OSU~EmEA-14

Emergy and Ecosystem Services

What are ecosystem services?
What is natural capital?
Case studies
Natural capital degradation
and sustainability

What is Natural Capital?...

Environmental Stocks “Real Wealth”

Natural Capital is the world's stocks of **natural** assets which include geology, soil, air, water and all living things.

What is Natural Capital?...

What are Ecosystem Services?...

Ecosystem services are the benefits people obtain from ecosystems.

These include...

- Provisioning services such as food and water,
- Regulating services such as flood and disease control,
- Cultural services such as spiritual, recreational, and cultural benefits; and
- Supporting services, such as nutrient or hydrologic cycling

What are Ecosystem Services?...

Provision of natural capital
Climate regulation
Water purification
Pests and diseases regulation
Air purification
Requlation of water flows
Maintenance of soil fertility
Gene pool protection
Erosion protection
Recreation & tourism
Spiritual experience
Aesthetic information
Design inspiration

Case Studies

Examples of valuation of ecosystem services and natural capital

What is the Value of Soil?...

Multiple ecosystem services at multiple scales

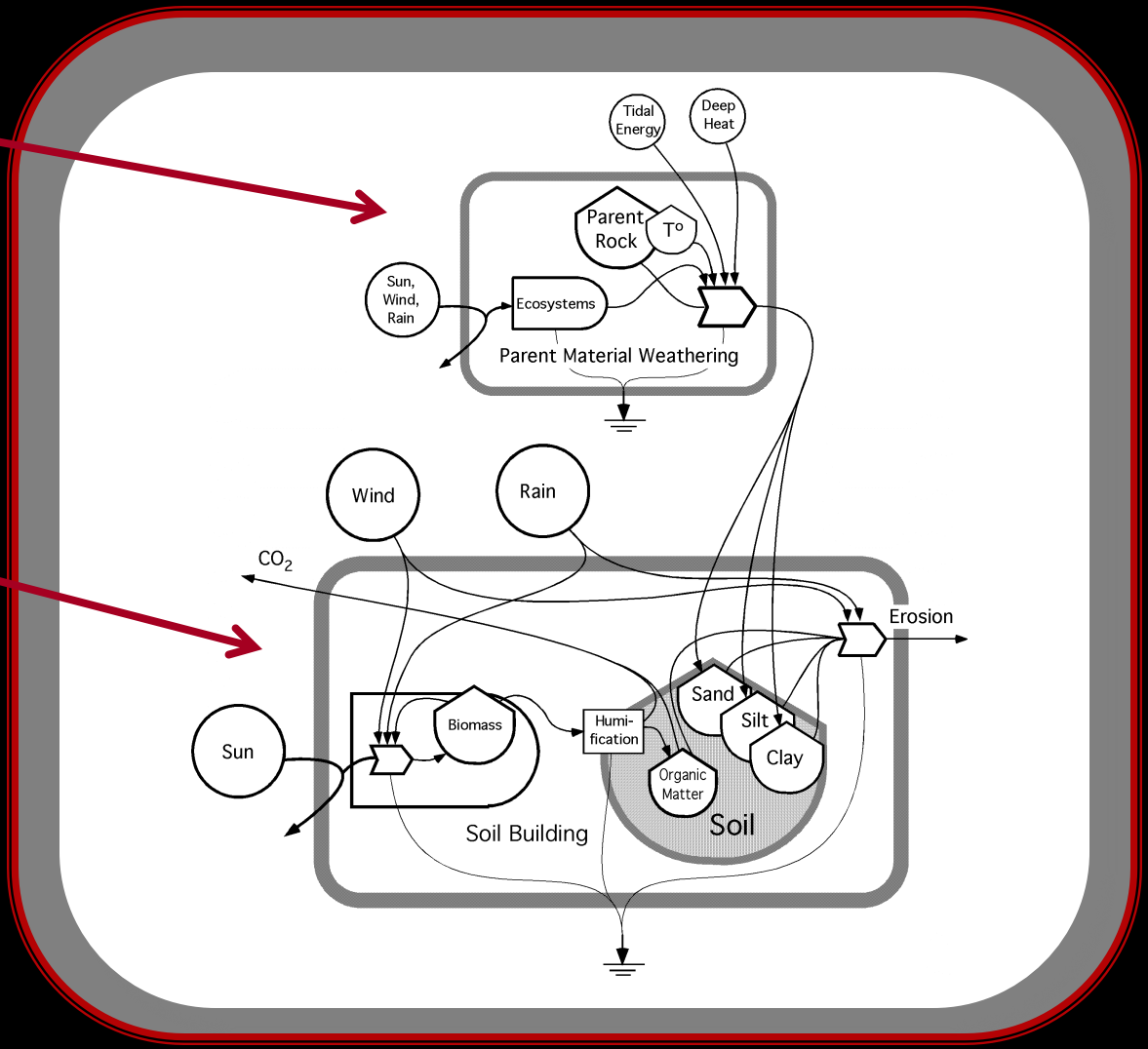
- Valued for:
  - Fertility
  - Sediment load
  - Structural role (water holding, root penetration)
- Slowly renewable
  - (~200 years/cm topsoil)
- Can be subsidized, but at cost
- Differentially vulnerable to degradation
- Structural role (water holding, root penetration)

What is the Value of Soil?...

Recall: Soils have two values

Mineral fraction

Organic fraction



What is the Value of Soil?...

Organic Fraction....

Recall:

Emergy of soil organic matter...

21 E9 sej kg^{-1} to 4666 E9 sej kg^{-1}

What is the Value of Soil?...

Mineral Fraction....

Recall: mineral fraction...

An average loamy soil of 40% sand, 40% silt and 20% clay has the following UEVs for each constituent (from the UEVdb):

Sand = 1.56 E9 sej kg^{-1}
Silt = 1.45 E9 sej kg^{-1}
Clay = 4.51 E9 sej kg^{-1}

…yielding a weighted average UEV for loamy soil of 2.11 E9 sej kg^{-1}.

What is the Value of Soil?...

1 cm of soil erosion....

Soil weighs 1.5 g cm^{-3} and average soil is about 4% organic matter...

Organic matter is about 50% carbon, thus carbon in 1 gram of of soil =

= 1.5 g cm^{-3} * 4% * 50%

= 0.03 g carbon

Emergy of soil carbon = 0.03 g * 40 E6 sej g^{-1}

= 1.2 E6 sej

Mineral fraction = 2.11E6 sej g^{-1} * 1.5 g = 3.2 E6 sej

Thus 1 cm3 of soil erosion = 1.2 E6 + 3.2 E6

= 4.42 E6 sej cm^{-3}

There are 1 E8 cm2 ha^{-1}

Therefore 4.4 E14 sej ha^{-1} or ($220 ha^{-1})

What is a Tree Worth?...

