Water Management in a Salt Marsh Leads to Enhanced Fish Production

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Introduction

Control of mosquito populations using means other than pesticides as been identified by some as a way to decrease potential environmental impacts associated with pesticide use while still allowing for control of pestiferous and potential vector mosquitoes. Alteration of mosquito habitats (by ditching and a suite of techniques lumped under the term "Open Marsh Water Management," OMWM) has been found to be effective at controlling mosquito populations (Dale and Hulsman, 1990). Ditches are unattractive, and may cause deleterious impacts to marsh ecology (Tonjes, in prep.). OMWM is thought to be a more environmentally sensitive approach to mosquito control. One aspect of OMWM techniques that may be beneficial to the environment is that it may lead to increases in native marsh fish populations (Wolfe, 1996). A study at the Wertheim National Wildlife Refuge has found this to be the case, as this paper reports, several years after an OMWM project was conducted there.

As part of the Suffolk County Vector Control and Wetlands Management Long-Term Plan, a water management demonstration project was conducted in the Wertheim National Wildlife Refuge (see Figure 1 and Figure 2). The design was intended to result in mosquito control, and also in various ecological function improvements including better avian and nekton habitats, and Phragmites control. In March, 2005, alterations were made to approximately 16 hectares (40 acres) of salt marsh (Area 1), and in February and March of 2006, to Area 2, which has a total size of approximately 18 hectares (45 acres) (Figure 3). The changes included the filling of nearly all of the pre-existing mosquito control ditches in the marsh, removal of plugs installed during previous projects at the end of some of the ditches, alteration of any remaining ditches to "naturalize" them by adding curves and other features found in natural waterways in salt marshes, construction of ponds of various sizes, creation of tidal channels to mimic naturally occurring salt marsh creeks, the digging of shallow connections between the ponds and the tidal channels, and use of excess fill from the ponds to smooth hummocky high marsh terrain that had been found to provide habitat for larval mosquitoes (Figure 4).

