OSU~EmEa - 13

EMERGY Evaluation of Ecosystems

What is a ecosystem?
GPP & NPP
Succession
Global biomes
Emergy of ecosystem components
Restoration

What is an ecosystem?...

Ecosystem = Ecological System

A spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries

Likens, 1992

What is an ecosystem?...

Ecosystems are composed of:

Abiotic substances basic inorganic and organic compounds…water, CO_2 calcium, nitrogen, phosphorus, amino and humic acids, etc.

Biotic organisms –

1. producer organisms or autotrophic organisms... Plants, algae, etc;

2. macroconsumers …heterotrophic organisms , or animals;

3. microconsumers or saprotrophs, heterotrophic organisms, chiefly bacteria and fungi that break

What is an ecosystem?...

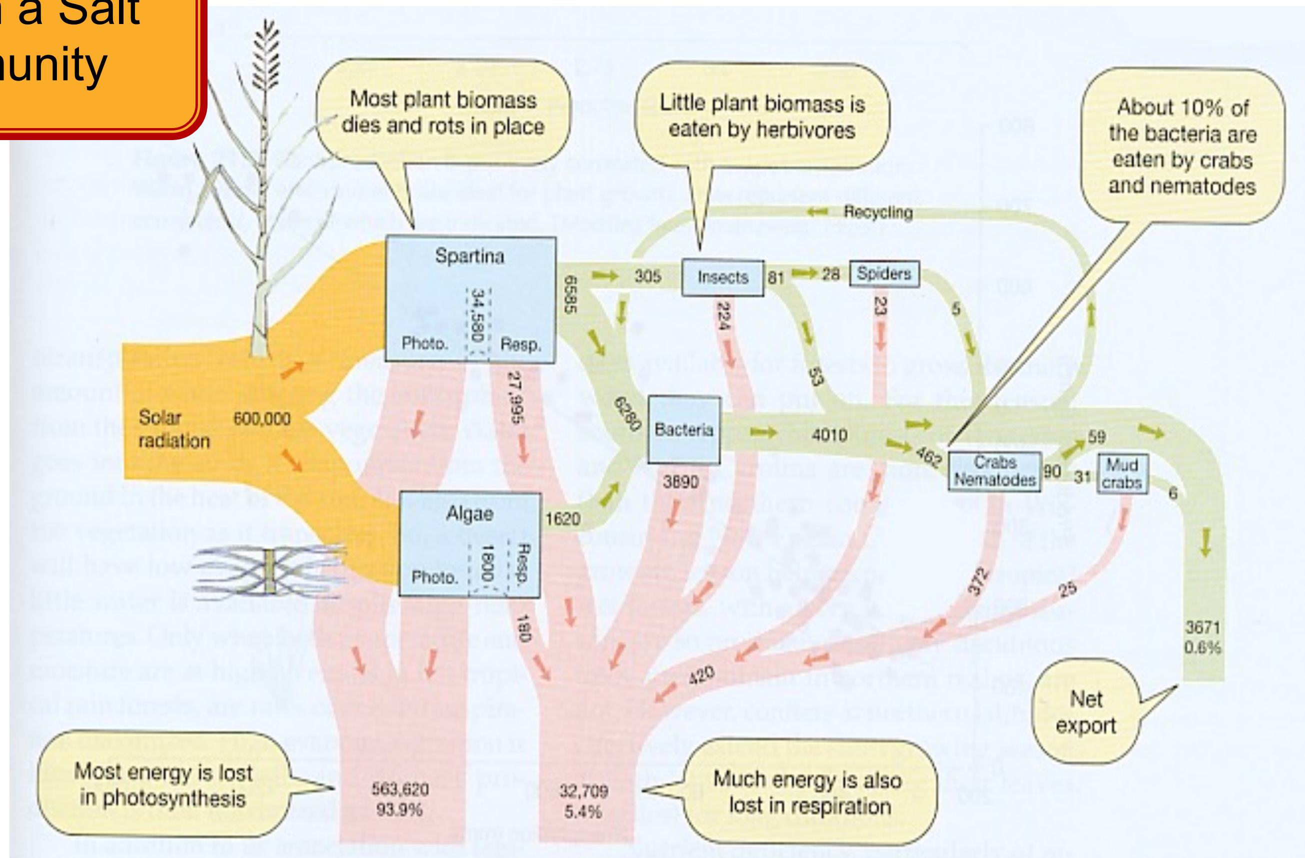
Autotroph from the Greek ***autos*** = self and ***trophe*** = nutrition) is an organism that produces organic compounds from carbon dioxide as a carbon source, using either light or reactions of inorganic chemical compounds, as a source of energy.

Heterotroph Greek ***heterone*** = (an)other and ***trophe*** = nutrition) is an organism that requires organic substrates to get its carbon for growth and development. If a species obtains carbon from organic compounds then there are two possible subtypes of these heterotrophs:

- photoheterotroph -- obtains energy from light
- chemoheterotroph -- obtains energy from the oxidation of inorganic compounds

What is Primary Productivity?...

Energy Flow in a Salt Marsh Community



What is Primary Productivity?...

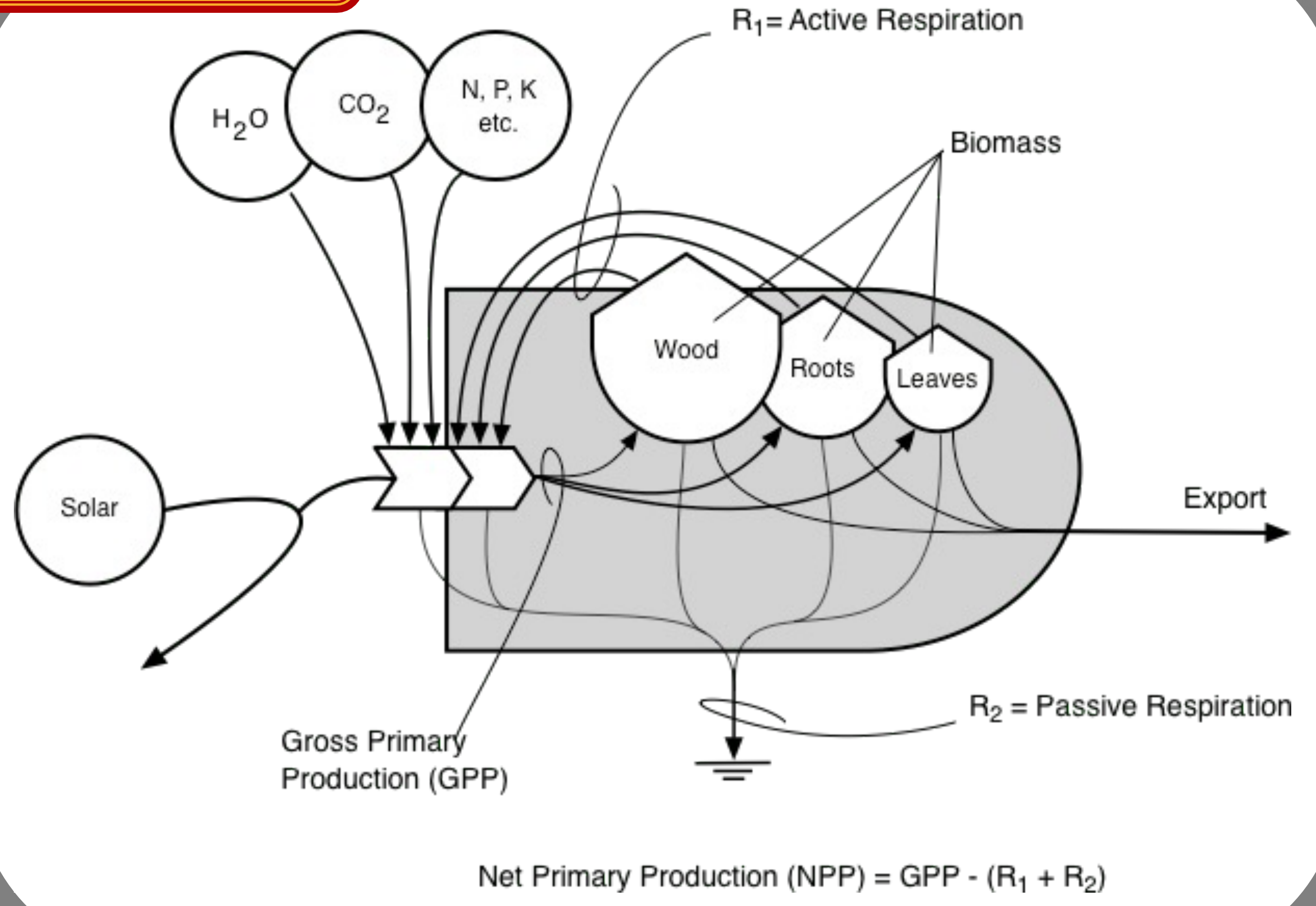
Primary Productivity is the rate at which energy is converted by photosynthetic and chemosynthetic autotrophs to organic substances.