Transpiration,

Cooling

Soil protection,

Soil OM building,

O_2 production

CO_2 absorption

Etc.…

What is a Tree Worth?...

Environmental Services:

Emergy = 230 E12 sej/yr = ^{em}116/yr

Natural Capital - 500 year old tree:

Emergy = 1.15 E17 sej = ^{em}57,800

What is a Tree Worth?...

Calculation of annual Environmental Services:

6.6E6 J/m2/yr (Gainesville rain) * 7E3 sej/j = 4.6 E10 sej m^{-2}

Tree area = 80m diameter = 40^{2} *3.14 = 5024 m^{2}

Annual Emergy = 4.6 E10 sej m^{-2} * 5024 m = 2.3 E14 sej yr^{-1}

Emdollar value = 2.3 E14 sej yr^{-1} / 2.0 E12 sej $\$^{-1}$ = $^{em}\$$ 116

What is a Tree Worth?...

Calculation of Natural Capital:

Age of Tree = 500 years

Annual Emergy = 4.6 E10 sej m^{-2} * 5024 m = 2.3 E14 sej yr^{-1}

Emergy of natural Capital = Annual Emergy * age

= 2.3 E14 sej yr-1 * 500 yr = 1.16E17 sej

Emdollar value = 1.16 E17sej / 2.0 E12 sej $ $^{-1}$ = ^{em}$ 57,800

What is a Swamp Worth?...

A swamp is a wetland that is forested

Swamps are characterized by slow-moving or still waters and have very low topographic relief.

Swamps provide valuable ecological services including flood control, fish production, water purification, carbon storage, and wildlife habitat.

What is a Swamp Worth?...

Environmental Services:

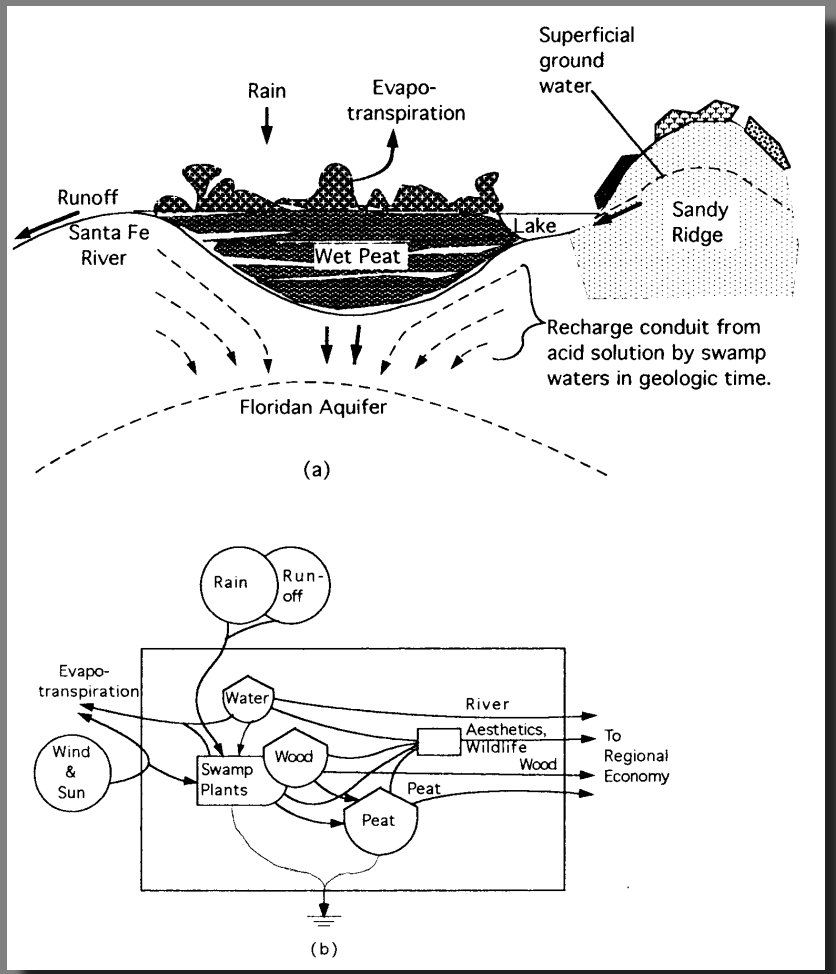
= em$470,000/yr

Natural capital:

Water = em$1.1 million

Wood = em$12.0 million

Peat = em$490 million



What is a Swamp Worth?...

Calculation of Ecosystem Services

Area of Santa Fe Swamp = 2.83 E7 m^2
Rainfall = 1.0 m yr^{-1}
UEV Rain = 3.31 E7 sej kg^{-1}

Env. Services:
Rain = 2.83 E7 m2 * 1.0 m * 1 E3 kg m- 3 = 2.83E10 kg yr^{-1}

Emergy = 2.83E10 kg yr^{-1} * 3.31 E7 sej kg^{-1} = 9.4 E17 sej yr^{-1}

Emdollar Value = 9.4 E17 sej yr^{-1} / 2 E12 sej $\$^{-1}$ = $^{em}\$$4.7 E5 yr^{-1}

What is a Swamp Worth?...

Calculation of Natural Capital

Mass of water = 0.5 m * 2.83 E7 = 1.4 E7 M^3 = 1.4 E10 kg
Mass of wood = 22.7 kg m^{-2} * 2.83 E7 m^2 = 6.4 E8 kg
Mass of peat (carbon) = 72.3 kg C m^{-2} * 2.83 E7 m^2 = 2.1 E9 kg

Natural Capital:
Emergy of water = 1.4 E10 kg * 1.6 E8 sej kg-1 = 2.2 E18 sej / 2 E12 sej $-1
= $1.1 E6

Emergy of wood = 6.4 E8 kg * 3.75 E10 sej kg-1 = 2.4 E19 sej / 2 E12 sej $-1
= $12.0 E6

Emergy of peat = 2.1 E9 kg * 4.67 E11 sej kg-1 = 9.8 E20 sej / 2 E12 sej $-1
=$ 4.9 E8

What is a Swamp Worth?...

Chicago Tribune

October 09. 1991

Georgia-Pacific fined: A federal judge Tuesday fined...

