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Review

Emergy Perspectives of Ecosystem Restoration in Korea

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Abstract : The emergy (spelled with an "m") concept was introduced to provide a new insight into ecosystem restoration efforts in Korea. The emergy is defined as the available energy of one kind previously required directly and indirectly to make a product or service. It is an effort to evaluate the true contributions of natural resources to our economy. It tries to include both contributions from natures free works and human services to develop and process natural resources. The emergy evaluation can be used to select a restoration alternative that yields more to the economy with less stress to the environment, by comparing different alternatives with indices expressed in emergy. It can also be used to assess the success of ecosystem restoration projects. Pulsing dynamics in which a slow build-up of production is followed by a frenzied consumption in relatively short time period seems to be a general feature of all systems. Any ecosystem restoration effort, therefore, should consider the whole pulsing cycle for a successful implementation.

Key words : ecosystem restoration, emergy, pulsing, hierarchy.

1. Introduction

Since the Industrial Revolution, the living standard of humans has increased through rapid growth of industrial economy based on intensive use of fossil fuels. Economic growth of human societies that requires continuous energy and material inputs from nature, however, has resulted in resource depletion and environmental degradation as by products of the growth.

Depletion of resources and deterioration of environment had restricted to areas where industrial activities were active in the early growth stage of the modern economy. They have now grown to a global scale, threatening the future prosperity of the human civilization. Recognizing the severity and scale of resource depletion and environmental degradation, recent efforts have been made to balance development and conservation to ensure sustainable society into the future.

In these efforts, however, the balance of development and conservation cannot be obtained without the sound evaluation of contribution of the natural environment to an economy. A more holistic approach in evaluating the contribution of environmental resources to our economy is also needed in an age of diminishing resources, not a reductionistic one that evaluates processes and components of a system separately.

Ecosystem restoration is an effort to sustain and restore valuable contributions of natural ecosystems to our economy. This paper introduces an emergy concept which is an holistic approach in valuing nature and can provide a new insight into ecosystem restoration efforts in Korea.

2. Valuation of ecosystem contributions

During the period of rapid economic growth, natural ecosystems have been treated as objects to yield economic benefits expressed only in terms of money. Value of ecosystems has, therefore, been judged as the size of the economic benefits that could be obtained from those systems. Reclamation of tidal flats in Korea, once considered as useless lands except for some fishery products, is a typical example of the conception we have had on natural ecosystems. It has been considered that the contribution of the tidal flats to our economy would increase through reclamation that provides lands for agriculture and industry.

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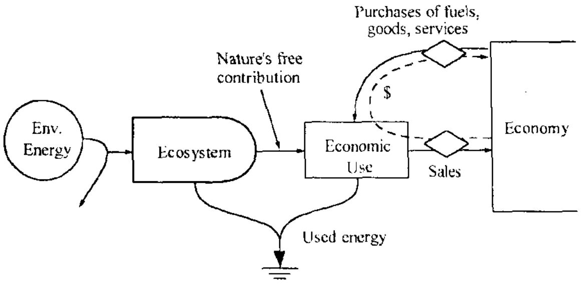


Fig. 1. Diagram of environmental production and its economic interface. The economy does not reinforce environmental production in this diagram. Money flow is shown in a dashed line.

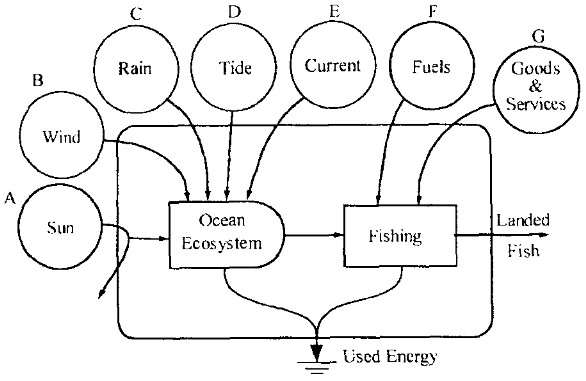
As in fig. 1 that shows the use of a natural ecosystem by an economic system, money is only paid to services provided by humans. Products and services of nature are nature's free inputs to the economy. Money paid for human services to develop and process resources from ecosystems cannot represent the real wealth contribution of ecosystem resources (Odum 1996).