Gross Primary Production (GPP) - total rate of new biomass generation before any losses

Net Primary Production (NPP) - the rate at which all the plants in an ecosystem produce net useful chemical energy…. GPP minus respiration

What is Primary Productivity?...

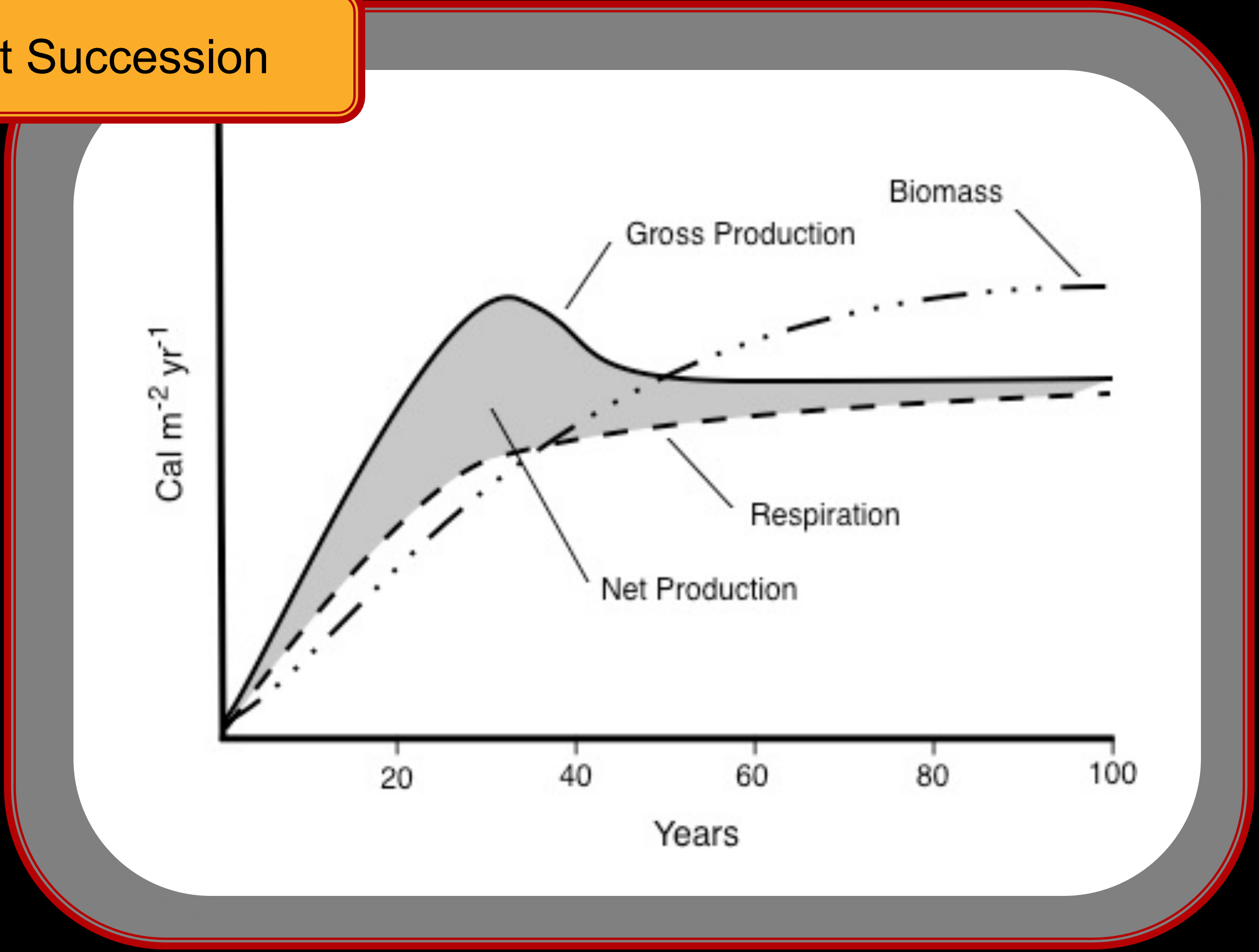
Autotrophic Production



What is Primary Productivity?...

Successional Development of Ecosystems….

Forest Succession



The difference between Gross Primary Production and Respiration is Net Production.

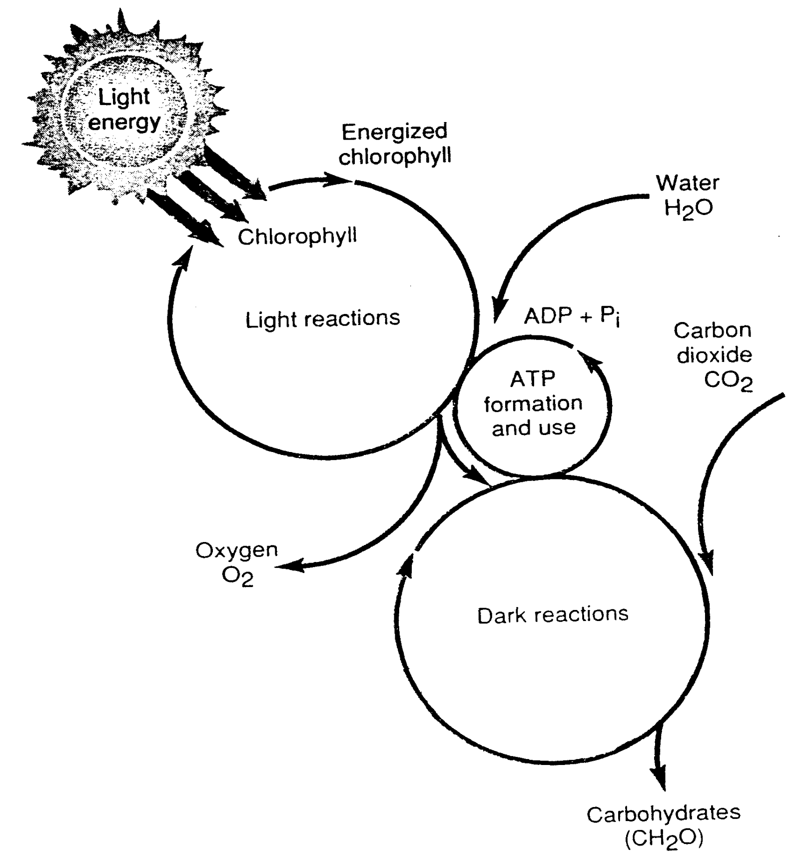
At climax, P = R and there is no net accumulation of biomass

What is Primary Productivity?...

PHOTOSYNTHESIS is composed of two processes…

LIGHT REACTIONS - create ATP and other high energy compounds that provide power for…

DARK REACTIONS - that carry out carbon fixation to create new carboydrate molecules



What is Primary Productivity?...

- Photosynthesis:

Sunlight

$$6CO_2 + 6H_2O + \text{nutrients} \xrightarrow{chl} C_6H_{12}O_6 + 6O_2$$

Glucose

Energy in 1 g glucose
= 15.94 kJ/g

Energy in 1 gram carbon
= 15.94 kJ / 0.40
= 39.85 kJ/g

$C_6\,H_{12}\,O_6$

Element	M. Weight	Total Weight	% of Total
Carbon	12.01	72.06	40%
Hydrogen	1.01	12.12	7%
Oxygen	16	96	53%
		180.18	100%

What is Primary Productivity?...

- Consumption/decomposition

$C_6H_{12}O_6$ + 6O2 6 CO_2 + $6H_2O$ + nutrients + ENERGY

15.94 kJ/g

What is Primary Productivity?...

Organic matter: the large pool of carbon-based compounds that has come from the remains of plants and animals and their waste products.

Generally, organic matter, in terms of weight, is:

45-55% carbon
35-45% oxygen
3-5% hydrogen
1-4% nitrogen

What is Primary Productivity?...

Energy in organic matter:

woodland soils = 5.04 Cal g^{-1} (21.1 kJ g^{-1})
swamp soils = 4.87 Cal g^{-1} (20.4 kJ g^{-1})
lake sediments = 5.24 Cal g^{-1} (21.9 kJ g^{-1})

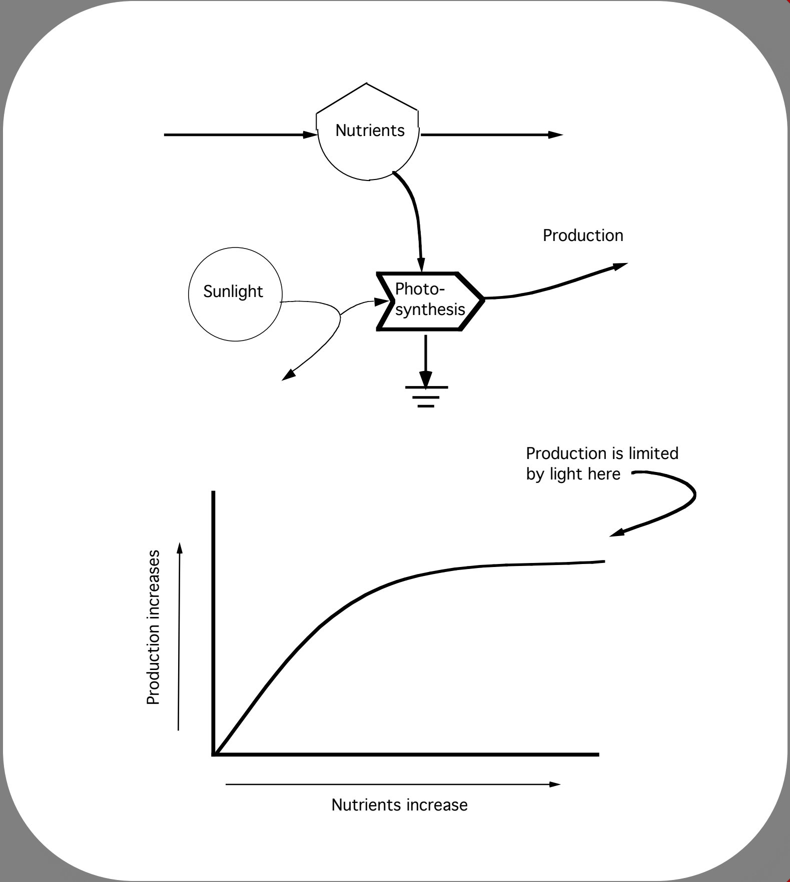
Measured as ash free dry weight

* note: Cal = kcal or 1000 calories

What is Primary Productivity?...

