Primary and Secondary Values of Wetland Ecosystems

ING-MARIE GREN[1], CARL FOLKE[1,2], KERRY TURNER[3], and IAN BATEMEN[3,4]
[1] *Beijer International Institute of Ecological Economics, The Royal Swedish Academy of Sciences, Stockholm;* [2] *Department of Systems Ecology, Stockholm University;* [3] *CSERGE, University of East Anglia, Norwich and University College, London;* [4] *School of Environmental Sciences, University of East Anglia, Norwich*

Abstract. Wetlands are continuously degraded in many parts of the world. One reason is the lack of the appropriate valuation of the multifunctionality of wetland. In an attempt to improve the understanding of the importance of this feature of wetlands an alternative classification of values is suggested; primary and secondary values. Primary value refers to the development and maintenance of ecosystems — their self-organizing capacity. Secondary values are defined as the outputs, life-support functions and services, generated by wetlands. Methods for measuring these values are discussed. Three case studies are presented which use different valuation methods and which to different degrees capture the primary and secondary values. It is concluded that only part of the total wetland value can be captured in monetary terms.

Key words: wetland, valuation, ecological functions, primary and secondary values, case studies.

1. Introduction

Should society be concerned about the alarming rates of loss of wetlands around the globe? All wetlands are under threat from a variety of locally or regionally-based human activities. But currently the perilous state of coastal wetlands are under an additional threat posed by global-scale pollution emissions and consequent global warming. The forecasted accelerated increase in average sea levels would have serious impacts on the worldwide distribution of coastal wetlands. Salt, brackish and freshwater marshes in temperate zones, and mangroves and other swamps in tropical zones would be inundated or eroded (Turner *et al.*, 1990).

One important reason for serious concern about the loss of wetlands is that they are multifunctional and can be considered as very valuable capital assets. Under an appropriate (sustainable) management regime they can produce a flow of functions such as nutrient purification, ground water buffering and biodiversity. This flow is generated by species, populations and communities dynamically interacting with their physical and chemical environment in what is referred to as life-support systems (Odum, 1989). Life-support systems generate a range of ecosystem produced functions of value to society (see e.g. Folke, 1991a; de Groot, 1992).

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Several attempts have been made to put a money measure on the value of wetlands (e.g. Barbier, 1989a,b; Batie and Shabman, 1982; Dixon, 1989; Lynne *et al.*, 1981; Turner, 1991). Some studies have explicitly valued life-support functions like flood and storm protection, nitrogen purification and water buffering in money terms (Thibodeau and Ostro, 1981; Faber, 1987; Folke, 1991b; Gren, 1992). Other studies have tried to estimate an aggregate value of a wetland, applying a direct valuation method such as the contingent valuation method (e.g. Bateman *et al.*, 1993; Bergström *et al.*, 1990). Less frequently, attempts have been made to estimate the life-support value of entire wetland ecosystems (Gosselink *et al.*, 1974; Costanza *et al.*, 1989).

It is, however, doubted whether the full contribution of component species and processes to the aggregate life-support services provided by ecosystems can be captured in monetary terms (e.g. Ehrlich and Ehrlich, 1992). In addition we would argue that the importance of succession and dynamic development and evolution of the ecosystem structure, which is the very basis for its life-support capacity, has been neglected (Odum, 1983; Holling, 1986). From a systems ecology perspective, the entire value of a wetland can thus be classified into two categories

(i) the value of the ecosystem's self-organizing capacity and
(ii) the value of life-support functions and ecological services that this capacity generates.

The purpose of this paper is to compare different approaches aimed at measuring the performance of wetlands, in particular with respect to their ability to capture the primary and secondary values of wetlands. Two categories of methods are considered; biophysical methods and methods based on behavioural models. Three case studies addressing primary and secondary values by applying either one or a combination of these methods are presented.

The paper is organized as follows. In the first section the functioning of wetlands is described. Next, a conceptual basis for the comparison of alternative classifications of environmental values is presented and the different valuation methods are briefly described. In section four the three case studies of wetland valuation are presented. The article ends with a discussion and a conclusion.

2. Roles and Values of Wetlands

Wetlands develop through a combination of changes brought about by species responding to environmental influences and species interacting within the biological community. Hydrological pathways, which transport energy and nutrients to and from wetlands are fundamental for the establishment and maintenance of these ecosystems and their processes. The hydrological regime influences pH, oxygen availability and nutrient flux. These parameters determine to a large extent the development of the biological part of the wetland.

The biological part in turn modifies the hydrologic conditions by trapping sediments, interrupting water flows and building peat deposits (Gosselink and Turner, 1978). Because of the accumulation of peat (soil organic material mainly from plants which have died) the variability of flooding is reduced and storage of nutrients is built up providing a steady source of nutrients to wetland plants. Plant species composition and the primary productivity of wetlands are controlled by the duration of flooding, the turnover rate of water and the quality of inflowing water (Ewel, 1991).

