

Long-term Decline in Eelgrass, *Zostera marina* L., Linked to Increased Housing Development

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Abstract

A case study of Ninigret Pond, Rhode Island, USA, shows eelgrass decline in a coastal lagoon over a 32 year period. During that time, housing in the watershed quadrupled, while areal distribution of eelgrass beds declined 41%. Eelgrass is a valuable marine vascular flowering plant with numerous functions which support fisheries, stabilize sediments, and purify estuarine waters. We relate eelgrass loss to indicators of increased eutrophication, and identify the source of nutrient enrichment to be groundwater discharge. By identifying the link between nutrient flow from home septic systems and the decline of the lagoon's eelgrass, we provide supporting evidence for an inverse correlation between seagrass area and housing. Using computer image analysis of four eelgrass distribution data sets for the 1960s, '70s, '80s, and '90s, we show a significant linear decline in eelgrass area. Aerial thermal infrared photography was used to locate major groundwater inputs into the lagoon, which coincided with the major areas of eelgrass loss. Our identification of the sources of groundwater inflow, coupled with other studies on both nutrient concentrations in groundwater and processes of nutrient-induced eelgrass loss, supports the explanation of eutrophication as the cause of eelgrass decline in Ninigret Pond. This case study identifies and explains the significant relationship between increasing housing development within a lagoonal watershed and declining areal distribution of the valuable eelgrass resource in the lagoon.

INTRODUCTION

Around the world, there are increasing reports of seagrass decline and loss, losses associated with human population growth and the accompanying development activities that decrease water quality in the coastal oceans (Walker and McComb 1992; Short and Wyllie-Echeverria, in press). Seagrasses are submerged marine plants that play important roles in sediment stabilization, water filtration, and support for fisheries and waterfowl (Wright, Cheadle, and Palmatier, 1949; Zieman, 1982; Thayer, Kenworthy and Fonseca, 1984). Recent studies of the causal factors important to seagrass decline have demonstrated that increases in anthropogenic inputs to the coastal zone are often linked to seagrass loss (Walker and McComb, 1992; Dennison *et al.*, 1993; Short and Burdick, in press). These studies have focused on the effects of decreased

water quality (Dennison *et al.*, 1993) and stimulation of algal growth that can stress and eliminate seagrass (Short, Burdick, and Kaldy, 1995).

Nutrient loading is the primary factor responsible for both the reduction of water quality and the stimulation of algae (Kemp *et al.*, 1983; Nixon and Pilson, 1983; Kautsky, 1991). In fact, increasing field evidence suggests that many of the losses of seagrass in coastal areas of the world result from nutrient loading (Short and Wyllie-Echeverria, in press). Direct evidence of the effects of anthropogenic nutrient loading on seagrass elimination has been shown by the recovery of seagrasses in Hillsborough Bay, Florida, USA after dramatic reduction in domestic sewage and industrial fertilizer discharge into the Bay (Johansson and Lewis, 1992). The rapid reestablishment of seagrass beds in Hillsborough Bay illustrates the stress imposed on

seagrasses by nutrient loading conditions as well as the ability of seagrass to recover once anthropogenic stress is decreased (Johansson and Lewis, 1992).

Short and Burdick (in press), analyzing a 5-year data set from Waquoit Bay, Massachusetts, USA, have related the decline of seagrass distribution in different sub-basins of this estuary to the degree of nutrient loading associated with each sub-watershed. Through change analysis of eelgrass distribution over a relatively short period, the amount of seagrass loss in Waquoit Bay was related to both nutrient loading, estimated from land cover analysis, and the number of houses within the various sub-watersheds of the Bay.

In Rhode Island, located in the northeastern US on the Atlantic coast, increased housing development and associated stress on coastal pond ecosystems have been documented for the past 10 years (Lee and Olsen, 1985). As in Waquoit Bay, the apparent cause of coastal pond degradation was groundwater nutrient loading (Nixon *et al.*, 1982; Lee and Olsen 1985). Similar conditions of groundwater enrichment have been identified in other lagoon-type estuaries where tidal flushing is restricted and in shallow embayments behind barrier islands where fresh water inflow is minimal. Increased housing in these well-drained, coarse, sandy soils leads to increases in nitrogen input to the groundwater because even properly operating traditional septic systems do not function adequately in such soil conditions. The effect of housing development with septic systems, located on sandy glacial outwash plains, has been observed on Cape Cod, Massachusetts, on the southern shore of Long Island, New York, and along the southern Rhode Island coast.

