

Paper

**HYDROLOGIC AND CHEMICAL IMPACTS OF DIKING AND DRAINAGE
OF A SMALL ESTUARY (CAPE COD NATIONAL SEASHORE):
EFFECTS ON WILDLIFE AND FISHERIES**

Speaker:

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Questions and Comments Follow This Paper



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OF A SMALL ESTUARY (CAPE COD NATIONAL SEASHORE):
EFFECTS ON WILDLIFE AND FISHERIES**

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Abstract: Ecological studies in the 400 ha Herring River estuary have documented impacts from the nearly 80 years of diking and drainage for mosquito control. These impacts include lowered wetland water levels and the invasion of upland vegetation, sulfur mobilization and stream acidification, summertime oxygen depletion, and consequent fish kills and pest insect outbreaks. Habitat changes have been dramatic with salt marsh generally replaced by brackish-freshwater wetlands and seasonally flooded herbaceous marsh invaded by woody species. The acidification of surface water, from the oxidation of pyrite, together with annual summertime stream anoxia, serve to exclude native predatory fish and invertebrates, while favoring the production of mosquitoes. Current efforts to restore this degraded wetland-estuarine system center on experimentation and modeling with increased tidal flow through the once unobstructed river mouth. Implications of restoration to wildlife, fisheries and other ecological aspects are discussed.

INTRODUCTION

Salt marsh diking has been commonly practiced in small estuaries along the Atlantic seaboard over the last century as a way of controlling tidal flooding, creating arable land, and, in particular, limiting *Aedes* mosquito breeding in coastal flood plains. In contrast to impoundments, dikes (when equipped with one-way flap valves) allow fresh water outflow while preventing upstream seawater flow; these are implaced to lower wetland water levels upstream. In addition, with the exclusion of seawater, surface waters behind dikes become brackish and ultimately fresh. Daiber (1986) provides a detailed review of the ecological implications of diking and draining tidal marshes. This paper provides a case study analysis of a system in southern New England, summarizes the ecological effects of diking and drainage, and describes current experimentation and modelling efforts intended to restore the system through increased tidal flow.

Since 1980, we have studied various ecological aspects of the 400 ha Herring River estuary of Wellfleet, Massachusetts (Fig. 1), diked primarily for salt marsh mosquito control in 1908. Mean tidal range downstream of the dike is approximately 2.7 m, while upstream the mean range is restricted to 0.5 m. Diking, together with subsequent ditching and stream channelization for mosquito control, has dramatically altered wetland hydrology and biogeochemistry and degraded aquatic habitat quality with consequent effects

