Roles of Forest Ecosystems in Sustainable Living and Their Systemic Valuations

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"Valuing nature is at the heart of sustainable development and is everybody's business"

IUCN Director General Julia Marton-Lefèvre

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History of forests as best reducers of thermal gradients

- Trees and forests, and other vascular plants, emerged approximately 400 million years ago. During this long history they evolved as best terrestrial reducers of thermal gradients and best producers of main life-supporting conditions for human species.
- *Homo sapiens* evolved between 400,000 and 250,000 years ago. Humans could evolve only due to very specific atmospheric and terrestrial conditions.
- Under the influence of incoming solar energy natural vegetation during hundreds million years has been repeatedly developing in succession processes toward climax vegetation (in our climatic conditions deciduous leafy forests) that maximizes biomass and symbiotic functions between organisms per unit of energy flow (Odum, 1969).

Irreplaceable significance of natural forests for humans

- As James Lovelock wrote:“The Earth’s natural ecosystems regulate the climate and the chemistry of the Earth and are not merely to supply us with food and raw materials (The Revenge of Gaia, p. 168).
- Only recently scientists started to warn (MEA, 2005) that replacing natural forests and wetlands by farmlands, forestry plantations or by constructed surfaces of highways, urban areas etc. has been launching irreversible damages in biosphere and in sensitive equilibrium between their autotrophic and heterotrophic ecosystems.

Natural forest losses accelerated by neoclassical concept of economic value

- **Since the end of 19th century quick vanishing of natural forests was accelerated by the neoclassical concept of <u>economic value determined subjectively by individual consumer and his/her marginal benefits</u> (with complete omission of production costs and nature consumption).**

This unilateral utilitarian concept dominates up to date, although it has been refused by the greatest neoclassicist A. Marshall who ironically wrote:

"*We might as reasonably dispute whether it is the upper or the under blade of a pair of scissors that cuts a piece of paper, as whether value is governed by utility or cost of production*" (Marshall, 1920, p. 203)

Marshall hoped to reconcile the classical (cost) and the neoclassical (marginal utility) theories of value.

Contradictions : theory, education and practice

In spite of clear definitions by A. Marshall, and by Daly and Farley, the majority of educational explanations and practical applications of the concept of economic value stick to the unilateral approach defining economic value in the straitjacket of individualism and subjectivism as only a utilitarian category defined by preferences of a human individual (without any reflection of nature consumption).

No wonder that this unilateral utilitarian approach has also been applied on measuring the non-marketed economic value of nature and her ecosystems. It could even be argued as more natural than in the case of man-made goods and services, as many ecosystem services are provided by nature as free public goods (seemingly for no costs of such provision).

Ecosystem services valued unilaterally

As for the utilitarian valuations, Costanza et al. (1997):

the global value of 17 services of 16 world biomes USD 16-54 trillion, with an average of USD 33 trillion per year, approx. double (1.8-fold) the annual world GDP (USD 18 trillion).

Costanza et al. (2014) published “Changes in the global value of ecosystem services”. They estimated that wetlands are:
37 times (15 times in 1997) more valuable than forests,
33 times (64 times in 1997) more valuable than grasslands
11 times (75 percent in 1997) more valuable than lakes and rivers.

Huge differences and changes in time disclose the subjectivity and disaffection of those unilateral subjective utilitarian values from the real thermodynamic efficiency of ecosystems.

Positive fact: for supporting and regulating services Costanza et al. (2014) accepted the replacement cost method.

