Restoration of a San Francisco Bay Salt Marsh: Evaluating Corixid and Mosquito Populations

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Abstract Restoration of marshland can create new habitat for aquatic invertebrates but also may create mosquito problems. A recent levee breach in a San Francisco Bay salt marsh has provided a unique occurrence whereby habitat restoration and the possible impact that levee construction has had on original San Francisco Bay mosquito populations may be examined. The flooding of marshes, and restoring of marshes that have been enclosed by levees, may be a possible method of mosquito control that could decrease maintenance by mosquito abatement districts, as well as concerns of local residents. Three marshes, including the recently breached one, with varying salinity were sampled for mosquitoes once a week from January 29 through April 11, 2001. Corixids (water boatmen) were similarly sampled for comparison and also to examine population trends between the three marshes. A D-frame net and a dipper were used to collect mosquitoes and corixids. Fifteen samples were taken randomly along one side of each marsh. Average numbers of species found in each marsh were compared. Mosquitoes were found once in the breached salt marsh, which, prior to the breach, had been treated by the Alameda County Abatement District frequently for *Aedes* spp. *Aedes squamiger, Culiseta inornata, and Culiseta incidens* were found in the other two marshes. The infrequency of mosquitoes in the breached marsh indicates the possibility of levee breaching, and therefore, hydrologic restoration as a means of mosquito control and management.

Introduction

Before 1850, the San Francisco Bay region sustained over 2,200 square kilometers of tidal marshes (Atwater et al. 1979). Due to development of the bay and a century of filling and diking (Nichols and Wright 1971), 95% of this habitat has been destructed, leaving only 125 square kilometers of tidal marsh (Josselyn 1983). About 85% of the historical tidal marshes have been altered or affected by human activity (Meiorin 1991). These changes to wetlands have directly, or indirectly, brought about changes in the migratory patterns of birds, local climate, and the makeup of plant and animal populations (Frenkel and Morlan 1990). Wetlands serve many valuable functions, including the following: (1) wetlands are natural filters of water, as plants in wetlands trap sediment and toxins, (2) wetlands are often highly productive, where many nutrients and other chemicals are naturally cycled, and (3) wetlands are one of the primary nursery grounds for fish, shellfish, aquatic birds, and other animals (Botkin and Keller 2000).

Restoration of salt marshes can take many forms, depending on the condition of the salt marsh, specifically the functions that have been degraded. Some marshes require the introduction of native species to restore their function as habitat, while marshes that have been diked or impounded may require the introduction of tidal circulation to restore various natural processes, such as anaerobic decomposition.

The benefits of the restoration of degraded or destroyed wetlands and creation of new wetlands have only recently been recognized (Frenkel and Morlan 1990). Wetland restoration and creation can help maintain the benefits of wetlands and their surrounding ecosystems. Salt marsh restoration will not only foster the reintroduction of species native to the marshes, such as smooth cordgrass and the endangered clapper rail, but it would also restore the various processes (anaerobic decomposition and exporting of organic energy into estuaries and coastal ocean) that make salt marshes some of the most productive ecosystems in the world (Mitsch and Gosselink 2000).

Though there has been increased research and monitoring of coastal marsh restoration and creation sites, research on marsh restoration has tended not to include detailed studies of macroinvertebrates, which may be good indicators of marsh condition and appear to influence plant productivity (Bertness 1984). In 1994, Peck et al. compared the macroinvertebrate populations of a restored impounded marsh and an unimpounded marsh in Connecticut to evaluate the restoration of degraded marshes. Tidal flushing had been introduced to the impounded marsh through the addition of culverts in 1978. Peck et al. assessed the numerical size and biomass of certain macroinvertebrate population, acknowledging that species composition alone is not sufficient for evaluating restoration. They found that restoration was in an advanced phase based on the presence, distribution, and abundance of various macroinvertebrates on the restored impounded marsh in comparison to marshes below the impoundment dike and to a nearby unimpounded valley marsh.

Restoration of degraded or destroyed wetlands into healthy, functioning wetlands can also reduce mosquito populations (IWCP 2001, elect. comm.). Mosquitoes are capable of transmitting diseases, and therefore pose a public health concern. Their aggressive outbreaks are of public concern as well. Wetland restoration decreases mosquito populations in two ways: by providing proper habitat for the natural enemies of mosquitoes, and by preventing or reducing flooding (in areas that are not normally wet and thus support mosquitoes but not their predators) (IWCP 2001, elect. comm.).