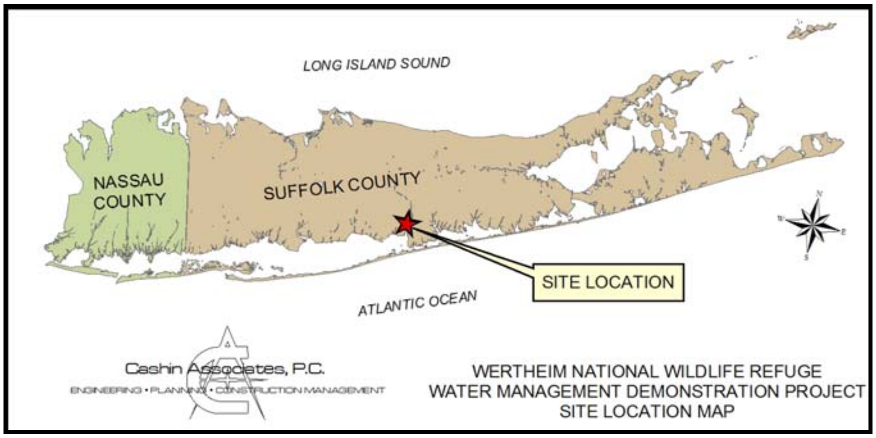

Figure 1. Site Location

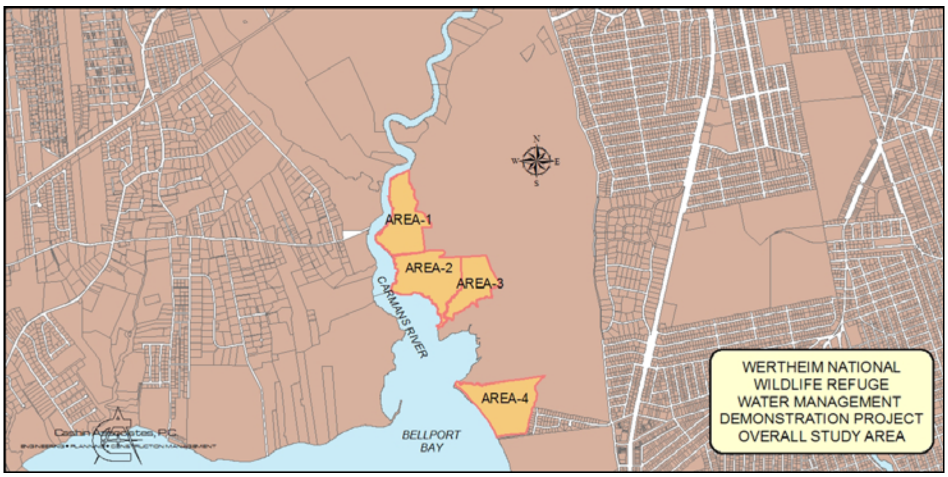

Figure 2. Study areas

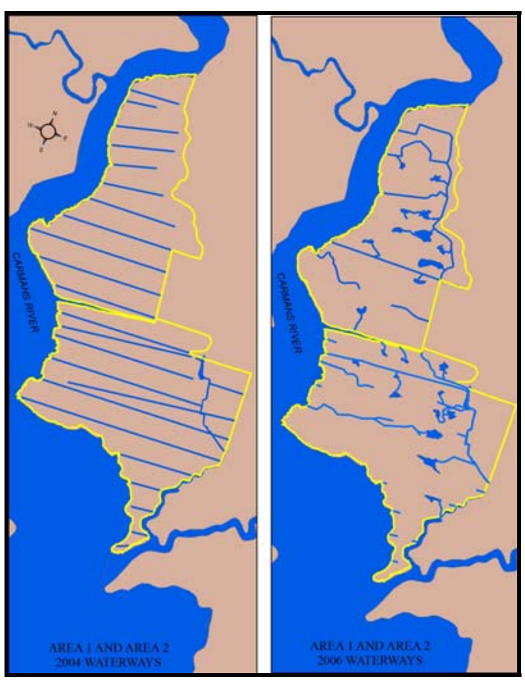

Figure 3. Pre-construction Ditches and Post-construction Waterways

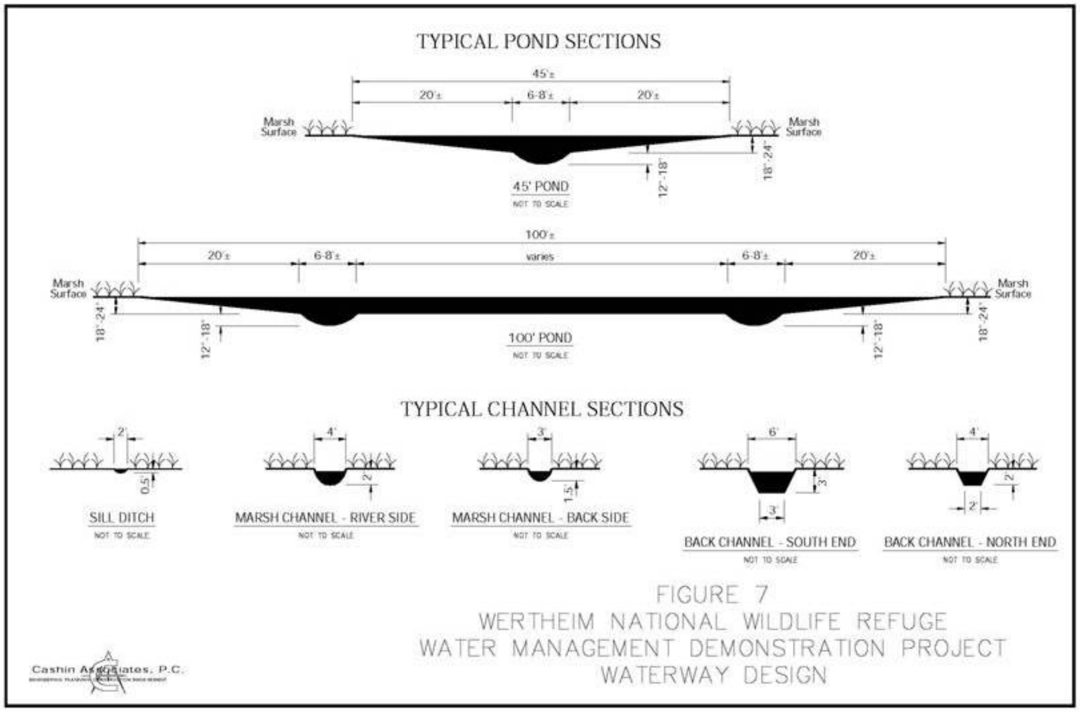

Figure 4. Waterway designs

This project was issued a permit by New York State Department of Environmental Conservation. As specified in the permit, monitoring at the site has been conducted. There have been three seasons of post-treatment monitoring in Area 1 (2005-2007), and two seasons in Area 2 (2006-2007). These data sets have been compared to pre-treatment monitoring data (2003-2004 for Area 1, and 2003-2005 for Area 2) and those data collected in the control areas, Area 3 and Area 4 from 2003-2007. This paper reports on results from fish monitoring.

Methods

Nekton sampling was conducted in accordance with USFWS/USGS protocols (James-Pirri et al., 2001) at all fish stations in all four marsh areas. Samples were collected near the end of spring, in mid-summer, and in early fall. A ditch net with 3 mm (1/8 in.) mesh nylon netting was used for all ditches and streams. The center of the net was placed along the sides and bottom of 1 linear meter of ditch. The width of the ditch or waterway was measured to support a calculation of the area being sampled. The nets were placed in the ditches at the station locations at least 30 minutes before sampling to minimize any disturbance to the fish caused by placing the net in the ditch. Two doors located on the open ends of the net were pulled to close the net after 30 minutes. Once closed, the ditch net enclosed an area of water 1 m long and as wide as the ditch. The net was quickly removed from the water onto the marsh surface, where the fish were identified, counted and measured. Water quality parameters were also collected and recorded at each sampling location.

