8 Evolutionary and Cyclical Change as Fundamental Attributes of the Estuary

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Introduction

The two decades of literature in landscape evaluation have focused more on the static than on the dynamic. While this preoccupation with current form was necessary to establish basic principles, a means must now be found for incorporating short- and long-term change into the philosophy and method of visual analysis. This chapter looks at the visual-cultural attributes of (1) the morphologic evolution and (2) the tidal cycles of estuaries. Both forms of landscape change are considered to be intrinsic characteristics of the resource, although emphasis is placed on evolution.

The Philosophy of Change as Meaning

Meaning is the ultimate phenomenon we seek to grasp in landscape evaluation, whether we are landscape manager or casual viewer. Certain categories of meaning take higher priority in our minds than others. The concept of change and all that is means is commonly applied to what we sense. We are unlikely to ask consciously about landscape change as we move about our daily routine. Yet when we look at a wetland and consider it as a significant part of our environment, we are capable of inquiring about its past and future states.

If, as Suzanne Langer says, the landscape operates as a language to convey meaning, we can think of visual analysis as having advanced to the point of identifying the important elements of vocabulary and syntax. What remains is to find ways of employing these static elements in a dynamic grammar that communicates richer and more complete landscape meanings. We know that a snapshot of another person is an incomplete picture of that person. It is easy to think beyond that image and see the person as having evolved from youth, of having a future morphologic state, and of having the ability to move about in his or her current morphologic state. We have acquired the information necessary to envisage the total image of another person from our own experience and from learned concepts of human maturation and development. However, the important concepts of wetland dynamics and maturation are only recently being made available to us.

The "uninformed" viewer of wetlands will be content to look for a pleasing texture and assemblage of color and perhaps a similarity to known landscapes: a lake or a field of wheat. Others will seek meaning about the scene from an explanation that may have been suggested to them. Thus, our task is to organize visual information about wetlands to convey an understanding of change.

Cyclical Change

Most landscapes undergo some form of cyclical change: That is, the viewer is aware of repetitive transformations in the set of visual attributes. If we think of the deciduous forest landscapes of the Adirondacks, the Rocky Mountains, or the Midwest, the sequence is predictable and cyclical. The estuary landscape is dominated by the tides. They undergo visual (and functional) change daily, monthly, and seasonally. These cyclical events are linked with the directional process of succession and evolution because tidal action determines how sediment erosion, transport, and deposition will combine with marsh invasion to transform the estuary slowly into a coastal meadow.

Wetland Evolution

Wetlands have been called the ephemeral landscape. While there are certain wetland forms that are relatively stable, we must assume that change is a fundamental characteristic of most wetland types.

Until fifteen years ago wetlands were a neglected and unappreciated landscape, being neither sound land nor good water. Then, in a wave of concern over their imminent loss, the public began to appreciate the attributes of marshes, bogs, swamps, and estuaries.

Not only succession but also the rate at which estuaries were evolving inspired a concern for preservation. This concern stemmed at first from the evidence that humans had transformed, through dredge and fill, much of our national estuarine resource into sound land and good water. The subsequent realization that Nature was at work, too, led to the conclusion that—in contrast to forest succession where the end product is still forest—the terminal condition for estuarine evolution was extinction of the resource and creation of a new landscape, the coastal meadow.

It was argued that some estuaries were "in their last stages of maturity" and others were "suffering from senescence," soon to be lost to the next successional state. The political dimensions of this controversy often centered on the question of whether to preserve the natural process of succession or to manipulate the hydrology of an estuary to arrest succession and preserve the wetland landscape.

Human Influence on Change

If we accept the premise that the human influence on nature and the visible changes it brings about is easily comprehended by most people, how in confronting the dynamics of an estuarine landscape can the visual analyst include in his or her interpretation an understanding of this dimension? Human influence of course is not to be thought of in only negative terms. A viewer of landscape often relates more easily to the human imprint, the artifacts of his species, than to the natural. Nature, to some, is alien. A touch of humanity provides a point of reference, especially if there are hints of antiquity and the raw edges of human action have been visibly worn by time. Insofar as we look to the landscape for meanings about our identity, relations among people, and, for some observers, relations between people and their dieties, we must assume that any landscape view is a medium for understanding the theater of life.*

We will consider human influence on the dynamics of the estuary primarily in terms of

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*Glacken (1967) argues that human modification of the natural environment is one of the great themes of Western civilization. He bases his argument on an analysis of the literature, but others agree that, along with time and space, negotiations ("conquest" is too simple, and it often exaggerates the relationship) with nature is a fundamental dimension of human life and not just a preoccupation of the literati.

succession. While tidal dynamics constitute an important visual consideration, human influences on cyclical change are of secondary importance. The types of human influence on successional change to be discussed are those activities that increase or decrease (1) the deposition rate and/or (2) the rate of plant invasion and development in the estuary.

The following section elaborates on the concept of estuarine evolution and describes the principal morphologic units of an estuary with an eye to how they typically change over time. The third section explains how to document estuarine evolution. The fourth section discusses how the visual characteristics of an estuary change during the tidal cycle. The fifth and sixth sections deal with the geographic and political contexts for interpreting cyclical and evolutionary change.

The Morphologic Evolution of Estuaries

The life cycle of an estuary begins when a coastal valley is flooded by coastal subsidence or rising sea levels. Its ontogeny is complete when under stable sea-level conditions the embayment is completely filled with sediment and invasion of terrestrial (nonwetland) vegetation creates a coastal meadow. Sea levels began their rise at the end of the last glaciation some ten to fifteen thousand years ago. Until about two to three thousand years ago, when sea levels began to stabilize, deposition rates in coastal embayments were seldom greater than the rate of sea-level rise. Only during the more recent period when sea levels became relatively stable did estuaries become "wetland landscapes" with elements of marsh, mudflat, and channel.

During the period of human habitation of the watersheds and littoral zones of the world's estuaries, sedimentation rates have increased, partly because of land use. In general, with sea levels remaining roughly what they are today, many estuaries and lagoons will enter the last phases of their lives within the next fifty to one hundred years. In some cases the speed with which they grow old will be influenced by humans: in some cases increased, in others decreased.

During the life cycle the most visible changes will be the creation of extensive mudflats, the constriction of channels, and the expansion of marsh, finally spilling into the channels to clog this circulatory system with vegetation. The direct visual consequences of morphologic change will be the changes in the relative extent of the three morphologic units: marsh, mudflat, and channels. Indirect consequences will follow. Changes in speciation and frequency of visible biota, primarily birdlife, will result from changes in the lower strata of their food chain (i.e., speciation and frequency of organisms inhabiting each morphologic unit).

Approaches to Describing Estuarine Evolution

The terms used in this chapter need some refinement. The classical notion of "succession" implies changes in plant and animal communities: changes in the presence and dominance of species and changes in production at various trophic levels. For some, succession implies an end state or "climax" that involves stabilization of the species mix and system equilibrium. Succession has been applied to generalized modes of wetland evolution in introductory texts in physical geography and ecology. The common example shown in Figure 8.1 employs morphologic units of vegetation and describes evolution using a sequence of profiles with some attention to the stratification of peat soils. Beyond this, there is no discussion of trophic changes or shifts in diversity and speciation at various stages in the successional sequence. It would seem obvious that wetland succession does not stabilize at a terminal climax but continues through the transition into a terrestrial sequence of succession. At the beginning of the terrestrial sequence, the wetland as a landscape entity becomes extinct.

