8

EMERGY Evaluation of Florida Salt Marsh and Its Contribution to Economic Wealth

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In this chapter, data on salt marshes typical of northwest Florida were used to estimate the contributions of marsh production and storage to real wealth using EMERGY (spelled with an "M"), a scientific measure of environmental work (Odum, 1986, 1988). Then, for perspective, the part of the regional economic buying power due to the EMERGY of marsh productivity is estimated by proportion. The contribution of marshes is evaluated for Cedar Key, Florida, and its surroundings, Levy County (Figure 8.1).

Money is paid only to people, not to nature. As money circulates, it facilitates human purchase of real wealth such as fuels, food, houses, books, etc. (Figure 8.2). The real wealth comes from environmental resources, some renewable (e.g., sun, wind, and waves) and some nonrenewable (in the short run) (e.g., oil, minerals, and virgin forest wood). To measure the real wealth, a scientific measure was proposed in 1967 (Odum, 1967, 1971), subsequently revised to include geologic processes, and given the name EMERGY in 1983.

Definitions

Solar EMERGY

In Figure 8.2, environmental production (salt marsh example) is connected to an economic use (economic production) process. Money, shown with a dashed

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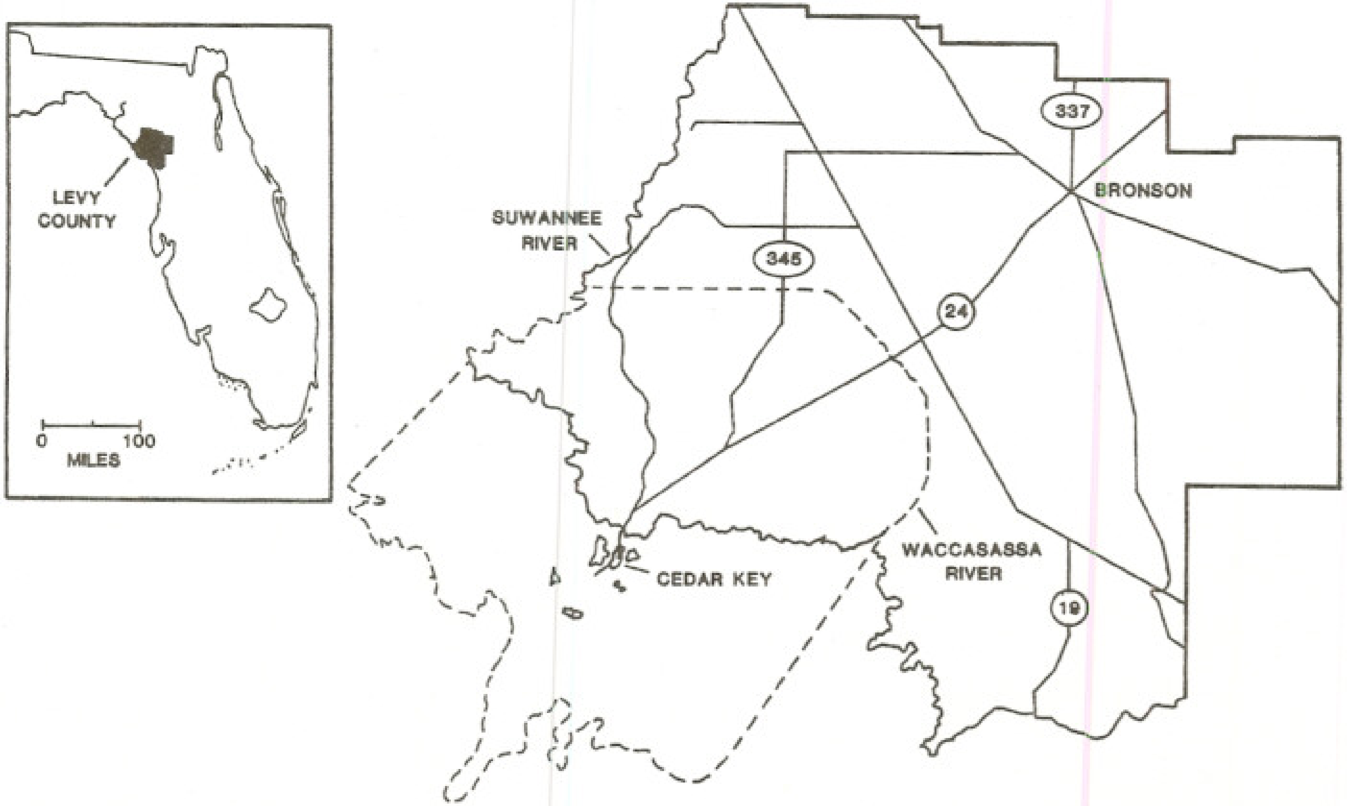

Figure 8.1 Area of land and water used for EMERGY evaluation of Levy County (encircled by the dashed line).

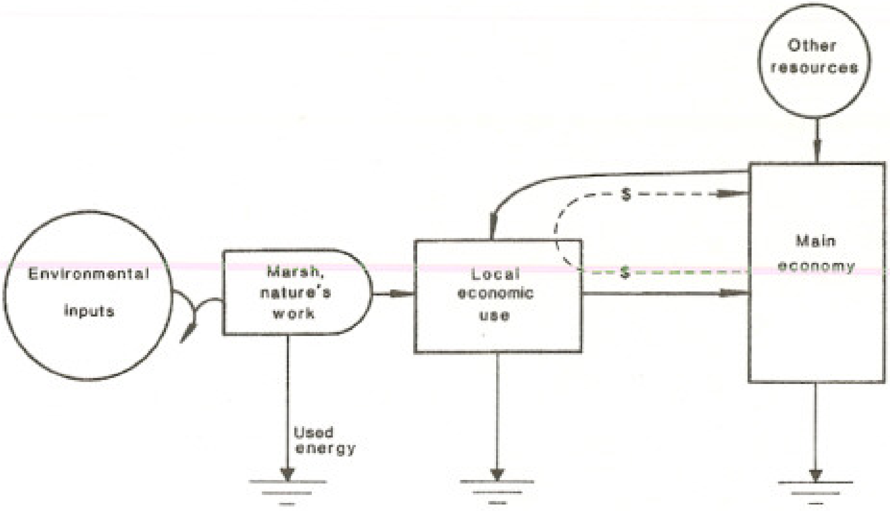

Figure 8.2 Energy diagram of an environmental system and its economic interface. Money flow is shown with a dashed line.

line, circulates as a counter current to the real items it purchases (example: fish landed by fishermen). Money is only paid for the human services. Services of nature come from many kinds of energy inputs to the salt marsh, including solar energy, wind energy, tidal energy, and the Gibbs free energy of rain and fresh water relative to salt water. The contribution from the salt marsh is measured by expressing all its inputs in the energy of one kind, the solar energy required to make each of the other kinds of energy input. The previously processed solar energy required for an input is its solar EMERGY.