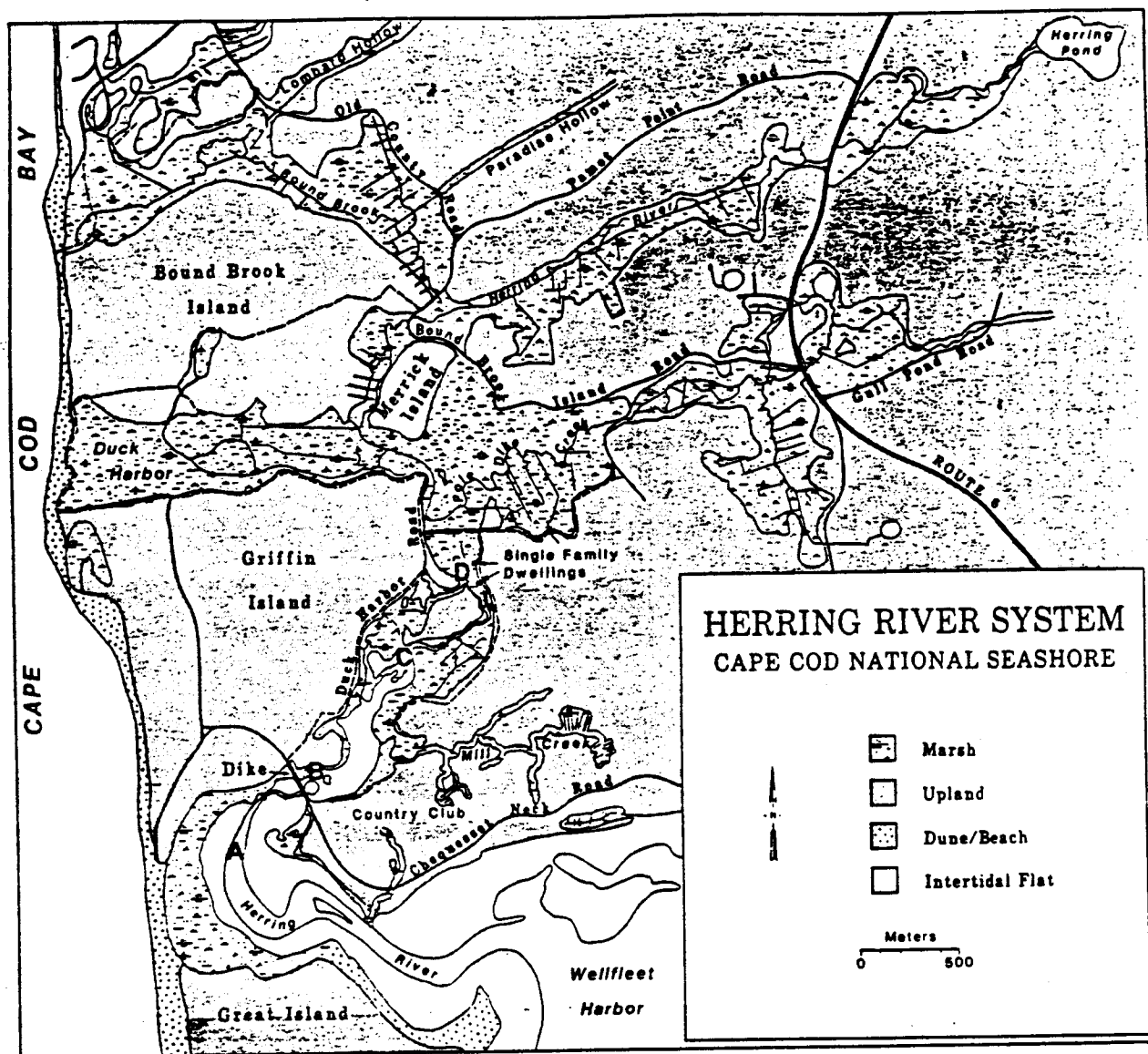


Figure 1. The Herring River system (Wellfleet, Massachusetts -- Cape Cod National Seashore). Note location of the dike, near the mouth of Herring River, and waterbird sampling stations (A, B, and C). Site D is the current upstream extent of seawater influence along the stream course.

on plant succession, fish and wildlife habitat, and pest insect breeding (Portnoy and Soukup 1982, Portnoy 1984, Soukup and Portnoy 1986). Recent data collection, experimentation and modeling have centered on predicting the effects of various degrees of seawater reintroduction with special attention to the increased salinity and flooding effects on vegetation, avian habitat use, and fisheries.

VEGETATION CHANGES

Aerial photographs (generally 1:25,000 scale) were examined for the years 1938, 1960, and 1977 to determine changes in vegetation cover within the Herring River flood plain. Herbaceous marsh, probably including Typha spp., Phragmites australis, Spartina patens and more typical freshwater species, persisted through the 1930's, despite the dramatic reduction of tidal flow 30 years before (Portnoy and Soukup 1982). Intensified ditch drainage and stream channelization for floodwater mosquito "source" control since the mid-1930's has dewatered most remaining marsh area. Effective drainage is dramatically apparent in subsequent photographs which document the invasion of woody species.

Table 1 summarizes photogrammetric data from 1960 and 1977 aerial coverage to the flood plain. Importantly, by 1960 this wetland had been effectively dewatered by combined 1908 diking and stream channelization (ca. 1934); thus, much of the open herbaceous marsh noted on 1938 photographs had already changed to an "old field" meadow-sweet/goldenrod (Spiraea/Solidago) community by 1960. Thereafter, shrubs (Myrica pennsylvanica, Prunus maritima, P. serotina) and trees (Pinus rigida) greatly increased, replacing old field forbs. As expected, the area of open water remained constant since all dewatering programs were in place before 1938.

