HISTORIC SEDIMENTATION IN AN ESTUARY: SALT MARSH SUCCESSION AND CHANGE BIG RIVER ESTUARY, MENDOCINO COUNTY, CALIFORNIA

Laurie Marcus and Steve Reneau[1/]

ABSTRACT

The salt marshes bordering Big River Estuary have exhibited rapid vegetative succession in response to an accelerated build-up of levees along the estuary banks. Since the advent of logging in the watershed in 1852, the estuary has experienced major geomorphic changes. The natural progression of river de-posits down the estuary has been greatly accelerated in the past 130 years.

Silt-laden flood water, slowed by tidewater flowing into the estuary, deposits sediment to form levees along the channel. These levees act to isolate salt marshes from tidal inflows. As tidal sloughs tilt in and saline influence into the marsh diminishes, an unusual vegetative succession begins. Halophytic salt marsh plant species are replaced by riparian and coastal scrub plants. Salt marsh habitat is lost as a direct result of accelerated erosion in the watershed.

Detailed vegetation maps and comparative diagrams illustrate the significant changes these tidal flats have undergone. Comparison of recent infra-red imagery, field surveys, aerial photographs and historic photographs dating from 1860, reveal the time sequence of these vegetative changes.

INTRODUCTION

The estuaries of north coastal California are limited in distribution and, excepting the San Francisco Bay system, generally small in size. They experience a broad range of conditions governed by both the tide and flood cycles of their distinctive components: ocean and river. As the confluence of these two components, the estuary receives both river-carried sediment and tide-borne sand (Steers 1967). Estuaries are sites of active sedimentation. During flood stages, high tide waters mix with and slow, silt laden river water resulting in the deposition of sediment in the estuary. If river sediment toads are large, deposition in the estuary will also be great. San Francisco Bay provides one example; the large amounts of sediment produced by hydraulic mining in the Sierras were deposited in the Bay, significantly reducing its depth (Gilbert 1917). Consequently an examination of the geomorphic patterns found in an estuary can reflect erosional processes occuring in the watershed.

[1/] Laurie Marcus, Madrone Associates, Novato, California
Steve Reneau, U.S. Geologic Survey, Menio Park, California

Big River is amongst the largest watersheds along the Mendocino coastline, draining an area of approximately 165 square miles. As with other north coast rivers, discharge is concentrated during the winter and early spring, and summer outflows are quite low. Tidewater extends up the lower 8 miles and a series of eight salt marsh flats border the lower three miles. Unlike many estuaries, Big River estuary is not lagoonal but instead has a long linear channel. Crescent-shaped tidal flats alternate on either side of the channel corresponding with the alluvial deposits of the river. Redwood and mixed coniferous forest cover the steep slopes which border the channel (Figure 1).

Big River estuary has experienced rapid sedimentation of its channel and salt marshes since the advent of logging in the watershed. Timber harvesting which began in 1852 has been and continues to be the primary land use. These lands have been continuously harvested for 120 years using a variety of methods. The resulting erosion and transport of sediment down the river is evidenced by the historic changes in the estuary. The changes are cumulative and represent the long-term effects of timber harvest operations in the watershed. This paper seeks to document the depositional process occuring in the estuary, describe a relative time scale for these events and present the effects of this process upon the biotic components of the estuary.

METHODS

In order to assess historic changes in the estuary, a survey comparing the estuary's present condition with that in the early logging days was necessary. Therefore we not only documented present conditions through vegetation maps and topographic studies but also researched past information. We were able to contact a local expert on the early logging of Big River (Francis Jackson) and obtain historic photographs of the estuary. Many of the old logging structures remain and their former position in relation to the shoreline (as evidenced in the photographs) could be compared with their present position.

The vegetation maps were produced from a variety of sources. Initially in-depth field checks of each flat were completed producing rough maps outlining slough locations and vegetation distributions. A series of 144 aerial photographs were taken of the flats using both color and infra-red modes. The photographic series was designed for a 60% overlap between slides to assure complete coverage. The slides were photographed from a pre-determined altitude (8,000 ft.) to provide the desired projected scale (1 inch:200 ft.). Another set of color slides of the flats taken from a lower altitude (1,000 ft.) also were made during this flight. The final set of slides was created by photographing 1978 U-2 Nasa infra-red aerial photographs of the Big River watershed. The slides were projected and an outline of each flat traced. Physiographic characters, slough systems, pans and vegetation forms, (trees, grasses, etc.) were mapped. The low altitude slide series was used to check vegetation lines and identifications. The field sketches were compared with the new maps to retain accuracy. Comparative diagrams of vegetation types were produced from black and white aerial photographs taken in 1952 and 1963. Vegetation types were defined by dominant species and all plant species encountered were collected and identified.