The modification and stabilisation of environmental variability, performed by the biological subsystem during the development of the wetland, insulates the ecosystem from its environment. The system is then made less dependent on and affected by external inputs. At the level of single species this occurs through structural and physiological genetic adaptations to mineral salt and sediments that are anoxic; and at the ecosystem level through the production of peat which makes nutrient recycling possible (Mitsch and Gosselink, 1986).

Wetlands are known for their flora and fauna, particularly rare plants and migratory bird species. The composition of species in wetlands vary both in time and between wetland sites. The diversity and abundance of plant and animal species in wetland ecosystems are discussed in e.g. Mitsch and Gosselink (1986), Williams (1990) and Ewel (1991). The presence and abundance of species living in a wetland depends on their life histories which are often short but complex and their specific adaptation to the environmental conditions of the wetland site. The wetland environment is in many ways a physiologically harsh habitat. Wetlands in general have low oxygen levels in the water column, anoxic soils, periods of drying and flooding and high water temperatures at the wetland surface. There is significant sediment-water exchange due to the shallow water in wetland; and a diversity of decomposing organisms in wetland sediments lead to processes such as denitrification and chemical precipitation which removes chemicals from the water. In general, physical and microbial processes are more important than vegetative uptake in controlling sediment and nutrient retention (Johnston, 1991).

In addition to water purification by retention of chemicals and nutrients, wetlands provide an abundance of ecological services of value to society. They prevent floods by changing sharp run-off peaks from heavy rains and storms to slower discharges over longer periods of time. Many wetlands act as sinks for inorganic nutrients and as sources of organic materials to downstream or adjacent ecosystem. They have a capacity to improve water quality, often serving as a filter for wastes and can therefore reduce the transport of nutrients and organic material, sediments and toxic substances into coastal areas. For this reason they are often referred to as the kidneys of the landscape. Wetlands are also involved in global biogeochemical cycles and contribute to the global stability of available nitrogen, atmospheric sulphur, carbon dioxide and methane. Furthermore, wetlands are important habitats for flora and fauna and serve as nursery and feeding areas for both aquatic and terrestrial migratory species.

3. Values and Measurement Methods

3.1. VALUES OF WETLANDS

According to the description of wetland ecosystems in Section 2, the total production output of a wetland system can be divided between three different uses; (i) for its own development and maintenance, (ii) exports to other ecosystems and/or (iii) exports to the human society. The first type of output refers to the build-up and organizing capacity of the wetland itself and the other two to exported life-support values. We find it useful to denote these two types of "output" values as *primary* and *secondary* values respectively.

The primary or "glue" value also includes the dynamic changes over time of the ecosystem, as well as its resilience. Resilience refers to an ecosystem's capacity to recover from disturbances (Holling, 1986). This capacity and the redundancy or "insurance" capacity of ecosystems, for example the emergence of new keystone species and processes as ecosystems respond to unexpected shocks, are also included in the primary value (Walker, 1992; Holling, 1993). The prior existence of primary value is necessary for the derivation of secondary values since there cannot be any production of life-support services, or outputs, without a proper prior build-up of the ecosystem. Total secondary value is thus conditional on the structure and functioning and on the continued "health" of the ecosystem (Costanza et al., 1992). The use of one ecological service, i.e. one secondary value, often also implies that other secondary values are affected. Each secondary value is dependent on the existence, operation and maintenance of the multifunctional wetland system — the life-support system (Folke, 1991a, b). Thus, in an 'ecosystems' perspective, the total value of a wetland consists of primary and secondary values.

This definition of the total value of an environmental resource differs from the concept commonly used in environmental economics. Since Krutilla (1967), total value has usually been divided into use and non-use values derived from individuals' preferences. Examples of use values are recreation, fishing and birdwatching. Two types of non-use benefits are usually identified; option value and existence value. Option value involves some kind of uncertainty influencing the individual's choice. Existence value can be defined as ". . . the value some individuals place on the knowledge of the mere existence of gifts of nature, even when they feel certain they will never have or choose an opportunity to experience them in situ." (Krutilla and Fisher, 1975, p. 124).

Another classification of environmental values has recently been suggested by Mäler (1992). He distinguishes between values revealed on markets and values not revealed on markets. The values revealed on markets "... correspond to the value derived from observed market behaviour" (Mäler, 1992, p. 6). The values not revealed on markets can be considered as all other values attributable to an environmental good which "... can never be revealed from observing individual behaviour in markets".