> Solar EMERGY is defined as the solar energy previously required for all the inputs necessary to make a product and is expressed as solar emjoules.

EMERGY measures both the products of nature and the goods and services of the human economy on a similar basis (energy of one type required). Decisions that maximize the EMERGY of the combined economy of humans and nature lead to more real wealth, more buying power for the circulating currency, and the highest standard of living. Maximum EMERGY use comes from using the local environment and the purchased inputs in a symbiotic way.

Joules of sunlight, waves, oil, electricity, zooplankton, whales, and human beings cannot be compared as equivalent until they are expressed in equivalents of one kind of EMERGY required. Here, as in previous papers, all energy flows or storages that are to be compared are represented in solar EMERGY (solar energy required to make the product). Calculations are facilitated by tables of solar transformity.

Solar Transformity

> Solar transformity is the solar energy required for one unit of another kind of energy and is expressed as solar emjoules per joule.

Tables of solar transformities (solar emjoules per joule) have been developed from previous EMERGY evaluations that sum the required inputs to various processes in nature and in the economy. Where data on materials are more easily calculated in grams or human services in dollars, we use solar EMERGY per gram and solar EMERGY per dollar to compute the solar EMERGY.

Transformities express the position a product has in the energy hierarchy of nature. The more solar EMERGY required per joule, the higher position is the product. Products of higher transformity are scarce because they take more resources to make. Higher transformity products that are regularly produced have higher effects in use, which justifies their large resource requirement. Higher transformity items require larger territories of support and have larger areas of influence. Higher transformity items tend to be larger, with longer replacement times.

Tables of transformities have been assembled from prior EMERGY evaluations of environmental systems. The EMERGY evaluations of marsh in this chapter generate a new set of solar transformities for marsh components and processes. Transformities of principal components and processes of the marsh show the position of these elements in the natural energy hierarchy of the marsh and the biosphere.

Macroeconomic Dollar Value for Public Policy Decisions

> Macroeconomic dollar value of a product is defined as the dollars of the gross economic product based on the EMERGY of that product. Macroeconomic value is that proportion of the dollars of gross economic product that the total EMERGY is of the total annual EMERGY.

Microeconomic Market Value vs. EMERGY-Based Macroeconomic Value

Since money is not paid to nature for its work processes, its contribution is not measured by payments of money. When environmental resources are abundant, they contribute most to wealth and a high standard of living, but this is when they are valued least by costs, prices, and market values. When resources (such as fisheries) become scarce, their costs and prices go up, so that as much of the real wealth of the economy is going into obtaining them as is yielded to the economy from nature. This is when the contribution to real wealth is least but the economic values are highest. Thus, market values and real wealth measured by EMERGY are inverse. It is incorrect to use market value to measure the contribution to wealth of environmental resources or the impacts on environment.

Previous Evaluations of Marsh

A number of preliminary evaluations have been made of the value of marshes using energy and productivity data. Leitch and Ekstrom (1989) provide an annotated entrance to a large body of literature. Lynne et al. (1981) and Bell (1989) use economic methods to evaluate marsh, all of which directly and indirectly evaluate the flow of money to people using marshes or their products. Lynne et al. (1981) used the labor substitution that would produce the same dollars of fishing income to evaluate the economic value of fishes based on marsh–estuarine nurseries. Bell (1989) extended these methods, finding $35.61 to be the economic value of the fish contributed by 1 acre of coastal wetland. (See further discussion by Bell and Lynne in Chapter 9.) Bergstrom et al. (1990) estimated annual economic value of recreational use of wetlands in Louisiana. Some of the previous estimates of value are given in Table 8.1.

Starting in 1967 and 1971, the authors and associates, while measuring the production processes of ecosystems, used measures of nature's work to evaluate the contribution of ecosystems to the economy. Several of these methods were compared by Gosselink et al. (1974). Wetlands were evaluated in 1978. Farber and Costanza (1987), followed by Turner et al. (1988), evaluated marshes using one of our methods: multiplying marsh production energy by an estimated coal equivalent per unit energy and then dividing by the coal equivalents per dollar for the U.S. economy. These results were compared with market values (Table 8.1).

In another approach, concepts were defined more rigorously in 1983, introducing the terms EMERGY and transformity for previous terms embodied by energy and energy transformational quotient. This clarification was ambiguous because of the use of these terms by others with different meanings (Odum, 1986, 1988, 1996).

Considerable confusion in environmental evaluation comes from mixing the two different kinds of measures: one the value to humans individually and their businesses and the other the value to the public economy as a whole. The measures in this chapter evaluate nature's work and human work on a similar

Table 8.1 Comparison of Estimates of Salt Marsh Value

Items	*Annual $/ha/year*
Economic value (market values, willingness to pay)	
Goldstein (1971) conversion to agriculture	0
Gosselink et al. (1974); fishery sales	
Georgia	270
Florida	188
Louisiana	120
Reimold et al. (1980); duck support	100
Farber and Costanza (1987)	85
Bell (1989)	89
Bergstrom et al. (1990); recreation in Louisiana marshes	89.4
EMERGY-derived "macroeconomic value"	
Odum (1978a)	500
Farber and Costanza (1987)	1560
Turner et al. (1988)	889
Florida west coast, Tables 8.2 and 8.3	
Spartina marsh	660
Juncus marsh	743

basis, and the dollar value of the product to the public economy is then inferred from the proportional part of the economy contributed by these previous works. There is no intent to use the EMERGY-derived value in place of microeconomic market values.

