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Biophysical energy analyses of non-market values of the Ebro Delta

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Abstract. Non-market values were estimated with energy analysis under four land cover scenarios in the Ebro Delta, Spain. The market value of agriculture, the primary use value, is compared. Conversion of the natural landscape to agricultural fields has resulted in a drop in total annual non-market value from $721 million in the pristine scenario to $11 million in the present scenario. The market value of the agricultural crops has risen over time, from $10 million to almost $52 million, contributing the major portion of the total value of the Delta. However, the rate of return has decreased from the pristine to the present delta, indicating that more energy is required to produce a smaller output. Energy analyses reveal that one form of value – non-market value – is being traded for another – market value.

Keywords: Biophysical valuation; Economic sustainability; Natural energy; Net primary productivity; Subsidy.

Abbreviation: EA = Energy Analysis; GNP = Gross National Product; FFE = Fossil Fuel Equivalents; GPP = Gross Primary Productivity.

Introduction

Current neoclassical environmental valuation methodologies are based on anthropocentric bases of value, primarily utilitarianism (Goulder & Kennedy 1997). 'Valuable' ecosystem goods or services must directly or indirectly bring humans satisfaction. People reveal satisfaction by the choices and preferences they make in spending their money and/or time. Estimates of satisfaction are based on the assumption that the value of a given good or service is the amount people are, or would be, willing to pay (WTP) (Tietenberg 1996).

Price is the satisfaction indicator for marketed goods. In perfect markets with well-defined property rights that are exclusive, transferable, and enforceable (Panayotou 1992), supply (marginal costs) equals demand (marginal benefit). Prices, therefore, provide measures of economic value. However, commercial markets fail to adequately capture the true value for ecosystem goods and services. Their common property nature prevents formation of efficient markets, resulting in under-valuation and/or over-consumption (Panayotou 1992). For extractive industries, such as wood products, the market economy tends to capture the value-added from transforming the natural resource into something directly useful to society. The actual cost of the basic production of the resource is assumed to be free or negligible. Thus the market price does not actually signal the true value (Goulder & Kennedy 1997).

Estimating value is more difficult for non-marketed goods and services (e.g. water purification, wetlands for fish habitat, etc.) as there is no direct, observable exchange of money to indicate willingness to pay. Methodologies such as contingent valuation, hedonic pricing, and travel cost estimates aim to determine value from expressed preferences, either real or hypothetical. Stated preference techniques work well for topics that are familiar and have well-defined preferences. However, studies report significant differences among techniques for issues with important information and functions less well-known and preferences more diffuse, as with ecosystem goods and services (Boxall et al. 1996). Thus, it becomes more difficult to elicit meaningful value estimates on non-market items.

Ecologists have a different notion of value. Instead of reserving the term 'value' solely for ecosystems of direct or indirect human satisfaction, areas of high biodiversity and productivity, ecosystems with endemic species, or areas free from human impacts, are valuable in and of themselves (e.g. Goulder & Kennedy 1997). However, in a world where economics is usually the bottom line, protecting or maintaining resources on the basis of intrinsic worth is often ineffective.

Energy Analysis

Energy Analysis (EA) is another form of valuation. Instead of using monetary flows, biophysical units of energy are the common numeraire for valuation of natural and man-made goods and services. Unlike neoclassical economic techniques where value is determined by human demand and preferences that can change, EA is based on the energy required for the natural resource production. Essentially, it amounts to a supply cost to the system (Brown & Herendeen 1996; Costanza & Farber 1984). Some ecologists have long argued for such valuation as more suitable for natural ecosystems (Bullard III & Herendeen 1975; Cleveland et al. 1984; Costanza 1980; Odum 1971; Odum 1996). Ecosystems have two production cost components: (1) the value-added cost, which is the extraction and transformation of the raw product to something socially desired and is captured by market prices, and (2) the system cost to produce the natural resource initially. This system cost has generally been considered a free good and, thus, ignored. EA specifically addresses this second component.