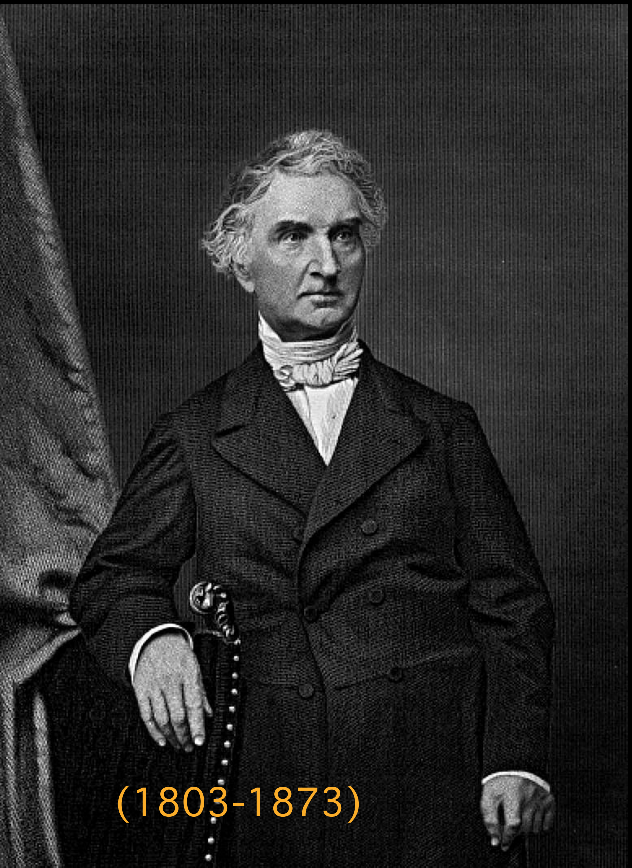
Primary Production & Limiting Factors...

Most production processes go faster when all inputs are available in larger quantities… however a reaction can only proceed at a rate that is determined by the supply of the input that is least available….



What is Primary Productivity?...

Liebig's Law of the Minimum



… a principle developed in agricultural science by Justus von Liebig. It states that growth is controlled not by the total of resources available, but by the scarcest resource.

What is Primary Succession?...

Succession is Self -organization…

The process by which the various parts (components) of a system become connected so as to work together...

- Interactions that contribute to better use of available resources succeed because they are reinforced
- Self-organization results in emergent properties of systems

Classical Succession...

Species in new communities are in time replaced by others until the climax associations are established.

Primary Succession -Begins with bare ground. Pioneer species arrive and become established…with time they alter the environment so that other species can survive.

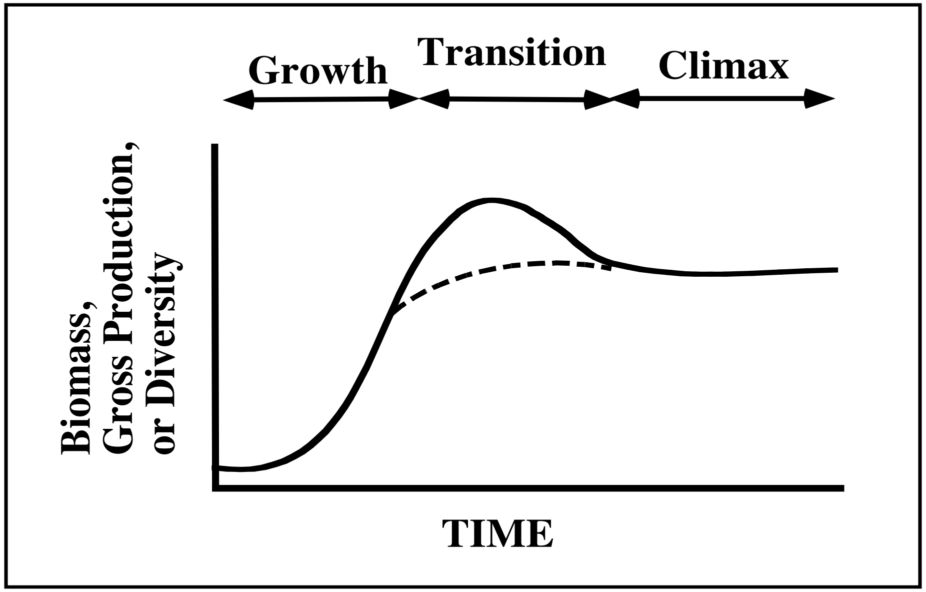
The floristic and structural complexity increases with time until environmental conditions become stabilized and a self-perpetuating climax association is formed. (Clements, 1916)

Classical Succession...

The stages of ecosystem development

growth
transition
climax

The community begins with relatively few pioneering plants and animals and develops through increasing complexity until it becomes stable or self-perpetuating as a climax community.



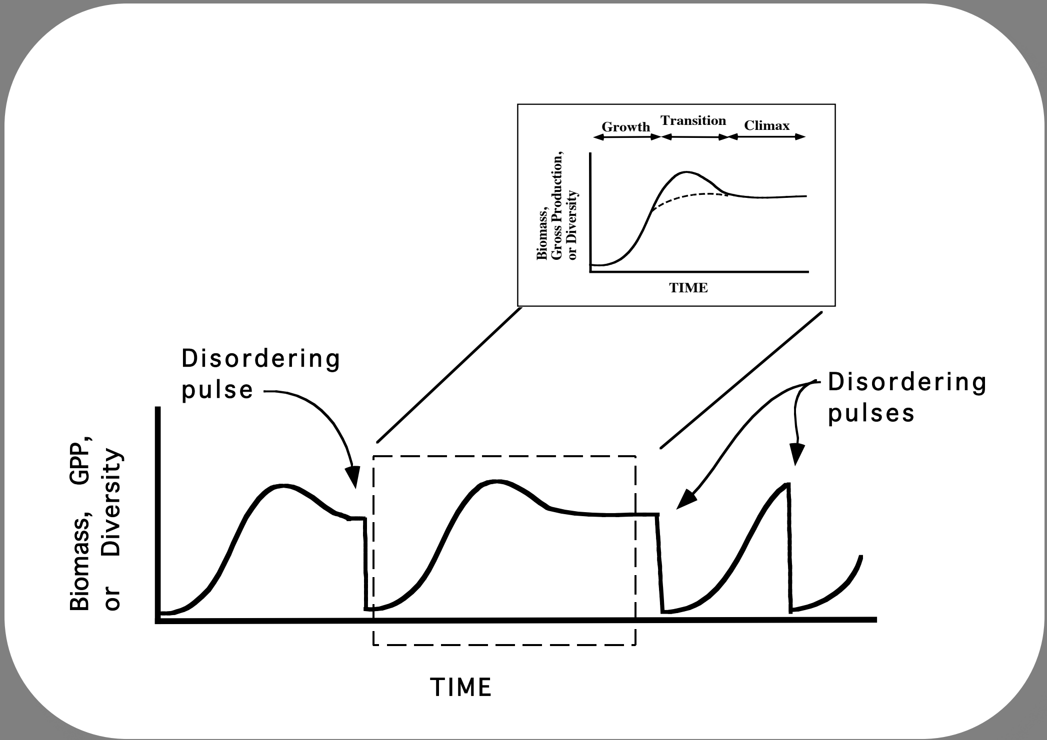
Pulsing Paradigm…

Reorganization and Oscillation resulting from pulses of disorder or consumer behavior…

Classical succession may be just a part of a much larger pattern of growth, transition, and decline that is characteristic of all systems

Pulsing Paradigm…

Classical succession … a part of a much larger pattern of ecosystem pulsing.



How Productive Are Ecosystems?...

Generally, the speed at which nutrients, carbon, and water cycle within an ecosystem determine its productivity.