Methods

For evaluating salt marshes, analyses were made at two scales: (1) for a hectare of typical marsh and (2) for an overview of a coastal region in which salt marshes were contributing (Cedar Key, Levy County, Florida).

Energy Systems Diagram

For EMERGY analysis, a systems diagram was developed first to organize knowledge of the main parts and processes to be evaluated. The salt marsh diagram is Figure 8.3 and the coastal economy diagram is Figure 8.4. A more detailed systems diagram showing more parts and processes of the marsh is given in the Introduction.

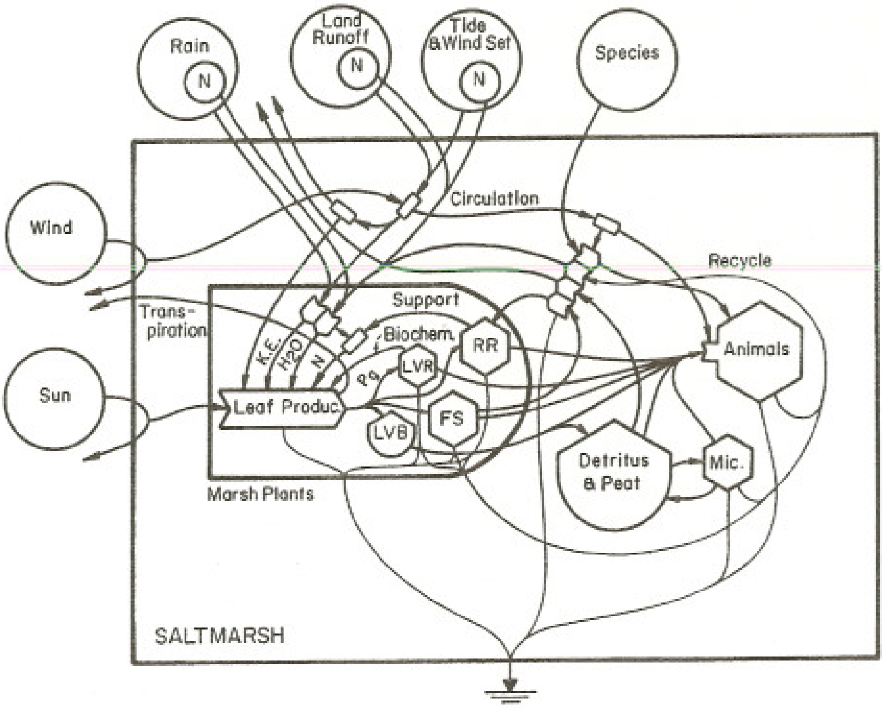

Figure 8.3 Energy systems diagram of a salt marsh showing the input sources evaluated in Table 8.2, storages evaluated in Table 8.3, and the pathways with transformity determinations in Table 8.4. Abbreviations: Biochem., flow of biochemical substances; FS, flowers and seeds; H_2O, water; K.E., kinetic energy of water motion; LVB, leaf biomass; LVR, leaf respiration; Mic., microbes; N, nutrients; Pg, gross photosynthesis; RR, runners and roots.

Procedure for Computing an EMERGY Analysis Table

Next, an EMERGY analysis table was prepared evaluating the main input sources and other flows of interest. The first example is Table 8.2, an evaluation of annual EMERGY flows of the marsh system drawn in Figure 8.3. Table 8.3 is the EMERGY evaluation of the main stored quantities of the marsh, those components that have replacement times longer than a year.

Each line item in the EMERGY table is a process or storage in an environmental system. The table includes the processes of nature and those of the economy. EMERGY analysis puts both the works of nature and those of humans on a common basis.

The first column indicates the number of the footnote where each calculation is shown. The next column lists the items. The next column gives the raw