GEOMORPHOLOGY

The deposition of sediment is a natural geologic process in estuaries. However Big River estuary exhibits greatly accelerated sedimentation and an unusual

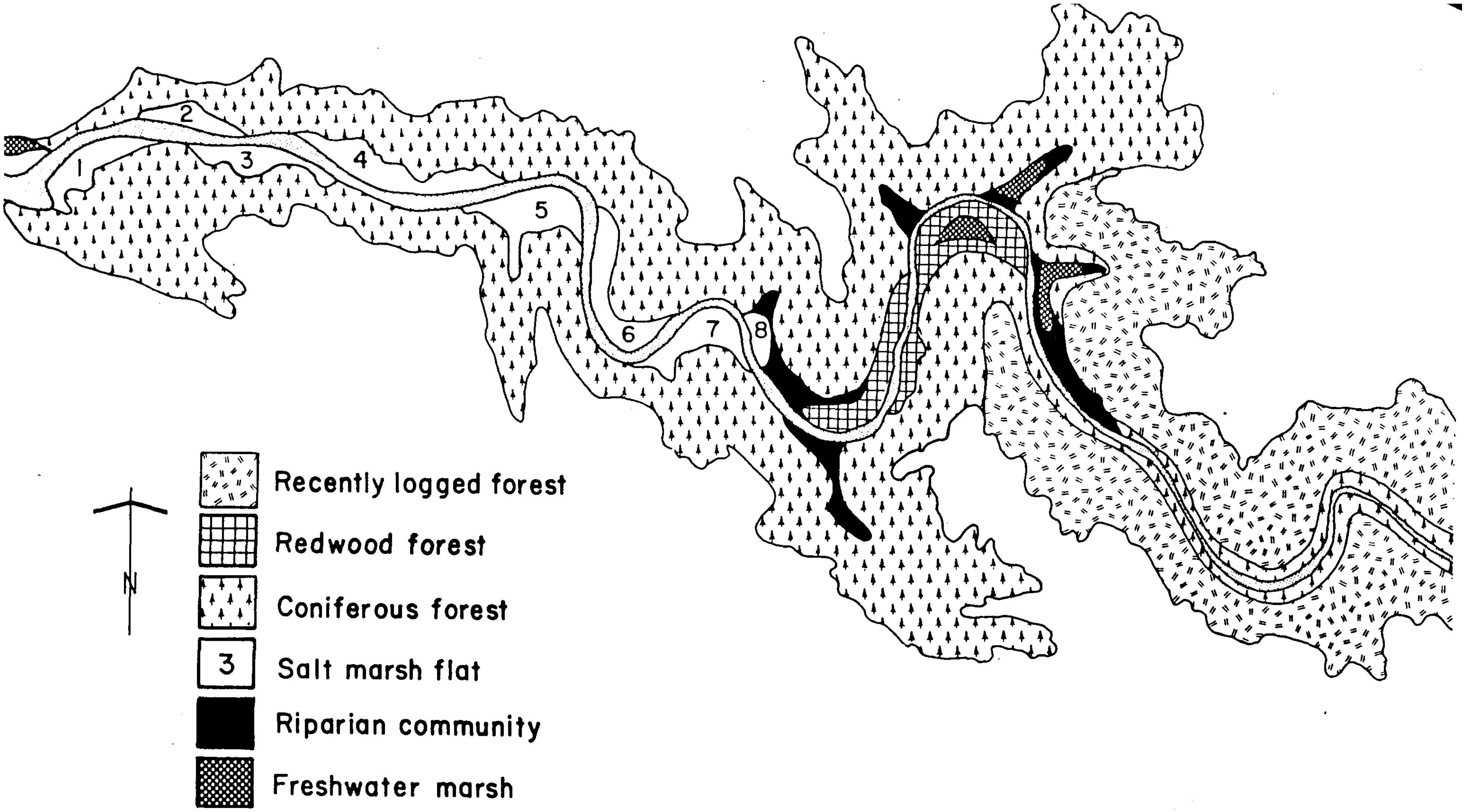

Figure 1. Big River Estuary, reference map of salt marsh flats.

pattern of deposition. The most obvious indicator of this accelerated process is the occurance of levees bordering the estuary channel. These levees extend along the channel down to 1.7 miles above the mouth and display a regular decrease in height. Their size varies from 40 ft. in width in the upper estuary to 10 ft. and less in the lower region. These levees record the transition in the estuary from primarily tidal influences (salt marsh and mudflat) to primarily river influences (floodplains).