Comparing the three definitions of total value of an environmental resource we note that the concept of secondary values, i.e. values of wetland life-support functions and the ecological services they generate, encompasses use values and market revealed values. For example, recreational use of a resource often implies the use of several secondary values such as birdwatching, fishing, and enjoying the view of a diversified landscape. Use values and values revealed on markets, however, refer only to human consumption and in general not to the exports to ecosystems outside the wetland in question. In order to capture these values the indirect use values can be estimated if the functional linkages between ecosystems are known. Due to the complexity in the function and structure of ecosystems, it is very likely, however, that not all of the exports to other ecosystems related to the generation of ecological services can be measured in this way. Thus, based on the above definition of primary and secondary values, we conclude that the secondary values of wetlands are larger than either use values or values revealed on markets.

Although it can be useful to compare secondary values with use values we do not find it meaningful to compare primary values with non-use values. The main reason being their different perspectives; the focus on wetland ecosystem functioning versus the focus on human preferences. According to our definition, primary value refers to the build up and self-organizing capacity of the wetland. Non-use values have in general no explicit reference to the structure and functioning of an ecosystem. They may include both primary and secondary values. Although both primary values and non-use values are quite likely to be positive they measure quite different aspects of a wetland. Our opinion is therefore that the primary benefits and non-use benefits are non-commensurable.

If human preferences and their valuation were consistent with perfect information on the functional properties of ecosystems as a basis for generating ecological services, both directly as exports to human society and indirectly through exports to other ecosystems, then the measurement of value according to either of the two classification schemes, primary or secondary values versus use and non-use values, would coincide. With such perfect information the existence of non-use values may be questioned. The reason is that ecosystems and the functions and services that they generate are interconnected, or "nested", in time and space (Allen and Hoekstra, 1992; Günther and Folke, 1993), which imply that humans use ecosystems directly or indirectly. Due to lack of information, true uncertainty, ecological knowledge and data we are, however, often not fully aware of our indirect uses of ecosystems.

The concept of values not revealed on markets refer to all environmental values that can not be observed by individuals' behaviour in markets. They therefore include the primary values as defined here. They are larger than the system's primary value because the secondary values not revealed in markets are also included.

3.2. METHODS FOR MEASURING VALUES

When classifying different methods for estimating values of environmental resources we follow Smith and Krutilla's (1982) classification taxonomy and identify two classes of methods: biophysical and technological methods, and methods based on behavioural models. The technological methods are not dealt with here. In biophysical models a physical measure like energy, biomass or material flows, is often used to measure the performance of an ecosystem and to identify different linkages between species or groups of species within an ecosystem, and transports between ecosystems (Jörgensen, 1992). Some biophysical models relate their measurements to human activities (see e.g. Cleveland 1987 for a review), but not directly to human economic behaviour. In general, these types of approaches do not claim that they measure the value of environmental resources, but functional relationships and the biophysical basis for value.

Methods for estimating values based on behavioural models can be divided into the direct and indirect methods of measuring environmental benefits. For an excellent review of the theoretical foundations of these methods see Johansson (1987). The direct methods imply that the demand for an environmental change is measured by means of a constructed or hypothetical market; see e.g. Mitchell and Carson (1989). People are then asked for their willingness to pay, or for their required compensation to accept a certain environmental change (Contingent Valuation Method, CVM). Another direct approach is to ask respondents for their ranking of certain alternatives (Contingent Ranking Method, CRM). Through the use of indirect methods, measurements of environmental benefits are obtained by estimating demand for a good that is either a substitute or a complement to the environmental good (Mäler, 1974, 1992). One example is the expenses for travel costs when visiting a certain recreation site.

The aim of many biophysical models is to describe and analyze the functioning of ecosystems; their build-up, dynamics and resilience. They can therefore be regarded as a foundation, as a prerequisite for the measurement of primary value and non-market revealed values. These methods are also important tools for generating inputs for the estimation of secondary values. Since the indirect measurement methods calculate the benefits from the use of an environmental resource they address secondary values, use or market revealed values. The direct methods also estimate secondary or use values. In addition they can be applied in the context of non-use value measurements. As stressed above, these non-use values cannot be compared with primary values.

When comparing different measurement approaches with respect to primary and secondary values we therefore conclude that the biophysical methods provide the necessary information and inputs for estimating both primary and secondary values. The behavioural models can be used only to measure secondary values, and only part of the total secondary value can be measured in money terms, mainly due to lack of information and true uncertainty over the functioning of complex systems like ecosystems.

4. Three Empirical Case Studies of Wetland Values

In this section three cases studies are presented which reflect different attempts at revealing the primary and secondary values of degraded, existing and restored wetlands. The contingent valuation, biophysical and/or household production function methods used to measure the values of the wetlands in question, are all analysed in this section of the paper.