Sampling at the pond locations was conducted using the alternate USGS/USFWS throw net technique (James-Pirri et al., 2001). This technique specifies that a throw trap approximately 1 meter square was to be thrown in an arbitrary direction into the pond over the sampler's shoulder then quickly pushed into the sediment in order to prevent escape of nekton from under the trap. Alternate procedures also specify that a random number generator can be used to specify the location the trap is to be thrown from, instead of using an arbitrary location. Samplers found the trap too cumbersome to be thrown over the shoulder, as then it often did not land square. The sampler therefore threw the trap from chest-level into the pond (the trap itself generally blocked the sampler's view, precluding aiming for visible fish). Nekton captured within the trap were collected, measured, and counted.

Because of alterations to the marsh, sampling locations were shifted following construction. Table 1 shows the changes in sampling sites post-construction.

Table 1. Number of Nekton Samples Collected from Various Environments

	Ditches	**Modified Ditches**	**Channels**	**Ponds**
2003	40			
2004	120			
2005	90	9	9	12
2006	60	16	15	20
2007	60	18	18	18

Results

All nekton data sets were analyzed using Kolmogorov-Smirnov tests (a non-parametric test) (calculator available on-line provided by the Physics Department at Saint Benedicts College-St. Johns University, MN [www.physics/csbsju.edu/stats]), with significance determined at $p<0.05$.

Table 2 summarizes the nekton sampling data. It should be understood that only one sampling event occurred in 2003. These data strongly suggest that the number and diversity of fish increased in Area 1 following alterations to the marsh there, and that the abundance of nekton in Area 2 also increased following changes. In Area 3, abundances were much greater in 2005 and 2007 than in other years; in Area 4, 2004 was clearly the year of peak abundance.