These levees are formed as silt laden flood waters are slowed along the edges of the channel (Figure 2). The coarser, heavier sediments settle out forming an embankment along tidal flats and estuary channels. Driftwood and eel grass beds located along the edges of the channel as well as tidal inflows act to slow down the flood waters and permit the sediment to settle out. Floculation of clay particles in the estuary may also contribute to this process. The increased sediment load resulting from erosion in the watershed cannot be transported out of the system by winter floods. The result is storage of the sediment in levees and on tidal flats.

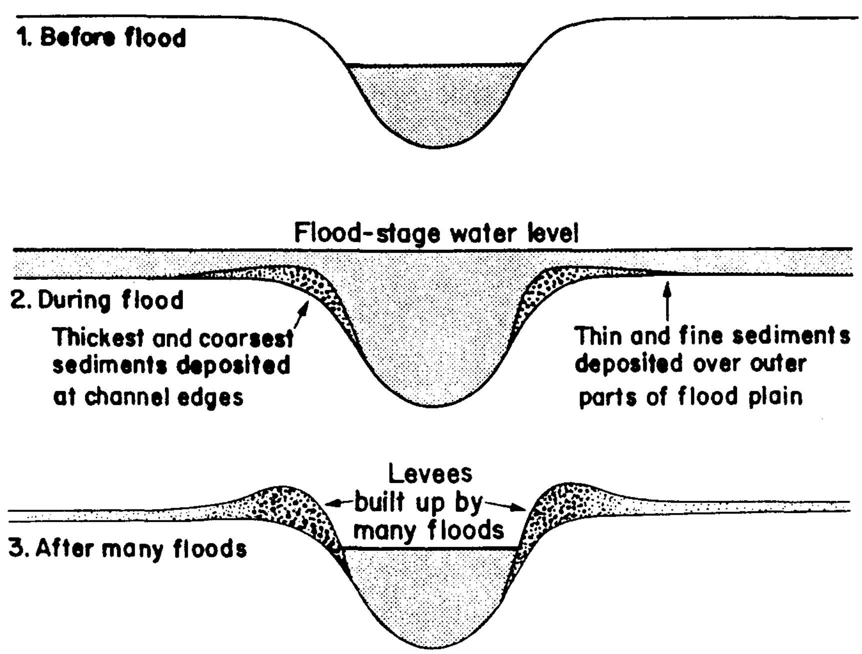

Figure 2. Formation of levees by river floods. As a river in flood stage overflows its banks, it rapidly decreases in velocity away from the channel and so drops most of its sediment, the coarser parts near the channel and the finer parts as a thinner layer of silt and clay over most of the floodplain. Successive floods build up the levees to ridges many meters high.

This sedimentation and levee build-up have taken several forms. The estuary banks have prograded resulting in a narrowing of the channel and an increase in ftoodplain size at the expense of mudflat and subtidal areas. Blockage or reduction in tidal influence has occured in the upper flats while a filling of sloughs and increase in mudflat height is found in the lower flats.

A few comparisons serve to illustrate these processes and estimate a time scale for their occurance. A railroad system was used to transport logs to the estuary during the early logging. A log dump located 3.8 miles upriver served as a spur of the railroad where logs could be dumped directly into the water. This log dump is shown in a historic photograph taken in the 1920s as standing in open water (Jackson 1975). The border of Flat 8 sloped gently away from the water. Today the pilings of this log dump stand adjacent to Flat 8, bordered by a levee 4 ft. in height. The historic development of this levee records a major change in the hydraulic conditions of the estuary. Winter floods were not able to deposit enough sediment to build levees at the site of the log dump prior to 1900. Since the photograph was taken, levees have developed 2 miles further down the estuary.

Once the logs were dumped into the estuary, they were rafted down to the sawmill at the mouth. To avoid stranding the logs on the tidal flats, rows of pilings were placed at the lower low tide line (Jackson 1975). Chains were stretched between these pilings and acted as a barrier to the floating logs. Presently in Flat 4, two sets of pilings occur, the outer one at approximately low tide line and the inner one trending back into the salt marsh. Two sets of pilings were installed during the logging operations before 1938 indicating that heavy sedimentation had extended the low tide line out into the channel, thus rendering the original set obsolete.

