The Value Of The Tidal Marsh

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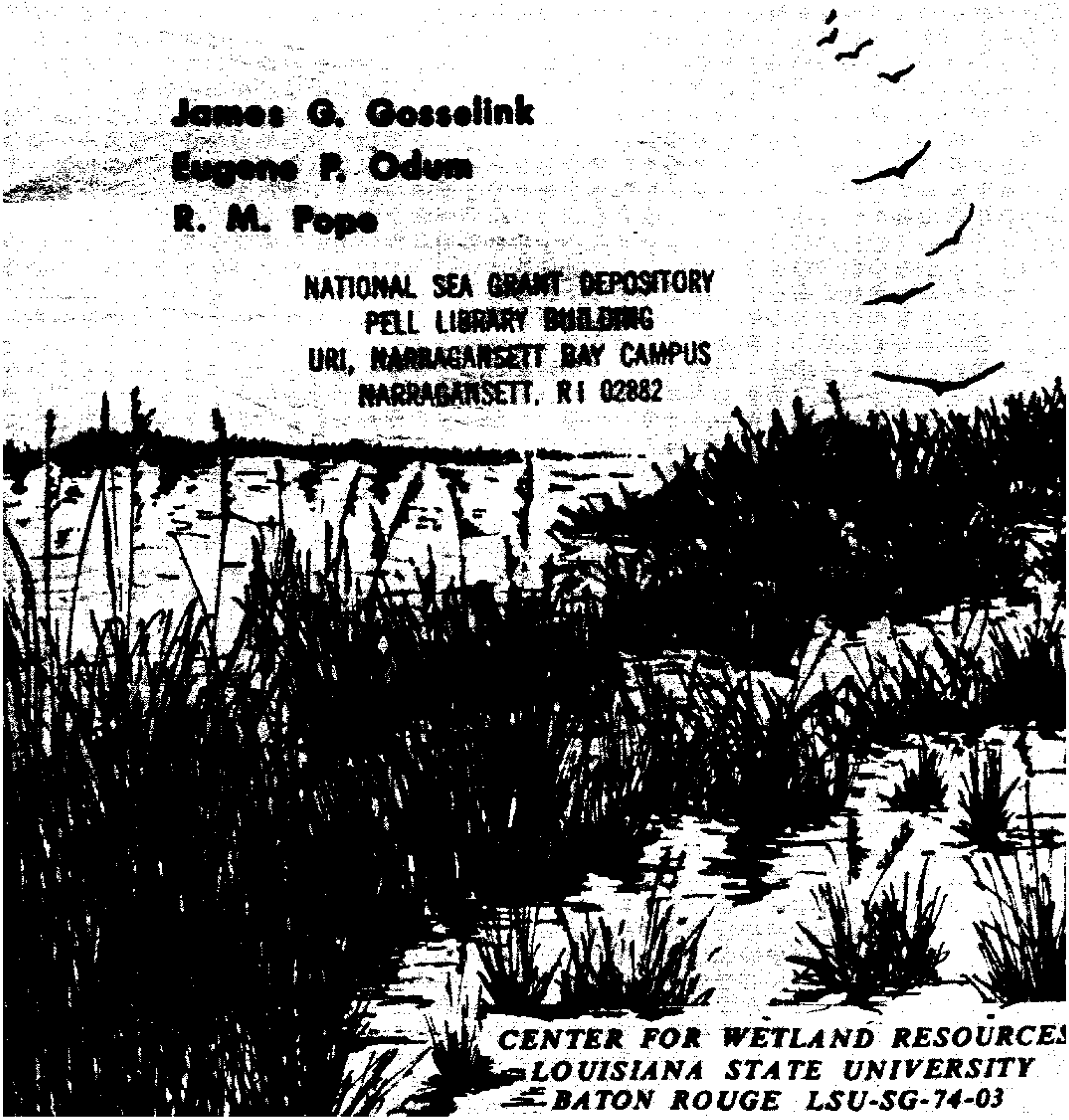

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THE VALUE OF THE TIDAL MARSH

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Abstract

Natural tidal marshes are evaluated in monetary terms. By-product production (fisheries, etc.) on a per-acre basis yields a value of only about $100 per year, even when the whole value of the fishery is imputed to the marsh. More intensive uses, such as oyster aquaculture, which preserve many of the natural functions of the marsh-estuarine ecosystem, have a potential up to $1000 per acre per year. The potential for waste assimilation is much higher, about $2500 per acre per year for tertiary treatment. Summation of the non-competing uses approaches an ecological life-support value of about $4000 per acre per year, based on the gross primary productivity (in energy terms) of the natural marsh, using a conversion ratio from energy to dollars based on the ratio of Gross National Product to National Energy Consumption. When these annual social values of $2500-$4000 are income capitalized at 5% interest the estimated total social values are $50,000-$80,000 per acre. Some estuaries, such as the Potomac or the Hudson, are now performing waste assimilation work of even greater value, but such estuaries are overloaded to the point of degradation.

Analysis based on the total value of the life support role of a natural tidal marsh-estuary suggests that a strategy of optimization in land use planning should replace, or supplement, reliance on the pricing system which is inadequate for preservation of natural systems that increase in value with the intensity of adjacent development.

