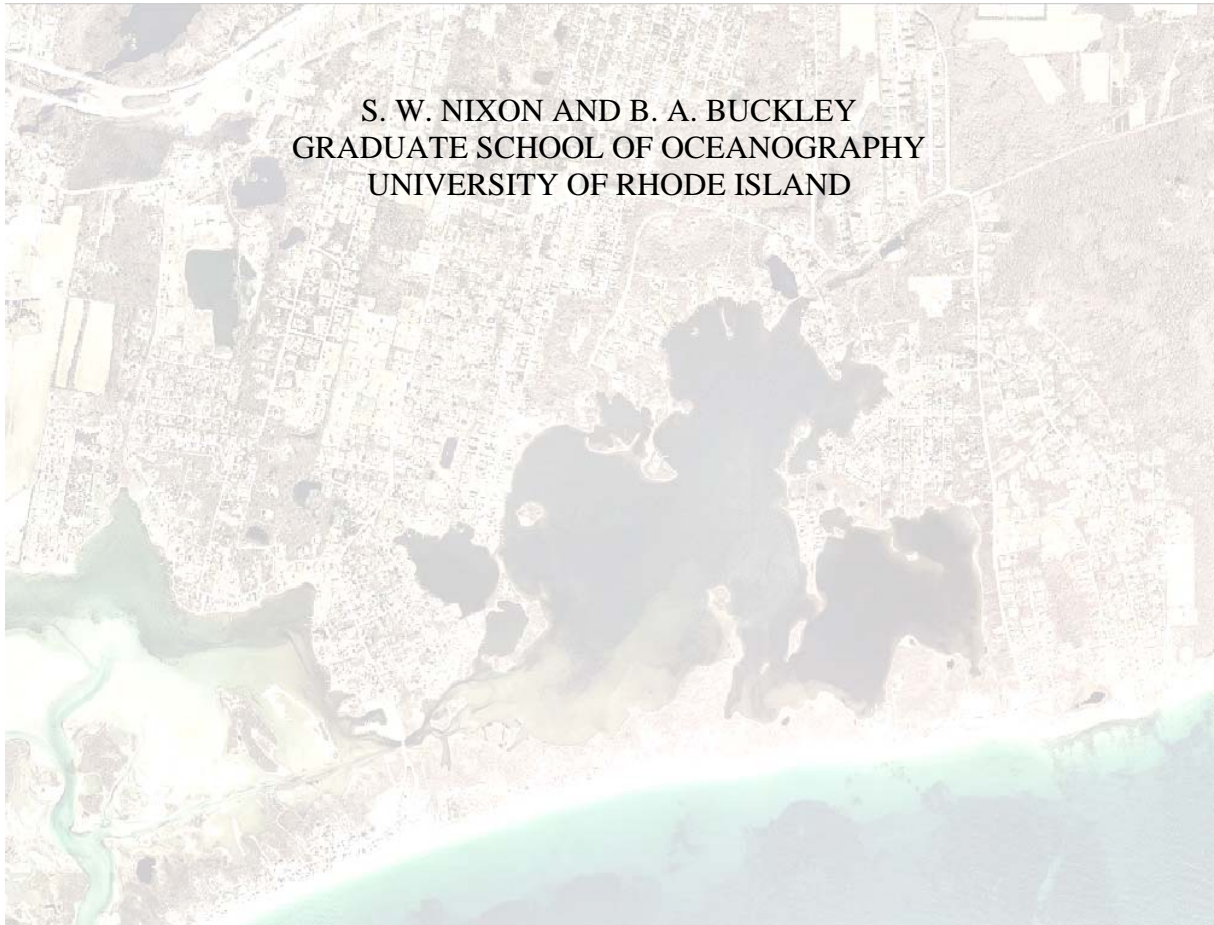


NITROGEN INPUTS TO RHODE ISLAND COASTAL SALT PONDS – TOO MUCH OF A GOOD THING

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A White Paper Prepared for the Rhode Island Coastal Resources Management Council

Spring 2007



In the early 1960's, Ninigret and Green Hill salt ponds (two of nine shallow coastal lagoons on the ocean coast of Rhode Island) were the site of one of the first integrated multidisciplinary studies of a coastal marine ecosystem. It was an ambitious undertaking for a team of scientists that included plankton biologists, benthic ecologists, botanists, a fisheries expert, chemists and geologists from the new Graduate School of Oceanography that had just evolved from the Narragansett Marine Laboratory at the University of Rhode Island. The study was supported by the US Public Health Service, and in one of their progress reports to the agency, H. P. Jeffries and colleagues (1964) began with a revealing comment – “The overall goal of this investigation was to identify and measure quantitatively the factors responsible for differences in biota and production rates in *areas as yet unaffected by industrial or domestic pollution.*” We have emphasized the final words to make the point that the last 45 years have changed our characterization of the salt pond region considerably. The recent Special Area Management Plan for the Salt Pond Region (CRMC 1999) identified a variety of pollution concerns in the ponds, particularly their growing enrichment with nitrogen from human activities. Similar concerns were expressed by the RI Department of Environmental Management (RIDEM 2006). Our purpose in this report is to review briefly some of the reasons for concerns about nitrogen in the salt ponds and to urge that the Rhode Island Coastal Resources Management Council and the Rhode Island Department of Environmental Management continue to pursue aggressive strategies to reduce the amount of nitrogen entering these systems. More detailed discussion of this issue is provided in Lee and Olsen (1985), Lee (1988), the Salt Pond Region Special Area Management Plan (CRMC 1999), Nixon (1993 and 1995), Nixon et al. (2001), and many others.

Why Worry?

Coastal ecologists and managers worry about increasing the amount of nitrogen entering marine waters because numerous studies have documented that it is the supply of this critical element that usually limits the growth of plants in temperate coastal marine environments. Local experiments in the salt ponds and in large mesocosms or “living models” of the salt ponds have confirmed this for Rhode Island (Harlin and Thorne-Miller 1981, Taylor et al. 1995). On first thought, growing more plants faster might seem like a good thing – after all, we fertilize lawns and gardens for this purpose all the time. But large amounts of plant material consume a lot of oxygen during respiration at night and a lot of oxygen is consumed when the plants die and decompose. On land, this is not a problem because the air is very well mixed and oxygen is never depleted. Water, however, is often not very well mixed, and the respiration and decomposition can lead to local oxygen depletion (hypoxia) or complete removal (anoxia) (Nixon 1993). Low oxygen conditions can stress many animals, reducing growth and reproduction, and anoxia may kill those that can not leave the area.

