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The Cost of Not Holding Back the Sea—Economic Vulnerability

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ABSTRACT

A method for quantifying the economic vulnerability of developed shoreline to the threat of greenhouse induced sea level rise is described and applied to Long Beach Island, New Jersey, USA. While the method carefully accounts for structure, land and beach vulnerability along arbitrary sea level rise scenarios from tax maps and careful geographical accounting, it does not produce opportunity cost estimates for abandonment. The data generated here are, nonetheless, the foundation from which such cost estimates can be constructed given market and individual reactions to subjective perceptions of the threat and its timing.

1 INTRODUCTION

Increased atmospheric concentrations of radiatively active gases (e.g. carbon dioxide, various chlorofluorocarbons, methane, nitrous oxides, etc.) are expected to cause the mean global temperature to rise by 2–5 °C over the course of the next century.[1] The effects of this greenhouse warming are likely to be widespread, but our understanding of their social, economic and political ramifications is clouded by the enormous uncertainty with which we view their future trajectories. Figure 1 displays, for example, a range of estimates for greenhouse induced sea level rise that have been advanced over the past few years.[2–7] Given the vast range reflected there, it is clear that the fundamental question in pondering our response to sea level rise, or

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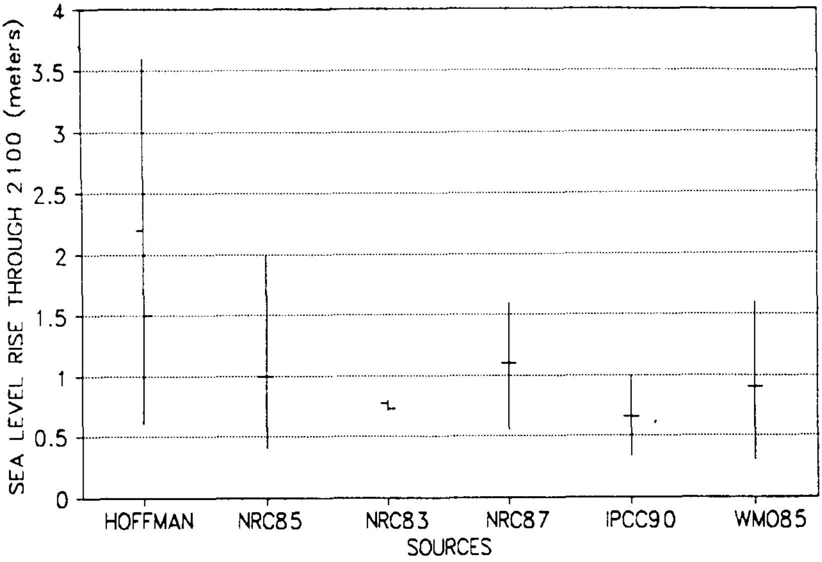

Fig. 1. Estimated sea level rise through 2100. For sources see refs 2–7.

any effect of global climate change for that matter, is one of determining whether or not anything should be done or even anticipated when we are so unsure of exactly what the future might hold. We are faced, in short, with a question of very long term decision making under conditions of extreme uncertainty for which methodologies based on the computation of expected present value are just now being developed.[8]

Our response to climate change might come in many forms. Some of our reaction might be designed to avert the problem by attacking its source (policies enacted to 'treat the disease' by, for example, reducing the emissions of one or more of the offending gases, cultivating new carbon sinks, etc.). Some might be designed to adapt to the problem by providing better means with which to cope with its effects (policies enacted to 'handle the symptons' by, for example, protecting threatened shorelines, actively managing the migration of forests, etc.). Still others might be complementary 'add-ons' that work either to ameliorate the greenhouse problem or to mitigate against its effects indirectly as a consequence of our reaction to apparently unrelated environmental or economic issues (e.g. the identification of 'no construction zones' along shorelines to protect inland resources from severe storm damage should also provide tidal marshes with areas into which they might migrate in the face of higher seas; improved automobile mileage capabilities should reduce emissions of the offending gases; etc.). The list of possible responses is thus long and varied, but evaluation of the relative efficacy of any response (or combination of responses) should be soundly based upon understanding of its range of potential local and regional consequences, even if it is envisioned on a national or international level.

As noted above, the appropriate objective function for ranking potential responses is easily articulated; it is the expected present value of the net benefit that each response should achieve. While the application of this ranking criterion to policy and timing decisions is not always straightforward, its very statement clearly identifies the type of information required to support that application. There are four major components involved in the calculation.

First, a subjective, time dependent distribution of the future values that might be assumed by some relevant state variables is necessary; in the area of sea level rise, a distribution of possible trajectories of mean spring high tide would be enough. The dispersion of expert opinion illustrated in Fig. 1 can be used to produce such a subjective distribution reflecting the best current view of what might happen.[9]

Second, an appropriate discount rate must be advanced, bringing to bear all of the controversy surrounding how to weigh the welfare claims of future generations against the welfare claims of those who presently inhabit the planet. Models of economic growth can, at least on theoretical grounds, be employed to suggest such a discount rate based on the 'golden rule' specification of the rate of growth of the 'effective' labor supply.[10–12]

Third, the cost of a proposed policy must be estimated, perhaps based upon engineering data with some uncertainty about future (relative) inflation rates incorporated in some ancillary sensitivity analysis. Returning to the sea level problem, the expenditure anticipated to build and maintain dikes or the sustained support of projects designed to raise the shoreline might, for example, be assessed, but other options can easily come to mind, as well.