The first case study, is an application of the contingent valuation method to the Broadland wetland in UK. It attempts to elicit recreation and amenity values from a large sample of wetland visitors and non-visitors. The study thus estimates part of the total secondary value. In the second case study, two types of estimates, one in economic and one in physical terms, of the lost life-support value of a wetland in Gotland, Sweden, are made. An energy analysis is used to quantify the lost life-support functions. An indirect method is used to estimate the economic value which is measured as the costs of replacing the life-support provided by the wetland with human-made technologies. The objective of the third study is to estimate the value of a restored wetland for the purpose of nitrogen abatement, taking into account the multifunctionality of wetland life-support, the temporal dynamics of restored wetland, and the equilibrium effects on the rest of the economy of Gotland, Sweden. A mix of indirect methods, biophysical and contingent valuation methods are used to estimate primary and secondary values.

4.1. A CONTINGENT VALUATION STUDY OF BROADLAND

Broadland represents a class “one” complex wetland because it is recognised as providing a wide range of functional and structural values. Broadland is, therefore, of considerable significance for wetland conservation. There are three National Nature Reserves within it, two of which appear on the list of wetland recognised by the British government (under the Ramsar Convention) as being of international importance. Broadland was also specifically designated an "Environmentally Sensitive Area" under the Agriculture Act of 1986.

The Broadland fens support reed- and sedge-beds and companion fauna. The grazing marshes support important wildfowl populations, and their drainage dykes contain oven a hundred different species of freshwater plants. The Broadland wetlands also provide for multiple-resource use and encompass multiple land-use systems. The area is a national centre for recreation. It supports a regionally important agriculture industry; substantial permanent populations; as well as a large seasonal tourist population.

The origins of the Broads lie in the flooding of medieval peat-diggings, in the connection of these shallow lakes to the main water courses, and in the creation of a marsh-based economy. Today, this semi-natural area supports a variety of intensive and extensive agricultural land uses on the pump-drained marshland. Broadland also remains under continued threat from flooding, some twenty thousand hectares lying below the surge tide level. This area is protected by over two hundred kilometres of tidal embankment many of which are old and in deteriorating condition.

The management of Broadland has proven to be a complex task, and several factors have helped to intensify land-use conflicts over recent years. Increasing demands on the productive use of wetland resources — such as for increased agricultural output; for more recreation; and for more water for consumption and/or effluent assimilation — have created undesirable side-effects. There has been an accelerated enrichment of the watercourses by nutrients (eutrophication), which has, in turn, led to algal growth and decay, and the associated loss of vegetation, and to organic decay. Changes in the characteristic landscape of the area have also been stimulated; loss of reed-banks; channelisation and quay-heading of river banks; loss of grazing marsh and of related dyke habitats; and loss of natural ornithological and invertebrate attributes (Turner and Brooke, 1988; Turner and Jones, 1991).

Most recently, a contingent valuation study (CVM) has been undertaken to try to assess the monetary value (willingness to pay; WTP) of conserving the Broads via a protection strategy designed to mitigate the increasing risk of flooding due to the long term deterioration of flood defence (Bateman *et al.*, 1993). More specifically the CVM aimed to examine the value of conserving the largely non-market assets of recreation and environmental quality as currently provided by the wetland complex, parts of the secondary values generated by the Broads.

The CVM study contained both an on-site survey of users and a mail questionnaire sent to non-users. Both groups were asked for their WTP to conserve Broadland in its present condition. The on-site research strategy was to use three alternative estimates of mean WTP, "what are you willing to pay? (OE), "are you willing to pay x £" (DC), and revised bids (IB), to produce a 'valuation spectrum' encompassing the true revelation of WTP. The OE and the DC estimates were expected to represent the lower and upper bounds for the WTP estimate range. Furthermore, the IB approach, by starting with the (upwardly biased) DC sum x and then allowing respondents to fix their own WTP (i.e. to free ride downwards), was expected to produce a mean WTP in between those derived from the OE and DC experiments.

The on-site survey instrument contained two forms of information provision — a 'constant information statement' which was read out by the trained interviewers to each respondent; and a visual display, information board which was on hand at each interview point. The information board was a largely pictorial display of the current Broadland landscape and other asset features (the 'before' pictures and likely conditions with frequent flooding the 'after' pictures).

Main on-site survey results indicated insignificant hypothetical bias problems. Refusals accounted for only 1% of the OE sample and 4.5% of the DC/IB sample. Partwhole (or mental account) bias was assessed by asking respondents to state their annual recreation/environment budget. This was then compared to their stated WTP to conserve Broadland. Analysis indicated that there was no evidence of any significant part-whole bias, with stated WTP coming out at around 16% of the annual budget for both subsamples. A checking procedure in the questionnaire also ensured that stated WTP did really represent annual rather than one-and-for-all payments.