Cycling “speed” is largely determined by temperature and humidity

How Productive Are Ecosystems?...

A general rule: the rates of chemical reactions double for each 10º C increase in temperature

Moist conditions increase rates of decomposition as well.

Thus decomposition tends to be fastest under warm <u>moist</u> conditions.

How Productive Are Ecosystems?...

Highest net productivities in wetlands, rainforests, coral reefs, and coastal estuaries

= 1800 to 2500 g dry OM. m^{-2} yr^{-1}

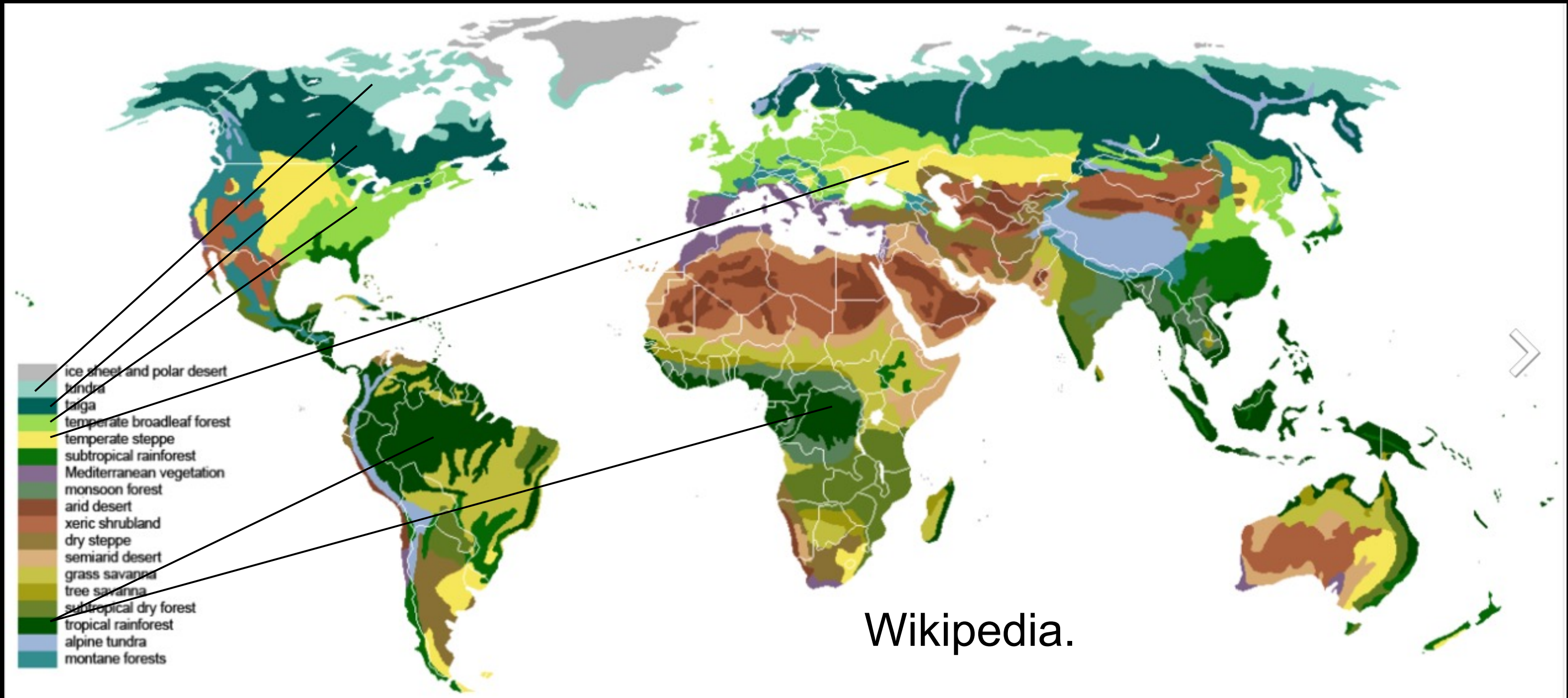
Open ocean = 125 g dry OM. m^{-2} yr^{-1}

Desert = 70 g dry OM. m^{-2} yr^{-1}

Lowest net productivities in barren sand, rock, ice fields = 3 g dry OM. m^{-2} yr^{-1}

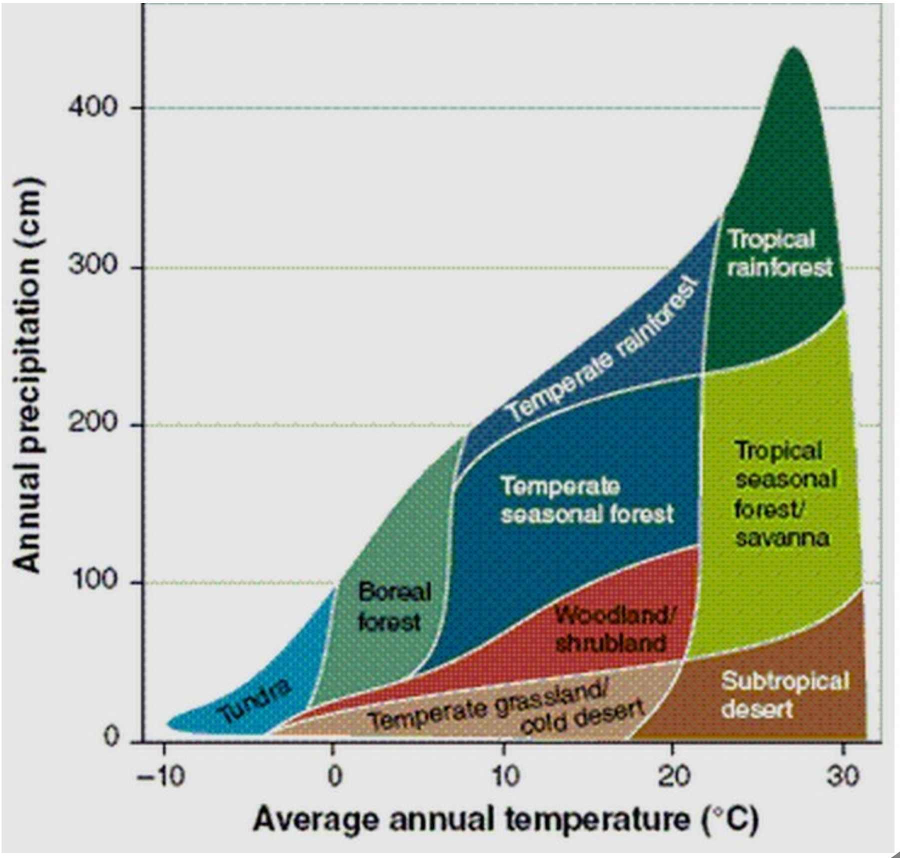
Global Biomes...

Biome - a formation of plants and animals that have common characteristics due to similar climates and can be found over a range of continents.



Global Biomes...

Distribution of biomes based on temperature and rainfall.



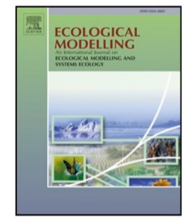
Wikipedia.

Global Biomes...

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel



Estimating the Value of Global Ecosystem Structure and Productivity: A Geographic Information System and Emergy Based Approach

Dong Joo Lee[a], Mark T. Brown[b,*]

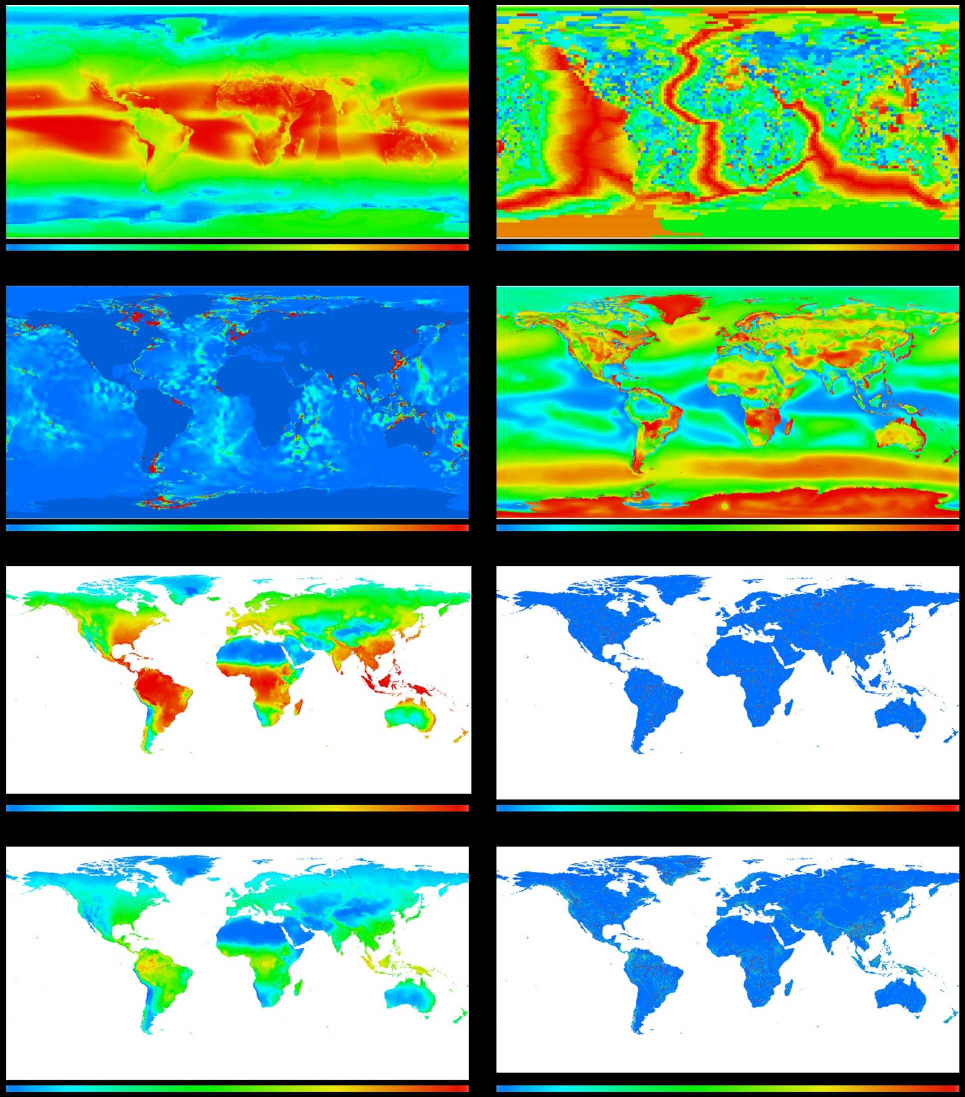
[a] School of Earth Sciences & Environemental Engineering, Gwangju Inst. Of Science & Tech, Gwangju, S. Korea
[b] Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL USA

