Common Terns (*Sterna hirundo*) as Indicators of Ecosystem Response to Urbanization in the Barnegat Bay Watershed Region of New Jersey: 1982-2007

by

Sheila Shukla

A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

In partial fulfillment of the requirements

For the degree of

Master of Science

Graduate Program in Geography

Written under the direction of

Dr. Laura Schneider

And approved by

____

____

____

New Brunswick, New Jersey

May, 2009

ABSTRACT OF THESIS

Common Terns (*Sterna hirundo*) as Indicators of Ecosystem Response to Urbanization in the Barnegat Bay Watershed of New Jersey: 1982-2007

by Sheila Shukla

Thesis Director: Dr. Laura Schneider

While recording avian populations in Barnegat Bay for more than 30 years, it was observed that out of 34 nesting islands inhabited by common terns (*Sterna hirundo*); only 15 currently host colonies of common terns. Within the same period of time, the region has experienced intense urban development, especially in recent years. The intent of this research is to provide a method to investigate the spatial relationship of changes in encroaching urbanization to common tern populations. Since the success of coastal communities is dependent upon sustainable coastal urbanization, integrating correlations between land-use change and avian populations can provide information to use when establishing conservation sites or protected areas. Conservation of avian ecosystems requires identifying critical habitat areas that are affected by urbanization. The null hypothesis of this research was that long-term population variability does not result from encroaching urbanization on common tern habitats. If common terns are adversely affected by the direct and indirect effects of increasing urbanization in the area, it could be an indication of declining ecosystem health. These birds serve as excellent bioindicators of ecosystem health because they feed at high trophic levels of food chains within the ecosystems in Barnegat Bay. To find correlations between changing urbanization and populations, 25 years of population data of common terns nesting on salt marsh islands in Barnegat Bay, New Jersey from 1984-2006 was compared with satellite imagery for 1984, 1995, 2001 and 2006 using Geographic Information Systems (GIS). The island group experiencing the greatest percent change (40.6%) in distance from the nearest edge of urbanization to tern habitats, also experienced the greatest overall decline in Common Tern populations over a 25 year period. Distance was calculated using the Euclidean Distance, or straight-line distance, tool in Spatial Analyst using ArcGIS. The change in distance indicates an encroachment of urbanized land in the direction on common tern nesting and breeding areas. During the study period, populations of common terns did not experience a linear decline; however, there was a linear increase in urbanization. Long-term population variability may be due to indirect effects of land-use change including volatile weather conditions, predation, and recreational disturbances or dredging projects.

ACKNOWLEDGMENTS

I extend deep gratitude to Laura Schneider, Joanna Burger and David Tulloch for their guidance, support and expertise. Also, thanks to Joanna Burger, CRSSA, NJDEP for the use of their existing data and to the NJDEP, USEPA, NIEHS and CRESP for funding parts of this project. Finally, thanks to Inga and David la Puma, Richard Lathrop, John Bognar, James Trimble, Chris Jeitner, Taryn Pittfield and Mark Donio for their technical support and to Vinod, Tara, Rita and Anita Shukla and Tanya Rohrbach, for their encouragement and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

Chapter I. BACKGROUND OF RESEARCH

INTRODUCTION

The consequences of urban sprawl, including pollution, loss of wildlife habitat, diminished watershed lands and decreasing biodiversity, are of concern to environmental policy makers and managers, conservationists and the public (Burger 2003; Haase 2004). Patterns of sprawling development that are incompatible with the natural environment may result in the decay of wildlife environments through the fragmentation of corridors and greenways, as well as disturbing critical habitats. Urbanization in coastal regions reduces areas of permeable land coverage, which contributes to increased run-off into surrounding aquatic environments. Additionally, encroachment upon sensitive lands, loss of wetlands, and endangered habitats are adverse impacts of urban growth that affect wildlife (Haase 2004). Biomass, such as sea grass and salt marsh plants, which play a significant role in sequestering heavy metals from estuarine cycles, are often decreased during land conversions (Coelho et al. 2008). Investigating the relationship of temporal population trends of common terns and proximity of habitats to landscape change in adjacent coastal urbanization can provide useful information for ecosystem managers to understand critical and sensitive habitats and to prioritize conservation and remediation efforts.