Since 1980, the DEP’s Office of Long Island Sound Programs (OLISP) has been systematically restoring degraded tidal wetlands along Connecticut’s coast (CDEP 2000, elect. comm.). To date, over 1600 acres of wetlands have been restored, benefiting the environment and the public. Restoration reestablishes important wetland functions including enhancing productivity of coastal waters, increasing production of fish, and a greater use by birds such as herons, shorebirds and waterfowl. Restoration also reduces mosquito-breeding areas and eliminates fire hazards.

For long-term control Northeast Massachusetts Mosquito Control and Wetland Management District uses open marsh water management (Dalia 1998, elect. comm.). Rather than dig ditches, control agencies are slowly filling in old ditches while creating or restoring natural shallow marsh ponds and pans similar to those naturally created in healthy salt marshes. These pans allow water to remain in the higher areas of the marsh even at low tides thus allowing fish to remain within the pools; these fish are potent predators on mosquito larvae. Additionally, many birds are attracted to the pools and they too will eat the mosquito larvae. By restoring the saltpans, the mosquito control district is also helping to restore the bird and wildlife habitats that ditching had destroyed. So far, these ecological strategies have proven to be about 97% effective in controlling mosquito populations and the mosquito control commissions are expecting this success rate to increase (Dalia 1998). Furthermore, saltpans require less maintenance effort than ditches since the normal disturbance regime of natural salt marshes regularly forms these pans and ponds.

In early 1999, a levee broke along Mud Slough in Fremont, CA, during heavy rains. This caused San Francisco Bay water (with salinity of up to 33 ppt; USACE 1998, elect. comm.) to flood a salt marsh one mile away called Brinker. Brinker's previous sources of water were rainwater and groundwater, and now the marsh consists of brackish water. Levee breaches and other mishaps can serve as natural experiments to see how ecosystems respond to the restoration of more natural hydrologic processes (Workshop 1985). Therefore, the impact of the levee breach, if any, on Brinker was examined. In addition, to examine the response of the salt marsh to hydrologic processes, observations of mosquito populations in the marshes were made to see if the studies mentioned above apply to Brinker. Altering marsh hydrology can provide long-term solutions to marsh mosquito problems, thereby minimizing the need for repeated larvicide applications (Kramer et al. 1995).

As in the Peck et al. (1994) study, macroinvertebrate populations were used in this study as a tool for comparison of Brinker and two neighboring marshes. By assessing the species abundance present in each of the different marshes, I was able to see differences that may have resulted from the flooding. Mosquito and water boatmen (corixid) were chosen as study organisms because both of them occur in all three marshes. The two neighboring marshes qualify for comparison for spatial reasons; they are located within a half-mile radius of Brinker. Temporally, it was not possible to examine populations in Brinker prior to the levee breach, nor would it be feasible in this project to examine populations in Brinker once it has been fully restored.

Study Sites Brinker is located approximately two miles north of Mud Slough in Fremont, CA (Figure 1).