Rather, market prices may be inversely related to the contribution of ecosystems to the real wealth of an economy (Odum 1996). When there are abundant resources available, the price of those resources is low, yet the economic system can produce many different commodities using the resources. As the amount of ecosystem resources decreases, their price increases, yet the real wealth contribution of resources decreases.

Recent studies have also revealed many beneficial functions of natural ecosystems as well, requiring new approaches in evaluating the contribution of ecosystems to an economy. Sound evaluation of ecosystem contributions to the economy is necessary to establish appropriate policies for sustainable economy and nature conservation.

The emergy concept, based on the assumption that the value of a resource is proportional to the energy required to produce it (Odum 1983, 1996), is an effort to evaluate the real wealth contribution of the natural ecosystems from a whole system perspective. Emergy is defined as "the available energy of one kind previously required directly and indirectly to make a product or service", and its unit is emjoule (Odum 1996).

The emergy evaluation tries to include both human services and nature's free contributions to the economy in fig. 1 in the evaluation of natural ecosystems. For example, the real value of marine products is the sum of human services that went into the development and processing of those products and works done by nature such as sun, wind, rain, tide, current, and so on (Fig. 2).



Emergy of landed fishes =
Sum of emergy of A + B + C + D + E + F + G

Fig. 2. A diagram showing the methodology for calculating emergy of a product in an ocean ecosystem.

Different types of energies have different abilities to do work. In the emergy evaluation, therefore, all energies are converted into a reference energy unit to compare them on a common basis. Solar energy is currently used as a common currency which other energies are converted into and compared with.

According to the emergy concept, solar energy and human energy have different quality. One joule of human energy is higher in quality than that of solar energy because human energy can do feedback controls and has wider area of influence. Many joules of solar energy are required to produce one joule of human energy through the network of energy transformation processes in ecosystems.

In the emergy evaluation, emergy values can be converted to more familiar monetary units, enabling comparisons between ecological processes and economic ones in monetary units. The emdollar value indicates the total amount of money circulating in an economy as a result of an emergy flow (Odum 1996). Emdollar values are calculated by dividing the emergy value of flows by the emergy money ratio for an economy, and their units are emdollars (em$). The emergy money ratio is calculated by dividing the total emergy used in an economy by the GDP of the economy.

Emergy evaluations on the natural environment and economy have provided many new perspectives on conservation and development controversies related to the natural environment (Odum 1996). Several previous studies in Korea have used the emergy concept to evaluate the environment and economy of Korea (Lee and Odum

1994), fisheries of Korea (Son *et al.* 1996), carrying capacity of fisheries of Korea (Eum *et al.* 1996), dam constructions (Kang and Park 1999a,b), cities (MOE 1996; Pusan 1998; Son 1999; Lee 1999; Kang 2001a), and a tidal flat ecosystem (Kang 2001b).

Odum and Hornbeck (1996) compared values of salt marshes calculated using emergy methodology and economic methodology. Salt marshes contributed $90-270/ha/yr in the economic analyses and $500-1560/ha/yr in the emergy evaluations to economy. The emergy evaluation that includes nature's free work in valuing natural resources showed higher contribution from natural ecosystems compared to the results from the economic analyses.

Engel *et al.* (1995) evaluated the values of ecosystem primary production in St. Lucie estuary in Florida, USA. The evaluation included three different types of estuarine ecosystems with a total area of 37.0 km^2: intertidal wetland ecosystem, planktonic ecosystem, and seagrass ecosystem.

The total value of primary production of the estuarine ecosystem was 5.1 million em$/yr, or 1,378 em$/ha/yr. The intertidal wetland ecosystem with an area of 14.7 km^2 contributed most with 4.4 million em$/yr, followed by the planktonic ecosystem (22.1 km^2) with 0.7 million em$/yr. The contribution of the seagrass ecosystem with an area of 0.2 km^2 was about 0.012 million em$/yr. The value of ecosystems per unit area was highest for the intertidal wetland ecosystem (2,993 em$/ha/yr), followed by the seagrass ecosystem (600 em$/ha/yr) and the planktonic ecosystem (317 em$/ha/yr).