From studies elsewhere (Roman et al. 1984; see review by Daiber 1986), we interpret the available vegetation data as describing a gradual freshening of original Spartina salt marsh after diking in 1908. The persistence of an open herbaceous marsh into the 1930's, together with reports (Wellfleet Town Records 1910-1930) of continued expenditures for floodwater mosquito control, suggests that freshwater discharge was sufficient to sustain high water levels and herbaceous hydrophytes until the intensified drainage associated with stream straightening and channelization in the mid-1930's. Thereafter, quantitative observations (1960-1977; Table 1) of the accelerated invasion of woody plants reflect conditions of effective and permanent year-round dewatering. Marsh surface flooding has been observed only twice in seven years from heavy rainfall, despite subsequent marsh surface subsidence due to peat oxidation and decomposition, and decreased estuarine sediment input. The 3.0 ha increase in Spartina from 1960-1977 (Table 1) reflects increased tidal flow through the tide gates beginning in the late 1960's with deterioration of the structure. In 1974, a new dike/tide gate structure was constructed. Currently tidal range upstream of the dike averages 0.5 m and seawater (approximately 1-5 ppt) reaches to "D" in Figure 1.

WATER CHEMISTRY, FISHERIES IMPACTS, AND MOSQUITO BREEDING

Investigations of biogeochemical disturbance in Herring River began with the observation of an eel (Anguilla rostrata) kill in the fall of 1980 involving several thousand individuals of all sizes. Mortality was correlated with low

Table 1. Vegetation changes in the Herring River flood plain between 1960 and 1977. The system was diked, eliminating tidal flow, in 1908 and channelized for mosquito control around 1934.

Species/Community	Area hectares		Change	Percent Change
	1960	1977		
<u>Pinus rigida</u>	12	52	+41	+361
<u>Acer rubrum</u>	2	5	+ 3	+117
<u>Myrica/Prunus</u>	17	132	+115	+679
<u>Spiraea/Solidago</u>	83	53	-30	- 36
<u>Vaccinium corymbosum/</u>				
<u>Rhododendron viscosum</u>	60	3	-57	-95
<u>Holcus lanatus</u>	51	0.5	-49.5	- 99
Mixed grasses	2	18	+16	+650
<u>Typha</u> spp. ¹	85	73	-12	-14
<u>Spartina</u> spp.	0	3	+3	
Open water	11	11	0	0

¹ This class includes an undetermined amount of Phragmites australis which was not differentiated from the Typha spp. on aerial photos.

pH, high sulfate and high aluminum in surface waters within the old salt marsh deposits. Moribund eels recovered when placed in seawater or in Herring River water upstream of the historic salt marsh at Route 6 (Figure 1).

Subsequent analyses of surface water and sediment from headwater ponds to the estuary, and from low-flow ditches to major tributaries and the mainstream, indicated that the high acidity was caused by sulfur oxidation and dissolution to sulfate (Soukup and Portnoy 1986). The process is mediated by water drawdown and salt marsh peat aeration allowing the oxidation of pyrite to sulfate, forming sulfuric acid in presently low alkalinity surface freshwater. Aluminum is in turn mobilized at pH below 4.5 (Nordstrom and Ball 1986). Ditch pH is normally near 3.0 with SO_4 values ranging from 100-500 ppm; total Al ranges from 3 ppm to extraordinarily high levels near 50 ppm. During the eel kill episode, sites of mortality exhibited pH, SO_4 and Al values of 4.15, 70 ppm and 4.0 ppm respectively. Acidic waters of pH less than 5 may be directly lethal to fish not well-adapted to these conditions (EIFAC 1969). Driscoll et al. (1980) considered Al levels of 0.3 ppm to be toxic to fish. It is suggested that high acidity was a major factor, if not the primary cause in the 1980 eel kill. Such episodes are intermittent and appear to be triggered by periods of low water, followed by heavy rainfall. We suggest that this regime pulses the accumulated products of pyrite oxidation into the mainstream.