Common terns are a colonial seabird, which inhabit salt marsh islands in the Barnegat Bay Region, and have populations that may be at risk due to increasing urbanization. The attractiveness of this coastal region to recreationists, tourists, and incoming residents creates an economic demand to build infrastructure. Land conversions to support growing human demands may conflict with the success of common tern populations. This landscape change may pose threats to seabirds in the region through higher contaminant levels, regional climate changes, disturbances, and competition for resources.

Landscape change, contamination and human disturbances resulting from urbanization may alter or impair the health of coastal ecosystems. Avian populations that are sensitive to ecosystem disturbances may not be stable in the face of pollution resulting from intense development and contributing to a depletion of fish as food sources. This sensitive response to polluted ecosystems could indicate areas in need of protection. Methods for understanding the relationship of avian species of to landscape change can provide information for management and policy-makers to designate critical habitats. If there is a negative relationship of heavily urbanized areas to avian populations, this may suggest declining ecosystem health. Ecosystem health, which is a measure of ecosystem's ability to recover and replenish itself, is beneficial to humans, as ecosystem services such as water filtration, carbon sequestration, fertile soil, drought and flood remediation and nutrient cycling (Kroeger and Casey 2007).

Urbanization in coastal environments may result in degradation or destruction of surrounding terrestrial and aquatic ecosystems, particularly for low-lying salt marsh islands (Milligan, et al. 2009). Anthropogenic emissions from urban, industrial and agricultural sources augment biogeochemical cycles and oceanic processes within ecosystems (Mailman 1980; Vitousek et al. 1997). While chemical contamination can directly affect reproduction and survival of coastal wildlife, urbanization or loss of undisturbed lands often reduces or fragments critical habitat, which may contribute to a loss of biodiversity and a decline in species (Randhir and Hawes 2009). Natural disturbances, such as hurricanes, fires and flooding, also shape landscapes and influence ecosystem patterns and processes (Foster, et al. 1998). The objective of this research is to explore patterns of encroaching urbanization as they relate to population levels of common terns over time, as well as the indirect effects of urbanization. While censusing avian populations in Barnegat Bay, declining numbers on the marsh islands have become apparent (BBEP 2000). Significant coastal development, dredging projects, increasing debris and human disturbances have also become clear in immediate areas containing seabird populations. With the availability of robust population data, as well as high quality satellite images classified by land cover and land-use, correlations between avian declines and habitat encroachment by urbanized land will be derived. The evidence of unstable avian populations, whose habitats have experienced encroachment by urbanized land, can inform land-use planners and conservationists of habitat areas that should be buffered or protected in the Barnegat Bay ecosystem (Kennish 1999). Protection of Barnegat bay holds important implications for human health, as healthy ecosystems provide services including clean water, air and uncontaminated fish and agricultural products.

Since the ecological, cultural, spiritual, historic and recreational values of coastal areas have long attracted tourism (van der Meulan and Udo de Haes 1996); human conflicts resulting from increased urbanization to accommodate tourists must be assessed by coastal zone managers to protect the natural environment. Recreational tourists are drawn to coastal regions to participate in boating, jet-skiing, sport-fishing, surfing, sun-bathing and swimming. These tourists introduce increased emissions from vehicles, litter and other types of pollution. While visiting destinations to observe and appreciate wildlife, ecotourists inevitably leave an ecological footprint by using vehicles, roads, waterways and various local facilities. Coastal regions respond to recreational demands by developing facilities, such as marinas, bait shops and hotels, to accommodate these activities. Species that share environments with seasonal tourists must adapt or find other habitats in order to survive and continue strong healthy populations (Burger et al. 1982).

