PEST MOSQUITO RESPONSE TO HUMAN ALTERATIONS OF COASTAL WETLAND ENVIRONMENTS

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ABSTRACT

Mosquito breeding phenology and reproductive success are intimately associated with the hydrologic and chemical characteristics of their breeding habitats; thus, human modifications to U. S. Atlantic coastal ecosystems since European settlement have precipitated marked changes in both native mosquito populations and the effectiveness of traditional control strategies. A review of mosquito population response, in terms of relative abundance and species composition, to extensive east coast grid-ditching, diking and impoundments is used to demonstrate the presently complex problem of appropriate National Park Service (NPS) wetlands management. Balancing NPS ecosystem preservation and recreation goals within perturbed coastal systems requires an understanding, among land managers, inholders and the visiting public alike, of the complex processes responsible for current mosquito outbreaks. For example, substantial mosquito production from some of the most heavily ditched or diked and drained salt marshes of Fire Island National Seashore and Cape Cod National Seashore, respectively, indicates a primary need for the restoration of more natural tidal conditions.

INTRODUCTION

National Park Service policies for preserving native ecosystems (NPS Organic Act of 1916) generally prescribe non-interference in the life cycles of native insects existing under natural conditions. Control may be permitted under the following circumstances: 1) to prevent the loss of the host or host-dependent species; 2) to prevent insects from spreading to uninfested areas outside NPS managed lands (usually in reference to forest or crop damage);3) to conserve threatened plants; 4) to protect flora and fauna in developed zones; and 5) for reasons of public health and safety (NPS Management Policies 1978). Management of native mosquito species on the east coast of the United States is generally allowed only to prevent the transmission of human disease. Within National Park lands along the northeastern coast, mosquito-borne disease transmission (most importantly eastern encephalomyelitis) is unlikely

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and, although pressure for mosquito control is often couched in terms of public health, suppression is actually aimed at a perceived public nuisance. Despite occasionally intense public and political pressure for control on and adjacent to federal lands at Fire Island and Cape Cod National Seashores in recent years, epidemiological surveillance has failed to reveal a mosquito-borne public health threat (Division of Vector-borne Viral Diseases, Centers for Disease Control, 1986; H. Maxfield, Encephalitis Field Station, Massachusetts Department of Public Health, 1984, see below).

Thus the NPS land manager, often amid intense public complaints accompanying a heavy mosquito year, must resolve only two basic questions in assessing the appropriateness of what amounts to <u>nuisance control</u>, vis-a-vis NPS management policy: 1) is this pest outbreak simply an expression of "the life cycle of a native insect existing under natural conditions" and 2) how is the intensity of mosquito production on NPS lands associated with past and current land management?

In the Northeast, coastal settlement and wetland alterations have proceeded for over 300 years and these questions can be extremely complicated. Centuries old traditional practices, alterations and their effects may be totally unrecognized by the NPS land manager, despite sometimes intense local disturbances to coastal ecology (Soukup and Portnoy 1986). What are "natural conditions" for wetlands in a given management unit? How do they compare with the environment modified by historic and current land management practices? And most importantly, how have native mosquito species responded, in terms of species composition and abundance, to hydrologic and chemical habitat change caused by human coastal developments?

This paper addresses some of these issues by developing an historic perspective of probable native conditions, selected anthropogenic ecological changes, and mosquito response to these changes in Atlantic coastal environments. Hopefully, this selective review will be more generally useful in appreciating the current breeding ecology of perceived pests in relation to NPS land management goals. Table 1 describes current mosquito breeding situations within NPS areas on the Atlantic Coast.

NPS area	Breeding habitats	Predominant pest species
Cape Cod N. S.	Diked, drained salt marsh Woodland pools	Aedes cantator A. canadensis
Fire Island N.S.	Grid ditched salt marsh	A. sollicitans, A. cantator
Assateague Is. N. S.	Ditched salt marsh	A. sollicitans
Cape Hatteras N. S.	High salt marsh Spoil areas Old impoundments	A. sollicitans, A. taeniorhynchus
Cape Lookout N. S.	High salt marsh	A. sollicitans, A. taeniorhynchus
Fort Sumter N. M.	Salt marsh Spoil areas	A. sollicitans
Fort Federica N.M.	Ditched, diked salt marsh Impounded spoil areas	A. sollicitans
Canaveral N. S.	High salt marsh (impounded)	A. taeniorhynchus
Bisayne N. M.	Salt marshes Saline sink holes Fill	A. taeniorhynchus, Culex spp.