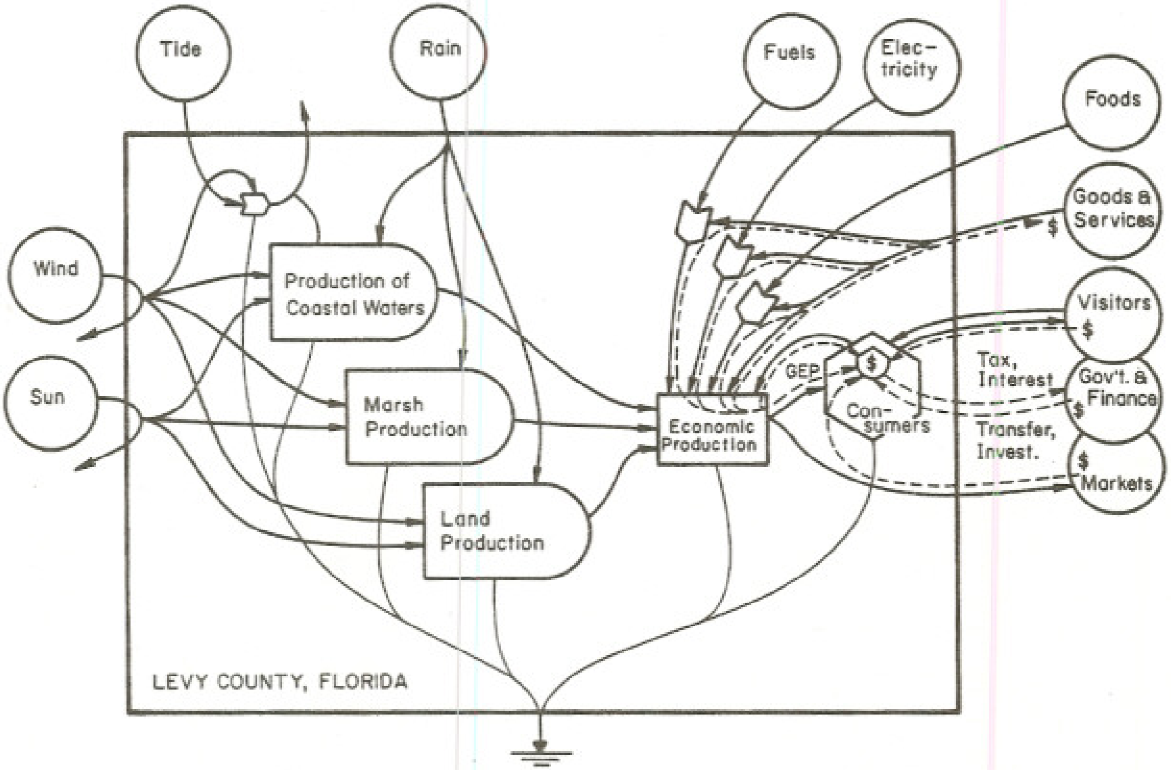

Figure 8.4 Energy systems diagram of the regional system of environment and nature in Figure 8.1. Dashed lines are flows of money.

Table 8.2 Annual EMERGY of Inputs to Salt Marsh in Northwest Florida (Figure 8.3)[a]

Note	*Item, units*	*Data (joules, J)*	*Solar transformity (sej/J)*	*Solar EMERGY E14 (sej/year)*	*Macroeconomic 1990 $/year*[b]
	Spartina marsh:				
1	Direct sun, J	5.95 E13	1	0.6	30
2	Tidal absorption, J	1.41 E10	23,564	3.3	165
3	Transpiration,[c] J	5.48 E10	18,000	9.9	495
4	Total (omitting #1)[d]			13.2	660
	Juncus marsh:				
5	Direct sun, J	5.95 E13	1	0.6	30
6	Tidal absorption, J	0.7 E10	23,564	1.65	83
7	Transpiration,[c] J	7.3 E10	18,000	13.2	660
8	Total (omitting #5)[d]			14.85	743

[a] 1 ha.

[b] 1990 U.S. $ obtained by dividing annual EMERGY values by 2.0 E12 sej/1990 $.

[c] Marsh transpiration, which is the fresh water used, includes that flowing in from land runoff and that exchanging in from the seaside of the marsh. Transpiration integrates the combined energy inputs of insolation, wind energy absorbed, vapor pressure gradients in air, and freshwater activity in the estuarine waters.

[d] Totals were corrected for double counting of sunlight which contributes to the world weather system that brings rain (separate evaluation not counted).

1 Gainesville insolation with 10% albedo: (1.58 E6 kcal/m^2/year) (1 – 0.10) (1 E4 m^2/ha) (4186 J/kcal) = 5.95 E13 J/ha/year.

2 Half of 80-cm tide absorbed: (0.50) (1.0 E4 m^2) (0.5×0.8 m) (1025 kg/m^3) (9.8 m/sec^2) (705 tides/year) = 1.41 E10 J/year.

3 Marsh transpiration: 3.0 mm/day ? for 365 days = 1095 mm (1.095 m) (1.0 E4 m^2) (1 E6 g/m^3) (5 J/g) = 5.475 E10 J/year.

4 Sum of #2 and #3.

5 Same as #1.

6 One-fourth of 80-cm tide absorbed: (0.25) (1.0 E4 m^2) (0.5×0.8 m) (1025 kg/m^3) (9.8 m/sec^2) (705 tides/year) = 0.7 E10 J/year.

7 Marsh transpiration: 4.0 mm/day ? for 365 days = 1460 mm (1.46 m) (1.0 E4 m^2) (1 E6 g/m^3) (5 J/g) = 7.3 E10 J/year.

8 Sum of #6 and #7.

Table 8.3 Evaluation of EMERGY Stored in Typical Salt Marsh of Northwest Florida[a,b]

Note	Item, units	Data (joules, J)	Solar transformity[c] (sej/J)	Solar EMERGY E14 (sej)	Em dollar × 1000[d]
Spartina marsh[b]					
1	Aboveground live biomass	0.78 E11	8,461	6.6	0.33
2	Aboveground dead biomass	0.51 E11	12,941	11.7	0.66
3	Detritus and peat, 1.14 m	496.00 E11	8,000	3,968.0	198.40
4	Total			3,986.3	199.39
Juncus marsh[b]					
5	Aboveground live biomass	1.86 E11	8,010	14.9	0.75
6	Underground marsh biomass	7.70 E11	9,867	76.0	3.80
7	Aboveground dead biomass	1.17 E11	10,132	11.9	0.60
8	Peaty sediment, 1.0 m	338.00 E11	13,185	4,456.5	222.83
9	Total			4,559.3	227.98
10	Fishes, crabs, shrimp	17.7 E6	2.7 E8	47.8	2.39
11	Tidal channel structure	9.8 E6	1.68 E9	164.6	8.23

[a] 1 ha.

[b] Hornbeck and Odum, Chapter 8 in this book.

[c] Table 8.4.

[d] 1990 U.S. $ obtained by dividing annual EMERGY values by 2.0 E12 sej/1990 $.

1 Aboveground live biomass: 463 dry g/m^2 (463 g/m^2) (1 E4 m^2) (4 kcal/g) (4186 J/kcal) = 7.75 E10 J/m^2.

2 Aboveground dead biomass: 307 dry g/m^2 (307 g/m^2) (4 kcal/g) (4186 J/kcal) (1/year) (1 E4 m^2/ha) = 5.1 E10 J/ha.

3 Energy in detritus and peat with data on organic carbon fraction in 4 levels (1.14-m total) of *Spartina* soil in Apalachee Bay (Coultas and Gross, 1975): (0.16 C × 0.18 m) + (0.136 C × 0.46 m) + (0.135 C × 0.25 m) + (0.116 C × 0.25 m)/1.14 m = 0.135 C; (0.135 C) (1.14 m^3/m^2) (0.7 E6 dry g/m^3) (11 kcal/g C) (4186 J/kcal) (1 E4 m^2/ha) = 4.96 E13 J/ha.