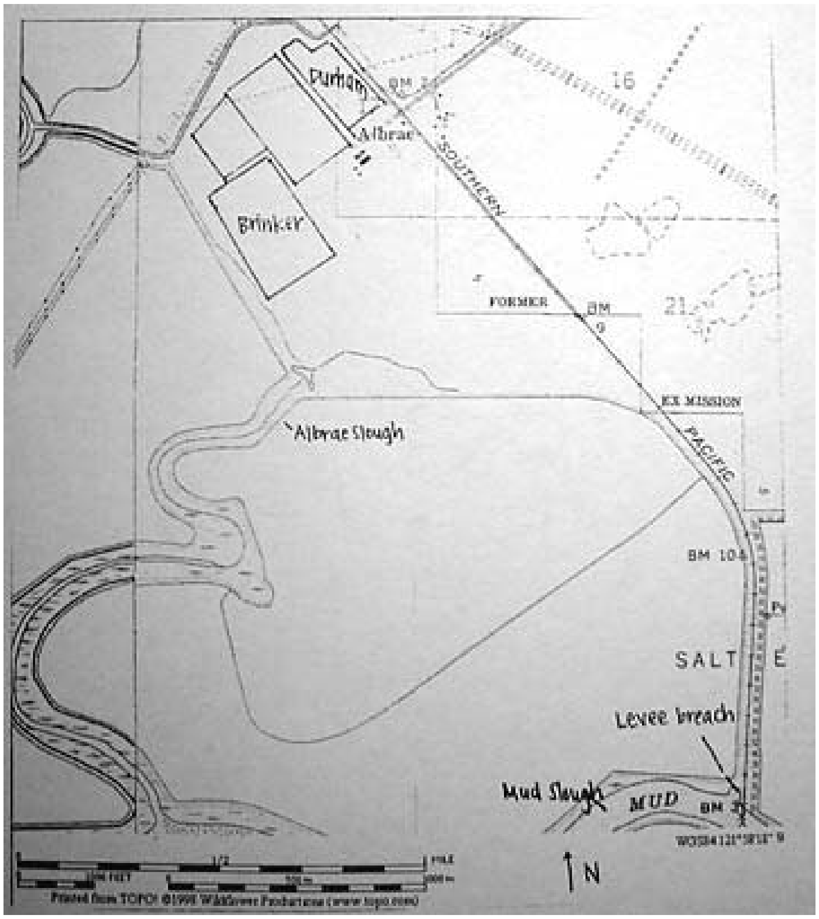

Figure 1. Source: www.topo.com

At the beginning of this study, Brinker had a salinity of about 18-20 parts per thousand. Durham, which is located 0.5 miles northeast of Brinker (Figure 1), receives water primarily from rainwater and groundwater, and its initial salinity ranged from 10 to 12 parts per thousand. This neighboring marsh is the most comparable to Brinker prior to the levee breach, in terms of vegetation and hydrology (Hamersky 2001, pers.comm.). I acknowledge that the reference site, Durham, probably differed somewhat from the original salt marsh that occurred at Brinker, but it provides a reasonable standard for determining the effect of the levee breach. Tidal circulation occurs in the third salt marsh called Albrae Slough, which is located approximately 0.5 miles south of Brinker (Figure 1) and has a salinity that varies from 25 to 75 parts per thousand (ppt). The salinity of 75 ppt is found along the edges of the slough and is due to the influence of salt evaporators located on either side of the slough.

Along a time continuum, Durham would represent the impounded salt marsh, while Albrae Slough would represent the completely restored, or natural, salt marsh, and Brinker falls somewhere in between. In addition, it is important to note that prior to the levee breach, all marshes were treated for mosquitoes by ACMAD (Hamersky 2001, pers. comm.).

Study Organisms Mosquito species *Aedes squamiger*, *Culiseta inornata*, and *Culiseta incidens.* were observed to provide information on the possibility of restoration as a means of mosquito control, as well as the effects of flooding on Brinker. The corixid species *Trichocorixa verticalis* occurs in all three marshes and was sampled to see effects of flooding on Brinker.

Aedes squamiger This mosquito species is univoltine and occurs in the intertidal marshes of the California coast. The following account of the seasonal history is based on studies conducted in the Bolinas (Marin County) area by Bohart, Mezger, and Telford (1953), and Telford (1958).

Following high tides and heavy rains, three to six major hatches have been observed during the fall months. Approximately 48 days are required for development from hatching to the adult stage. Adult eclosion has occurred from February through March with a peak in mid-March. Most adults presumably migrate to nearby foothills immediately after emergence. From March through April, gravid females filter back to the marsh to oviposit. Those remaining in the foothills are presumably killed by the first hot days of summer.

In the spring, when a majority of female oviposit, the lower areas of the marsh are still under water. Only the higher, exposed portions are suitable for egg deposition at this time. Consequently, most eggs are located in higher areas where tides without a rain supplement will not reach them. By late spring, when the water recedes, a few tardy females oviposit lower on the marsh. These late eggs hatch the following fall, when flooded by tides alone. Major hatches occur as fall rains and high tides progressively flood higher on the marsh. Although there is a series of hatches each year, a long developmental period and a summer dormancy of its eggs limit *squamiger* to one generation annually.

The summer dormancy, which may extend from April through September, is interpreted as an obligatory diapause, which is terminated by decreasing or low fall temperatures. (Bohart and Washino 1978)

Culiseta inornata The larvae of this mosquito are found in a wide variety of aquatic habitats. In the Central Valley, they have been collected in duck club ponds, ditches, canals, irrigation and tail water impoundments, seepages and rainpools. They appear to be fairly tolerant of saline water since they have been recovered in Marin County salt marshes from pools with 0.8-2.6% salt content (Telford 1958).

The seasonal abundance in California is similar to the pattern reported from southern U.S. where *inornata* is essentially a fall, winter, and spring mosquito. Studies in Texas indicated that at least a part of the population in that area might pass the summer in the egg stage (Wilkins and Breland 1949; Buxton and Breland 1952). Kern County studies do not support this contention and suggest that survival through summer periods in that area of California depends upon adult females persisting in small numbers (Washino et al. 1962).

The seasonal history of *inornata* varies considerably within the north-south range of its distribution. For example, this mosquito reaches peak abundance during spring and fall period in the San Joaquin Valley of California, and during the winter months in the Sonoran desert in Imperial and Riverside counties of southern California (Bohart and Washino 1978).