Table 1. Current mosquito breeding situations within NPS management units on the Atlantic Coast.

For a review of the general ecological effects of mosquito control practices see Bradbury (1938), Bourn and Cottam (1950), Teal (1962), Kuenzler and Marshall (1973), Provost (1977), Gulf South Research Institute (1977), and Shisler (1979). For background on mosquito biology and monitoring techniques see Bates (1970) and Service (1976).

NATIVE CONDITIONS AND MOSQUITO HABITAT SPECIFICITY

Salt marsh mosquito breeding prior to European settlement on the Atlantic coast probably consisted of floodwater Aedes spp., predominantly A. sollicitans, with A. cantator north of Virginia and A. taeniorhynchus south of New York (Carpenter and LaCasse 1955, Darsie and Ward 1981). Breeding was generally confined to depressions (pannes) in the high Spartina patens/ Distichlis spicata marsh, flooded on biweekly spring tides or heavy rains (Smith 1902, 1904, Richards 1938, Provost 1977). Breeding was (and is) predictably less significant in intertidal Spartina alterniflora flooded on a daily basis (Florschutz 1959, Catts et al. 1963). Consequently, coastal wetlands with low tidal range and proportionately greater high marsh (Provost 1976) would have produced more salt marsh mosquitoes than marshes

experiencing higher tidal amplitudes and more extensive daily flushing.

Recent work on habitat preference (at oviposition) and tolerance (for aquatic larvae) among salt marsh species (Petersen 1969, Petersen and Chapman 1970, Magnarelli 1978, Slavin 1983) indicates that *A. sollicitans* and *A. taeniorhynchus* generally breed in more saline situations than *A.* cantator, which in unaltered systems commonly breeds in brackish water along the salt marsh/upland ecotone. More freshwater-breeding species, nevertheless associated with Atlantic coastal environments, include floodwater *A. vexans* and *A. canadensis*, and permanent-pool breeding *Culex salinarius* and *Coquilledidia perturbans*. Although some overlap can occur, aquatic habitat utilization is highly species-specific and affected by water quantity (flooding regime) and quality, substrate, and vegetation parameters (McGaughey 1968, Petersen 1969, Petersen and Chapman 1970, Horsfall et al. 1975, Fleetwood et al. 1978, Cassani, and Bland 1978, Angerilli and Beirne 1980, Beier et al. 1983). Thus, hydrological or biogeochemical changes, human-induced or otherwise, in oviposition sites or larval habitat can produce species-specific changes in egg deposition rate, larval survival, and ultimately pest species composition and abundance.

EARLY SETTLEMENT AND MOSQUITO "PROBLEMS"

Prior to the twentieth century, salt marsh mosquitoes were considered a natural component of coastal living, to be avoided by appropriately siting homes and other centers of human activity (Nisbet 1972, Axtell 1983). Thus, insect infested lowlands were viewed as simply uninhabitable (Smith 1904).

Early coastal alterations included diking to restrict seawater from small estuaries and ditch drainage. Diking was variously undertaken either for the direct extension of agricultural land including salt hay farming, or incidentally along with road and railroad construction across coastal flood plains. Effects of these early developments on mosquito production are poorly documented but probably included a decrease in *A. sollicitans* and increase in more brackish and freshwater species (*A. cantator*, *A. canadensis*, etc.) as wetlands behind the dikes freshened. Interestingly, the failure of diking to eliminate the "mosquito pest" is reflected in Massachusetts Town Meeting records authorizing increased expenditures for larvicides and ditching to control mosquitoes after diking.