Ninigret Pond, on the southern coast of Rhode Island, was selected for our assessment because of a long-term distribution record of eelgrass, *Zostera marina* L. Data from various sources, including the present study, extend over a 32 year period (1960-1992). The earliest work documenting eelgrass beds in Ninigret Pond was a 1949 survey of "duck food plants," including eelgrass, in Rhode Island salt ponds which discussed presence and abundance of eelgrass but did not map plant distribution (Wright *et al.*, 1949). The first map of eelgrass distribution in Ninigret Pond provided field-determined estimates of percent cover throughout the entire lagoon (Brown, 1962). Eelgrass distribution in conjunction with macroalgal abundance was surveyed and mapped in the pond in 1963 (Conover, 1964). However, it was not possible to distinguish actual eelgrass distribution from that of other

macrophytes in the Conover survey. Mapping of eelgrass from aerial photography was completed for much of Ninigret Pond in 1974 (Short, Nixon and Oviatt, 1974; Short, 1975). Eelgrass was ground truthed and mapped according to shoot density. Between June 1979 and June 1980, eelgrass distribution was again mapped with ground based surveys of eelgrass and macroalgal biomass (Thorne-Miller *et al.*, 1983; Thorne-Miller and Harlin, 1984).

Over the same time period that eelgrass abundance and distribution were monitored in Ninigret Pond, several studies examined changes in human activity and documented increases in housing development on the southern coast of Rhode Island (Lee, 1980; Lee and Olsen, 1985; Ely, 1990). Additionally, a potential source of nutrient pollution to the pond systems was identified to be nitrogen-enriched groundwater (Nixon *et al.*, 1982; Lee and Olsen, 1985). As seen in other barrier island lagoon systems, groundwater is enriched in nitrate by septic leachate. The leachate quickly enters the groundwater through the porous sand soils and moves with the groundwater into the coastal lagoons (Capone and Bautista, 1985; Valiela *et al.*, 1990). Our purpose in this study was to examine a long-term record of historical changes in eelgrass distribution in a coastal lagoon; we found a relationship between housing increase (Ely, 1990) and eelgrass loss spanning 32 years.

SITE DESCRIPTION AND METHODS

Ninigret Pond is a shallow coastal lagoon behind a barrier beach on the south coast of Rhode Island (41°22'N; 71°39'W). The pond, also known locally as Charlestown Pond, is a microtidal estuary with an average depth of one meter and restricted tidal flushing through a narrow man-made breachway. In the 1940s Ninigret Pond was described as having "its northern border ... made up of brush swamp and farmland (mostly hay), an airport, summer colony and some wasteland. Scattered summer cottages line the east and west shores..." (Wright *et al.*, 1949). Eelgrass is described by these same authors as occurring throughout the pond and "...recovering from an earlier decimation caused by disease." Wright *et al.* are referring to the wasting disease epidemic of the 1930s, as chronicled in Cotton (1933).

Historical records of eelgrass distribution in Ninigret Pond were compiled onto a common base map for comparative analysis. Eelgrass distribution maps from 1960 (Brown, 1962), 1974 (Short *et al.*, 1974), and 1979-80 (Thorne-Miller and Harlin, 1984), were digitized

Figure 1: Maps of eelgrass distribution from four surveys of Ninigret Pond, Rhode Island. Distributions redrawn on a common base map for 1960 (Brown, 1962), 1974 (Short *et al.*, 1974), 1979-80 (Thorne-Miller and Harlin, 1984), and 1992 (this study).

using a flat bed scanner onto a Macintosh IIfx computer. The images for each of the historical data sets were adjusted to a base map at the same scale. The eelgrass distributions were then digitally analyzed on an image analysis program (NIH, 1990) to determine the area of eelgrass distribution for each of the time periods. Although the historical eelgrass distributions present various metrics for reporting eelgrass abundance, here we considered only the presence or absence of eelgrass for comparative analysis.