Culiseta incidens Larvae and adults have been collected in all months, but peak abundance is limited to the cooler months of the year. Larvae occur in both fresh and brackish water along the coast. In California, *C. incidens* are abundant along the coast, in the foothills, and in the Sierra to an altitude of 9,500 feet (Bohart and Washino 1978). Based on the few studies on feeding habitats by precipitin test in Washington and California, *C. incidens* show predominant feeding on large domestic mammals (Reeves and Hammon, 1944; Tempelis and Washino, 1967).

Trichocorixa verticalis. Corixids (water boatmen) are the most numerous of all aquatic Hemiptera, both in species and in individuals. They occur from below sea level (Death Valley, CA) to 15,000 feet elevation (Himalaya Mtns.). They seem equally adapted to the cold waters of the subarctic and to tropical waters. Corixids play an important role in aquatic communities because they serve as an early link in the animal food chain. The water boatmen differ from all other Hemiptera in their feeding habits. They feed on the ooze (i.e. microcrustaceans, bacteria, etc.) that live at the bottom of the water. Other food consists of small benthic organisms. Some corixids feed on small midges and mosquito larvae, and to this extent corixids are predatory.

In California, *Trichocorixa reticulata* and *T. verticalis* are the halobionts, living exclusively in brackish or saline waters. The former species has been found in the ocean and occurs in the brine pools (Leslie Salt Company) on the south shore of San Francisco Bay together with the brine shrimp *Artemia salina*, and the brine fly, *Ephydra gracilis*. The bugs also occur in the saline waters of former lakebeds in the California deserts. They are the dominant insect of the extensive inland Salton Sea and thrive at Badwater in Death Valley.

The winter is passed in the adult stage, the adults exhibiting considerable activity even in waters covered by a layer of ice. Eggs are laid in the spring and attached to stems and leaves of various water plants, sticks, boards, and even shells of living snails. The incubation period was one to two weeks at Ithaca, New York. The five nymphal instars required about one week each, except the last stage, which occupied a few days longer (Ross et al. 1982).

Methods

Sampling of the three marshes began on January 29, 2001. The marshes were each sampled once every week. To ensure an adequate depth for D-frame net sampling in Albrae Slough, sampling at the slough, and the other two marshes, took place at high tide. Therefore, sampling did not occur exactly every seven days. Sampling ended on April 23, and this study consists of data collected from 13 sampling weeks.

Due to accessibility and depth, the salt marshes were sampled along one side only; Durham was sampled along the west edge, Brinker was sampled along the east edge, and Albrae Slough was sampled along a ditch in the middle of the slough.

A D-frame sweep net (1-mm mesh size, 30 cm width) was used to sample the corixids. The net was drawn through the top 30 cm of the water column. Each sample consisted of three 1-m long sweeps (S-shaped movement) through the top 30 cm of the water column at randomly selected locations along the edge, and 15 samples total were taken in each of the three marshes. Samples were transferred into a white enamel pan, and corixids were counted or estimated (for samples of more than 50). Because water level decreased to less than 30 cm in Durham by April, D-frame net sampling was not possible. Therefore, corixid numbers for the last four sampling dates are based on the number of corixids collected by dipper sampling (using a dipper).

A dipper was used to sample the mosquito larvae. Dip sampling occurred at randomly selected locations. A total of 15 samples were taken from each of the three marshes. Samples were transferred into ziplock bags and identified in the laboratory.

Results

The number of corixids found in Durham remained low through the three months of sampling (Figure 2).