Mean OE (WTP) came out at £67 per household per year and IB at £75 (1991 prices) — see Table II. Given the unique status of the Broadland complex these results are roughly in line with other UK CVM studies (Turner *et al.*, 1992). Thus, a recent study of river water quality (many substitute goods) recorded a mean OE WTP of just over £12 per annum (1987 prices) (Green and Tunstall, 1991). A study investigating the conservation value of The Yorkshire Dales (mountain and valley landscape with only a few equivalent substitute sites) found a mean OE WTP of £35 per annum (1989 prices) (Willis and Garrod, 1991). The signs and significance of explanatory variables such as income, age, first or repeat visit, membership of environmental pressure groups etc. were all satisfactory and in accordance with economic theory.

The mean DC (WTP) result was £140 per household per annum on a bid function that proved robust and consistent with theory. Further testing confirmed the existence of a strong upward anchoring bias in DC WTP responses. Table I presents a range of user value estimates for the Broads wetland. The results are differentiated in terms of the elicitation method used and are based on the most 'conservative' forecasted annual visiting rate for the area.

In addition to the on-site survey of users, a mail survey across Britain was also used. The objective of this latter survey was to estimate conservation values (existence-type values) held by non-users. Both socioeconomic factors

Table I. Broadland recreation and amenity, use value estimates (£ million, 1991 prices)

	N	Mean WTP (£)	Median WTP (£)	St. dev.	Min. bid (£)	Max. bid (£)
Open ended WTP study	846	67	30	114	0	1250
Iterative bidding WTP study	2051	75	25	130	0	2500
Dichotomous choice study	2070	140	139	–	–	–

and a distance (from the Broads area) decay factor were listed for in the stated WTP results.

Only the distance-decay relationship appeared to be significant with those respondents living in a defined 'New Broadland' zone having a higher WTP (£12.45 per household producing an aggregate annual non-use value of £32.5 millions for the zone) than those living in the 'Elsewhere GB' zone (£4.08 per household producing an aggregate non-use value of £7.3 millions for the zone). However, these results did not adequately distinguish between past users of the Boards and pure non-users and cannot therefore be classified as pure non-use values.

The aim of this CVM study was to estimate the willingness to conserve the Boards. Except for mitigation of the increasing risk of flooding no explicit references were made to the functional properties of the ecosystem. Only part of the secondary values were therefore estimated. Additional estimates may have been included if the individual, who participated in the investigation, recognized and valued them.

4.2. REPLACEMENT COSTS AND BIOPHYSICAL EVALUATION OF LIFE-SUPPORT FUNCTIONS

This case study, based on Folke (1991b), is an attempt to quantify the life-support value of a Swedish wetland system, the Martebo mire, on the island of Gotland in the Baltic Sea. The mire has been subject to extensive draining and most of the wetland derived goods and services have been lost. The purpose was to evaluate the loss of life-support capacity of the wetland to society. This was done by comparing the loss of the wetland's functions with the costs of replacing them with feasible human-made technologies. The wetland-produced functions, services and goods, and the human-made replacement technologies are summarised in Table II.

In ecology, the amount of energy captured via photosynthesis (gross primary production, GPP) is a common measure of an ecosystems' potential

Table II. Life-support functions, environmental goods and services of the Martebo mire, Exploitation Effects, and Replacement Technologies (modified from Folke, 1991a)

Societal Support	Exploitation Effects	Replacement Technologies
Peat accumulation	Peat layer reduction and disappearance through decomposition, intensive farming, and wind erosion, degraded soil quality	Artificial fertilizers re-draining of ditches
	Reduced water storage	
Maintaining drinking water quality	lost source for urban area	Water transports
Maintaining ground water level	dried wells	pipeline to distance source
Maintaining drinking water quality	saltwater intrusion	well drilling
	nitrate in drinking water	saltwater filtering
	pesticides in drinking water	water quality controls
		water purification plant
		silos for manure from domestic
Maintaining surface water level	decreased evaporation and precipitation, reduced amount of water	animals nitrogen filtering water transports dams for irrigation pumping water to dam
Moderation of waterflows		irrigation pipes and machines
	pulsed run-offs	water transport for domestic
	decreased average water flow in associated stream	animals regulating wire pumping water to stream
Processing sewage, cleansing chemicals	reduced capacity	mechanical sewage nutrient
	eutrophication of ditches and stream	and removal sewage transports sewage treatment plant clear-cutting of ditches and stream nitrogen reduction in sewage treatment plants
filter to coastal waters	adding to eutrophication	
providing		
— food for humans	loss of food sources	agriculture production
— food for domesticate animals	loss of food sources	imports of food
— roof cover	loss of construction materials	
sustaining		roof materials
— andromous trout populations	degraded habitat, commercial and sport fishery losses	releases of hatchery raised trout
	loss of habitat	farmed salmon
	loss of habitat	
— other fish species	endangered species	
— wetland dependant flora and fauna	lost	
species diversity	lost	
storehouse for genetic materials		
bird watching, sport fishing, boating and other recreational values	lost	
aesthetic and spiritual values	lost	