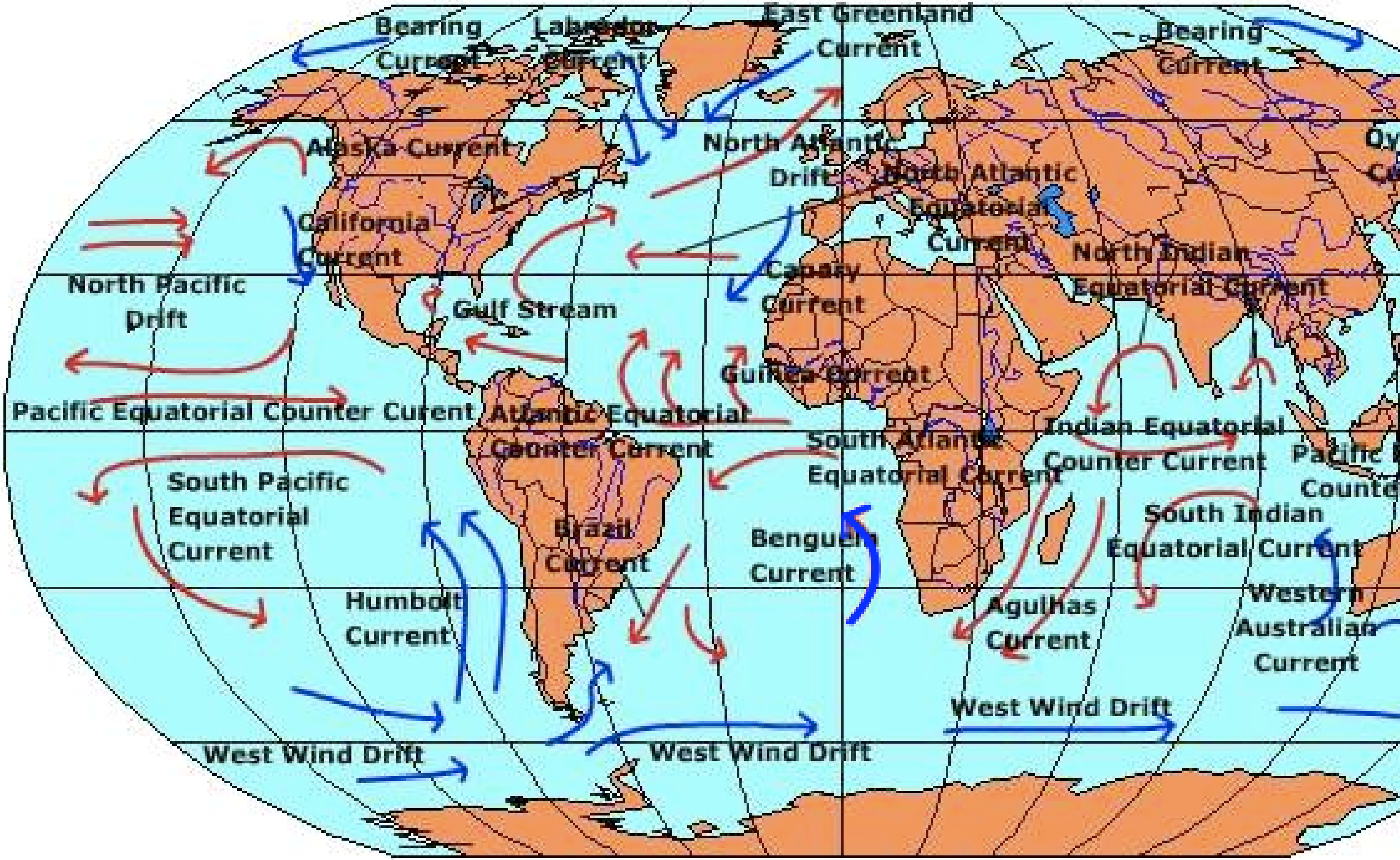
Energy-Water-Vegetation Method

Economic value of ecosystem services should be measured not only by individual preferences, but by comparing them with the costs of human technological abilities to substitute (replace) dissipativelly most efficient natural ecosystems.