Finally, the potential benefit to be derived from a policy response, usually based on the opportunity cost associated with anticipated climate change that would be avoided by that policy, needs to be evaluated. As we consider various strategies that might be empolyed to protect the shoreline, their net benefit will be based on the economic cost that would be incurred if we abandoned the coast in lieu of any protective strategy; it is a cost that will ultimately turn on how fast we learn and how fully informed our markets thereby become. It is in satisfying this final need to quantify the benefit side of the net benefit calculation that we presently fall well short of the mark, and it is toward filling that gap that this paper is addressed.

More specifically, it must be frankly accepted that there does not yet exist a comprehensive methodology with which decision makers can assess the future economic losses that would be created by abandoning the coast line in the face of some arbitrary scenario of future sea level rise. Previous studies have been suggestive and have attracted our attention, but they stop well short of providing the state-contingent, time-dependent data that are required to support the requisite expected net benefit analysis; more succinctly, careful economic analysis of the threat of future sea level rise require time series of potential damage tied directly to specific sea level scenarios.

Schneider and Chen (1980),[13] for example, report the potential cost of a 4·6 m rise along the US coastline at nearly US $450 billion (converted to 1990 dollars by the producer price index) with an associated displacement of 6% of the US population; their estimates for a 7·6 m rise are, correspondingly, over US $720 billion in economic loss with an 8% displacement. These are potentially staggering numbers, but they reveal no contingent time profile; in addition few now accept their underlying sea level scenarios as reasonable. Figure 1 displays the range of more recent estimates; the uncertainty portrayed there is enormous, but all of the underlying sea level rise trajectories fall short of adding 2 m to the oceans through 2100. The IPCC Report[7] has, in fact, gone further. After reviewing these and other studies, its authors suggest that the best current scientific evidence supports estimates of future sea level rise between 3 cm and 10 cm per decade through the year 2100.

Barth and Titus[14] reported the qualitative results of a small sample of local studies using more realistic scenarios. They included, in their accounting, not only the likely inundation of developed, undeveloped and marsh areas, but also the potential for saltwater intrusion, associated groundwater deterioration, and increased damage from enlarged storm surges. Even if they moved from physical impacts to economic impacts, however, their analysis would still produce only static pictures of the coastline for two years (2025 and 2075) and three specific scenarios. Gibbs[15] produced high national cost estimates based upon assumed rates of economic growth and aggregate data, but also stopped short of reflecting a time series at the micro-level where markets might operate to adjust and direct that growth. If we are to progress toward understanding the potential cost of abandonment in a way that accurately reflects the intertemporal opportunity cost values required to support our decisions, then attention must begin to be paid to collecting and manipulating the requisite micro-data.

The first step in providing these data is to develop a methodology by which researchers can catalog and measure the current value of real sources of economic wealth that might be threatened at specific sites along a coastline. Such measures, termed here 'economic vulnerability', represent initial, if naive, estimates of the social cost that would be incurred at each site if a decision to forego any protection from rising seas were made. If the sites chosen for application of the methodology were chosen as part of a national sample, then the localized estimates that they support could eventually be used to judge the potential vulnerability of a universally applied decision of no protection. They could, in other words, be used to produce a first cut at a measure of economic vulnerability across the US to greenhouse-induced sea level rise.

This paper reports on the early steps of a process designed to produce, ultimately, such a national estimate for the US based upon the sampling/mapping work of Richard Park and his colleagues at the Holcomb Research Institute.[16] The first three sections outline a methodology by which site-specific vulnerability estimates can be achieved, and report upon the results of its application to one of the sites in the Park sample—Long Beach Island, New Jersey. The underlying theory of the measurement is described in Section 2. There are three areas of focus: the value of threatened structure, the value of threatened land and, where appropriate, the social value of threatened coastline. The results of applying the theory to Long Beach Island are recorded in Section 3, with discussion of broader perspective postponed to a fourth section. A concluding section narrows the focus to consider the applicability of the methods developed here to issues of regional and local coastal management.

2 THE THEORY BEHIND MEASURING VULNERABILITY

The cost of not holding back the sea should flow from at least four separate sources: (1) the value of lost structure, (2) the value of lost land, (3) the value of lost social 'services' delivered from the existing coastline, and (4) adjustment costs associated with redeploying productive resources once applied to the lost land. The present effort considers only the first three of these sources, because they relate more to immediate measures of vulnerability. Consideration of the frictional costs of redeployment is postponed for future work—work designed to translate vulnerability to opportunity cost which will require careful modeling of intertemporal market adjustments to long term risk. Complete coverage of this translation is beyond the scope of this initial exercise.

2.1 The value of threatened structure

The precise notion employed to compute the current value of threatened structure is that people will abandon a structure when the land upon which it rests is covered by water at mean spring high tide. In fact, the inundation scenarios upon which most of the vulnerability calculations will be based are not sufficiently detailed to apply that notion exactly. The shoreline retreat scenarios provided by Park[16] indicate, for each site within his national sample, only the percentages of developed cells (usually 500 m^2) that are flooded as the seas rise. In practice, therefore, the percentage of structure currently located in each cell and deemed abandoned with each increment of sea level rise must be taken to be the percentage of that cell that is flooded.

More precisely, the current value of structure located within any specific cell can be estimated from tax records or housing and business census data on the basis of a sample of structures presently located within its boundaries. To be sure, neither tax records nor census data necessarily reflect current market value. A reasonable correction from recorded value to current market value can, however, be accomplished by noting (1) the percentage of market value reported by the assessor's office, and (2) some degree of inflation since the last assessment. The accuracy of the correction can, in addition, be validated by comparing the assessed values of structures now on the market with their quoted prices. Moving to an estimate of the value of threatened structure within that cell can then be accomplished using the percentages indicated by the inundation scenarios. If, for example, a 50 cm sea level rise is expected to put $x\%$ of the region under water by the year 2075, then it can be assumed that $x\%$ of the estimated value of the structure located in that region is lost by 2075. Adding across all threatened regions can finally produce a site-specific cost estimate of potential structure loss.