The filling of these tidal sloughs by sediment is demonstrated by the presence of several barges, buried in Flat 4. These barges were used for transport in the estuary. The barges are 42 ft. in width and were moored in the tidal slough, indicating the original slough was at least this wide. Presently the same slough is 7 ft. in width and the barge is buried adjacent to the bank.

SALT MARSH SUCCESSION

Accompanying levee build-up and siltation of slough systems are significant changes in the vegetative composition of the flats. As tidewater inflow to the flats is blocked rapid vegetative succession from salt tolerant or halophytic plant species to non salt-tolerant plants occurs. This successional scheme is unusual for salt marshes and represents a significant loss of wetland habitat in the estuary.

The circulation of salt water throughout the marsh is most important in determining the species distribution of marsh plants. Studies from England, North Carolina, San Francisco Bay and Oregon (Adams 1962; Hinde 1954; Miller 1950; Eilers 1979; Chapman 1938; Atwater 1979) have found tidal inundation to be the strongest determining factor in plant species distribution.

The channel systems found on Big River's flats are dendritic drainage sloughs formed through erosion by ebbing tides (Pestrong 1972). These flats are not completely inundated by tidewater and the slough channels are the only agent for tidewater inflows. Therefore, the distribution of these channel systems and their proportionate area within each flat is a direct measurement of saline influence to each marsh. The channel systems are extensive in the lower three flats becoming reduced to non-functional in the upper flats. Vegetation patterns coincide with the placement and extension of these slough systems.

Salt marsh plants, such as the succulent pickleweed, are specifically adapted for saline soils. They are able to store water in their tissues and thus avoid dessication. When saline inflows are reduced to marsh soils, as in the upper flats at Big River, the halophytes loose their adaptive advantage and are replaced by other species.

TABLE 1

FRESHWATER AND SALT MARSH PLANT ASSOCIATIONS

*--indicates dominant species

Vegetation Type	Species Composition	
pickleweed	Salicornia virginica	PICKLEWEED*
	Triglochin striata	ARROW GRASS*
	Jaumea carnosa	
	Cuscuta salina	PARASITIC DODDER
rushes	Juncus lesueurii	RUSH*
	Distichlis spicata	SALT GRASS
	Gramineae spp.	GRASSES
	Holcus lanatus	VELVET GRASS
	Hierochloe occidentalis	VANILLA GRASS
alders	Alnus rubra	RED ALDER
	Salix lasiolepis	WILLOW
coastal scrub	Baccharis pilularis	COYOTE BRUSH*
	Lupinus rivularis	LUPINE*
	Rubus ursinus	CALIFORNIA BLACKBERRY*
	Anaphalis margaritacea	PEARLY EVERLASTING*
	Senecio jacobaea	RAGWORT
	Foeniculum vulgare	SWEET FENNEL
	Erechtites arguta	FIRE WEED
	Rumex crassus	DOCK
	Carex salinaeformis	SEDGE
	Orthocarpus castillejoides	OWL'S CLOVER
	Pteridium aquilinum	BRACKEN FERN
	Rhus diversiloba	POISON OAK
	Convolvulus occidentalis	MORNING GLORY CRANESBILL
	Geranium molle	
	Gentiana amarella	FELWORT
freshwater or brackish-water marsh species	Typha latifolia	CATTAILS*
	Scirpus robustus	BULRUSH*
	Cicuta douglasii	WATER HEMLOCK
	Torilis arvensis	HEDGE PARSLEY
	Juncus effusus	RUSH
	Scirpus arnuus	BULRUSH
	Carex obnupta	SLOUGH SEDGE
	Plantago hirtella	PLANTAIN
	Potentilla egedei	PACIFIC SILVERWEED

The plant associations in the salt marsh flats are listed in Table 1. Vegetation types are defined by the dominant plant species (e.g. pickleweed, rushes). The coastal scrub assication while being dominated by coyote brush and lupine, contains many plant species from the disturbed ground community.

The various flats along the estuary have distinctly different vegetation. The lower three flats exhibit extensive slough systems and are covered with halo-phytic plants, pickleweed and rushes. The rushes, being less salt tolerant, occupy the more elevated areas of marsh where soils are less saline (see Figure 3).