4 Sum of #1–3.

5 Aboveground live biomass: 1111 dry g/m^2 (1111 g/m^2) (4 kcal/g) (4186 J/kcal) (1/year) (1 E4 m^2/ha) = 1.86 E11 J/ha.

6 Underground biomass: 4600 dry g/m^2 (Kruczynski et al., 1978): (4600 g/m^2) (4 kcal/g) (4186 J/kcal) (1 E4 m^2/ha) = 7.7 E11 J/ha.

7 Aboveground dead biomass: 880 dry g/m^2 (880 g/m^2) (4 kcal/g) (4186 J/kcal) (1/year) (1 E4 m^2/ha) = 1.17 E11 J/ha.

8 Peaty sediment, 1-m thick: 10.5% organic carbon (Coultas and Calhoun, 1976) (0.105) (1 E4 m^3/ha) (0.7 E6 g/m^3) (11 kcal/g C) (4186 J/kcal) = 3.38 E13 J/ha.

9 Sum of #5–8.

Table 8.3 (continued) Evaluation of EMERGY Stored in Typical Salt Marsh of Northwest Florida[a,b]

10 Larger nekton in tidal channels: 5.3 g preserved wt/m^2 of channels (Homer, 1977); channels occupying 10% of the marsh area: (5.3 g/m^2) (0.1) (1 E4 m^3/ha) (0.2 dry) (4 kcal/g) (4186 J/kcal) = 17.7 E6 J.

11 Tidal channels covering 10% ? of area; work of excavation: (0.1) (1 E4 m^2/ha) (1 m) (1000 kg/m^3) (0.5 m) (9.8 m/sec^2) = 9.8 E6 J/ha.

data in joules, grams, or dollars. The fourth column gives the solar transformities from previous studies (the solar emjoules per joule, solar emjoules per gram, or solar emjoules per dollar). In the fifth column, the raw data in column 4 are multiplied by the transformities in column 5 to obtain the solar EMERGY values. Finally, some perspective is provided by expressing the EMERGY as the part of the gross economic product due to that wealth. This is done by dividing the solar EMERGY values in column 5 by the ratio of solar EMERGY per dollar previously determined by analysis of the state economy for a particular year. As explained in a later section, EMERGY-based evaluation of dollars due to a resource should not be confused with or substituted for regular economic market values.

Some of the line items in the table may include other items in the table, but care has been taken to avoid double counting in the lines which are totals. By evaluating the source inputs, crossing the boundaries of the hectare of marsh, we obtain the total EMERGY, which is operating the marsh ecosystem. After minor corrections to prevent double counting, the solar EMERGY inputs used by the ecosystem are summed. For the *Spartina* marsh found closest to open water and inundated by tide and wind-set more often, 50% of the tidal energy was estimated to be absorbed. For the *Juncus* marsh, usually further from the open water and inundated less often, 25% of the tidal energy was estimated to be absorbed.

After the calculations are made, various items are summed or ratios calculated to provide insights on the contributions of the environment to the wealth of the economy. In this chapter, the solar EMERGY contributions of the salt marshes were related to the total economy of Cedar Key and Levy County, Florida.

Procedure for Calculating a Table of Solar Transformities for Marshes

Having evaluated the total annual EMERGY basis for salt marshes, solar transformities were obtained by dividing the proportion of the total marsh

EMERGY budget by the energy of the component process or product produced for the same time. For some marsh products, such as total gross production, it is appropriate to use the total annual EMERGY budget. For some components of the marsh, it is appropriate to use only a part of the total annual EMERGY budget, namely that part of the energy at the same hierarchical level due to the component. The transformities are as good as the data on energy flow through the marsh ecosystem food web, usually represented in an evaluated energy diagram or equivalent table. Details of assumptions and calculations were given in the footnotes to the transformity table.

Procedure for EMERGY Evaluation of a Coastal Region

The main inputs to the combined economy of nature and humans were recognized in diagramming. Figure 8.4 represents three environmental areas (coastal waters, salt marshes, and terrestrial ecosystems) from Figure 8.1 and the monied economy. An EMERGY analysis table was prepared including main solar EMERGY inputs from the three environmental areas.

For the purchased inputs, goods and services purchased from outside the county were estimated by comparing the proportions of income for various sectors with the average proportions to support normal consumers. That income for a sector in greater proportion than normal consumer economy was inferred to be from export.

The solar EMERGY budget for Florida was previously estimated (Odum et al., 1993), and from this a solar EMERGY/GNP $ ratio was estimated for 1983 as 5.4 E12 sej/$, more than twice that for the United States as a whole in 1983 (2.4 E12 sej/$) (Odum et al., 1987). The money circulating in for exports was assumed to purchase goods and services from outside (Figure 8.4). These dollar figures multiplied by the Floridian EMERGY/$ ratio provided an estimate of the EMERGY of the goods and services, including human services, exported. The purchases made from outside bring in goods and services, which are evaluated using the EMERGY/$ ratio of the U.S. The solar EMERGY equivalent of the fuels and electricity itself (different from the services involved) was obtained from data on their use and multiplied by appropriate solar transformities to obtain solar EMERGY uses.

Results

EMERGY analysis results include Tables 8.2 to 8.4 for salt marsh and Table 8.5 for the coastal economy.

Table 8.4 Solar Transformities of Components and Processes of Salt Marsh

Note	*Item*	*Solar EMERGY (sej)*	*Energy (J)*	*Solar transformity*[a,b] *(sej/J)*
PROCESSES, replacement times <1 year				
1	Solar insolation	—	—	1
Spartina:			13.2 E14	
2	Gross photosynthesis		2.85 E11	4,280
3	Day net photosynthesis		1.47 E11	8,979
4	24-hr net photosynthesis		2.62 E11	5,038
5	Aboveground live biomass		0.78 E11	8,461
6	Peaty sediment		1.65 E11	8,000
7	Aboveground dead biomass		0.51 E11	12,941
8	Annual detritus production		2.5 E10	52,800
9	Detritus export		1.26 E10	104,761
Juncus:			14.9 E14	
10	Gross photosynthesis		6.1 E11	2,442
11	Day net photosynthesis		3.9 E11	3,820
12	24-hr net photosynthesis		1.91 E11	7,801
13	Aboveground live biomass		1.86 E11	8,010
14	Underground organic matter		1.54 E11	9,867
15	Aboveground dead biomass		1.47 E11	10,132
16	Detritus production		1.17 E11	12,735
17	Peaty sediment		1.13 E11	13,185
18	Fishes, crabs, shrimp	3.8 E15	2.74 E8	1.38 E7
19	Tidal channel landform	1.65 E16	9.8 E6	1.68 E9

[a] Quotient of two previous columns (solar EMERGY/energy).

