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The Emergy Analysis on Coastal Wetland Ecosystem of Chiku, Taiwan

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PREFACE

Wetlands are the kinds of ecosystems which have a high economical basic productivity; among those, lagoons (coastal wetlands) are primarily having net productivity higher than any other kinds of marine ecosystems. Chiku Coastal Wetland is the largest wetland in Taiwan. It is a complex ecosystem containing estuaries, littorals and wetlands. The ecosystem of a coastal wetland is not only rich in biodiversity and high productivity, but also having high ecological and economical values. Nevertheless, the land development and utilization have given a considerable impact to the coastal wetlands; those are sensitive to the environmental changes. According to the results of recent research, the Chiku Wetlands are facing problems such as shoreline retreat, lagoon shrinkage, and flora extinction. Therefore, it is very important to obtain a sufficient assessment for the ecological system of coastal wetlands.

AIMS

Scopes of this study were to quantitatively evaluate the economics of this coastal wetland ecological system as well as its emergy and material flux by using the emergy Analysis Theory of Odum (1987). In addition, the realization and estimation of the environmental stresses of the region have also been performed.

ABSTRACT

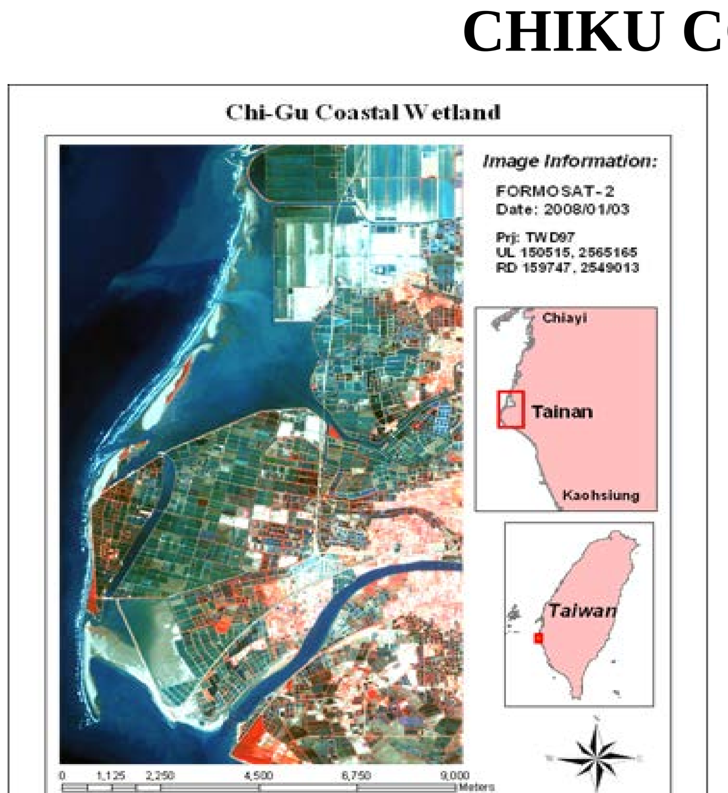
This study presents a quantitative evaluation for ecological benefits of the Chiku Coastal Wetland in Taiwan for the years from 2004 to 2008. Methods of Erergy Analysis were applied to illustrate the values of such wetland ecosystem via evaluation of the economics and environmental inputs, and its consequent yields as well as the assessment of sustainability for the Chiku Coastal Wetland. The indicators for the integrated ecological and economic system, such as emergy Yield Ratio (EYR=3.62), emergy Investment Ratio (EIR=4.30), Environmental Loading Ratio (ELR=4.59), emergy Exchange Ratio (EER=0.30), and emergy Sustainable Indicator (ESI=0.79) were all calculated, compared, analyzed, and discussed. The non-renewable investments in Chiku Coastal Wetland were greater than renewable investments, which leaded to an unsustainable development of the system. High EYR indicates that the Chiku Coastal Wetland, an integrated ecological system, had generated huge profits for the people living around it; while ELR and ESI revealed that human activities have been a heavy burden on the environment, and its countermeasures should be taken by the government agencies to relieve and resolve these problems.

METHODOLOGY

INRODUCTION

In this study, sustainability is discussed based on emergy. emergy is a form of energy analysis that quantifies values of natural and economic resources for a large-scale environmental support to the human economy. emergy is used as the principal conceptual tool for expressing the inter-relationship of energetic flows and quality of the resources, as well as for linking systems of the natural environment and human economy together. As a result, emergy analysis is a type of embodied energy analysis that can provide common units (emergy) for comparison of environmental and economic commodities by summing the energy of one type required directly or indirectly for production of such commodity.