Global Biomes...

Coverages of global renewable emergy inputs by source.

From top left:

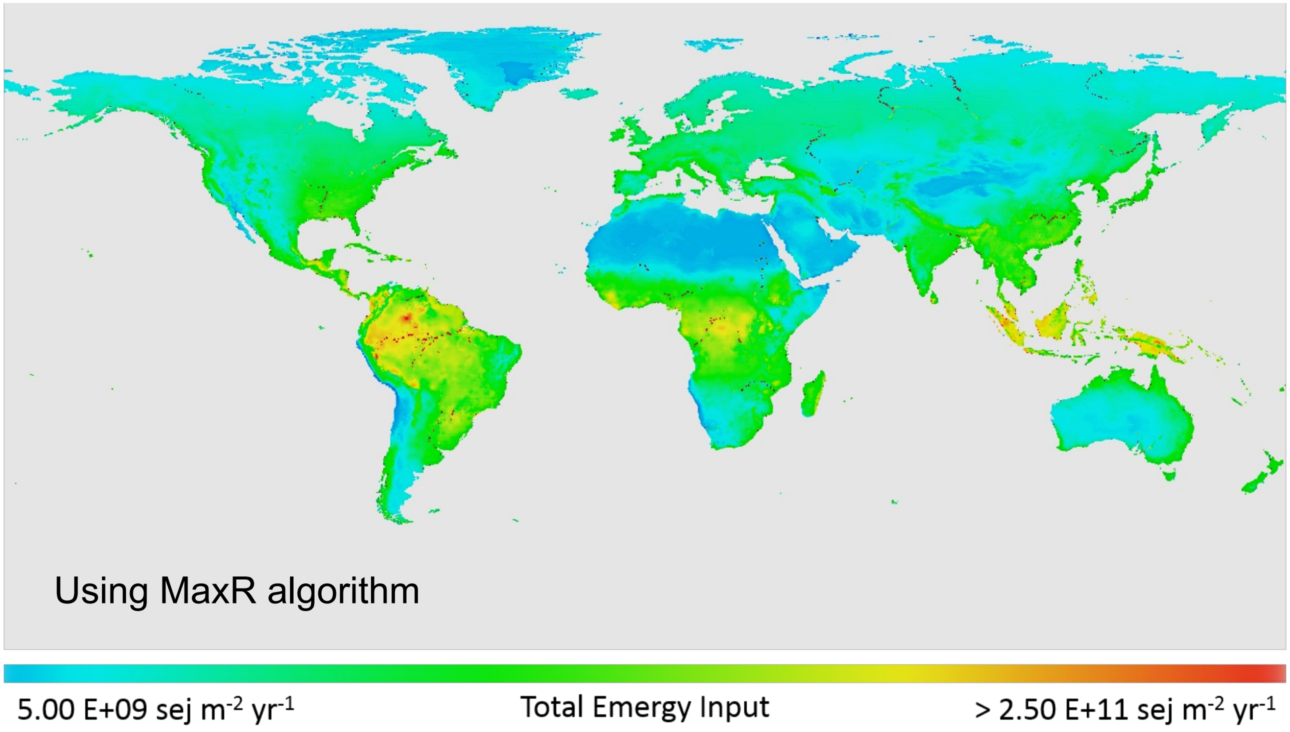
Solar, Geothermal,
Tidal, Wind,
Rain$_{\text{chem pot}}$, Runoff$_{\text{chem pot}}$
Tot Water$_{\text{chem pot}}$ Runoff$_{\text{geopot}}$.



Lee & Brown, 2021

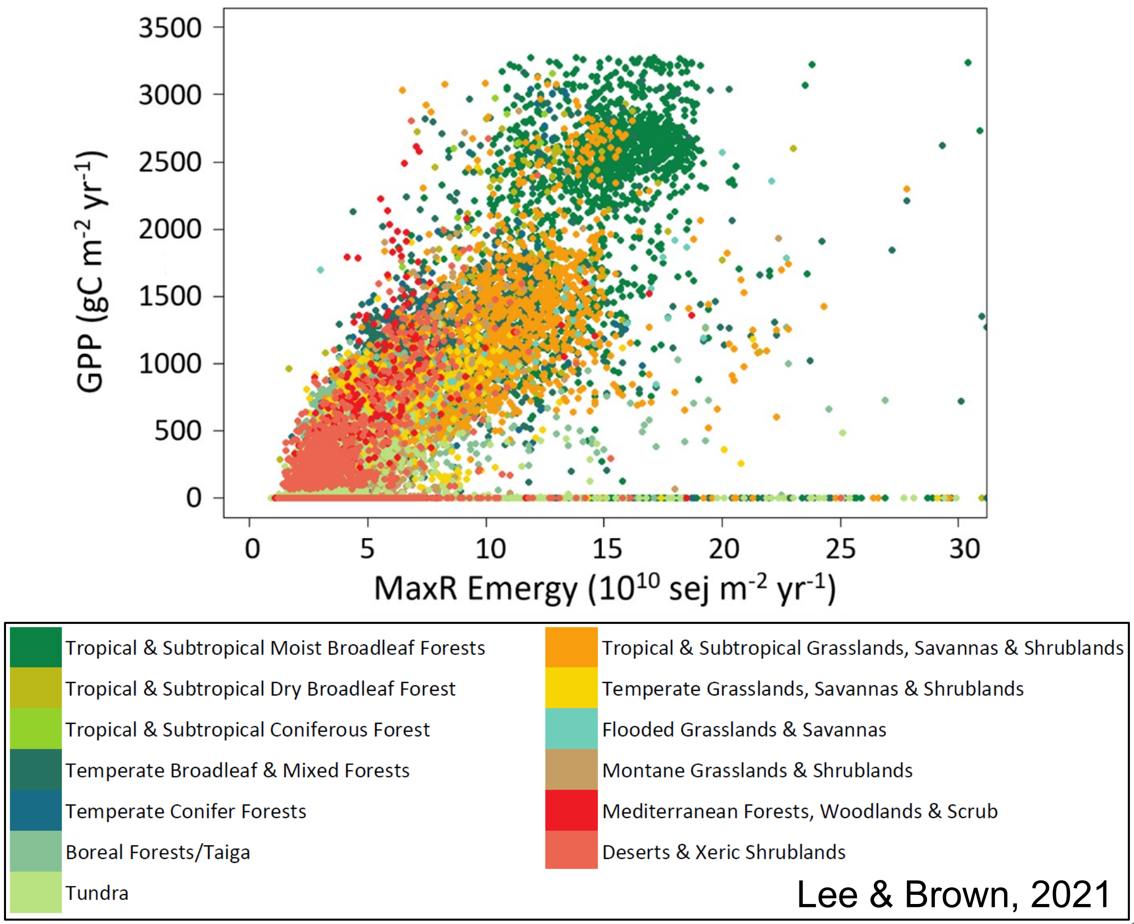
Global Biomes...

Global aerial empower intensity (AEI) of terrestrial renewable emergy.



Lee & Brown, 2021

Global Biomes...



Global Biomes...