to generate ecological functions and services. The decrease in functional value as an indicator of total value (including primary and secondary values) was approximated through an analysis of how much of the capacity of wetland plants to capture the sun's energy had been lost. The annual loss corresponded to about 730 TJ of GPP (unexploited wetland 1725 TJ GPP per year — exploited 995 TJ GPP per year).

The evaluation of the costs of human-made technologies aimed at replacing lost component values generated by the life-support system prior to destruction, were made through monetary estimates, and industrial energy estimates. It should be noted that using energy analysis is *not* to argue for an energy theory of value. The energy approach as applied here is a complement to economic analysis, since it might help to reveal ecological interrelations not reflected in monetary valuations, and also assist in the identification of the biophysical basis for economic activity. The strength and weaknesses of the method are discussed in e.g. Folke (1991b), and Cleveland (1992).

The results of the study indicate that it takes considerable amounts of costly industrial energy to replace the loss of wetland produced goods and services. These goods and services were previously generated "for free" by the wetland system. The major part of the costs, whether monetary or biophysical, are related to technical substitutes for the biogeochemical processes in the wetland, such as those related to flows of nitrogen and phosphorus, followed by substitutes for the services associated with the hydrological cycle, such as water storing capacity, drinking water supply, and water filtering and purification. Not more than about 10 per cent are directly related to the biological part of the system, which might reflect a lower priority and also the difficulty of substituting for the loss of species diversity and genetic variability (irreversibility).

The estimate of the monetary replacement costs indicates that the annual (undiscounted) cost of replacing the wetland's functions is about 2.5—7 millions of SEK. This is an estimate of some of the secondary value. In the context of a wetland conservation versus development situation we might compare such estimates with the benefits of alternative uses of the wetland, but we would still have an underestimate of the total value of the wetland. Such comparisons are especially critical if the alternative uses being appraised are based on potentially unsustainable options such as intensive agriculture (Daly and Cobb, 1989).

Furthermore, a monetary estimate does not tell us how much of the actual welfare support function of the wetland has been revealed through the valuation. There is no measurement of the total support value to relate the estimated value to. Hence, there is a need for complementary estimates of the physical foundations and interrelations between ecosystems and economic systems. The energy analysis applied in this case study provided a biophysical indicator of the lost life-support functions to society. It is also an attempt to explicitly include the loss of primary value, or the glue value as discussed above. The loss of this life-support capacity was compared with the costs of the technical replacements. This was done by comparing the industrial energy used throughout the economy to produce and maintain the replacement technologies with the solar energy required by the wetland system to produce and maintain similar ecological functions. The analysis indicated that the biophysical cost of producing technical replacements in the economy, 15—50 TJ fossil fuel equivalents per year, was almost as high as the loss of life-support functions measured as solar energy fixing ability by plants (55—75 TJ fossil fuel equivalents per year). However, this is not an 'equivalent' substitution because the human-made replacements for the wetland's life-support functions have not been successful in restoring the original ambient quality. Despite the technologies, there are still severe environmental problems in the area and clearly the substitution between human-made physical capital and the natural capital of the wetland was not an equivalent one (Pearce and Turner, 1990).

The difference between the measure of replacement cost and the solar fixing ability may be interpreted as an ecological measurement of the primary value. If we assume that the technological replacements would include all secondary values, the primary value would correspond to 30—60 per cent of the total value. However, this is an overestimate of primary value since, as mentioned above, only parts of the secondary values that were lost have been replaced.

Hence, according to this study's results, technical replacements only represent a partial substitute for the ecosystem support. Further, expensive and environmentally degrading fossil fuels are used directly and indirectly in the economy to produce and maintain the replacements. From a societal perspective, it would therefore be wiser to use these "replacement fuels" in a prior effort to maintain and enhance the free support of ecosystems, instead of trying to replace it with human-made technologies after it has been destroyed (Bormann, 1976). One solution along these lines would be to apply eco-technologies (Mitsch and Jörgensen, 1989) to restore wetlands for drinking water supply, recreation, and as filters for nitrogen to coastal waters (Nichols, 1983; Ewel and Odum, 1984). The economics of wetland restoration for nitrogen purification will be analyzed in the third case study presented below.