One sampling procedure upon which the estimation process can rest given more detailed inundation descriptions looks at strips of land running inland from the shoreline past a point at which (1) property and structure are no longer threatened by sea level rise and (2) property values no longer reflect surplus location rent derived from proximity to the shore. Series of real estate valuations along these strips should be sufficient to support aggregate potential cost estimates subject, of course, to some sampling error. Sampling error could be avoided completely if the inundation scenarios were sufficiently detailed and if tax records were digitized, but neither of these conditions is met in reality. Resulting estimates must rely, instead, on the efficient operation of real estate markets to keep the sampling errors low.

2.2 The value of threatened property

The same sampling procedure can also be used to produce estimates of the current value of lost land. There is, in fact, only one additional wrinkle which must be considered: exactly what parcel of land is lost when the sea rises? For structures, the answer to this question is simple; the structure that is abandoned is the one that is lost. For land, however, loss of a shoreline lot means that the next lot is now a shoreline lot. Economic vulnerability should, therefore, be measured at some interior lot away from the coastline.

To see this more precisely, consult Fig. 2; a hypothetical value gradient for one-eighth acre lots is displayed there. Note that values are assumed, for the sake of illustration, to start at US $100 000 on the shoreline and eventually to stabilize at US $50 000 some 500 feet from the shoreline. These are not real numbers, but they can be used to make a point. Were the sea to rise so that the first lot were lost, then the second lot would become a shoreline lot and assume the US $100 000 value originally attributed to the first. The value of the third lot would climb to US $90 000, and so on. The community would, in effect, lose the economic value of an interior lot located initially more than 500 feet from the shoreline. The true economic loss would be the equivalent of a US $50 000 lot instead of the shoreline US $100 000 lot; there would be a distributional effect, to be sure, but the vulnerability measure of net social loss would be US $50 000.[17] Where appropriate and accessible, this sort of accounting procedure

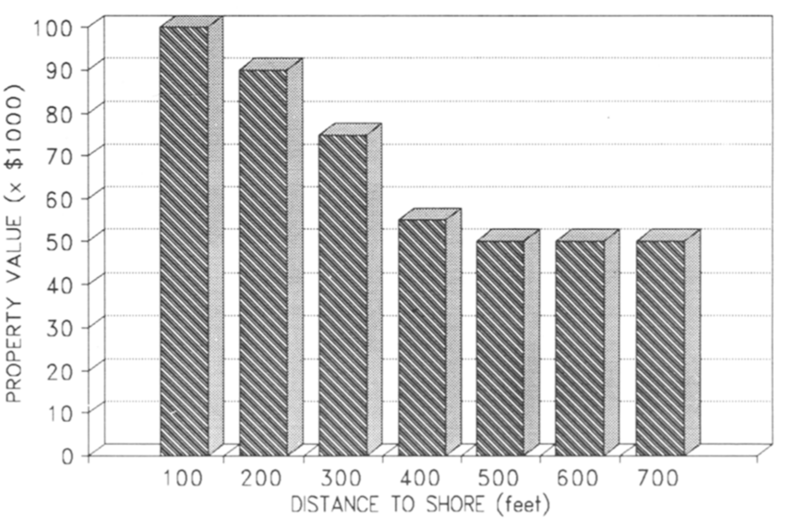

Fig. 2. Representative property value gradient.

can be applied in the property value loss calculations. The strip sampling method is, in fact, specifically designed to provide enough information to support its application. Note, as well, that the interior valuation process works from all directions for an island. The value of an interior plot of land can, as a result, rise, at least for a while. Proper sampling design for an island therefore involves looking at strips that run its entire length or width.

2.3 The social value of threatened coastline

The third source of potential economic loss from sea level rise can be traced to the social value of the coastline itself. Beaches are recreational areas, for example, which are generally available for use at the price of a beach badge; estimation of even their recreational value is therefore extremely difficult. The literature, building on work by Clawson,[18] suggests using transportation cost to construct at least a partial measure of value. More specifically, if using the beach is essentially free except for the cost of getting there and getting home, then the prices that families, for example, pay to use the beach are simply equal to the expenses that they incur getting to the beach and getting back home. Use surveys can then be employed to construct demand curves for beach services by matching these prices with quantities demanded (people living various distances from the beach pay different prices to enjoy its services). The contribution of the beach to general social welfare can then be taken to be the usual consumer surplus area under this demand curve.

There are, of course, an array of other benefits generated by our coastlines which are not captured by this travel cost measure, and the problem of estimating the cost of losing a coastline region is one of measuring the value of all of these benefits. One approach that showed some promise in moving toward a more general measure was developed by Knetsch[19] and David.[20] They both noted that property values increase with proximity to the recreation area like a beach. Since these increases reflect, quite simply, a willingness to pay for the general amenities provided by a beach, Knetsch[19] and David[20] argued that the sum of these increases could be employed as a measure of the value of that beach. As a beach disappears, then, the economic cost of its disappearance might be estimated by keeping track of the losses in these proximity generated surplus economic rents.

There are, however, several difficulties in applying the Knetsch–David notion directly. Some of the amenity, and thus some of the slope in a property value gradient, comes from views of the ocean that please residents with or without a beach. Attributing the entire slope to the beach proximity would, therefore, produce an overestimate of beach value. On the other hand, there are many people who do not live near the beach but who nonetheless use the beach. Using a property value gradient exclusively would miss the value of the beach services that they enjoy, and would thus produce an underestimate of beach value. Finally, there is considerable storm protection value provided to inland property by a beach and its associated dune structure which is captured by neither transportation cost surveys nor property value gradients. Still, a rough Knetsch–David style estimate can provide context—an order of magnitude guess against which to judge more careful estimates derived in other ways.