Table 1. Matrix of Biome inputs

Earth exergy flux (J/yr)	3.59E+24	6.73E+20	1.17E+20	1.52E+22	5.34E+20	2.91E+20	1.76E+20	1.57E+20	9.88E+21
Transformity (sej/J)	1	4900	30900	790	7008	12840	21300	76200	4130
					J/yr				
Biome	**Sun**	**Heat**	**Tide**	**Wind**	**Rain**	**Runoff Geo**	**Runoff Chem**	**Currents**	**Waves**
Tundra	2.1E+22	7.8E+18		1.2E+20	4.0E+12				9.9E+17
Swamps/floodplains	1.1E+22	1.7E+18		7.0E+18	2.9E+18		6.3E+19		
Tropical forest	1.7E+23	2.0E+19		5.3E+19	5.5E+19				0.0E+00
Ocean shelf	2.1E+23	3.6E+19	9.3E+16	3.2E+21	3.3E+19				1.7E+20
Grass/rangelands	3.2E+23	4.1E+19		1.2E+20	1.3E+19				
Temperate/boreal forest	1.6E+23	3.1E+19		1.7E+20	1.7E+19				
Desert	1.6E+23	2.0E+19		1.1E+20	4.6E+10				
Ice/rock	1.8E+22	1.7E+19		4.0E+20	1.1E+19				1.1E+19
Open ocean	2.2E+24	4.3E+20	1.1E+20	3.2E+21	3.5E+20			1.4E+20	8.9E+21
Lakes	1.3E+22	2.1E+18		6.1E+18	1.2E+18		1.6E+19		
Tidal Marsh, mangroves	1.3E+22	1.7E+18	5.8E+17	1.3E+19	5.2E+18		4.1E+19		
Estuaries	1.3E+22	2.3E+18	6.3E+17	3.2E+21	2.1E+18		4.1E+19		
Coral reefs	4.5E+21	9.0E+17	2.2E+13	3.2E+21	7.2E+17				1.9E+18
Rivers	1.0E+22	1.6E+18		1.0E+19	8.9E+17	2.7E+20			

Lee & Brown, 2021

Global Biomes...

Areal Empower Intensity

- emergy per unit time (empower) per unit area (intensity).

Biome	Areal Empower Intensity (E12 sej ha^{-1} yr^{-1})
Tundra	69.3
Desert	102.7
Grass/rangelands	107.1
Temperate/boreal forest	183.2
Ice/rock	212.4
Lakes	247.1
Ocean shelf	362.6
Open ocean	623.7
Rivers	873.2
Tropical forest	907.3
Tidal Marsh, mangroves	956.3
Swamps/floodplains	1137.7
Coral reefs	2067.2
Estuaries	9818.2

Lee & Brown, 2021

Global Biomes...

Table 2. Transformity and specific emergy of biome biomass

Biome	Areal empower (E+14 sej ha^{-1} yr^{-1})	NPP energy (E+11 J ha^{-1} yr^{-1})	NPP mass (E+7 g ha^{-1} yr^{-1})	Transformity (sej J^{-1})	Specific emergy (E+03 sej kg^{-1})
Tundra	1.3	2.45	1.30	544	10.2
Swamps/floodplains	79.4	3.52	2.00	22578	397.0
Tropical forest	2.0	4.28	2.48	473	8.2
Ocean shelf	8.9	0.68	0.36	13157	247.9
Grass/rangelands	1.3	17.08	10.20	79	1.3
Temperate/boreal forest	1.0	1.51	0.78	691	13.5
Desert	1.3	1.67	0.88	805	15.2
Ice/rock	1.9	0	0	0	-
Open ocean	12.2	0.27	0.13	45716	937.9
Lakes	17.2	0.94	0.50	18306	344.9
Tidal Marsh, mangroves	51.2	3.52	2.00	14546	255.8
Estuaries	141.8	3.39	1.80	41809	787.7
Coral reefs	425.4	3.77	2.00	112884	2126.9
Rivers	228.8	0.94	0.50	242890	4576.4
Terrestrial world ave[6]	3.1	6.4	3.7	859	15.54
World average[7]	11.16	2.06	1.19	31608	644.6

Lee & Brown, 2021

Global Biomes...

Table 3. Transformity and specific emergy of soil C in biomes

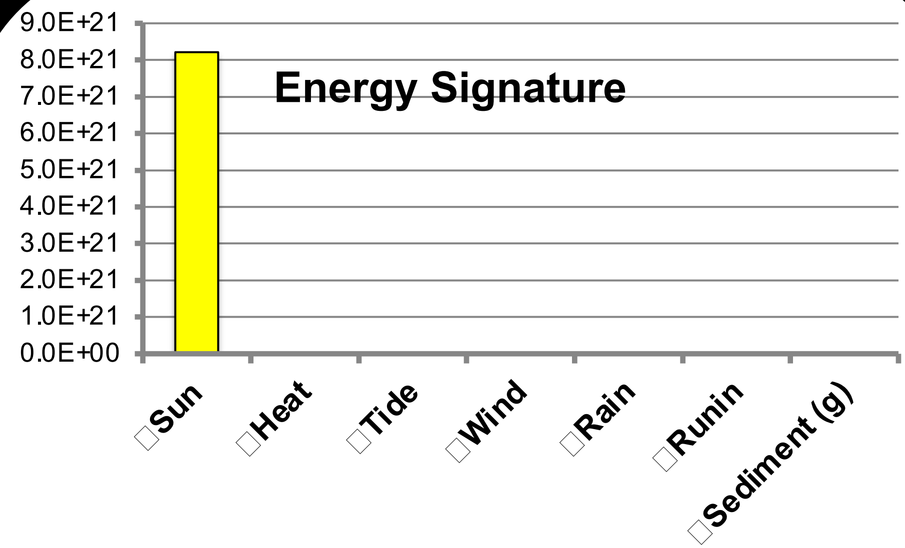
Biome	Soil C (kg C m^{-2})	Energy (E+12 J ha^{-1})	Areal empower (E+14 sej ha-1 yr^{-1})	Turnover (yr)	Specific emergy (E+03 sej kg^{-1})	Transformity (sej J^{-1})
Woodland	6.90	2.89	1.04	14	21.19	506.10
Temperate forests	13.40	5.61	1.04	29	22.60	539.82
Tropical grassland	4.20	1.76	1.35	10	32.07	765.99
Temperate grassland	18.90	7.91	1.35	61	43.48	1038.35
Boreal forest	20.60	8.63	1.04	91	46.14	1101.88
Tropical forest6	11.73	4.91	2.02	38	65.50	1564.35
Desert	2.58	1.08	1.34	37	192.02	4586.01
Tundra	20.40	8.54	1.33	490	319.77	7637.19
Swamps and marshes	72.30	30.27	64.88	520	4666.33	111448.02
Cultivated lands9	7.90	3.31	3.07	21	81.49	1946.20

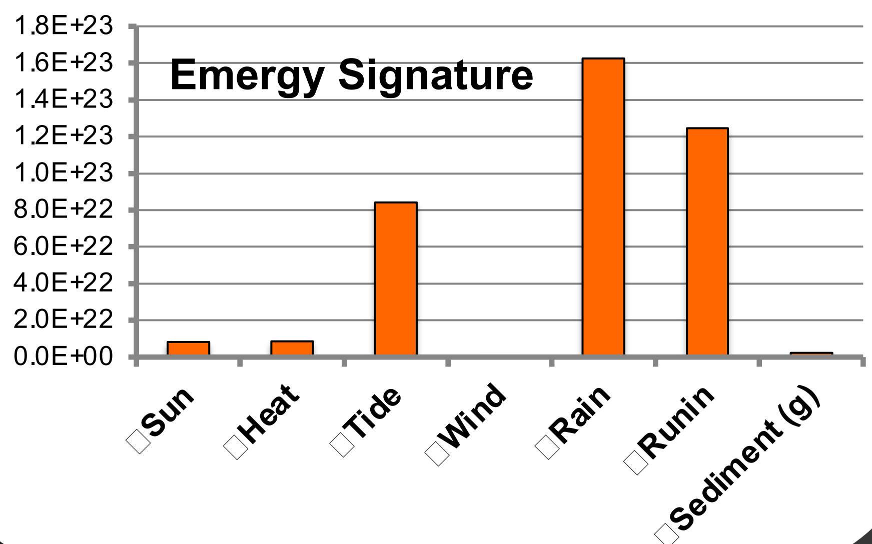
Lee & Brown, 2021

Emergy Signature...