And it is not just too much plant matter that can cause problems. While the addition of nitrogen to deep water where single celled phytoplankton are the only plants of importance can cause shifts in the relative abundance of the different species of phytoplankton, nitrogen addition to shallow systems can change the kinds of plants

that flourish. Shallow systems have a much more complex base of primary producers. In the shallow salt ponds light reaches to the bottom and single celled plants that grow on the sediment can be important as can larger macroalgae or seaweeds and rooted flowering plants like eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). Smaller algae also grow as epiphytes on the seaweeds and on the seagrass leaves.

It is becoming increasingly evident that eelgrass, an important part of the ecosystem in most of the salt ponds, is very sensitive to the input of nitrogen (Nixon et al. 2001, Hauxwell et al. 2003, Latimer et al. 2007). Unlike many plants, it does not do well with the addition of more nitrogen. Local mesocosm experiments at URI Graduate School of Oceanography (GSO), as well as observations in salt ponds on Cape Cod, have shown that seagrass is replaced by fast growing blooms of green macroalgae even at very low rates of nitrogen input (Fig. 1) (Nixon et al. 2001, Bowen

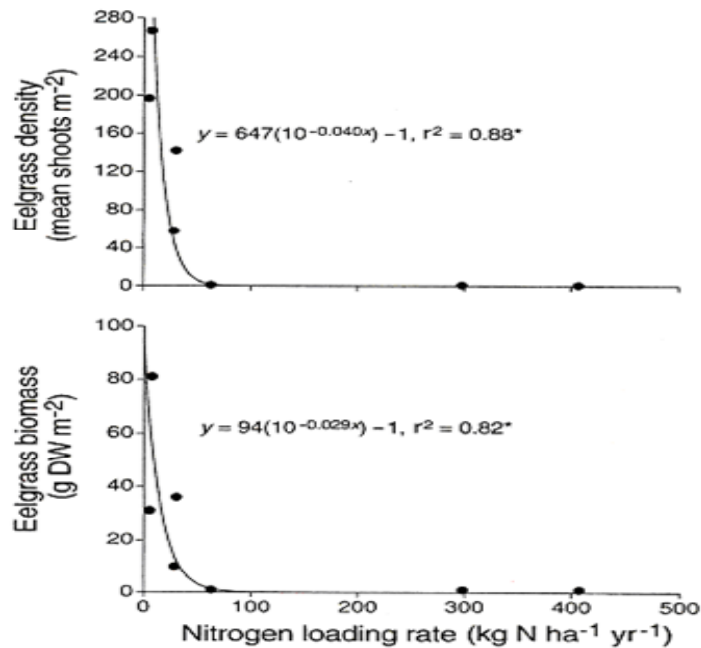


Figure 1. Mean annual shoot density (top) and areal biomass (bottom) of eelgrass in estuaries of the Waquiot Bay system, Cape Cod, subject to different rates of nitrogen loading. From Hauxwell et al. (2003).

and Valiela 2001, Bintz et al. 2003). The replacement of seagrass by dense blooms of macroalgae results in negative impacts on benthic or bottom dwelling animals, including shellfish and fin fish, in the lagoons (Fig.2) (Valiela et al. 1992, Bowen and Valiela 2001, Deegan et al. 2002, Huxwell et al. 2003).

A recent experiment in the RI salt pond mesocosms also showed that there is a strong interaction between warmer summer water temperature and the harmful impact