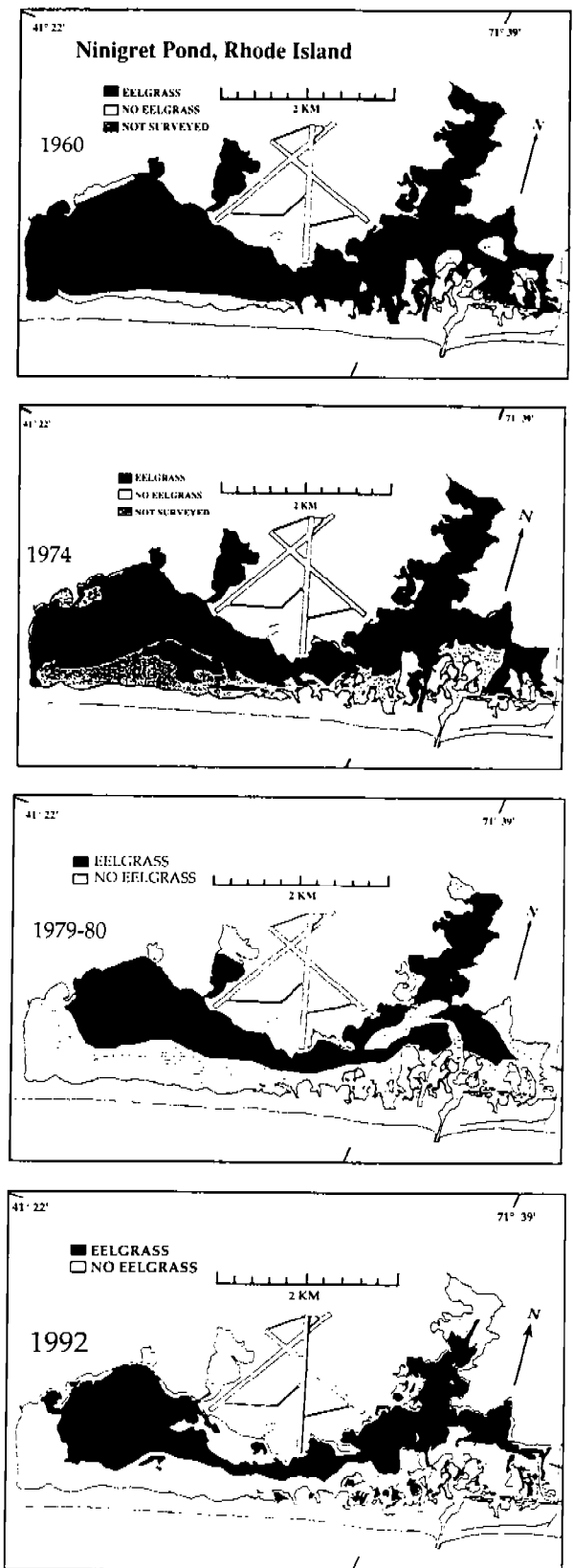
Eelgrass distribution for 1992 was determined by photo interpretation of aerial photography from July 1992. Following C-CAP protocol (Klemas *et al.*, 1993), photographs were taken at a scale of 1 to 12,000 and interpreted on 21 cm x 21 cm color transparencies; the distribution was mapped directly from the color imagery and ground truth assessment was done within one month. Eelgrass was digitized in the image analysis program as above. The area of eelgrass in Ninigret Pond for each of the sampling years was digitally calculated in an image analysis program at a sensitivity of 300 dpi, resulting in a pixel size of 1.25 m. Ground truth assessment was conducted by surveying the pond from a small boat within a month of the 1992 aerial photography. The presence and absence of eelgrass and the occurrence of various algal competitors within the eelgrass meadows were noted.

Changes in eelgrass distribution and housing density over time were modelled with least squares linear regression analysis using one-tailed tests and alpha set at 0.05 (Abacus 1992). Linear regression analysis was also used to develop a relationship between declines in eelgrass distribution and increases in housing density.