CHIKU COASTAL WETLAND



- Area : 12,582 hectares
- Annual average temperature: 23.5 ˚ C
- Wind speed; 4.4 m / s
- Evaporation: 1903.5 mm
- Mean tidal range: 1 m
- Solar radiation：119.35kcal/cm^2
- Species：650 species

Fig.1 Location of Chiku Coastal Wetland

Table 1 The raw data of Chiku Coastal Wetland between 2004 to 2008.

	Rainfall (mm)	Vegetation Area (m^2)	Investment and Service ($$10^6$)	Aquaculture production (10^7kg)	Economic emergy Output ($$10^6$)	Fry, Feedstuff… ($$10^8$)
2004	1392.9	513849	3.59	1	0.98	2.97
2005	2947	462464	12.02	1	0.98	2.97
2006	1506	416218	5.34	1.04	1	2.98
2007	1813	374596	2.29	1.16	1.16	3.34
2008	1651.7	337136		1.14	1.36	3.95

EMERGY ANALYSIS

Scopes of this study are to quantitatively evaluate the economics of this coastal wetland ecological system as well as its emergy and material flux by using the emergy Analysis Theory of Odum (1987). In addition, the realization and estimation of the environmental stresses of the region will also be performed. The emergy assessment process for wetland ecological benefits include four steps such as:

(1) Construction of a conceptual model for the emergy analysis system;
(2) Draft out the emergy analysis table with the calculated emergy values;
(3) Estimation of emergy indices;
(4) Expatiation on wetland ecological benefits in accordance with the analytical tables of emergy indices system and the emergy schemes.

Table 2 Definitions of emergy analysis concepts.

Item	Definition
emergy	*Energy of a single type required directly and indirectly for transformation in order to generate a product or service.*
Solar emergy	*Solar energy required directly and indirectly to produce a product or service, with a unit of solar emjoules (sej).*
Transformity	*emergy per unit energy required for a given product or service in a system.*
Solar transformity	*Solar emergy per unit energy, with a unit of solar emjoules˙Joule^{-1} (sej˙J^{-1}).*
emergy per unit mass	*emergy of a single type required to generate a flow or storage of a unit mass of a material, with a unit of sej˙g.*
Empower	*emergy flow per unit time, usually per year, with a unit of sej˙y^{-1}.*
Solar empower	*Solar emergy flow per unit time, usually per year, with a unit of sej˙y^{-1}.*
Emergy / money ratio	*Ratio of emergy flow to money flow, commonly applied to a state or nation, calculated as annual emergy use divided by the value of the gross national product, with a unit of sej˙$\$^{-1}$.*

EMERGY EVALUATION INDICES

Diagramming is done with energy system symbols. Pathways may indicate clear interactions, show material cycles, or carry information, but always with some energy flow (Fig. 2); where some indices may be chosen to directly evaluate the relationship between economical and environmental subsystems：

- EYR=Y/F
- ESI=EYR/ELR
- EIR=F/(R+N)
- EER=F/O
- ELR=(N+F)/R

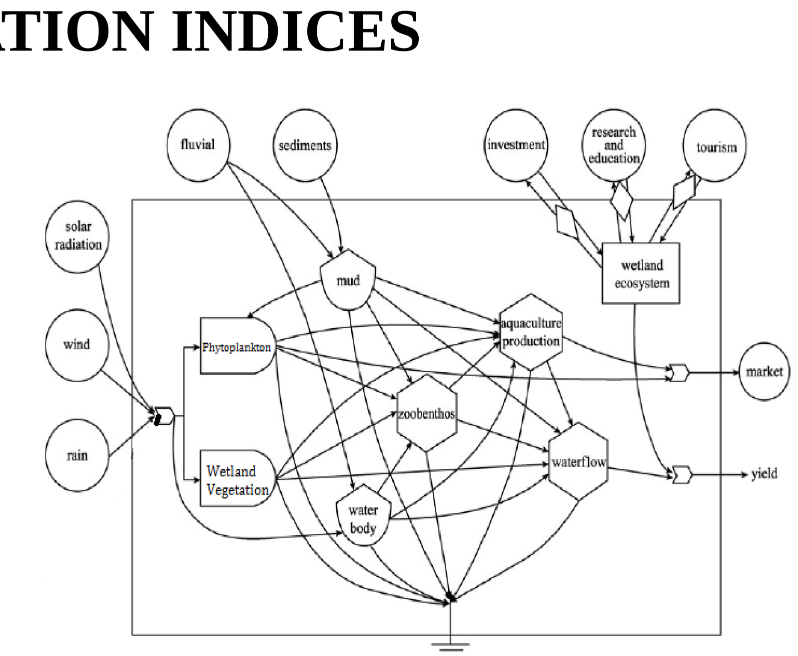


Fig. 2 Energy flow in Chiku Coastal Wetland ecosystem.