The emergy evaluation of the southern Kangwha tidal flat, with a total area of 90 km^2, in Korea revealed the macroeconomic contribution of the ecosystem to the Korean economy to be 18,700 em$/ha/yr (recalculated from Kang 2001b). This value was higher than that (14,200 $/ha/yr) of Lee (1998) that was calculated for the entire tidal flat in Korea using an economic methodology.

The emergy reflects characteristics of a larger system that surrounds the system under consideration because it evaluates input energies from outside the given system (Odum 1996). The emergy evaluation, therefore, cannot be complete without knowledge on the larger system higher in the energy transformation hierarchy.

3. Emergy cost-benefit evaluation of ecosystem restoration

Degradation of natural ecosystems is a result of ecosystem uses without any feedback to sustain ecosystem structures, functions, and productivity, as represented in fig. 1. Excessive use of natural ecosystems and lack of feedback inputs from the economy to maintain ecosystem integrity have degraded natural ecosystems. Ecosystem restoration can be considered as a feedback mechanism to restore useful works of natural ecosystems to the human economy.

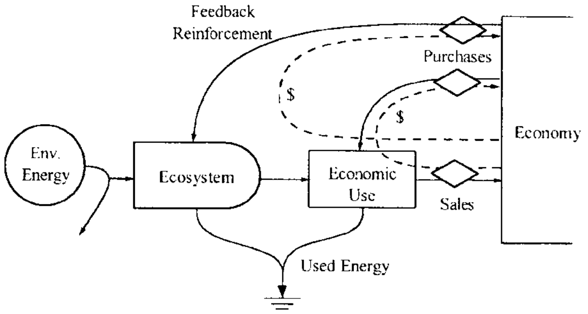
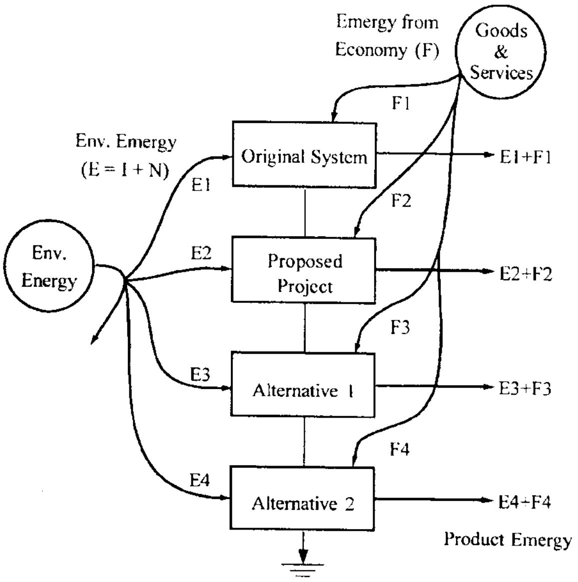


Fig. 3. Diagram of environmental production and its economic interface with a feedback flow from the economy to reinforce environmental production. Money flows are shown with dashed lines.

Fig. 3 illustrates this feedback concept of ecosystem restoration. Compared to fig. 1, a pathway that connects the main economic system and the natural ecosystem is added in the diagram. This pathway represents any energy and material inputs to maintain and restore the productivity of natural ecosystems. The system in fig. 3, therefore, could prevail over the system in fig. 1 in a long-term perspective.

Economic development of natural ecosystems is essential to maintain the current living standard in the modern economy. The cost-benefit analyses on development projects have, however, focused only on economic aspects of those projects, with little consideration on changes in ecosystem structures and functions associated with them. Even though some cost-benefit analyses have included this aspect of development, only qualitative aspects of those changes have been considered in the analyses.

The emergy concept evaluates the contribution of natural ecosystems, in terms of energy, that cannot be easily translated into monetary value of the market system, providing a quantitative tool to assess benefits and costs of any development or restoration proposal. By comparing development or restoration alternatives including the original system using the emergy evaluation, a more environmentally friendly and sustainable alternative could be selected (Fig. 4).