The alternative procedure employed here attempts to account for all of the sources of value to the degree actually recognized by shoreline communities by judging beach value from community behavior when beaches are threatened. As a matter of law, in some places like Texas (Texas Open Beach Act), and of practice, in other places like New Jersey and North Carolina, a structure located along a beachfront must be abandoned and/or torn down when the land upon which it sits is inundated during the mean spring high tide. The Beachfront Management Act (BMA) passed in 1989 by South Carolina goes one step further, prohibiting the reconstruction of irreparably damaged structures within zones defined shoreward from current coastlines by 40 years (sometimes 80) worth of historically validated rates of erosion; the idea is to abandon coastline regions before mean spring high tide gets there.

All of these programs are designed to allow a beach and its supporting dune structure to migrate inland, albeit at the expense of property owners whose property will be in the way, but to the good of the inland community. By revealed preference, therefore, the social value of a beach must be at least as high as the value of beachfront structures which would be abandoned if the beach were to erode. It is, in other words, reasonable to assume that a beachfront structure is sacrificed to preserve the social value of coastline whenever a searise scenario brings the water within a certain minimum distance of its foundation. Titus[21] submits that minimum width is 40 feet; South Carolina sets the minimum at 20 feet in the BMA.

Refer again to Fig. 2 to see how this procedure might work in operation. Suppose, for the sake of argument, that US $200 000 structures were located on each lot and that there were a minimum 40 foot beach on the ocean side of the first lot. Recall that the lots are all 100 feet long moving away from the water. Now let the ocean rise, eroding 100 feet of beach and dune. What has been the cost? Any structure on the first lot is now within 40 feet of the ocean. To maintain the minimum beach width, therefore, that structure must be abandoned and perhaps torn down; the loss, attributable to the social value of the beach, is thus at least US $200 000 derived from the lost structure. What about the land? An additional US $25 000, representing half of the land value of an interior lot, has been lost, as well, because half of the first lot is gone.[22]

Should this loss be added to the land and structure loss accounting outlined in the previous subsections, or should it be attributed to the beach value accounting just noted? Ultimately, the answer to this question does not matter as long at it is not added in both places. Total vulnerability is, after all, the sum of the losses attributed to structure, coastline, and property. To emphasize the importance of preserving the social services provided by coastline, though, the accounting procedure adopted here attributes all land and structure loss associated with maintaining a coastline to the value of preserving that coastline.

3 VULNERABILITY FOR LONG BEACH ISLAND, NEW JERSEY—AN APPLICATION

Estimates of economic vulnerability for Long Beach Island were prepared from a systematic sampling of assessed property and structure values along 25 separate strips of land. Two of the strips were designed to sample from atypical developments on the bay side of the northern part of the island. The remaining 23 were each approximately 200 feet wide, evenly distributed along the 18 mile length of the island and extending from the ocean to the bay; they were designed to sample from the more traditional development pattern of the majority of the island. Table 1 identifies the sample sites, and Fig. 3 locates Long Beach Island off the eastern shore of New Jersey just south of New York City.

The general cross-sectional topography of the island, and thus of 23 of the 25 strips, is portrayed in Fig. 4. There was some variation in development pattern. The north shows big houses on large lots and located well away from wide beaches; the south shows smaller houses on smaller lots packed up against narrower beaches. Nonetheless, their remarkable 'local' consistency made it possible to interpolate inundation scenarios for each strip into integrated inundation scenarios for the entire island.

Beginning on the bay side, significant inundation would usually begin

TABLE 1
Sample Sites—Long Beach Island, New Jersey

Number	*Tax ID*	*Southern street*	*Northern street*
1	A-6	Cleveland Avenue	McKinley Avenue
2	A-33	Carolina Avenue	Inlet Avenue
3	A-52	Joshua Avenue	Magnolia Avenue
4	A-80	—	Marshall Avenue
5	D-27	17th Street	18th Street
6	E-22	25th Street	26th Street
7	F-38	33rd Street	34th Street
8	H-11	Marine Lane	Ryerson Lane
9	J-22	Mississippi Avenue	Idaho Avenue
10	K-10	Kansas Avenue	Lillie Avenue
11	L-13	Cape Cod Lane	Ocean View Drive
12	M-24	Rhode Island Avenue	Massachusetts Avenue
13	O-11	Burwell Avenue	Dayton Avenue
14	O-32	Dupont Avenue	Goldsborough Avenue
15	O-62	Beardsley Avenue	Kirkland Avenue
16	O-98	46th Street	45th Street
17	O-128	37th Street	36th Street
18	R-20	—	Windward Road
19	R-62	Roxie Avenue	—
20	R-100	—	Lagoon Road
21	T-7/8	87th Street	—
22	T-40	—	Loveladies Lane
23	T-144	—	Beacon Drive
24	T-176	North–south through Loveladies	
25	T-176		
25	W-5/6	Amherst Road	Arnold Boulevard

after a 1 foot rise; there are places where the bulkhead is a bit higher, but rarely could it restrain more than a 3 foot rise. Once begun, inundation would proceed quickly over the virtually flat area located between the bay and Long Beach Boulevard. On the ocean side of the Boulevard, the rate of inundation would slow as elevations rise more quickly, but it would by no means stop until the island is completely under water. Ten feet above mean high tide is the usual maximum altitude of developed property at the base of the ocean-side protecting dunes.