Georgia-Pacific fined: A federal judge Tuesday fined Georgia-Pacific Corp. $5 million for tax evasion. The company pleaded guilty to trying to take a $24 million tax deduction for a $2 million piece of Florida swampland that it donated to the state. Georgia-Pacific also must pay the Internal Revenue Service $16 million in back taxes and penalties.

"Again, I apologize for any embarrassment this causes our employees, shareholders and customers". Georgia-Pacific Chairman T. Marshall Hahn said in a prepared statement.

What is a Species Worth?...

Plant or animal itself…

~

The species….

What is a Species Worth?...

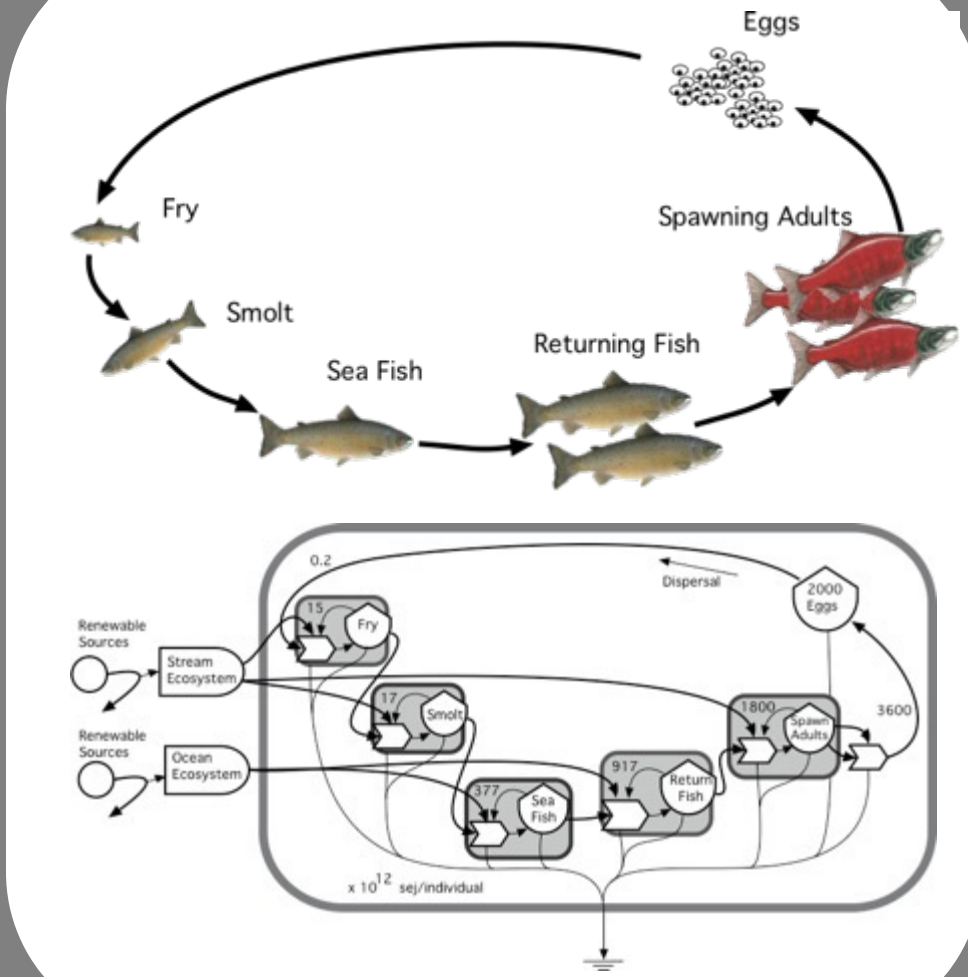
Species are information…each individual is a carrier…

and

Information must cycle....

Information sequestered in unreachable or unusable storages is of no value and often soon loses its importance and relevance.

Cycling allows for the continuous maintenance information.

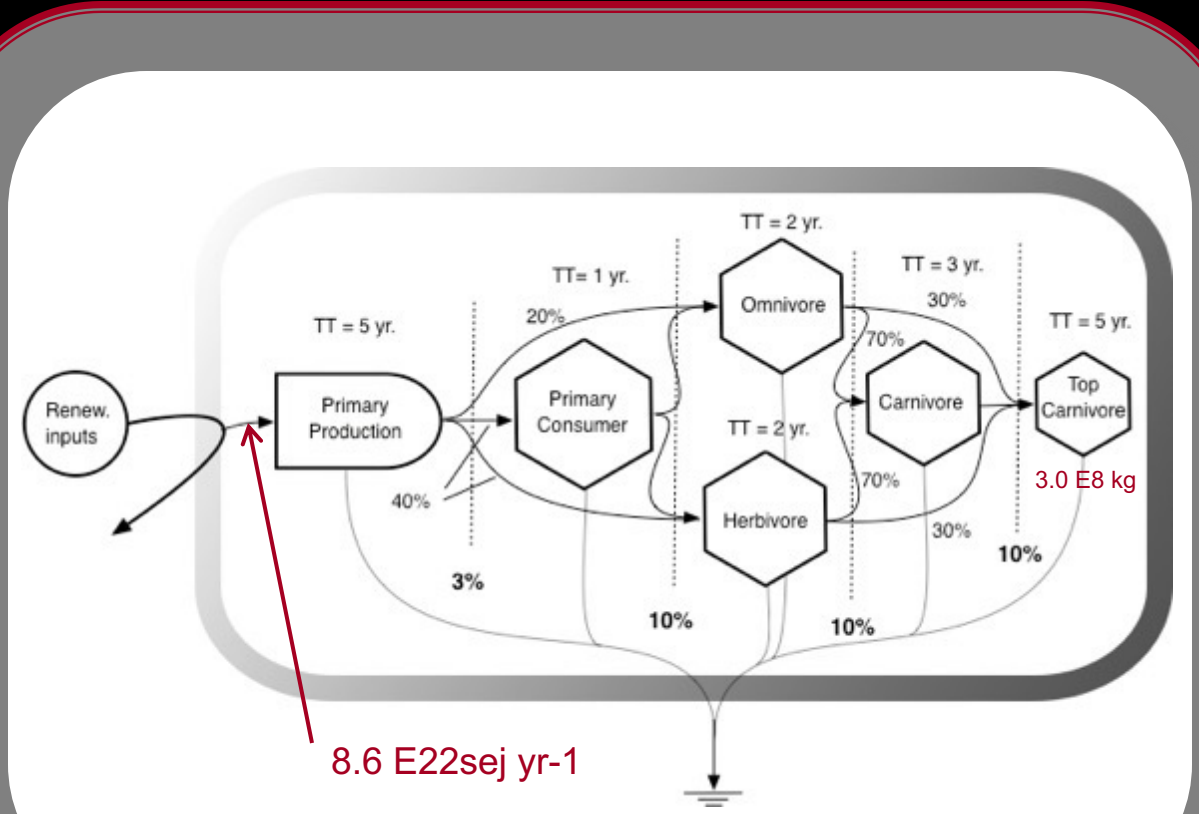


What is a Species Worth?...