More appropriate to the topic is Redfield's (1972) portrayal of the development of Barnstable Marsh in Massachusetts. For the period 1300 B.C. to A.D. 1950 Redfield employs a sequence of maps that shows changes in four morphologic units: upland, sand dunes, intertidal marsh, and high marsh (Figure 8.2). If the visual analyst and land manager are to characterize the evolution of an estuary, the selection of morphologic units must be based only on intrinsic wetland attributes. Thus the method presented in this chapter varies from Redfield's ap-

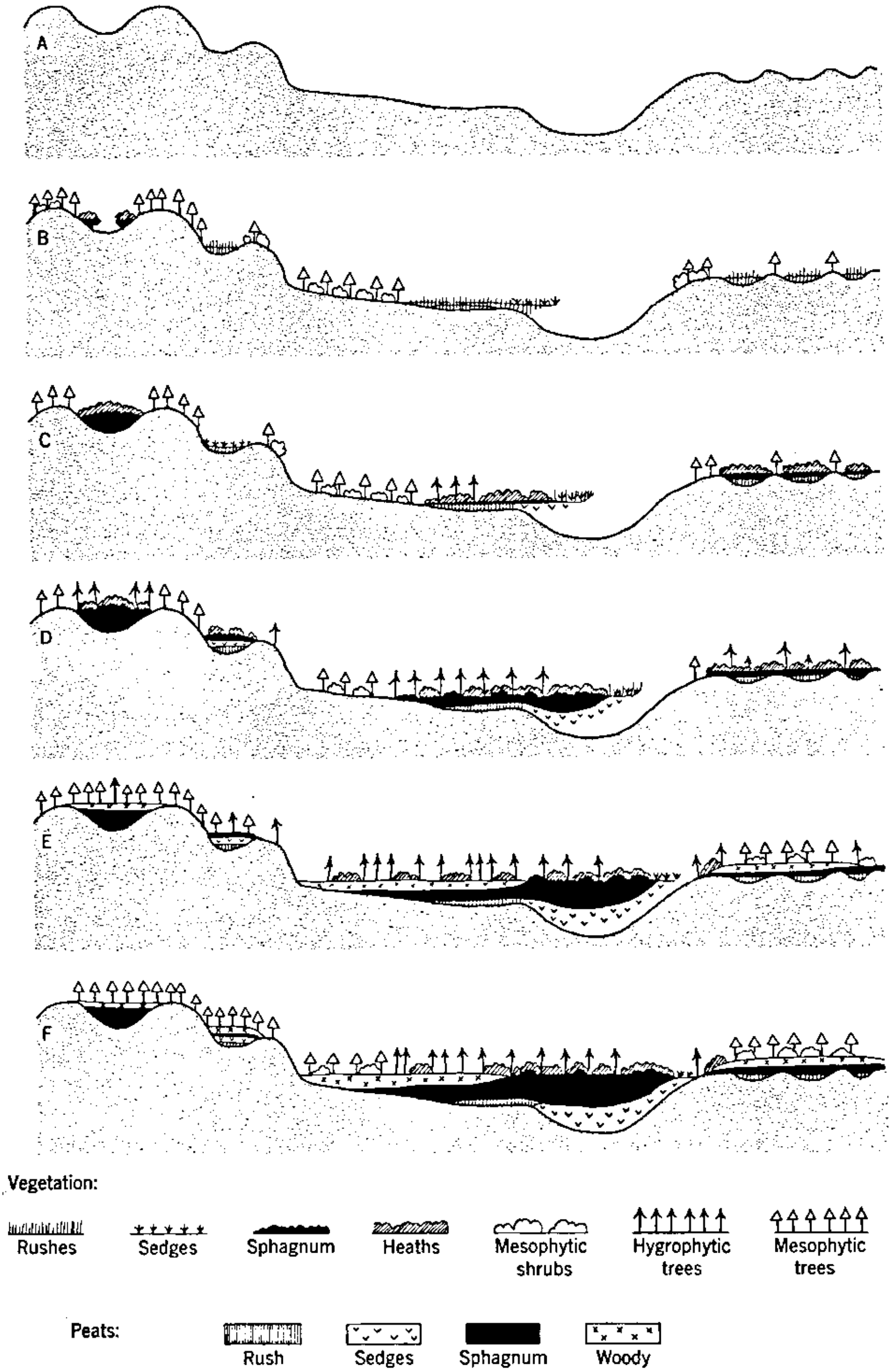

Figure 8.1. A typical model of wetland succession. Vertical profiles of autogenic bog succession from A. N. Strahler, *Physical Geography*, 3rd ed. (New York: John Wiley & Sons, 1969), p. 336. After Dansereau and Segadas-Vianna, 1952, *Canadian Journal of Botany* 30. Reprinted by permission.

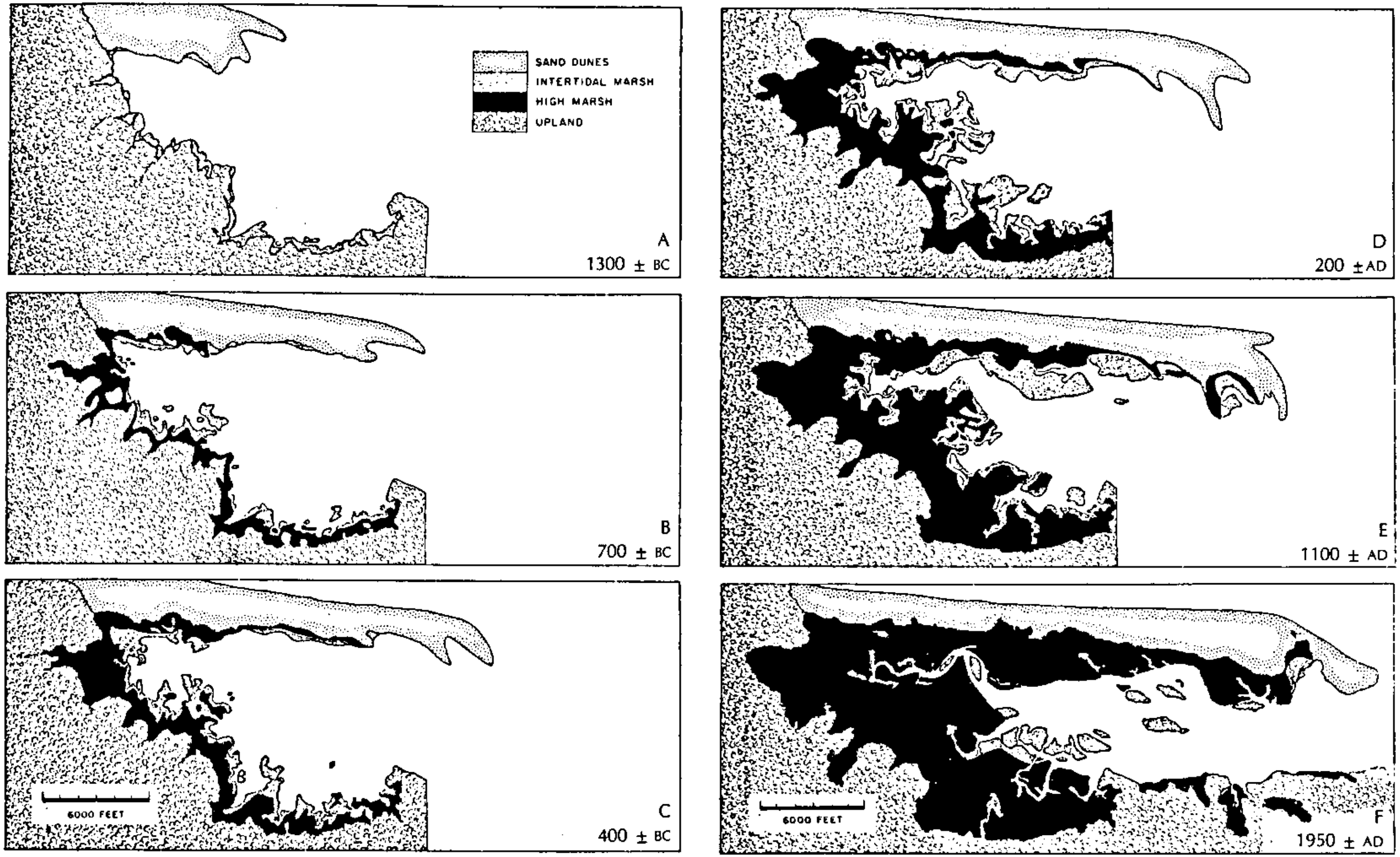

Figure 8.2. An example of estuary succession. Marsh evolution at Barnstable, Massachusetts, 1300 BC to AD 1950 from A. C. Redfield, "Development of a New England Salt Marsh," *Ecological Monographs* 1972, 42, pages 212–13. Reprinted by permission of the Ecological Society of America.