Table of Contents

List of Tables

Introduction

The objective evaluation of different land use strategies has been severely hampered by the difficulty of stating the value of alternate objectives in a common currency. Cost accounting techniques for industrial, commercial and residential interests are well developed and these interests can bring strong pressures to bear because of the nearly universal acceptance of evaluation techniques which show the cash value of a particular management alternative. Against these evaluation techniques conservationists and natural resource economists have been at a disadvantage because of the difficulty of translating the value of natural or undeveloped areas into monetary terms. Frequently, therefore, the alternative management decision of leaving land in its natural state is not adequately defended nor seriously considered. Although recreation, for instance, is recognized as a legitimate land use it is difficult to place a cash value on the esthetic pleasure derived from an unspoiled forest or a natural lake (for a discussion of this problem, see *Pope* [1972]). As a result, hearings on proposed land use developments are usually charged with a great deal of emotion and frustration for all parties involved. In this paper we develop a step-wise means of assessing the true value of natural tidal marshes to society as a whole--a value based not only on commercial usage, but on social usage and the monetary value of natural (i.e. "undeveloped") estuarine environment.

Tidal marshes are lands which are particularly vulnerable to capricious development [*W. E. Odum,* 1970], because many of the real values of the marshes are not recognized, or accrue some distance from the marsh itself. *Teal* [1962] estimated that 45% of the net primary production of a Georgia *Spartina alterniflora* marsh was flushed into the adjacent bay by tidal action. *Odum and de la Cruz* [1967] estimated that the net export of organic matter (which includes many mineral nutrients) from 62 acres of such marsh was 100 lb and 310 lb on a neap and spring tidal cycle respectively. *Stowe et al.,* [1971] have estimated that well over one half of the total production of organic matter in a Gulf coast estuary originates from the surrounding marshes. In this way coastal marshes and other shallow water production areas (reefs, seaweed and seagrass beds, etc.) all over the world export mineral and organic nutrients that support much of the production of the adjacent estuarine and coastal waters [*E. P. Odum*, 1971]. Furthermore, as is well documented, estuaries serve as a nursery ground for commercially important coastal fish and shellfish. *McHugh* [1966] estimates that two-thirds of the cash value of species harvested on the Atlantic and Gulf coasts are "estuarine dependent." Thus, productive marshes are an integral part of the estuarine system which not only exports nutrients but also grows seafood that may be harvested in adjacent waters. Nursery ground is not the only valuable function of an undisturbed marsh, but it is an important, and now generally recognized, one. Even though the marsh may be privately owned the production of that marsh does not, at present, accrue directly to the owner, but to a commercial fishery, perhaps many miles away. Thus, the true value of a flowing-water exporting system must be based on a much broader cost-accounting than is usually employed in real estate evaluation.

At the other end of the spectrum of interested parties is the land developer. Because the coasts are often the most densely populated parts of the country, there is strong pressure to fill marshland for commercial, industrial and residential use. Indeed, with high marsh in prime commercial areas of New Jersey selling for as much as $80,000 per acre, the economic incentive to develop marshland is extremely strong. California has lost 67% of its marshland in this way, New York and New Jersey 10-25% [*Sweet*, 1971]. Additionally, alterations in natural processes brought about by land management decisions strongly influence coastal marshes. Louisiana, for example, is currently losing 16.5 square miles of marshland per year, largely as a result of management practices for the Mississippi, Red and Atchafalaya rivers [*Gagliano, Kwon and van Beek*, 1970].

In the paragraphs below we present first the value of a natural tidal marsh-estuary based on identifiable present commercial and recreational uses for which monetary values can be rather well determined. Since this omits a number of other values the marsh has, which are identifiable, but more difficult to quantify, we discuss next some potential additional values and attempt to equate these with dollars. Thirdly, we calculate the total "life support" value of the tidal marsh according to the procedure suggested by *Odum and Odum* [1972]. Finally, a summary table is presented which is a method of integrating and summing values as a basis for land use planning in the coastal zone.

Fishery Production Based on Harvest of Naturally Produced Organisms

Since, as already acknowledged, fishery production in estuarine and coastal waters is linked to shallow water production zones such as tidal marshes, reefs and seagrass beds, one can estimate the present value of a unit of marsh and its associated tidal creeks by evaluating the dependent commercial fishery. For instance, on the Georgia coast the dockside value of fish and shellfish (including shrimp) in 1965 was $3.7 million [*Carley*, 1968]. Value added in processing amounted to $5.23 million, raising the total value to $8.9 million (Table 1). Georgia has 393,000 acres of coastal marshland [*Spinner*, 1969]. Directly proportioned this works out to about $23 per acre per year.* Sport

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* Conventional economics would dictate that a portion of the value of the catch be imputed to labor, capital (i.e., the shrimpboats), and management. Such an approach appears logical, but the value of the fish and shellfish then becomes zero, as a common property resource, i.e., the fish are worth nothing until caught, and when caught their final price is allocated among the fishery-owned inputs used in their capture. The present approach, imputing all of the value of the fish to the area providing the beginning of the food chain and the nursery space, indicates the dependency of jobs and commercial fisheries <u>on</u> the existence of these free resources. To be more complete, an attempt might be made at evaluating the consumer surplus derived from the consumption of these marine products, that is, the difference between purchase price and the highest price that the consumer would be willing to pay. (Example: a consumer buys and enjoys a pound of shrimp for $1.5 but would be willing to pay $2.00 per pound rather than do without shrimp. The difference, 50¢ per pound, is his consumer surplus, and is attributable the productivity of the marsh.)