Environmental emergy (E) = Renewable (I) + Nonrenewable (N)
Emergy output = E + F
Environmental loading ratio (ELR) = (N + F)/I

Fig. 4. Emergy benefit comparison of various alternative development or restoration proposals with the original system. Environmental emergy (E) includes renewable emergy (I) and nonrenewable emergy (N). An alternative with the most emergy output (E+F) and least environmental stress ((N+F)/I) would be selected.

The emergy evaluation can provide useful indicators in judging the success of ecosystem restoration projects. For example, an environmental loading ratio (ELR) that is the ratio of nonrenewable emergy (indigenous nonrenewable emergy, N and purchased emergy from outside, F in fig. 4; e.g. fossil fuels) to renewable emergy (I in fig. 4; e.g. sun, rain, tide, and so on) in an alternative can be used to measure environmental impacts of goods and services that go into an ecosystem restoration effort. High environmental loading ratios suggest greater stress to ecosystems. Brown and Ulgiati (1997) suggested that systems with ELRs less than 3 are under relatively low environmental impacts and those with ELRs greater than 10 experience relatively concentrated environmental impacts. ELRs between 3 and 10 were suggested to be indicative of moderate impacts.

Maximum empower principle states that "prevailing systems are those whose designs maximize empower by reinforcing resource intake at the optimum efficiency" (Odum 1996). Here empower is defined as the flow of emergy per unit time. Among alternatives in fig. 4, one that yields more emergy (higher E + F) and imposes less stress (lower ELR) to the ecosystem would be selected.

Odum *et al.* (1997) compared six restoration alternatives for Puerto Rican forests: natural succession of areas within or adjacent to mature forest; reforestation that starts with colonizing by an exotic tree; reforestation by starting plantations for harvest; reforestation starting with a plantation which is left unharvested; direct planting of seedlings of a variety of tree species; starting patches of forest that can spread later. They found that volunteer spread of the exotic leguminous tree was most efficient, requiring the least emergy from the economy, but the quality was less.

Engel *et al.* (1995) estimated the emdollar value of primary production of restored ecosystems in St. Lucie estuary in Florida, USA, and compared the estimate with that of the current ecosystems. They assumed no change in the intertidal estuarine ecosystem and estimated the value of the planktonic ecosystem assuming an increase of 2.7 times the current planktonic production. The value of the seagrass ecosystem was estimated assuming about 29 times increase in the area of seagrass ecosystem (5.7 km^2) and 4 times increase in the production. Compared to the value of the current estuarine ecosystem of 5.1 million em$/yr, the value of the restored ecosystem was estimated to be 7.6 million em$/yr (or 1,788 em$/ha/yr), an increase by 50 %. The emdollar values of restored planktonic and seagrass ecosystems were 905 em$/ha/yr and 2,105 em$/ha/yr, respectively.

4. Pulsing and ecosystem restoration

A traditional way of seeing development of ecosystem and other systems has been based on the steady-state concept in which systems reach certain levels determined by resources available and stay there for a long time if there are no major disturbances (Kang 1998). Policies on ecosystems and economy have focused on attaining this steady state. Recent studies on many different systems have, however, shown that continuous fluctuations may be an inherent property of all systems in nature, either by internal mechanisms or external factors, or by combination of both. We can find examples of these fluctuations in rising and falling of economies and also in the human history such as rising and sudden collapse of various civilizations. As a new paradigm (Odum 1983; Odum *et al.* 1995), pulsing may reveal the true nature of the systems.

Pulsing can be defined as alternation of the gradual

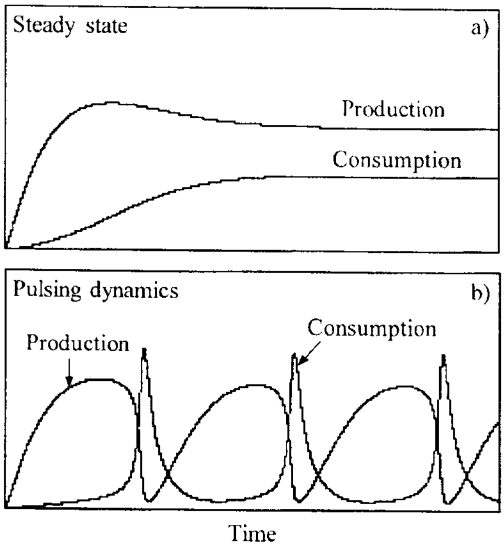


Fig. 5. Two different views on systems development over time. (a) Steady state concept in which system components level off after growth, (b) Pulsing dynamics with alternations of slow production and fast consumption (Kang 1998).