EA captures the amount of energy required for the system to produce a certain good. It focuses on the energy consumed within a natural system. This approach assumes that sunlight is the most significant free net energy input to the biosphere. This total energy is known as the 'embodied energy' (Costanza 1980). The critical link is the conversion of embodied energy to economic value. This conversion is based on an assumption of proportionality between energy inputs in the economy and aggregate Gross National Product (GNP), which remains controversial (Bullard III & Herendeen 1975; Cleveland et al. 1984; Costanza 1980; Mansson & McGlade 1993). Critics contend that economic values are not necessarily related to energy consumption (Huettner 1982). Whereas direct usage and value are not related to energy consumption, direct and indirect energy usage are (Cleveland et al. 1984; Costanza 1980). The critical hypothesis is that natural and human products would correlate with their economic value if all market imperfections were removed (Costanza & Farber 1984). Recent studies further support a biophysical basis of valuation. Templet 1995 showed that for developing countries Net Primary Productivity (NPP), an index for solar energy, correlated positively and significantly to Gross National Product (GNP). NPP for the major biomes has also been found to be highly correlated with value estimates (Costanza et al. 1998).

There are certain limitations to EAs. Energy analyses do not resolve the challenge of valuing unique or rare ecosystems as they measures total energy flow. They also do not account for habitat interdependence, differences within habitat, uniqueness, or extremely rare, important features. Also, EAs may include services that are not directly economically valuable.

Objectives

In this paper we performed an EA to estimate the non-market value of the Ebro Delta, Spain, under different land cover scenarios for the purpose of comparing economic impacts of landscape changes. The Ebro Delta has undergone large landscape transformations over the past century largely due to intense agricultural activities (Grau Folch & Sorribes Monserrat 1985; Anon. 1997). The market value of the agricultural harvest is also presented for comparison.

Study area

The Ebro Delta is located on the Spanish Mediterranean about 200 km south of Barcelona. It has an area of ca. 330 km^2, most of which is used for agricultural production, mainly rice fields. Only 25% of the natural landscape remains and is composed of wetlands, lagoons and beaches. Though human impacts in the Ebro Delta date back hundred of years, intense humanization of the landscape began in the 1860s with the construction of agricultural irrigation canals (Grau Folch & Sorribes Monserrat 1985; Anon. 1997). The transformation from a pristine delta into what is essentially a large agricultural field has altered critical natural energies, undermining hydrological and sedimentary transport dynamics. Dams in the catchment basin have reduced freshwater and sediment transport. The mean annual flow of the lower Ebro river has been reduced almost 50% since the early 1900s (Ibàñez et al. 1997). Large reservoirs have reduced the annual sediment transport by about 99% since the turn of the century (Ibàñez et al. 1996), impacting both vertical and horizontal delta formation. The delta plain is losing elevation because subsidence is no longer offset by clay and silt sediment inputs. In addition, drainage waters from rice fields export sediments at a rate equivalent to ca. 0.2 $mm.yr^{-1}$ loss in elevation (Ibàñez et al. 1997). Reduction of coarse sands has led to reworking along the delta fringe without an increase to the coastal sediment budget (Sanzhez-Arcilla et al. 1998).

Methods

Energy Analysis

The technique used in this study follows Costanza and Farber's (1984) and Turner et al.'s (1988) easily calculated, simplified version of the more data intensive input-output energy methodology (Costanza 1980). It involves three steps:

1. Calculate gross primary productivity (GPP) of the natural system

GPP is the index for embodied energy of the system. It measures the solar energy that drives ecological systems. In this study, GPP was estimated from measurements of NPP for each habitat as reported in (Cardoch 2000; Cardoch et al. subm.) and NPP was converted to GPP based on reported ratios (Turner et al. 1988). All are reported in $kg.ha^{-1}.yr^{-1}$.