Interestingly the extent of high acidity throughout the diked Herring River basin was reflected in the 1982 analyses of diatom remains in stream sediment, dominated by the acidobiontic Eunotia exigua, normally monotypically abundant in extremely acid mining leachate and Sphagnum bogs (Winkler 1985).

Another decimating factor for fish within the diked Herring River is apparent from observations of periodic summertime oxygen depletions in the lower mainstream. Since 1983 we have documented total stream anoxia lasting for 10 to 17 days and usually accompanied by massive die-offs of emigrating young-of-the-year alosids (Alosa pseudoharengus, A. aestivalis; Portnoy, unpubl. data). In 1985 the kill was estimated at 19,000 individuals, probably representing a major depression on annual recruitment (P. Brady, Massachusetts Division of Fisheries and Wildlife, personal communication).

Daily monitoring of stream temperature, ground water flow levels, dissolved oxygen and carbon dioxide, and periodic measurements of chemical oxygen demand (COD) and photosynthetic oxygen production, suggests that anoxia is primarily due to the high oxygen demand of the old salt marsh deposits (Portnoy and Soukup, in prep.). Dissolved oxygen levels always decrease as stream water passes through the diked salt marsh deposits. In midsummer, when water temperature and BOD/COD are highest, deoxygenation is most pronounced and can reduce dissolved oxygen levels to zero during high marsh-surface runoff events following heavy precipitation.

Low summertime dissolved oxygen is a common feature of tidal freshwater marshes due to the high suspended sediment loads, highly organic sediment, abundant nutrients and high phytoplankton production (Odum et al. 1984). Low DO is also expected in the upper portions of estuaries due to these same conditions plus low tidal exchange rate (W.E. Odum, University of Virginia, personal communication; C.A.S. Hall, unpubl. data). Restriction of seawater flow and flushing rate may have greatly extended this area of normally low

dissolved oxygen by artificially limiting oxygenated seawater incursion within an extensive and highly organic sediment sink behind the dike. Moreover, this restriction plus maintenance of drainage ditches has exposed high BOD/COD materials, previously saturated and somewhat isolated from the mainstream.

Since 1980, periodic fish and invertebrate surveys by various workers (K. Hartel, Harvard Museum of Comparative Zoology; B. Amaral, Massachusetts Division of Marine Fisheries; K. Able, R. Grizzle, and G. Marteinsdottir, Rutgers University) have revealed a depauperate fauna. This is expected considering the physical reduction of intertidal habitat imposed by the diking and drainage, and the chemical limitations (acidity and anoxia) in remaining surface water. The ecological effects are expressed in various ways for the various resident and migratory fish species. Residents, including the golden shiner (Notemigonus chryssoleucas), pumpkinseed (Lepomis gibbosus) and chain pickerel (Esox niger) may detect and avoid low pH and low DO (Hansen 1975), but at the same time are affected by diminished habitat. Migratory species, as has been seen, often continue their seasonal passage through affected stream reaches, occasionally with devastating results. The probable importance of surface water acidity and/or anoxia as chemical barriers to the normal use and movement of resident and migratory species through untenable habitat should also be appreciated.

Despite the intensive century-long program of tidal restriction and drainage for mosquito control, current mosquito production from Herring River marshes remains high. Ecological studies of mosquito breeding using larval and adult surveys from 1981 through 1984, with concurrent water quality sampling, demonstrate that most individuals of the locally predominant public nuisance species emerge from the acidic drainage ditches (Portnoy 1984). Ironically, the brown salt marsh mosquito (Aedes cantator) has been favored over native fish and invertebrate predators by the very water management regime implemented to control mosquitoes. Aedes cantator larvae and pupae survived in ditch water at pH 2.8 and SO_4 concentrations of 500 ppm; as air-breathing organisms, they were unaffected by low DO. The selective exclusion of predatory fish by low pH, to the benefit of salt marsh mosquitoes, has apparently been observed in flooded New Jersey marshes as well (K. Able, personal communication). Further encouraging mosquito breeding, high SO_4 water or substrates may act as attractants to ovipositing female Aedes cantator (Portnoy 1984).