Turning now to the ocean side, 100 feet of beach is lost on Long Beach Island for every 1 foot of sea level rise.[23] Since the beach is less than 50 feet wide in some spots, particularly on the south end of the island with houses built up the inland sides to the tops of the dunes, maintaining the beach for social value by abandoning structure and land

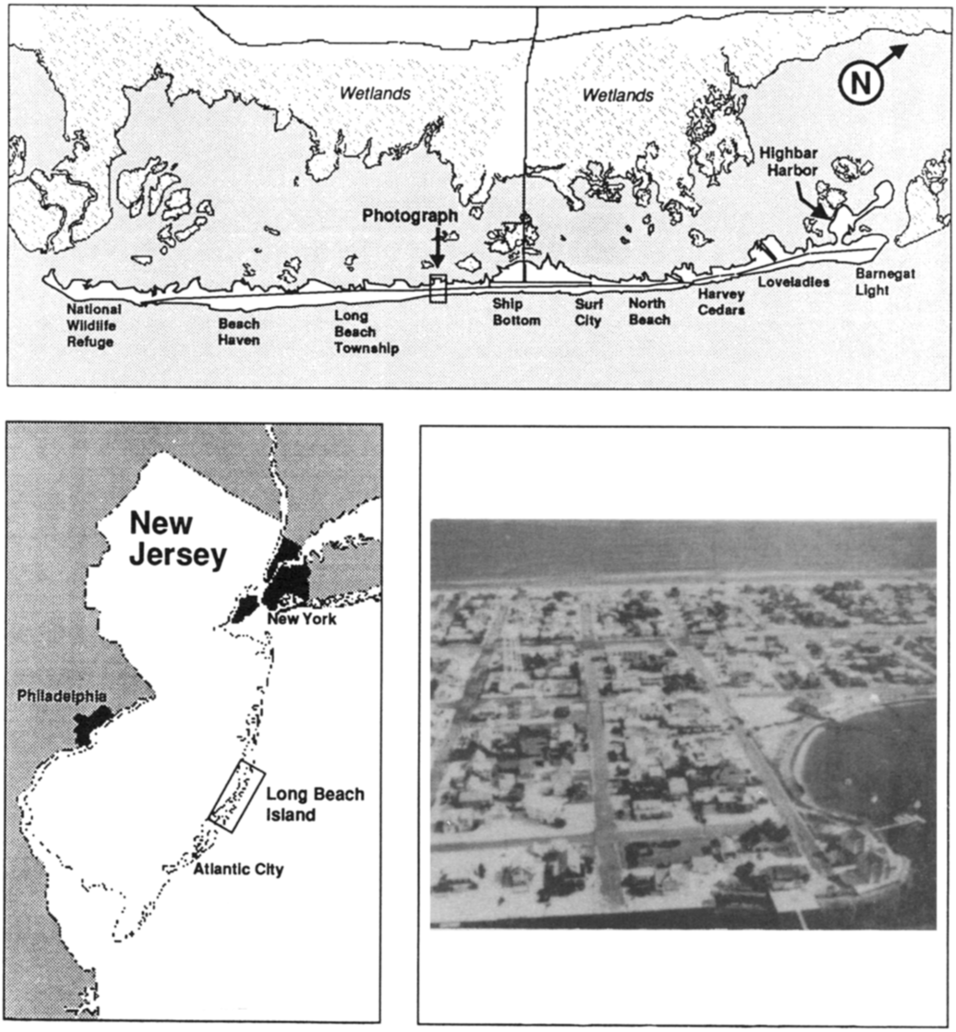

Fig. 3. Location of Long Island Beach.

would involve some potential economic loss even with a 6 inch rise. The vulnerability associated with maintaining the beach and the dunes would climb until, at about 4 feet of sea level rise, nearly 75% of the US $2 billion value of the island would be lost.

With inundation boundaries defined along each strip of the sample (and, by interpolation, along the entire length of the island) for 6 inch, 1 foot, 18 inch, 2 feet, 3 feet, 4 feet and 6 feet searise scenarios, it remained only to estimate the land, structure, and beach values threatened by each step of the process according to the procedure outlined in the introduction. Estimates for both land and structure,

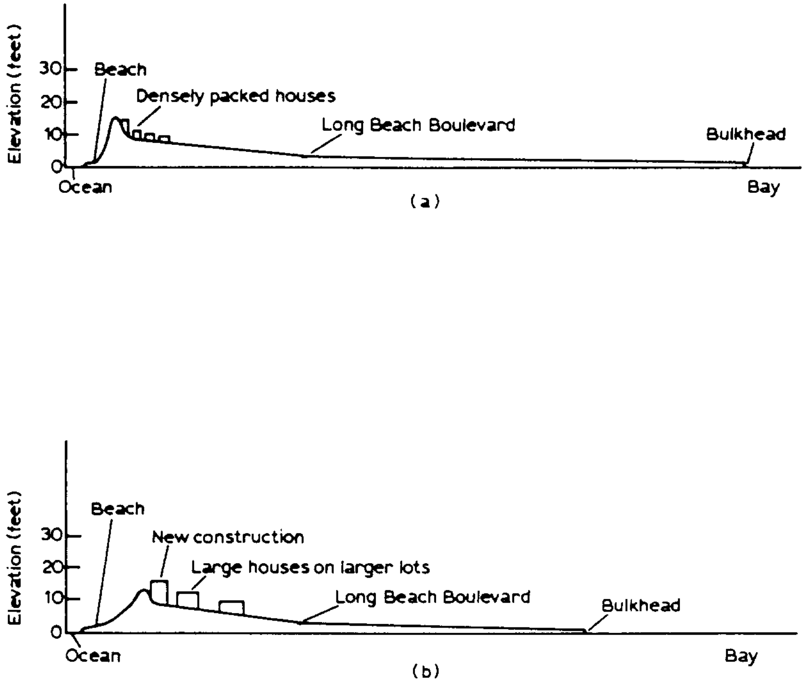

Fig. 4. Topographical sketches of Long Island Beach. (a) South end of the island with a long stretch of land west of Long Beach Boulevard vulnerable to inundation from the bay and development packed up to land on top of the dune of a narrow beach. (b) North end of the island with less property to the west of Long Beach Boulevard and larger houses on larger lots placed further from the dune and a wider beach. Some new construction is going in on the west side of the dunes.