2. Calculate fossil fuel equivalents

The link to derive economic value from GPP lies in part in the conversion to Fossil Fuel Equivalents (FFE). Whereas GPP is a good measure of the total system energy, it needs to be converted to an economically relevant energy source, such as fossil fuels. This conversion involves two steps. First, GPP is converted from kg of dry matter production to kcal, based on a factor of 4×10^6 kcal plant production/mT dry matter (Costanza & Farber 1984). Next, kcal are converted to FFE based on a factor of 0.05 kcal FFE/kcal plant production; this is due to the difference in energy quality among the fuel sources, i.e. plant biomass has an energy concentration $20 \times$ less than fossil fuel (Odum & Odum 1976).

3. Calculate economic value

Economic value is derived from converting FFE to a monetary equivalent based on a conversion factor of 15,000 FFE/1982$ (Turner et al. 1988). There is a high correlation between direct and indirect energy consumption and US dollar values in the US economy (Cleveland et al. 1984; Costanza 1980). Dollar values were converted to 1998 using the Consumer Price Index. Present values are presented as a suite of discount rates.

Discounting

Whereas it is not the scope of this paper to discuss discounting at length and the controversy surrounding the use of different rates (cf. Hanley & Spash 1993), it is useful to point out a few salient features. Discounting calculates the present value of the series of future costs and benefits. Essentially, the higher the discount rate the less value we place on the future worth. A high discount rate implies that future benefits are worth less than benefits received closer in time, and, thus, discourages investments.

A low discount rate for natural resource projects is not equivocally the answer for habitat protection. Interestingly, the US government used 2.5% in its dam construction and irrigation projects during the 1960s and 1970s. Using a higher discount rate would have rendered the present value of those projects unprofitable and thus halted construction (Page 1977, as cited in Hanley & Spash 1993). High discount rates would render other habitat altering projects, such as wetland drainage and river channelization, less profitable as the high capital expenditures associated with those activities would bring fewer returns. High discount rates discourage investments and would also render development of alternative technologies less desirable. A low discount rate would favour investment, but would also increase the amount of energy used to support the investments. Thus, unequivocally endorsing a certain discount rate does not always ensure beneficial outcomes for natural resources. However, when calculating the benefits accrued from non-marketed natural resources, a lower discount rate presents a more favourable estimate of the present worth of those resources.

Turner et al. (1996) endorsed a social discount rate from 0.5% to 3% as a rate compatible with goals of sustainability. They argue that discount rates should be closer to the social rate of time preference, which differs from the private rate, than to the market rates, which range from 8% - 10%. In this paper, we apply three discount rates where present values are used: 2% representative of a social discount rate, 9% representative of the market discount rate, and 5% an intermediate position. Presenting the results as a suite of alternatives illustrates the importance of discounting for policy analyses (Turner et al. 1996).

Scenarios

Non-market market values were determined for four land cover scenarios that document the change from a relatively undisturbed delta to the present intensive transformed agricultural delta: a pristine delta, an historic delta, the present delta, and a future delta (Fig. 1). The pristine delta is the hypothetical case of the delta before human intervention with 100% natural vegetation (Curcó et al. 1996). The historic delta (ca. 1860) marks the start of intense agricultural transformations, with ca. 25% used for agriculture (Anon. 1997). The present delta is the current land cover scenario in which agriculture covers over 75% of the landscape.