AVIAN HABITAT USE

Most studies have shown a reduction in avian use of salt marsh habitats following the drainage of high marsh pannes (Urber 1935, Bradbury 1930, Bourne and Cottam 1939, Ferrigno et al. 1975). Reinert et al. (1981), noting that waterfowl primarily use permanent ponds or tidal water (i.e. open water), found greater anseriform use in unditched vs. parallel grid-ditched marshes in Rhode Island; they also related greater heron, gull, tern and shorebird use to the preservation of high marsh pannes. Black ducks (Anas rubripes), common terns (Sterna hirundo) and red-winged blackbirds (Agelaius phoeniceus) all nested near open water whenever it was available. Open water within the marsh is attractive to shorebirds and waterfowl because of the abundance of preferred invertebrate and plant foods (Reinert et al. 1981).

With the advent and implementation of Open Marsh Water Management in New Jersey tidal marshes (Ferrigno and Jobbins 1968), many avian species

appeared to benefit from the restoration of marsh ponds (Shisler 1979). However, water management within diked systems in the Northeast has for the most part remained unchanged. Here, effects of nearly complete marsh dewatering on marsh dependent birds have not been documented.

From 15 August through 30 October 1985, we recorded waterbird use immediately below, above and approximately 450 m upriver of the Herring River Dike (sites A, B, and C, respectively, Fig. 1), with the primary objective of establishing a baseline of current habitat utilization for predicting bird use with proposed increases in tidal volume. Thus, an effort was made to relate avian abundance to tidal range, intertidal area and extent of open water.

Site A covered about 5.7 ha of largely intertidal mudflats (75-80%) at the mouth of the river below the dike. This site was bordered on the east and south by Spartina marsh. A 15-20 m wide creek bisected the site at low tide. Site B encompassed about 2.6 ha of intertidal (25%) and subtidal (70%) habitat, and was bordered by Spartina marsh. The upstream site C was almost entirely subtidal (90%), with small patches of Phragmites-vegetated stream bank exposed at low water.

Observations were made at 5-min intervals at sites A and B throughout the tidal cycle: site C was visited irregularly throughout the study period. Bird use was recorded for each observation period by species, tidal stage, and specific habitat, including salt marsh, marsh edge, intertidal flats and subtidal bottom. Some preliminary results are presented in Figure 2, plotting waterbird abundance over the entire census period vs. tidal stage below the dike. Note that highest shorebird counts at site B, occurring two to three hours after low water at site A (below the dike) reflect the time lag for upstream low water imposed by the dike; expectedly, shorebird use at both A and B corresponded positively with extent of intertidal flat exposure.

The extensive intertidal area within site A was apparently responsible for the dominance of shorebirds (51%) over gulls (28%) and waterfowl (16%); semipalmated plovers (Charadrius semipalmatus), black-bellied plovers (Pluvialis squatarola), and greater yellowlegs (Tringa melanoleuca) were most abundant. In October, red-breasted mergansers (Mergus serrator) began using site A for both feeding and non-feeding activities.

In contrast, site B was heavily used by waterfowl, especially American black ducks, apparently attracted to the quasi-impoundment of open water which was vegetated with submerged widgeon grass (Ruppia maritima). Waterfowl, gulls and shorebirds comprised 62, 30, and 7 percent of total birds recorded, respectively.