Increasing numbers of personal watercrafts (PWCs) in coastal waterways and estuaries contribute to disruptions of natural systems through chemical pollution, debris, over fishing and boat oil (Burger and Leonard 2000; Munoz et al. 2004). Personal water crafts that are navigated too close to nesting areas disturb birds and thus affect the reproductive success of these nesting birds. PWCs can also disturb the spawning of fish and shellfish, depleting food sources for breeding birds (Burger and Leonard 2000; Munoz et al. 2004).

Development of new housing and paved areas to accommodate rising human populations in coastal regions contribute to pollution of adjacent waters. Impervious surfaces, which destroy the capacity for underlying soil to percolate or naturally filter water, result from newly built infrastructure (Haase 2004). Impervious surfaces contribute to higher levels of non-point source pollution of water, thus affecting organisms of all trophic levels of the food chain (Nilsson et al. 2003).

The ecological consequences of urbanization should be assessed, particularly in coastal, high density regions, and managed to prevent irreversible damage to ecosystems (Lee et al. 1998). To assess the response of ecosystems to urbanization, economic and social drivers of public land use, policy implementation, the roles of institutions and biophysical conditions should be addressed (DeFries et al. 2004). Technology, coupled with long-term social and population data, can be used to assess potential effects of urbanization on species in an ecosystem and provide valuable information that can implement the establishment of protected areas. Spatial technologies, i.e. GIS, can be implemented to understand avian conservation challenges by relating variables that are detrimental to species to habitat locations. Temporal satellite imagery, categorized by land cover or land-use, can add another dimension to historic population data. Spatial software allows for the identification of areas of land cover change and the spatial relationship to declining or thriving populations and their habits

Uniqueness of Research

Although existing research similarly addresses population trends in common terns, this research is unique in that it frames land-use change and avian population trends within the context of urbanization in adjacent environments. Spatially linking responses of common tern populations to increasing urbanization in the Barnegat Bay Watershed provide a unique method of assessing marsh islands that have both experienced common tern declines and were closest to encroaching urbanization. Comparing this changing encroachment over periods of time to long-term common tern populations can aid in determining areas that are sensitive to ecosystem change. Conservation organizations may use this method to inform land managers or policy makers of areas that should be protected from development to prevent unstable populations, declines or even extinctions of common terns or other species in Barnegat Bay. The relationships amongst land-cover types, habitat structure and avian communities are useful for examining effects of land-use on breeding birds at both stand and landscape level and should be addressed when assessing habitat quality (DeGraaf 1991; Scott et al. 1993). This research can also serve as a model for similar research elsewhere.

RESEARCH OBJECTIVES

The intent of this study is to (1) identify habitat areas which experienced decline in common tern populations over the study period and compare those areas to changes in proximal urbanization; (2) discuss natural and anthropogenic threats to avian population viability that should be monitored in the future.

The thesis outline is as follows: (1) a literature review of avian populations and of drivers of land-use change (2) a description of the Barnegat Bay region and the conservation of Barnegat Bay (4) a description of common terns and threats to common terns (4) an explanation of the data and methods used in this research, followed by the results, discussion and implications of future research.

LITERATURE REVIEW

Review of Land Change and Avian Species

Land change science integrates social, natural and geographical sciences in relation to land cover change with empirical evidence to understand patterns, causation and effects of land-use change (Kinzig et al. 2000; Lambin et al. 2004; Turner et al. 2004). This grouping of ecological and social disciplines can provide a knowledge base for land-use planners, as well as environmental policy makers, to make ecosystem-sensitive decisions. Causal relationships between individual choices and land-use change can allow researchers to understand economic processes associated with land-use change