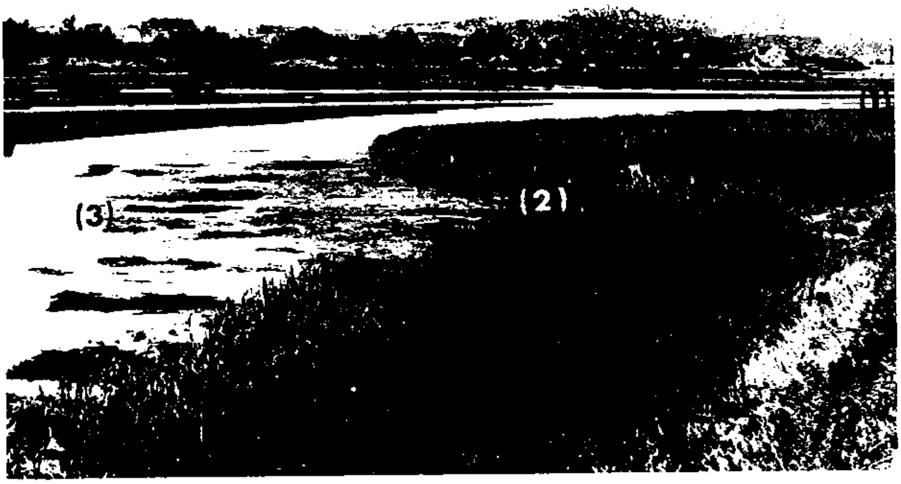

Figure 8.3. Morphologic units of an estuary as principal visual components. (1) Intertidal marsh, extending from right margin of photograph; (2) mudflats, a rich substrate for feeding shore birds; and (3) channels full of water, even at low tide.

proach by eliminating upland and sand dunes because they are elements of the terrestrial landscape and generally lie above the traditional boundaries of the estuary, mean high water. Furthermore, no distinction is made between high marsh and intertidal marsh. In California, where I did my field studies, the high-marsh community of *Distichlis spicata* (saltgrass) was more often than not of relatively minor areal extent, in contrast to the large fields of saltgrass contiguous to eastern estuaries. Also, historical references rarely distinguished between high and intertidal marshes, making it difficult or impossible to reconstruct the evolution of an estuary employing that boundary. Finally, two additional morphologic units have been added—mudflats and channels—to those used by Redfield to allow for a more comprehensive treatment of estuarine evolution.

The Principal Morphologic Units of an Estuary

I have divided the estuary into three morphologic units: (1) the intertidal marsh, (2) the mudflat, and (3) the channel (Figure 8.3). These compose the gross visual structure under either static or dynamic conditions and are valid units for both visual analysis and ecological function. Thus in this classification are the principal components that compose the food chain and act together to engineer estuarine succession. This congruence of apparent visual attributes with ecologic attributes qualifies the estuary as a landscape potent for interpretation and meaning.

The Intertidal Marsh: From the line of mean high water (MHW: on the Pacific Coast, mean higher of high water, or MHHW) down to the lower edge of the intertidal vegetation, several plant communities exist in zones determined mostly by elevation and tidal submergence. The upper boundary between intertidal marsh and the adjacent terrestrial vegetation is not well delineated: often it shows a "diffuse" edge. (The visual terminology is from Litton et al., 1974). Within the marsh the boundaries between communities are either "digitate" or "butt." These fairly clear lines of demarcation result from differences in the physiology of the dominant species, especially with respect to salt tolerance and the ability to withstand submergence.

One of the most important visual considerations in the marsh component of estuaries is the distinction between those estuaries with a predominantly *Salicornia* marsh as opposed to those with a *Spartina* marsh. In many of the world's estuaries the marsh is dominated by the low-growing pickleweed, *Salicornia*, which forms a bunchy cover. In a *Spartina* marsh fields of tall cordgrass undulate in the shore breeze in an entirely different visual display (Figure 8.4).

The Mudflats: The unvegetated zone lying between the marsh and the channel is the mudflat or tidal flat. At first encounter, this zone seems visually barren. Yet much of the estuary action takes place here. Loaded with benthic organisms, the mudflat is an important feeding ground for shorebirds. They take worms and ghost shrimp from the mud as the tide goes out and cull young fish from the first incoming waters of the flood tide. In addition, this is the zone of active marsh invasion, where fingers of vegetation reach out to claim the rich substrate.

The Channels: The remaining portion of the estuary below the mean low water line (MLW: on the Pacific Coast, mean lower of low water, or MLLW) can be termed "channel." Even at low tide these winding incisions in the estuary bottom are full of water. A complex of tributary channels, lying technically above the MLW elevation, together with the main channels, constitutes the estuary's circulatory system. The complete network forms a sinuous branching pattern that is one of the estuary's more predominant visual characteristics. While some of the channels may shift their location from year to year, the pattern is essentially permanent, given repeated visual emphasis by the *galleria* of shorebirds waiting along the channel banks at each incoming tide.

Ulrich (1976) asserts that observers prefer those landscapes that display "ordered or patterned complexity" and show low preference for those that exhibit unordered or random complexity. The incised, branched network of estuarine channels is a familiar pattern in the environment of *Homo sapiens*, and it conforms to Ulrich's definition of ordered complexity. The tides flow through, visually unifying the principal components of the estuary.

A Method of Documenting Morphologic Evolution

The purpose of describing morphologic evolution for visual assessment is to provide a picture of the areal extent of each of the three morphologic units—marsh, mudflat, and channel—at intervals during which there are adequate data. Most often these intervals are restricted to the tenure of human habitation or exploration. A picture of the historical evolution of an estuary provides a basis for making estimates of how the morphology will change, and at what rate, under different future conditions. The first step is to characterize the estuary's present morphologic status.

Delineating Current Morphologic Status

The work cannot proceed easily without a set of aerial photographs taken at the scale and resolution determined by the analyst to be appropriate to the morphologic complexity of the estuary. The choice of black and white or color in any of the spectral classes is often determined by how well the photography allows one to separate (1) upper marsh from terrestrial vegetation, (2) lower marsh from mudflat, and (3) mudflat from water in the channels. Black-and-white infrared or color infrared provides good delineation in most estuaries. The investigator should be aware of the problem of algae deposition on the mudflats, which will give a reflectance somewhat similar to that given by lower marsh at small scales and low resolution.

The air photography should be taken at a time of year when vegetation reflectance signatures provide clear distinctions and at a time of the day when the tide is at MLW, the elevation at which channel units are distinguishable from mudflat. The best conditions, both in terms of plant color differences and atmospheric clarity, are often found in fall and spring along all three coasts of the United States.

If possible, an elevation and distance survey should be conducted to allow accurate calculations of areal extent of marsh, mudflat, and channel units. (Most estuaries are near survey benchmarks.) This is the only means of determining the line of MHW (MHHW) that serves as the boundary of the estuary. This boundary

Figure 8.4. Comparison of *Spartina* and *Salicornia* form. (*Left*) Wheatlike *Spartina* (cordgrass) occurs as tall, undulating fields (specimens of *Spartina foliosa* shown here are shorter than the aggressive *Spartina alterniflora* of the Atlantic and Pacific coasts), compared with (*center*) low, bunchy *Salicornia* (pickleweed) that produces dense mat. (*Right*) Field of *Spartina foliosa* (California), colonizing the mudflat abutting the channel, is one of the principal visual features of many estuaries.

sometimes coincides with a vegetational transition that can be seen on the air photographs, making the delineation fairly simple. In many estuaries the transition from high marsh to terrestrial vegetation occurs at an elevation above MHW.

The upper and lower elevations of each morphologic unit can be very useful to ecologic interpretations, which will add meaning to any understanding of cyclical or directional change. For example, elevations of the lowest marsh plants indicate the rate and form of mudflat conversion to marsh and how fast channel patterns are being stabilized by marsh vegetation. Elevations of this kind can be compared to those for other estuaries to suggest relative rates of marsh invasion and consequently to determine whether the estuary is changing morphologically more slowly or faster than others in the same geographic region.

