff potential which can be divided into surface and subsurface runoff. The ratio between these two types of nutrient sources is given by the parameter $proportion\_subsurface_i$; therefore, the $load$ ($kg \cdot ha^{-1} \cdot yr^{-1}$) for pixel i is defined as:

$$load_{surf,i} = (1 - proportion\_subsurface_i) \times modified\_load_i$$

$$load_{subsurf,i} = proportion\_subsurface_i \times modified\_load_i$$

$$modified\_load_i = load_i \times RPI_i$$

$$RPI_i = \frac{RP_i}{RP_a}$$

where RPI_i is the runoff potential index for pixel i, RP_i is the nutrient runoff proxy for runoff on pixel i, and RP_a is the average RP over the entire area.

The delivery ratios ($NDR_{surf,i}$ and $NDR_{subs,i}$) are computed based on the concept of the nutrient delivery ratio.

(1) Surface NDR

The surface NDR is the product of a delivery factor, representing the ability of downstream pixels to transport nutrients without retention, and a topographic index, representing the position on the landscape. For pixel i:

$$NDR_{surf,i} = NDR_{0,i}(1+\exp(\frac{IC_i - IC_0}{k}))^{-1}$$

where IC_0 and k are calibration parameters, IC_i is a topographic index, and $NDR_{0,i}$ is the proportion of nutrient that is not retained by downstream pixels (irrespective of the position of the pixel on the landscape).

$$NDR_{0,i} = 1 - eff_i^{'}$$

$$eff_i^{'} = \begin{cases} eff_{LULC_j} \cdot (1-s_i) & \text{if } down_i \text{ is a stream pixel} \\ eff_{down_i}^{'} \cdot s_i + eff_{LULC_j} \cdot (1-s_i) & \text{if } eff_{LULC_j} > eff_{down_i}^{'} \\ eff_{down_i}^{'} & \text{otherwise} \end{cases}$$

where $eff_i^{'}$ is retention efficiency for pixel i, eff_{LULC_j} is the maximum retention efficiency that $LULC_j$ can reach, $eff_{down_i}^{'}$ is the effective downstream retention on the pixel directly downstream from pixel i, and s_i is the step factor defined as:

$$s_i = \exp(\frac{1-5l_{i_{down}}}{l_{LULC_i}})$$

Where $l_{i_{down}}$ is the length of the flow path from pixel i to its downstream neighbor, l_{LULC_i} is the LULC retention length of the land cover type on pixel i.

IC is the index of connectivity:

$$IC = \log_{10}(\frac{D_{up}}{D_{dn}})$$

$$D_{up} = \overline{S}\sqrt{A}, \quad D_{dn} = \sum_i \frac{d_i}{S_i}$$

where $\overline{S}$ (m/m) is the average slope gradient of the upslope contributing area, A (m^2) is the upslope contributing area, and d_i (m) is the length of the flow path along the pixel i.

(2) Subsurface NDR

$$NDR_{subs,i} = 1 - eff_{subs}(1 - e^{\frac{-5l_i}{l_{subs}}})$$

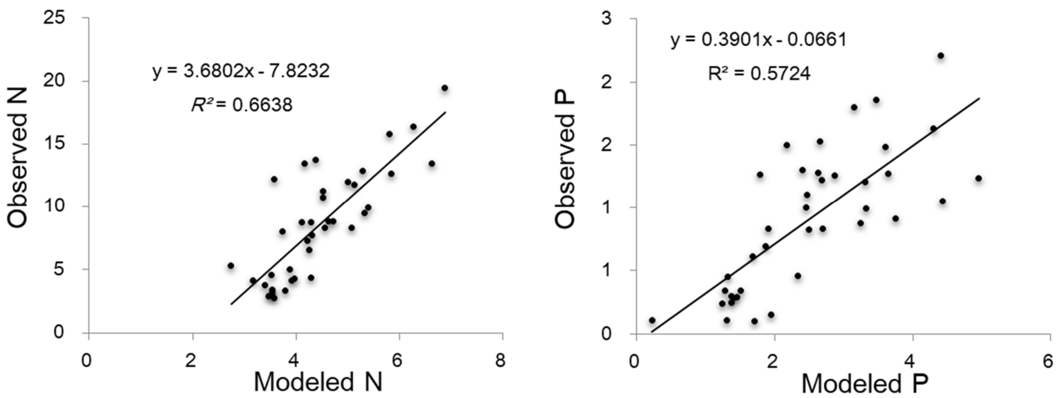
where eff_{subs} is the maximum nutrient retention efficiency that can be reached through subsurface flow, l_i is the distance from the pixel to the stream, and l_{subs} is the subsurface flow retention length (i.e. the distance after which it can be assumed that soil retains nutrient at its maximum capacity).