(Irwin and Geoghegan 2001). Boren et al. (1999) examined breeding bird habitats as they relate to changes in land-use and found a decrease in avian species due to loss of vegetation and landscape fragmentation. Boren noted that avian species composition change was directly related to land-use intensification related to changes in management practices. There are over thirty years of data on population levels and trends of common terns in Barnegat Bay, New Jersey (Burger and Gochfeld 1991; Burger et al. 2001). In 2003, Burger and Gochfeld found locational differences of heavy metals; including arsenic, cadmium, chromium, lead, manganese, mercury and selenium in eggs which they hypothesize may contribute to population declines and attributed these declines to heavily urbanized areas or lack of dilution capacity and flushing of the bay.

Review of Land-Use Change Drivers

Integrative interests grow as global change sciences extend beyond climate and include issues of ecosystem services and health, biotic diversity, land degradation and coupled human environmental consequences (Turner et. al. 2004). A shift towards sustainable development and other behaviors in response to global climate change exemplify the sociological aspect of land use change. The National Research Council states the following:

> "Sustainability promises to engender research attention on coupled human-environment systems promoting multi- and interdisciplinary programs and activities to the array of themes and issues dealing with the human-environment condition (NRC 1999)".

As environmental managers attempt to conserve threatened species within fragile ecosystems, the importance of understanding social drivers of land use change of individuals, as well as regulatory or governing bodies that do the zoning is becoming evident. Ecologically sound land management practices depend on gaining knowledge of the coupled human-environmental dimension for assessing long-term consequences of land change. Turner et al. (2007) recognizes the new field of land change science, which addresses motivations of land-use change within a scientific framework, to synthesize social and biophysical sciences (Turner et al. 2007).

> "Most social sciences enter environmental questions through concerns about the ways in which culture, economy and political organization shape the perception and use of nature and the social consequences of interactions with nature (Turner 2004)".

Since post World War II, the "pleasure periphery" has been apparent with mass tourism becoming prevalent in coastal areas (Turner and Ash 1975). In the 18th century, coastal areas became attractive to people when sun bathing became fashionable (Berry 2002), and in the 19th century, tourism numbers expanded with the increase in leisure time and the growth of rail systems for easier access to the coast (Jennings 2004). The healing benefits of coastal areas were replaced leisure or pleasure motivations for tourism (Anderson 1996).

Land-use change may be motivated or restricted based on the economic power of society and may have a relationship of income, race and class (Blaikie and Brookfield 1987; Lambin et al. 2001). Lambin et al. (2001) noted that restrictions of poverty drive improper land-uses, while wealthy state and corporate land alterations lead to excessive extraction of natural resources and mega-development. Johnson et al. (1997) found low-income African Americans workers to choose recreation in wild areas and prefer subsistence recreation, such as fishing or hunting. Wolch and Zhang, (2004) attributed this recreational choice to the history of oppression and poverty of African Americans. Alternatively, White Americans with higher incomes chose metropolitan activities (Wolch and Zhang 2004) as opposed to outdoor recreation.

Chapter II. BARNEGAT BAY AND COMMON TERNS

STUDY AREA

The Barnegat Bay Watershed (Figure 1), in Ocean County, is located along the central coastline and outer coastal plain of the southeastern region of New Jersey (Latitude: 394817N, Longitude: 0740843W) (Conway 2001; Kennish 2001). The area is part of the Pinelands ecosystem, and is comprised of vast forested wetlands, pine-oak uplands and is locally known as the Pine Barrens (Conway and Lathrop 2005). Barnegat Bay is a shallow, lagoon-type estuarine system located between the Atlantic coastal barrier islands, which border the 660 mile area of the watershed (U.S.A.C.E. 2000; Kennish 2001). The watershed includes barrier islands, salt and freshwater wetlands, and forested uplands (Conway 2001; Burger 2006; Forman 1998). Barnegat Bay contains wetland ecosystems, which are essential for biodiversity, protecting land from harsh weather elements and filtering contaminants from the bay.