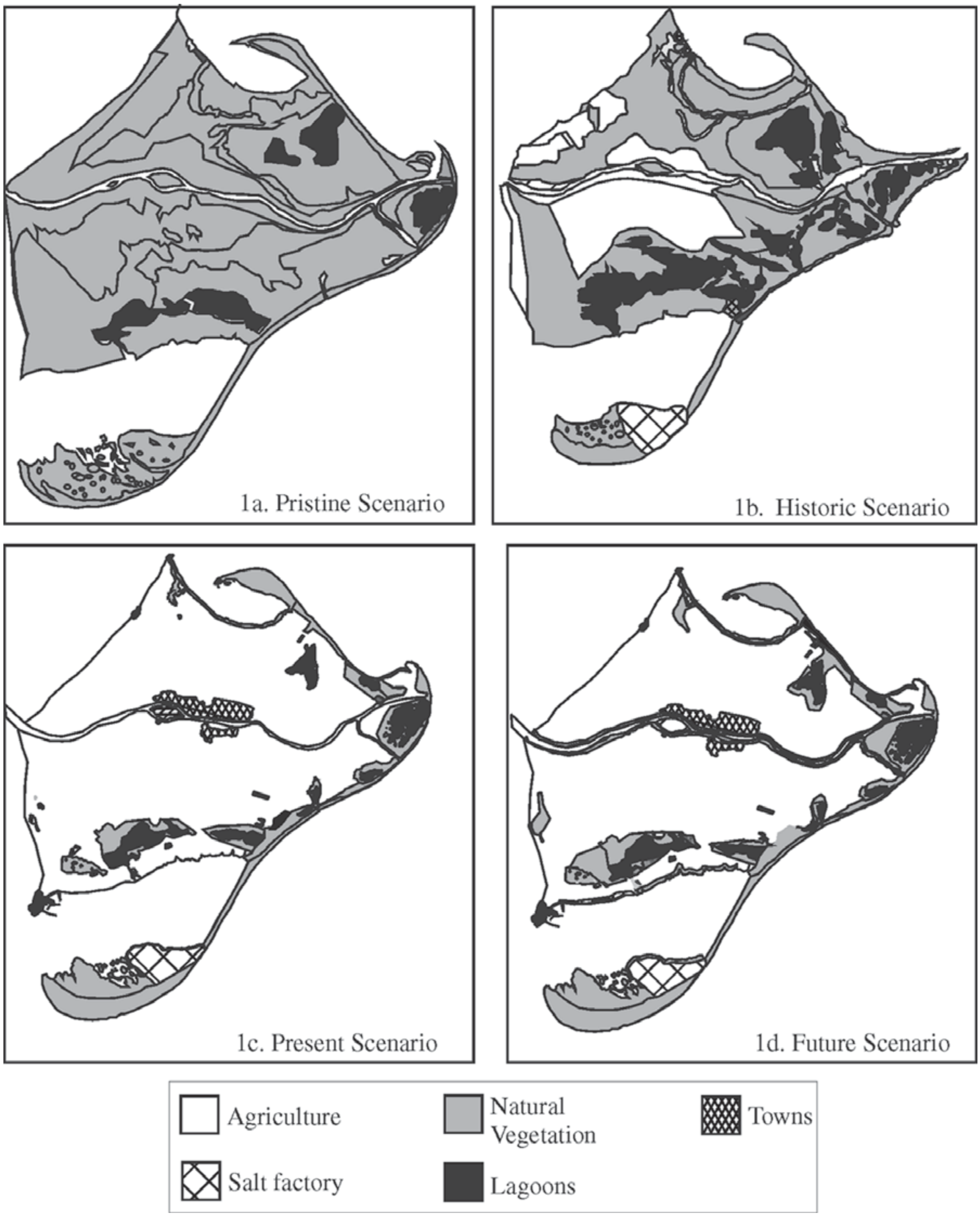

Fig. 1. Land use and vegetation scenarios of the Ebro Delta: **a.** All natural vegetation; **b.** Ca. 1860. Limited agricultural activities, concentrated primarily on natural levees; **c.** Ca. 1990. Land areas are under agricultural production; natural areas are limited to lagoons and dunes. **d.** Land cover under a proposed management scenario that converts agricultural land back to its natural vegetation and increases buffer zones. Enlargement of natural areas occurs around the river mouth, internal lagoons, and the southern fringe of the delta. (Adapted from Cardoch 2000; Cardoch et al. in press.)

The future scenario is based on a conservation management proposal whereby some agricultural areas would be converted back to natural vegetation (Ibàñez 1997). For scenarios with agriculture, only the crop residues were used in the EA as the rest of the biomass produced is removed from the landscape as harvest. We obtained all production and NPP estimates from Ibàñez et al. (2000), Cardoch (2000), and Cardoch et al. (in press).