As part of the survey, the general distribution of dominant marsh species should be noted. This will assist in estimating the rate and form of marsh invasion of mudflat units. For example, in many California estuaries *Spartina foliosa* (cordgrass) is a more active invader of the mudflat than *Salicornia* (pickleweed), the other common marsh plant. Each has its own pattern of invasion. However, *Spartina* is not present in all California estuaries, and it is absent from most estuaries in Oregon and Washington. Consequently, those estuaries with *Spartina* dominating the lower marsh will exhibit a different pattern and rate of morphologic evolution than those estuaries where *Salicornia,* exclusively, composes the marsh. Because both occur in nearly pure stands, noting their presence and location also helps in describing the static visual characteristics of the estuary. During tidal transformations estuaries dominated by either *Spartina* or *Salicornia* will look quite different from one another.

Interpreting Historical Patterns of Change

One can work backwards in time, seeking first the most recent historical map of the estuary, then uncovering earlier documentation. However, there is no reason why the investigator should not go directly to the first coastal survey. It is critical to remember that the information contained on any particular map will be related to the purpose of the map and mission of those doing the mapping and cartography. The following examples taken from Bolinas Lagoon in Marin County, California, will emphasize this point.

The first map (1897) constructed by the U.S. Geological Survey of Bolinas Lagoon and vicinity occurs as part of the Tamalpais Quadrangle (Figure 8.5). It would appear that the lagoon was in a "youthful" stage of its morphologic evolution, exhibiting no marsh and mudflat components. The picture conveyed by this map is one of a simple embayment with a bar and inlet. However, the mission of the USGS was to map terrestrial features, not wetland environments. The map is of no use for documenting morphologic change within the estuary. The first map of Bolinas Lagoon done by a legitimate agency capable of accurately documenting estuarine geography was constructed by the U.S. Surveyor General in 1858 to confirm the boundaries of the Baulinas Rancho land grant (Figure 8.6). In 1858 the government wanted to survey only lands above the approximate line of mean higher of high water and to delineate ground solid enough for grazing, agriculture, and the construction of rancho homes. There was no intention of including tidal land unsuitable for these purposes, and therefore it is not surprising that the map omits marshes, mudflats, deltas, and islands or a full rendering of the bar across the embayment.

In contrast to and predating these two maps, the first U.S. Coast Survey map of Bolinas Lagoon dated 1854 is an excellent base for reconstructing the estuary's morphology (Figure 8.7). To prepare a morphologic picture from this map, one must use Aaron Shalowitz's "Shore and sea boundaries, with special reference to the interpretation and use of Coast and Geodetic Survey data" (1964). The following sections should be noted: "Symbolization of Topographic Surveys" (pp. 188-92); "The Line of Mean High Water" (pp. 172–76); and "The Low Water Line" (pp. 183-89). The heavy solid line on the map represents the line of mean higher of high water, which is assumed for purposes of morphologic analysis to be the boundary of the estuary. Where marshes exist, the seaward edge of the marsh represents only the edge of the vegetation, as noted by the surveyor, and does not conform to a particular tidal plane. The in-

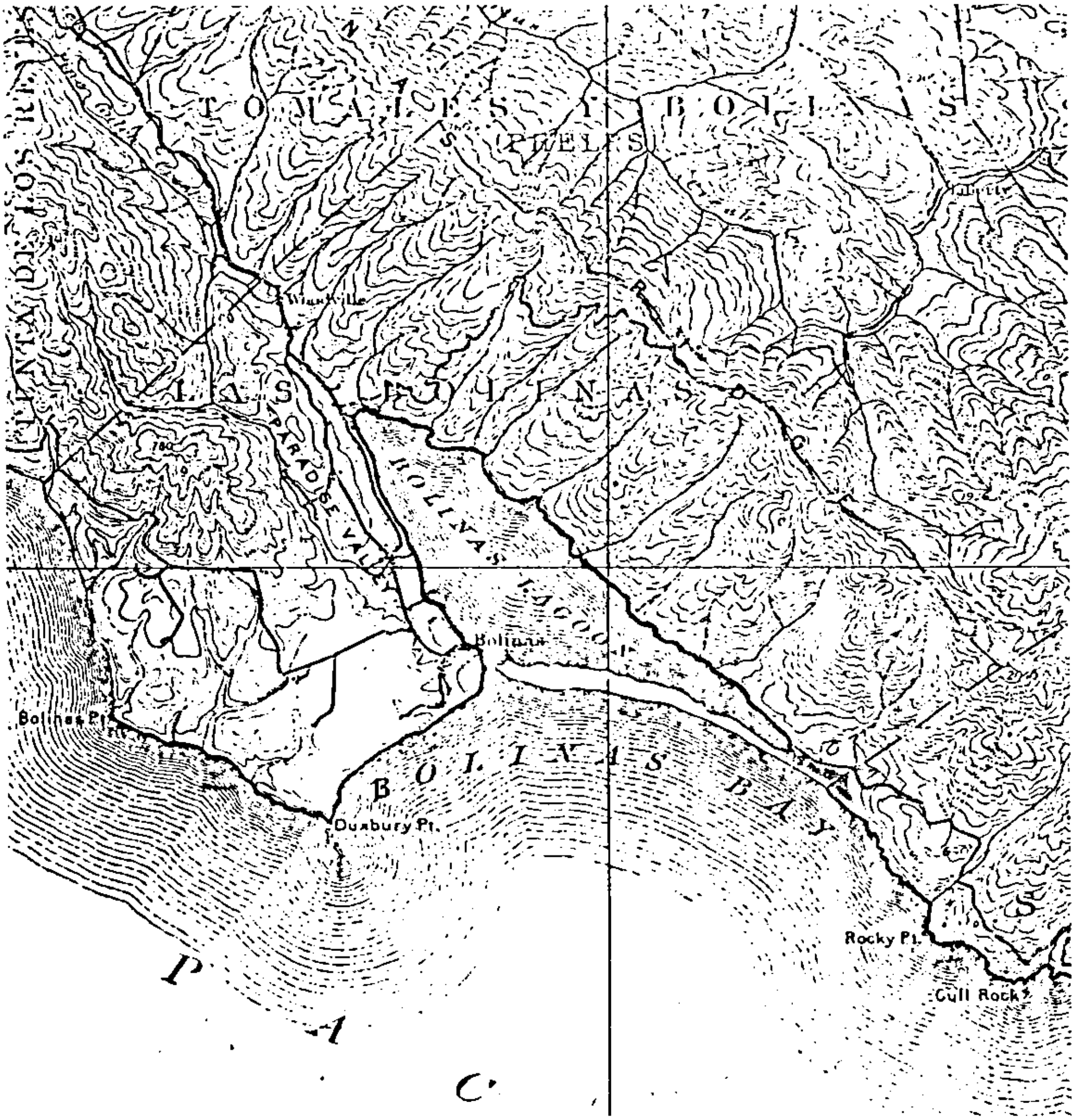

Figure 8.5. First U.S. Geological Survey map of Bolinas Lagoon vicinity, 1897. Note the absence of morphologic detail within the estuary.