Barnegat Bay is not only picturesque and attractive to recreationists; it also hosts a diversity of avian wildlife. Along with common terns, this watershed is home to black skimmers, oystercatchers, blue herons, great egrets, herring gulls, double-crested cormorants and several other avian species. Barnegat Bay hosts a diversity of species of wildlife that are federally-listed endangered, such as roseate terns and peregrine falcons, federally-listed threatened, like the piping plover, state-listed endangered, such as northern pine snakes and northern diamond-backed terrapins and state-listed threatened species, such as great blue herons and ospreys (Kennish 2001a). Wildlife in the Barnegat Bay must adapt to the undesirable effects of new urbanization or face threat of declining populations.

Over the last 50 years, urban sprawl has greatly impacted the Barnegat Bay region (Conway 2001). Human land-use in Barnegat Bay is greater in heavily developed areas and comprises 28% of the watershed area (Lathrop and Bognar 1997). Land-use intensification has introduced increasing influxes of non-point source pollutants into the bay from surface run-off and percolation into groundwater, which negatively affects estuarine organisms (Kennish 2001a, Charbonneau and Kondolf 1993). The loss of natural habitats and the increase of impervious surfaces due to human impacts have significantly influenced contaminant concentrations, as increasing shifts in stream morphology result from the depletion of sea grass and salt marsh plants (Alan and Castillo 2007; Coelho 2008).

Current land-use patterns in Barnegat bay include infrastructure development that decreases in density from north to south (Kennish 2001a). The eastern point of the watershed has a densely developed barrier beach complex, whereas the western mainland includes sparsely developed, environmentally protected areas of the Pinelands (Kennish 2001b). Heavy development in the northeastern area of the watershed contains few protected areas, whereas the sparsely developed southeastern mainland has protected habitats: Barnegat National Wildlife Refuge and the Manahawkin Fish and Wildlife Management Area (BBEP 2000).