Table 2. Nekton Sampling Summary

Area	Year	Species Caught	Total Caught
1	2003	2	49
	2004	3	27
	2005	9*	375
	2006	8*	745
	2007	7	439
2	2003	4	164
	2004	4*	444
	2005	5*	259
	2006	7	695
	2007	8*	621
3	2003	3	144
	2004	3	182
	2005	7*	380
	2006	5*	155
	2007	5	474
4	2003	4	116
	2004	6*	332
	2005	6*	151
	2006	5	58
	2007	5	94
Total	2003	5	473
	2004	8*	985
	2005	10*	1165
	2006	9*	1653
	2007	9*	1628

* plus unidentified juvenile fish

Table 3 provides more detail regarding the distributions of the fish caught in sampling. Post-treatment in Area 1, *Fundulus heteroclitus* (mummichogs) increased in abundance tremendously, as did *Cyprinodon variegates* (sheepshead minnow). *Palaemonetes spp*. (grass shrimp) numbers were also greatly increased (at least for 2005-2006; there was a decline in 2007 from the initial increases). *Menidia menidia* (Atlantic silverside) spiked in the second year post-construction. On the other hand, abundances of *Lucania parva* (rainwater killifish) declined.

For Area 2, almost the exact same patterns were seen (except grass shrimp abundances declined in 2007 in only the second year post-treatment; this is unlikely to be solely the result of particular 2007 marsh conditions, as numbers were maintained in Area 3 relative to preceding years). This suggests that the installation of tidal channels and ponds increases the overall quality of fish habitat compared to the pre-treatment ditches.

Table 3. Total Nekton Abundance

Year	Area	*Anguilla rostrata*	*Apeltes quadracus*	*Callinectes sapidus*	*Cyprinodon variegates*	*Fundulus diaphanus*	*Fundulus heteroclitus*	*Fundulus luciae*	*Lucania parva*	*Menidia spp.*	*Palaemonetes spp.*	*Bolinopsis infundibulum*	*Pungitius pungitius*	Juvenile Unknown	**TOTAL NEKTON**
2003	**1**	-	-	-	-	-	6	-	43	-	-	-	-	-	**49**
	2	-	-	-	2	-	75	-	18	-	69	-	-	-	**164**
	3	-	-	-	-	-	45	-	30	-	69	-	-	-	**144**
	4	-	-	-	-	-	20	-	6	-	89	-	1	-	**116**
2004	**1**	-	2	-	-	-	5	-	20	-	-	-	-	-	**27**
	2	-	-	2	-	-	201	-	123	-	111	-	-	7	**444**
	3	-	-	-	-	-	89	-	39	-	54	-	-	-	**182**
	4	-	-	-	-	-	125	1	11	1	192	-	1	1	**332**
2005	**1**	5	1	1	50	-	132	1	35	31	96	-	-	23	**375**
	2	-	-	-	-	1	81	2	28	-	146	-	-	1	**259**
	3	1	-	-	4	-	189	13	55	2	111	-	-	5	**380**
	4	-	-	-	5	-	86	2	20	1	33	-	-	4	**151**
2006	**1**	2	2	3	238	-	335	-	14	1	145	-	-	5	**745**
	2	-	-	5	48	-	409	-	6	46	177	4	-	-	**695**
	3	-	-	4	11	-	23	-	24	-	89	-	-	4	**155**
	4	-	1	-	2	-	10	-	34	-	11	-	-	-	**58**
2007	**1**	5	-	-	102	-	282	2	9	5	34	-	-	-	**439**
	2	-	-	2	128	-	379	17	2	73	15	1	-	4	**621**
	3	-	-	-	13	-	210	-	159	15	77	-	-	-	**474**
	4	-	-	2	1	-	44	-	37	-	10	-	-	-	**94**