normalized per eighth-acre lots, were produced directly from 1988 tax maps and a complete grand list for each level of inundation within each sampling strip. A comparison between asking price and assessed value for properties currently listed in the real estate market revealed a close match; no disparities of more than 10% were discovered, and no consistent bias in either direction was noted. Moving from these sampling estimates to land, structure, and beach value estimates for the entire island was finally accomplished by interpolation, taking note of both the area inundated by each increment of sea level rise within the sample sites and the likely area inundated by each increment between sample strips.

Table 2 records the results of this entire process; it shows cumulative vulnerability estimates for the entire island for each increment of sea level rise. Sampling errors (1 standard deviation) for the sample means are registered in the parentheses; the market works so well that thorough incorporation of the values recorded within the sample of 25

TABLE 2
Economic Vulnerability[a]

Sealevel Rise	*Property*	*Structure*	*Beach*	*Increment*	*Total*
0–6 inches	$0	$0	$15	$15	$15
	(0)	(0)	(1)	(1)	(1)
6–12 inches	$0	$0	$40	$40	$55
	(0)	(0)	(2)	(2)	(2)
12–18 inches	$80	$83	$62	$225	$270
	(4)	(4)	(2)	(6)	(6)
18–24 inches	$70	$72	$50	$192	$462
	(4)	(4)	(2)	(6)	(9)
2–3 feet	$129	$137	$115	$381	$843
	(9)	(8)	(5)	(13)	(16)
3–4 feet	$315	$345	$45	$705	1548
	(8)	(7)	(2)	(11)	(19)
4–6 feet	$175	$184	$26	$385	$1932
	(4)	(5)	(1)	(7)	(20)

[a] Measured in US $ millions. The numbers in parentheses represent standard errors of estimation around the sample means of total or incremental dollar vulnerability. The total value of the island stands at approximately US $2 billion.

strips was sufficient to support t-statistics consistently well in excess of 20, in most cases, and never less than 10.

Notice that the total value attributed to the beach over the entire range of sea rise is US $353 million. Comparing property values on Long Beach Island with the average of a small sample taken in Manahawkin (just across the bay), revealed a US $346 million difference between the total actual value of property on the island and what it would be worth if it were located on the mainland. This difference can be viewed as a rough approximation of the total Knetsch–Davis 'on island' location premium. There is, in addition, an estimated US $89 million location premium for island property in direct proximity with the ocean and bay shorelines.[24] A total property value increment of US $435 million can therefore be supported by a crude application of the Knetsch–David technique, suggestion that the structure–property based estimate of the social value of the beach reported in the tables may be a bit conservative.

4 DISCUSSION

The process by which the vulnerability estimates of Table 2 are paired with temporal scenarios of greenhouse-induced sea level rise must also reflect the 3·9 mm annual rate of unrelated natural subsidence of Long Beach Island. Table 3 tracks, in ten year increments, sea level scenarios that impose 50 cm, 10 cm and 200 cm of greenhouse sea level rise through 2100 on top of anticipated future subsidence. Table 4 translates the cumulative cost estimates of Table 2 into time dependent estimates for each of the three scenarios; Fig. 5 portrays each trajectory graphically. Annual losses are reflected in Fig. 6 and Table 5. Both highlight the losses which can be expected on an annual basis for the decade following the indicated year. The figures show that marginal costs do not always climb; for the 2 m scenario, e.g. marginal cost at 2100 is zero because the island was completely lost by the year 2090. By way of contrast, only modest potential vulnerability is evident through the year 2020 even in the 2 m case.

For planning purposes, of course, it is essential to note not only the potential vulnerability to sea level rise for each scenario, but also the relative likelihood of each scenario. Application of a technique developed earlier[9] to produce probabilistic scenarios of carbon emissions to the dispersion of expert opinion reflected in Fig. 1 can produce a workable subjective distribution of what the future might hold for our coastlines. Assuming a log normal distribution and including only the more recent EPA projections, the procedure suggests associating the 50 cm, 100 cm and 200 cm trajectories considered here with the 40th,

TABLE 3
Amount of Sea Level Rise for Various Scenarios

	Scenario[a]		
Year	*50 cm*	*100 cm*	*200 cm*
2000	0·14	0·15	0·18
2010	0·31	0·36	0·47
2020	0·51	0·63	0·87
2030	0·73	0·94	1·38
2040	0·98	1·32	1·99
2050	1·25	1·74	2·71
2060	1·56	2·22	3·55
2070	1·89	2·76	4·49
2080	2·25	3·34	5·53
2090	2·63	3·99	6·69
2100	3·05	4·68	7·95

[a] Measured in feet, including the natural trend of 3·9 mm per year. The scenario identification indicates the amount of sea level rise attributed to greenhouse warming above and beyond this natural trend.

