A Comparative Analysis on the Functional Values of Coastal Wetland and Rice Paddy Ecosystems in Korea

표 희 동*
Hee-Dong Pyo

〈CONTENTS〉

Abstract : Functional values of coastal wetland and rice paddy ecosystems were quantified and an illustration was given on how to integrate biophysical parameters into a valuation framework. This is one of the most controversial issues in economic analysis for wetland preservation versus wetland conversion to agricultural use. This paper includes a comparative classification of ecosystem functions and services of coastal wetlands and rice paddies, the value of nutrient cycling/waste treatment regulation and atmospheric regulation, and the functional values of coastal wetland and rice paddy ecosystems. For ecosystem functional values of coastal wetland and rice paddy, the integration of biophysical data and replacement cost method is employed. Specific physical and geographical characteristics and data on ecosystem functions and services in coastal wetlands and rice paddies are addressed by evaluating their values in economic terms. In particular this paper

* Associate Research Fellow of Korea Maritime Institute

indicates double counting problems in the previous studies, and demonstrates how to avoid them and to maintain the consistency of valuation process involving a least-cost method, thus enabling an accurate integration of the coastal wetland ecology and wetland economics. As a result, the annual economical value of water purification by coastal wetland is estimated at $839.46/ha, and the net value of the effects by rice paddy is $174.06/ha. Of them, the total ecological value of water quality purification, $81,300.81/ha was distinguished from the total economic values, $10,493.22/ha because their marginal values were different. To this end and for further reliability and validity of functional values for natural resources, it is noteworthy that a general equilibrium framework that could directly incorporate the interdependence importance (value) between ecosystem functions and services be preferred to the partial equilibrium framework.

Ⅰ. Introduction

Costanza *et al*. (1997) provides synthesised valuation estimates for the ecosystem goods and services of the world. The value of the total ecosystem services is almost U$33trillion, which is 1.8 times the global GNP at the current value margin of 1997.

As Costanza *et al*. (1997) indicates, there are a number of errors and limitations in estimating the total current economic value of ecosystem services. Given the specific ecosystems and regional characteristics, we need to set up a framework to analyse these in further detail. This paper is to quantify and compare the economic values of positive and negative effects of various ecosystem functions in natural coastal wetland and rice paddy created by reclamation. In addition, this paper estimates annual ecological and economic values as well as total present value per unit of land area, using the interrelationship between physical and economic parameters. Benefit-cost analyses of converting coastal wetlands into agricultural use are often controversial due to both the estimation methods employed and the results obtained.

In this paper, most of the previous studies cited in Costanza *et al.* (1997) are examined in order to compare and distinguish the physical and economic parameters of ecosystem services and functions in coastal wetlands and rice paddies. In particular, for nutrient cycling/waste treatment regulation and atmospheric characteristics, regional data and recent studies are reflected. The assimilative capacity of wetlands to remove nitrogen and other pollutants from water systems has been studied by natural scientists (e.g., Mitsch and Gosselink, 1993; Nichols, 1983; Wellsbury *et al.*, 1996; Aoyama, *et al.*, 1996, Korea Ministry of Environment, 1998). Most economic studies focused on the economic losses of wetland degradation (Barbier, 1989;

Bergstrom *et al.*, 1990; Costanza *et al.*, 1989; Hamilton *et al.*, 1990; Folke, 1990; Turner and Jones, 1990). A few economic studies attempted to compare the economic efficiency in nitrogen abatement of created wetland, sewage treatment plants, and reduction in agricultural use, using an integrated model of biophysical and economic models (Gren, 1995; Gren *et al.*, 1994; Byström *et al.*, 2000).

On the other hand, the Intergovernmental Panel on Climate Change (IPCC) focused on the negative function of the emissions of three greenhouse gases such as carbon dioxide (CO2), methane (CH4), and laughing gas (N2O). In this paper, however, the positive function of rice paddy through an organic mechanism of photosynthesis as well as the negative effect of the emission of nitrogen from agricultural use, are evaluated by using a combination of biophysical and replacement cost methods.

This paper is organised as follows. First, the ecosystem functions and services of coastal wetland and rice paddies are classified and compared. Second, the theory underlying the replacement cost method is developed. Third, focusing on the value of nutrient cycling/waste treatment regulation and atmosphere regulation, the functional values of coastal wetland and rice paddy ecosystems are comprehensively estimated according to the regional characteristics of the resources. Finally, I conduct a comparative analysis of the values of coastal wetland and rice paddy ecosystem and derive policy implications from the analysis.

Ⅱ. Ecosystem Functions and Services of Coastal Wetland and Rice Paddy

Wetlands, as a natural resource, are an important habitat of animals and plants, and generally speaking, are known as high productivity ecosystems since they accommodate approximately 20% of living resources on earth. Wetlands can provide life-support functions, soco-cultural functions, and production functions (Bond *et al.*, 1992),[1] all of which are organically related to each other and contribute to sustainable development through coordination and cooperation. For the specific purpose of the paper, we focus on coastal wetlands including estuaries, tidal marshes, and seagrass/algae beds. Coastal wetlands are being continuously degraded or decreased in Korea, and since 1980, about 30 percent of Korean wetlands have been converted into landfill and reclamation. Remaining areas are under great development pressure for agricultural, industrial, and other uses.