TABLE 1. Estimated Annual Value of Estuaries for Current Level of Shellfish and Sport Fishing on the Georgia Coast, on the Assumption that Fisheries Depend on the Marsh-Estuaries Lying within the Outer Barrier Islands.

	Dollars Per Year million	Dollars Per Acre per year[3]
Shell-Fishery[1]		
Dockside value (1965)	3.7	
Value added (in processing)	5.2	
Total	8.9	$23
Sport Fishing		
281,418 salt-water fishermen @ $80[2]	22.5	57
Recreation other than sport fishing (boating, hunting)	11.2	28
Annual Value per Acre		$108

[1] *Carley*, 1968.

[2] *Odum, E. P.*, 1968, page G-12, Table 8; prorated to include whole state.

[3] Assuming 393,000 acres of coastal marsh estuaries in Georgia (*Spinner*, 1969).

fishing along the Georgia coast is estimated to involve 280,000 fishermen who spend an average of $80 each per year [*E. P. Odum*, 1968]. Other recreational uses such as hunting and boating are arbitrarily valued at one-half the sport fishing so that a total fishery and sporting value comes to $108 per acre per year (Table 1). Comparable statistics for Louisiana and Florida marshes are shown in Table 2. They vary somewhat from the Georgia figure but yield similar estimates suggesting a minimal value of about $100 per year per acre of marsh just from the standpoint of fishery and recreational values.

These figures place a value upon a piece of real estate which is easily comprehended in terms of present evaluation techniques. Using the income-capitalization approach (see *Barlowe* [1965], page 188) the formula, $V = R/i$ where V represents the value of a parcel of land, R represents the annual return from it, and i represents the appropriate interest rate, it may be easily seen that the minimum value of an acre of marshland, due to fishery and recreational returns is $2000, if $R =$ $100 and we assume an interest rate of 5%.

Admittedly the estimate of $2000 can be questioned since one cannot prove that all the fishery would be destroyed if the marshes were; nor can one say exactly how many acres of marsh are necessary to support the present level of fishery activity in estuarine and offshore waters. And, repeating, all of the value of the fishery harvest is here imputed to the marsh, imputing nothing to capital, labor and management. The low *Spartina alterniflora* marshes, because they are subjected to vigorous tidal flushing that acts as an "energy subsidy," are certainly more valuable per unit area for estuarine productivity than the higher, dwarf *Spartina* or *Juncus* marshes [*Odum and Fanning*, 1973]. Of course, if the latter cover large areas, the total contribution can be considerable. As we aim to show even this inflated value based only on the harvest of naturally produced by-products falls far short of the value obtained by a more complete cost accounting that includes other, and in the long run, more important considerations.

TABLE 2. Annual Value of Coastal Marshland for Commercial Fisheries in Louisiana (1970) and Florida (1971).[1]

	Lbs per Year million	Dollars per Year million	Dollars per Acre per year[2]
Louisiana Fisheries			
Oyster	8.6	3.6	
Shrimp	91.0	34.6	
Blue Crab	10.3	.9	
Atlantic Menhaden	959.8	19.9	
Finfish (other than Menhaden)	4.2	.7	
Total Dockside Value		59.7	
Value Added in Processing (75% of dockside value)		44.9	
Total Value		104.6	$48
Florida Fisheries			
Shellfish	61.5	28.4	
Finfish	103.8	14.8	
Total Dockside Value		43.2	
Value Added in Processing (75% of dockside value)		32.5	
Total Value			$75

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[1] U.S. Dept. of Commerce, Current Fisheries Statistics NO. 5794 and 5919. Louisiana Landings, Annual Summary 1970.

[2] Assuming 2.2 million acres of saline and brackish marsh in Louisiana [*Chabreck*, 1970], 1.05 million acres of total estuarine habitat in Florida [*Sweet*, 1971].

Another approach to evaluation of land is to consider its potential for development; this is usually the major factor in conventional real estate dealings. In estuaries, development could range anywhere from intensive aquaculture to draining and filling for industrial or other use. Since this paper is concerned with evaluation of natural marshes we will consider only practices which would use the marsh as a renewable resource, but retain it in its more or less self-maintaining natural state. Oyster aquaculture provides a promising possibility since less modification of the estuary is required than for intensive shrimp or fish culture. Coastal estuaries can certainly support oyster production on a more intensive scale than is found at present. Estimates for income that might be obtained from this kind of development are shown in Table 3. Annual yields of 1800 pounds of oyster meat per acre, worth $1000 (with value added), were obtained by the late Dr. Robert Lunz, with moderately intensive culture in the marsh-bordered estuaries at Bear Bluff, S.C. [*E. P. Odum*, 1968]. A well-managed, leased oyster ground with heated hatchery and larval feeding yields about 4500 pounds of oyster meat per acre with a wholesale value of $1,575 per year. Very intensive raft culture, as developed in Japan, with rafts covering one-fourth of the water surface, could theoretically yield as high as 17,500 pounds per acre [*Bardach*, 1968] at a value of $6,125 per year (Table 3). This kind of intensive aquaculture is possible only in flowing water systems where the organic production of a large area passes across the oyster rafts, and the feces produced by the concentrated oyster population are also carried away from the rafts. For instance, if the net primary production of a marsh-estuary system is about 18,000 pounds dry weight per acre (Table 6 and *Stowe et al.* [1971]) and a 10% conversion efficiency to oyster meat is assumed, then the primary production of 4 acres is required to support 1 acre of intensive raft culture of oysters.