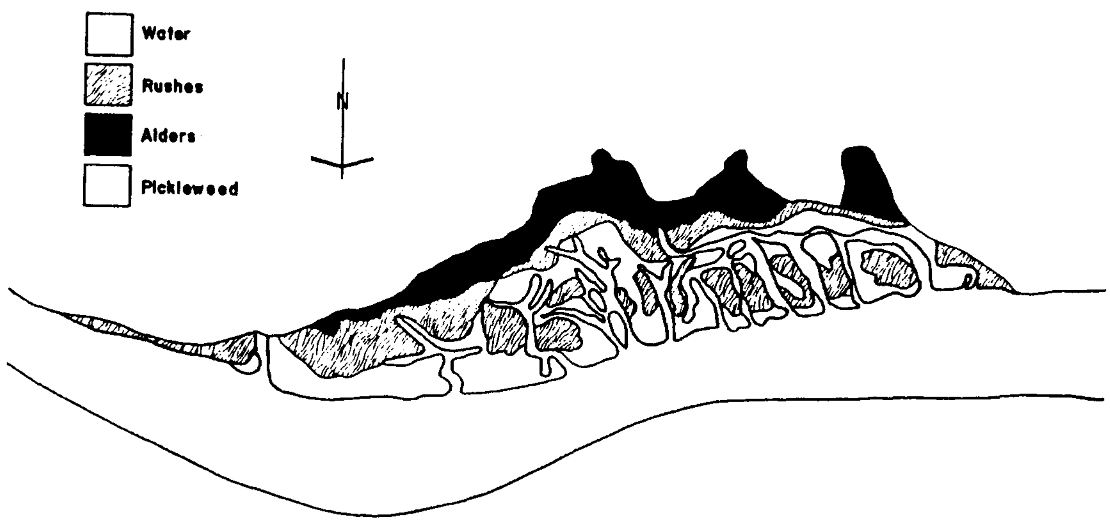

Figure 3. Vegetation map of Flat 3. An extensive slough system and predominance of halophytic vegetation characterize the lower flats.

The upper flats, however, exhibit a very different plant distribution pattern. Beginning in Flat 4, a levee occurs along the estuary bank blocking tidal inflows to the interior of the flat. The levee is higher than the surrounding marsh and is colonized by non-halophytic plant species of the coastal scrub and alder communities. Several of these plant species are nitrogen-fixing, containing nitrate producing bacteria in their root nodules. Consequently they have an advantage on the newly deposited, non-saline soils of the levees. Inside this levee in the marsh interior are low, depressed areas filled with pickleweed.

In Flats 5-8 a levee encloses the perimeter of much of the marsh, restricting tidewater inflows. Slough systems are greatly reduced or non-existent. Dead pickleweed patches which occur within Flat 7 are enclosed by a thick corridor of alder and scrub plants (see Figure 5). In this flat tidal inflows have been