Ditching tidal marshes, although no doubt practiced before 1900 to drain high marsh breeding sites, was begun extensively by 1912 in New Jersey (Provost 1977) and

Long Island (Richards 1938). The cheap work force provided by 1930's employment programs led to the grid ditching of 90 percent of Atlantic seaboard marshes by the late 1930's (Bourn and Cottam 1950). The indiscriminate nature of this work, with little regard for mosquito breeding habits and likely breeding sites, nevertheless produced incidental benefits by increasing tidal circulation (Richards 1938, Teal 1962) over so much marsh area. However, many of the millions of linear feet of ditches were unnecessary and in some cases counterproductive for mosquito control (Vogt 1937).

PRESENT MOSQUITO BREEDING ECOLOGY IN ALTERED ATLANTIC HABITATS

Today, breeding conditions for the original salt marsh species are present in the remaining coastal wetland habitats that have survived drainage and filling. These habitats have been nevertheless altered by a multitude of projects including: pre-1900 ditching and diking, 1930's grid ditching, intensified programs of agricultural drainage, navigational dredging, spoil disposal, flood control, urban and suburban construction, and ditching, diking and impounding for mosquito control itself. These perturbations to already complex ecosystems make interpretations of current insect breeding ecology difficult at best.

It is important to realize, as noted by Nisbet (1972) and Axtell (1983), that the single factor responsible for the emergence and intensification of the "mosquito problem" is an increase not in coastal mosquitoes but in coastal people. The preservation of our National Seashores is a ready example of the environmental benefits of this aesthetic and recreational attraction to coastal environments. However, and unfortunately for coastal systems, increased contact between humans (especially those unaccustomed to blood-feeding insects) and biting mosquitoes has resulted in unavoidable clamor for control. The presence of mosquitoes at residences near wetlands should, however, be considered inevitable.

The greatest success in achieving publicly acceptable suppression without major ecological loss has resulted from site specific methods tailored to improve flushing of and predation at known breeding sites. Mitigation of excessive grid ditching dates back to the 1930's (Bradbury 1938) and is presently represented in the methods of open marsh water management, developed in New Jersey and Delaware (Ferrigno and Jobbins 1968) and recently successfully applied on an experimental basis in New England (Hruby et al. 1985). Common to all these efforts is the facilitation of natural mosquito control through restoration or enhancement of predatory fish habitat. In addition,

several mid-Atlantic workers report increased productivity at some trophic levels (Ferrigno 1970, Shisler and Jobbins 1975, 1977).

The effects of the foregoing series of marsh and estuarine alterations on mosquito populations have been diverse but largely predictable from the degree of success either in eliminating breeding habitat (draining, permanently flooding, or tidally flushing depressions holding flood water) or in facilitating access to predators (especially endemic fish, vide Harrington and Harrington 1961).

IMPOUNDMENTS

On the mid-Atlantic, south Atlantic and Gulf of Mexico Coasts, artificial impoundments are a popular means of effectively eliminating, through permanent or seasonal flooding, salt marsh Aedes oviposition sites while creating habitat for commercially valuable fish, waterfowl, and furbearers (Darsie and Springer 1957, Catts et al. 1963, Provost 1969, Lake and Murphy 1970, and for historical review, LaSalle and Knight 1974). Despite the generation of habitat for more permanent water mosquitoes, including Anopheles and Culex species within emergent vegetation, impoundments have substantially reduced heavy Aedes populations in irregularly flooded high marsh in North Carolina (LaSalle and Knight 1974) and Florida (W. Leenhouts, pers. comm.) On the other hand, some impoundments for the control of Aedes sollicitans in New Jersey, Delaware, Florida and Louisiana have produced major populations of nuisance Culex salinarius mosquitoes in those states, thereby substituting one public nuisance for another (Chapman and Ferrigno 1956, Catts et al. 1963, Slaff and Crans 1982). Wildlife management impoundments in South Carolina have produced even salt marsh mosquitoes at eight times the densities of nearby unaltered salt marsh habitats (Vorgetts et al. 1980), due to ineffective water level control.

Obviously, this practice should not be viewed as universally beneficial either from the standpoint of mosquito control or salt marsh conservation. Also, the ecological and hydrological effects of impoundments on adjacent wetlands are poorly understood (LaSalle and Knight 1974, Montague et al. 1985).