Identification of groundwater sources to Ninigret Pond was made using interpretation of aerial thermal-infrared photography from August 1978 (Nixon, unpublished). These oblique black and white photographs provide an image of the relative temperatures of objects on the ground, clearly showing cooler ground waters entering the warmer surface waters of the pond.

RESULTS

The progressive loss of eelgrass area in Ninigret Pond was clearly documented by the maps of eelgrass distribution over time (Fig. 1). These data on the



spatial distribution of eelgrass habitat in Ninigret Pond showed a progressive decline in the area of bottom

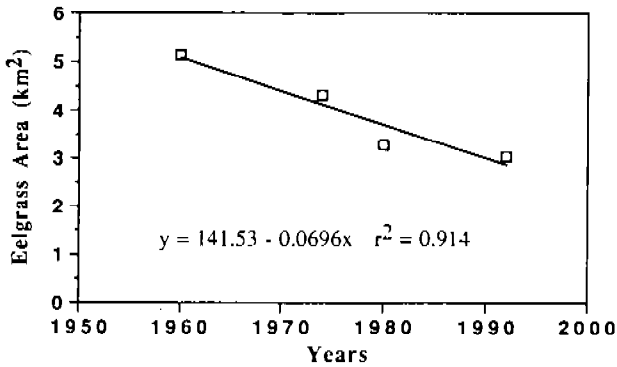


Figure 2: Area of eelgrass beds in Ninigret Pond for the years 1960-1992. Eelgrass area is derived from image analysis of eelgrass distribution maps (Fig. 1). Linear regression shows the rate of habitat loss based on the change in eelgrass area over the four mapping dates.

covered by eelgrass, with losses of 2.1 km², representing 30.4% of the pond area, between 1960 and 1992. Digital analysis of these distributions showed a significant linear trend of decreased eelgrass area over time, with $R^2 = 0.914$ (Fig. 2). Results of the analysis of eelgrass area for the four dates show 77% of the pond covered by eelgrass in 1960, 72% in 1974, 48% in 1979-80, and 44% in 1992, after correcting for the unsurveyed areas in 1960 and 1974.

Groundwater is a major source of freshwater input to Ninigret Pond, seeping into the surface water at the northern pond shoreline as shown in the 1978 aerial thermal infrared photography (Fig. 3). The warm water emanating from the pond at the breachway (light gray) is distinct from the cooler ocean water of Long Island Sound (dark gray). Similarly, the warm pond water is distinct from numerous intrusions of cooler groundwater (dark gray) entering the pond along the northern shoreline (Fig. 3). From these photographic images, a map showing major sites of groundwater



Figure 3: Three aerial thermal infrared photographs of Ninigret Pond showing the West Basin, the breachway area, and the Fort Neck/Central Basin area. White or light color in the pond indicates warm water; darker plumes indicate cold water. A white plume of warm pond water can be seen leaving the breachway on an ebb tide, and the dark plumes of groundwater can be seen entering from the shoreline in Fort Neck, the Central Basin, Foster Cove, and the West Basin.