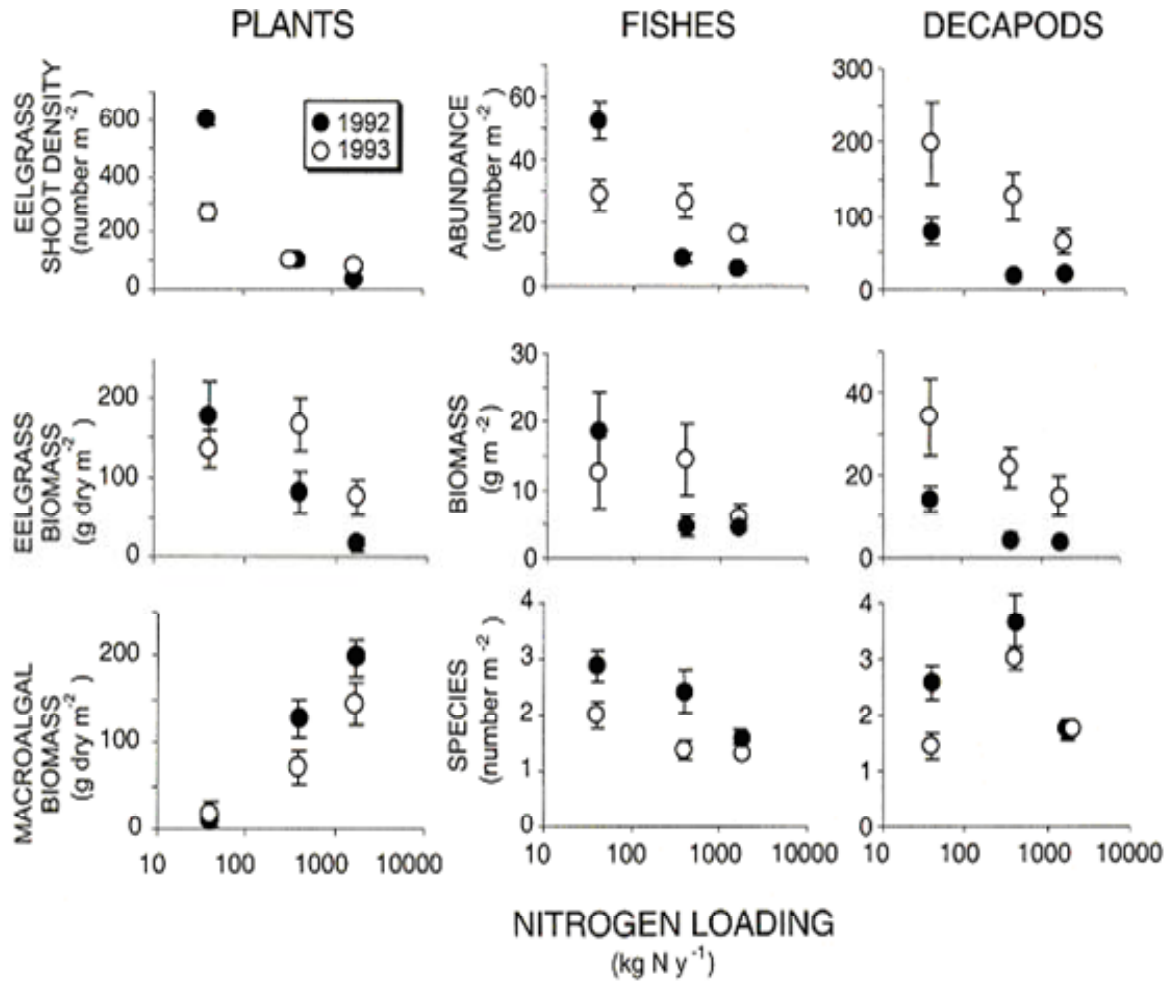


Figure 2. Mean biomass of eelgrass and macroalgae, eelgrass shoot density, and biomass and abundance of fishes and decapods in estuaries of Waquoit Bay, Cape Cod. From Deegan et al. (2002).

of nitrogen on eelgrass and the stimulation by nitrogen of nuisance macro algal blooms (Figs. 3a & b)(Bintz et al. 2003). Recent warming trends have made eelgrass more sensitive to nitrogen inputs and increased the likelihood of nuisance macroalgal blooms.

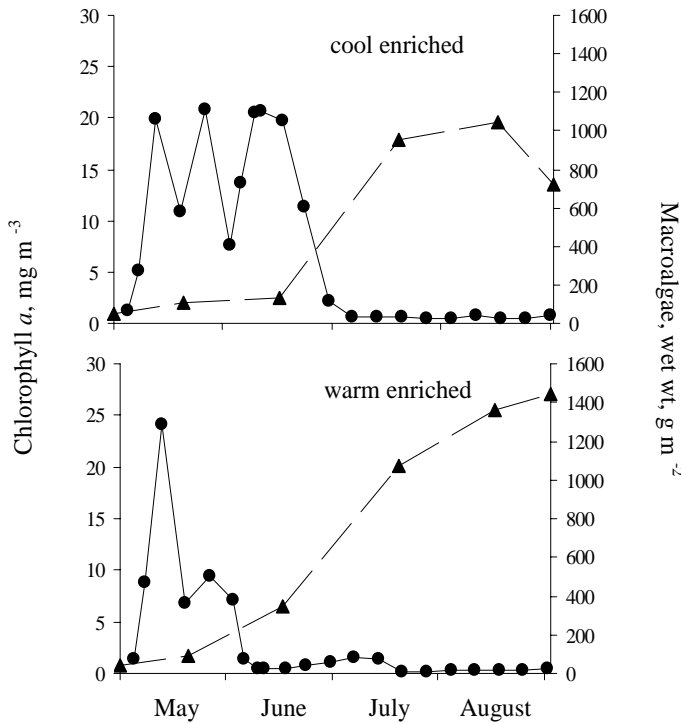


Figure 3a. Alternating abundance of phytoplankton (measured as chlorophyll *a* (circles)) and macroalgae (triangles)(almost exclusively the opportunistic species *Enteromorpha intestinalis* and *Cladophora sericea*) in cool and warm mesocosms enriched with nutrients. From Bintz et al. (2003).

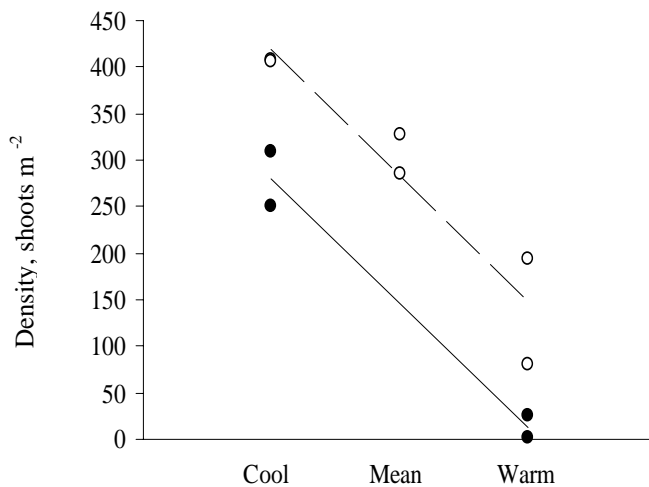


Figure 3b. The density of eelgrass, *Zostera marina* shoots at the end of the mesocosm experiment in September 1999. Solid symbols represent nutrient enriched systems and open symbols represent systems with no added nutrients. The effect of both temperature ($p < 0.001$), and enrichment ($p = 0.009$), on the density of eelgrass were statistically significant and additive. From Bintz et al. (2003).

Where Does The Nitrogen Come From?

Even in the early 1960's there must have been some pollution of the salt ponds with anthropogenic nitrogen. As Virginia Lee (1980) pointed out in *An Elusive Compromise*, her brief but beautiful ecological history of the salt ponds, there had

been farming around the ponds for 200 years, and summer recreational housing began growing rapidly in the late 1940's. The farms may have contributed some nitrogen because of the runoff of animal waste and synthetic fertilizer, though the latter only began to be used intensively after World War II, when agriculture was becoming less important in this area. And the summer houses, though modest in number, were connected to cesspools and septic systems that added nitrogen from human waste to the groundwater flowing toward the ponds.

Deposition of nitrogen from the atmosphere also increased markedly after the war as a result of increasing fossil fuel combustion in automobiles and electric power generating plants. High temperature combustion oxidizes the otherwise unreactive nitrogen gas in the air and converts it into a form available to plants. The burning of coal also releases fossil nitrogen into the atmosphere as nitrogen oxides that are biologically available. The nitrogen from the atmosphere is deposited directly on the surface of the ponds and on their watersheds. While much of the latter may be taken up by the woods and pastures, some may enter the salt ponds in surface streams or groundwater.