2. InVEST parameterization and validation

For water retention, the most important parameters for reducing model errors are climate variables, in particular annual precipitation and potential evapotranspiration (PET). We obtained annual precipitation from PRISM [10] and PET from the Global Aridity and PET Database [11]. Among the model outputs, actual evapotranspiration (AET) is a feasible proxy for validation, as opposed to of water retention which is difficult to measure at the ecosystem scale. We compared our modeled AET to three studies that measured AET for a number of catchments in the southern Appalachian Mountains where our study area is located. Due to the different time periods in those studies, annual precipitation is different. We also calculated AET divided by precipitation to do the validation. The modeled average AET was 507mm, and the average percentage of AET divided by precipitation was 42.35%. The value of AET from 15 watersheds in Tennessee, North Carolina, and Georgia was observed to have a range of 491-1023mm [12]. In their study, the range of AET percentages was 30%-57%, with a mean value of 44%. Based on data collected from six watersheds in North Carolina, [9] reported the range of AET percentages as 17%-56%, with a mean value of 40%. Another study [7] observed the range of AET percentages in two watersheds in North Carolina as 43.91% and 45.30%. Our modeled AET percentage was quite similar to these observed values.

For sediment export, the value of threshold flow accumulation may be a key parameter in the InVEST model [13]. We used the value of 10 ha, corresponding to an intermittent stream network, as the total accumulation of tributary area, under the rationale that sediment delivery occurs during rain events when intermittent streams are flowing [14]. Our final model outputs are the total and average sediment export values (ton ha^{-1} yr^{-1}). We compared our model results to four studies that measured sediment export in the Southern Appalachian Mountains [7], West Virginia [15], and North Carolina [16]. Measured sediment export values in these studies ranged from 0.02-17.7 tons ha^{-1} yr^{-1}; our modeled value was 0.55 tons ha^{-1} yr^{-1}, which falls within range of previously observed values. Specifically, the modeled average forest sediment export value was 0.23 tons ha^{-1} yr^{-1}, similar to the observed values of 0.14 and 0.23 tons ha^{-1} yr^{-1} [7]. The sediment export value after commercial clearcutting of mixed hardwoods was used to represent the value for grassland. The modeled average grassland sediment export value was 0.44 tons ha^{-1} yr^{-1}, similar to the observed value of 0.34 tons ha^{-1} yr^{-1} [7]. Sediment export in highway construction areas was assumed to be comparable to sediment export in barren land in this study. The modeled average sediment export value for barren land was 5.5 tons ha^{-1} yr^{-1}, which falls within range of observed values of 2.7-17.7 during construction [16].

For nutrient export, the most important model parameters for reducing model errors are nitrogen and phosphorus loads. We obtained nitrogen load from [17] and phosphorus load from [18], both of which were derived from the literature based on observed data ([17,18]). A study by [19] assigned nitrogen and phosphorus export values to 818 eight-digit hydrologic units (HUC) in the Mississippi/Atchafalaya river basin. From his data, we extracted 43 HUCs, which which were completely or partially located in Kentucky. The range of nitrogen export values from 43 HUCs was 2.75-30.24 kg ha^{-1} yr^{-1}, with a mean value of 9.70 kg ha^{-1} yr^{-1}. The range of phosphorus export values was 0.1-4.01 kg ha^{-1} yr^{-1}, with a mean value of 1.04 kg ha^{-1} yr^{-1} [20]. The modeled average nitrogen and phosphorus export values were 4.41 kg ha^{-1} yr^{-1} and 2.48 kg ha^{-1} yr^{-1}, respectively, both of which fall within the range, and close to the mean values of the other observations. Furthermore, we extracted our modeled values for 43 HUCs and analyzed the correlations between the modeled values and observed values. The results showed that the modeled values and observed values for both nitrogen and phosphorus showed a perfect linear regression, with R^2 values of 0.66 and 0.57 (P<0.001), respectively (See Supplementary Fig. 1).



Supplementary Figure S1 the observed data versus modeled data (kg ha^{-1} yr^{-1})

3. Customized models

3.1.Supplementary 3.1 Timber production

Due to the lack of harvest intensity level and rotation cycle information from natural forests and managed plantations, this study evaluated the forest stand volume and considered this as the potential timber production. The forest stand volume is calculated as forest biomass multiply by biomass-volume conversion coefficient. Forest biomass map was downloaded online from [1] at a spatial resolution of 1 km. The original forest biomass map was then resampled to 30 m resolution. The biomass-volume conversion coefficient was extracted from IPCC report (Charpter 4: Forest land). A mean value of 1.59 was used, which was corresponding to temperate climatic zone, hardwoods forest type in all growing stock level [21].

3.2. Carbon sequestration

Net primary productivity for carbon sequestration was directly downloaded from Numerical Terradynamic Simulation Group (NTSG, http://files.ntsg.umt.edu) at a 30 m spatial resolution [19].