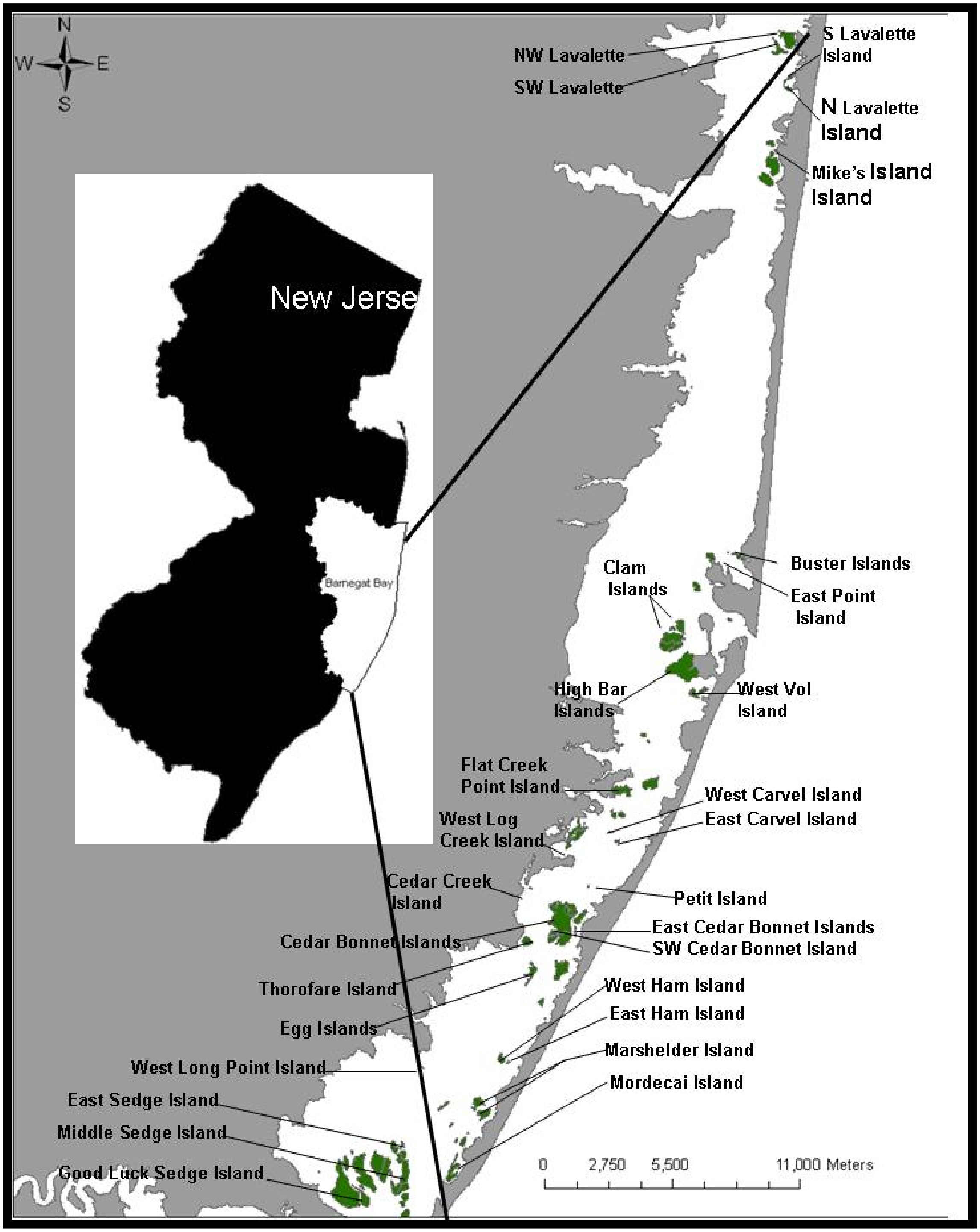

Figure 1. Map of Islands in Barnegat Bay, New Jersey.

Land-Use Change from 1984-2006

Europeans were the first to impact the region with resource extraction in the 1700s by logging, ore mining, and fishing (Conway 2001). In the 19th century, small villages were the center of development on the mainland (Conway 2001). After World War II, the region experienced a population increase of 800% between 1950 and 2000 (US Census 1990, 2001). Today, Barnegat Bay is experiencing high levels of residential growth, including the addition of several retirement communities in the northern sub-watershed of Tom's River (Lathrop et al. 1999). This increasing urbanization in the Barnegat Bay region may be driven by growing numbers of recreationalists and residents who are drawn to the area to enjoy the appealing aesthetics of the coastal environment and inexpensive land prices, respectively.

In the last 25 years, urban land-use in Barnegat Bay has grown significantly. From 1986 to 1995, there was an 11% increase in total urban land in the Barnegat Bay region (Haase and Lathrop 2001). Specifically, Barnegat Bay experienced a 17% loss of agricultural land, a 5% loss of forested land, a 2% loss of wetland areas, and a 2% loss of bare land from 1986 to 1995. These percentages were calculated using data reported by Haase and Lathrop in 2001. In 2007, Lathrop and Haag reported that urban land-use increased from 25% in 1995 to 30% in 2006.

Some land-use changes in recent years in Barnegat Bay stem from human demands. Natural resources, such as agriculture and forest products, have been depleted through the construction of residential, commercial and industrial infrastructure, as well as new roadways (Kennish 2001a). These impervious structures lead to degraded estuarine water quality in the bay by acting as a conduit for non-point source contaminants to pass into streams, rivers and eventually, into the bay (Kennish 2001a). Dredging, dredge material disposal, bulk-heading, diking and ditching in wetland area and waterway creation for PWCs have caused habitat alteration in Barnegat Bay (Kennish 2001b). Additionally, the Oyster Creek Nuclear Generating Station, which went online in 1969, is a nuclear plant that uses the bay for cooling, and discharges pollutants that are harmful to aquatic organisms in the Barnegat Bay (BBEP 2000).