But at the time of that first URI study, the impacts of anthropogenic nitrogen must not have been apparent to the scientists studying the Ninigret and Green Hill salt ponds. And they would have been aware of the potential negative impact of nitrogen enrichment in coastal lagoons such as these. John Ryther had published his influential work on the impact of nitrogen from duck waste on the ecology of Moriches Bay and Great South Bay (coastal lagoons on Long Island similar to the Rhode Island salt ponds) in 1954.

Within about 15 years of the first URI salt pond study, concerns of deteriorating conditions in the lagoons caused the RI CRMC, RI Sea Grant, RI Statewide Planning, US EPA, and the towns of South Kingstown and Narragansett to fund a second multidisciplinary ecosystem study by scientists at URI. This work documented symptoms of eutrophication (an increase in the supply of organic matter to an ecosystem; Nixon 1995), especially large quantities of macroalgae (Thorn-Miller et al. 1983). It also identified septic systems as the major source of nitrogen entering most of the salt ponds (Nixon et al. 1982, Lee and Olsen 1985). To be sure, lawn and garden fertilizer, pet waste, and atmospheric deposition also contribute nitrogen to the salt ponds, but human waste is by far the dominant source for the larger ponds. In their study of nitrogen inputs to Pt. Judith, Potter, Cards, Trustom, Green Hill, and Ninigret Ponds, Nixon et al. (1982) estimated that 70 to 95% of the nitrogen entering from land and atmosphere came from ground water. A more recent assessment by Ernst (1996) found that residential septic systems provided the following fractions of the nitrogen input to the groundwater:

Pt. Judith	85%	Potter	80%
Cards	45%	Trustom	35%
Green Hill	90%	Ninigret	60%

This work underestimates the total contribution of septic nitrogen because some of the nitrogen carried into the ponds in surface streams may actually come from septic enriched ground water. An analysis for Green Hill and Ninigret ponds using the URI MANAGE model suggested that under current conditions almost 75% of the total N input to Green Hill and 60% of the input to Ninigret was due to septic systems (Horsley Witten 2007).

While there are no long time series records of nitrogen in the ground water or surface water entering the salt ponds, there is some information available on the relative magnitude of the major source of nitrogen to the groundwater, human waste, as indicated by the numbers of houses in the different watersheds (Lee 1988, Ernst 1996, CRMC 1999) (Fig. 4). With the exception of some areas around Pt. Judith Pond, all of the houses are on septic systems. In the area where the most detailed counts have been compiled, the Ninigret-Green Hill watershed, the number of houses grew exponentially between 1940 and 1990 at 4.6% per year. In other words, the number of houses doubled every 15 years over that 50 year period. Interpreting the various sets of house count data is not necessarily straightforward, however, because some earlier counts were restricted to the area south of Rt. 1, while more recent counts included the entire watershed. This may not be as much of a problem as it first sounds because the differences in area are usually in the Charlestown moraine and development on the moraine was relatively slow until the past decade or so. Also, some counts include commercial as well as residential structures. And all the counts need to be brought up to date using a uniform method. It is also a bit challenging in these watersheds to translate house numbers into estimates of nitrogen loading to the groundwater (see

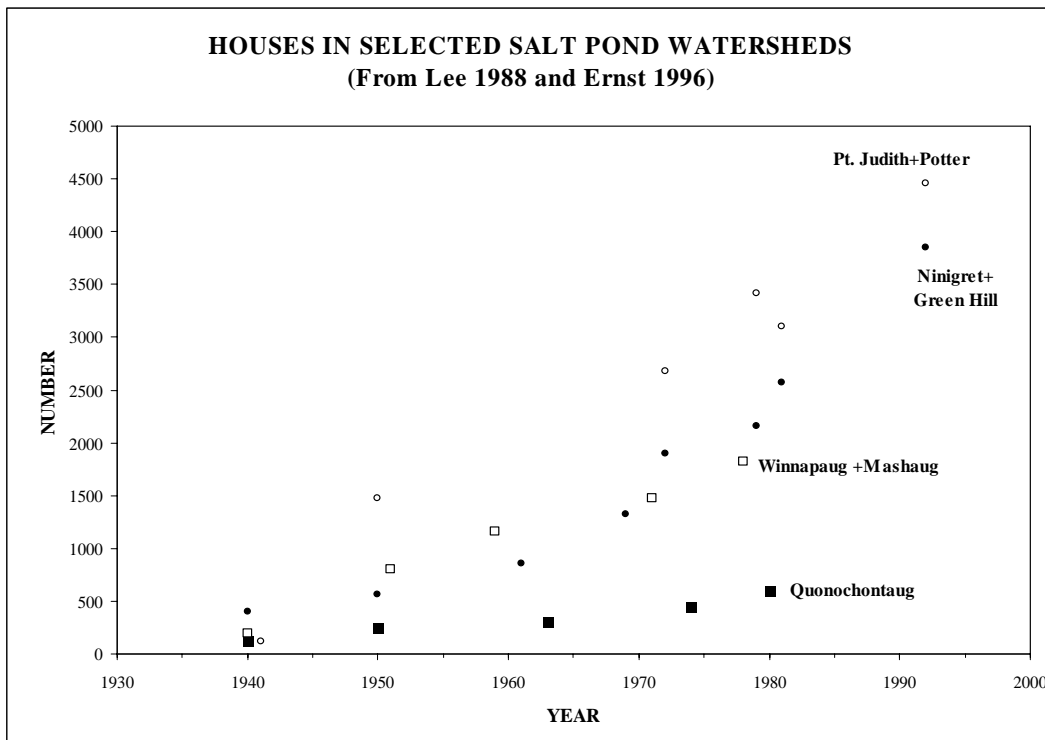


Figure 4.

Ernst 1996) because of seasonal occupation. Summer visitors may also have more people per house than year round residents and an unknown number of houses have been converted from seasonal to year round occupancy. It seems clear, however, that the input of nitrogen from human waste has been increasing, in some cases dramatically, over recent decades.

How Much Nitrogen is Too Much?