build-up of production and a short period of frenzied consumption that recycles materials for another cycle of production and consumption (Kang 1998). Fig. 5 compares the concepts of steady state and pulsing paradigm. Forest fires, volcanic explosions, and growth of modern human civilization based on fossil fuels are some examples of pulsing dynamics. Pulsing paradigm argues that pulsing systems may prevail over the steady-state ones because "more energy is transformed during operations that pulse than during those at steady state" (Odum and Odum 2001).

Any system in nature consists of components and processes with various sizes and time scales (Kang 1998). These are organized into a hierarchy in which many small components support a few large units. Pulses in each hierarchy can be viewed as combined results of the pulsing characteristics in their own scale and the pulsing patterns in the next scales larger and smaller, because units in one scale are connected to smaller and larger scales through the energy transformation hierarchy. Pulses from the smaller scale often appear as random noises in the larger scale systems, while larger scale pulses are considered as catastrophic. For example, typhoons in the summer time are considered as a catastrophe on a smaller regional scale, yet they are periodic pulses that play a very important role in distributing energy over the globe on a larger global scale.

Pulsing paradigm and other theories on system fluctuations suggest that ecosystem restoration efforts that are focused only on a period of pulsing cycles could fail. Lewin (1986) showed that policies on biodiversity preservation that did not take account of ecosystem fluctuations rather resulted in lost biodiversity, which was the opposite that many park managers and conservationists believed. Leach and Givinish (1996) and Wootton *et al.* (1996) also found that pulses were important in maintaining diversity and integrity of ecosystems. Any ecosystem restoration proposals, therefore, should consider characteristic pulsing dynamics of ecosystems.

5. Design for coexistence of humanity and nature

If we want to maintain the current living standard, development of natural ecosystems and resources is inevitable. This, however, should not impair the natural ecosystems on which our modern economy is based. It is also obvious that blind conservation of natural ecosystems cannot enhance our living standard.

Degradation of natural ecosystems and depletion of resources require a new concept on the relationship between humanity and nature. Designs with which humanity and nature can coexist are urgently required in an age of diminishing resources, such as in fig. 3. In those designs, an awareness is required that humans are not a controller existing outside the larger environmental system, but a part of the larger system depending their very basic requirements on the environmental system. Ecosystem restoration is a very important work in this regard.

The emergy methodology not only evaluates the value of ecosystems, but also provides several indices for assessing the status of ecosystems and impacts of human activities; how much a restoration project can contribute to our economy (emergy yield ratio), how much restoration activities can impact environments (environmental loading ratio), how much a restored ecosystem is sustainable (sustainability index), and so on. These results can be used to provide guidelines in setting up priority areas in restoring ecosystems such as vegetated coastal wetlands. Alternatives for restoring ecosystems can be compared and the best alternative that yields more to the economy and imposes less stress to the surrounding environment can be chosen to avoid unnecessary or duplicate works in restoration efforts. Indices calculated in the emergy evaluation can also be used to assess the success of restoration projects, and provide insights for future works to be done to improve the projects.

Until now a reductionistic approach that treats component parts of ecosystems separately has been dominant in efforts to solve problems occurring in ecosystems. This approach, however, have not solved all the problems. Every system on the globe is a collection of component parts and processes working together to make a whole. They are connected in a myriad of relationships with other systems smaller and larger. Complexity and scales of modern environmental problems, thus, call for a holistic approach (synthesis) in dealing with them as well as the reductionistic one (analysis).

The value of natural ecosystems is not just in the ecosystem itself, but it can be materialized when it is considered in relation to economic activities of human society. Preservation and restoration of ecosystems, therefore, should be evaluated in terms of the larger system around it as well as in terms of the ecosystem itself.