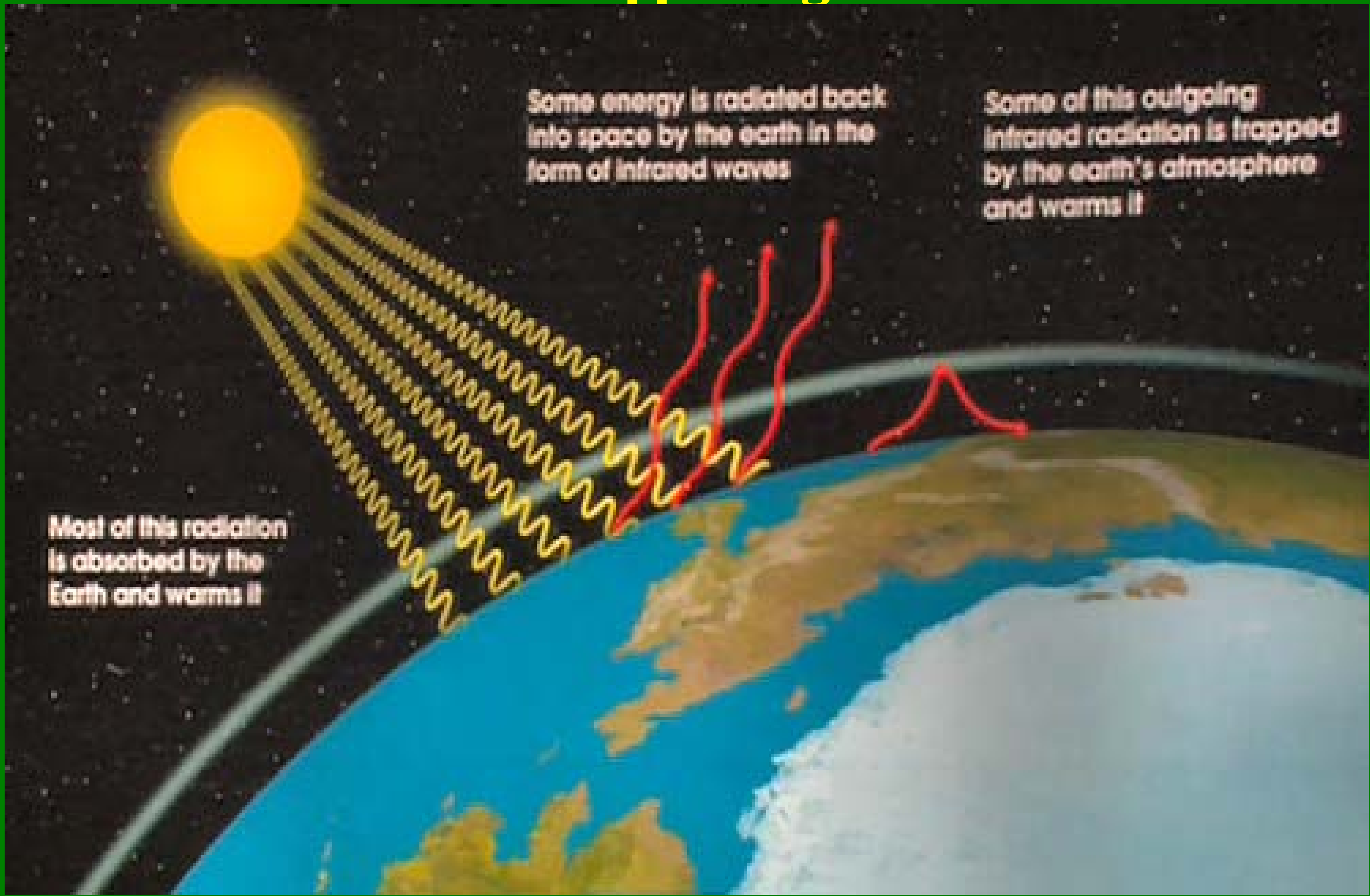
Ecosystems are nonequilibrium dissipative processes (Schneider, Sagan, 2005, p. 186). Energy-water-vegetation method (EWVM) comes from the recognition that later mature ecosystems are in dissipation more efficient than their predecessors (Odum, 1969; Schneider 1988), draws on the Energy-Transport-Reaction (*ETR*) model (Ripl 1995, 2003) and estimates the main forms of benefits that nature and her autotrophic ecosystems provide in the form of delivering ecosystem services for society (air-conditioning service, water retention service, oxygen production service, sustaining biodiversity, etc.).

Decisive ecosystem processes are driven by incoming solar energy in symbiosis with vegetation and water changes.

It is the energy of Sun and liquid water in the form of ocean streams, moving from Equator to poles, that warms the continents.



It is the energy of the Sun and water vapour in the form of atmospheric greenhouse envelope that keep temperatures on the Earth surface within the life-supporting borders suitable for life.



And it is the symbiosis of the Sun energy-water-vegetation on continents that controls temperatures within the life-supporting borders suitable for life.

EWVM: For alluvial deciduous forest ecosystem saturated with water, the estimations of services are the following:

1. Biodiversity: L2.3 Hardwood forests of lowland rivers are valued according to BVM by 66 points per 1 m2, per 1 ha it means 660,000 points x CZK12.36 per point = CZK 8 157 600 of stock value, with 5% discount rate it means annual service at the level € 16.300
2. Oxygen production: In temperate zone, 1 ha of deciduous forest produces annually around 10 tons of biomass (expressed in dry mass). It corresponds to the release of 10.6 tons of oxygen. Production of oxygen has been calculated from the fundamental equation of photosynthesis where formation of one molecule of 6 carbon sugar is associated with a release of 6 molecule of oxygen, i.e. formation of 180 grams of sugar (cellulose etc.) is associated with a release of 192 grams of oxygen. From this stoichiometry follows that the production of 10 metric tons of dry mass is accompanied by the release of 10.6 metric tons of oxygen. According to Avogadro law, one gram-molecule of gas under normal atmospheric pressure and temperature 20oC has a volume of 22.4 litres, i.e., 32 grams of oxygen take up 22.4 litres. Then, mass of 1 litre of oxygen is 1.429 g, or 1kg of oxygen holds the volume of 700 litres. 10,600 kg ha-1 x 700 litres = 7,42 mil. litres x € 0,02 per litre = € 148.400
3. Climatizing (air-conditioning) service: In temperate zone, 1 ha of deciduous forest transpires around 800 litres of water from 1m2 during vegetation season. Forest saturated with water evaporates around 5 litres of water during a sunny day from 1 m2. Whereas photosynthesis (biomass production) uses less than 1% of the incoming solar energy, by evapotranspiration (latent heat) around 80 % can be used in water saturated vegetation. Latent heat of 1 litre of water is equal to c. 0.7kWh. It is necessary to emphasize the double air-conditioning effect of evapotranspiration: first, a tree cools itself and its environment by evaporation of water (solar energy is used as latent heat), second, water vapour condensates on cool surfaces (or in cool air) and releases latent heat. Considering the double airconditioning effect (cooling during evapotranspiration and warming during water vapour condensation), the annual climatizing service of 1 ha can thus be estimated 800 l x 1.4 kWh (0.7 kWh cooling, 0.7 kWh warming) x 10,000 x €0.08 (electricity cost price)= € 896.000
4. Support of short water cycles and water retention service: returned 600 litres m^{-2} brings an annual service: (600 litres m^{-2}) x € 0.114 (distilled water price) x 10,000 m2 € 684.000

Annual services from 1 ha forest € 1.744.700

Summarizing the main annual ecosystem service values of 1 ha of river floodplain (estimated by replacement value approach and biotope valuation method):

1. Flood control service: investment costs for the retention of 1 m3 of water by a man-made pond, in the Czech Republic, is CZK 100 (€ 4). For 1 ha of floodplain with flood control capacity of 5,000 m3 it is CZK 0.5 million of capital costs, which brings annual service (5% discount rate) € 1,000

2. Biomass production: 5 tonnes annually x 4 MWh (=4,000 kWh) x € 0.08 x 0,5 (efficiency) € 800

3. Nutrient retention: 1 tonne of base cations and nutrients compared to drained arable lands = 1,000 kg x CZK 30-40 (€ 1.4 = price of 1 kg fertilizers) € 1,400

4. Biodiversity: Alluvial *Alopecurus* meadows T 1.4 are valued (Sejak 2003) by 46 points per 1 m2, per 1 ha it means 460,000 points x € 0.4944/point = € 227,424 of capital value which means, with 5% discount rate, annual service € 11,370

5. Oxygen production: 3.5 mil. litres O2 x CZK 0.25-0.73 /litre (CZK 0.50 = € 0.02) € 70,000

6. Support of short water cycles and water retention service: returned 500 litres/m2 of water brings annual service: (500 l/m2) x € 0.114 (distilled water price of 1 litre) x 10,000 m2 € 570,000

7. Climatizing (air-conditioning) service: 700 litres of evapotranspired water from 1m^2 during vegetation season. Annual climatizing service of 1 ha can thus be estimated 700 x 1.4 kWh (0.7 kWh cooling, 0.7 kWh warming) x 10000 x € 0.08 € 784,000

Annual services from 1 ha of river floodplain € 1,438,570

If the natural landscape is drained, as the following scheme of drained foothill pasture (brook straightening and recessing) shows, ecosystem services substantially decline:

1. Biodiversity: Intensively managed or degraded mesic meadows X T.3 are valued according to BVM by 13 points per 1 m2, per 1 ha it means 130,000 points x € 0.4944 per point = € 64,272 of capital value, with 5% discount rate, annual service € 3.200

2. Oxygen production: 3.5 mil. litres O2 x CZK 0.25-0.73 per litre (CZK0.50 = € 0.02) € 70.000

3. Climatizing service: Around 300 litres of evapotranspired water from 1 m2 during vegetation season. Annual climatizing service of 1 ha can thus be estimated 300 x 1.4 kWh (0.7 kWh cooling, 0.7 kWh warming) x 10,000 x €0.08 (electricity cost price) € 336.000

4. Support of short water cycles and water retention service: evapotraspirated 300 litres of water per 1 m2 brings an annual service: (300 litres per m2) x € 0.114 (distil. water price) x 10,000 m2 = € 342.000