Additionally, we determined total delta value, total net delta value, and the rate of return of the Ebro Delta scenarios. Total value was obtained by adding the market and non-market values. The market value was derived from the primary use value, which is agriculture. The use value of the delta was determined as the market price generated from rice harvests (Ibàñez 1997). The few areas of other crops were assumed to have the same profit margins. The total net value was obtained by subtracting the costs of production (Ibàñez 1997) and financial subsidies from the total delta value. The financial subsidies are derived from farm aid sponsored by the European Union. The rate of return was calculated by dividing the total value by the costs. All of the above calculations are in 1998 US dollars, or pesetas, where applicable.

Results

The pristine delta has the highest total non-market value at almost $ 21 million/yr (Table 1), as this is the area with the highest productivity remaining in the delta. Total annual non-market value drops from almost $ 17 million in the historic delta to $ 11 million in the present delta. Future value would rise to about $ 14 million due to conversion of agriculture fields to natural vegetation, thereby reducing harvesting pressures and increasing remaining productivity.

The present delta has the largest agricultural production and the highest market value at almost $52 million (Table 2). The market value has increased ca. 500% since the historic delta when agriculture was only a small part of the delta. However, incorporating the producer costs and financial subsidies from outside the delta that contribute to crop production causes the net benefit, or profit, to be much reduced (Table 2). Financial subsidies come from two agricultural programs sponsored by the European Union under the Common Agricultural Policy: (1) intervention prices and (2) agri-environmental programs. Intervention prices establish a minimum revenue level for farm products. Deficiency payments compensate farmers for gaps between market

Table 1. Energy Analysis of the Non-Market Values in the Ebro Delta.

Delta	Land cover	Total production (kg/yr)[1]	NPP (kg/ha/yr)[2]	GPP (kg/ha/yr)[3]	Annual value (1998$/ha/yr)[4]	Area (ha)	Total annual Value (1998$/yr)
Pristine	Wetlands / Natural areas	2.68E+08	8 115	27 024	631	33030	20827421
							Total $20 827 421
Historic	Rice residue	5,70E+06	3800	5852	137	1500	204820
	Crop residue	3.88E+02	388	596,75	14	3300	45950
	Wetlands / Natural areas	2.13E+08	7 778	25 901	604	27420	16571293
							Total $16 822 063
Present	Rice residue	1.27E+08	6040	9302	217	21000	4557784
	Crop residue	4.65E+06	1550	2387	56	3000	167090
	Wetlands / Natural areas	7.62E+07	8 303	27 648	645	9184	5924723
							Total $10 649 597
Future	Rice residue	1.15E+08	6 040	9 302	217	19100	4145413
	Crop residue	4.50E+06	1 550	2 387	56	2900	161520
	Wetlands / Natural areas	9.40E+07	11 183	37 239	869	11183	9717122
							Total $14 024 056

[1]From Cardoch (2000) and Cardoch et al. (in press); [2]Average NPP based on total production/natural area; [3]GPP for agriculture is NPP*1.54; GPP for wetlands is NPP*3.33, as per Turner et al. (1988); [4]Annual value based on 4×106 kcal/mT GPP, 0.05 kcal FFE/kcal GPP, and 15 000 kcal FEE/1982 $ production. Consumer price index of 1.75 used for 1998 $.

Table 2. Market value of the Ebro Delta.

Delta	Market price[1]	Producer cost[1]	Other financial inputs[2]	Profit net benefit
Historic	$ 10 358 400	$ 7 272 000	$ 0	$ 3 086 400
Present	$ 51 792 000	$ 36 360 000	$ 6 200 000	$ 9 232 000
Future	$ 47 476 000	$ 33 330 000	$ 6 200 000	$ 7 946 000

[1]Market Price and Producer Cost based on rice industry estimates in Ibanez (1997); market price based on 47 Spanish pesestas/kg, 6500kg/ha,160 Spanish pesetas/1993$ and areas farmed. Cost based on 33 Spanish pesetas/kg, 6500kg/ha, 160 Spanish pesetas/1993$, and area farmed. Consumer Price Index of 1.13 for 1998$. Assume same profit margin for rice and other crops.
[2]Level of economic aid from the European Union assumed to be the same for the future delta as the present.