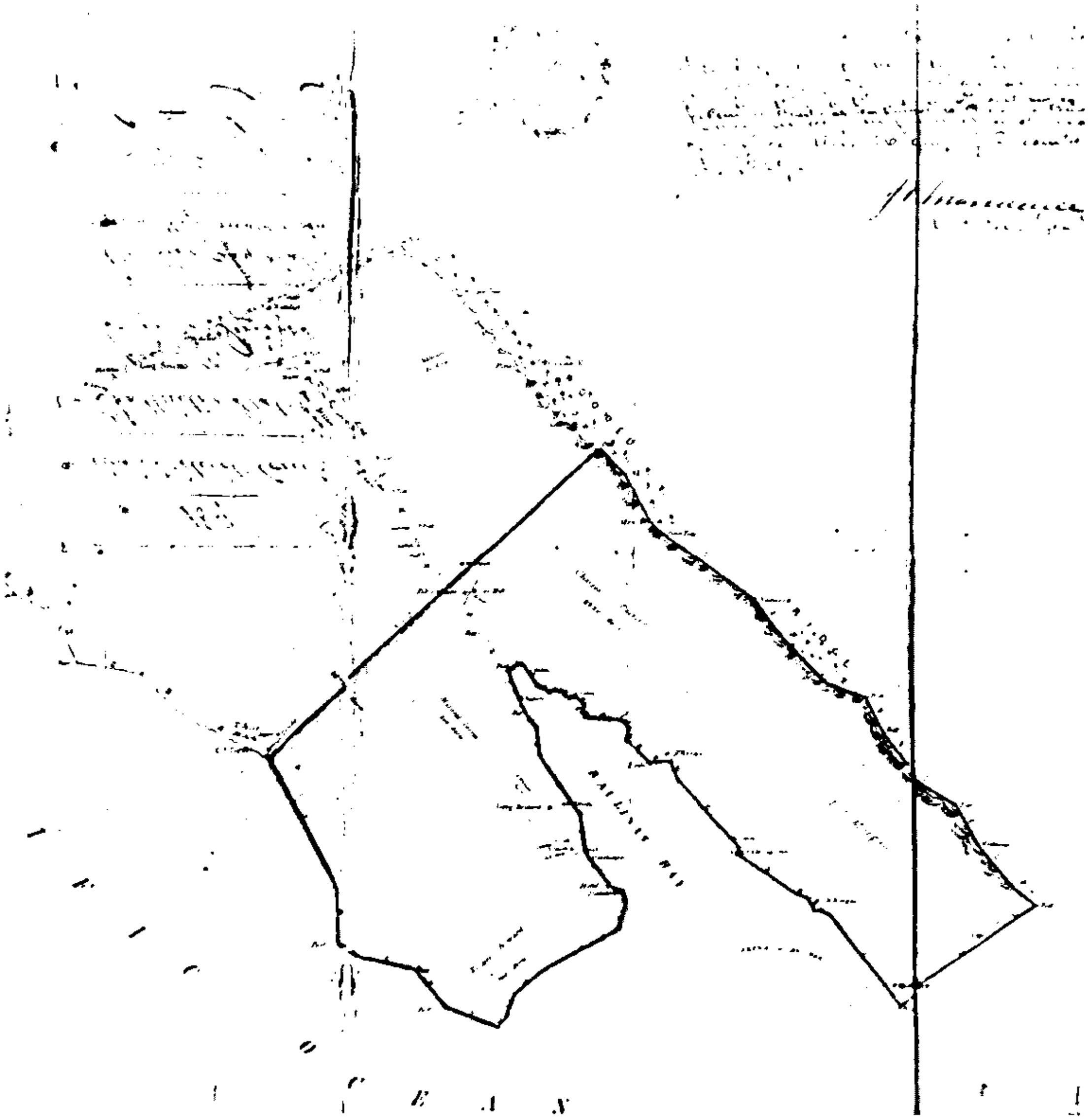

Figure 8.6. First U.S. government map of Bolinas Lagoon vicinity, done by Surveyor General, 1858. Note the absence of morphologic detail in the estuary and token (erroneous) representation of the sandspit across the mouth of the lagoon.

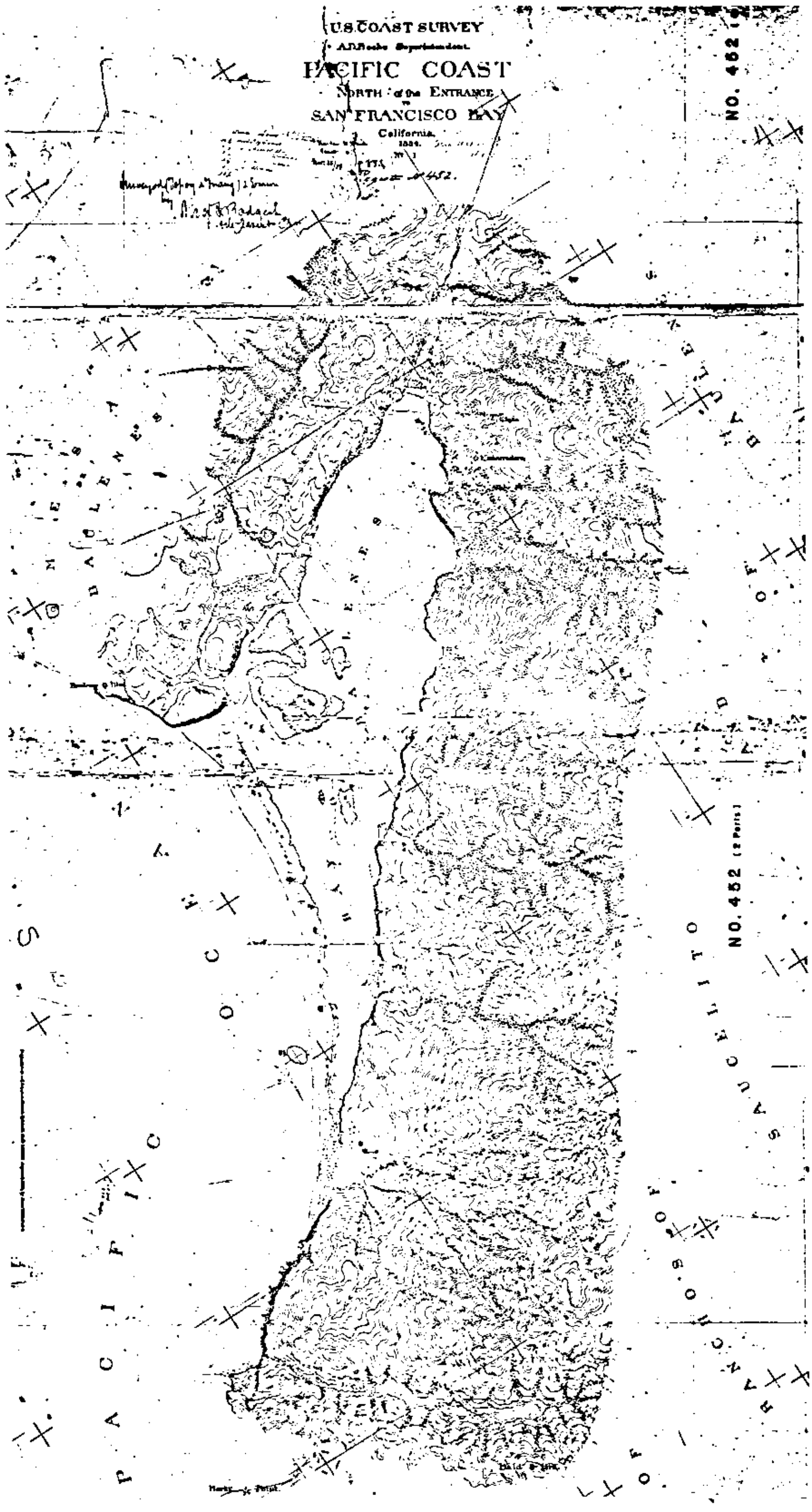

Figure 8.7. First accurate survey of estuary conducted by U.S. Coast Survey, 1854. (Representation of marsh, mudflats, and channels provides a good picture of the lagoon's morphology.)

ner edge of the marsh, shown on the map, for the most part corresponds to the line of mean higher of high water. Where it was difficult for the surveyor to discern the MHHW line of the marsh, the inner edge will not conform precisely to that elevation.

The U.S. Coast Survey (later the U.S. Coast and Geodetic Survey) completed two sets of maps for most areas. They are denoted as either "topographic" or "hydrographic" maps. The topographic maps show marshes and lines of MHW (MHHW), MLW (MLLW), with some upland vegetation and selected roads or buildings. The hydrographic maps note the depths of navigable water at spot locations using the topographic map as a base. The hydrographic map for Bolinas Lagoon (1854), a companion to the topographic map in Figure 8.7, indicates water depths in the bay outside the lagoon entrance and in the entrance itself. No depths are given within the lagoon proper. Hydrographic maps of other estuaries that I have seen provide similar information. When they are available, the U.S. Coast Survey topographic and hydrographic maps can be used together to construct a morphologic picture of an estuary for that time. Those who are fortunate will find several sets spanning a century, which together can provide a fine sequence of morphologic evolution.