On NPS lands along the Atlantic Coast, impoundments currently seem to play little role in mosquito production. At Cape Canaveral, the impoundment of virtually all 20,000 acres of high marsh within adjacent Merritt Island National Wildlife Refuge between 1961 and 1973 effected a 90 percent reduction in

mosquito landing rates (Leenhouts 1985). Although the creation of fresh open water habitats increased waterfowl and shorebird use, the negative effects of reduced habitat for native marine organisms are unknown. Remnant waterfowl hunting club impoundments at Cape Hatteras National Seashore, where deteriorating weirs have allowed the reestablishment of some tidal flow, do not produce sufficient mosquitoes to evoke public complaints K. Turner, pers. comm.).

DITCH DRAINAGE

As mentioned, by the late 1930's the great majority of Atlantic seaboard salt marshes, including some areas presently managed by NPS, had been grid-ditched. A good case history, where grid ditching was the prime water management method for "source control" of salt marsh mosquitoes (*A. sollicitans* and *A. cantator*), is Fire Island National Seashore. Between 1933 and 1938, most of the present Seashore's 1000 acres of tidal marshes were dissected by approximately 200,000 linear feet of ditches (Bobinchock 1983). It is uncertain what proportion of these ditches, spaced 100 to 200 feet across the marsh, effectively reduced floodwater breeding sites, but ditch maintenance (together with chemical pesticides) apparently produced some level of mosquito suppression until Seashore establishment in 1964. Thereafter, control by the local county agency continued under a special use permit until 1976, when control efforts were suspended for NPS review. Fire Island's General Management Plan, approved in 1978, placed all tidal marshes in an Environmental Protection/Primitive Zone limiting mosquito control to public health emergencies which, after intensive surveillance, are currently viewed as unlikely (Division of Vector-borne Viral Diseases, Centers for Disease Control 1986).

Low populations of the principal enzootic vector for eastern encephalitis (EE), the bird biting mosquito *Culiseta melanura*, reduce the potential for virus amplification within the local bird population. With a low local reservoir of EE virus, transmission to humans, via mosquitoes that bite both birds and man, is highly improbable. The scarcity of *C. melanura* at Fire Island is attributable to the limited extent of suitable larval habitat, acidic cedar and maple swamps.

Since 1978, the intent of Seashore management has been to return ditched marshes to their natural state. Lacking the resources and ecologically acceptable methodology to fill existing ditches, the Park has had to determine appropriate action (or no action) for the control of a _native_ insect (the salt marsh mosquito) breeding within and up-gradient of _artificial_ ditches

now blocked by sloughing and the accumulation of natural organic debris. After much public and political pressure for aerial spraying of Seashore marshes in the summer of 1982, NPS mark-recapture experiments during 1983 showed that the vast majority of adult mosquitoes found within Long Island mainland communities were not produced in Fire Island marshes (Ginsberg and Rolf 1985). Given these observations, plus the lack of a public health threat, NPS management is currently passive. Although local control agents are permitted to remove eelgrass dams blocking the tidal ebb through old ditches, no work of this nature has been done in the last two years (A. O'Connell, pers. comm.).

Similar trends in mosquito production from old grid ditch networks have been reported from Essex County, Massachusetts (Hruby et al. 1985) and from New Jersey (Ferrigno 1970), where more selective attempts to restore tidal circulation, using methods of "open marsh water management" (Ferrigno and Jobbins 1968) are being substituted. However, additional modifications to already altered (eg. grid ditched) NPS lands would be inadvisable without detailed ecological study, regardless of presumed restorative benefits.

SALT MARSH DIKING

As emphasized by Provost (1977), ditching intertidal areas cannot result in marsh drainage simply because of the semi-diurnal flood of Atlantic tides; however, when combined with diking to restrict or eliminate tidal flow, ditch drainage becomes very effective in dewatering wetlands. Diking followed by creek channelization and ditching was a common way of eliminating flooding in small Northeast estuaries to exploit richly organic acreage for agriculture, to provide for coastal construction, and/or to reduce mosquito breeding. Several wetlands within what is now Cape Cod National Seashore were diked between 1860 and 1910 and provide good examples of the combined diking and drainage effects on vegetation (Portnoy and Soukup 1982), water quality (Soukup and Portnoy 1986), and mosquito breeding ecology (Portnoy 1984).