Table 4 compares overall pre-treatment and post-treatment distributions of the numerous, persistent species (so Atlantic silverside and other species were not included). The differences in distributions between pre- and post-treatment abundances of sheepshead minnow, mummichogs, rainwater minnows, grass shrimp and total nekton abundances for Area 1 and its controls were all statistically significant, as were pre- and post-treatment differences in the Area 1 results, and pre- and post-treatment differences for the controls. The differences in distribution for post-treatment Area 2 and its controls were all significant; differences for pre-treatment and post-treatment Area 2 data were significant for sheepshead minnow and rainwater killifish.

Table 4. Pre- and post-treatment nekton comparisons (fish per sample)

Class		**Area 1**	**Area 1 controls**	**Area 2**	**Area 2 controls**
C. variegates	Pre-treatment	0	0	0.0	0.1
	Post-treatment	4.8	0.2	3.4	0.2
F. heteroclitus	Pre-treatment	0.3	3.5	5.1	4.0
	Post-treatment	9.1	3.1	15.2	2.4
L. parva	Pre-treatment	1.6	1.1	2.4	1.2
	Post-treatment	0.7	1.8	0.2	2.1
Palaemonetes spp.	Pre-treatment	0	5.1	4.7	3.9
	Post-treatment	3.4	1.8	3.7	1.6
Total	Pre-treatment	1.9	9.7	12.4	9.3
	Post-treatment	19.0	7.2	25.3	6.5

Comparisons of the distribution of the nekton post-treatment in Areas 1 and 2 (Table 5) show that the fish are distributed differently in the new habitat areas, although each habitat area had approximately the same overall abundance per sample. The dominant species in ponds was sheepshead minnows, with mummichogs also important. In the modified tidal channels, mummichogs were the dominant fish. The modified ditches were a mummichog-grass shrimp distribution, which was similar to what was found in most of the unmodified ditches (although rainwater killifish were also common in the unmodified ditches).

Table 5. Distribution of nekton detected post-treatment, Area 1 (2005-2007) and Area 2 (2006-2007) (fish per sample)

HABITAT	*Anguilla rostrata*	*Apeltes quadracus*	*Callinectes sapidus*	*Cyprinodon variegates*	*Fundulus heteroclitus*	*Fundulus luciae*	*Lucania parva*	*Menidia spp.*	*Palaemonetes spp.*	*Bolinopsis infundibulum*	Juvenile Unknown	**TOTAL NEKTON**
Ponds	0.0	0	0.1	11.4	7.9	0.4	0.6	1.3	3.1	0	1.6	**25.4**
Tidal channels	0.0	0.0	0.0	0.3	16.4	0.0	0.6	1.4	1.3	0.0	0.1	**20.3**
Modified ditches	0.4	0	0.1	3.0	14.2	0.1	0.3	0.1	7.5	0	0	**25.6**

In addition to the quantitative analysis of the nekton changes, the sampling crew added the following subjective observations:

- An immediate fish presence was observed in Area 1 ponds once they were fully inundated, approximately one to two tidal cycles post creation. A slower fish response was observed for the Area 2 ponds.
- A *Prionotus carolinus* (Northern sea robin) was observed in the northern tidal channel of Area 1, two months post alterations.
- Ponds were observed “bubbling” with fish when the sampling crew would come within approximately 15 feet of a pond in Area 1 post alterations; this phenomenon earned these kinds of structures a name of “champagne” pools in New Jersey.
- *Callinectes sapidus* (blue claw crabs) were repeatedly observed in the sills of Area 1 throughout 2005 through 2007.