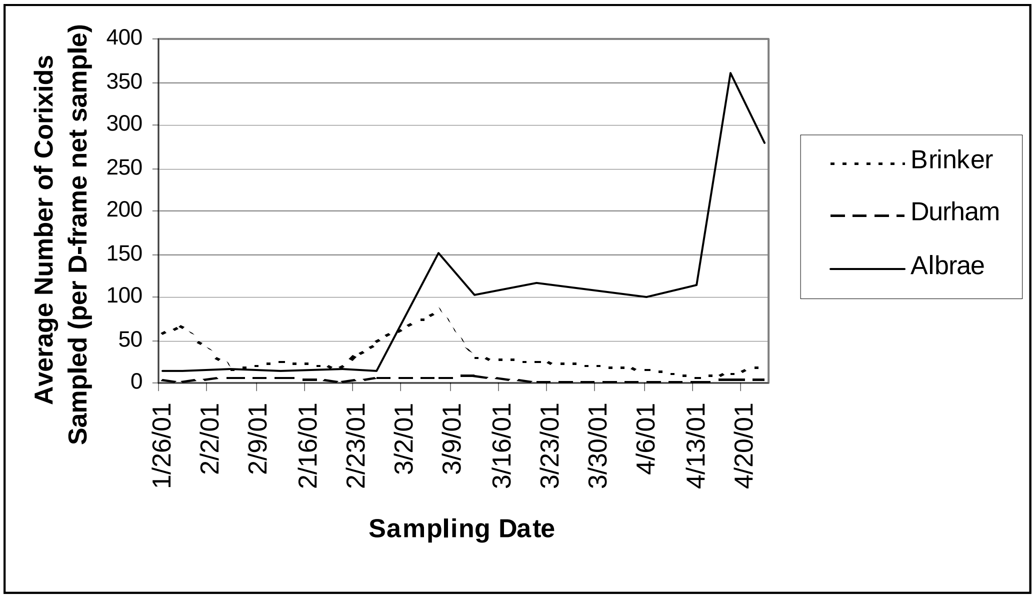

Figure 2. (Note: Dipper was used in Durham on April 6 and thereafter.)

In Brinker, the number of corixids found ranged from approximately 20 to 80 corixids, with fluctuation. The number of corixids found in Albrae remained below 20 until the beginning of March where the number nearly increased by one magnitude. In mid-April, the number of corixids tripled. No mosquitoes were found in Brinker, except for one occurrence of *Culex incidens* on April 6 (Figure 3).

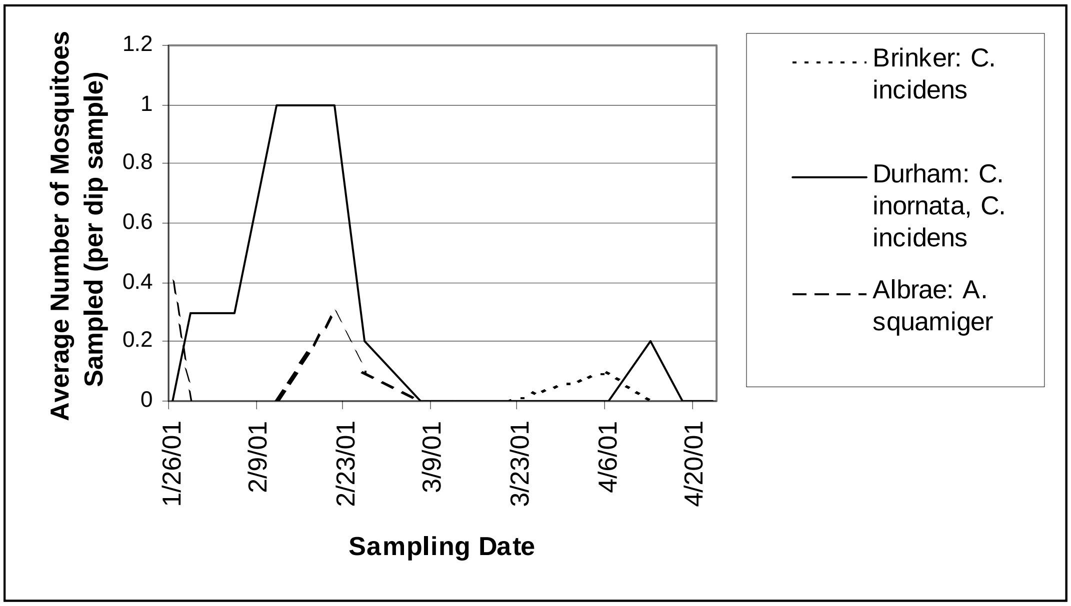

Figure 3.

The number of mosquitoes found in Durham increased the first three weeks of sampling and began decreasing at the end of February. In Albrae, mosquito numbers ranged from 0 to 0.4 (per dip sample), with a second peak occurring on February 21. The average numbers used for analysis were based on the dipper sampling of mosquitoes and the D-frame net sampling of corixids. The sole mosquito species sampled in Albrae Slough was *Aedes squamiger*. *Culex incidens* was found in both Brinker and Durham, while *Culiseta inornata* was only found in Durham.

The overall average of corixids found in Brinker through this study was 33. The overall average of mosquitoes found in Brinker was 0. For Durham, an average of 0.2 mosquitoes and an average of 4.8 corixids were sampled. An average of 0.1 mosquitoes and an average of 101 corixids were sampled at Albrae Slough. Population sizes at the three marshes were not compared statistically since the estimating at each sampling time was not independent.