Table A-2. Tidal marsh, mangroves, 17 E7 ha

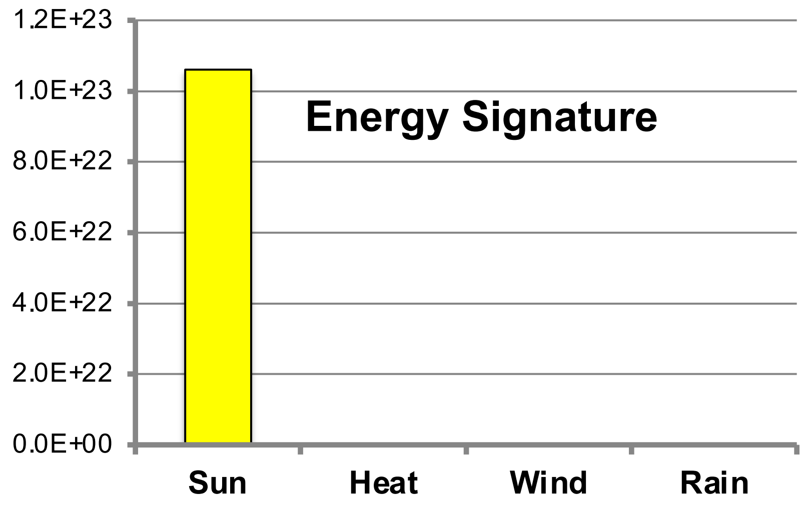
	INPUTS	Annual Exergy J yr^{-1}	Unit Emergy sej $unit^{-1}$	Annual emergy sej yr^{-1}
1	Sun	8.21E+21	1	8.21E+21
4	Heat	1.75E+18	4.90E+03	8.58E+21
5	Tide	2.72E+18	3.09E+04	8.40E+22
2	Wind	6.17E+17	7.90E+02	4.87E+20
3	Rain	2.32E+19	7.01E+03	1.63E+23
6	Runin	5.85E+18	2.13E+04	1.25E+23
7	Sediment (g)	4.32E+12	5.58E+08	2.41E+21
	Total			1.63E+23
	Empower density, sej/hectare			**9.56E+14**

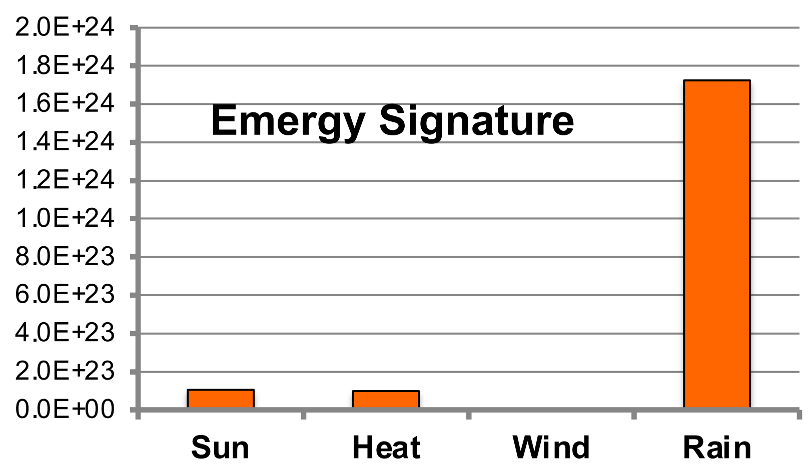




Emergy Signature...

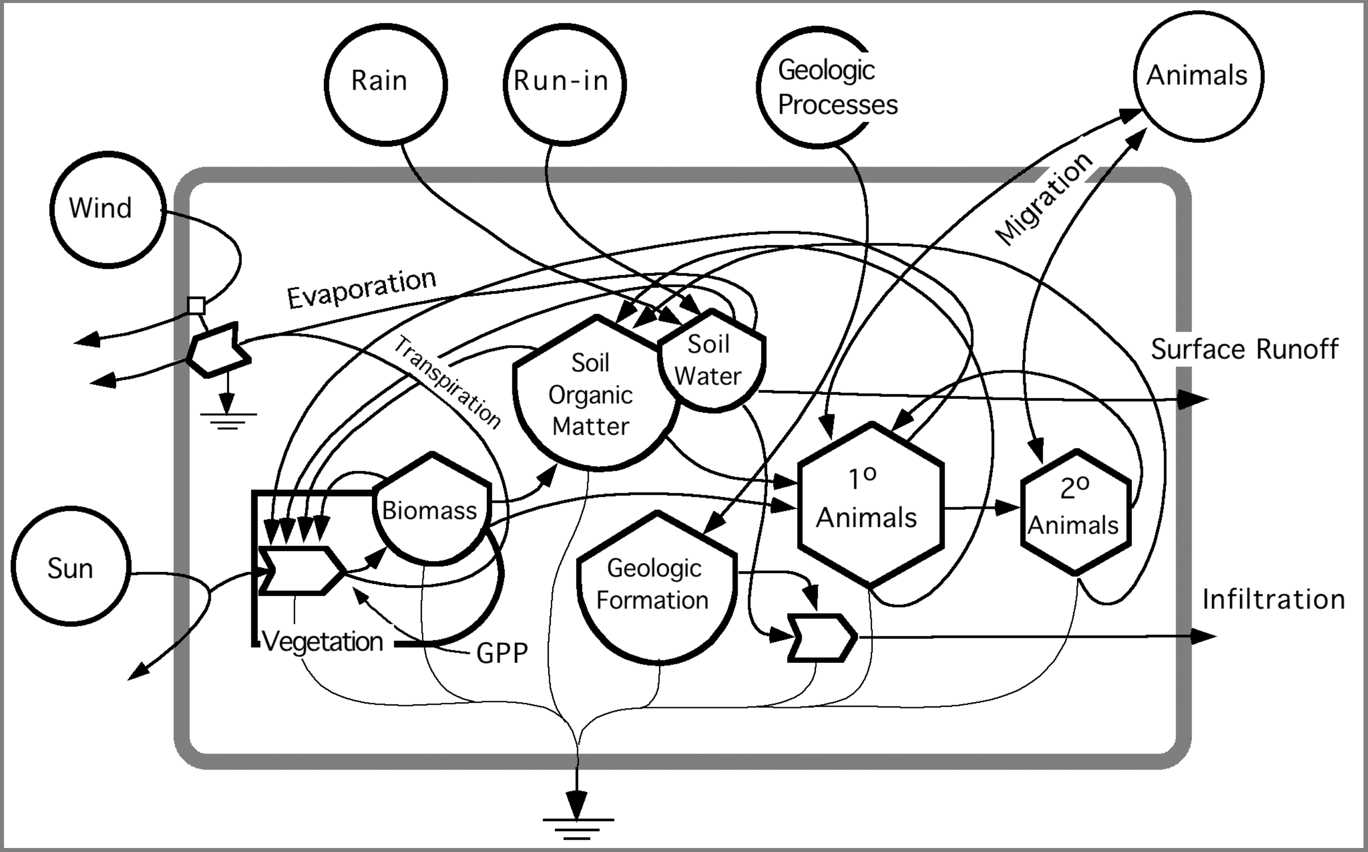
Table A-7. Tropical Forest, 190 E7 ha				
	INPUTS	Annual Exergy J yr-1	Unit Emergy sej J-1	Annual emergy sej yr-1
1	Sun	1.06E+23	1	1.06E+23
3	Heat	2.01E+19	4.90E+03	9.85E+22
2	Wind	2.58E+18	7.90E+02	2.04E+21
4	Rain	2.46E+20	7.01E+03	1.72E+24
	Total			1.72E+24
		Empower density, sej/hectare		**9.07E+14**





Emergy of Ecosystem Components...

Generic Ecosystem



Emergy of Ecosystem Components...

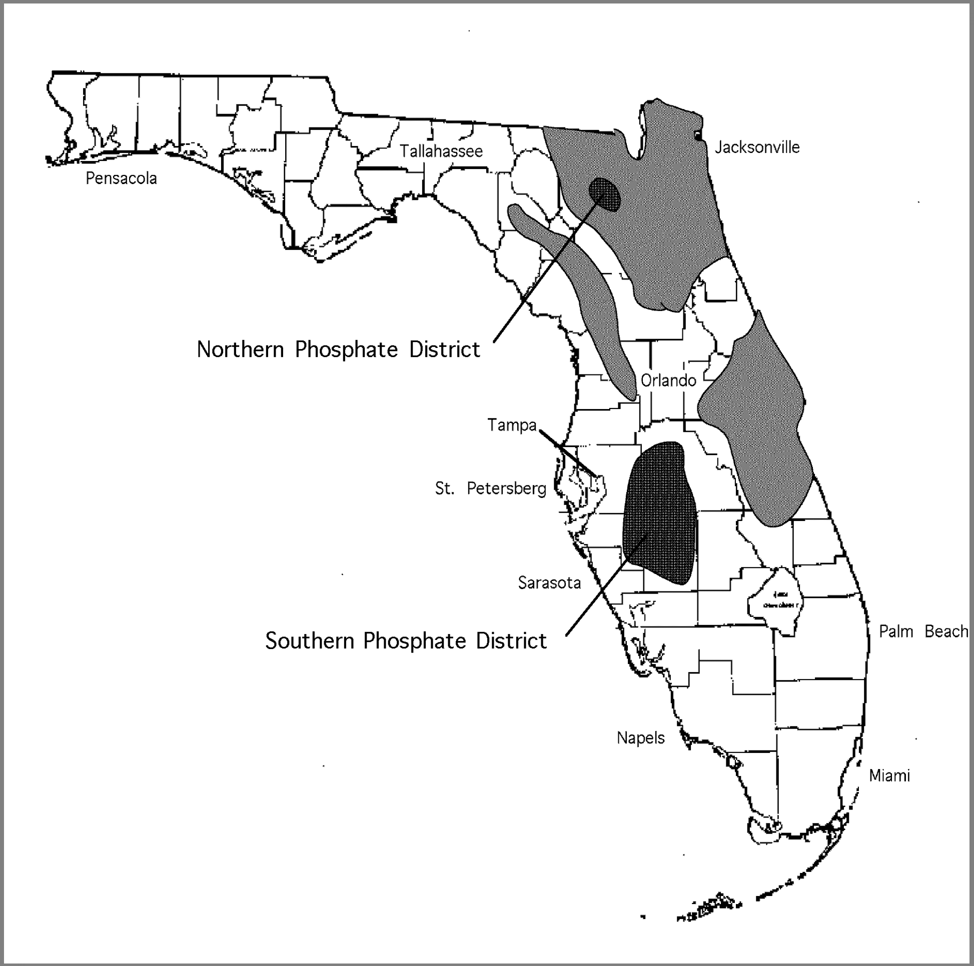
Table 1. Summary of Wood Transformities and Specific Emergy