Recent studies in salt ponds on Cape Cod (Hauxwell et al. 2003) suggest that 80 to 90% of eelgrass bed area is lost when nitrogen inputs to the ponds reach about 30 kg N/ha/y (about 27 lbs/acre/y) and that eelgrass is completely eliminated by inputs twice this amount (see Fig. 1). It is not easy to know precisely how much nitrogen is currently entering the Rhode Island salt ponds, and the amount must vary somewhat from year to year with rainfall and other factors. We are now in a better position to make some rough estimates because of a report just released by the USGS (supported by CRMC) on surface and ground water flows to each of the South Shore salt ponds (Masterson et al. 2007). We have multiplied their calibrated groundwater flow into each pond by the range of dissolved inorganic nitrogen concentrations that have been found in samples of over 150 wells in the salt pond watershed in the mid 1990's (Ernst 1996). Since the means for each pond watershed from Point Judith to Ninigret ranged from 103 to 265 μM , we used a range of 100 to 200 μM (1.4 to 2.8 ppm or mg/liter).

The USGS report also provides estimates of surface water flow into each of the ponds and we have multiplied these by the average dissolved inorganic nitrogen concentrations in the streams during the same time period (Ernst 1996). We have also included direct atmospheric deposition of nitrogen on the pond surface using measurements of wet and dry deposition made on Prudence Island in Narragansett Bay by Fraher (1991) with an addition of dissolved organic nitrogen (Nixon et al. 1995). The results (Table 1) suggest that nitrogen loadings to all of the mainland salt ponds are already at or beyond 30 kg N/ha/y (27 lbs/acre/year), consistent with our observations that eelgrass has been declining in Ninigret Pond (Short et al. 1996) and Pt. Judith Pond, and that there is virtually none in Winnapaug Pond. Recent surveys in Quonochontaug Pond, perhaps the least nitrogen enriched, found some 80 acres of eelgrass (Ford 2003). Surprisingly, Potter and Green Hill Ponds apparently still have considerable areas with eelgrass in spite of nitrogen loads that the Cape Cod results suggest would be too high. It must be remembered, of course, that the estimates we have made are very rough and do not account for the notoriously patchy distribution of ground water flows and nitrogen concentrations. For example, while the ground water nitrogen concentrations around Potter Pond varied widely, the lowest concentrations (below 50 μM , Ernst 1996) may have been associated with the areas of greatest water flow. If so, the procedure we have used would grossly overestimate the actual flux of nitrogen into the pond by this route. The salinity is too low to sustain eelgrass in Cards, Trustom, and Maschaug Ponds.

Table 1

Estimated input of dissolved inorganic nitrogen to the Rhode Island salt ponds from land plus total nitrogen deposited directly on the ponds from the atmosphere. Groundwater and stream input calculated using calibrated water flows from the USGS model study (Masterson et al. 2007), a concentration of 100 to 200 μM (1.4 to 2.8 mg/liter) nitrogen in ground water (see text), and stream concentrations measured by Ernst (1996). Atmospheric deposition from Nixon et al. (1995).

	kg/ha/y	lbs/acre/y	% from ground water
Pt. Judith	66 – 85	59 – 76	28 – 44
Potter	88 – 163	78 – 145	85 – 92
Cards	132 – 245	117 – 218	86 – 92
Trustom	76 – 138	67 – 123	83 – 91
Green Hill	60 – 87	53 – 78	46 – 63
Ninigret	39 – 63	34 – 56	64 – 78
Quonochontaug	29 – 44	26 – 40	53 – 70
Winnapaug	69 – 125	61 – 111	82 – 90
Maschaug	40 – 66	35 – 59	68 – 81

Our rough estimates of nitrogen loading for Green Hill and Ninigret Ponds are in good agreement with estimates by RIDEM (2006) and Horsley Witten (2007) of 81 kg/ha/y and 52 kg/ha/y, respectively. We should emphasize, however, that they estimated nitrogen input in a very different way. In short, they back calculated the input using the Buzzards Bay Project “eutrophication score” formula and observations of dissolved oxygen, chlorophyll, water clarity, and nitrate concentrations in the ponds. They also evaluated the impact of nitrogen loading in a very different way than we have, though we have both used the responses of Cape Cod estuaries as a frame of reference. A discussion of the merits and limitations of the “Buzzards Bay Project Approach” (BBA) that RIDEM (2006) used is far beyond the scope of this brief paper. In its favor, the BBA includes dissolved oxygen, dissolved nitrogen concentrations,

water clarity, and water column chlorophyll as response metrics while we have focused on eelgrass habitat. The down side of the BBA is that more data and assumptions are required, including estimates of the water residence time of the pond and decisions about how to weight the different metrics (equal weighting was used by DEM). As noted in the appendix to this paper, we also believe that the nitrate concentrations used in the DEM calculations may be too high. Based on their assessment, RIDEM (2006) concluded that nitrogen loading to Green Hill should be reduced by 80% and that no reduction was needed to produce acceptable water quality in Ninigret Pond. Using their “allowable load” and our estimates of loading, Green Hill would require a nitrogen reduction of 73 to 81% and Ninigret a reduction of 0 to 12%. Using an eelgrass criterion of achieving a loading of less than 30 kg/ha/year (27 lbs/acre/year) would require a nitrogen reduction of at least 50 to 65 % for Green Hill and at least 25 to 50% for Ninigret Pond. But recall that the studies on Cape Cod suggest that 80 to 90% of eelgrass bed area would be lost with a loading of 30 kg/ha/y (Hauxwell et al. 2003). Reducing nitrogen loading to half this amount (15 kg/ha/y) would require reducing loads to Green Hill Pond by 75 to 83% and loads to Ninigret Pond by 60 to 75%. While both of these systems still contain some eelgrass, its future under current or increasing nitrogen input is very doubtful.

Recommendations

We strongly urge that the Rhode Island Coastal Resources Management Council and the Rhode Island Department of Environmental Management continue to pursue aggressive strategies to reduce the amount of nitrogen entering these coastal pond systems. As part of this mix, we believe that additional applications of innovative technology solutions for N removal should be considered. With support from CRMC and DEM, our on going monitoring of the performance of wood chip “barriers” is very encouraging in this regard. These systems may be helpful in reducing non-point nitrogen in ground water in combination with improved nitrogen removal performance as part of advanced onsite wastewater treatment systems and better fertilizer management (especially residential applications). Because of the importance of monitoring ecological conditions in the salt ponds, we also recommend that support and training should be provided to facilitate the work of the Salt Pond Watchers.