Intertidal habitat is negligible at site C, explaining the low frequency of shorebirds. Open water habitat at this site and further upstream are dramatically decreased as a function of decreased width of the river course. Waterfowl use is correspondingly limited (Fig. 2). Moreover, upstream of normal seawater excursion (site D, Fig. 1), waterfowl activity is especially sparse (Portnoy, personal observations). The loss of salt marsh breeding habitat for species such as black ducks, which commonly breed in New England coastal marshes (H. Heusman, Massachusetts Division of Fisheries and Wildlife, personal communication), may exemplify a factor contributing to coastwide

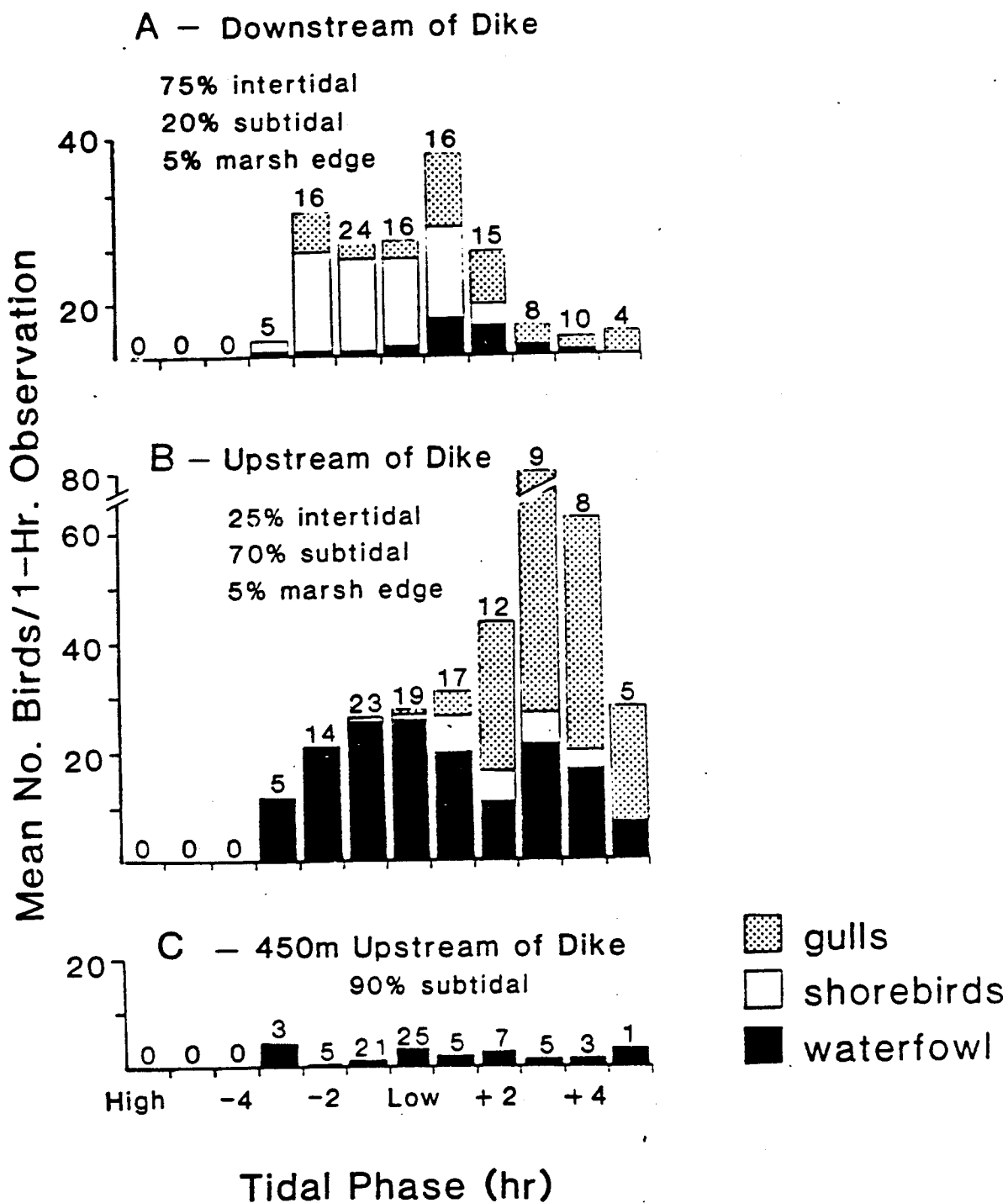


Figure 2. Gull, shorebird and waterfowl abundance at three sites along the Herring River, downstream and upstream of the dike. Tidal phase is indicated by hours $\pm$ low water. Numbers above bars are counts per 1-hr period.

population declines.