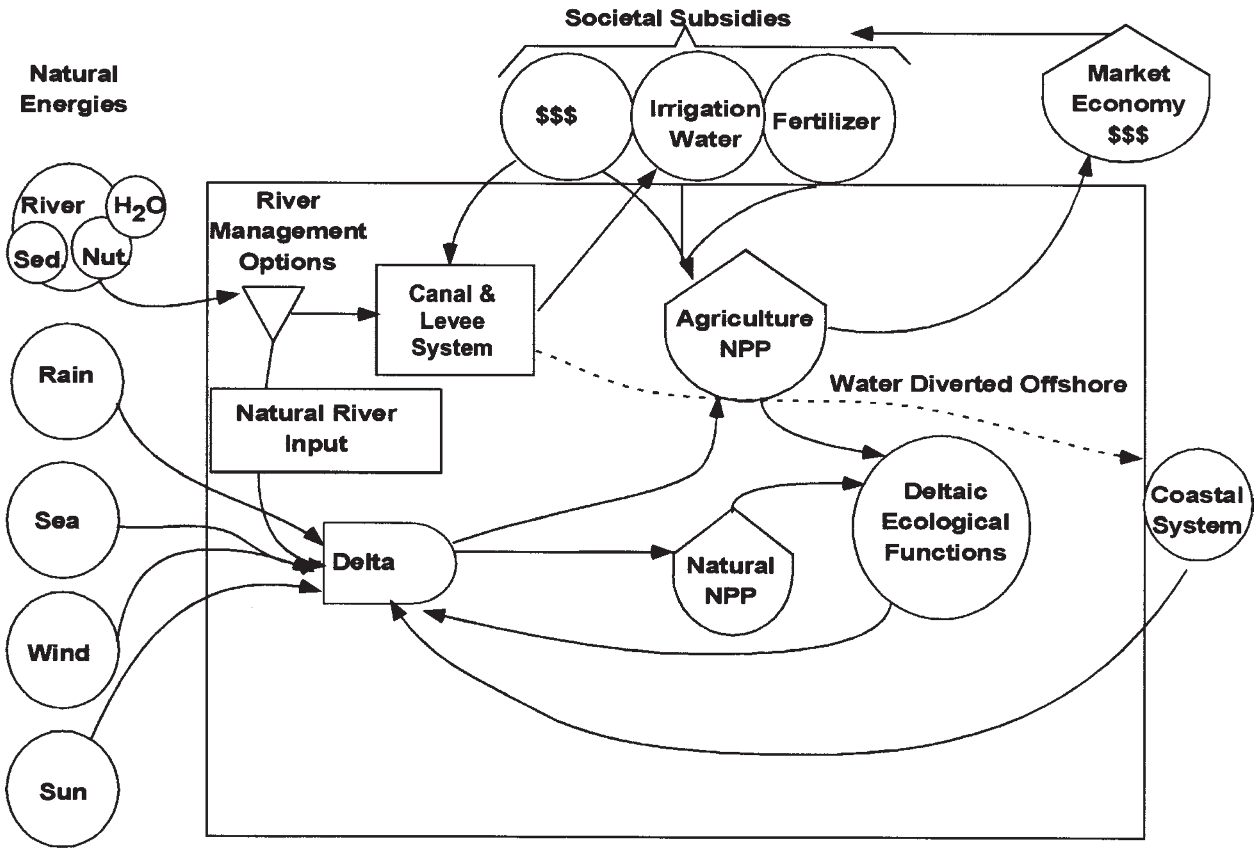

Fig. 2. Conceptual diagram of the Ebro Delta. River management options allow the river water to reach the delta marshes or maintain it within a canal and levee system for agriculture, flood control, and navigation. Water that enters the canal and levee system is lost from the delta and diverted offshore, thereby reducing natural NPP. Agriculture also reduces natural NPP because the harvest is exported from the delta. As natural energies are diverted from the delta, societal subsidies, in the form of irrigation, fertilizers, and money, replace nature's free inputs of water, sediments, and nutrients. Dashed line indicates water that is diverted offshore, by passing the delta.