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APPENDIX

The RIDEM (2006, Appendix A, p.3) report noted that, “Examination of available in-pond water quality data shows significant increases in nitrate-N concentrations with less notable increases in Chlorophyll-a concentrations.” These concentrations entered into their assessment of load reductions required to achieve acceptable water quality. While we agree with the DEM assessment of the chlorophyll data they considered, we believe that the situation with regard to nitrate (and ammonia) concentrations in Ninigret and Green Hill Ponds may be quite different. Their analysis only included the results of volunteer monitoring carried out between 1985-1993 and between 2000-2005. There are a number of other data sets that have been collected at the same or nearby stations by different groups of scientists from the Graduate School of Oceanography at URI, the Avery Point Laboratory of the University of Connecticut, and the Marine Research Corporation. The results of these studies show concentrations that are generally lower and much less variable than the volunteer monitoring (Figs A-1-A-4). They also do not show any dramatic recent increase in concentrations. The reasons for these discrepancies remain unknown but deserve resolution as quickly as possible.

It would be very surprising to see dissolved inorganic nitrogen concentrations rising markedly during summer monitoring without some response in water column chlorophyll. What others may find even more surprising, however, is that there does not appear to have been a dramatic increase in nitrate or ammonia concentrations with the increasing numbers of houses in the watershed. This is less remarkable than it may seem, however, because the plants within these shallow systems can take up large amounts of nitrogen very quickly during summer. In summer studies with lagoon mesocosms we have seen nitrate concentrations from experimental additions be reduced by over 50% /hour (Nixon et al. 2001). The best time, however, to measure nitrogen concentrations as a response to nitrogen loading is during the winter, as done by Lee et al. (1997) who found a positive correlation between housing density and winter nitrate concentrations in the RI salt ponds (Fig A-5).

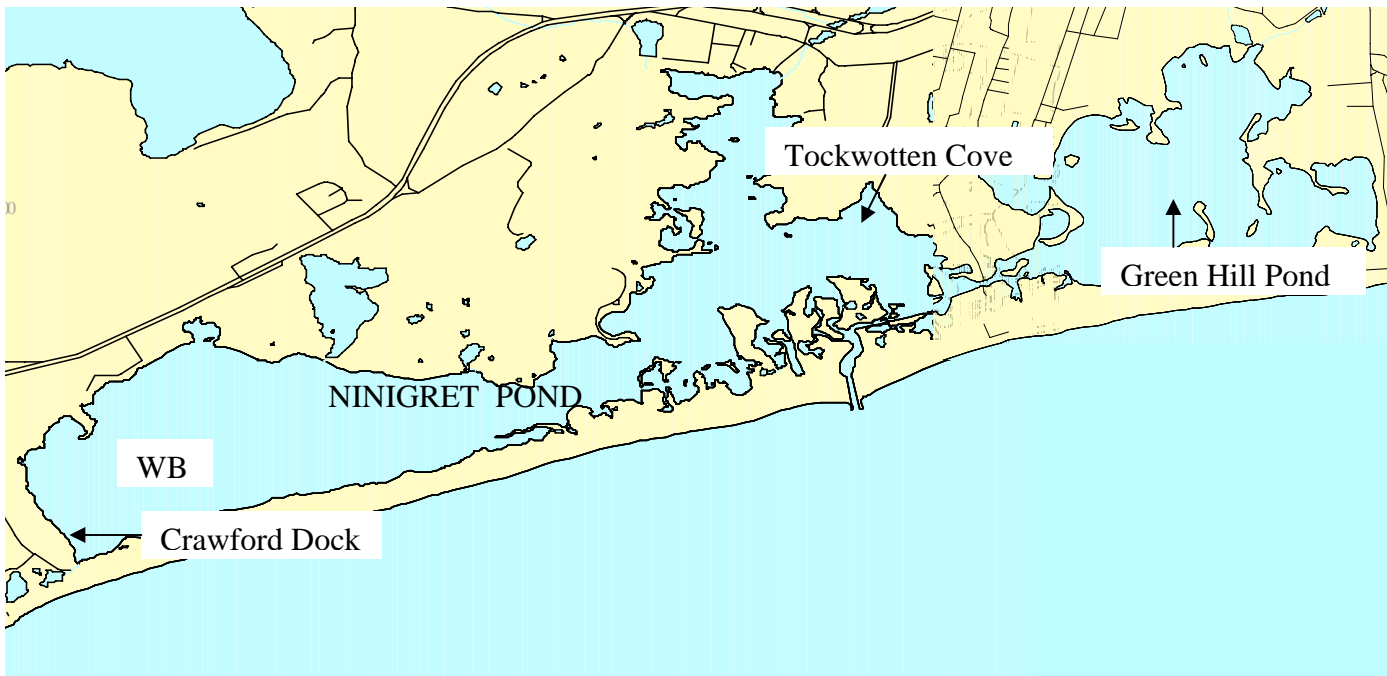


Figure A-1 Ninigret and Green Hill Ponds, Rhode Island. Showing location of the various sampling locations plotted in figures A2-A4.