Unique and aesthetically pleasing coastal areas often attract residents as well as tourists for recreation. While tourism brings economic growth to coastal areas, it also drives the development of infrastructure to accommodate tourists. Each summer, tourists in the Barnegat Bay region almost double in population in the area, as boaters, photographers, jet-skiers, fisherman, swimmers, eco-tourists, golfers and hikers migrate to the area (U.S. EPA 2009).

> “The Barnegat Bay Estuary supports a thriving tourism industry, with thousands of people visiting Ocean County each year. In 1995, tourists expended $1.71 billion in Ocean County. At that time, roughly 45,000 tourist industry jobs were registered in the county, accounting for more than $631 million in annual payroll. A more detailed study by Longwoods International found that in 1998 tourists spent more than $1.67 billion (BBEP 2000).”

The construction of new of boating facilities, restaurants, fishing-related infrastructure, condos, and other housing to accommodate the growing tourism each year contributes to high levels of coastal urbanization. The economic value of tourism, urban development and fisheries in the Barnegat Bay Watershed area are all driver land-use change. Survey responses from a study by Burger (2003) show high ratings for communing with nature, ecotourism and fishing as motivations for recreating in Barnegat Bay.

Drivers of Land-Use Change

Incentives to reside in the Barnegat Bay grow with opportunities for quieter living for urban commuters, highway access and tax relief. As economic and social pressures of city living mount, Barnegat Bay's proximity to New York City and Philadelphia makes the area attractive to those who earn high wages in cities, but want a more peaceful, higher quality of life away from the city. Access to the Garden State Parkway from the Barnegat Bay area makes the location of housing desirable for commuters. Additionally, an incentive for homeowners to live in Barnegat Bay is a break in property taxes for donating a portion of their land to preservation (TPL 2009).

Economically and politically driven decisions for land conversions in Barnegat Bay are dependent on regulations regarding zoning, cluster development, wetlands and water buffers, and open space protection (Conway and Lathrop 2005). CAFRA's zoning laws prevent building on wetland, riparian and water buffers and may deter or drive development based on consumer preferences (NEP). Economic incentive to produce agricultural products may be attributed to the Trust for Public Land in Barnegat Bay, which was partially funded by residents and protects and promotes farmland and ranches (TPL 2009). CAFRA requires cluster development (NEP) in most areas of Barnegat Bay, as opposed to sprawling development, which may be desirable to potential residents because of the social value of close communities and neighborhoods.

The desirability of coastal areas, resulting in increasing recreation by local and seasonal tourists in coastal systems, may contribute to changes in land-use in Barnegat Bay. Aesthetically attractive areas, like Barnegat Bay, have high socio-economic value to consumers seeking convenient day or weekend destinations away from the hectic aspects of urban life. The local economy may experience pressure to develop open parcels of land increases because of opportunities for economic growth both seasonally and year-round (Wolch and Zhang 2004).

The emotional, social, recreational and economic benefits of viewing and enjoying wildlife has manifested in the emergence of ecotourism (Burger, et al. 1995). There is an economic advantage to conserving and protecting wildlife areas, as tourists are drawn to areas that host birds, mammals and other species of interest. Sustaining ecotourism is essential in predominantly urban landscapes, like New Jersey, where people seek the sanctuary of nature.