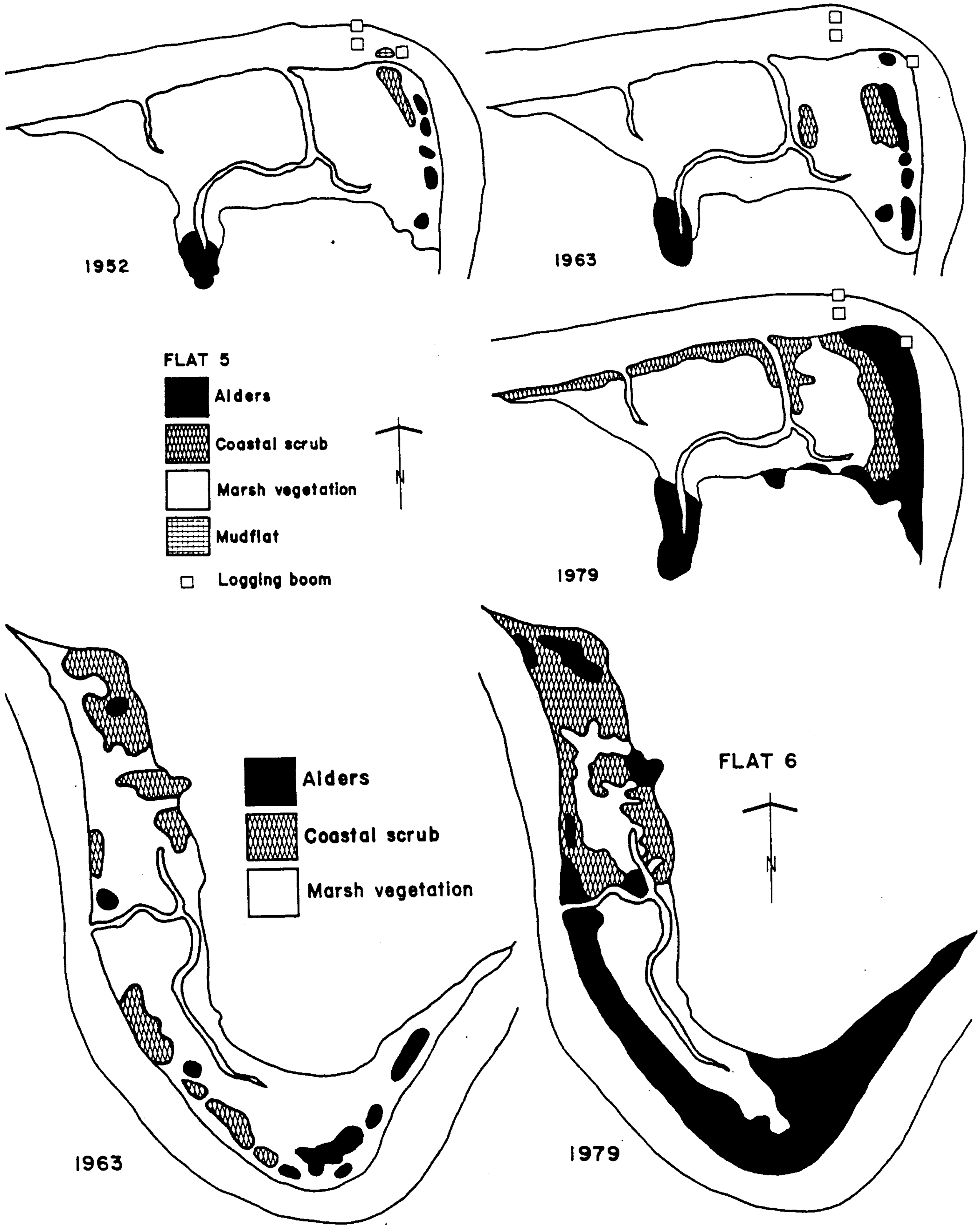

Figure 4. Comparison of vegetation in Flats 5 and 6.

completely blocked; a lower salinity level in the soils, allows for the replacement of salt marsh plants.

In Flats 4 and 5 salt pans are found, just inside the levee and indicate the rapid deposition of sediment. These pans form as the marsh changes (Yapp 1971). During rapid sedimentation and halophytic plant colonization of muds, some regions become isolated. Normal submergence is restricted and with no drainage slough connections, the tidewater is trapped in these isolated regions. After this tidewater is caught within these pans, vegetative colonization is restricted. Even after evaporation has occured, the salinity level of the soil is prohibitive to plant growth.

Figures 4 and 5 illustrate the vegetative changes which have occured in the upper flats over the past 30 years. The replacement of marsh vegetation by coastal scrub and eventually alder, indicate a significant loss of salt marsh in the estuary. The enlargement of the levee is also illustrated in Flats 5 and 7.