Korea is geographically located in an Asian monsoon belt, where heavy rain is received in the summer. During this season, rainfall ranges between 600 and 800 mm, accounting for approximately 60 percent of the average annual precipitation. Due to this seasonal pattern of precipitation and high dependence on rice for staple food, rice paddy farming predominate over upland farming in agricultural production in the country. Rice paddy has, besides the obvious internal economic effects of producing rice and other foods, various

1) Recent work in both the United State and Europe has focused on the possibilities of predicting wetland ecosystem functioning by their hydrogeomorphic characterisation. The functions addressed by the Functional Analysis of European Wetland Ecosystems (FWEWE) are classified into three categories hydrological functions (floodwater retention, groundwater recharge, groundwater discharge, and sediment retention); biogeochemical functions (nutrient retention/abatement, nutrient export, and peat accumulation); and ecological functions (ecosystem maintenance and food web support). For more details, see Turner *et al.* (1998).

external economic effects on the environment, both positive and negative functions. Rice paddys positive impact on the environment encompasses flood control, water resource containment, mitigation of soil erosion, improvements of air and water quality, and aesthetic and recreational functions. Negative external effects include contamination of water and soil by fertilizer and agricultural chemicals, and acceleration of global warming by the discharge of methane and nitrous oxide.

Table 1 considers the specific physical and geographical characteristics of ecosystem functions and services in Korean coastal wetlands and rice paddies with the basic classification given by Costanza *et al.* (1997). This classification differs in several ways from that of Costanza *et al.* (1997). First, direct use values such as food production, raw materials, genetic resources, recreation, and cultural values are excluded in this paper. Second, direct use values of food production can contain the value of ecosystem services such as pollination, biological control, and refugia. They, therefore, are excluded in this study so as to avoid double counting (Barbier, 2000). Finally, the negative effect on waste treatment regulation and atmosphere regulation of rice paddies are newly analysed considering the regional characteristics.

〈Table 1〉 **Ecosystem Services and Functions of Coastal Wetlands and Rice Paddies**

Ecosystem services	Coastal wetlands	Rice paddies	Ecosystem functions and examples
Nutrient cycling/ waste treatment	(+)	(−)	Nitrogen fixation, N, P and other element or nutrient cycles, pollution control, detoxification, and waste treatment
Atmosphere regulation		(+, −)	Regulation of atmosphere chemical composition, climate, and greenhouse gas
Disturbance regulation/ groundwater recharge	(+)	(+, −)	Capacitance, damping and integrity of ecosystem response to environmental fluctuations (e.g. flood control, storm protection, etc.) and groundwater recharge
Water use		(+)	Storage and retention of water, agricultural or industrial use from freshwater reservoir
Erosion control/ sediment retention	(+)	(+)	Prevention of loss of soil, sediment retention

Note : 1. (+) represents the positive effects on ecosystem service, while (−) the negative effects.
2. The negative effect on disturbance regulation of rice paddy come from floods that occur because of the construction of seawall owing to some special situation in the area.

Ⅲ. Theoretical Considerations

The issue of valuation is inseparable from the choices and decisions on ecological functions and systems. Various methods have been used to estimate the value of ecosystem functions and services, most of which do not have direct market values. Conventional economic valuation may not be sufficient when the value is closely involved in ecosystem functions and environmental systems. Alternatively, biophysical models can be integrated with an economic model which may be indirectly used by deployment of damage avoidance, substitution service, or replacement cost methods (Turner, 1999).

The replacement cost method, which is used mainly in this paper, in particular has been used to value the indirect benefits from waste water treatment and gas regulation of wetlands and rice paddies. However, note that the validity of the replacement cost method depends critically on three conditions which tend to be neglected.[2)]

i) Substitutes can provide similar functions or services of the natural resources.

ii) The alternative is the least-cost alternative. The replacement cost method and the avoided loss or the damage cost method often fail to measure social welfare and does not take into account consumers WTP. The estimates do not take into account other available substitutes or the potential for mitigating behaviour associated with waste assimilation benefits from wetlands (Anderson and Rockel, 1991). Therefore, in order to avoid overstating economic surplus or to avoid double counting mainly due to multi-functional contribution, the alternative chosen should always be the least cost combination of the substitutes.

iii) In the economic perspective, an alternative capacity being applied to replacement cost should be within the range of the amount of effluence rather than total assimilative capacity of the resource which can receive a certain level of waste and convert it into harmless beneficial products.

For example, in Figure 1, the level of assimilative capacity of natural resource or the level of waste, Q, is shown on the horizontal axis. Cost and benefits in monetary terms are on the vertical axis. Here curve 'D' is the marginal benefit to polluters which can get from

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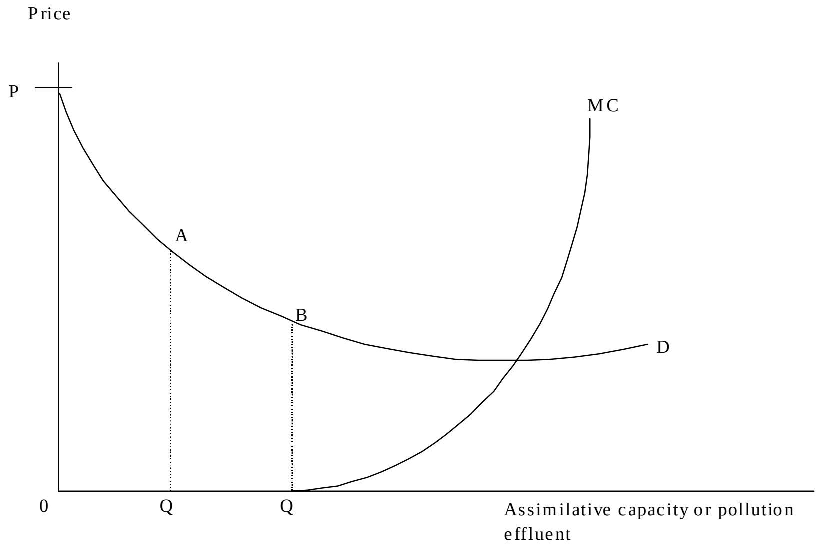
2) The first and second conditions are cited from Pearce and Turner (1990).