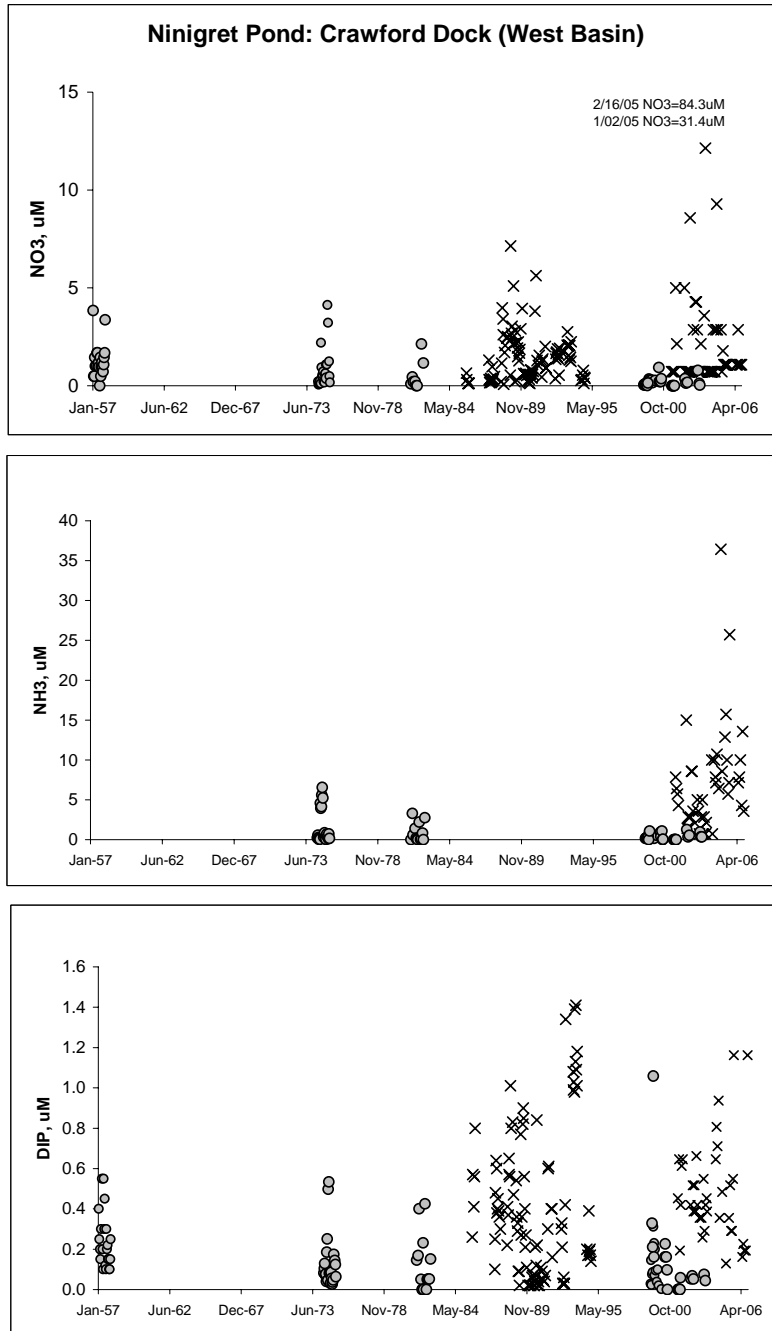


Figure A-2. Surface water nutrient concentrations (nitrate, NO₃, ammonium, NH₃, and phosphate, DIP, in Ninigret Pond. Sample locations are shown in Fig. A-1. All samples were taken at Crawford Dock except 1957, 1974-75 and 1999 samples were taken in the west basin (WB), and 1981-82 samples were taken in upper west basin. Samples shown with (X) were collected by volunteer Pond Watchers. Filled circles were collected by scientists from URI-GSO, Marine Research, and U. Conn. (see data sources).

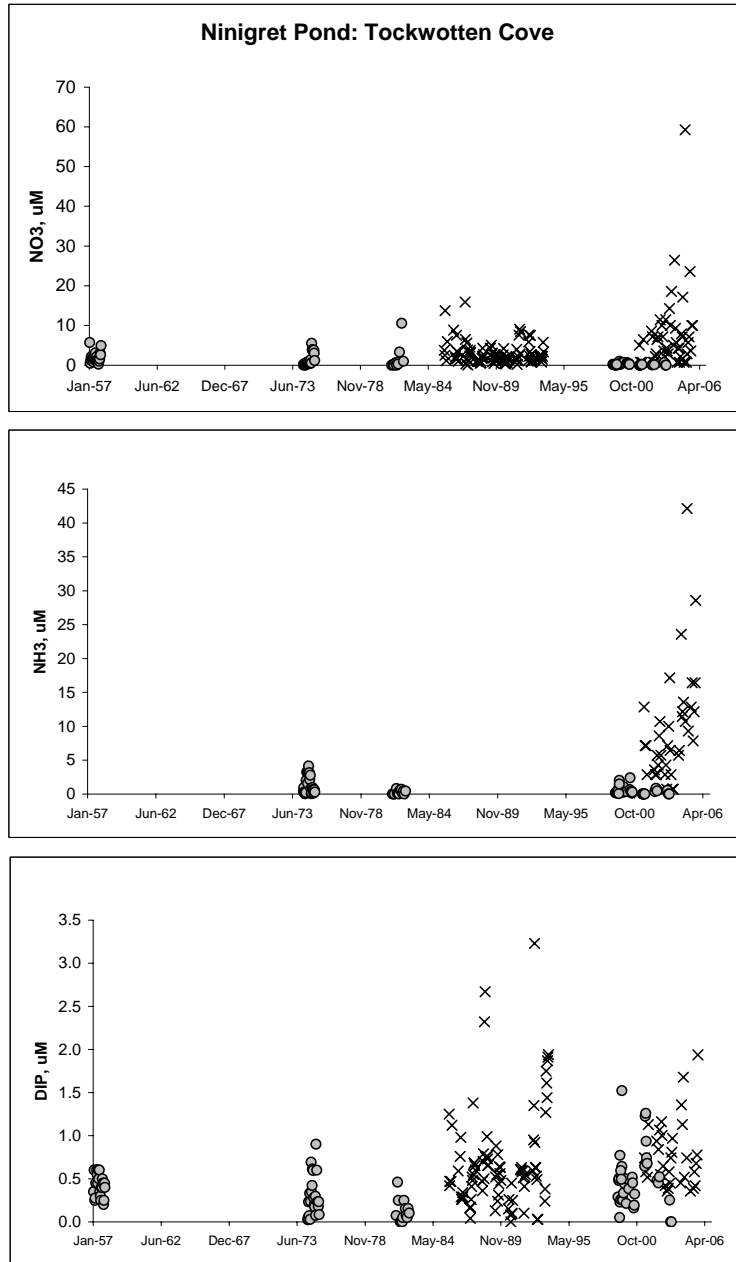


Figure A-3. Surface water nutrient concentrations (nitrate, NO_3 , ammonium, NH_3 , and phosphate, DIP, in Ninigret Pond. Sample locations are shown in Fig. A-1. All samples were taken in Tockwotten Cove except 1957 samples were taken in mid-central basin and in 1974-75 they were taken just outside Tockwotten Cove. Samples shown with (X) were collected by volunteer Pond Watchers. Filled circles were collected by scientists from URI-GSO, Marine Research, and U. Conn. (see data sources).