Applying the income-capitalization approach as described in the preceding section, the three estimates for annual return for oyster

TABLE 3. Estimates of the Annual and Total Values of an Acre of Tidal Marsh-Estuary in Terms of its *Potential* for Aquaculture Development

	Annual Return	Total Income Capitalization Value (round figures, at interest rate of 5%)[1]
Oyster Aquaculture - Moderate Culture Level		
1800 lb oyster meat per yr @ $.35/lb[2]	$ 630	$ 12,600
Oyster Aquaculture - Intensive Culture on Leased Oyster Grounds		
4500 lb oyster meat per yr @ $.35/lb[3]	1,575	31,500
Oyster Aquaculture - Intensive Raft Culture		
17,500 lb @ $.35/lb[3]	6,125	122,500

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[1] See text for explanation.

[2] *Odum, E. P.*, 1968, Page C-15, Table 11; based on data of R. Lunz.

[3] *Bardach*, 1968, p. 1102 and Table 1.

culture development would place the value of an acre of marsh-estuary at \$12,600, \$31,500 and \$122,500 for increasing intensities of oyster culture (Table 3). Again these figures impute no value to the capital, labor and management involved in the harvest. The value for intensive culture, in particular, is inflated, because of the high energy subsidy required to achieve this level of secondary production.

Waste Treatment Work as a Basis for Economic Evaluation

The shortcomings of evaluating environment in terms of direct uses or products only, is that such cost-accounting ignores the extremely valuable life-support work that natural areas carry on without any development or direct use by man. It is this "free work of nature" that is grossly undervalued, simply because it has always been taken for granted, or assumed to be unlimited in capacity. Because development by man may adversely affect this work, it is important to evaluate it before deciding what kind of development, if any, is in the long-term best interest of both the environment and the economy.

One very important contribution estuaries make to the growth and economic wealth of highly urbanized regions is the waste treatment that active ecosystems can accomplish without appreciable reduction in water quality. *Sweet's* [1971] estimate of the waste assimilated by five mid-Atlantic estuaries, in terms of BOD load received, is shown in Table 4. In general, the sewage discharge in these estuaries has received at least primary treatment. The secondary treatment work done by these estuaries to remove an average 19.4 lb BOD per acre per day can be valued at \$283 per acre per year, assuming incremental secondary treatment cost of \$.04 per pound (Table 5). However, waste assimilation in estuaries does not stop at the "secondary" stage but continues through the "tertiary" stage of nutrient removal and assimilation. Since artificial tertiary treatment of sewage is very much more expensive than secondary, then an acre of marsh-estuary is doing about \$14,000 worth of work per year at a daily loading of nutrients equivalent to 19.4 lb BOD, assuming the cost of

TABLE 4. Present Waste Loading of Mid-Atlantic Estuaries.[1]

	Area (acres)	Pounds BOD Discharged per day after treatment	Average BOD Load (per acre-day)
Delaware	70,500	1,030,000	14.6
Potomac	17,000	140,000	8.2
James	5,120	225,000	44.0
East River	18,800	339,000	18.0
Hudson	5,250	525,000	100.0
		Mean (weighted)	19.4

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[1] Data from *Sweet*, 1971.

artificial tertiary treatment is $2/lb BOD (Table 5). In other words, this is what it would cost man to deal directly with his wastes, if the acre was not available to do this work. Resorting, again, to the income-capitalization calculation an acre of estuary that is able to handle the mean waste loading shown in Table 4 is worth a whopping $280,000 (Table 5, Column 2). It is no wonder that large cities and industrial complexes tend to be located where large bodies of water are available for "free" treatment plants!*

Of course, it is apparent that mid-Atlantic estuaries are now overloaded (see especially Hudson and James estuaries, Table 4) to the extent that oxygen and other water quality aspects are reduced to an undesirable level, especially in terms of fisheries and recreation. The value of $280,000/acre thus represents a large "overload" of work that has serious pollution side-effects, and if continued or increased could result in system breakdown. If the BOD load can be reduced, these estuaries would function better as tertiary treatment plants and be more valuable overall.

In a detailed study of the Delaware estuary the Federal Water Pollution Control Administration estimated the cost of waste treatment to increase the minimum dissolved oxygen level to 4.5 parts per million (a very minimum water quality level) at $460 million (amortized capital and operating costs for 25 years). This works out to $264 per acre per year. The resulting improvement in water quality would yield recreational benefits and, more important, reduce stress on the system's ability to do tertiary treatment. It seems a small annual price to pay $264/acre to insure that the acre can safely do thousands of dollars of work free!

It is clear, then, that estuaries are not really effective in secondary treatment, because large amounts of organic matter introduced into systems naturally high in organic detritus reduce the dissolved oxyger

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* Some people would raise the issue of whether or not this work would be done at all if payment were necessary, and therefore whether it is appropriate to evaluate the marsh's work on such a basis. The answer is obvious. Witl out such treatment, accelerated pollution accumulation would soon exact payment, either through direct payment or indirect means, such as increasec medical costs, loss of recreational areas, loss of fisheries, etc.

TABLE 5. Estimated Value of an Acre of Marsh-Estuary in Terms of Waste Assimilation.