Table 3. Total annual Delta value and Total annual net value.

Delta	Market value[1]	Non-market[2]	Total Delta value[3]	Costs[4]	Net Delta value[5]	Rate of return
Pristine	$ 0	$ 20 827 421	$ 20 827 421	$ 0	$ 20 827 421	very large
Historic	$ 10 358 400	$ 16 822 063	$ 27 180 463	$ 7 272 000	$ 19 908 463	3,74
Present	$ 51 792 000	$ 10 649 597	$ 62 441 597	$ 42 560 000	$ 19 881 597	1,47
Future	$ 47 476 000	$ 14 024 056	$ 61 500 056	$ 39 530 000	$ 21 970 056	1,56

[1]From Table 2.
[2]From Table 1.
[3]Sum of market value and non-market value.
[4]From Table 2, total of producer costs and other financial inputs.
[5]Difference of total Delta value - costs.

prices and the intervention prices (European Commission 1999). Average market prices for Spanish paddy rice ranged from 91 - 99% of the intervention price (European Commission 1998). Using average market prices and deficiency payments for the rice sold from the Ebro Delta, the subsidy to Ebro farmers would total ca. 191 000 000 Spanish pesetas (ca. $ 1.2 million). The agri-environmental program provides aid to farmer for environmentally friendly methods of production and pays for losses of income or costs associated with environmental measures. In the Ebro Delta, the program aims to have agricultural practices more compatible with the conservation of wetlands. Yearly funding for this program is about 812 000 000 Spanish pesetas (ca. $ 5 million) (Segura 1996). Thus financial subsidies or costs necessary to maintain agriculture in the Ebro Delta are ca. $ 6.2 million. Consequently, the net profit is ca. $ 9.5 million.

Value shifts from non-market to market as wetlands are converted to agriculture (Table 3). Total delta value rises from $ 20 million in the historic delta to over $ 62 million for the present delta. However, once the costs of production are removed, the net delta value for all four scenarios is almost the same, ca. $ 20 million. The rate of return has steadily declined since the historic delta. In the pristine delta, all of the total value is free. There are no producer costs associated since all of the inputs are natural services. The rate of return is thus very large. For the historic delta, the rate of return was 3.74. However, in the present delta, the rate of return is only 1.47. For the future scenario, it rises to 1.56.

Discussion

The economics of pulsing cycles

Fig. 2 is a conceptual diagram of the Ebro Delta that demonstrates the interaction of natural and societal energies on NPP and market and non-market values. Two main sources of energies affect productivity: natural energies and societal subsidies. The natural energies include sunlight, rain, wind, and the river, which delivers freshwater, nutrients, and sediments. These are the only energies affecting pristine deltas. Deltas are dynamic systems that have been built and maintained with riverine water, sediments, and nutrients over the past 7000 years (Roberts 1997; Stanley & Warne 1998).

In human-impacted deltas, however, management strategies have eliminated the natural dynamics of the riverine contribution as most of the river water is diverted before it reaches the delta – e.g. the Nile (Stanley & Warne 1993), the Po (Sestini 1996). Presently there are 170 dams in the Ebro River basin that reduce freshwater and sediment transport by ca. 50% and 99%, respectively (Ibàñez 1996, 1997). During growing season, irrigation canals control flow into the fields and disrupt the natural hydrology.

Disruptions and diversions of natural energies with levees or canals, for example, undermine the viability of the natural resources and lead to detrimental environmental and economic consequences. This is evident in the Ebro Delta where the delta plain is losing elevation because subsidence is no longer offset by sediment input to the delta. In addition, drainage waters from rice fields export sediments at a rate equivalent to ca. 0.2 mm yr^{-1} loss in elevation (Ibàñez et al. 1996), causing additional compensatory economic expenditures. For example, pumping stations are now taking the place of gravity drainage as the delta surface falls below sea level and declines in ecological productivity result in lost non-market values since the onset of human intervention. Similar results are also documented for the Mississippi Delta, USA (Cardoch & Day 2001).