4.3. WETLAND RESTORATION FOR NITROGEN PURIFICATION IN GOTLAND, SWEDEN

The most serious environmental problem in Gotland is an insufficient supply of drinking water of acceptable quality, particularly during the dry summer months. The average level of nitrage in Gotland is high, 40 mg NO_3/l, compared to the rest of Sweden at 10 mg NO_3/l (Spiller, 1978). In some wells the level of nitrage exceeds 100 mg NO_3/l. High levels of nitrate are carcinogenic and may cause methemoglobinia in infants. A study was therefore undertaken in order to estimate and compare different measures aimed at decreasing the level of nitrate in ground-water (Gren, 1992). In the following the main results from this study are summarized.

The main sources of nitrogen to the ground water are the instantaneous leakage of nitrogen from drained mires and farmers' application of nitrogen fertiliser and manure. Sewage from households and industry accounts for a minor part of the total emissions of nitrogen. The mitigation measures to reduce the content of nitrogen in the sewage were thus, restoration of the wetlands, reductions in the farmers' application of fertiliser, and increases in the capacity of the sewage treatment plants.

The value of investments in wetlands and sewage treatment plants are measured as their associated current and future streams of values (Mäler, 1974, 1992). Since the purpose of the investments is to improve water quality, this constitutes one type of value. However, as discussed in Section 4.2, investments in wetlands not only improve water quality but also generate other secondary values such as provision of habitats and storage of ground water. Such a multifunctional production of values is usually not possible if sewage treatment plants are utilised.

Another difference between the value of investment in a wetland and that in a sewage treatment plant concerns the capacities to produce secondary values in the future. The capacity of a restored wetland to provide for such values increases over time, as the plants grow and spread and the biological community develops until the ecosystem reaches its mature state. This initial increasing capacity of a wetland to provide secondary values is due to its structuring and build-up and can therefore, according to our definition in Section 3, be regarded as an increase in the primary value of the wetland. This is not the case with sewage treatment plants. Instead investments in sewage treatment plants are usually subject to physical depreciation due to the wearing out of the machinery and equipment.

When considering nitrogen abatement measures within the agricultural sector we include only the reduction in farmers' use of nitrogen fertiliser. Such a reduction is not regarded as an investment which has any impacts on future values. The value of reducing the use of nitrogen in a certain period is then simply an improvement of the water quality in the same period. It should be noted that other types of measures concerning the agricultural sector such as improvement of the capacity to store manure or cultivation of energy forests imply future effects. However, due to lack of data such measures are not included here.

Thus, the value of investment in a wetland for nitrogen abatement is likely to exceed corresponding investments in sewage treatment plants and decreases in farmers' use of nitrogen due to two factors; (i) provision of other secondary values, and (ii) future growth in the capacity to produce secondary values, or equivalently, increase in primary value.

When measuring the value of an investment in a wetland, in sewage treatment plants and reductions in farmers' use of nitrogen, two types of information are required; (i) a value function for improved water quality, and (ii) functions relating the application of nitrogen to the ground water quality. A value function of water quality was obtained from a Swedish study in which CVM was applied to estimate the WTP for a water quality of no more than 50 mg NO_3/l (Silvander, 1991). According to the results, the average WTP was SEK 600/person/annum (1990 prices). The sample group included Swedish citizens between the age of 16 and 74.

In order to relate the load of nitrogen to the water quality a hydrological model of Gotland was used (Spiller, 1978). According to the simulation results, the relationship between the load of nitrogen and the level of nitrate can be described by a linear function. When combining this function with the linear valuation function the result is that the value of improved water quality is constant and amounts to SEK 5/kg N-reduction.

The monetary measurement of the value of investment in wetland requires further information on the production functions for nitrogen abatement and other secondary values, monetary measurements of other secondary values, and a measurement of the change over time in the wetland's capacity to produce secondary values. The estimated nitrogen purification capacity of wetlands is based on the results of a Swedish study, according to which the denitrification of mature wetland varies between 100 and 500 kg N/ha per annum depending on type of wetland and on the locality (Lars Leonardsson, Limnology, Lund University, Sweden, pers. comm.). In order to account for the time that it takes for a restored wetland to reach its maximum nitrogen abatement capacity, the lower level of nitrogen purification was assumed, i.e. 100 kg N/ha per annum.

A measurement of other secondary values in money terms was obtained from the study of Martebo mire described in Section 4.2. However, since the results from this study are from a mature mire it is supposed that only a fraction, 10 per cent, of this aggregated value can be assigned to a restored wetland. Given that the nitrogen purification is 100 kg N/ha/annum the aggregated value of other secondary services then corresponds to SEK 3/kg N-reduction.