	Annual Return	Income-Capitalization[1]
For Incremental Secondary Treatment of Domestic (organic) Wastes		
19.4 lb BOD removal per day (see Table 4) @ $.04/lb	$283	$5,660
For Tertiary Treatment of Domestic (organic) Wastes		
Phosphorous removal (see text)	$480 - $1,420	$9,600 - $28,400
Total Tertiary Treatment Cost of Artificial Nutrient Removal of the Present Loading of Mid-Atlantic Estuaries (Table 4). Nutrients equivalent to 19.4 lb BOD per day @ $2/lb	$14,162	$283,240[2]

[1] See text for explanation of this calculation.

[2] Since present loading of mid-Atlantic estuaries is having severe pollution side-effects, this large sum is, in part, indicative of waste treatment costs that are not now being paid by cities and industries, but must be paid in the future. See text for further discussion.

levels to an undesirable extent. And, as we have seen, the economic value of estuaries as secondary treatment plants is relatively small, since the energy and money necessary for artificial secondary treatment is not large per unit volume of waste. For instance, a Rand report (R-1098-NSF; 1972) lists the amount of electrical energy needed for secondary treatment of 1 million gallons of municipal wastes as 660 kilowatt hours (about 56.8×10^4 kcal) which on a per capita basis is less than 1% of the electricity now consumed in an urban area.

The most important contribution marshes and estuaries can make in waste treatment is in tertiary treatment to remove and recycle inorganic nutrients, a very expensive process, as we have seen, if carried out by man in artificial systems. When nutrient-rich effluents enter a marsh the nutrients are effectively trapped by the tidal circulation pattern [*Bowden*, 1967], and assimilated in the productive biological system. Estuarine ecosystems have evolved adaptations to high nutrient levels, and have a large capacity to buffer nutrient changes. *Pomeroy et al.* [1972] have shown that the phosphate recycle system is so large and homeostatic in Georgia estuarine and marsh sediments that the level of phosphate in those waters varies little throughout the year, despite variation in input. Studies in Louisiana [*Ho et al.*, 1970] confirm this. The sediments act as both source and sink, effectively buffering the effects of large additions of phosphate to the estuarine system.

Although research results are not as clear for nitrogen, flooded marshes appear to be uniquely adapted for denitrification and, therefore, may be extremely valuable for treatment of inorganic nitrogen wastes also. Studies in flooded swamp and marsh soils [*Patrick et al.*, 1971] have shown substantial loss of inorganic nitrogen by denitrification in the anaerobic zone.

Experimental confirmation of these important water quality functions of marsh-estuarine systems is slowly evolving. *Valiela and Teal* [1972] treated salt marsh plots with sludge from a secondary sewage treatment plant, and measured the inorganic nitrogen and phosphorous loss on the first tide following each application. From late May through mid-November they applied 25.2 g sludge $m^{-2}wk^{-1}$ for a total of about 560 pounds nitrogen and 455 pounds phosphorous per acre. Through August losses from the marsh were almost negligible, less than 5%; they increased as winter approached. Roughly 500 pounds of nitrogen and 400 pounds of phosphorous were removed per acre of marsh in these tests.

Grant and Patrick [1970] give a second example in Tinicum marsh, Pennyslvania. Water flowing out of this marsh showed an average daily reduction per acre of 6.4 pounds of phosphorous (as phosphate) and 13.1 pounds of nitrogen (nitrate and ammonia), as compared with polluted waters flowing into the marsh.

Using the estimate of *Culp and Roderick* [1966] of tertiary treatment costs at $100 per million gallons and *Weibel's* [1966] estimate of 10 ppm phosphorous in sewage water, 83 pounds of phosphorous could be removed at a cost of $100. At this rate, the work done by the marsh in phosphorous removal alone is worth $480 per year (*Valiela and Teal's* data) to $1,420 per year (*Grant and Patrick's* data, assuming effective biological activity of 185 days per year). Income-capitalization of these data yield a per acre valuation of $9,600 and $28,400, respectively, for removal of only one major nutrient (Table 5).

In summary, it is clear that man should pay for secondary treatment of wastes since such treatment is relatively inexpensive, and untreated organic materials greatly stress any natural aquatic system, but especially marsh-estuaries. However, man will and should depend on productive natural ecosystems for tertiary treatment of huge volumes of low level wastes which would be extremely expensive to treat artificially. Thus, the economic value of estuaries as *tertiary* treatment plants can be *valued in tens of thousands of dollars per acre as compared to mere hundreds that accrue from by-product uses. The shallow-water zones occupied by marshes play a major role in this very valuable life-support work since their contribution to the overall metabolism of the estuary is proportionally high.*

Other Marsh Functions

Other functions of the natural marsh are more difficult to quantify, but no less real. Perhaps the most important of these is the role of the marsh in global cycles of nitrogen and sulfur. The continuing normal function of the biosphere depends on the chemical reduction of carbon, nitrogen and sulfur, which are incorporated into all living tissues. While carbon reduction occurs through photosynthesis in oxidizing atmosphere, completion of the cycle of the other two elements depends on microbial action in a reducing environment [*Deevey*, 1970]. Nitrogen fixation in the world has been nearly doubled by industrial fertilizer production [*Delwiche*, 1970]. Some of this reduced nitrogen is accumulating in the slowly increasing biomass on the earth's surface, as shown by eutrophied water bodies, but apparently the global biosphere has compensated for increased nitrogen inputs to some extent by increased denitrification. This microbial process requires the close proximity of oxidized and reduced zones. Nitrogen of biological origin is oxidized to nitrate in the oxidized layer, diffuses into the reduced zone and is reduced to nitrogen gas, escaping to the atmosphere. Tidal marshes are ideally suited for this function. Tidal waters carry nutrients to the marsh surface where they diffuse through a thin layer of oxidized sediment to the anaerobic zone below. The sulfur cycle, in the same way, depends on reduction of sulfates in anaerobic muds to sulfur and sulfides. Oxygen is a by-product of the reaction. In Linsley Pond, Conn., sulfate reduction may be as much as 10% of carbon reduction [*Deevey*, 1970], so its magnitude is of some significance. The industrial contribution to atmospheric sulfur has increased to about one-third of the total atmospheric sulfur burden [*Kellogg et al.*, 1972]. This sulfur is washed from the atmosphere by rain, primarily as sulfate. The lack of widespread accumulation of sulfuric acid is evidence of the efficiency of the sulfate reduction system in anaerobic muds.