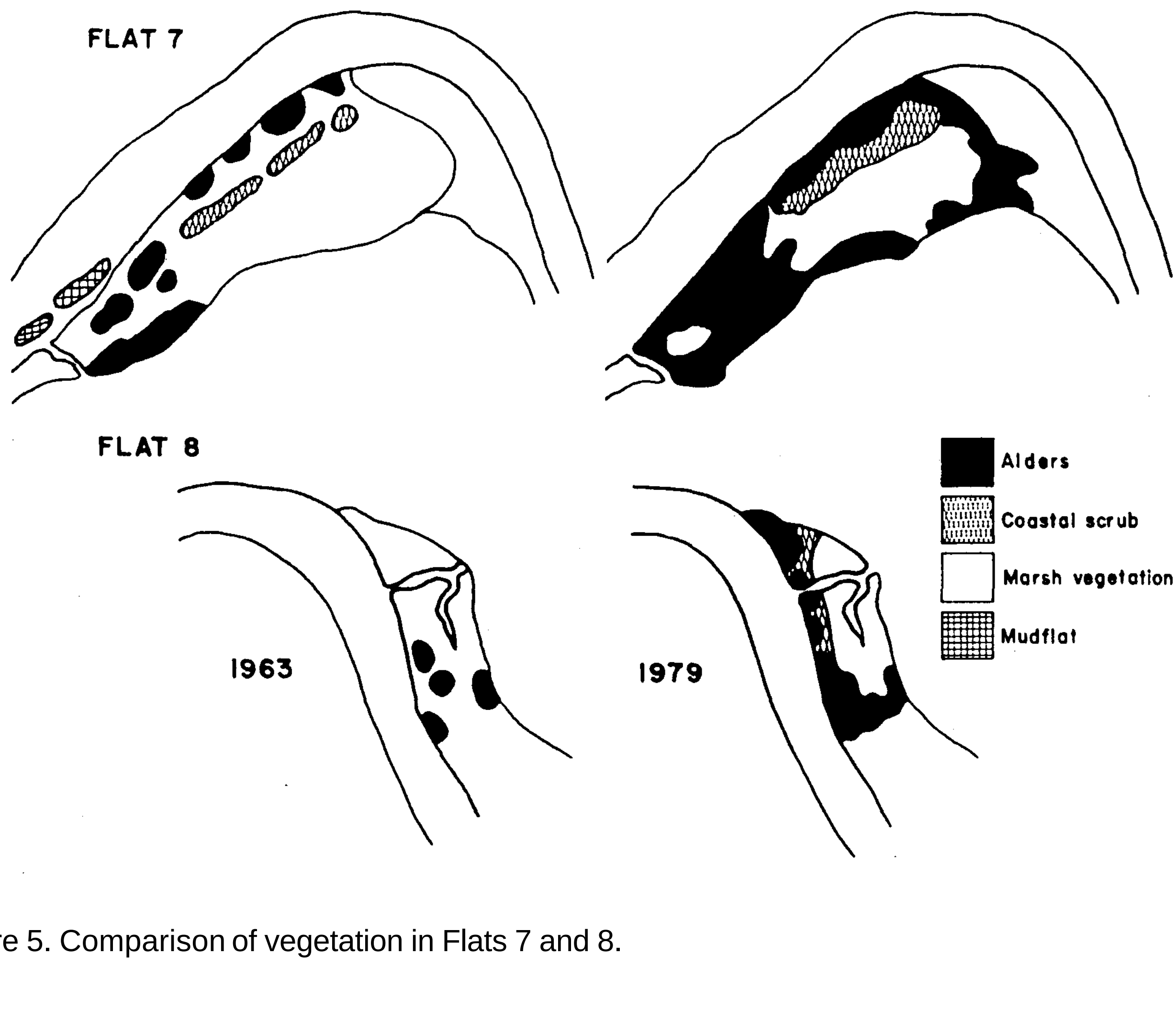

Figure 5. Comparison of vegetation in Flats 7 and 8.

Historic photographs (circa 1900) of Flat 1 reveal a mudflat with no vegetation of any type. Presently about half of this flat is covered with halophytic plants indicating a substantial rise in height of the flat. In addition this flat was across the channel from the logging mill pond. A row of old pilings still crosses its reaches diagonally. These pilings are the remnants of a wingdam, built in 1884 and used to direct the river's current toward the mill to flush sawdust and other debris (Jackson 1975). If the placement of these pilings in 1884 was such as to direct current movements then it may be assumed that they were placed in areas covered by water most of the time. At present, these pilings can have no effect on channel water currents, for they are located in a slough surrounded by islands of vegetation.

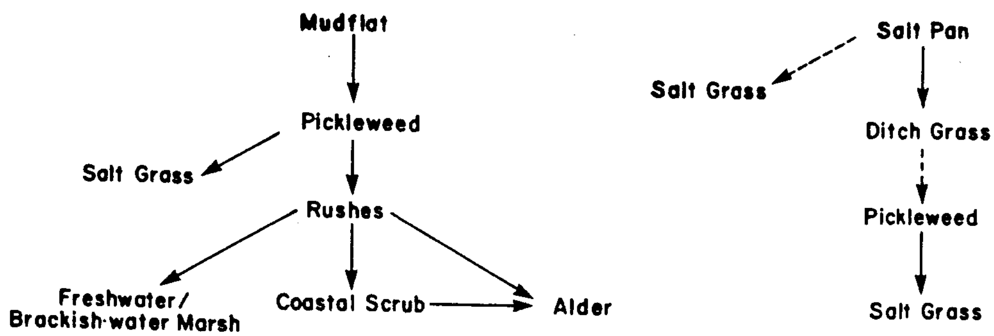

Figure 6. Salt marsh vegetation succession at Big River Estuary. Dotted arrow indicates hypothesized future vegetation succession.

By comparing the changes in the flats over time and between marshes, we have devised a successional scheme (Figure 6). The most unusual change in this salt marsh succession is the direct replacement of rushes by alder and coastal scrub. Other successional patterns (Chapman 1976) for European marshes result in freshwater marsh ultimately replacing salt marsh. While coastal scrub species are occasionally distributed around the periphery of salt marshes (Wherry 1920) wetland areas are not normally replaced by this community. The direct colonization of newly deposited levees by alder and coastal scrub acts to produce riparian woodlands over former wetlands. In addition sediment accretion in other salt marshes is commonly a gradual process with sediment distributed approximately evenly over the flooded area (Steers 1948).