[b] Solar transformities based on world energy flows (Odum et al., 1983, 1987): average wind, 623; rain over continents (chemical purity), 18,000; tide absorbed, 23,664; land runoff, 48,459.

1 Unity by definition.

2–8 EMERGY, 13.2 E14 sej/ha/year from Table 8.2.

2 Energy in gross production: (2.33 g C/m^2/day) (8 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 2.85 E11 J/ha/year.

3 Energy in day net production: (1.21 g C/m^2/day) (8 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 1.47 E11 J/ha/year.

4 Energy in 24-hr net photosynthesis: (2.15 g C/m^2/day) (8 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 2.62 E11 J/ha/year.

5 Aboveground live biomass: 463 dry g/m^2, replacement time 1 year (463 g/m^2) (4 kcal/g) (4186 J/kcal) (1/year) (1 E4 m^2/ha) = 7.75 E10 J/ha/year.

Table 8.4 (continued) Solar Transformities of Components and Processes of Salt Marsh

6 Peaty sediment, 13.5% organic carbon in 1.14 m; see footnote #4 in Table 8.3, replacement time 300 years? (0.135 C) (1.14 m^3/m^2) (0.7 E6 dry g/m^3) (11 kcal/g C) (4186 J/kcal) (1 E4 m^2/ha)/300 year = 1.65 E11 J/ha/year.

7 Aboveground dead biomass: 307 dry g/m^2, replacement time 1 year (307 g/m^2) (4 kcal/g(4186 J/kcal) (1/year) (1 E4 m^2/ha) = 5.1 E10 J/ha/year.

8 Energy in detritus formation (0.15 g C/m^2/day) (11 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 2.5 E10 J/ha/year.

9 Energy in detritus export assuming half of that formed (0.075 g C/m^2/day) (11 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 1.26 E10 J/ha/year.

10–17 EMERGY, 14.9 E14 sej/ha/year from Table 8.2.

10 Energy in gross production: (5 g C/m^2/day) (8 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 6.11 E11 J/ha/year.

11 Energy in day net production: (3.2 g C/m^2/day) (8 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 3.9 E11 J/ha/year.

12 Energy in 24-hr net photosynthesis: (1.57 g C/m^2/day) (8 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 1.91 E11 J/ha/year.

13 Aboveground live biomass: 1111 dry g/m^2, replacement time 1 year (1111 g/m^2) (4 kcal/g) (4186 J/kcal) (1/year) (1 E4 m^2/ha) = 1.86 E11 J/ha/year.

14 Underground biomass: 4600 dry g/m^2 (Kruczynski et al., 1978); replacement time 5 years? (4600 g/m^2) (4 kcal/g) (4186 J/kcal) (1 E4 m^2/ha)/(5 year) = 3.8 E12 J/ha/year.

15 Aboveground dead biomass: 880 dry g/m^2, replacement time 1 year (880 g/m^2) (4 kcal/g) (4186 J/kcal) (1/year) (1 E4 m^2/ha) = 1.47 E11 J/ha/year.

16 Energy in underground and detritus annual net production: (0.7 g C/m^2/day) (11 kcal/g C) (4186 J/kcal) (365 days/year) (1 E4 m^2/ha) = 1.17 E11 J/ha/year.

17 Peaty sediment, 1 m thick: 10.5% organic carbon in 1.0 m, replacement time 300 years? (0.105 C) (1.0 m^3/m^2) (0.7 E6 dry g/m^3) (11 kcal/g C) (4186 J/kcal) (1 E4 m^2/ha)/300 year = 1.128 E11 J/ha/year.

18 Fish, crabs, and shrimp in and out of the marsh, 8.2 g preserved wt/m^2; 24-month replacement; food chain based on 5 g/m^2/day organic matter at start of consumer chain (Homer, 1977; Hall et al., 1986); transformity of base organic matter assumed 10,000 sej/J. EMERGY supporting the animals: (5 g/m^2/day) (365 days/year) (5 kcal/g) (4186 J/kcal) (1 E4 m^2/ha) (10,000 sej/J) = 3.8 E15 sej/m^2/year. Energy: (8.2 g/m^2/year) (0.2 dry) (4 kcal/g) (4186 J/kcal) (1 E4 m^2/ha) = 1.37 E8 J/ha/year.

19 Tidal channel landform if generated in 100 years (sedimentation and erosion). Half of tidal energy per marsh flooding-draining area (#2 in Table 8.2). EMERGY: (0.5) (100 year) (3.3 E14 sej/ha/year) = 1.65 E16 sej/ha. Energy of displacing mud, 1 m deep, 10% of area, 1000 kg/m^3 mud displaced, center of gravity 0.5 m: (0.1) (1 E4 m^2/ha) (1 m mean depth) (1000 kg/m^3) (0.5 m) (9.8 m/sec^2) = 9.8 E6 J/ha.