These two processes have not been quantified on an area basis in estuarine systems but impressive evidence points to the importance of the coastal anaerobic muds to continued normal functioning of global cycles of nitrogen and sulfur.

There are still other marsh functions worthy of mention for which cost accounting is yet to be accomplished. A salt marsh is an important buffer against storms. In particular, it absorbs the enormous energy of storm waves and acts as a water reservoir for coastal storm waters, thus reducing damage farther inland. Some idea of the protective value of a wide band of energy-absorbing marshes and barrier islands is seen in the increasing national cost for "disaster relief" in coastal areas which either lack these natural protective "breakwaters" or where they have been filled in or "bulkheaded" for housing or other development; marsh and island-protected coasts suffer comparatively little damage even in fierce hurricanes. Rising costs of coastal development are very often the result of ill-planned modification of natural protective systems, not the result of increased storm intensity.

It is also becoming apparent that marshes are important in the protection of the beautiful white sand beaches of the outer barrier islands and "banks" (see *Hoyt,* [1967]; *Dolan et al, Godfrey, and W. E. Odum* [1973]). Where the energy and muddy sediments of storm tides can be absorbed by large areas of marsh-estuary the natural erosion of beaches is at least balanced by formation of new beaches. Beaches are degraded or lost where they receive the full brunt of storm tides unless man resorts to very expensive artificial breakwaters. Therefore, one is justified in adding some of the enormous economic value of outer beaches to the value of the inner marsh-estuaries. The powerful flow of water in and out of large tidal basins also tends to keep harbors and inlets "dredged"—another example of useful "free work of nature." Recently reprinted in "Benchmark Papers in Geology" [*Coates,* 1972] is an article by M. Burrows, published in 1888, that describes how all of the early harbors on the southeastern coast of England were silted in when the great marshes were first diked and filled in; constant dredging and "a vast expenditure of national funds" then became necessary to keep harbors operational.

One value of coastal marshes that is generally recognized is their importance as habitats for migratory birds which have esthetic and hunting values, not only locally, but elsewhere on the continent. Tidal marshes that receive large inputs of freshwater are especially valuable in this regard. For example, almost the entire North American population of snow geese and blue geese (millions of birds) are dependent on the marshes of the Texas and Louisiana coasts, which are their sole wintering grounds. Some of these same low-salinity marshes are also highly valued for their production of muskrat fur, but again the monetary value of such by-products on an acre basis is not large.

Life-Support Value as a Function of Productive Energy Flow

So far in this article we have resorted to the "component" approach, that is, identifying and separately evaluating products, uses and functions that are judged to have a value, or potential value, to man. The shortcoming of this lies in the difficulty of integrating or summing the component values, because many of the uses conflict with one another. Thus, intensive aquaculture would reduce sport fishing and recreational boating values, or heavy use for secondary treatment of sewage would greatly reduce many other values. Therefore, it is difficult to obtain an overall value by the component approach. Also, most of the component values so far discussed relate to the total estuarine system and not to the marshes per se; yet it is the marshlands that need to be valued in monetary terms since they are the parts of the system most vulnerable to modification and development by man.

H. T. Odum [1971] has suggested an "ecosystem" approach for translating the total work of nature into monetary terms, so that the overall value of a delimited natural area can be determined without having to specify how the work flow might be divided into different uses and functions. *Odum and Odum* [1972] have extended this approach in terms of land-use planning in which natural areas are considered as a necessary part of man's total environment. Since the exchange of energy and money is the basis for economic transactions, it is suggested that the ratio of Gross National Product to National Energy Consumption can be used to equate energy with money. The use of such a ratio is undertaken with the full understanding that both indices are approximations and not firm values. Gross National Product is the approximation of the total value of all the goods and services produced in the nation annually, including the value of capital goods used up in the production process. Though it has many shortcomings (i.e., work done by a housewife in lieu of hired help is not valued, the same work done by hired help is valued), it is widely accepted as the best approximation available. This level of output is achieved by consuming (approximately) the amount of energy reflected in the National Energy Consumption index. The use of these indices together permits us to determine an approximation of the amount of energy consumed per dollar of output on a national average basis. In round figures for the United States, 10^{16} kilocalories are consumed yearly to produce a Gross National Product of 10^{12} dollars, so that approximately 10^{4} kilocalories is equal to one dollar. Since the rate of primary production is a measure of the energy flow of a natural community, and an index of the useful work that might be accomplished, the ratio can be used to place a dollar value on any part of the natural environment where primary production can be measured or estimated.

One further qualification is worth mentioning. The value of a unit of energy generated in a natural system may not be directly comparable to a unit of energy delivered in the form of electricity to an industrial plant or home. The natural energy units are, however, essential to life, and for this reason the approximation may actually be a gross understatement in dollar terms.