discharging an additional unit of pollution. 'MC' is marginal costs, i.e. the value of the extra damage done by pollution arising from the activity measured by Q. In this case the level of waste, Q_1, is less than this assimilative capacity, Q_0. *The economic value* of waste treatment regulation should be $0PAQ_1$ rather than $0PBQ_0$ which is said to be its total potential value or its *total ecosystem value.* Therefore, the total cost savings should be the present value of total annual cost reflecting the construction costs and operation and maintenance costs of a waste treatment facility which can handle Q1 of waste discharged into the resource like wetland rather than Q0.

〈Figure 1〉 **The Ecological and Economic Value of Pollution Control**



If the level of waste emitted (Q_1) is less than the assimilative capacity, Q_0, then the unused assimilative capacity takes place and the environment will eventually return to normal once the waste degradation process has taken place without any additional cost to handle it. In this context we note that the opportunity cost for assimilative function is zero if the maximum possible level of waste is less than the unused assimilative capacity (Q_1Q_0) of the remaining wetlands after part of wetlands is converted. That is, in benefit-cost analysis for wetland development, the opportunity cost for lost assimilative function depends upon the difference between the maximum level of waste and unused assimilative capacity of the remaining wetlands.

Ⅳ. Evaluation of Ecosystem Services in Coastal Wetlands

Coastal wetlands are highly productive and dynamic systems, performing many services to society in their natural state. In conventional economics, however, the ecological characteristics and services are mainly neglected, and therefore, wetlands has been continuously degraded and converted. An appropriate valuation of the multifunctionality of wetland is required so as to capture the importance of the contribution of wetlands, and to reflect it in project appraisal involving development versus conservation of wetlands.

The estimates of both social and economic value of most functions will vary considerably, depending on the geographic and economic situations of the countries involved and the types of wetlands being considered. As noted earlier in section 2, the estimates of wetland functions are limited to nutrient cycling/waste treatment, disturbance regulation/ground water recharge (flood control/storm protection), and erosion control/sediment retention. The scope of this study does not extend to the atmosphere regulation due to lack of information, although the ecological and economic importance may be considerable.

1. Nutrient cycling/waste treatment regulation

The water purification function of natural resources is a foundation for steady and balanced ecological cycling through degradation of organics and filtration of water. This process also determines resource production and stability. Costanza *et al.* (1997) distinguishes between nutrient cycling and waste treatment regulation. The former focuses on the aspects of provisions of the major nutrients for plant functioning growth, storage, internal cycling, processing and acquisition of nutrients. The latter represents the breakdown or removal of pollution. The nutrient cycling function takes place mainly in open oceans, estuaries, seagrass/algae beds, and shelves while the waste treatment function is done by forests, grssslands/rangelands, tidal marsh/mangroves, coral reefs, and lakes/rivers. Therefore, coastal wetlands play a very important role in nutrient cycling and waste treatment. To avoid double counting and tradeoffs between direct and indirect use values, this paper treats them as an integrated function to remove nitrogen and phosphorous.

As is well known, major sources of water pollution are water-borne point sources (e.g. industry, sewage treatment plants, etc.), non-point sources (e.g. runoff from agricultural and other lands), and air sources (e.g.power plants, transportation sources, municipal waste combustors, etc.). The assimilative capacity of coastal wetlands depends on temperature, seasonal variation, precipitation, contaminants, total dimension and condition of the wetlands, and many other factors. The ecological systems of wetlands have the ability to decompose the organic matters influxed, and sustain high productivity using the inorganic substrates resulted from the organic breakdown. For example, nitrogen is converted or removed through complex processes including ammonification, nitrification, denitrification, uptake in biomass, sedimentation, or fixation. However, industrial and agricultural activities by humans have drastically increased the influx of nitrogen and phosphorous into the marine system, and their high levels in the water have been linked to a condition known as eutrophication (Mitsch and Gosselink, 1993).

Several studies has shown that assimilative capacity in wetlands is of significant magnitude, using scientific measures such as nitrogen abatement, biological oxygen demand (BOD) or chemical oxygen demand (COD).[3] Thiborean and Ostro (1981), Wellsbury *et al.* (1996), Leonardson (1994),[4] and the Korean Ministry of Environment (1998) show that the capacities of natural wetlands to assimilate nitrogen range from 430.7kg N/ha/year, 440kg N/ha/year, 500~1,000kg N/ha/year, and 517~1270kg N/ha/year, respectively. In fact, there seems to be no real consensus on what is the normal rate of abatement in wetlands because it depends on various factors such as the type of wetland and its location. An appropriate figure for the assimilative capacity of nitrogen can be taken to be 500kg N/ha/year, and that is what we assume in this analysis.