TABLE 4
Cumulative Economic Vulnerability[a]

Year	*50 cm*	*100 cm*	*200 cm*
2000	$3	$4	$6
2010	$9	$11	$14
2020	$15	$23	$39
2030	$34	$49	$215
2040	$56	$175	$457
2050	$155	$355	$671
2060	$280	$527	$1168
2070	$315	$720	$1633
2080	$405	$1041	$1831
2090	$518	$1540	[b]
2100	$873	$1651	[b]

[a] Measured in US $ millions. The scenarios are identified in Table 3; the source of the cost estimates is Table 2.
[b] The entire island is lost at this point.

70th and 90th percentiles, respectively.[25] A wide, but not unreasonable range is thus captured by the three cases.

Turning now to consider precisely what is and is not measured in the recorded vulnerability statistics, it is important to note that market prices reflect the discounted values of future streams of housing service incomes when real estate markets work well. This reflection is implicit

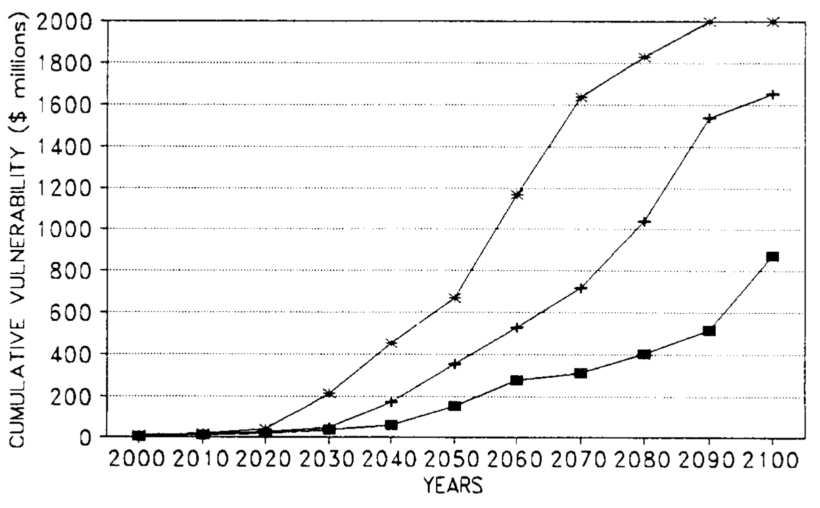

Fig. 5. Cumulative economic vulnerability. (■) 50 cm scenario, (+) 100 cm scenario and (*) 200 cm scenario.

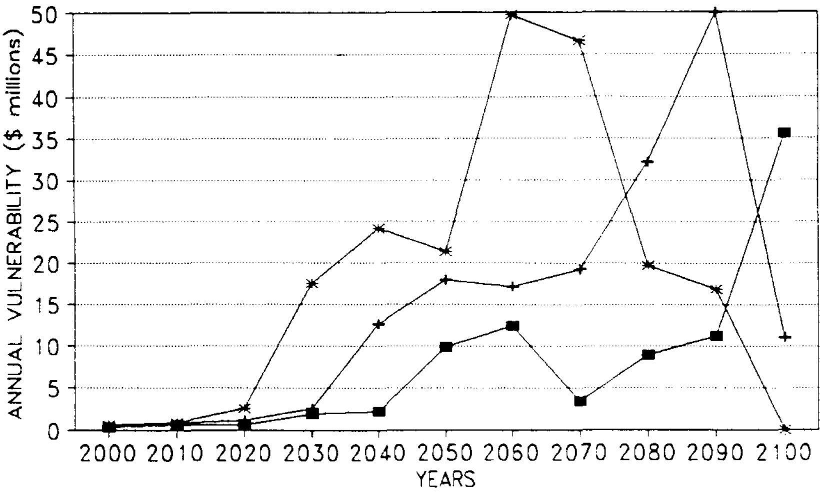

Fig. 6. Annual economic vulnerability. (■) 50 cm scenario, (+) 100 cm scenario and (∗) 200 cm scenario.

in the case of owner occupied housing and explicit in the case of rental property. It is, therefore, interesting to consider the trajectory of lost economic rent that would have supported property values that were lost. Figure 7 illustrates lost economic rent embodied in cumulative economic cost for a 10% return on investment. Higher returns would, of course, produce higher loss profiles; lower returns, lower profiles.

TABLE 5
Annual Increases in Economic Vulnerability[a]

Year	*50 cm*	*100 cm*	*200 cm*
2000	$0·0	$0·0	$0·0
2010	$0·4	$0·5	$0·7
2020	$0·6	$1·0	$1·2
2030	$1·3	$1·8	$9·8
2040	$2·0	$7·8	$20·9
2050	$6·0	$14·3	$22·8
2060	$11·2	$16·6	$35·5
2070	$3·0	$18·3	$48·3
2080	$9·0	$25·7	$33·7
2090	$10·2	$41·0	$17·0
2100	$18·4	$30·5	[b]

[a] Measured in US $ millions. The scenarios are identified in Table 3; the source of the cost estimates is Table 2.
[b] The entire island was lost in 2090.

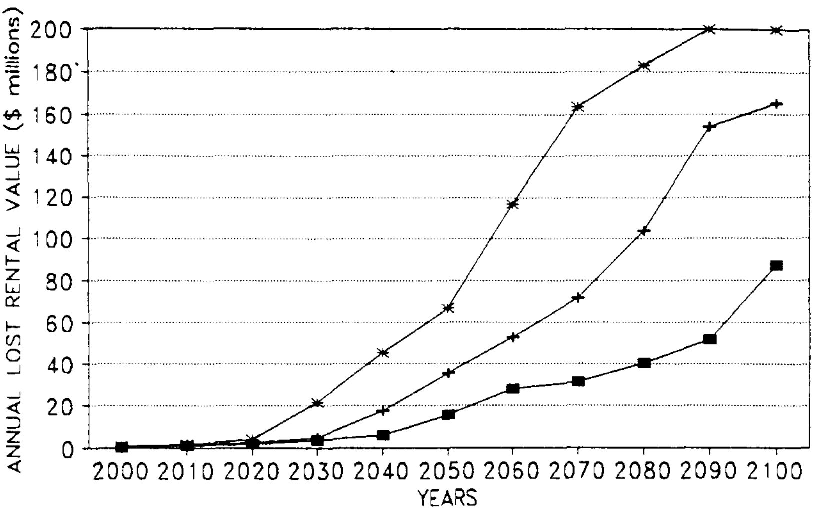

Fig. 7. Annual lost rental value. (■) 50 cm scenario, (+) 100 cm scenario and (*) 200 cm scenario.