Individual organism (top carnivore)

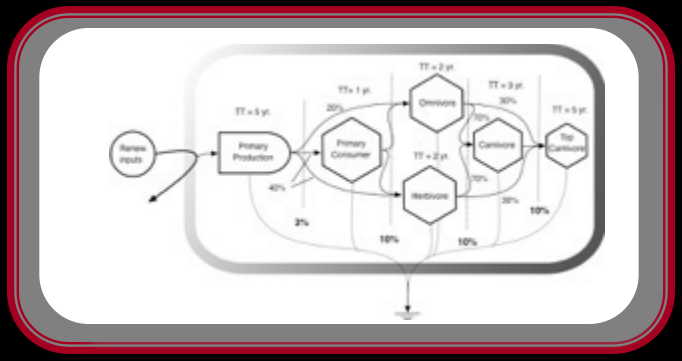
Energy Transfer Across Trophic Level.

Numbers that are **bolded** represent trophic efficiencies, numbers on pathways represent the percent of transfer from each trophic level to the next.



What is a Species Worth?...

Calculation of emergy of individual top carnivore animal.
Based on all top canvivores in N. America



TOP CARNIVORE

Driving emergy (N.A.) = 8.60E+23 sej yr^{-1}

Biomass of all TCs = 3.00E+08 kg

TT = 5 yr

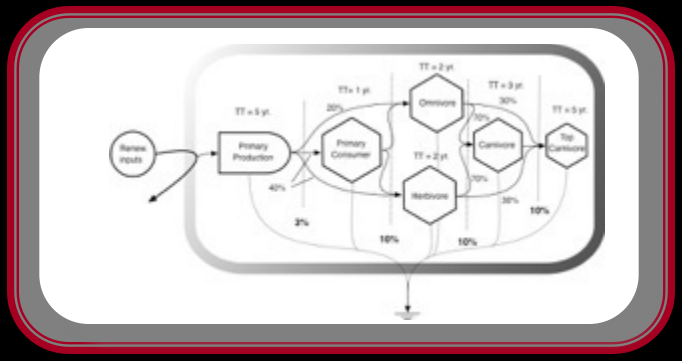
Average weight of TC = 100kg

Emergy = 8.60E+23 sej yr^{-1} * 5 yr = 4.3E+24 sej

Emergy of TC//kg = 4.3 E24sej / 3.0 E 8 = 1.4 E16 sej kg^{-1}

Em$ TC = 1.4 E16 * 100 kg / 2 E12 sej $\$^{-1}$ = $^{em}\$7.2$ E5

What is a Species Worth?...



Calculation of emergy to maintain Minimum Viable Population (MVP) Based on Fl Panther population in S. Florida

Min. Via Population

Area = 2.92E+09 m2

Rain mass = 1.4 m * 2.92E+09 m2 * 1000 kg m^{-3}

= 4.1E+12 kg

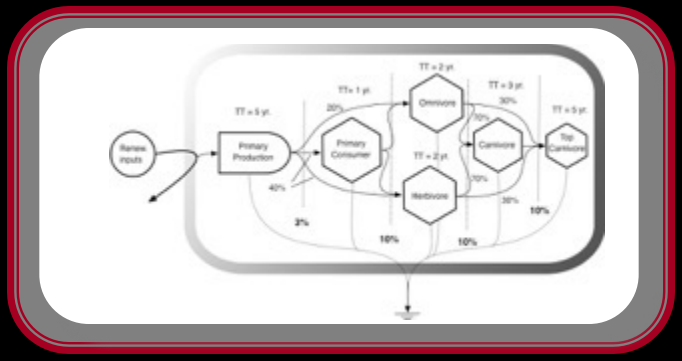
Rain emergy = 4.1E+12 kg * 3.3 E7 sej kg^{-1}

= 1.35 E 20 sej

Em$ = 1.35 E 20 sej / 2.0 E12 sej $ $^{-1}$ = ^{em}$6.8 E7

What is a Species Worth?...

Calculation of emergy to maintain Species
Based on all Spp on Earth



Species:

Total spp = 1.20E+07

Years since mass extinction= 2.50E+08 yr

Driving emergy = 1.20E+25 sej yr^{-1}

Total Driving emergy = 2.50E+08 yr * 1.20E+25 sej yr^{-1}
= 3.0 E+33 sej

Emergy per species = 3.0 E+33 sej / 1.2 E7
= 2.5 E26 sej spp^{-1}

Em$ = 2.5 E26 sej spp^{-1} /2 e!2 sej $\$^{-1}$ =1.25 E14 $^{em}\$$

What is a Species Worth?...

Emergy value of an individual (carrier)

The emergy required to maintain…

Emergy value of the Population

The emergy required to maintain MVP…

Emergy value of species (information)

The emergy required to develop the species….

Individual organism (top carnivore)

^{em} 720,000

Population (top carnivore)

^{em} 68 million

Species (top carnivore)