Types of wood	Transformity (sej J^{-1})	Specific Emergy (sej kg^{-1})	Specific Emergy (sej m^{-3})
Boreal spruce and pine		5.49E+10	
Southern mixed hardwood	563	9.38E+09	5.72E+12
Pine flatwood	418	7.43E+09	4.01E+12
Cypress dominated floodplain		3.75E+10	
Subtropical Cypress wetland	2614	1.05E+11	
Temperate forest	11581	1.70E+11	
Southern mixed hardwood swamp		6.55E+11	
Tropical lowland forest		1.09E+12	

Ecosystem Restoration

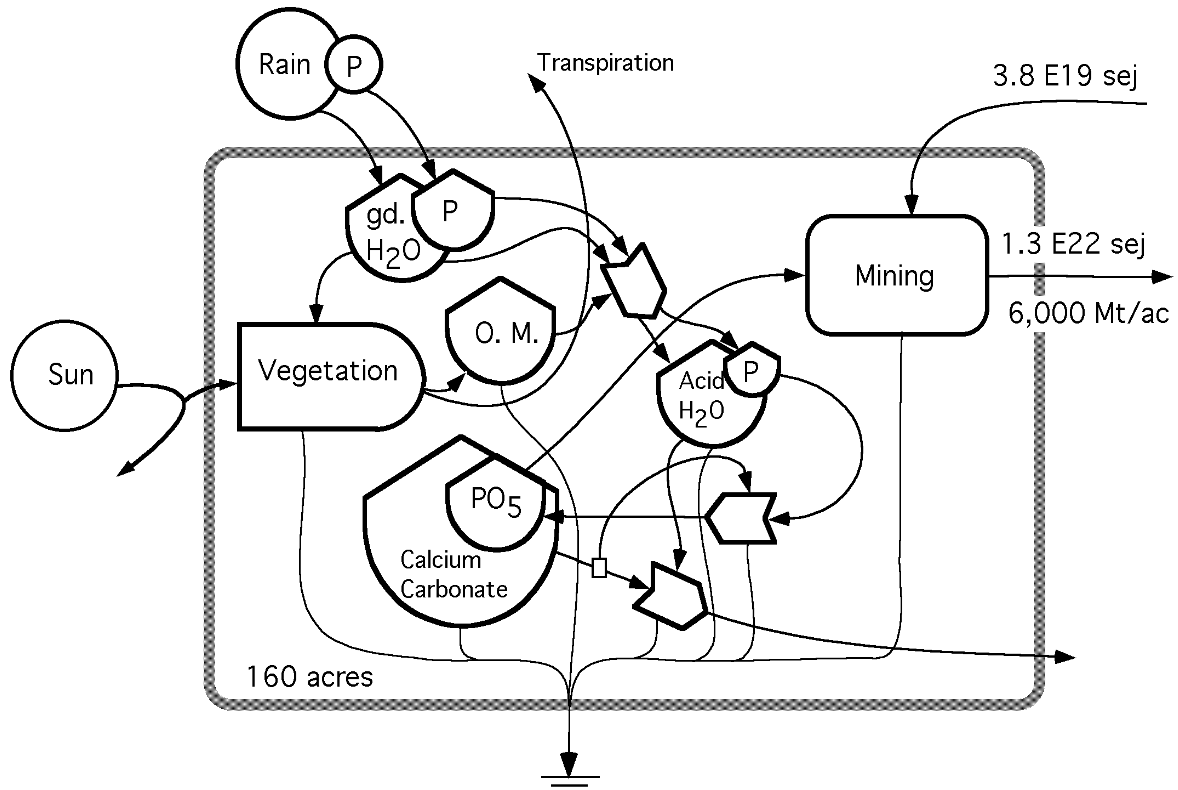
Emergy of Ecosystem Restoration…

Phosphate Mining



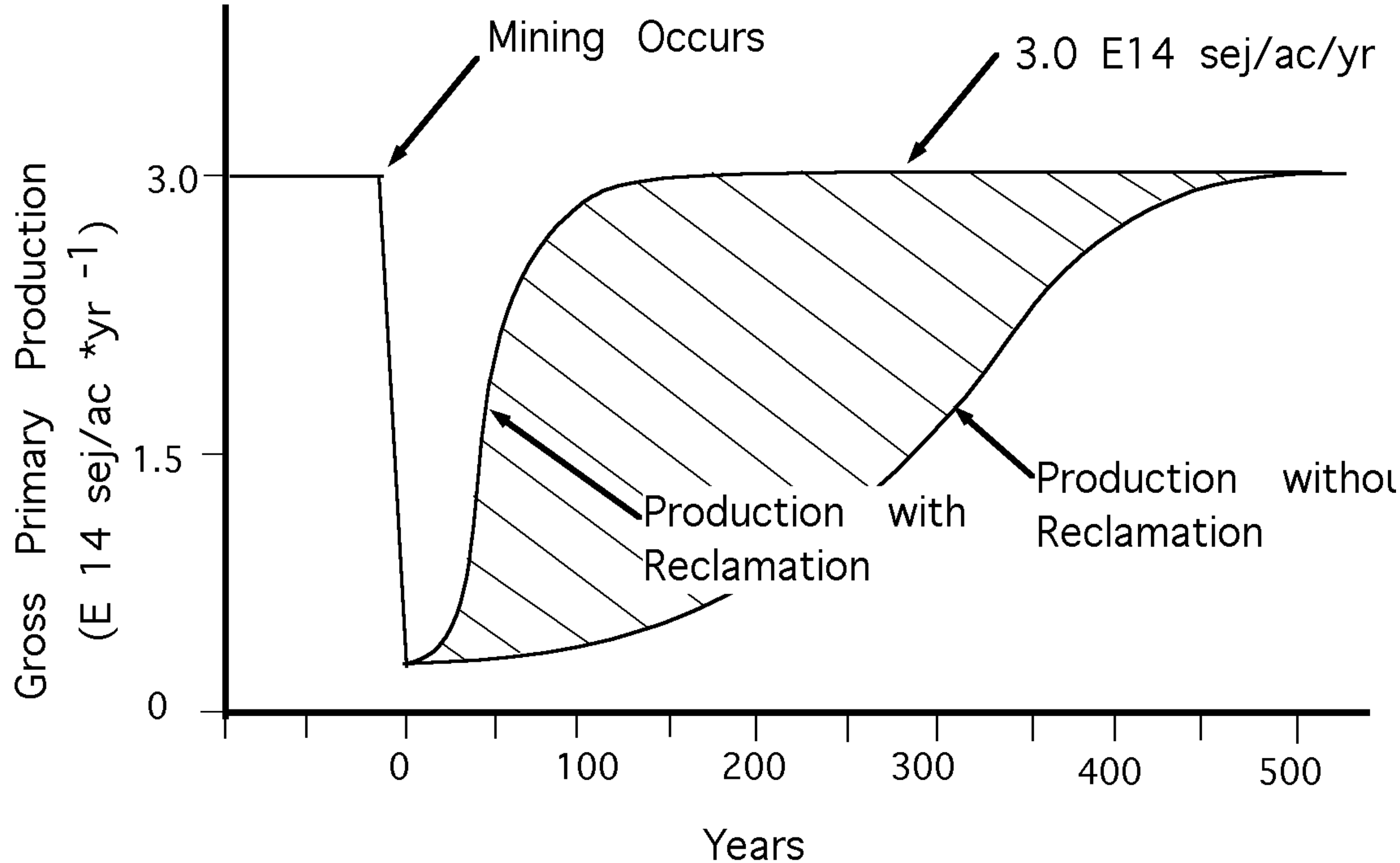
Emergy of Ecosystem Restoration…

Phosphate Mining



Emergy of Ecosystem Restoration…

Phosphate Mining



[e]fforts by economists and others have been made in the last two decades to “internalize the externalities” or to modify market valuation to give more consideration to ecosystems.

What is needed is the reverse: to “externalize the internalities” to put the contributions of the economy on the same basis as the work of the environment. We suggest that the best way to do this is to use one kind of energy [emergy] as the common denominator.

Odum, H. T., and E. P. Odum. 2000. The energetic basis for valuation of ecosystem services. Ecosystems **3:**21–23.

Questions?