TIDAL RESTORATION

Diking and draining the Herring River marshes have produced both conspicuous and subtle effects degrading fish and wildlife habitat (Fig. 3). Research is currently underway to evaluate the potential for restoration of this degraded estuarine system. An assessment of ecological changes and socio-cultural impacts that could occur under various restoration management alternatives is based primarily on hydrological and mixing models. The hydrological model predicts water levels over complete tidal cycles for numerous openings of the Herring River tide gates. Thus, when coupled with data on elevation of the wetland surface, it is possible to predict the extent and duration of wetland flooding that would occur under various manipulations of the tide gate structure (i.e., partial openings to fully open). The mixing model predicts salinity structure and flushing times under the various manipulations. Although the extent of predicted changes are variable with respect to the different gate manipulations, it is generally suggested that the expected increase in flushing time will improve water column oxygenation, fish survival and mosquito control. The predicted increase in marsh surface flooding is expected to reduce peat oxidation and sulfur mobilization, thus improving fish habitat. Further, as the vegetation responds to increased flooding and salinity changes, wildlife habitat will be restored. Socio-economic factors such as the identification of flood prone areas under the various manipulations can also be evaluated by reference to the models.

This study clearly suggests that restoration of the Herring River estuary, at least the lower portions, is feasible. Considering that a significant proportion of estuarine habitat in the Northeast has been lost or is degraded, it seems essential that restoration management be implemented where feasible. The modeling approach taken in this case study allows resource managers to adequately balance ecological benefits and socio-economic consequences associated with management alternatives for the restoration of fish and wildlife habitat.

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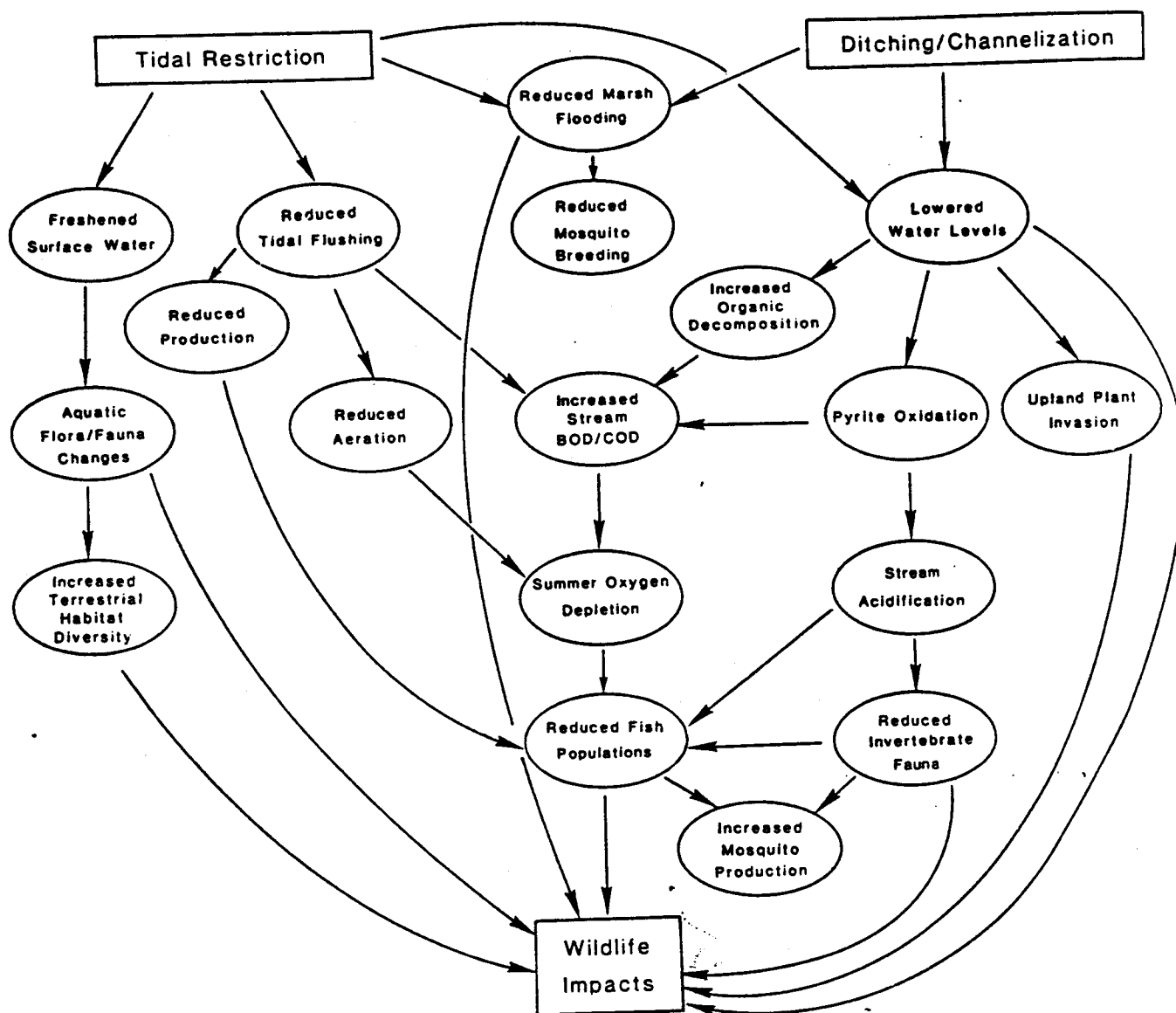