Annual services from 1 ha of drained pasture € 751.200

Supporting and Regul. Services of Czech ecosystems

22 Biotope Groups in the Czech Republic According to Their Provision of four ES

No.	Biotope groups	Area	Ecosystem services (€/m2/year)				Total of four ES	
		km2	Climate regul. s.	Short Water Cycle	02 production	BD	Relat. value €/m2/year	Total value billion €/year
1	Water bodies, courses	675	67	57	25	0.5	150	101
2	Peatbogs	23	90	74	3	1.5	168	4
3	Other wetlands	364	90	74	30	1	195	71
4	Ext. used mesic pastures meadows	2601	67	34	16	1.2	118	308
5	Intens. used mesic pastures meadows	5579	56	34	21	0.3	111	623
6	Degraded mesic pastures meadows	4609	45	20	12	0.3	77	355
7	Dry closed grasslands	40	45	11	11	1.2	68	3
8	Dry interspaced grasslands	172	33	9	6	1.2	49	9
9	Xeric scrub	426	45	17	12	0.8	75	32
10	Mesic scrub	1959	56	34	16	0.8	107	209
11	Alluvial hygrophilous scub	17	67	55	17	1.1	140	2
12	Dry pine forests	298	45	26	13	1.2	85	25
13	Other conifer forests	6050	56	46	23	1	126	761
14	Damaged conifer forests	8222	45	34	19	0.5	98	807
15	Leafy forests	6636	78	69	27	1.4	175	1160
16	Leafy forests degraded	1632	56	40	19	0.6	115	189
17	Alluvial flooded forests	924	90	80	30	1.5	201	186
18	Solitary trees, alleys	1276	56	34	21	0.6	112	143
19	Arable land: cereal, root-crops	27605	33	9	13	0.2	55	1541
20	Arable land: fodder, durable stands	141	45	20	30	0.2	95	13
21	Areas without vegetation	2938	11	3	0	0	14	41
22	Rock biotopes	113	23	11	3	1.2	38	4
23	Other (semi) natural biotopes	3780	66	50	22	1	140	528
24	Other anthropically influenc. biotopes	2787	38	17	14	0.3	70	196
	Czech Rep. total	**78869**						**7310**

Clim. s.= climate-regulation service, expressed by litres of evapotranspired and condensed water, double air-conditioning effect (evapotranspiration and cooling effect,condensation and warming effect, both latent heat changes of 1 litre of water=1.4 kWh); l/m2/year x €0.08 (electricity cost price).
SWC=water retention service of the short water cycle; l/m2/year x €0.114 (cost price of 1 litre of distilled water).
O_2 production= O_2 (kg/m2/year) x 700 (kg changed to litres) x €0.02 (cost price of 1 litre of oxygen).
BD=habitat provision service (valued by biotope valuation method; Sejak et al., 2003).
Source: Sejak et al. (2010); Exchange rate €=CZK 25

Biotope, ecosystem service and economic values of 1 m^2 in €

LAND COVER 1:100000	Biotope values	Annual ES values	ES capital values	Official prices	Notes
1.1.1. Continuous urban fabric	0 - 1.20	27	535	1.4 - 90	acc. to urban size
1.1.2. Discontinuous urban fabric	5.04	78	1557	1.4 - 90	acc. to urban size
1.2.1. Industrial or commercial units	0 - 1.32	32	638	1.4 - 90	acc. to urban size
1.2.2. Road and rail networks and assoc. land	4.00	58	1156	1.4 - 90	acc. to urban size
1.2.3. Port areas	3.92	70	1398	1.4 - 90	acc. to urban size
1.2.4. Airports	5.92	80	1591	1.4 - 90	acc. to urban size
1.3.1. Mineral extraction sites	6.64	43	864	1.4 - 90	acc. to urban size
1.3.2. Dump sites	3.88	99	1981	0.04	
1.3.3. Construction sites	3.52	42	844	1.4 - 90	acc. to urban size
1.4.1. Green urban areas	9.52	106	2127	1.4 - 33	
1.4.2. Sport and leisure facilities	9.28	79	1589	0.4 - 0.6	
2.1.1. Non-irrigated arable land	5.12	62	1242	0.04 - 0.7	acc. to soil quality
2.2.1. Vineyards	7.52	88	1769	0.04 - 6.4	
2.2.2. Fruit trees and berry plantations	7.00	88	1764	0.04 - 4	
2.3.1. Pastures	10.28	102	2050	0.04 - 0.4	drained ann.ES € 74 m^{-2}
2.4.2. Complex cultivation	6.96	85	1696	0.04 - 0.4	acc. to soil quality
2.4.3. Land with agricult.& natural vegetation	10.64	100	1996	0.04 - 0.4	acc. to soil quality
3.1.1. Broad-leaved forest	20.12	156	3118	0.1 - 4.4	
3.1.2. Coniferous forest	12.96	124	2490	0.1 - 4.4	
3.1.3. Mixed forest	14.08	131	2616	0.1 - 4.4	
3.2.1. Natural grassland	16.32	109	2177	0.04	
3.2.2. Moors and heathland	26.20	129	2576	0.04	
3.2.4. Transitional woodland shrub	11.64	106	2128	0.04	
3.3.2. Bare rock	19.68	107	2144	0.04	
4.1.1. Inland marshes	16.56	159	3174	0.04	
4.1.2.Peatbogs	26.36	168	3361	0.04	
5.1.1. Water courses	11.44	139	2776	0.3	
5.1.2. Water bodies	9.24	148	2962	0.3	