Prior to attempting economic valuation of these effects, three essential assumptions are considered.

i) Wastewater treatment facilities and artificial wetlands can be considered as alternative means to abate pollutants. However, artificial wetlands are not wide spread especially in Korea. In a study of current technology to construct the artificial wetlands, the unit construction cost was found to be much higher than that of the capital cost and the operation cost of a sewage treatment plan t.[5] Therefore, here a waste treatment plant should be considered as the alternative.

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3) Assimilative capacity in wetlands and treatment cost of sewage treatment plants can be varied according to different scientific measures. Here the capacity of nitrogen abatement is the primary focus as cited in most studies

4) It is referred to by Bystrom (1998).

5) Gren (1995), Saderqvist *et al.* (1999), and Hammer (1992) prove that artificial wetlands are more cost-effective than traditional waste treatment methods in Sweden or USA. However, even their costs converted are not competitive to the cost of sewage treatment plants in Korea.

ii) A great amount of water flows in and out of the tidal flats and rice paddies, and it is unrealistic to expect a complete treatment of the waters through wastewater treatment facilities.[6] To perform a comparative evaluation of the value, the volume of the contaminants coming in and going out must be determined. For calculating the replacement cost, the rate of treating the load of nitrogen of a sewage treatment plant is used as a potential measure. It is therefore assumed that the abatement capacity of nitrogen in sewage treatment plants is 12.3g N per ton of wastewater inflow to sewage treatment plants based on using national data for three years of 1996～1998 (the Korean Ministry of Environment, 1999).[7]

iii) In general, the type of sewage treatment plants in Korea is the standard active sludge method. In 1999, when applying the sludge method, the total cost of wastewater treatment per ton was $0.16.[8]

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6) Costanza *et al.* (1997) assume the oceans and coastal waters are serving as a sink to all the worlds water and they provide a nutrient cycling service. However, this assumption is not realistic, and further may largely overestimate its value compared to that of the nitrogen load rate.

7) Wastewater quality inflowing into sewage treatment contains pollutants such as BOD (98.8 mg/l), COD (59.8mg/l), sulphur (111.5mg/l), nitrogen (32.6mg/l), and phosphorous (2.9mg/l) in Korea. And water quality outflowing from sewage treatment plants remains as BOD (12.2 mg/l), COD (12.8mg/l), sulphur (8.4mg/l), nitrogen (20.3mg/l), and phosphorous (1.2mg/l). Therefore, the difference between inflow and outflow water quality equals the abatement capacity of pollutants.

8) Total cost of wastewater treatment per ton is calculated using national actual data for the same period as follows:

- total cost/ton (TC_{se}) = capital cost /ton+operating cost/ton=0.11+0.05=$0.16

$$\circ \text{ capital cost/ton} = F \times \frac{r(1+r)^n}{(1+r)^n - 1} \div V = \$0.11$$

where F : total investment cost of sewage treatment plants in Korea, that is, $5,860,700,000.
r : discount rate (8%)
n : average durable years of sewage treatment plants (50 years)
V : annually total amount of wastewater treatment (=11,422.4 thousand ton/day ×365 days)

Note : 1) US $1 is assumed to be equal to 1,000 Korean currencies.
2) Total cost per ton of waste water treated in sewage treatment plants ($0.16) is quite similar to replacement cost used by Costanza *et al.* (1997), $0.15～0.42/ton.

Under the above assumptions that affect the estimated costs, the assimilative function of coastal wetlands is then converted to an ecological and economic value. As noted earlier in section 3, the ecological value ($0PAQ_0$ in Figure 1) of wetlands in water purification is the maximum value of the water purification function of wetlands, regardless of the actual volume of pollutant discharge. The economic value ($0PAQ_1$ in Figure 1) of the water purification function in wetlands indicates the purification value only for its actual volume of nitrogen load into the remaining wetlands after the development of the area. In addition, the total present value represents the sum of all the value flows in present value terms, assuming that the life span of the resources are infinite and that the annual value remain the same. The estimation functions and the estimated values are summarised in Table 2.

〈Table 2〉 **Estimated Equations and Values for Nitrogen a Batement of Wetlands**

Items	Estimated equations	Estimated Values ($/ha)
1. Annual ecological value	$FV_{wa}^{we} = (TC_{se} / v_n^{se}) \times v_n^{we}$	6,504.07
2. Total ecological value	$TFV_{wa}^{we} = FV_{wa}^{we} / r$	81,300.81
3. Annual economic value	$EV_{wa}^{we} = FV_{wa}^{we} \times L_n^{we} / (v_n^{we} \times S_{re}^{we})$	839.46
4. Total economic value	$TEV_{wa}^{we} = EV_{wa}^{we} / r$	10,493.22

Note : 1) TC_{se} = Total cost of wastewater treatment per ton (=$0.16/ton)

2) v_n^{se} = Abatement capacity of nitrogen in wastewater treatment plants ($= 0.0123kg\ N \times 10^{-3} / ton$)

3) v_n^{we} = Annually abatement capacity of wetland per ha ($= 500kg\ N \times 10^{-3} / ha$)

4) L_n^{we} = Annually potential nitrogen load into wetlands (=1,825 ton/year)

5) S_{re}^{we} = Remaining dimension of wetland after development (=28,280ha)
6) r = Discount rate (8%)
7) L_{n}^{we} is possible nitrogen load based on the population (500,000 persons) of a certain area, coastal wetland around Yuongsan river basin in Korea cited fro×10g/person/day m Pyo *et al.* (2000). It is calculated: 500,000 persons×365 days/year = 1,825 ton/year