^{em} 125 trillion

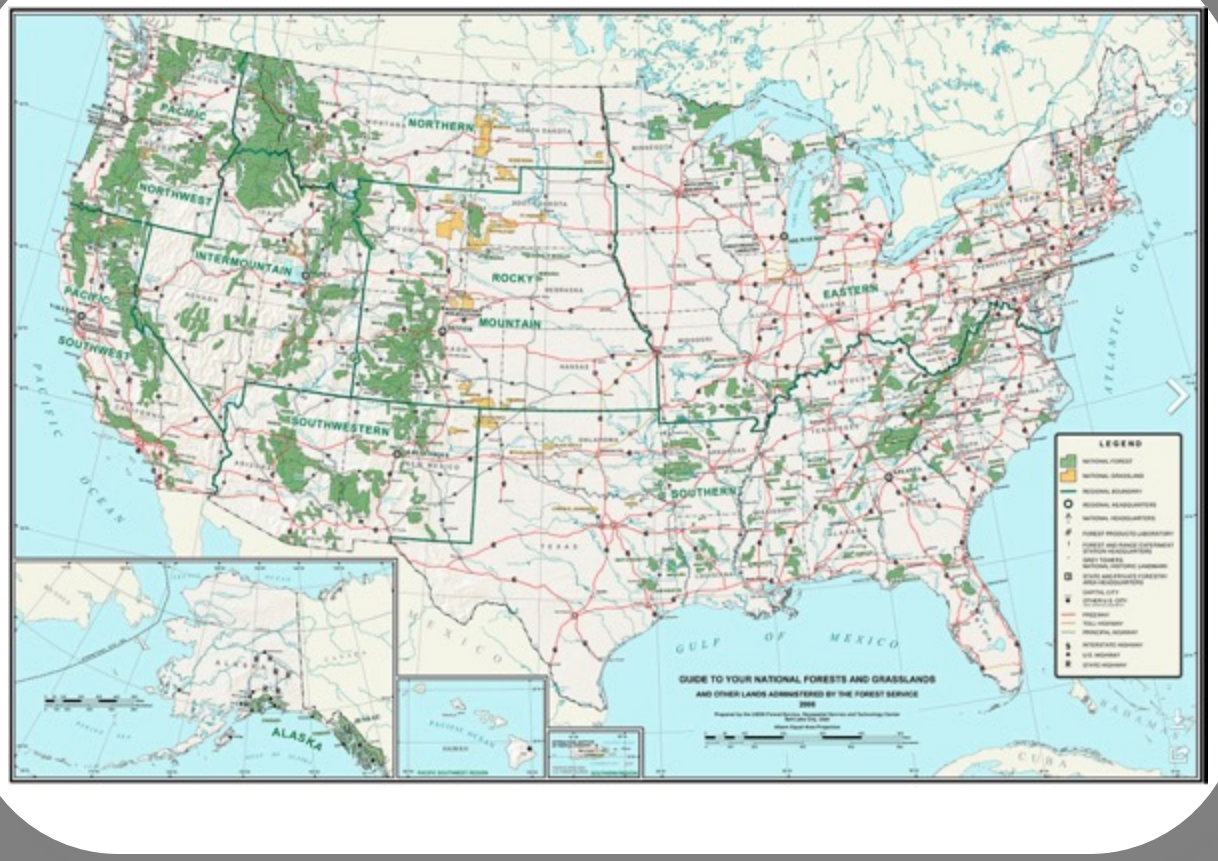
Case Study

Emergy Evaluation of the USA National Forest System

Ecosystem Values...

National Forests are largely forest areas owned by the federal government, and managed by the United States Forest Service.

In the US there are 155 National Forests totaling an area of 769,000 km^2



Ecosystem Values...

Systems Diagram
National Forest System (2005)

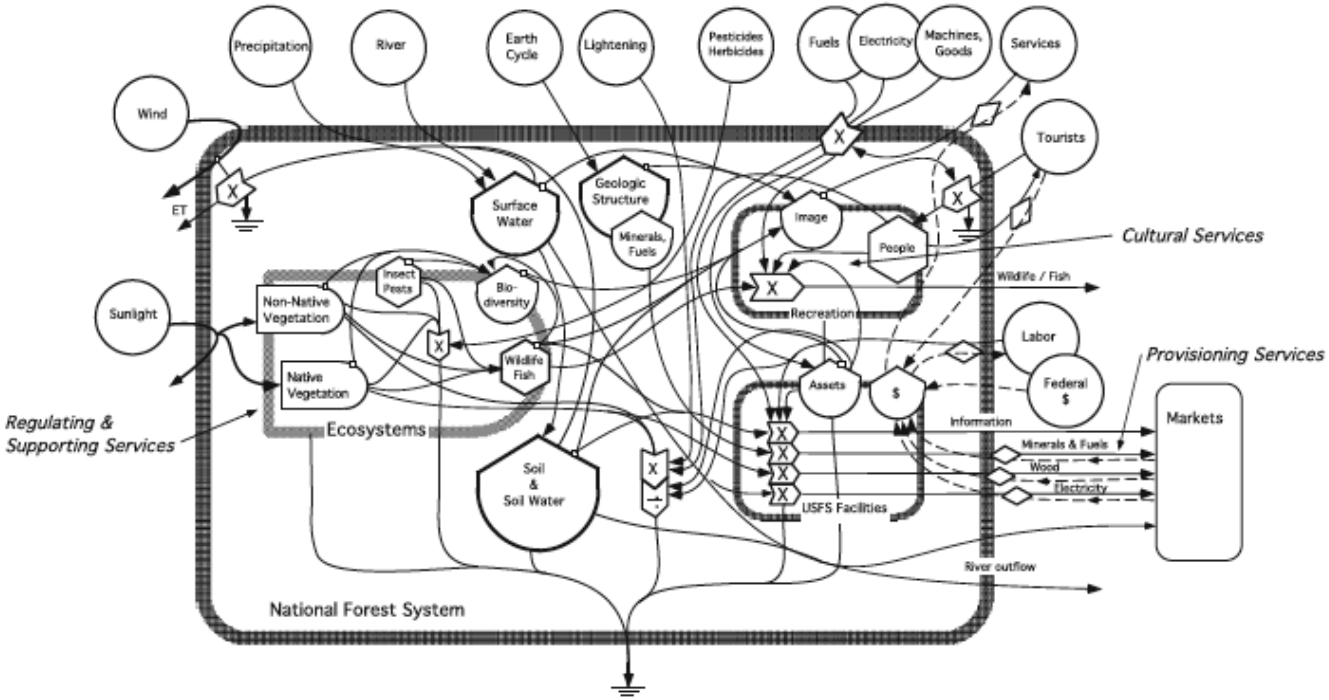


Fig. 1 Systems diagram of the USFS system (after Brown and Campbell 2007) showing the interplay of ecosystems, facilities and recreation in providing ecosystem services

Ecosystem Values...

Emergy flows supporting the USFS

The analysis was carried out using the 10 regions of the USFS and then summed to obtain this summary table.