Comparing 4ES efforts: agregated biotope groups

CR=78 869 km^2, 4ES in total= 182 743 bln. CZK/year, GDP 3689 bln. CZK

Arable, anthrop.land	km2	4 ES, CZK billion	CZK/m2/year
arable: grain, root-crops	27605	38535	**1396**
arable: fodder, peren. plant	141	334	**2363**
Other anthrop. Infl. land	2787	4896	
∑	30533	43765	
Share in national sum	**0,39**	**0,24**	**(0,6)**

Grasslands	km2	4 ES, CZK billion	CZK/m2/year
Extens. used mesophilic meadow, pastures	2601	7690	**2957**
Intens. used mesophilic meadow, pastures	5579	15517	**2781**
Degraded used mesophilic meadow, pastures	4609	8868	**1924**
Dry closed grasslands	40	68	**1698**
Dry interspaced grasslands	172	213	**1235**
∑	13001	32356	
Share in national sum	**0,165**	**0,177**	**(1,07)**

Forests, scrub	km^2	4 ES, CZK billion	CZK/m2/year
Xeric scrub	426	796	**1865**
Mesophilic scrub	1959	5232	**2671**
Alluvial hydrophilic scrub	17	58	**3496**
Dry pine forests	298	633	**2128**
Other conifer forests	6050	19031	**3146**
Damaged conifer forests	8222	20168	**2453**
Leafy forests	6636	29015	**4372**
Leafy forests degraded	1632	4717	**2891**
Alluvial flooded forests	924	4648	**5032**
Solitary trees, alleys	1276	3577	**2802**
Other natural biotopes	3780	13211	**3495**
∑	31220	101086	
Share in national sum	**0,40**	**0,55**	**(1,4)**

Waters, wetlands	km2	4 ES, CZK billion	CZK/m2/year
Water bodies, courses	675	2524	**3740**
Wetlands, peatbogs	387	1873	**4878**
Share in national sum	**0,013**	**0,024**	**(1,8)**

Rest of national territory (4%) covered by antropogenically changed areas with minimal ES efforts

Conclusions:

1. The market economies suffer from applying the unilateral utilitarian concept of economic value, which has led to the separation of financial markets and world of money from the real physical economies and enabled speculation and usury. This unilateral concept of economic value has also been applied on the valuation of ES. The utilitarian valuation substantially undervalues the supporting and regulating ES that, as free public goods, create biophysical basis of the life-supporting role of nature for human species.
2. Costanza et al. (1997) estimated the total value of world annual ES (defining value as benefit) as 1.8 fold of the world GDP. They also estimated that per hectare, wetlands are 15 times (37 times in 2014) more valuable than forests, and 64 times (33 times in 2014) more valuable than grasslands. From the viewpoint of thermodynamics and biophysics, such ratios are flawed.
3. Systemic valuation of ES must respect the biophysical and thermodynamic substance of ecosystems and define value as the result of a full cost-benefit comparison. Then the deeply rooted leafy forests and wetlands as climax vegetations in Central-European climatic conditions produce by 40-80 % more ES compared to grass and arable lands.
4. In order to stop biodiversity loss and restore natural landscape, the self-organized processes must be supported and natural landscape optimally restored using integrated criteria of an ecologic-economic cost-benefit analysis.

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Energy-water-vegetation method (EWVM): http://fzp.ujep.cz/projekty/valuingecosystemservices.pdf