2. Disturbance regulation/erosion control and soil formation in coastal wetland

Flood control and storm protection values are based on the estimations of prevented damages or the potential, or in some cases, actual costs of replacing this function of the wetland by artificial constructions, but the capacity in these functions depends on the types of wetlands. For example, storm protection values for tidal marshes range from $1/ha/year for estimated damage costs in the USA (Farber and Costanza, 1987), to $567/ha/year in willingness-to-pay for maintenance of a tidal marsh for this function (Costanza *et al.*, 1989) and $7.337/ha/year for replacement costs of the storm protection function of tidal marshes in the UK (Turner, 1989). In a comparison of coastal wetland and rice paddy and freshwater reservoir with embankment developed by wetland reclamation, however, the benefit of coastal wetland functions can be offset by those of rice paddy and freshwater reservoir with seawall. The value of erosion control and soil formation is also included in other functions such as disturbance regulation and food production.

Ⅴ. Evaluation of Ecosystem Services in Rice Paddies

1. Negative effect of water quality in rice paddy

Rice paddies has an intrinsic ability to reduce their own contaminants produced by fertilizers, pesticide, *etc.*, but exceeded contaminants may be released into the waterways. This section provides the link between economic valuation and physical parameters increasing the pollutants from rice paddies.

Previous studies conducted in Korea fail to consider water pollution effect of rice paddies, and only considered their positive effects because they assumed that rice paddies purify residential and industrial wastewater. However, the irrigated waters for rice paddies are not from the residential or industrial wastewater, and therefore are not so polluted. The assimilative function of rice paddies is limited to the contaminants resulted from fertilizers and pesticides. This indicates that the positive effect of water assimilation is 'zero'. Rather, the negative effect due to contamination through fertilizers and pesticides should be considered. Moreover, the contaminants from farming are the main source of water pollution and ecological degradation.

Important non-point pollution sources for rice paddies include pesticides, insecticides, fungicides, and fertilizers, which can accumulate in the sediments. The non-point source pollution heavily depends on soil conditions, fertilization composition, and irrigation conditions. Therefore, the loads of pollutants contributed by farmlands are difficult to monitor and assess. The Korean Ministry of Environment shows that during the periods of 1996 to1998 non-point source contaminants are BOD of 5.5～26.6kg/ha/year, nitrogen leakage of 19.3～50kg/ha/year, phosphorous leakage of 0.037～16.4kg/ha/year, and COD of 22.6～135kg/ha/year.[9] It is therefore assumed that nitrogen leakage was set at 35kg/ha/year, which is the median of the range and 50% of the nitrogen is sunk in the freshwater reservoir. With the physical data and the replacement cost data estimated earlier, water pollution cost of rice paddies can be calculated as in Table 3.

〈Table 3〉**Pollution Cost of Water Quality of Rice Paddies**

Cost item	Estimated equation	Estimated cost ($/ha)
Annual pollution cost of water quality	$EV_{wa}^{ri} = (TC_{se} / v_n^{se}) \times v_n^{ri} \times v_n^{fr}$	227.64
Total present cost of water quality	$TEV_{wa}^{ri} = EV_{wa}^{ri} / r$	2,845.50

Note : 1) v_n^{ri} = Annually nitrogen leakage from rice paddy ($= 35kg\ N \times 10^{-3} / ha / year$)
2) v_n^{fr} = The rate of nitrogen sink in freshwater reservoir (=50%)

2. Atmospheric regulation

Over the recent decades, the use of fossil energy has been drastically increasing with the result that the emission of carbon dioxide into the atmosphere has now risen globally to a rate of 3,000,000 tons per year. Temperature increases due to such

9) According to Elofsson (1997), nitrogen leakage from arable land area is estimated at 4～50kg/ha/year which is similar with that of Korea Ministry of Environment.

phenomena will lead to the global warming. Scientists estimate that the average temperature of the Earth will increase by 2~5C toward the end of the 21st century with the sea level rising by 30~100 cm. These events will drastically change the ecosystem as well as the global climate, causing complicated and difficult problems.

The function of gas and climate regulation is sustained through the ecosystem function balancing carbon dioxide and ozone layers, and other gases. Carbon gases released by agricultural activities are consumed by photosynthesis which also releases oxygen into the air, thus functioning as a purification process. On the other hand, continuously or intermittently flooded irrigation releases methane gases (CH_4) as well as the laughing gases (N_2O) into the atmosphere, polluting the air. These gases are the major culprits in polluting the atmosphere.

1) Positive effect of rice paddies on atmosphere quality

Carbon dioxide absorption and oxygen discharge by rice paddies are often overestimated due to the inclusion of the effects on self-generated pollutants such as fertilizers and pesticides. Therefore, a no-fertilizer and no-pesticide case should be used, where carbon absorption is about 2.99 tons/ha.[10] The figure was calculated as 10.96 x (12/44), where the figure of 10.96 ton/ha is the carbon dioxide absorption using the experiment in Korea (Korea Rural Development Administration, 1998), and 12/44 is the standard estimated rate for pure carbon to be converted to carbon dioxide.