Overall, the number of species of fish across Area 1 increased notably, and the number of fish increased tremendously (so that the area changed from a fish-depauperate marsh to one that teems with fish). The changes in Area 2 were also notable, if not on quite the same scale. Although there was some variability in the nekton data for control sites and pre-project samples in Area 2, the weight of the data is strongly supportive of improved fish habitat due to the marsh alterations. Although there were some shifts in species composition associated with the changes to the marshes, with the exception of declines in rainwater killifish, most other fish had absolute increases in abundance.

The total area of open water across the treatment areas was approximately doubled because of the project (from 0.61 ha to 1.43 ha). Table 6 provides very broad estimates for marsh-wide changes in numbers of the persistent fish species, estimated from the sampling data. This suggests the total number of nekton, especially sheepshead minnows and mummichogs, clearly increased post-treatment. Rainwater killifish numbers may have decreased somewhat over the entire study area, and grass shrimp numbers fluctuated across areas and years (but appear to be somewhat the same from pre-treatment to post-treatment).

Table 6. Estimated total abundances (in thousands)

Class	**Years**	**Area 1**	**Area 2**	**Area 3**	**Area 4**	**Total**
C. variegates	2003	0	1	0	0	1
	2004	0	0	0	0	0
	2005	12	0	0	1	12
	2006	66	14	0	0	80
	2007	26	35	1	0	60
F. heteroclitus	2003	2	27	11	7	47
	2004	1	37	8	18	63
	2005	30	10	16	8	63
	2006	92	121	2	1	217
	2007	72	104	18	5	198
L. parva	2003	11	6	8	2	27
	2004	2	23	3	1	29
	2005	8	3	5	3	19
	2006	4	1	2	4	12
	2007	2	1	13	4	20
Palaemonetes spp.	2003	0	25	17	32	74
	2004	0	36	5	23	63
	2005	22	18	9	4	53
	2006	40	53	8	1	102
	2007	9	4	7	1	21

The reason for the increase in fish numbers appears to be improvements in generalized water quality in the OMWM features compared to the mosquito ditches. Table 7 compares treatment and control areas for these parameters (control areas and pre-treatment areas are all composed of ditches). The temperature increases associated with treatment in Areas 1 and 2 were significant, but for Area 1, the control areas also experienced a significant increase in temperature. The salinity decreases associated with the treatment in Areas 1 and 2 were also significant. The dissolved oxygen concentration increases for Areas 1 and 2 post-treatment were also significant. Although this presentation does not show standard deviations for the data, the measurements were highly variable, with some of the results reflecting very high temperatures and very low dissolved oxygen concentrations in the post-treatment modified environments.

Table 7. Comparison of Treatment and Control Area Means for Field Parameters Collected during Nekton Sampling

	Temperature (°C)	Salinity (psu)	Dissolved Oxygen (mg/l)
Area 1 Pre-treatment	19.8	8.0	2.0
Area 1 Post-treatment (all)	24.5	6.6	4.6
Modified Ditches	24.1	4.5	5.3
Tidal Channels	24.0	6.5	4.4
Ponds	25.5	8.8	4.1
Area 1 Controls Pre-treatment	21.4	11.2	3.1
Area 1 Controls Post-treatment	25.4	9.9	3.1
Area 2 Pre-treatment	22.1	14.9	2.4
Area 2 Post-treatment (all)	24.0	9.5	4.4
Modified Ditches	23.6	9.0	5.5
Tidal Channels	23.5	7.9	4.0
Ponds	24.9	11.9	3.7
Area 2 Controls Pre-treatment	23.4	11.3	2.7
Area 2 Controls Post-treatment	24.7	9.1	3.1

Summary

Fish populations were increased by the alterations to the marsh. The increased numbers of fish appears to be fostered by general improvements to water quality making the overall habitat more amenable for native marsh fish. However, poor water quality conditions continue to occur on the marsh, so use of such an altered marsh by other species of fish other than native marsh fish is not likely. Increased populations of marsh fish may increase the transfer of marsh production to the estuary and provide support for fisheries of human interest, however (Odum, 2000; Deegan et al., 2000).

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