Table 8.5 Annual EMERGY of the Coastal Economy of Levy County, Florida (Figure 8.1)[a]

Note	*Item, units*	*Data*	*Solar EMERGY/unit (sej/unit)*	*Solar EMERGY E18 (sej/year)*	*Macroeconomic 1990 $ (million $/year)[b]*
	Coastal waters:				
1	Direct sun, J	4.44 E18	1	4.4	2.2
2	Tidal absorption, J	1.16 E15	23,564	27.3	13.6
3	Rain, J	4.1 E15	18,000	73.8	36.9
4	Runoff	6.0 E14	18,000	10.8	5.4
5	Total[c]			111.9	55.9
	Salt marshes:				
6	Direct sun, J	0.57 E18	1	0.57	0.29
7	Tidal absorption, J	2.69 E14	23,564	6.3	3.2
8	Transpiration, J	5.20 E14	18,000	9.4	4.7
9	Total[c]			15.7	7.9
	Land environment:				
10	Direct sun, J	3.57 E18	1	3.6	1.8
11	Transpiration, J	3.0 E15	18,000	54.0	27.0
12	Total[c]			57.6	28.8
13	Total of all environmental areas			185.2	92.6
	Human economy (1974):				
14	Electricity use, J	2.62 E13	1.59 E5	4.2	2.1
15	Gasoline use, J	1.49 E14	6.6 E4	98.3	49.2
16	Natural gas use, J	2.63 E12	4.8 E4	0.13	0.07
17	Goods and services, $	1.78 E6	5.8 E12	10.3	5.15
18	Total of the economy			112.9	56.52
19	Total environment and economy			298.1	149.12
20	Fisheries landed (1974)				
	Mullet, J	7.5 E11	5 E5?	0.37	0.19
	Game fish, J	3.1 E11	30 E6?	9.1	4.55
	Blue crabs, J	11.5 E11	4 E6?	4.65	2.3
	Total			14.1	7.0
	Fishery sales, 1974 $	5.63 E5	5.5 E12	3.1	1.55

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[a] Areas: coastal waters, 8.2 E8 m^2; marsh, 9.47 E7 m^2; land, 6.0 E8 m^2.

[b] 1990 U.S. $ obtained by dividing annual EMERGY values by 2.0 E12 sej/1990 $.

[c] Totals were corrected for double counting by omitting sunlight, which contributes to the world weather system that brings rain.

Table 8.5 (continued) Annual EMERGY of the Coastal Economy of Levy County, Florida (Figure 8.1)[a]

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1 Gainesville insolation, 1.58 E6 kcal/m^2/year, with 18% albedo: (1.58 E6 kcal/m^2/year) (1 – 0.18) (8.2 E8) (4186 J/kcal) = 4.45 E18 J/year.

2 Tidal absorption in coastal waters as 50% of tidal energy, 80-cm mean tide with half of amplitude for center of gravity: (8.2 E8 m^2) (0.5 × 0.8 m) (1025 kg/m^3) (9.8 m/sec^2) (0.5) (705 tides/year) = 1.16 E15 J/year.

3 Rain: 1.0 m ?; 5 J Gibbs free energy per gram relative to sea water (1.0 m/year) (8.2 E8 m^2) (1 E6 G/m^3) (5 J/g) = 4.1 E15.

4 Runoff estimated as 20% of land rain in #11: (0.2 m) (6.0 E8 m^2) (1 E6 g/m^3) (5 J/g) = 6.0 E14 J/year.

5 Sum of #2–4.

6 Gainesville insolation with 10% albedo: (1.58 E6 kcal/m^2/year) (1 – 0.10) (9.5 E7 m^2) (4186 J/kcal) = 5.67 E17 J/year.

7 All of 80-cm tide absorbed: (9.5 E7 m^2) (0.5 × 0.8 m) (1025 kg/m^3) (9.8 m/sec^2) (705 tides/year) = 2.68 E14 J/year.

8 Marsh transpiration: 3.0 mm/day for 365 days = 1095 mm (1.095 m) (9.5 E7 m^2) (1 E6 g/m^3) (5 J/g) = 5.20 E14 J/year.

9 Sum of #6 and #7.

10 Gainesville insolation with 10% albedo: (1.58 E6 kcal/m^2/year) (1 – 0.10) (6.0 E8) (4186 J/kcal) = 3.57 E18 J/year.

11 Transpiration as 80% of rainfall (1.0 m): (1.0 m) (6.0 E8 m^2) (1 E6 g/m^3) (5 J/g) = 3.0 E15 J/year.

12 Sum of #5, #9, and #12.

14 Electricity use: (83 E6 kWh/year/Levy County) (0.0876 area people/total people) (7.27 E6 kWh/year) (860 kcal/kWh) (4186 J/kcal) = 2.62 E13 J/year.

15 Gasoline: (11.2 E6 gal/year/county) (0.0876 population fraction) = 9.8 E5 gal/year; (9.8 E5 gal/year) (36,225 kcal/gal) (4186 J/kcal) = 1.49 E 14 J/year.

16 Natural gas per person, 1.87 E6 Btu/year (Florida Department of Administration, 1978): (1.87 E6 Btu/year) (1338 people) (1054 J/Btu) = 2.63 E12 J/year.

17 Money for purchases: the difference between transfer funds plus sales minus taxes: ($0.725 E6 + 2.278 E6 – 0.43 E6) = 2.573 E6 $/year. Goods and services estimated by subtracting prices paid for fuels from total money for purchase: (2.573 E6 – 0.786 E6) = 1.787 E6 $/year.

18 Sum of #14–17.

19 Sum of #12 and #18.

20 Catch ratios for Levy County in the period 1970–1972 from Prochaska and Cato (1975) were multiplied by total catches (Mathis et al., 1978). Mullet: 301 E6 fresh wt/year; 10% dry organic: (301 E6 g/year) (0.1) (6 kcal/g) (4186 J/kcal) = 7.5 E11 J/year. Game fish: 150 E6 fresh wt/year; 10% organic dry: (150 E6 g/year) (0.1) (5 kcal/g) (4186 J/kcal) = 3.1 E11 J/year. Blue crabs: 687 E6 g fresh wt/year; 8% organic dry: (687 E6 g/year) (0.08) (5 kcal/g) (4186 J/kcal) = 1.15 E12 J/year. Fishery sales multiplied by 5.5 sej/$ in 1974.

Solar Transformities for Salt Marsh Ecosystems

Table 8.4 presents solar transformities of some principal component processes and populations of the marsh, which were calculated by dividing their solar EMERGY share by their energy flow. The more successive transformations and stages of storage, the higher the transformity, as more and more resources are required per unit of energy transformed. Thus, transformities increase from sun to photosynthate to organic biomass to detritus to fishes, etc.