Carbon gas is generally treated in two stages: separation and disposal. Each stage involves various methods and costs. According

10) Compared to carbon absorption of grass/rangelands, 10 ton ha-1, in Costanza *et al.* (1997), the carbon absorption of grass/rangelands is about three times that of rice paddy which means this figure seems to be quite reasonable.

to Ormerod *et al.* (1993) there are several methods to produce power including IGCC (Integrated Coal-Gasification Combined Cycle), and carbon gas treatment cost for power generated through IGCC is $45 per carbon ton which is the lowest among the methods available. The cheapest way of disposing of pollutant is ocean dumping at $30 per carbon ton. The total lowest cost of treating and disposing carbon gas pollutants is, therefore, $76 per ton. Biological treatment of the carbon pollutants is also done through photosynthetic processes of forests which store the gas on the average for 50 years. This method is relatively cheap ($3.5), because it involves only forest management cost. Forest not only cleans the atmosphere, but also adds to the ecological functions including climate regulation. Likewise, air cleaning through forest is suggested as a least-cost alternative, creating benefit of cleaning air pollution and providing oxygen as well as providing climate regulation simultaneously. That means that the value of gas regulation and climate regulation of rice paddy should not be estimated separately, when forest can be the replacement method for gas and climate regulation. That is because a double counting problem may arise.

Costanza *et al.* (1997) limits the value of gas regulation to the open oceans, swamps and grasslands/rangelands, and the value of climate regulation to forest and grasslands/rangelands resources. The study did not include the value of tidal flats nor rice paddies. For the open oceans and grass/rangelands, the value of reducing carbon dioxide is estimated at $20.4/ton C by the opportunity cost method used based on Frankauser and Pearce (1994).[11] Meanwhile, the ecological value of climate regulation of grass/rangelands and forests was evaluated at $0.11/ha/year using a mesoscale climate model (Costanza *et al.*,

11) Unlike open ocean and grass/rangelands, the value of swamps/wetlands as a sink for the carbon gases was estimated by the damage avoided cost method used by Kumari (1995).

1997) and \$223/ha/year using a loss damage cost method respectively. I find that Costanza *et al.* (1997) neglected the double counting for the value of grass/rangelands by evaluating the values of gas and climate regulation separately even though the value of climate regulation is quite trivial, and did not maintain the consistency of using a least-cost method.

For the reflection of regional characteristics, the cost of afforestation is calculated at \$31.4/ton C (Korea Energy Economics Institute, 1997) which is higher than the figure, \$20.4/ton C estimated by Frankauser and Pearce (1994). The positive value of atmosphere regulation of rice paddies is summarized in the Table 4.

〈Table 4〉 **The Positive Value of Atmosphere Quality in Rice Paddy**

Cost item	Estimated equation	Estimated cost (\$/ha)
Annual value	$EV_{at}^{ri} = TC_{fo} \times v_{c}^{ri}$	93.89
Total present value	$TEV_{at}^{ri} = EV_{at}^{ri} / r$	1,173.58

Note : 1) TC_{fo} = the cost of afforestation per ton of carbon (=\$31.4)
2) v_{n}^{ri} =Annually carbon absorption from rice paddy (=10.96ton/ha×(12/44)=2.99ton/ha)

2) Negative effect of rice paddies on atmospheric regulation

Methane gas (CH_4) is a colourless, odourless, combustible gas which is produced from anoxic environments such as rice paddies or swamps. Its lifetime is about ten years in the atmosphere and contributes 15 % of the green house gas. The volume of methane gas discharged from rice paddies is calculated considering regional climate, water management technique, freshwater supply period, the area of rice paddies, *etc*. Table 5 shows the differences between the OECD and the IPCC calculation methods, and the present study employed the average of the two, which is 0.363 ton/ha.

Nitrous oxide (N_2O) also exists in a colourless gas form, and is released into the atmosphere by the oceans, soil, burning of fossil fuel or other biomasses, and from nitrogen-based chemical fertilisers used in agriculture activities. Some argue that among these sources, 25 % of the total gas releases have origins in rice paddies. The life span of nitrogen oxide in the atmosphere is approximately 150 years, and its contribution to the greenhouse effect for the last 10 years is estimated to be about 6 % (Korea Energy Economics Institute, 1995). Differences in discharge estimation may exist depending on such factors as temperature and others, but the present study uses the mean value (0.0048 tons/ha) of the OECD and the IPCC estimates.

〈Table 5〉 **CH_4, and N_2O Emissions in Rice Paddy and Their CO_2 Equivalents**

Unit: ton/ha

Items	Methane		Nitrous oxide	
	CH_4 emissions	CO_2 equivalents	N_2O emissions	CO_2 equivalents
OECD	0.330	3.630	0.00078	0.2106
IPCC	0.396	4.356	0.0088	2.3760
Average	0.363	3.993	0.0048	1.2960

Note: The large difference between nitrous oxide emissions of IPCC and OECD is due to the fact that OECD considers the emissions of each fertiliser, and IPCC assumes the emissions of nitrogenous fertiliser regardless of the types of fertilisers.