Salinity was measured on January 29, March 12, April 18, and April 23 using a refractometer. Salinity decreased in Durham and Brinker during the month of February, and then increased through the end of March. Salinity at Albrae steadily increased through the entire sampling period.

Measured Salinity

Date/Marsh	Durham	Brinker	Albrae
1/29	10 to 12	18 to 20	25 to 75
3/12	6	11	25
4/18	13	19	30
4/23	12	15 to 16	45

Table 1.

An increased water level was observed at Durham and Brinker on February 26. No increase in water level was observed at Albrae during the three months of sampling. A decreased water level was observed at Durham and Brinker on April 6. On April 23, the water level at Brinker was observed to have decreased even more. No decrease in water level was observed at Albrae. One fish was caught in the D-frame net in Brinker on average approximately once every two sampling dates. No fish were found in either Albrae Slough or Durham.

Treatment of Marshes ACMAD is required to treat areas where certain species of mosquito are found, especially *Aedes* spp. The compounds used by ACMAD are Bti (*Bacillus thuringiensis israelensis*) and Altosid (methoprene). To be effective, Bti must be eaten by insects during their feeding stage of development, when they are larvae. It is ineffective against adult insects. Bti is considered ideal for pest management because of its specificity to pests and because of its lack of toxicity to humans or the natural enemies of many crop pests. Altosid (methoprene) is biodegradable and nonpersistent, even in plants treated at very high rates. Plants grown in treated soil are not expected to contain methoprene residues. Methoprene is a compound that mimics the action of an insect growth regulation hormone. It is used as an insecticide because it interferes with the normal maturation process. In a normal life cycle, an insect goes from egg to larva, to pupa, and eventually to adult. Methoprene artificially stunts insect development, making it impossible for insects to mature to the adult stages, and thus preventing them from reproducing. Methoprene is not toxic to the pupal or adult stages. Treated larvae will pupate but adults do not hatch from the pupal stage. Methoprene is also considered a larvicide since it is effective in controlling the larval stage of insects. (NYDH 2000, elect. comm.)

According to ACMAD, Brinker had been treated multiple times in previous winters for *Aedes dorsalis* and *A. squamiger*, but since the levee breach, no treatment has been required.

The most common threat at Albrae Slough has been *A. dorsalis*. This winter was unusual in that treatment was required for *A. squamiger*, which has not been found in the slough before. The slough was treated this year with Bti granules on February 8,9,13,14,20, and 22. Methoprene was applied on February 22. On March 2, a helicopter drop released both Bti and methoprene.

Durham had been treated in previous years for mosquitoes. This year, methoprene was used to treat *A. squamiger* along the east edge of the marsh on March 12 (Kirkpatrick 2001, pers.comm.).

Discussion

Restoring the hydrology of salt marshes is an important step for effective rehabilitation of wetlands (Coats et al. 1989; Roman et al. 1995; Brockmeyer et al. 199; Burdick et al. 1997; Turner and Lewis 1997), but little is known about the effect of simply removing barriers to tidal inundation on the production of mosquitoes in otherwise unmanaged marshes. The present study found differences between macroinvertebrate populations in the three marshes that could have been caused, in part, by the levee breach along Mud Slough.

Populations of mosquitoes and corixids varied in abundance between the three marshes sampled in this study. Based on the assumption that the condition of Durham is comparable to initial conditions of Brinker, it appears that Brinker has changed since the levee breach. Whether the changes in Brinker are due to the levee breach alone cannot be determined indefinitely by this study, but possible effects due to the levee breach are investigated and other factors contributing to any differences suggested.

Corixids populations seem to vary with salinity between the three marshes. In a 1993 study, *Trichocorixa* species were found to be generally more abundant at 8.5-17 ppt, but were never observed at 51 ppt (Greenwald et al.). Albrae Slough had the highest salinity of all the three marshes, at 25 ppt and above. Beginning in March, the slough had the highest number of corixids sampled compared to that sampled in the other two marshes. The high salinity is likely due to tidal circulation, or the flow of seawater (which, as mentioned earlier, has a salinity of approximately 33 ppt), as well as the presence of salt evaporators around the slough. The increase in the Albrae corixid population in March could also be due, in part, to the high production and turnover rates of bacteria and algae, as observed of *T. reticulata* by Balling and

Resh (1984). Through time, there was an increase in salinity at Albrae Slough, as well as an increase in the number of corixids sampled. Because the purpose of this study was to observe the populations present in each of the three marshes, correlation between salinity and number of corixids found was not tested. The levee breach introduced seawater to Brinker, which would have caused an increase in its salinity. This increase salinity had, in turn, a positive effect on the corixid population. Durham, which is considered to have brackish water, had the lowest number of corixids. This also indicates a possible correlation between salinity and number of corixids.