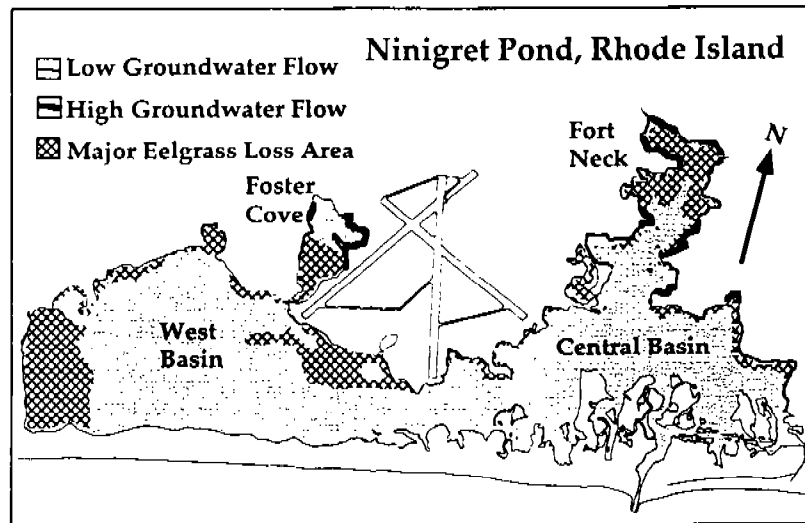


Figure 4: Map of groundwater inflow to Ninigret Pond. The distinction between high and low flow was determined from the relative intensity of the thermal signal and the expanse of the plume, as seen in Figure 3. Areas of eelgrass loss are taken from the 1992 distribution map.

flow was constructed on the digital base map (Fig. 4). Groundwater sources were verified in a ground truth survey by identifying near shore sediments stained with iron oxide, a sign of fresh water intrusion, and by identifying stands of *Phragmites australis*, a species known to invade the marine environment if adequate fresh water is available.

We compared the observed loss in eelgrass distribution in Ninigret Pond (Fig. 2) with previous measurements of housing development (Fig. 5). Housing numbers for the years eelgrass distribution data are available were interpolated from Ely (1990). Regressing eelgrass area for those 4 distribution data sets versus housing density for the same years (Fig. 6) showed a significant linear decrease in eelgrass distribution with an increase in housing around the pond.

DISCUSSION

The area of eelgrass distribution in Ninigret Pond decreased 41% between 1960 and 1992. Over this 32-year time period for which eelgrass distribution information was available, the rate of eelgrass loss in the pond was relatively constant (Fig. 4). In 1949, eelgrass was found throughout Ninigret Pond but was still in the process of recovering from the wasting disease of the 1930s (Wright *et al.*, 1949). By 1960, when the first distribution map of eelgrass in Ninigret Pond was produced (Brown, 1962) eelgrass was found to cover 77% of the pond area, nearly all of the area suitable

for supporting eelgrass habitat. The 23% of the pond without eelgrass included the sandy barrier beach side of the pond's West Basin and areas around the breachway to the ocean, all locations where eelgrass was rarely found during any of the years surveyed. No information on eelgrass in Foster Cove was available for 1960.

By 1974, eelgrass cover of Ninigret Pond was down to 72% (Short *et al.*, 1974), with the barrier beach side showing much less eelgrass, new pockets of unvegetated bottom along the shoreline of the Central Basin, and with an enlarged unvegetated area near the breachway.

The survey and mapping of eelgrass in Ninigret Pond in 1979 and 1980 was motivated by the observation of eutrophic conditions throughout many of the coastal ponds by scientists at the University of Rhode Island (Harlin and Thorne-Miller, 1981; Lee and Olsen, 1985). The 1979-80 survey showed eelgrass covered 48% of Ninigret Pond, with reductions in the West Basin, the Central Basin and the very northern end of Fort Neck. Additionally, the first available distribution map for Foster Cove showed eelgrass only in the southern half of the cove.

Our recent survey in 1992 showed eelgrass covering 44% of the pond, with loss of eelgrass in many areas of the pond, and with major losses occurring adjacent to the abandoned airport in the West Basin, along the shoreline of the Central Basin, and further loss in northern Fort Neck. In Foster Cove, eelgrass

had nearly completely disappeared by 1992, with only a small bed left at the mouth of the cove. Although some areas of the pond showed expansion of eelgrass into unvegetated areas, the predominant tendency was for beds throughout Ninigret Pond to be reduced in size compared to what they were just 12 years earlier in 1980.

We found areas of eelgrass loss in many cases were associated with sites of groundwater input. Comparing the sources of groundwater input (Fig. 4) with the areas of eelgrass mapped in 1992 (Fig. 1), eelgrass loss and groundwater sources were both evident along the north and west sides of the West Basin, the northern part of Foster Cove, and the shoreline areas nearest the abandoned airport. In the well flushed Central Basin, there was substantial groundwater input and loss of the nearshore beds. In the north half of Fort Neck Cove, where the largest observed sources of groundwater were present, eelgrass decline was dramatic. Overall, there was definite co-occurrence of sites of groundwater input and areas where eelgrass was lost.