On the other hand, since all of the three greenhouse gases (i.e. CO_2, CH_4, and N_2O) contribute to the same ecological problem of increasing the greenhouse gas effect, it makes no sense to determine critical flows for each substance. Instead, the substances are aggregated into CO_2 equivalents according to their global warming potentials (GWP) in a time scale of 100 years, i.e. CO_2=1, CH_4=11, and N_2O=270 (IPCC, 1994)

〈Table 6〉 **The Negative Value of Atmosphere Quality in Rice Paddy**

Items		Estimated equations	Estimated costs ($/ha)
CH_4	Annual cost	$EC_{atc}^{ri} = TC_{fo} \times v_{ma}^{eq} \times v_c$	34.19
	Total present cost	$TEC_{atc}^{ri} = EC_{atc}^{ri} / r$	427.43
N_2O	Annual cost	$EC_{atn}^{ri} = TC_{fo} \times v_{ni}^{eq} \times v_c$	11.10
	Total present cost	$TEC_{atn}^{ri} = EC_{atn}^{ri} / r$	138.73

Note : 1) v_{ma}^{eq} = CO_2 equivalents to CH_4 (=3.993ton/ha)
2) v_{ni}^{eq} = CO_2 equivalents to N_2O (=1.2960ton/ha)
3) v_c = The rate of net carbon to CO_2 (=12/44)

The separation technique for the treatment of methane gas and nitrous oxide is not as developed as it is for nitrogen dioxide gas. Therefore estimating the pollution contribution by methane gas can be treated using the global warming potentials.

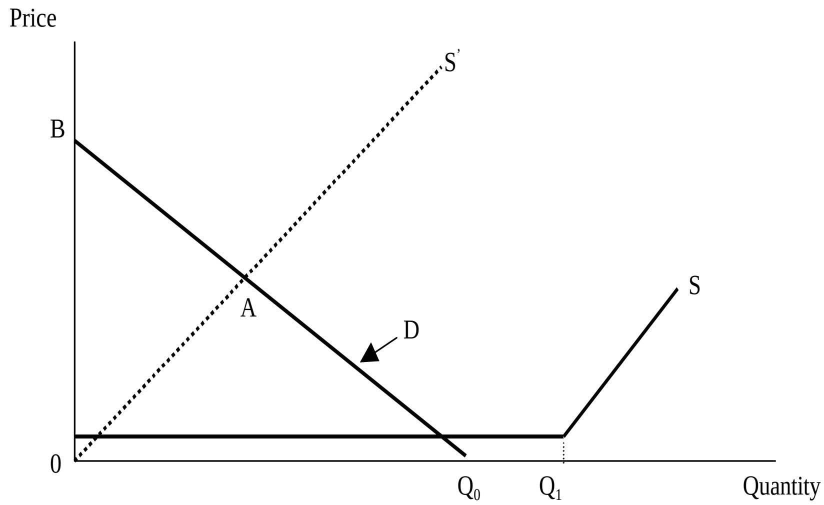
Table 6 shows a summary of methane and nitrogen gases' contribution to the atmospheric pollution. It is noted that the greenhouse effects contribution by total methane and nitrous oxide is estimated to be 1.7 % and 0.54% respectively. The contribution of methane is three times the effect of nitrous oxide, and so is the costs in terms of atmospheric pollution.

3. Disturbance regulation/groundwater recharge/water use/erosion control/sediment retention of rice paddy and freshwater reservoir

Gupta and Foster (1975) quantified the benefits of flood control using a damage or avoided cost method which overestimates benefits because it ignores possible opportunities of altering behaviour. The use of avoided losses or damage costs is an inappropriate method to measure the change in social welfare. Figure 2 shows graphically the correct measure of welfare. Assume here that curve D represents the demand for flood control services of the rice paddies. Its shape is determined by the prices of available substitutes for flood control, peoples income, and the degree of their risk-aversion as well as other personal tastes. Currently, flood control services are being consumed at Q_1. The supply of these flood control services MC, requiring no other human input, effectively runs along the horizontal (costless) axis until it reaches amount Q_0 provided by the rice paddys function for flood control. Beyond that point human intervention becomes necessary at a cost. This is depicted as the upward sloping segment of the supply curve beyond Q_0. If all flood control services of the rice paddies were to cease, the horizontal segment of supply would disappear, and a residual supply would be that obtainable with human intervention like S. Benefits of $0BQ_0$ provided by rice paddies will be lost, but replaced in part by the benefit of human intervention, 0AB. The loss of welfare would be $0AQ_0$.

In Korea, most of the land area is mountainous and hilly and the catchment areas of most rivers are small. A large proportion of the annual precipitation is concentrated in summer and torrential rainfalls are frequent during this season. As this rainy season is when most rice crops are in the very middle of growth, an aggregation of ridges between paddy fields are used which are designed to store water and which function as huge dams for flood control purpose. The amount of water that can be stored in paddy fields during each flood is calculated at 2,378 MT/ha.[12)]

〈Figure 2〉**Flood Control Benefit Provided by Rice Paddies**



As rice paddy fields contain water during most periods of rice planting and growth, water is absorbed through paddy soils into the

12) It is calculated as follows (Ministry of Agriculture and Food, 1999): $X1 = (A1 - B1) + (C1 \times D1)$ where X1 is the amount of water which can be stored in paddy field (MT/m2), A1 is the average height of the ridges (2600mm), B1 is the level of water in paddy fields suitable for rice planting and growth (mm), C1 is the weighted average velocity where water permeates into paddy soils (mm/day), and D1 is the estimated average period when each flood occurs and comes to an end.

ground. The amount of groundwater recharge supplied by paddy fields is estimated at 4,685 MT/ha.[13)]

In the meantime, freshwater reservoirs created by coastal wetland reclamation provide water for uses in agricultural production and domestic water consumption. However, it should be noted that the use for agricultural production should be excluded because it is included in the value of agricultural production. For example, there is a plan for rice paddy development (16,450ha) and freshwater reservoir (11,870ha) through coastal wetland reclamation in Korea. This new reservoir provides 400,000,000 tons/year of water for agricultural production and 200,000,000 tons/year for possible domestic water consumption. Here the value of the use for domestic water consumption can be attributed to part of the value of rice paddy per ha which is the value of 7,062 ton/ha (=200,000,000 ton/28,320ha).