The present study found a possible impact of the levee breach, and introduced Bay water, on mosquito production in Brinker, but based on water level observations, restoration of full tidal circulation is yet to be seen. Kramer et al. (1995) found that restoration of full tidal action to the marsh could achieve desired levels of mosquito control. Their study on the reduction of *Aedes dorsalis* suggested that enhanced tidal circulation might have reduced mosquito abundance by impeding the conditioning process of the eggs, by promoting predator circulation, or by decreasing the amount of standing water available for mosquito. Although the levee breach at Mud Slough allowed for Bay water to flood Brinker, based on the observations of water level, it does not appear that there is much tidal action occurring in the marsh. Water levels increased and decreased due to rainfall and evaporation in both Brinker and Durham at similar times. This shows that hydrologic processes are yet to be fully restored at Brinker, and currently, changes in water level appear to be the same as that of the impounded marsh.

The increase and decrease of water volume also explains the fluctuation in salinity seen in Table 1. The salt content of actual or potential mosquito breeding sites influences the species of larvae that occur in such sites because some may be halophilic and others merely tolerant of saltwater (Rogo et al. 1985). For this reason, it is understood that different species will be found in the three marshes due to varying salinity. Fluctuation of salinity, as seen in Table 1, corresponded to the increase and decrease of water level in the marshes. Assuming that rainwater and evaporation were the only inflow and outflow movements of water, then as water level and volume increased, the salinity decreased (as seen in mid-March, Table 1). When the water level and volume decreased, the salinity became more concentrated, and therefore increased.

Although the original mosquito populations of Brinker are not known, we can infer, from the frequent treatments of the marsh during winter seasons prior to the levee breach, that mosquitoes were, at one time, present in the marsh. The data collected in this study show that no mosquitoes were found in Brinker, except for sampling on April 13. If we were to base mosquito breeding solely dependent on salinity though, since the *Aedes* spp. are salt marsh mosquitoes, then we would expect breeding to continue in Brinker, but there are other factors that determine whether or not mosquito breeding can occur. Some of these factors were observed during the present study.

The flooding of Brinker, due to the levee breach, and the consequential rise in water level, caused ideal breeding habitat, such as pickleweed, to become unavailable. Vegetation is one requirement for breeding to occur, and the lack of vegetation affects the survival of mosquito larvae. Vegetation is important for mosquitoes in wetlands because it protects larvae from predators and physical disturbance, and enhances food resources (Kramer and Garcia, 1989). Without proper vegetation, female mosquitoes are not likely to oviposit in the marsh. Mosquito oviposition is typically higher in areas with dense emergent cover (Orr and Resh 1992). Also, overall reductions in the cover of saltmarsh plants may contribute to the reduction of oviposition because eggshell densities are correlated with the presence and percentage coverage of these plants (Kerridge 1971; Horsfall et al. 1975; Dale et al. 1986; Turner and Streever 1997).

Another factor that influences the breeding and development of mosquitoes is the movement of water; more specifically, whether or not standing water is present. The increased volume of water in the Brinker allowed for more water movement within the marsh, and this too has been found to be helpful in reducing mosquito populations; riffle zones provide turbulence that is detrimental to larvae (Russell 1999). Larvae live at or near the water's surface, and this exposes them to visual predators and surface turbulence caused by wind action (Eriksen, Resh, and 1996). The increase in water level also changes the depth of the marsh. Densities of *Culiseta inornata* mosquitoes were found to be low at depths of 60 cm and high at depths of 40 cm by Batzer and Resh (1992).

As mentioned earlier, restoration of wetlands can decrease mosquito populations by providing proper habitat for natural enemies of mosquitoes. Fish were observed in Brinker, and they were likely introduced into the marsh by the flooding of Bay water. Although the exact species of these fish are unknown, they were likely predatory and influential in the absence of mosquitoes in Brinker. Invertebrate predation by fish is higher in open water habitats than in densely vegetated areas (Heck and Crowder 1991; Schriver et al. 1995). The flooding of Brinker provided open water habitats, and the brackish water was suitable for fish. No fish were found in Albrae Slough, which is densely vegetated, and no fish were found in Durham, which is an impounded marsh.