The economic value of public goods and services which are simultaneously threatened by inundation is also capitalized in the values of land and structure when real estate markets operate efficiently. No separate accounting of public goods and services is therefore necessary with one important caveat. Since no notion of critical mass is employed, some early vulnerability estimates for regions—like Long Beach Island which will essentially disappear in the face of sea level rise—may be too low. They will capture the total loss of the value of public activity only when the last piece of property is lost even though, in fact, public activity probably stopped years earlier.

A procedure which uses current value as a measure of potential future cost can, on more fundamental grounds, be criticized for several reasons. For one thing, the sites being studied will surely enjoy economic growth over the next half-century or so. Current value misses that growth entirely. For another, structure prices may inflate more or less quickly than a general price index. Estimates based on current value might therefore be conservative to the degree that they ignore either or both of these phenomena.

On the other hand, using current value sidesteps both the vagaries of social discounting and the potential that threatened structures will be allowed to fall into disrepair when it becomes known that they may be under water in the foreseeable future. In as much as the cost of not holding back the sea will be compared with the cost of protection on a year-to-year (or decade-to-decade) basis as various future scenarios unfold, however, the problems created by not discounting are not necessarily as severe as they might at first appear. Reswitching phenomena are unlikely; and the effects of discounting the net benefit of some protection scheme should influence only the size and not the sign of net benefits. Moreover, it may turn out that the growth and relative inflation trends just noted proceed over the long term at a rate which roughly offsets the effect of discounting on the real value of threatened structure. Current value and present value estimates of the cost of abandonment might then almost match over the long term if not over decades.

The issue of not maintaining structure is also one of timing. If, for example, the owner of a US $200 000 structure that will be inundated in the year 2050 were to ignore its physical upkeep over the 25 year period from the year 2025 to 2050, then that owner would suffer a smaller loss in 2025 than he would otherwise. How much smaller? The present value, in 2050, of the money that he did not spend maintaining the property since the year 2025 net of the reduced rent that he received as the property deteriorated. If, however, it were known that the structure were going to be abandoned in 2050, then the market value of that structure would begin to decline well before 2050. An accurate accounting of the economic loss might therefore also start recording this decline in value years ahead of the 2050 collapse, thereby moving the loss forward, and increasing its current present value. Which effect would dominate is, at this point, anybody's guess. It is certainly an issue which warrants further consideration, especially in light of likely investment in alternative sites that should be inspired by the economic depreciation of threatened property.

5 CONCLUDING REMARKS

The appropriate criteria with which to judge policy response to the potential effects of climate change, including the potential for rising seas, is net benefits. Given uncertainty and long time horizons, in fact, computations of the expected present value of net benefits are required if we are to judge now what we might be doing in the future. The point of this paper is not, however, to advance such a computation. It is, instead, to outline a methodology by which we can produce state contingent time series data to support the benefit side of the requisite calculations for green house induced sea level rise. Current values for land, structure and beach services have been highlighted and summed to produce vulnerability estimates, and these are estimates from which the requisite economic cost series can be generated under a variety of conditions.

An enormous range of intertemporal issues will have to be considered as those cost series are generated, focusing carefully on 'who knows what and when do they know it?' Reliable estimates of potential cost will be available, more specifically, only when models which accommodate growth with substitution away from threatened property in response to the (expected) economic depreciation are applied to vulnerability data for specific future scenarios. These adjustments must, in addition, be made in the context of how quickly markets will be able to recognize, with gradually shrinking degrees of uncertainty, that we are on that specific trajectory and learn from that recognition to limit the range of what to expect in the subsequent future.

National estimates of these cost series will, of course, be important as the international community ponders the expensive set of global response options designed to avert the problem. Since cost estimates are likely to fall short of vulnerability estimates, in fact, a national estimate of expected vulnerability might even be enough to support an informal warning to proceed with caution in pursuit of a rating policy.

Given the likely difficulty in achieving international cooperation in averting policies, though, regional and local estimates may be even more important in protecting our long run welfare as regional and local decision makers decide how to manage their coastlines. The method described here provides the means by which they can, in their own jurisdictions, begin the process.

Armed with series of vulnerability estimates, more specifically, regional and local leaders should be able to visualize, at least conceptually if not through accurate measures of potential cost, how their communities might respond to a growing consciousness of the threat of sea level rise. They will be able to judge the value of this response and determine if existing on contemplated policies might aid or hinder its progress. Do their zoning laws help or hurt? Does subsidized flood insurance help or hurt? Do their development plans exacerbate or ameliorate the potential problem? Do their social infrastructure investments adequately accommodate response to the threat? And, perhaps most importantly, have their policy stances with regard to sea level rise been articulated with sufficient clarity that real estate transactions made in full cognizance of what might happen and how government will respond. Vulnerability estimates, in short, provide more than grist for the policy debate mill; they provide context and a sense of proportion when sea level rise problems associated with global climate change are cast into the social consciousness.

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