Significant inputs of fresh water enter Ninigret Pond along the inland shoreline and represent a potential pathway of nitrogen flux into the pond. Previous studies have examined nitrogen loading into Ninigret Pond through stream input, storm runoff, precipitation, groundwater sources and tidal exchange (Nixon *et al.*, 1982; Lee and Olsen, 1985). Monitoring groundwater wells and measuring nutrient input via stream flow and precipitation have confirmed the dominance of groundwater nitrate as the primary source of nitrogen to Ninigret Pond (Lee and Olsen, 1985).

Groundwater transport into shallow sandy lagoons has been characterized as a constant slow moving mass of subsurface water from upland sources impelled by gravitational forces toward the ocean (Bokuniewicz, 1980). This mechanism provides a significant source of fresh water transport in many of the coastal areas of the northeastern U.S. (Capone and Bautista, 1985; Lee and Olsen, 1985; Valiela *et al.*, 1990). In all the coastal salt ponds of Rhode Island, groundwater is the primary transport mechanism of fresh water (Lee and Olsen, 1985). The groundwater flow rate is controlled by the height of the groundwater table, which varies seasonally and between years, the permeability of the soil, and tidal fluctuation in the pond which alters the groundwater elevation differential.

In Ninigret Pond, the discharge of groundwater is localized in specific areas along the northern shore, demonstrating a nonhomogeneous pattern of freshwater input. Our thermal infrared photography illustrates

localized points of groundwater discharge as evidenced by the cooler temperature of groundwater entering some areas of the pond (Fig. 3). The size of the cool water plume is indicative of the magnitude of groundwater input since water depths throughout most of the pond are relatively uniform at 1 meter (Short *et al.*, 1974). The greatest volume of groundwater discharge into the pond occurs along the shorelines of Fort Neck and Foster Cove (Fig. 4). To a lesser extent, groundwater flow enters the northern shore of the Central and West Basins.

Additional evidence for shoreline input of groundwater exists in the distribution of an invasive wetland species, *Phragmites australis*, along the shoreline. *Phragmites* can thrive in areas of moderate salinity conditions if sufficient fresh water is available (Hellings and Gallagher, 1992). We suggest the use of this species as an indicator of groundwater intrusion

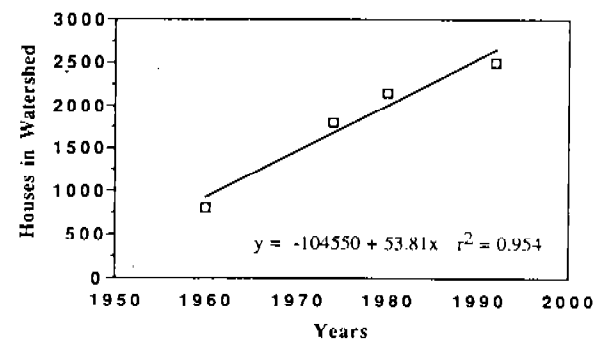


Figure 5: Housing numbers in the Ninigret Pond watershed over the years 1960-1992. Data was interpolated from data presented in Ely 1990.

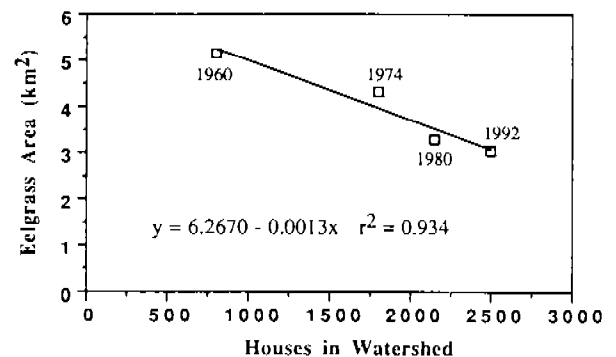


Figure 6: Linear regression analysis of eelgrass area in Ninigret Pond (from Fig. 2) and housing numbers in the Ninigret Pond watershed (from Fig. 5).

into saline lagoons in southern New England where this reed is widely distributed. Through the identification of *Phragmites* stands, we verified the position of consistent groundwater sources into Ninigret Pond previously identified using thermal photography (Fig. 3).