Once these marshes are isolated from tidal influences, their productive capacity is lost. Juvenile estuarine fish, benthic invertebrates and algal blooms are common in the backwaters of tidal sloughs. Recent research indicates that tidal sloughs in Pacific salt marshes may be the location of the primary productive food base for the estuary (Zedler 1978; Eilers 1979). The reduction of slough systems reduces estuarine habitat available and consequently the productivity of the entire system. The long-term effects upon Big River estuary of this sedimentation and loss of salt marsh is undocumented. Further research is needed to determine the exact consequences.

LITERATURE CITED

Adams, David, 1962. Factors Influencing Vascular Plant Zonation in North Carolina Salt Marshes, Ecology 44(3):445-456.

Atwater, B.F., S. G. Conrad, J. N. Dowden, C. W. Hedel, R. L. Macdonald and W. Savage. 1979. History land-forms, and vegetation of the estuary's tidal marshes. Pages 347-385 in T. J. Conomos, ed. San Francisco Bay: The Urganized Estuary. Pacific Division A.A.A.S., San Francisco.

Brereton, A. J., 1971. The Structure of Species Populations in the Initial Stages of Salt Marsh Succession, J. Ecol. 59(2):321-338.

Chapman, V. J., 1938. Studies in Salt Marsh Ecology Sections I to III, J. Ecol. 26:144-179.

________. 1939. Studies in Salt Marsh Ecology Section IV-V, J. Ecol. 27:160-201.

________. 1940. Studies in Salt Marsh Ecology Sections VI-VII, J. Ecol. 28:118-152.

________. 1976. Coastal Vegetation. New York: Pergamon Press.

Dyer, K. R., 1971. Sedimentation in Estuaries. in R. S. K. Barnes, editor. The Estuarine Environment. Applied Science Publishers Ltd., London.

Eilers, Peter, 1979. Production Ecology in an Oregon Coastal Salt Marsh. Estuarine and Coastal Marine Science, 8(5):399-410.

Gilbert, G. K., 1917. Hydraulic-mining debris in the Sierra Nevada. U. S. Geol. Survey Prof. Pager 105.

Hinde, Howard P., 1954, The Vertical Distribution of Salt Marsh Phanerograms in Relation to Tide Levels, Ecol. Mono., 24:209-225.

Jackson, Francis, 1975. Big River was Dammed, Milles Print Company.

Jefferies, R. L., 1971. Aspects of Salt Marsh Ecology with Particular Reference to Inorganic Plant Nutrition, in R. S. K. Barnes, editor. The Estuarine Environment. Applied Science Publishers Ltd., London.

Johannessen, Carl L., 1964. Marshes Propagrading in Oregon: aerial photographs, Science 146:1575-1578.

MacDonald, Keith B. and Michael G. Barbour, 1974. Beach and Salt Marsh Vegetation of the North American Pacific Coast. in Robert J. Reinhold, editor. Ecology of Halophytes. Academic Press, New York.

Mason, H. T., 1957. A Flora of the Marshes of California, Berkeley: University of California Press.

Pestrong, Raymond, 1972. San Francisco Bay Tidelands, California Geology, 25(2):27-40.

Purer, Edith A., 1942. Plant Ecology of the Coastal Salt Marshland of San Diego County, California. Ecol. Mono., 12:83-111.

Steers, J. A. 1967. Geomorphology and coastal processes. In G. H. Lauff, editor. Estuaries, Am. Assoc. Adv. Sci. Publication 83.

Steirs, J. A., 1948. Twelve Years Measurement of Accretion on Norfolk Salt Marshes Geological Mag., 85:163-166.

Valiela, Ivan and John M. Teal, 1974. Nutrient Limitation in Salt Marsh Vegetation in Robert J. Reinold, editor. Ecology of Halophytes. Academic Press, New York.

Wherry, Edgar T., 1929. Plant Distribution Around Salt Marshes in Relation to Soil Acidity. Ecology 1(1):42-48.

Yapp, R. H., D. John and 0. T. Jones, 1971. The Dovey Salt Marshes, J. Ecol., 5:65-103.

Zedler, J. B., T. Winfield and D. Mauriello. 1978. Primary productivity in a southern California estuary. Pages 649-662 in Coastal Zone '78. Am. Soc. Civil. Eng., New York.