Culiseta inornata were found in the beginning of the study at Durham. It is not known whether or not the decrease in species has to do with seasonal abundance, since *C. inornata* is a fall, winter, and spring mosquito. The decrease is not likely due to the decrease in salinity. The decrease in mosquitoes sampled along the west edge of the marsh can be attributed to the rise in water level due to winter rains. Pickleweed was no longer available as breeding habitat, and there was increased water movement along the edge. Because the marsh slopes down westward, the east edge is slightly higher. Along the east edge, which was not sampled but was treated for *A. squamiger*, areas that were dry prior to the rains were flooded with a level of water ideal for breeding. Because mosquito breeding was still occurring in the marsh, we cannot assume that the absence of *C. inornata* was necessarily due to the decrease in salinity.

Because spraying did occur at Albrae Slough, the data collected of *A. squamiger* found at the slough are not representative of the populations that would have naturally emerged without the spraying. As described earlier, *A. squamiger* adults emerge in February through March, which would mean that larvae are present January through February, as supported in Figure 2. The slough has ditches, which are a form of mosquito management, and the discovery of few or no mosquitoes is a sign that the ditches are effective. The slough has been sprayed by ACMAD every year (Hamersky 2001), and it is likely that without treatment, there would be frequent outbreaks of *A. dorsalis*, or *A. squamiger*.

Culiseta incidens was found in Brinker once. Because the species was discovered in Durham on the same sampling date, it is possible that the appearance of the mosquitoes was due to seasonal factors and marsh conditions. The decreased water level observed in Brinker, as well as Durham, allowed for exposure of vegetation, which probably harbored and protected mosquito larvae. *Culiseta incidens,* as mentioned earlier, is a year-round mosquito, and because temperature was not measured in this study, it is not clear if cooler temperatures occurred for appearance in Brinker.

Treatment of Albrae Slough resulted in the collection of data that may not have been representative of naturally occurring, undisturbed *A. squamiger* populations, and it was difficult to attribute population changes to the treatment or to seasonal variation. Summer dormancy is known to begin in April, though, a cause, beside Bti, for the absence of *A. squamiger* in Albrae prior to April is unknown.

This study took place only two years after the levee breach. Further studies would be required in the following years to observe restoration progress and monitor both mosquito and corixid populations. The difference between corixid populations and mosquito populations may not have been due to salinity (and thus the flooding). Abundance differences could have been intrinsic to the marshes, or other factors that differed between the marshes may have influenced differences in abundance. Other macroinvertebrate populations should be observed to either further examine differences between the marshes or to find possible trophic relationships with corixids and mosquitoes. Plant coverage and species should be examined as well, since breeding habitats are partly based on the vegetation available. Salinity should be monitored weekly in order to make possible correlations with population fluctuations. Other factors that influence mosquito populations, besides vegetation, salinity, and water movement, include temperature. Temperature is known to affect rate of development of the larvae, and hence time of emergence (Pritchard and Mutch 1985).

To perform a more thorough study on the effects of restoration, such as a levee breach, it would be best to sample before and after the breach to reduce the number of factors that may influence results found. A study done over a period of at least two years would be appropriate. This would allow for observation and comparison of seasonal fluctuations in macroinvertebrate populations, as well as hydrologic processes. Also, it is important to choose, as study organisms, species that do not pose a threat to the local communities or that require treatment. This would ensure that observations are being made in similar conditions (without treatment) before and after restoration has been initiated. For this study, the varying salinity caused different species to occur at the three marshes, and differences between the populations could have been due to seasonal cycles, rather than or in conjunction with differences between the marshes themselves.

Based on the data collected in this study, it appears that Brinker has changed due to the flooding. The increase in salinity has allowed for an increased corixid population, and the rise in water level has discouraged mosquito breeding in the marsh. The increase in salinity and introduction of fish, both a result of the flooding, serve as indicators of the restoration process. Although salt marshes vary, and degraded functions differ, Brinker does not appear to be at the same stage as Durham along a restoration time continuum.

The hydrologic restoration of Brinker appears to have had an effect on mosquito populations in the marsh, but lack of full tidal circulation will not guarantee permanent absence of mosquitoes. The studies initially presented state that a decrease in populations occurred due to wetland restoration. In this study, restoration, or more specifically levee breaching, appears to serve as a more permanent solution against mosquito breeding in comparison to frequent larvicide applications; flooding and other factors discourage breeding and inhibit larval survival. As the marsh evolves, parameters affecting mosquito production change and need to be monitored (Kramer et al. 1995). Levee breaching can serve as the first step in controlling mosquito populations, but planning is required to ensure proper hydrologic restoration.

Acknowledgements

I would like to thank Dr. Vincent Resh for helping me find and set up this project; John Latto for all his advice and patience; Bruce Elderidge and the UC Mosquito Research Mosquito Program for funding; and John Rusmisel, William Hamersky, and Bruce Kirkpatrick at the Alameda County Mosquito Abatement District for their guidance and funding.

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