Several recent estimates of the annual net primary production of coastal salt marshes are listed in Table 6. Several of these estimates, and most of those published prior to 1968, are underestimates because they are based on "standing crops" uncorrected for dry matter exported by the tides during the annual cycle. We judge the Louisiana and Georgia figures, as shown in Table 6, to be most representative of the highly productive marshes of the Gulf and south Atlantic coasts. Since, as already indicated, productivity is to a certain extent a function of water flow separate estimates are given for the higher or inner marshes (that receive less water flow subsidy) and the outer or low marshes (Table 6, Columns 1 and 2, respectively). Conservative estimates in

TABLE 6. Annual Net Production in Pounds per acre of *Spartina alterniflora* Marshes.

	Inland and High Marsh	Streamside and Low Marsh	Combined	Reference
Louisiana	11,750	23,600	--	*Kirby*, 1971
New York	4,520	7,350	--	*Udell et al.*, 1969
Delaware	--	--	3,780	*Morgan*, 1961
N. Carolina	--	--	5,770	*Williams and Murdoch*, 1969
N. Carolina	2,930	11,520	--	*Stroud and Cooper*, 1968
N. Carolina	5,420	11,560	--	*Marshall*, 1970
Georgia	6,200	18,750	--	*Gallagher et al.*, 1972
Georgia	--	25,700	--	*Odum and Fanning*, 1973
Georgia	--	--	17,880*	

*Calculated on basis that 40% of total Georgia *Spartina* marshes are high marshes and 60% are low marshes.

round figures, then, are: 9000 lb/acre for high marshes; 27,000 lb/acre for well-irrigated low marshes; and 18,000 lb/acre for large areas of total marsh with an approximate equal distribution of high and low types. Satisfactory measurements of total, or gross, primary production have not yet been accomplished for salt marshes. Since *Spartina* grasses utilize the recently discovered C_4 photosynthetic pathway, the amount of photosynthate dissipated in respiration is probably not as large as estimated earlier by *Teal* [1962]. Based on the efficiency of other C_4 plants adding 25% to the net production would give a reasonable estimate of gross production. Thus, annual gross primary production is probably of the order of 22,000 lb dry matter/acre overall, 11,000 lb/acre for high marshes, and 33,000 lb/acre for the more productive low marsh stands.

To estimate the dollar value of an acre of marsh based on the energy/money conversion outlined in the second paragraph of this section we need only to multiply the round figure productivity estimates by 1850 kcal/lb to get kcal/acre (see *Odum and Fanning,* [1973]), and divide by 10^4 kcal/dollar to get dollars/acre. Such a calculation gives a value of $4,070/year for the marsh as a whole (range: $2,035 for high marsh and $6,105 for low marsh). The income-capitalized value would be $81,400 per acre overall. This is a larger value than obtained by any of the component estimates, except for the "overloaded" tertiary treatment value (Table 5), which as already discussed is unreasonably high, and the intensive raft culture of oysters (Table 3), which requires large energy subsidies by man. The advantage of cost accounting based on productivity (i.e. capacity for life support work) is that it can be applied to a particular acre, or acres, of marshland itself as it functions as a part of the whole estuary.

Discussion

Round-figure values based on by-products, waste treatment and productivity are summarized in Table 7. The value of estuaries for waste assimilation and general life support is greater than that accruing from by-products. Extremely intensive aquaculture, such as raft culture of

TABLE 7. Marsh-Estuary Values as Determined by Various Methods of Evaluation.

Basis for Evaluation	Annual Return per acre	Income-Capitalization Value per Acre (at interest rate 5%)
(1) Commercial and Sports Fisheries	$ 100	$ 2,000
(2) Aquaculture Potential (Table 3)		
(a) Moderate oyster culture level	630	12,600
(b) Intensive culture of oyster beds	1,575	32,000
(3) Waste Treatment (Table 5)		
(a) Secondary	280	5,600
(b) Phosphorous removal[1]	950	19,000
(c) Adjusted tertiary[2]	2,500	50,000
(4) Maximum Non-Competitive Summation of values		
(a) 1 + 3c	2,600	52,000
(b) 2b + 3c	4,075	81,500
(5) Total Life-Support Value[3]	4,100	82,000

[1] Mean of two values shown in Table 5.

[2] BOD loading (as shown in Table 4) reduced to 3.5 lb/day, a level that reduces O_2 levels about 1 ppm.

[3] See text for calculation based on gross primary production.

oysters, is ignored here because of the high energy subsidy required by man and the fact that if carried out on a large scale it would eliminate most other natural functions. Summing values for components that could conceivably be non-competitive gives a "multiple-use" value approaching that based on productivity. As already emphasized the latter value (Table 7, No. 5) pertains directly to the marshlands, whereas all the other values summarized in Table 7 are based on the estuarine system as it functions as a whole.

Demonstrating that marshlands and estuaries have a substantial dollar value in their natural state certainly provides a big boost to preservation of such areas that are in public ownership. If large values such as those in Table 7 (items 4 and 5) are generally recognized and accepted, then state or federal agencies or commissions which have jurisdiction over the property or resource will be less likely to lease, give away, or sell valuable marshlands for capricious development. Also, planners will have a greater incentive and public support for zoning such areas into permanent protective categories.