Figure 3. Conceptual model of predicted and documented ecological effects of the 1908 diking and subsequent drainage of the Herring River estuary.

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QUESTIONS AND COMMENTS

Question 1: Steve Sanford, New York Dept. Environ. Conserv.

You mentioned that most of the estuary could be reclaimed, but not all of it. What prevents you from reclaiming all of it?

Answer: John Portnoy, National Park Service

The question was what prevents us from reclaiming the entire estuary, not just the lower portion. There are various problems, some of them political, but some physical ones also, such as previous dikes that we don't have title for. We have to look at all of them, once we've made the initial stepped-increase flow model for the lower basin.

Question 2: Steve Sanford, New York Dept. Environ. Conserv.

Then, biologically and hydrologically you could do it if it weren't for these problems?

Answer: John Portnoy, National Park Service

Yes, but we'd also have to consider the amount of flooding of the marsh given the marsh subsidence over the last eighty years.

Question 3: Unidentified person

The mosquito species that was the largest component in your study, is it ovipositing on the edge of filled ditches? Or do the ditches go dry and then reflood? Would you know the ovipositioning habits of this species?

Answer: John Portnoy, National Park Service

I wouldn't, except that the mosquito control agency has a biologist who has been looking at this. He's found eggs in both locations, both at the edge of the ditch and on the marsh surface. But I don't think he's found significant differences.

Question 4: Bill Meredith, Delaware Division of Fish and Wildlife

I understand that there's hesitancy on the part of the mosquito control personnel on Cape Cod to go along with this restoration project. One of the points I've heard brought up was that you might be substituting Aedes sollicitans breeding for cantator breeding if you get restoration, and also that the problem with cantator breeding is overstated. How would you respond to their concerns?

Answer: John Portnoy, National Park Service.

Well, first of all, as far as the problem with cantator being overstated, it certainly is from my experience in Louisiana. But another important

note is that we rarely see sollicitans out on Cape Cod. I have to conclude, after many years of being bitten by mosquitoes on Cape Cod, that they just have never really been a problem that far out on the Cape, because of the tidal flow and limited extent of patens marsh. I'm not sure that I answered the first part of your question, but I think my first reaction is that mosquito control on Cape Cod has become more amenable to increased tidal flow in these old diked situations.