The enrichment of groundwater with nitrogen is becoming a widely acknowledged problem (Capone and Bautista, 1985; Lee and Olsen, 1985; Ely, 1990; Valiela *et al.*, 1990). Nitrogen enters the groundwater through sandy soils that have such a rapid percolation rate that denitrification does not occur sufficiently to remove nitrates before they reach the groundwater. Once in the groundwater, nitrate moves with the groundwater under hydrostatic pressure (Capone and Bautista, 1985; Valiela *et al.*, 1990) and enters a lagoon as nutrient enriched fresh water (Maier and Pregnall, 1990; Granger, unpublished) that has a significant impact on the nitrogen loading to shallow coastal lagoon systems such as Ninigret Pond (Lee and Olsen, 1985).

Obviously the number of houses having traditional septic systems in the watershed of a lagoon affects the potential amount of nitrogen reaching the lagoon. A strong connection between number of houses in the watershed of sub-basins in the Waquoit Bay Estuary and the percent eelgrass cover within the sub-basins suggests a link between the extent of housing development and the ability of an estuarine sub-basin to sustain eelgrass populations (Short and Burdick, in press). In analyzing the data for Ninigret Pond, we take the next step in looking at long-term change analysis of eelgrass habitat and relating it to long-term change in housing density (Fig. 6).

In our study of the Ninigret Pond system, the circumstances connecting increased housing development to decline in eelgrass distribution are the same as those found in the Waquoit Bay study (Short and Burdick, in press), i.e., the enrichment of the estuarine pond system by nitrate in groundwater. As with the Waquoit Bay study, the linkage that directly connects groundwater nitrogen loading from septic systems in well-drained soils to the processes that result in the demise of eelgrass within the pond system is not clearly known. However, the weight-of-evidence strongly supports the hypothesized groundwater enrichment model. This evidence includes:

- significant findings relating eelgrass distribution to housing density in sub-watersheds of Waquoit Bay (Short and Burdick, in press)

- declining eelgrass distribution and increasing housing density over time in Ninigret Pond (Fig. 6)
- mesocosm experiments demonstrating the indirect effect of nitrogen on eelgrass, namely, a stimulation of algal competitors which eliminates eelgrass populations (Short *et al.*, 1995; Taylor *et al.*, 1995)
- nitrate directly affecting eelgrass survival (Burkholder, Mason, and Glasgow, 1992)
- field observations (Harlin and Thorne-Miller, 1981; Short and Burdick, in press) providing ample evidence of processes observed in mesocosm experiments (above)

World wide losses of seagrass habitat have been linked to human induced causes and specifically to effects of nutrient loading and eutrophication (Short and Wyllie Echeverria, in review). Ninigret Pond is a case study providing documentation of the link between increased housing development and the loss of seagrass habitat. These results support the findings of our Waquoit Bay research (Short and Burdick, in press), adding evidence that eelgrass habitat loss is related to housing development. What Waquoit Bay and Ninigret Pond have in common is groundwater nitrate loading as a driving force causing eutrophication within their lagoon systems.

The overall impact of eelgrass habitat loss in coastal lagoons like Ninigret Pond is a decline in estuarine health. Independent evidence of reduced health in Ninigret Pond, as well as Waquoit Bay, emerges from recently documented reductions in hard clam and scallop harvests (Valiela *et al.*, 1992; Granger, per. obs.), as well as episodes of low oxygen conditions leading to fish kills (D'Avanzo and Kremer, 1994). Unfortunately, because the pool of nitrate enriched groundwater is large and slow moving, source reductions may take decades to solve problems of nutrient enriched groundwater in coastal lagoons. More immediate results may require increasing pond flushing or creating nutrient absorbing habitats to restore estuarine productivity. However, the hard-learned lesson here and in Waquoit Bay should serve to instigate new regulations that are more protective of the environment, particularly in the immediate coastal zone.

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