Sedimentation Rates as Supplemental Indexes of Change

The process of sedimentation is the fundamental mechanism that creates morphologic change. Many people are concerned about increases in sedimentation rates—as an index of rapid evolution of the estuary—that result from land uses such as logging and residential development on the estuary's watershed. Analysts should know the possibilities and pitfalls of using sedimentation as another measure of evolutionary rate. They can then respond more effectively to public interest about how fast an estuary is changing under natural conditions, compared to how fast it would change if different types of human activities were allowed in any of the three sedimentation locales: the estuary itself, the watershed, or the littoral zone.

Sedimentation is a process of erosion, transport, and deposition. All material eroded from the watershed or adjacent littoral bluffs and beaches may not be transported to the estuary, and what is transported may not remain there. Some of it is removed by the tides. Thus, simply calculating erosion rates from the watershed under natural versus cultural conditions will not provide an accurate estimate of deposition rates in the estuary.

The interpretation of evolutionary change eventually focuses on the following questions: How fast did the estuary change in precultural times (essentially, before European man)? How fast has it been changing in recent years (under "current land-use conditions")? How fast will it change in the near future (given increases or decreases in human activity)? And how long before the estuary is extinct as a wetland landscape? An understanding of deposition rates in the estuary helps to answer some of these questions, but good data are hard to come by. This is one of the reasons why characterizing morphological change is perhaps more practical as well as inherently more suitable for visual-cultural assessment.

Human influences on how fast a natural feature like an estuary will evolve into maturity, senescence, and extinction are often best described using estimated sedimentation rates only as comparative measures for different intensities of human activity. Conventional wisdom assumes that aboriginal man increased erosion rates over those rates existing before human habitation and that "modern man" has sped up the rate of erosion even more. Table 8.1 illustrates this using hypothetical data from a small estuary. Documenting the history of deposition in relation to land use is difficult. The best method is to analyze sediment cores from the estuary. In the absence of cores, deposition rates may be estimated. This involves a series of speculative extrapolations from partial data on streamflow, tidal volume, and the like to rates of sediment transport into the estuary and then to rates of actual deposition. The procedure becomes more speculative when one attempts to reconstruct historical patterns.

The person who assesses visual-cultural values of estuaries will probably operate within the context of controversy over how fast the estuary is evolving toward extinction and what human activities in the vicinity of the estuary are doing to speed or slow the process. The partici-

Table 8.1 The Role of Human Influence on Estuary Evolution, Using Estimated Deposition Rates for Five Historical Periods

Historical Period	Rate (1,000 meters^3/year)
1. Preaboriginal: Estuary evolving at a rate representative of truly natural conditions.	20
2. Aboriginal: Hunter-gatherer tribes; no agriculture but occasional fires that could produce episodes of increased sedimentation.	21
3. European: Farming and logging by settlers; occasional fires.	25
4. Contemporary: Limited suburban and second home development; limited logging, grazing, and farming.	30
5. Future:	
Growth: Continued suburban and second-home development, logging, and road building; diminished grazing and farming; no removal of sediment from estuary.	35
Management: Restrictions on rate and locale of building, logging, and roads to minimize sedimentation; removal of sediment from estuary.	28

Time to Extinction

(assumption: tidal prism to MHW is $1{,}400 \times 10^3$ meters^3)

Tidal prism divided by future "management" rate = 50 years.

Tidal prism divided by future "growth" rate = 40 years.

pants in the controversy may speak in terms of deposition rates, for they are a convenient means for describing the rate of evolution and the relative influence of man and nature. However, without an accurate technique for measuring contemporary deposition rates, and in the absence of sediment cores for historical analysis, the primary effort of characterizing the evolution of an estuary should be restricted to the depiction of morphological change using historical maps and air photography.

The Portrayal of Morphologic Evolution

Morphologic evolution can be depicted in both tabular and cartographic form. Figure 8.8 portrays morphologic evolution of Bolinas Lagoon over the 170-year period from about 1850 to 1970. This sequence was constructed from interpretations of historical maps, descriptive records, and recent air photographs. Table 8.2 provides areal data for morphologic units at four dates during the period.

It would be a simple matter to extend this portrayal back in time to the point where sea levels stabilized and the estuary began its evolution. The first map, dated perhaps two or three thousand years ago, would show a thin fringe of marsh with an incipient delta at the mouth of the major stream. The estuary would be quite open to the sea, with segments of a spit beginning to develop. This could be said to represent preaboriginal conditions, although at that date there may have been small bands of coastal Indians in the vicinity of the lagoon. A second map, dated about a thousand years ago, would show the stream delta somewhat enlarged, with two small islands emerging inside the lagoon. In the interim between the two maps, there would have been significant growth of the spit or bay mouth bar. A third map could be added for the period around A.D. 1500 to suggest how Bolinas Lagoon would have looked to the first European explorers, perhaps even to Sir Francis Drake himself, who is reported to have come ashore not far from this estuary. The main fluvial delta and the tidal delta (the two islands inside the mouth of the estuary) would have grown. The spit across the seaward face of the lagoon would now be more fully developed, but it still might be segmented, being breached by high tides and storm waves at regular intervals.

A sequence of morphological maps as described here is an effective means of communicating the history and future of evolutionary change. Used as a medium for public interpretation, the morphologic stages can be characterized along a time line beginning with stabilization of sea level (two to three thousand years ago) and ending with conversion to a coastal meadow. The information in Table 8.1

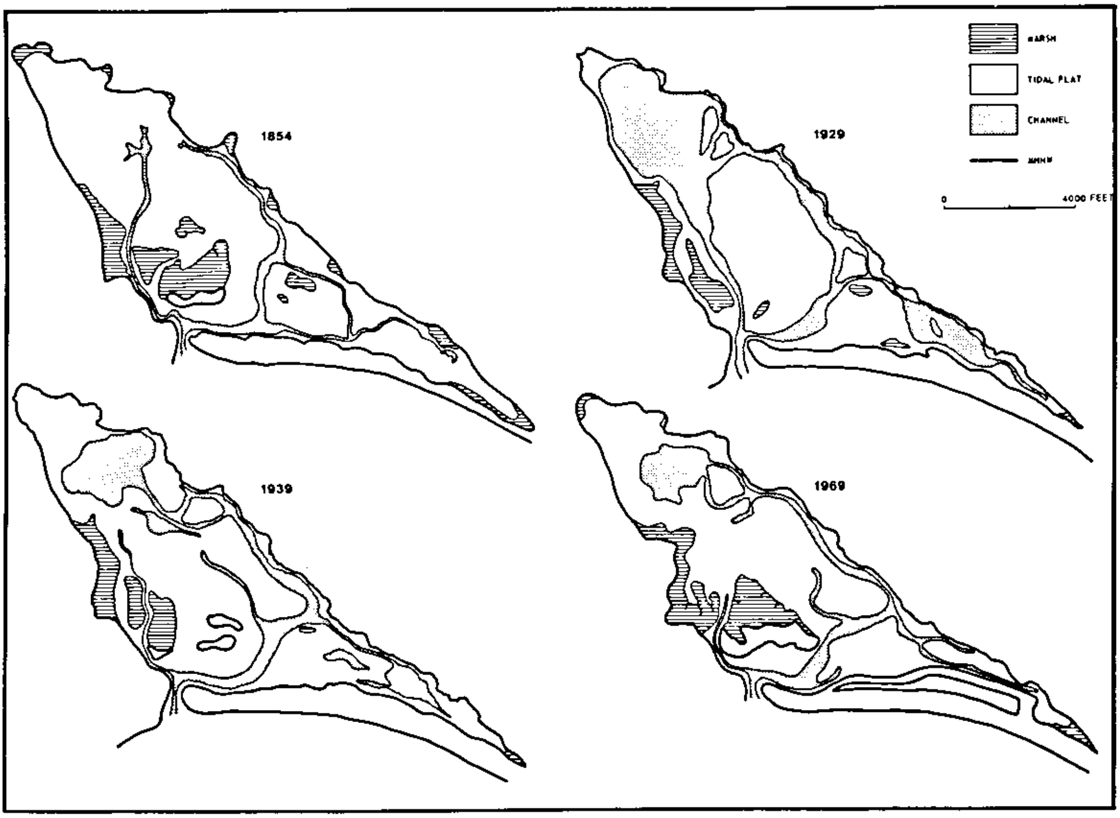

Figure 8.8. Morphologic change in Bolinas Lagoon, 1854-1969. (Sources: 1854–U.S. Coast Survey; 1929–U.S. Coast and Geodetic Survey; 1939–U.S. Army Corps of Engineers survey; 1969–air photographs.)

and Figure 8.8 has been combined in Figure 8.9, to illustrate how alternate future patterns and time to extinction can be incorporated in one presentation.