When there are conflicts between development and preservation of natural ecosystems, various alternatives should be compared using new methodologies such as the emergy evaluation to increase the real wealth of our economy and ensure sustainable growth into the future.

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References

Engel, V.C., C.L. Montague, and H.T. Odum. 1995. Emergy evaluation of environmental alternatives in Martin County. Center for Environmental Policy, University of Florida, Gainesville, Florida. 62 p.

Eum, K.H., J.H. Son, E.I. Cho, S.M. Lee, and C.K. Park. 1996. The estimation of carrying capacity in Deukryang Bay by emergy analysis. *J. Korean Fish. Soc.*, 29, 629-636 (In Korean).

Kang, D. 1998. Pulsing and self-organization. Ph.D. Dissertation, Environmental Engineering Sciences, University of Florida, Gainesville. 283 p.

Kang, D. 2001a. Emergy evaluation perspectives on the natural environment and economy of Seoul. *Environmental Sci.*, 10, 1-10.

Kang, D. 2001b. Emergy evaluation of the Kangwha tidal flat. *J. Korean Soc. Oceanogr.*, 36, 51-58.

Kang, D. and S.S. Park. 1999a. A methodological study on ecological economic evaluation of a multipurpose dam construction using emergy concept. *J. Environ. Impact Assmt.*, 8, 45-51 (In Korean).

Kang, D. and S.S. Park. 1999b. Emergy cost-benefit evaluation on a proposal of water supply using water diversion. *Korean J. Limnol.*, 32, 238-244 (In Korean).

Lee, H.-D. 1998. Economic value comparison between preservation and agricultural use of coastal wetlands. *Ocean Res.*, 20, 145-152.

Leach, M.K. and T.J. Givnish. 1996. Ecological determinants of species loss in remnant prairies. *Science*, 273, 1555-1558.

Lee, C.W. 1999. A study on the environmental capacity assessment of Seoul. Seoul Development Institute. 144 p. (In Korean).

Lee, S.M. and H.T. Odum. 1994. Emergy analysis overview of Korea. *J. Korean Environ. Sci. Soc.*, 3, 165-175.

Lewin, R. 1986. In ecology, change brings stability. *Science*, 234, 1071-1073.

MOE (Ministry of Environment). 1996. A study on the establishment of basic plan for eco-city development. 250 p. (In Korean).

Odum, H.T. 1983. *Systems Ecology*. Wiley, New York, 644 p.

Odum, H.T. 1996. *Environmental Accounting: Emergy and Decision Making*. Wiley, New York, 370 p.

Odum, H.T., S.J. Doherty, F. Scatena, and P. Kharecha. 1997. Emergy evaluation of reforestation alternatives in Puerto Rico. Center for Environmental Policy, Environmental Engineering Sciences, University of Florida, Gainesvill, Florida. 62 p.

Odum, H.T. and D.A. Hornbeck. 1996. EMERGY evaluation of Florida salt marsh and its contribution to economic health. p. 209-230. In: *Ecology and Management of Tidal Marshes: A Model from the Gulf of Mexico*, eds. by C.L. Coultas and Y.-P. Hsieh. St. Lucie Press, Delray Beach, FL.

Odum, H.T. and E.C. Odum. 2001. *A Prosperous Way Down*. University Press of Colorado, Niwot, 326 p.

Odum, W.E., E.P. Odum, and H.T. Odum. 1995. Nature's Pulsing Paradigm. *Estuaries*, 18, 547-555.

Pusan. 1998. Complex plan for environmental conservation of the city of Pusan. 709 p. (In Korean).

Son, J.H. 1999. A study on the sustainable development of a city by the emergy evaluation. Ph.D. Dissertation, Department of Environmental Engineering, Pukyong National University, 141 p. (In Korean).

Son, J.H., S.K. Shin, E.I. Cho, and S.M. Lee. 1996. Emergy analysis of Korean fisheries. *J. Korean Fish. Soc.*, 29, 698-700 (In Korean).

Wootton, J.T., M.S. Parker, and M.E. Power. 1996. Effects of disturbance on river food webs. *Science*, 273, 1558-1561.

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