The ffect of disturbance regulation, groundwater recharge and water use function by rice paddies and the freshwater reservoir in this case can be measured in value terms, provided that the water-storing capacity of the paddy field is equivalent to that of a dam. In the case of treating a dam as a substitute resource, note that it can simultaneously satisfy these three functions. Using the estimated replacement cost, $0.05 per ton of water,[14)] the annual value of disturbance regulation, groundwater recharge, and water use by rice paddy and freshwater reservoir is estimated at $353.10/ha/year (=7,062ton×$0.05).

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13) Its equation is:
$X2 = C1 \times B2 \times (1 - C2)$, where X2 is the amount of ground water which is fostered by paddy field (MT/m2), B2 is the average annual period of rice cultivation (137 days), and C2 is the share of water flowing into rivers in the total amount of water permeated through paddy soils into the ground (45%).

14) It is estimated by the annual capital cost plus maintenance costs of a representative dam.

Ⅵ. Discussion

Table 7 summarizes the economic value of waste treatment by coastal wetlands, and the value of atmosphere regulation, disturbance/water use and water pollution by rice paddies created by reclamation.

First, the estimated annual economical value of water purification by coastal wetlands is $839.46/ha, and the net value of the effect from rice paddy is $174.06/ha. On the other hand, total economic value represents a sum of the present values of all the value flows, assuming that resources last infinitely and the annual value and the rate of discount (8%) is constant over the years.[15] However, we need to bear in mind that the total absolute value of a rice paddy must be adjusted because externalities occur in a certain period, which is assumed to be 10 year, after the reclamation project. If a rice paddy through reclamation produces the products immediately, the approach overstates the benefits. That is, the net value for a rice paddy is not $2,175.75/ha, but $1,000.79/ha. Therefore, in the case of different value flows such as coastal wetland and rice paddy, a comparison of total values should be appropriate because a comparison of their annual values not normalized causes to have a bias on the magnitude of real values.

Second, the ecological values of water quality purification (i.e. annual ecological value of $6,504.07/ha/year and total ecological value of $81,300.81/ha) is distinguished from the economic values (i.e. annual economic value of $839.46/ha/year and total economic value of $10,493.22/ha) because their marginal values are different.

Third, the intrinsic ability to reduce paddys own contaminants

15) Annual values of alternatives can be sensitive to their relative price change and technical advances. In order to sufficiently take into account the potential change of their values in the future, therefore, extended research needs to be developed.

produced in part by its production factors such as fertilizers and pesticides, etc. cannot be valued. Rather, the release of their excess contaminants is a source of water pollution which is a negative function of rice paddy.

To this end, for further reliability and validity of functional values for natural resources, it is noteworthy that a general equilibrium framework that incorporates the interdependence between ecosystem functions and services would be preferred to the partial equilibrium framework. This is necessary in order to avoid double counting, and to ensure that the consistency of a least-cost method be maintained. In addition, the lack of information on the link between biophysical models and economic models results in difficulties in valuation processes. Therefore, more scientific and objective information and data compilation are urgently needed to accurately reflect the true value of natural resource ecosystems.

〈Table 7〉 **A Comparison of the Functional Values in Coastal Wetland and Rice Paddy**

Unit: U$/ha

Item	Coastal wetland	Rice paddy created by reclamation			
	Nutrient cycling/ waste treatment	Atmosphere regulation(a)	Water use(b)	Nutrient cycling/ waste treatment (d)	Net value (a+b-c)
Annual value	839.46	48.60	353.10	-227.64	174.06
Total value	10,493.22	543.62	2,044.42	-1,318.02	1,007.79

Note: 1. The economic values of disturbance regulation/groundwater recharge and erosion control/sediment retention in the coastal wetlands are supposed to be offset by those in the rice paddies and the freshwater reservoir.
2. The economic value of atmosphere regulation is calculated by the positive effect minus the negative effect, that is, 48.60 = 93.89-45.29.

Ⅶ. Conclusion

As one of the most important wetlands in the world, Korean coastal wetlands provide many important services such as life-support, social/cultural, and production functions to human society, but are simultaneously sensitive and irreversible to ecological systems. This requires sustainable management strategies including adoption of the safe minimum standards and the precautionary principle for natural resource ecosystems. However, about 30% of the Korean coastal wetlands have been converted into land uses for agriculture, industries, and others since 1980. Even remaining ones are under great development pressure.

The aim of this paper has been to quantify the economic values associated with positive and negative functions of coastal wetland and rice paddy developed through wetland reclamation. This is one of most controversial issues in economic analysis of wetland preservation versus wetland conversion to agricultural use. What is important in the quantification are the accuracy of biophysical parameters such as self-assimilation capacity or pollutant emissions which are indicators of those benefits, and the integration parameters into a valuation framework. Integrated wetland research combining social and natural sciences can help in part to solve the information failure to achieve the required consistency across various government policies. This paper provides a sound foundation for project appraisal, particularly involving coastal wetland conservation versus conversion into agricultural use. Specifically, it has attempted to avoid double-counting problems, to maintain consistency in valuation process involving a least-cost method, and to formulate integrated links between coastal wetland ecology and wetland economics.

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