Restoration of wetlands is a recently established area of research and few experimental results are available which could be used in this model. It was therefore simply assumed that the rate of natural change in the stock of wetland is constant and amounts to 0.01/annum. In order to simplify calculations we have not included the physical depreciation of investments in sewage treatment plants. The discount rate used is 0.06 which is the level recommended by the National Swedish Audit Bureau.

Given all the above mentioned assumptions the total value of investment in wetland, in sewage treatment plants and reductions in farmers' use of nitrogen are calculated. The total value of investment in wetlands includes both primary and secondary benefits. Remember that the primary value is defined as the structuring and build-up of an ecosystem. It is assumed that one dimension of this value can be interpreted as the change in the wetland's capacity to produce secondary value. We therefore calculate the primary value as the difference in future streams of values with and without the growth rate of 0.01. The results are presented in Table III.

Table III. Values of investments in wetland, sewage treatment plants and reductions in farmers' use of nitrogen, SEK/kg N-reduction (1990 prices)

	Secondary values	Primary values	Total values
Restoration of wetland	168	42	210
Sewage treatment plants	105		105
Reductions in farmers' use of nitrogen	5		5

According to the results presented in Table III, the total value from investing in a wetland is at least twice as high as the values from other alternative investments. This is due to the wetland's multifunctional production of secondary values and to the growth in the production capacity. Note that the value from improved water quality as secondary value is the same for investments in wetland and sewage treatment plants. The additional secondary value obtained from wetlands amounts to SEK 53/kg N-reduction. The calculated primary value, which constitutes the growth in the secondary values, amounts to about 25 per cent of the total value.

It should be noted that the primary value is sensitive to the level of the growth rate. If this is doubled, from 0.01 to 0.02 the primary value increases from 42 to 110. In a similar way the results are sensitive to the choice of discount rate. When the discount rate decreases from 0.05 to 0.04 the total value from investment in wetlands and sewage treatment plants increases by about 30 and 25 per cent respectively. Inclusion of a depreciation rate for the investment in sewage treatment plants would reduce their future stream of values from water quality below the results presented in Table III.

5. Discussion

Many of the wetland functions and services discussed in this chapter do not have a direct market value. This is one fundamental reason why the wetlands' often unperceived but real and long-lasting societal support value has been destroyed or degraded via conversion to land use activities that generate a short-term, directly capturable and immediate income stream.

The aggregate value of the environment as a factor of production, and the 'free' support of ecosystems are not yet fully recognised within economic systems, although economies are dependent on this support to be able to function. For example, the human-made technical replacements discussed in the biophysical case study above, were installed because of a need in society to mitigate environmental and natural resource degradation and loss problems. But when replacements where in place (which in any case proved less than equivalent) it was generally forgotten that the original need for the replacement investment was the loss of the wetland's already existing life-support functions.

In the economics literature, the commonly used classification of values into use and non-use values is not fully satisfactory, since it does not explicitly differentiate between alternative life-support functions of an environmental resource. The direct methods, applied to measure use and non-use values, usually contingent valuation, are therefore in many cases inadequate for revealing the full functional value of the environment. Direct methods have, however, a role to play when measuring the value of certain environmental services, such as recreation values or aesthetic values, which was shown by the case study of the Broads.

In order to gain a better understanding of the different functions of wetlands another value classification system has been suggested here; primary and secondary values. The primary value refers to the structure and build up of an ecosystem and the secondary value is defined as the outputs, the life-support services, provided by the wetland. Part of the secondary values can be valued by both direct and indirect methods. However, in order to find a measurement of the primary value biophysical models of ecosystem functions are needed.

This paper provided two examples of measuring the primary value. The case study of Martebo Mire used a biophysical model. In the case study of wetland restoration in Gotland, biophysical models were integrated with an economic model. The results from these studies indicated that investments in wetlands to gain one ecological service, also generate several other secondary values. This is due to the multifunctionality of the wetland which results in large benefits relative to those available from more conventional technologies. Restoring wetlands also creates 'new' habitats for species, and generally makes the landscape more diverse. In fact, using a living system in this way implies using biological diversity for the production of goods and services.

6. Conclusions

On balance, given the historical and on-going large scale loss of wetland and the argument that most wetland, once destroyed, can only be partially and imperfectly replaced by man, a precautionary approach to further wetland exploitation is strongly recommended. Although the case studies presented here show that the estimation of wetland values can be improved by a good understanding of the functioning of the ecosystem they also show that only part of the total value can be measured in money terms. In the context of project appraisal involving development versus wetland conservation conflicts, it would therefore seem appropriate to require that cost-benefit analysis be used to choose between alternatives only within a choice set bounded by sustainability (ecosystem stability and resilience) constraints (Common and Perrings, 1992).

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