Marsh Invasion and Rate of Evolution

The primary colonizers invading the bare mudflat help to determine the visual character of the estuary in both static and dynamic terms. In both respects the major distinction is between two common invaders, *Salicornia* (pickleweed) and *Spartina* (cordgrass). On the west coast of England, *Salicornia* is the dominant colonizer. Along the English Channel, *Spartina* (the aggressive hybrid, *S. townsendii*) has within several decades changed the visual character of a large number of estuaries. *Spartina foliosa,* a cousin of the European species, actively expands onto the lower elevations of selected California estuaries. *Spartina alterniflora* covers the marsh in estuaries along the Atlantic, and to a lesser degree on the Gulf Coast of the United States (this species is also prevalent on the east coast of South America and in the English Channel). *Spartina* is generally absent from the estuaries of Oregon and Washington.

There is a marked visual difference between marshes boasting the tall (three to five feet), wheatlike *Spartina* and those having a low (six to ten inches) mat of *Salicornia* (Figure 8.4). The thick, shiny-leafed cordgrass undulates in the shore breeze, presenting a clear edge to adjoining communities and to the bare mudflat. It browns in winter, whereas the pickleweed remains a grayish-green. Circular groves of cordgrass are commonly seen standing amid an ex-

Table 8.2 Morphologic Elements of Bolinas Lagoon Expressed as Acres and as Percentage of Total Estuary Areas, 1850-1970

	Area of	Marsh	Mudflats	Channel
Year	Lagoon	Acres : %	Acres : %	Acres : %
1850	1216	157 :13	909 :75	150 :12
1930	1130	72 : 6	653 :58	402 :36
1940	1096	88 : 8	742 :68	266 :24
1970	938	118 :13	654 :70	166 :17

tensive pickleweed mat or along the lower edge of the mat in a distinct band ten to twenty yards wide. These are the static attributes of *Spartina* and *Salicornia* communities, but what are the dynamic aspects?

Spartina is thought to be the more aggressive colonizer. Once it is introduced to an estuary, rates of morphologic change are likely to increase there. The cordgrass is able to withstand longer periods of tidal submergence; consequently it extends itself farther down on the mudflats than the pickleweed. Like other pioneer vegetation, cordgrass seems to thrive on disturbance. It is common for *Spartina* to invade tidal channels, and these aggressive plants are often torn out by the rushing water of a heavy rainstorm occurring at low tide. If they are not removed this way, the cordgrass-clogged channels may be dredged to restore the flushing action of the estuarine circulatory system. In either case the broken but viable *Spartina* rhizomes float off to sprout new colonies elsewhere. Many estuaries in central and northern California have previously had only moderate amounts of cordgrass, but these colonies are expanding and in the near future will probably dominate these landscapes.

The Tides: Visual Attributes of Cyclical Change

To this point, the discussion has focused on morphologic evolution, with the implicit understanding that tidal cycles work in conjunction with morphology to produce an estuary's set of visual attributes. Each morphologic change produces a different stage on which the tides produce different visual scenes.

When a viewer comes to an estuary, he or she may hold the image of a placid body of water. Confronting the estuary in reality may be disappointing because at low tide it looks like a drained reservoir. To characterize the estuary visually as a body of water is simply a technical error. As shown by the tide curve in Figure 8.10, the estuary is full only 20 percent of the time and empty 20 percent of the time. During flooding or ebbing ("midstage" in Figure 8.10), the mudflats are teeming with birdlife. Thus to overlook the visual attributes of a half-filled estuary is to neglect the most common as well as the richest stage of its tidal cycle.

The Tides as a Unifying Medium

In the tidal cycle we can find a solution to the old conflict between visual complexity and visual unity. Litton et al. (1974) identified three critical aesthetic criteria for the evaluation of environmental stimuli: unity, vividness, and variety. "Unity is that concern or expression whereby parts are joined together to a coherent and single harmonious unit" (p. 105). But, he goes on to say, "Variety does have a potential conflict with unity" (p. 107) unless there can be found some cohesion in diversity. (The terms *variety, diversity,* and *complexity* are used synonymously to denote the array of elements in a landscape display.) To see unity in a *static* landscape, the observer must infer some degree of structural cohesion or coherence among the parts. To see unity in the *dynamic* landscape of the estuary, the observer witnesses the repeated linking of morphologic units by tidal action. These units are the visible components of the estuarine system. Tidal flow is the dynamic medium that unifies them by immersion. This unifying process is given visual elaboration by the action of shorebirds at each tidal stage. As the incoming tide begins to join channel with mudflat, mudflat with marsh, the diggers move about poking in the mud for worms and small crustaceans, while the egrets and herons stand in deeper water and wait for fingerlings. Birds fly back and forth between channel, marsh, and mudflat, and the observer can see with ease the estuary as an intergrated whole composed of distinct parts.