Table 2 Emergy evaluation of the flows supporting US National Forest System

Note[a]	Item	Units	Quantity	Emergy intensity (sej/unit)	Solar emergy ($\times 10^{21}$ sej)	EmDollars ($\times 10^{6}$ 2004$)
Renewable resources						
1	Sunlight	J	4.37E+21	1.00E+00	4,371.0	2,300.5
2	Rain chemical potential	J	2.62E+18	6.36E+03	16,637.8	8,756.7
3	Transpiration	J	1.18E+18	6.36E+03	7,506.8	3,950.9
4	Rain geopotential	J	1.08E+18	1.10E+04	11,844.7	6,234.0
5	Wind kinetic	J	3.40E+18	1.58E+03	5,362.9	2,822.6
6	Hurricanes	J	3.38E+17	6.49E+03	2,193.6	1,154.5
7	Waves	J	6.11E+17	2.22E+04	13,544.0	7,128.4
8	Tides	J	1.96E+17	7.24E+04	14,170.3	7,458.0
9	Geothermal energy	J	6.87E+16	2.03E+04	1,394.3	733.8
Total renewable[b]					19,935.5	10,492.4
Indigenous non-renewable resources						
10	Soil loss (harvesting)	g	9.73E+10	1.68E+09	163.5	86.1
10a	Soil OM loss (harvesting)	J	8.04E+13	1.18E+04	0.9	0.5
11	Miscellaneous products (plants)	J	2.50E+13	5.04E+04	1.3	0.7
Total and non-renewable					165.7	87.2
Purchased inputs						
12	Petroleum products	J	4.04E+15	1.87E+05	756.0	397.9
13	Machinery, equipment	g	4.95E+09	1.13E+10	55.8	29.4
14	Misc. goods	g	7.22E+07	2.49E+10	1.79	0.9
15	Electricity	J	1.17E+15	2.92E+05	341.8	179.9
16	Services (incl Labor)	$	8.66E+09	1.90E+12	16,454.0	8,660.0
Total imports					17,609.4	9,268.1
17	Visitors' time	J	1.60E+15	1.50E+07	23,995.7	12,629.3
Exports						
18	Extracted firewood	J	1.17E+16	3.06E+04	358.9	188.9
19	Harvested wood	J	1.02E+17	5.04E+04	5,158.3	2,714.9
20	Water, chemical potential	J	1.26E+18	1.08E+04	13,566.5	7,140.2
21	Water, geopotential	J	2.01E+18	1.10E+04	22,144.8	11,655.1
22	Minerals	g	4.16E+12	1.46E+10	60,691.1	31,942.7
23	Fossil fuels	J	1.52E+18	1.31E+05	198,798.7	104,630.9
24	Harvested wildlife	J	5.50E+14	9.46E+05	520.6	274.0
25	Harvested fish	J	9.96E+13	2.10E+06	209.2	110.1
26	Information	Hrs	1.94E+07	2.35E+14	4,562.9	2,401.5
Total exports					306,011.0	161,058.4
Economic payments received						
27	US Gov't budget allocation	$	5.55E+09			
28	Payment for timber	$	2.24E+08			
29	Payments for minerals/fuels extracted	$	2.84E+09			

Ecosystem Values...

Natural and Economic Capital

Total Natural Capital
(24.3 E12 ^{em}$)

Total Economic Capital
(301 E9 $)

Table 3 Emergy in natural and economic capital of US National Forest System

Note[a]	Item	Units	Quantity	Emergy intensities (seJ/unit)	Solar emergy ($\times 10^{21}$ seJ)	EmDollars ($\times 10^{9}$ Em$)
Natural capital						
1	Herb./shrub biomass	J	6.91E+18	9.79E+03	67.7	35.6
2	Surface water	J	1.57E+18	5.04E+04	79.0	41.6
3	Land area	ha	7.80E+07	1.05E+15	81.9	43.1
4	Ground water	J	2.80E+18	1.91E+05	535.0	281.6
5	Fauna	g	6.02E+13	1.72E+10	1,037.9	546.3
6	Soil OM	J	1.50E+20	1.18E+04	1,771.1	932.2
7	Tree biomass	J	7.71E+19	5.04E+04	3,885.8	2,045.2
8	Glaciers	g	6.23E+17	6.40E+06	3,986.2	2,098.0
9	Minerals (possible reserve)	g	2.20E+13	3.75E+11	8,243.2	4,338.5
10	Fossil fuels (possible reserve)	J	9.74E+19	9.76E+04	9,506.1	5,003.2
11	Biodiversity	# of spp.	5.97E+03	2.85E+21	16,984.9	8,939.4
Total natural capital					46,178.8	24,304.6
Economic capital						
12	Office equipment	g	3.84E+10	1.13E+10	0.4	0.2
13	Machinery & tools	g	9.91E+10	1.13E+10	1.1	0.6
14	Buildings	g	1.02E+12	6.50E+09	6.6	3.5
15	Roads (paved)	g	4.81E+12	2.77E+09	13.3	7.0
16	Roads (dirt)	$	3.14E+10	1.90E+12	59.7	31.4
17	Roads (gravel)	g	7.15E+13	1.68E+09	120.1	63.2
18	Knowledge	# emp	3.15E+04	1.18E+19	370.6	195.0
Total economic capital					571.9	301.0

[a] Notes to Table 3 can be found in Appendix 2

Ecosystem Values...

Emdollar & Economic Value of Services USFS (2005)

The economic value was:

$71 billion

While the emergy value of Ecosystem service was:

^{Em}197 billion

Table 4 Emergy, emdollar, and economic value of services of the National Forest System (2005)

Note[a]	Parameter	Emergy value (10^{21} seJ/year)	Emdollars[b] (10^{9} Em$/year)	Economic value (10^{9} $/year)
Provisioning services				
1	Fish harvest	0.2	0.1	1.3
2	Extracted firewood	0.4	0.2	0.1
3	Wildlife harvest	0.5	0.3	2.9
4	Harvested timber	5.2	2.7	0.2
5	Water supply	13.6	7.2	12.4
6	Minerals extracted	60.7	31.9	1.1
7	Fossil fuels extracted	198.1	104.3	1.7
Regulating services				
8	Carbon sink	6.6	3.5	0.4
9	Clean air	23.7	12.5	3.3
10	Clean water	19.9	10.5	1.0
Supporting services				
11	Gross primary productivity	16.6	8.7	36.8
Cultural services				
12	Organized recreation	24.0	12.6	9.2
13	Information produced	4.6	2.4	0.2
Total ecosystem services/year			196.9	70.7

[a] Notes to Table 4 can be found in Appendix 3

[b] Emdollars are calculated by dividing emergy in column 3 by 1.9E+12 seJ/$, the average ratio of emergy to money in the USA economy in 2005

Ecosystem Values...

Emergy and emdollar value of **Natural & Economic Capital** of the National Forest System (2005)

Natural Capital
^{em}$ 24.3 trillion!!