Supplementary Table S5. **LULC class definitions from NLCD 2001 and 2011, used in the maps for Kentucky (from https://www.mrlc.gov)**

Code	Class\ Value	Descriptions
11 (NLCD class 11)	Water	All areas of open water, generally with less than 25% vegetation or soil cover.
21 (NLCD classes 21-24)	Developed	Includes developed open spaces with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses such as large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. Also included are lands of low, medium, and high intensity development with a mixture of constructed materials and vegetation, such as single-family housing units, multifamily housing units, and areas of retail, commercial, and industrial uses.
31 (NLCD classes 31-33)	Barren	Areas of bedrock, pavement, scarps, talus, slides, glacial debris, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
41 (NLCD classes 41-43)	Forest	All areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25% to 100% of the cover.
52 (NLCD classes 52)	Shrubland*	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
71 (NLCD classes 71)	Grassland*	Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
81 (NLCD class 81)	Pasture	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82 (NLCD classes 81-85)	Cultivated	Includes cultivated crops – Cultivated crops are described as areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. This class also includes all actively tilled land.
91 (NLCD classes 90-92, 95)	Wetlands	Includes woody wetlands and herbaceous wetlands – Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water. This class also includes areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Supplementary Table S6 The biophysical term of each ecosystem service

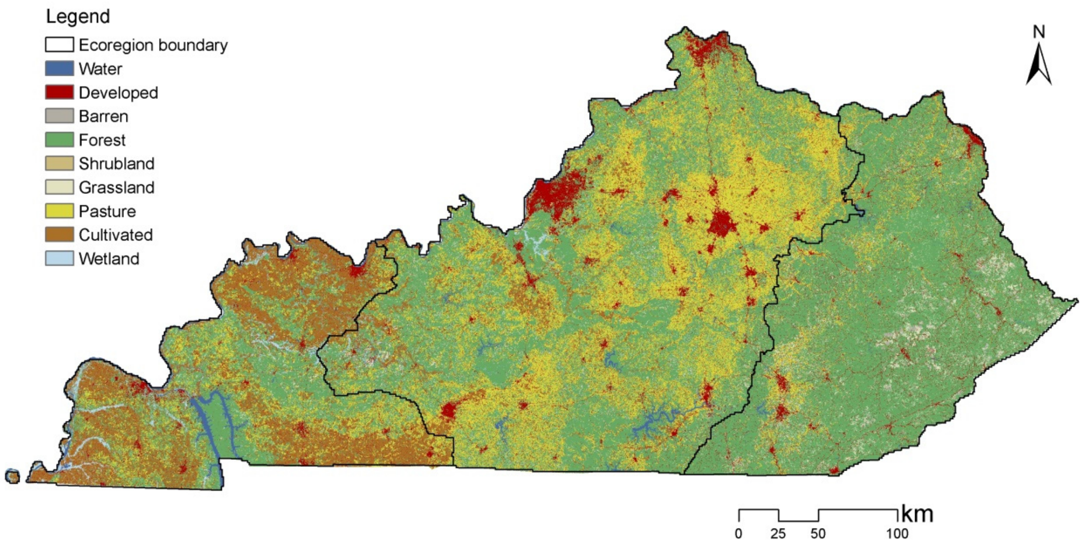
Types	Amounts	Units
Timber production	0.78	billion m^3
Carbon sequestration	38626.7	tonne
Water provision	55.71	billion m^3
Water retention	14.66	billion m^3
Soil retention	26.46	million tonne
Nitrogen retention	46.85	million kg
Phosphorus retention	9.9	million kg

Supplementary Table S7 Land use and land cover composition in each ecosystem service hotspots

hotspots	Forest	Shrub	water	developed	barren	grassland	pasture	cultivated	wetlands
Timber production	100.00%	0	0	0	0	0	0	0	0
Carbon sequestration	99.30%	0.70%	0	0	0	0	0	0	0
Water provision	0	0	1.37%	43.03%	2.89%	0.65%	6.23%	45.04%	0.79%
Water retention	86.84%	0.51%	0	0	0	6.03%	6.61%	0.01%	0
Soil retention	96.53%	0.52%	0	0	0.41%	2.09%	0.41%	0	0.04%
Nitrogen retention	100%	0	0	0	0	0	0	0	0
Phosphorus retention	100%	0	0	0	0	0	0	0	0

Supplementary Table S8 The number of overlap of ecosystem services hotspots

Number of overlap	Area	Percentage
0	44482.21	42.50%
1	31447.34	30.05%
2	17818.37	17.03%
3	9528.58	9.10%
4	1276.95	1.22%
5	105.44	0.10%
6	0.11	<0.00%