RESULTS and DISCUSSIONS

Table 3 emergy flow of the Chiku Coastal Wetland ecosystem.

2004-2008				
Item	Raw Data (J or \$)	Transformity (sej/Unit)	Solar emergy (10^{18}sej)	Emdollars (10^5\$)
Renewable sources/J				
Solar radiation	4.57×10^{17}	1	0.46	0.55
Wind	8.7×10^{17}	623	542	653
Rain chemical pot	1.19×10^{15}	15444	18	21.7
Energy of vaporization	5.35×10^{14}	15423	8.25	10
Total			568.71	685.25
Nonrenewable sources/J				
Mud	1.62×10^{15}	3509	5.7	6.9
Water	5.29×10^{14}	48000	25.4	30.6
Total			31.1	37.5
Economic feedback/\$				
Investment and service	3×10^{6}	8.3×10^{12}	24.9	30
Fry, feed stuff…	3.1×10^{8}	8.3×10^{12}	2573	3100
Total			2579.9	3130
emergy output				
Phytoplankton	5.87×10^{15}	4700	27.6	33
Wetland vegetation	0.92×10^{13}	1.47×10^{4}	0.14	1.7
Waterflow	1.36×10^{11}	1.03×10^{8}	14	16.87
Aquaculture production	5.25×10^{13}	1.29×10^{7}	677	816
Economic emergy output	1.04×10^{9}	8.3×10^{12}	8632	10400
Total			9350.74	11267.75

Note： Main source of the system uses 5% of the total energy.
emergy/money ratio is calculated as 8.3x1012 Sej /\$.

During 2004~2008, the average renewable resources within the Chiku Coastal Wetland from solar, rainfall and wind energy and emergy of non-renewable resources (mud, sediment, and water) are equal to 568.71 $x10^{18}$ sej and 31.1 $x10^{18}$ sej, respectively.

Compared with environmental input, social feedback input is much higher, with a value of 2579.9 $x10^{18}$ sej. The social feedback input mainly focuses on constructing fish ponds and infrastructures, investing in fish fry and feedstuff.

Of all kinds of emergy outputs, the emdollars of aquaculture show that Chiku Coastal Wetland is an important aquaculture production site which accounts for the highest emergy in this system — $10400x10^{5}$ \$. The second highest output is waterfowl emergy, with a value of $816x10^{5}$ \$, and which indicates that the Chiku Coastal Wetland is a vital habitat and reproduction location for many rare birds and waterfowls, which also are playing an important role in biodiversity.

Table 4 emergy indicators of Chiku Coastal Wetland ecosystem.

Name of index	Expression	Value
Renewable sources	R	568.71 $x10^{18}$ sej
Nonrenewable sources	N	31.1 $x10^{18}$ sej
Economic feedback	F	2579.9 $x10^{18}$ sej
Economic emergy output	O	8632 $x10^{18}$ sej
Total emergy output	Y	9350.74 $x10^{18}$ sej
Emergy yield ratio	EYR	3.62
Emergy investment ratio	EIR	4.30
Envionmental loading ratio	ELR	4.59
Emergy exchange ratio	EER	0.3
Emergy sustainable index	ESI	0.79

Emergy indicators (Table 4) were calculated by aggregating data from Table 3. These indicators, relating flows from the economy to flows of the environment, were used to compare net yields and environmental loading, and to evaluate the sustainability, as well as to identify more sufficient methods for sustainability.

- The net EYR of the area is about 3.62, which is regarded as comparatively high; namely, the greater the emergy yield ratio value is, the higher the eco-economic benefits are given by the wetland, as well as the higher economical contribution to the society.
- The ELR is about 4.59, which is also regarded as a comparatively high value. A main reason for this higher value is due to a great deal of development and investment were devoted to the aquaculture farming; the artificial wetlands, that results in high loading capacity for this regional environment.
- The EER is about 0.3, which nevertheless indicates that the local market price does not show the true values for the products of the wetland resources. Taking the emergy into consideration, the product of the wetland results in a greater loss in the economic system of the society.
- The emergy Sustainable Indices of Chiku Wetland is about 0.79, Ulgiata and Brown (1998) have stated ‘a system has vitality and potential to develop, while ESI is lower than 1’; thus, it indicates the system cannot be sustained.