EMERGY Overview of Levy County

Table 8.5 is the overview EMERGY evaluation of the coastal county. Comparison of the total EMERGY from the marsh to the total for the county provides perspective on the importance of the marsh: about 9% of the environmental contributions and 5% of the total wealth of the county for 1974. With the coastal waters (grass flat, mud flat, and plankton ecosystems) and land ecosystems (forests, freshwater wetlands, successional ecosystems) included, environmental contributions as a whole were 62% of the annual county EMERGY value (7.9 million 1990 U.S. $) to the coastal economy.

Macroeconomic Value of a Hectare of Salt Marsh

In the last column of Tables 8.2 and 8.3, the annual EMERGY production of the marsh and other components of wealth was divided by the solar EMERGY/$ ratio of Florida to obtain the macroeconomic $ values. Direct studies of people making economic use of the marsh in fishing, for example, were not made, but a value of $89 in Table 8.1 may be appropriate and could be added.

Macroeconomic contributions of *Spartina* and *Juncus* marshes in Table 8.2—660 $/year/ha (264 $/year/acre) and 743 $/year/ha (297 $/year/acre)—were larger than was obtained from economic evaluations that measure only the services of humans (Table 8.1).

For Levy County as a whole, the macroeconomic value was 7.9 million 1990 U.S. $. In other words, the portion of the gross economic product due to environmental work supporting the economy, mostly indirectly, was $7.9 million/year.

EMERGY Investment Ratio Measure of Environmental Matching

In addition to the direct EMERGY contributions to the economy of nature and humans, environmental resources are the basis for attracting matching EMERGY from economic investment. Marshes and their fisheries attract fishing, tourists, human settlements for retirees, etc. Purchased EMERGY comes into a local economy as the electricity, fuels, goods and services, etc. (Figures 8.2 and 8.4). The ratio of the purchased EMERGY to the environmental EMERGY is called the EMERGY investment ratio. For Florida as a whole, as for the United States as a whole, the typical regional ratio is 7.0.

From Table 8.5 in Levy County in 1974, however, the ratio of purchased EMERGY to free environmental energy was 112.9/185.2 = 0.61, a lower value than the present state and national average. This means that economic activities in the Cedar Key area had more than usual environmental support, providing more opportunity for environmental waste absorption, aesthetics, and other natural services which in cities require payment and higher tax. Areas with lower investment ratio may be expected to continue economic growth relative to those with higher ratios. Certainly, Cedar Key has exhibited economic growth since 1974.

Ratio of Services to Environmental Contributions

Our EMERGY analysis procedure includes line items for regular economic values, and these are expressed in solar EMERGY units for comparison with the environmental EMERGY contributions. Measuring the degree of development and environmental loading is the ratio of human services to the environmental contribution, both expressed in EMERGY units (or macroeconomic $).

For example, from Table 8.1, $89/ha/year economic contribution (services) may be divided by $700/ha/year macroeconomic value from environment, which results in 0.127 (12.7%). Studies by Stellar (1976) and Sell (1977) had much higher human loading to mangroves in the Marco Island area of Florida.

Regional EMERGY Imports Attracted by Environmental Contributions

In one sense, the attracted EMERGY flows depend on the environmental ones, and thus all the EMERGY wealth can be attributed to the presence of the environmental resource in the sense that potential for economic matching is destroyed in proportion as the environmental resources are eliminated.

In this sense, a hectare of marsh had the macroeconomic value of its direct annual EMERGY contribution (Table 8.2), plus the economic matching according to the regional investment ratio at Cedar Key in 1974 (0.61), for a total of $12.7 million/year. If this value is divided by the area of marsh (9470 ha), the macroeconomic value that results is $1341 (1990 $)/ha/year.

The potential for growth due to the environmental value of the marsh in Levy County is the direct free contribution ($7.9 million) times the state EMERGY investment ratio (7.0), which is $55.3 million (1990 $)/year. Dividing by the area of marsh (9470 ha), the potential public value that depends on marshes is $5839/ha/year.

Public Policy, EMERGY Value, and Economic Value

Officials responsible for purchase of environmental lands have voiced concerns that EMERGY-based evaluation might be used for land appraisal in determining money to be paid to owners. This is a misconception. Market values concern the contributions of humans and their businesses, which are small values, because human services involved in utilizing environmental products and services are generally small compared to the large work in the environmental products and services themselves. It is wrong to pay individuals for the work of nature.

On the other hand, it is appropriate to consider the EMERGY-based macroeconomic dollars in deciding what the marsh is worth to the public good as compared with proposals for alternative use. Tax reductions so as to preserve marshes may be appropriately judged as some fraction of the macroeconomic dollar value.

A new trend in law, the public trust doctrine, is giving priority to the rights of the public to environmental values over rights to private property, and EMERGY evaluations are a means for quantitative implementation. One of our calculations was used to settle a court case on mangrove damage in south Florida in 1990.

As described by Johnston (1990), the public trust doctrine is

> an ancient, but rapidly expanding judicially-created doctrine that says: the public has an interest akin to an easement, which predates all private ownership for the protection of navigation, commerce, wildlife habitat, and kindred interests.

Mitigation

Laws and policies for environmental regulation now concern mitigation, the substitution of one environmental value for another. The EMERGY and transformity tables in this chapter provide ready means for judging equivalent values in salt marshes for comparison with other areas of nature and the economy. A set of similar tables for the main 10 to 20 types of ecosystem in Florida needs to be constructed. These and some procedural guidelines will constitute a mitigation manual.

Data Needs

Whereas EMERGY evaluations were herewith completed for marshes and a coastal county, a number of approximations and assumptions were made. The results can be made more precise with further measurements or location of other data. Among the data needs are time for deposition of 1 m of marsh–peaty soil, annual export of detritus and food extracted by nekton, rates of transpiration, and percentages of tidal energy absorbed in various coastal zones. With more data, some changes in transformities are to be expected, but probably not order of magnitude changes.

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