Supplementary Figure S2 Kentucky land use and land cover in 2011

Reference

1. Avitabile V, H.M., Heuvelink G, Lewis SL, Phillips OL, Asner GP et al. . An integrated pan-tropical biomass maps using multiple reference datasets. *Glob Chang Biol*, **2016**, *22*, 538-541.
2. Donohue, R.J.; Roderick, M.L.; McVicar, T.R. Roots, storms and soil pores: Incorporating key ecohydrological processes into Budyko's hydrological model. *J Hydrol*, **2012**, *436*, 35-50.
3. Sharp, R.; Tallis, H.; Ricketts, T.; Guerry, A.; Wood, S.; Chaplin-Kramer, R.; Nelson, E.; Ennaanay, D.; Wolny, S.; Olwero, N., *InVEST+ VERSION+ User's Guide* ed. S.U. The Natural Capital Project, University of Minnesota, The Nature Conservancy, and World Wildlife Fund. 2016.
4. Fu, B. On the calculation of the evaporation from land surface. *Sci Atmos Sin*, **1981**, *5*, 23-31.
5. Zhang, L.; Hickel, K.; Dawes, W.; Chiew, F.H.; Western, A.; Briggs, P. A rational function approach for estimating mean annual evapotranspiration. *Water Resour Res*, **2004**, *40*.
6. Marek, M.J.D.D., Texas, USA. Hydraulic Design Manual, Texas Department of Transportation (TxDOT). **2011**.
7. Swank, W.T.; Vose, J.; Elliott, K. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. *Forest Ecology*, **2001**, *143*, 163-178.
8. Hayes, D.C.; Young, R.L., *Comparison of peak discharge and runoff characteristic estimates from the rational method to field observations for small basins in central Virginia*. 2006.
9. Caldwell, P.V.; Miniat, C.F.; Elliott, K.J.; Swank, W.T.; Brantley, S.T.; Laseter, S.H. Declining water yield from forested mountain watersheds in response to climate change and forest mesophication. *Glob Chang Biol*, **2016**, *22*, 2997-3012.
10. Group, P.C. Oregon State University Available online http://prism.oregonstate.edu Accessed on 2 February 2018.
11. Zomer, R.J.; Trabucco, A.; Bossio, D.A.; Verchot, L.V. Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. *Agric Ecosyst Environ*, **2008**, *126*, 67-80.
12. Kove, K.M. *Water yield in the southern Appalachian Mountains*. Dissertation. University of Minnesota, Minnesota, May, 2011.
13. Hamel, P.; Chaplin-Kramer, R.; Sim, S.; Mueller, C. A new approach to modeling the sediment retention service (InVEST 3.0): Case study of the Cape Fear catchment, North Carolina, USA. *Sci Total Environ*, **2015**, *524*, 166-177.
14. Villines, J.A.; Agouridis, C.T.; Warner, R.C.; Barton, C.D. Using GIS to delineate headwater stream origins in the Appalachian Coalfields of Kentucky. *JAWRA*, **2015**, *51*, 1667-1687.
15. Kochenderfer, J.N.; Edwards, P.J.; Wood, F. Hydrologic impacts of logging an Appalachian watershed using West Virginia's best management practices. *Northern J Appl Forestry*, **1997**, *14*, 207-218.
16. Line, D.; Shaffer, M.; Blackwell, J. Sediment export from a highway construction site in central North Carolina. *Trans ASABE*, **2011**, *54*, 105-111.
17. Berg, C.E.; Mineau, M.M.; Rogers, S.H. Examining the ecosystem service of nutrient removal in a coastal watershed. *Ecosyst Serv*, **2016**, *20*, 104-112.
18. Kovacs, K.; Polasky, S.; Nelson, E.; Keeler, B.L.; Pennington, D.; Plantinga, A.J.; Taff, S.J.

Evaluating the return in ecosystem services from investment in public land acquisitions. *PloS one*, **2013**, *8*, e62202.
19. Robinson, N.P.; Allred, B.W.; Smith, W.K.; Jones, M.O.; Moreno, A.; Erickson, T.A.; Naugle, D.E.; Running, S.W. Terrestrial primary production for the conterminous United States derived from Landsat 30 m and MODIS 250 m. *Remote Sens Ecol Conserv*, **2018**, *4*, 264-280.
20. Robertson, D.M.; Schwarz, G.E.; Saad, D.A.; Alexander, R.B. Incorporating Uncertainty Into the Ranking of SPARROW Model Nutrient Yields From Mississippi/Atchafalaya River Basin Watersheds 1. *JAWRA*, **2009**, *45*, 534-549.
21. Eggleston, H.; Buendia, L.; Miwa, K.; Ngara, T.; Tanabe, K. IPCC Guidelines for National Greenhouse Gas Inventories. Agriculture, Forestry and Other Land Use. **2006**, *4*.