Most of our work has centered around the diked 1000-acre Herring River salt marsh system of Wellfleet, Massachusetts. Diking in 1908 prevented nearly all tidal flow, and subsequent systematic drainage of the freshened floodplain was undertaken to control mosquito breeding. However, research from 1981 through 1984 showed that most of the local mosquito nuisance (*Aedes cantator*) emerged from the diked flood plain (Table 2).

Species	Females/trap-night 1982(N=145)	1983(N=96)	1984(N=76)	Percent of pest species 1982	1983	1984
Aedes						
cantator	70.9	37.0	23.2	72	56	57
canadensis	23.7	25.3	15.3	24	38	38
vexans	1.2	T	T	1	T	T
cinereus	0.9	0.7	0.4	1	1	1
excrucians	0.2	T	0	T	T	-
sollicitans	0.1	T	T	T	T	T
provocans	T	0	0	T	-	-
triseriatus	T	T	T	T	T	T
Culex spp.	28.3	7.3	6.0	0	0	0
Culiseta						
minnesotae	8.1	0.6	0.1	0	0	0
melanura	0.3	0.8	0.2	0	0	0
morsitans	T	T	0	0	0	-
Coquilletidia						
perturbans	1.6	3.2	1.5	2	5	4
Orthopodomyia						
signifera	T	0	0	0	-	-

Table 2. Summary of 1982, 1983, and 1984 mosquito trapping results in the Herring River Basin. T=trace.

Principal breeding sites are the ditches themselves, which, due to drainage, peat dessication, sulfur mobilization and consequent surface water acidification (ca. pH 3.0), are devoid of fish and invertebrate mosquito predators. Also, because of the lack of tidal flow, ditches are rarely flushed into the estuary. Besides being free of predators, high sulfate ditches may in fact attract ovipositing female *A. cantator* (Dixon 1957, McGaughey 1968). A preadaptation to low pH (MacGregor 1929) further enhances survival of immatures in acidified ditches. Quadrat sampling of late instar *A. cantator* larvae in 1981 revealed over 700,000 immatures per 150m of 2-m wide ditch.

Although improved tidal circulation would benefit both interests of pest control and ecosystem preservation (Ferrigno and Jobbins 1968, Portnoy 1984, J. Shisler, pers. comm.), Cape Cod National Seashore managers must

contend with long-standing land uses (there are two residences and a golf course presently in the floodplain) and the traditions of a county mosquito-control agency which refuses to abandon drainage behind the dikes. Meanwhile, public sentiment is manipulated in favor of current practice by spuriously relating inevitable pest population outbreaks (during wet years) to NPS interference.

Recent NPS studies of annual and prolonged summertime oxygen depletion and consequent fish kills in the diked Herring River, when taken together with the acidification problem, hopefully will build public support toward a more restorative approach in managing previously diked systems. Ongoing studies of the hydrological and ecological effects of increased tidal flow into Herring River marshlands (Roman in prep.) should allow predictions of future mosquito species composition and relative abundance.

CONCLUSIONS

Clearly, a major feature of seashore environments, in pristine condition or otherwise, is and will be biting mosquitoes. Although many existing mosquito nuisance "problems" can be attributable to human caused perturbations (Fig. 1), natural salt marsh Aedes breeding will continue to contribute periodically to public discomfort. As more and more people are attracted to coastal areas, human/mosquito contact and perceived problems must increase. In the absence of a mosquito-vectored public health threat, NPS management effort should be best directed toward educating the visiting public. Appropriate public expectations, based upon the findings of sound monitoring and ecological research, can go far in reducing both human/mosquito encounters and public reactions to unavoidable native insect outbreaks. Importantly, information on the source and dispersal patterns of mosquito species (Nisbet 1972) and populations (Ginsberg and Rolf 1985) can significantly improve our understanding and predictions of nuisance problems, often neutralize accusatory statements, and improve public relations. For example, the species-specific habitat requirements of immatures provide a means to relate the abundance of adult mosquitoes, identified to species, to surrounding wetland conditions and management.