On the other hand, if the marshland is in private ownership, the owner will stand to gain by selling for development no matter how high the appraisal, since leaving the area in its natural state earns the owner little or no return. *The dichotomy of interests between the value to the owner and the value to society becomes an increasingly serious problem as population growth and industrial development accelerate.* The pricing system, which one school of economics holds will solve all economic problems if left to operate unhampered, offers no solution to this problem since development becomes essentially an irreversible action. Thus, even though the value of marshland increases as it becomes scarcer to an eventual point that its life-support value could "outbid" other land uses there is no way to convert the previous development back to its former (and now more valuable) state. The irony of dependence on the price system is that it can make a reasonable sounding argument for developing marshland, and it can even offer an argument that a point will be reached when the land should be converted back to marsh, but it cannot effectively re-create marshland, a very expensive process, even if technically possible.

It is worth mentioning that, as high as the values herein determined for marsh acreage may seem to be, and though these values are average values, the principle of marginalism applies and the values will tend to increase with each increment of marsh lost to an alternative use, as well as through increases in population and industrial development. Less acreage in natural marsh doing the same or more work for man than is now done would indicate a higher value per acre to society, but it is apparent that a limit may be reached, beyond which further reduction of marsh acreage may prove disastrous.

Professor Herman Daly (LSU Department of Economics, personal communication) suggests that another approach to evaluating the tidal marshlands may be to simply catalog all of the functions which they carry out, and impute as the value of each function the costs which would be incurred if the next best method was used to accomplish the same result. This is the economist's "least-cost alternative" approach, and such an approach, summing all of the least-cost alternative costs, may well turn up values for marsh that would dwarf those reported in this paper.

Evaluation of marshland as a renewable resource, e.g. as an income stream stretching into the future and increasing continually, represents one way to alleviate the destructive tendency inherent in the pricing system as it now operates. The time has come to seek ways to let the owners of natural resources with value to society receive a return. Direct purchase by Government is one solution, of course; scenic or open-space easement and tax relief are other approaches. Setting up wetland "banks" where the owner is paid not to develop (as in "soil banks") is perhaps a feasible "delayed option" procedure in cases where outright purchase cannot be made at a particular time.

The best solution is a "look ahead" land-use plan which delimits the amount and location of life-support natural areas that will be necessary to support a future desirable level of development. Such areas can then be acquired or zoned into the public domain before the spiral of land speculation raises the market price. *Odum and Odum* [1971] present an overall model to show how the ratio of undeveloped to developed compartments could be objectively determined. Since many coastal wetlands are more productive than adjacent areas, they would generally receive high priority for inclusion into the undeveloped compartment.

Summary

Four levels were selected for monetary evaluation of marshlands and estuaries of the south Atlantic and Gulf coasts: (1) by-product production (fisheries, etc.); (2) potential for aquacultural development; (3) waste assimilation; and (4) total "life-support" value in terms of the "work of nature" as a function of primary production. Money values of marsh-estuaries in their natural state were calculated in terms of (a) annual return and (b) an income-capitalized value. Round-figure values per acre at the four levels were: (1) a, \$100; b, \$2,000; (2) a, \$1,000; b, \$20,000; (3) a, \$2,500; b, \$50,000; and (4) a, \$4,100; b, \$82,000.

The value of waste assimilation and total life-support work (levels 3 and 4) are several times higher than that which can be obtained from by-products, except possibly under intensive aquacultural development which in itself would eliminate recreational and most other uses. These high values (levels 3 and 4) represent estimates of what man would have to pay (i.e. "internalize") in terms of the value of the useful work of an acre of estuary should it not be available to do this work. Summing values for specific functions judged to be non-competitive results in a value approaching that obtained by a total life-support calculation (level 4), but the weakness of such a "component approach" is that most "multiple uses" do, in fact, compete at high levels of use. The advantage of level 4 cost accounting is that it can be applied to a particular acre, or acres, of marshland without having to specify how the work flow might be divided into different uses and functions (which will vary from time to time and place to place).

Detailed analysis of waste assimilation shows that marshes and estuaries are not very effective (and, therefore, not very valuable) for secondary treatment of municipal wastes, but that they have a tremendous capacity for tertiary treatment of nutrients, especially phosphorous. Since secondary treatment is relatively inexpensive and tertiary treatment very expensive if done by man in artificial systems, it is clear that the large BOD loading now borne by many estuaries should be greatly reduced by organic matter digestion in man's treatment plants in order that the natural systems can effectively carry out tertiary treatment and maintain a water quality that preserves or even increases seafood production, recreation and other by-product uses.

Demonstrating that marshlands have a substantial dollar value in their natural state provides an incentive for preservation of wetlands that are in public ownership, but not for preservation of those in private ownership since the owner may receive little or no direct return no matter how high the appraised value to society. The pricing system, as it now operates, does not work in this case since real estate development of marshlands becomes essentially an irreversible action. It is clear that marshlands must be evaluated as a renewable resource with a value that increases with urban-industrial development.

The time has come to seek means of letting owners of natural resources with high value to society receive a return. The best long term solution is a land-use plan which delimits the amount and location of natural areas that will be necessary to support a future optimum level of urban-industrial development. Then such natural areas can be acquired, or zoned, before the spiral of land speculation raises the market price. The technology of systems ecology is now being developed to the point that an objective compartmentalization between developed and undeveloped environment can be made. Since many coastal wetlands are more productive than adjacent areas, they would generally receive high priority for inclusion into the undeveloped compartment.

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