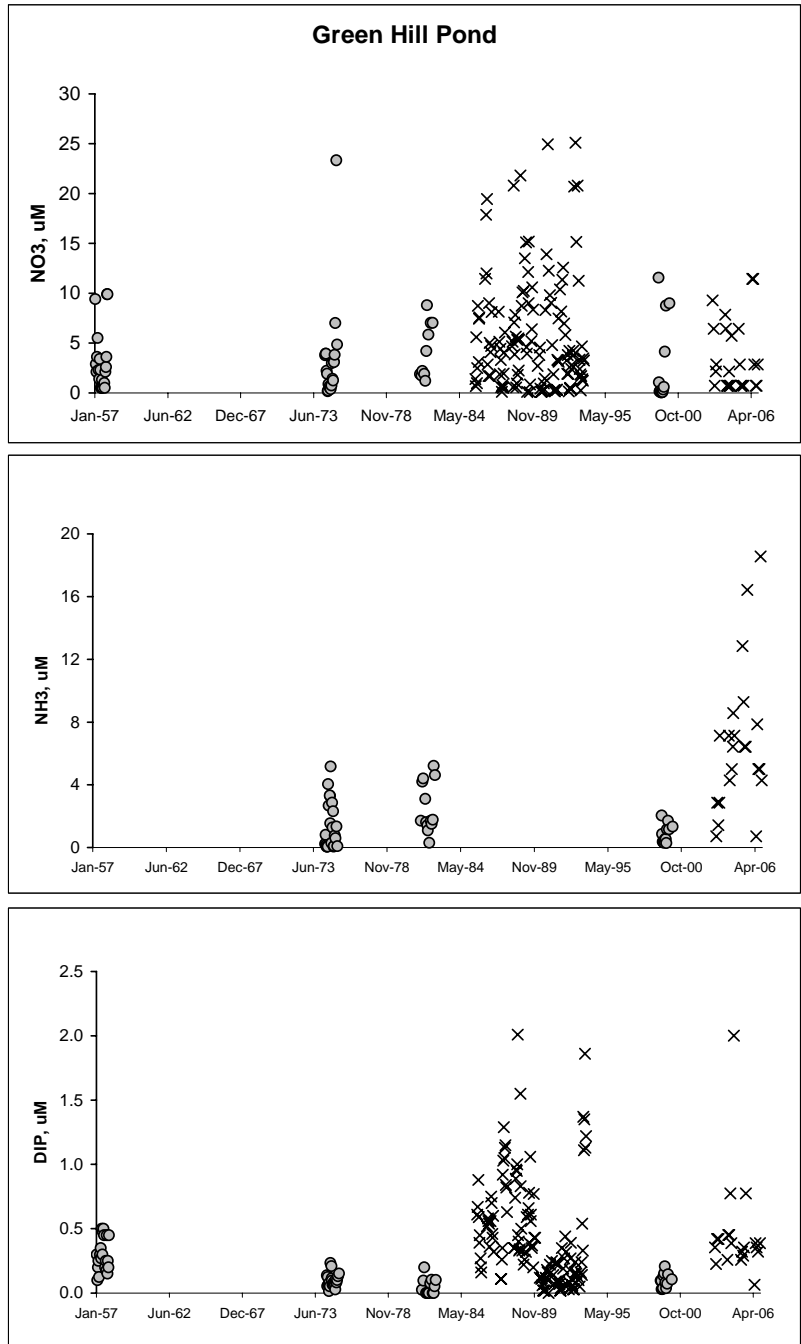


Figure A-4. Surface water nutrient concentrations (nitrate, NO₃, ammonium, NH₃, and phosphate, DIP). Sample locations are shown in Fig. A-1. All samples were taken in mid-Green Hill Pond except Pond watcher 1985-94 samples which were taken in upper green Hill Pond. Samples shown with (X) were collected by volunteer Pond Watchers. Filled circles were collected by scientists from URI-GSO, Marine Research, and U. Conn. (see data sources).

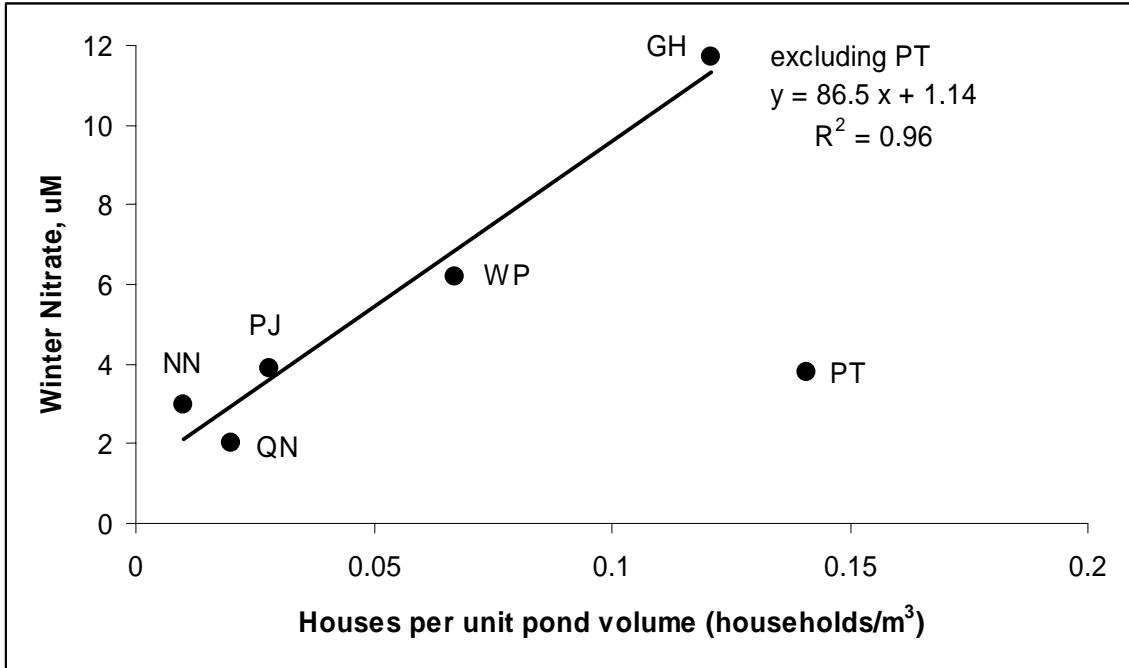


Figure A-5. Winter nitrate concentrations in the Rhode Island salt ponds during 1987 as a function of housing density normalized to pond volume. From Lee et al. (1997).

APPENDIX: DATA SOURCES

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