Activities that incorporate natural energies from pulsing cycles will ultimately require fewer subsidies and maintain the resource base, as shown by Table 3. The declining trend for the rate of return indicates that humanization and manipulation of the system has resulted in more input per unit output. Humanization increases the total flow of money and supports a larger economy with more infrastructure, as shown by the total delta value, but it also incurs higher costs caused by the elimination of ecologically-critical and economically-valuable pulsing cycles, as shown by the net delta value. Eliminated natural, free riverine energies are replaced with socio-economic subsidies, such as fertilizers, irrigation water, and monetary aid. Economic estimates that incorporate environmental degradation reveal true costs of operating in those environments and could ultimately result in better environmental management as a result of long-term economic incentives (Daily & Ehrlich 1996; Daly 1991; O'Neill 1996).

Implications for sustainability

Day et al. (1997) and Cardoch et al. (in press) hypothesized that deltas are economically sustainable if the output of economic goods and services is greater than the economic inputs or subsidies required for production. Natural system dynamics maintain pristine deltas, but additional anthropogenic inputs are necessary to maintain and control the landscape in humanized deltas. Delta mismanagement (e.g. inappropriate strategies) or neglect (e.g. failure to consider activities upstream) leads to deltaic deterioration, diminished returns from associated goods and services, and ultimately results in an economically unsustainable delta (Cardoch et al. submitted; Day et al. 1997; Milliman et al. 1989; Stanley & Warne 1993).

Whereas we are unable to explicitly conclude that the Ebro Delta is economically unsustainable as only a limited number of activities were considered, the declining rate of return indicates that management strategies have been detrimental and could ultimately lead to economic insustainability. Furthermore, present practices violate the fundamental concept of sustainable Hicksian income (Hicks 1946). Hicks maintained that in order to have sustainable income the critical notion was to maintain capital stocks – the very source of income. Economic activities based on drawing down the resource base are inherently unsustainable as this constitutes a cannibalization of the capital stock, evident in the reduction in remaining NPP in the Ebro.

At a basic level of sustainability, the capital stock needs to exist. Yet, in the Ebro Delta, the capital stock of the delta itself is literally sinking. Human impacts have reduced accretionary processes necessary to offset subsidence and maintain elevation (Ibàñez et al. 1996, 1997). Dominant socio-economic activities currently undermine critical hydrologic and sedimentary processes that lead to geomorphic sustainability and sustainable Hicksian income (Cardoch 2000; Cardoch et al. submitted; Day et al. 1997). Unless this depreciation of sediments is addressed, loss of the capital stock will continue.

Biophysical valuation

The strength of biophysical valuation methods lies in identifying the impact of ecological changes on the economy. Energy analyses reveal that one form of value is being traded for another. Valuations that deduct depleted resources from total values or incomes dispel the notion that natural resources are free (Repetto 1992; Repetto et al. 1989; van Dieren 1995). In the Ebro Delta, the agricultural industry causes water quality problems due to the overuse of pesticides and fertilizers (Manosa 1997), declines in lagoonal fisheries (Museu del Montsia 1997), and soil depletion (Ibàñez et al. 1997). All of these losses should be incorporated into accounting evaluations of the agriculture industry on the delta. Whereas an industry may be profitable at the individual business level, it may be a losing proposition at the societal level. Energy analyses serve as an interface between the natural system and the human economy and can provide valuable information for evaluating impact of management scenarios on sustainability.

Conclusion

Large landscape transformations have reduced available energies in the Ebro Delta since the 1900s. The energy analysis accounts for these changes and indicates declines in non-market value due to human appropriation of net primary productivity in the form of agricultural harvests. Clearly, the human induced transformations have come at a cost to the system; there is a decline in the overall quality of the environment as total production for the same area drops and larger capital investments are required to maintain the same level of production. Quantifying the energy lost or diverted, integrates geomorphic conditions, provides a measure of value not captured by traditional economic analyses, and allows for more complete evaluations that can be used when determining sustainability of different management scenarios.

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