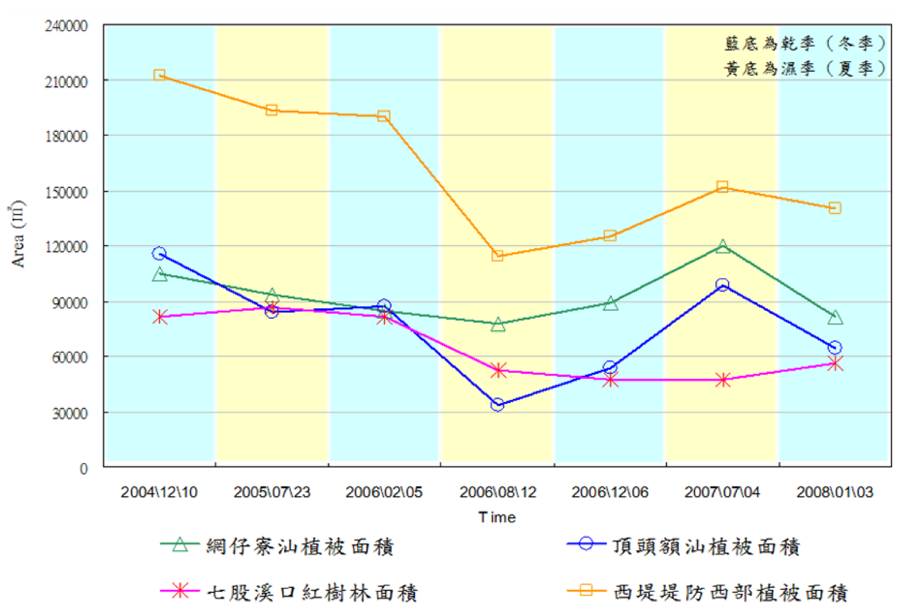


Fig.3 Spatial and temporal changes of Chiku Coastal Wetland vegetation area statistics.

- Even though with an increase of the terrestrial vegetation nearly a one third due to reduction during the monitoring period, it is because of that the watery areas were increasingly converted into habitats of aquatic organisms; namely, it has been leading to an increase of output for the overall emergy of this wetland system.

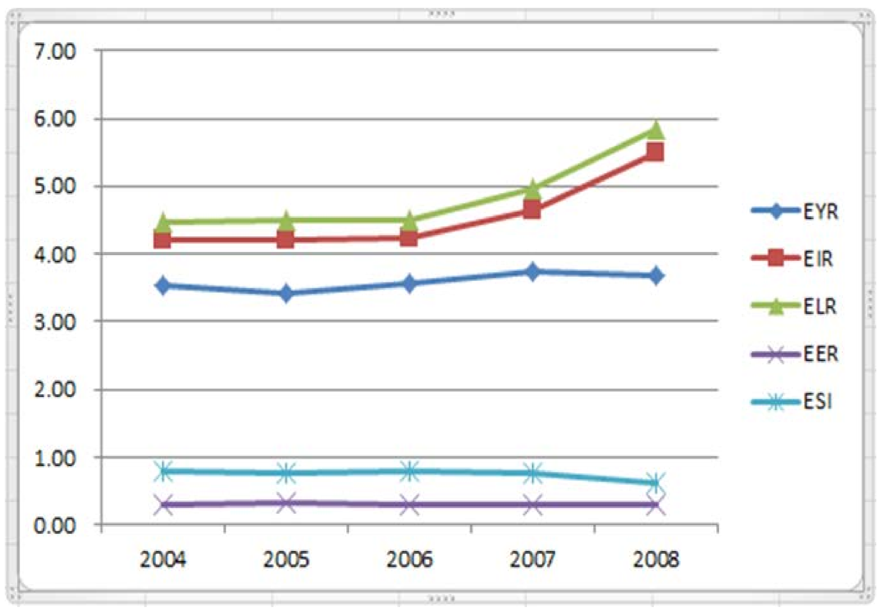


Fig. 4 The index change between 2004 to 2008.

	EYR	EIR	ELR	EER	ESI
2004	3.53	4.19	4.48	0.31	0.79
2005	3.43	4.21	4.49	0.32	0.76
2006	3.57	4.22	4.51	0.30	0.79
2007	3.73	4.66	4.97	0.29	0.75
2008	3.67	5.49	5.84	0.29	0.63

Table 5 The index change between 2004 to 2008.

According to Table 5 and Fig. 4, it is obvious that overall the indices have not much changes. However, in the year of 2007 and 2008; the ELR and EIR are showing an increasing trend, which is because of the typhoon disaster had led to a great loss of wetland economic in the above two years. Therefore, we were regarded that human activities and typhoons are the primary reason to caused higher ELR value in this area.

CONCLUSIONS

In Chiku Coastal Wetland, due to the development of aquaculture, the wetlands have shown a high output value, however, in relate to the environmental stresses, it is also high. Thus, it indicates that the system has a great deal of negative effect on the environment; namely, the wetland is in fact a deteriorating environment. The functions of the wetlands are also constantly degraded. Overall wetlands have given and unsustainable sign. It has been to much relying on the social investments; in order to maintain the ecological balance of wetlands.

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