Economic Capital
^{em}$ 301 billion!!

ic Capital of US National Forest System

Note*	Item	Units	Quantity	Emergy Intensities (seJ/unit)	Solar Emergy ($x10^{21}$seJ)	EmDollars ($x10^{9}$ Em$)
NATURAL CAPITAL						
1	Herb./Shrub Biomass	J	6.91E+18	9.79E+03	67.7	35.6
2	Surface Water	J	1.57E+18	5.04E+04	79.0	41.6
3	Land Area	ha	7.80E+07	1.05E+15	81.9	43.1
4	Ground Water	J	2.80E+18	1.91E+05	535.0	281.6
5	Fauna	g	6.02E+13	1.72E+10	1037.9	546.3
6	Soil OM	J	1.50E+20	1.18E+04	1771.1	932.2
7	Tree Biomass	J	7.71E+19	5.04E+04	3885.8	2045.2
8	Glaciers	g	6.23E+17	6.40E+06	3986.2	2098.0
9	Minerals (possible reserve)	g	2.20E+13	3.75E+11	8243.2	4338.5
10	Fossil Fuels (possible reserve)	J	9.74E+19	9.76E+04	9506.1	5003.2
11	Biodiversity	# of species	5.97E+03	2.85E+21	16984.9	8939.4
				Total Natural Capital	**46178.8**	**24304.6**
ECONOMIC CAPITAL						
12	Office Equipment	g	3.84E+10	1.13E+10	0.4	0.2
13	Machinery & tools	g	9.91E+10	1.13E+10	1.1	0.6
14	Buildings	g	1.02E+12	6.50E+09	6.6	3.5
15	Roads (paved)	g	4.81E+12	2.77E+09	13.3	7.0
16	Roads (dirt)	$	3.14E+10	1.90E+12	59.7	31.4
17	Roads (gravel)	g	7.15E+13	1.68E+09	120.1	63.2
18	Knowledge	employees	3.15E+04	1.18E+19	370.6	195.0
				Total Economic Capital	**571.9**	**301.0**

Ecosystem Values...

Emergy and emdollar value of **services** of the National Forest System (2005)

Note	Parameter	Emergy Value (10^{21} seJ/yr)	Emdollars* (10^{9} Em$/yr)
Provisioning Services			
1	Fish Harvest	0.2	0.1
2	Extracted Firewood	0.4	0.2
3	Wildlife harvest	0.5	0.3
4	Harvested Timber	5.2	2.7
5	Water supply	13.6	7.2
		60.7	31.9
		198.1	104.3
		6.6	3.5
		23.7	12.5
		19.9	10.5
11	Gross primary productivity	16.6	8.7
Cultural Services			
12	Organized recreation	24.0	12.6
13	Information produced	4.6	2.4
		Total Ecosystem Services/yr.	**196.9**

Annual NFS budget = $5.6 billion
Benefit cost ratio of **35/1**

Campbell & Brown, 2012

Case Study

Ecosystem degradation &
Sustainability

Ecosystem Degradation...

Ecosystem Degradation...

Where a nation (or region) obtains its wealth is a primary factor in sustainability.

Cohen, Sweeney & Brown 2010

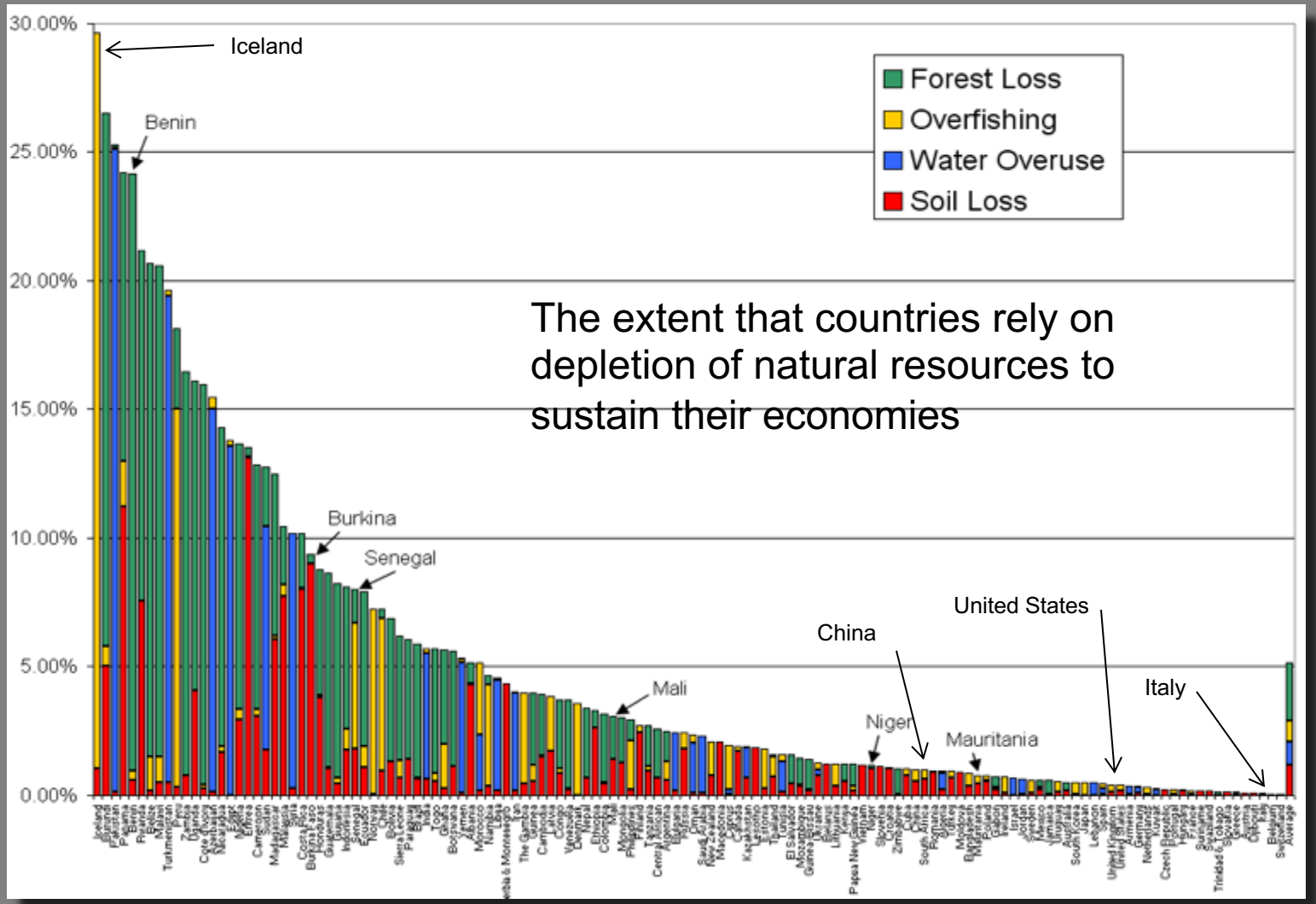
Ecosystem Degradation...