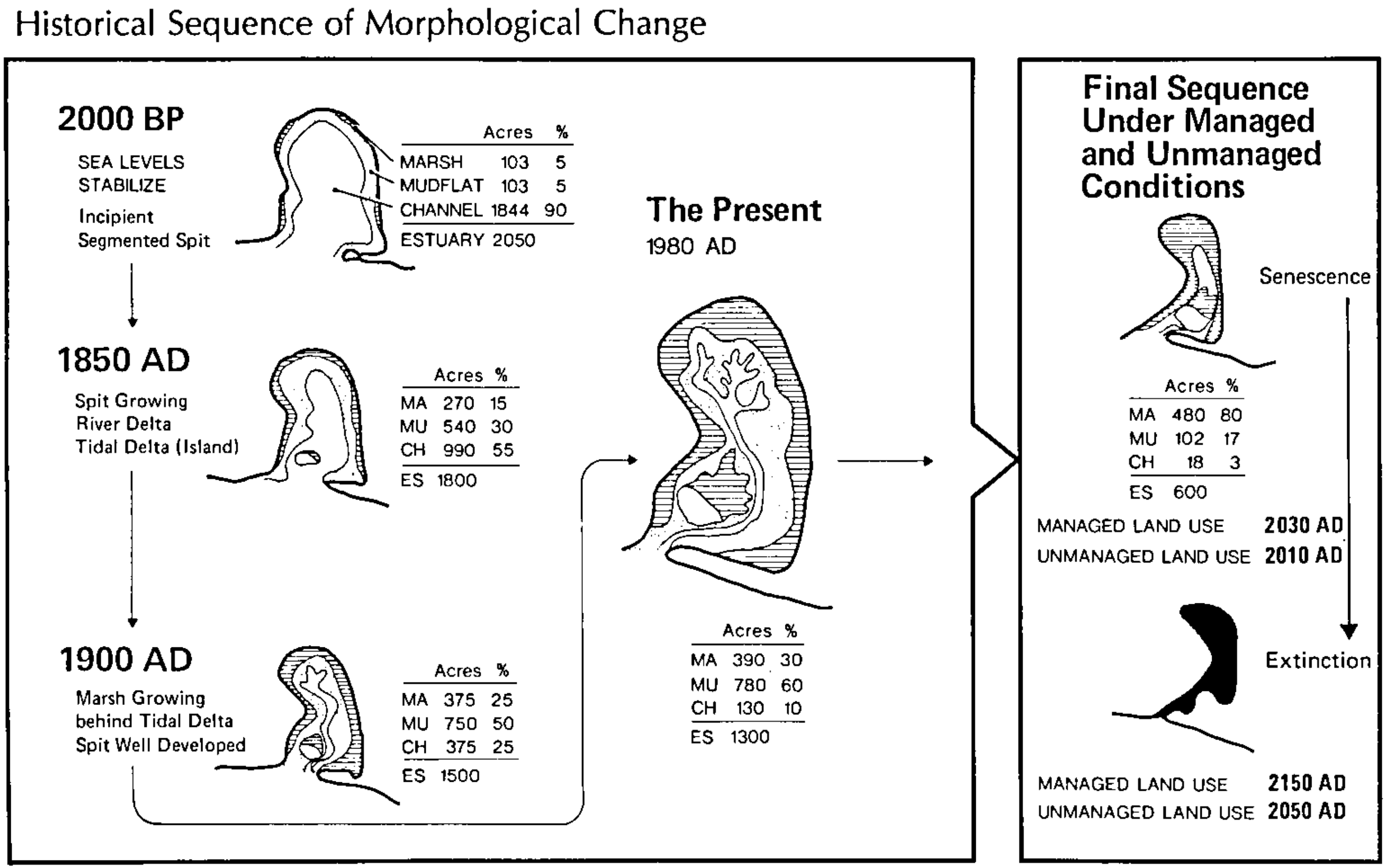

Figure 8.9. Estuarine evolution can be portrayed so that the time to "senescence" and, finally, "extinction" is seen as resulting from the decision to manage, or not manage, land use in and around the estuary. This idealized picture is created from existing knowledge and presents the question in terms of a choice to extend the life of the estuary. Dates and time periods will vary greatly among estuaries having different geographic properties.

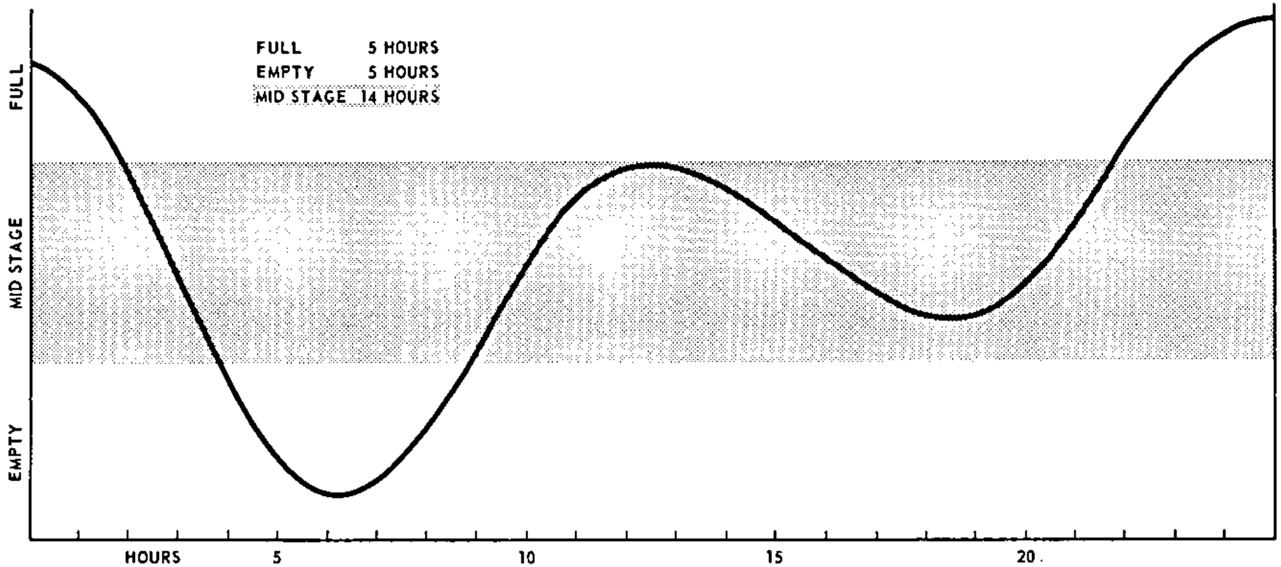

Figure 8.10. Mean tidal curve for a typical Pacific Coast estuary (Bolinas Lagoon). The estuary is "full" only 20 percent of the time, "empty" only 20 percent of the time. The most common visual state is at "midstage," when the tides are ebbing or flooding. During this time the mudflats are covered with shorebirds, which add a rich dimension to the visual character of the estuary.

Evolutionary Changes in Visual Attributes of the Tidal Cycle

As an estuary ages, the visual attributes of the tidal cycle change. The direct changes are by now obvious and have been touched on above. A youthful estuary, when full of water, looks like a lake; when empty, it looks like a muddy, drained reservoir. A water-filled, mature estuary with extensive marsh appears as a grassland; but when flooded to three-fourths the height of the *Spartina*, it looks like a true "marsh." A mature estuary lacking *Spartina* may be flooded above the height of the *Salicornia* or *Distichlis*, giving more the impression of a lake than a marsh. A senescent estuary with deeply incised channels among raised marsh beds may never give the visual impression of being a wetland if the flood-tide water is contained in the channels.

The morphologic evolution of a given estuary continuously reapportions a finite number of acres among the three morphologic units. For example, the more marsh, the less mudflat. Consequently, the kinds and abundance of birds that appear at different times in the tidal cycle will change with each stage of morphologic evolution. The mudflat supplies the food for the medium-sized and smaller shorebirds (Figure 8.11, bottom). Primarily diggers, the swarms of sandpipers, aggressive willets, dowitchers, dunlins, and oystercatchers are squeezed ed out as the ratio of marsh to mudflat increases. The mudflat stage offers prime visibility, a dance floor on which the trophic ballet is repeated with each tidal cycle. In the last stages of evolution, when the marsh abuts the channels, those smaller birds that still use the estuary will be hidden from view. The large birds—herons, egrets, and cranes—remain with an estuary after the mudflat unit has disappeared (Figure 8.11, top). They can stand knee-deep in the channels and feed, although they, too, will often be hidden from view as the channels become narrow and constricted.

Tidal Range and Visual Character: Tidal ranges (the vertical distance from MHW to MLW) vary from place to place. The variation is several feet in southern California and four times that in northern Maine. An average annual tidal curve similar to the one in Figure 8.10 could be used as the basis for calculating the area and duration of tidal filling. The vertical axis would represent the elevational scale, and once the estuary was surveyed, the area covered by—and the duration of—any stage of the tide could be calculated and graphically documented. A variation of this method would be necessary if no survey could be done. Using standard tide tables that note the time of day of high and low tides, an estimate could be made as to when a given stage would occur. Photographs could then be taken of the estuary landscape at, for example, low water plus one foot, low water plus two feet, midtide, low water plus three feet, and high tide. The photographs would be correlated with the duration (taken from the tidal curve) at each stage to document the visual attributes for different percentages of time for the daily cycle.

The tidal range of an estuary determines the range of visual conditions that will be produced. At low tide, estuaries with large tidal ranges, such as those in Maine, exhibit a great expanse of mudflat. Under these conditions the mudflat component of the estuary may visually overwhelm the presence of marsh and any remaining water in the channels. The relationship between tidal range and the rate and form of morphologic evolution is unclear. Some hypothesize that those estuaries with small tidal ranges evolve more rapidly than those with ranges of six feet or more.

The Geographic Context for Interpretation

In the Introduction it was suggested that the visual attributes of landscape—those inventoried in conventional assessments—were analogous to the static elements of a language, and the challenge was to find a way of using these elements in some dynamic grammar to convey meaning. Yet, pursuing the analogy further, a well-constructed sentence taken out of context may not be able to convey meaning adequately or accurately.

For any single estuary the meaning of morphologic change and rate of evolution emerges best when the case at hand is compared to other estuaries, measured against a theoretical norm, or set among the range of evolutionary conditions found within a geographic region. A good point of departure is the question of abundance and form of estuaries taken at the national scale.