Fortunately, recent promulgation of local, state and federal laws (albeit often with exemptions for "proper" mosquito control) has made further coastal wetland modifications more difficult. However, as has been shown, NPS land managers must contend with many inherited

wetland management mistakes. The preservation of native ecosystems for the appreciation of future generations may require correcting recent 20th century errors (vide Soukup 1978). In light of the preservation and recreation goals variously addressed in each park's enabling legislation, and given the complexity of coastal ecosystems, restoration will require extensive active collaboration among resource managers, ecologists, and pest management specialists, all in frequent consultation with local private and public interests.

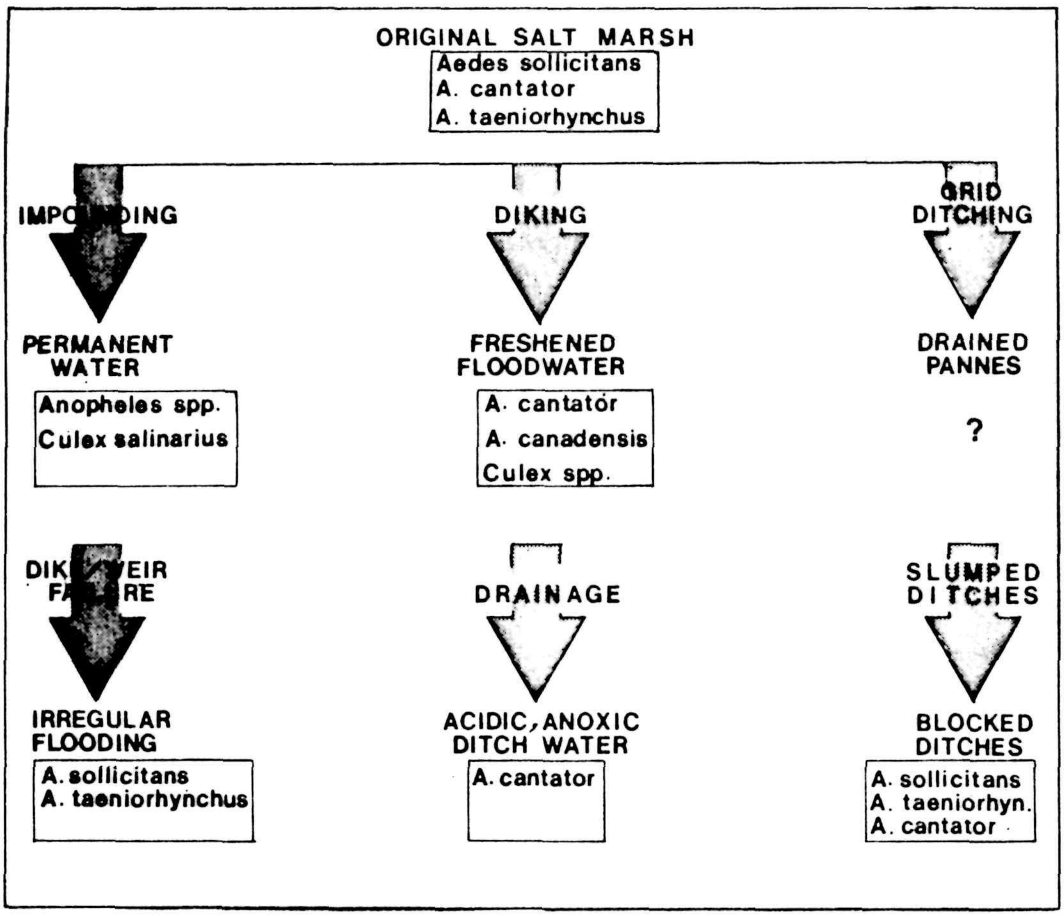

Figure 1. Mosquito species associated with historical water management practices, and their effects, on Atlantic Coast salt marshes.

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