- How is national wealth generated?
  1. Transformation of renewable flows
     - Sunlight/wind/soil into agricultural products
  2. Transformation of very high quality non-renewables
     - Electricity into information
  3. Transformation of natural capital into raw products
     - Forestry, mining, fishing, water extraction, soil erosion

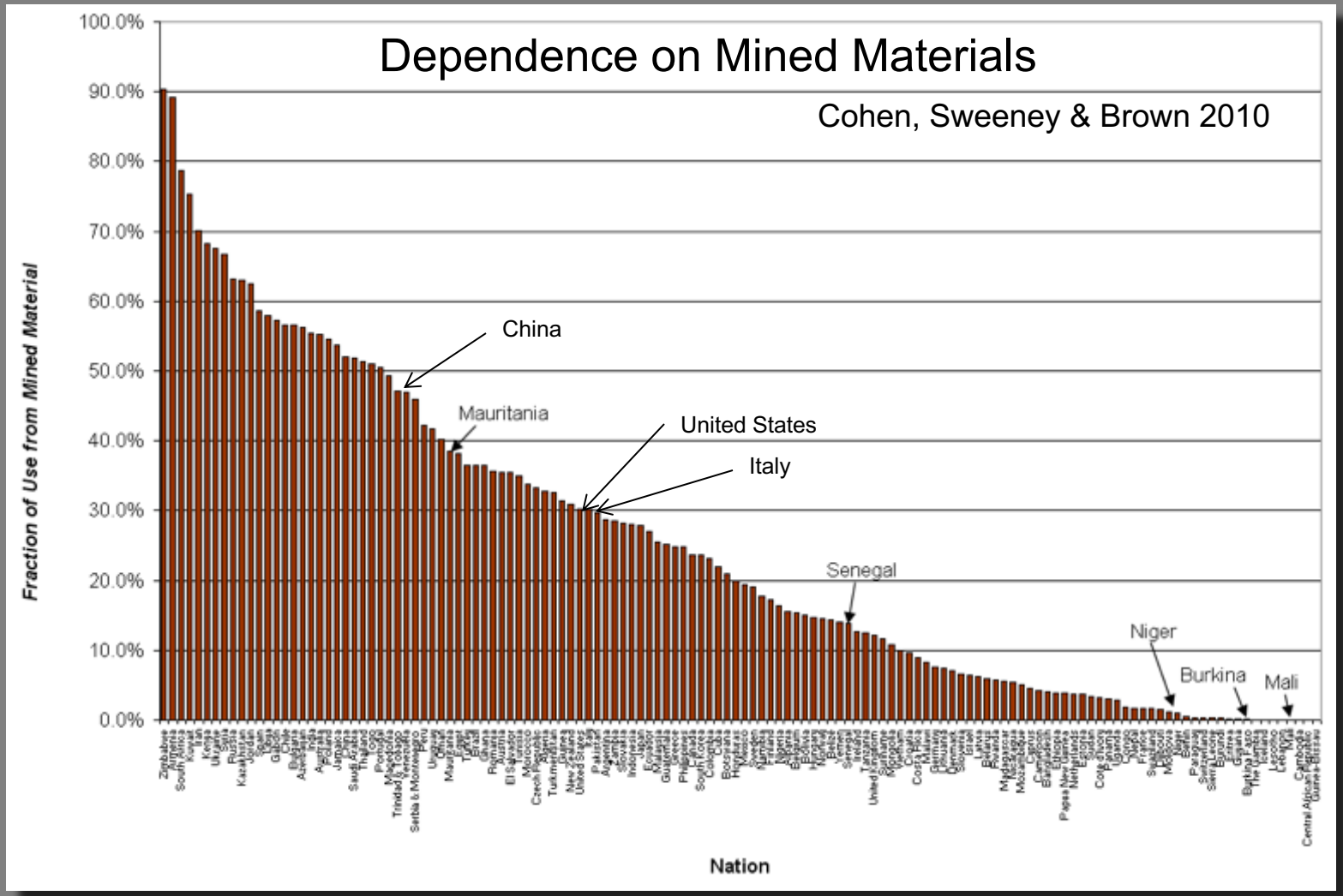
Cohen, Sweeney & Brown 2010

Natural Capital Depletion...

Cohen, Sweeney & Brown 2010



Natural Capital Depletion...



Natural Capital Depletion...

Quantifying a National Soil Erosion Problem
575 million tons of soil loss annually

nd cover classes in Kenya (after Barber 1983).

Zone	Area(m^2)	Area %	Soil Loss (g/m^2)	Annual Soil Loss (E6 tons)
Barren or Sparsely Vegetated	3.51E+10	6.1%	250	8.77E+00
Broadleaf Deciduous Forest	9.83E+09	1.7%	100	9.83E-01
Cropland/Grassland Mosaic	7.22E+10	12.4%	3000	2.17E+02
Cropland/Woodland Mosaic	2.30E+09	0.4%	2500	5.74E+00
Dry Cropland and Pasture	2.26E+10	3.9%	4500	1.02E+02
Evergreen Broadleaf Forest	1.49E+10	2.6%	100	1.49E+00
Grassland	1.06E+11	18.3%	500	5.30E+01
Savanna	1.64E+11	28.4%	500	8.22E+01
Shrubland	1.39E+11	23.9%	750	1.04E+02
Urban	1.55E+08	0.0%	5000	7.74E-01
Water Bodies	1.40E+10	2.4%	0	0.00E+00
Total	5.80E+11			5.75E+02

Cohen, Sweeney & Brown 2010

Problem of Soil Erosion

National Scale Analysis (Kenya)

- Erosion Losses = 45.2E20 sej/yr ~ ^{em}$390 million
  - % of Total Use = 3.77%
  - Equivalent in magnitude to export of all agricultural goods
- Forest losses (clearing) = 41.5E20 sej/yr ~ ^{em}$350 million
  - % of Total Use = 3.5%
- Combined an external cost of ~ 7% of total emergy use annually

Cohen, Sweeney & Brown 2010

Conclusion….

We propose a sustainability indicator:

% of Total Use that is derived from “Avoidable Depletion” of Natural Capital.

Soil erosion
Depletion of groundwater
Forest harvest faster that renewed
Fisheries harvest

Cohen, Sweeney & Brown 2010

Thank You...

Questions?