Conservation of Barnegat Bay

The negative impacts from rapid urbanization must be assessed by environmental managers and conservation organizations to prevent irreversible damage to Barnegat Bay’s ecosystem. Development may diminish permeable ground cover and wetlands areas that filter contaminants in water and provide flood control, along with vegetative cover that contributes to better air quality. Urbanization contributes to saltwater intrusion, due to low stream flows, shifts in aquatic biota due to non-point source contaminants and degradation of terrestrial and aquatic habitats, which have resulted from current development in the Barnegat Bay region (Conway and Lathrop

2005). Efforts by groups in New Jersey to protect the region's natural features from future development include the Pinelands Commission, developed in 1960. Created in 1973, the Coastal Area Facilities Review Act (CAFRA) protects 46% of BB Watershed. Barnegat Bay is currently protected by the National Estuary Program (NEP), which was established by the Environmental Protection Agency (EPA) and created under the Clean Water act to maintain the integrity and health of estuaries that are potentially at risk (Poole 1996; Conway 2001). The Barnegat Bay National Estuary Program adheres to NEPA standards, which include the creation of a management structure, identifying natural resources that are affected by human impacts and developing and monitoring management goals (Kennish 1999). Coastal zone management and water resource management fall under the jurisdiction of the New Jersey Department of Environmental Protection (NJDEP), in areas not included in the Pinelands Management area (Conway and Lathrop 2005). The NJDEP also protects endangered and threatened species, as well as species of special concern. Regional and municipal planners have incorporated policies to mandate urban development in order to protect ecological regions and include downsizing, cluster development, wetlands/water undevelopable buffer zones and open space protection (Conway and Lathrop 2005).

STUDY SPECIES

***Common terns* (*Sterna hirundo*)**

Common terns are colonial nesting birds that generally breed from the ages of 2 and 3. They can be found from the Atlantic Coast through the North American interior on sandy beaches, dredged islands, rocky islets, shell bars and salt marshes (Burger and

Gochfeld 1991). Rarely nesting solitarily, common terns form monospecific and mixed species colonialism and may nest with other avian species, such as black skimmers and herring gulls (Burger and Gochfeld 1991). Establishing areas to utilize for courtship, mating and caring for chicks until they are ready to take flight is an important for the success of common tern colonies. In 1991, Burger and Gochfeld attributed reproductive success and reduced predation to the colonial nature of common terns.

Common terns are listed as endangered, threatened, or of special concern in many states. In New Jersey, they are considered a species of special concern. Banding studies show that they live more than 15 years and breed a dozen times in their lives (Burger and Gochfeld 1991). They mainly feed on fish and small invertebrates and require an estimated foraging radius of 12 kilometers (NJLP).

Within the Barnegat Bay watershed, there are 34 salt marsh islands on which common terns can be found (Burger et al. 2001). These islands are roughly circular in shape and range in diameter from 50-300m and extend from the Lavalette group in the north (39 57’ N) to Hester Sedge and Tow (39 31’N) approximately 55km. This accounts for all of the common tern colonies in Ocean County NJ. On these islands, terns usually build nests from dead stems of *Spartina alterniflora* or wrack, or nestle directly in soft, grass-like *Spartina patens.* Although most salt marsh islands are usually left alone by humans, there are adverse impacts on populations of common terns due to human disturbances.

Common terns (*Sterna hirundo*) are excellent bioindicators of pollution in marine systems as they occupy higher trophic levels, primarily feeding on fish (Burger 2006). These seabirds nest on salt marsh islands in inland bays and estuaries (Burger and

Gochfeld 1991). While their islands are not normally exposed to human use, their aquatic foraging habitat is affected by changes in the land-use of adjacent uplands. These birds are valued as sentinels of public health due to their exposure to similar recreational risks, toxins, and food sources as humans sharing their environment (Schmidt 2009). While exposure to toxins may affect reproductive health, reduce eggshell thickness, cause birth defects and slowed sexual maturation of common terns; chemical exposure in humans are more likely to cause declines in fecundity, endocrine disruption, neurological disorders and birth defects (Burger et al. 2006, Burger and Gochfeld 2005).

Common tern population declines caused by competition for food and habitat, as well as human disturbances to breeding and foraging habitats, can indirectly result from recreational activities associated with urbanization. Because terns breed, live and forage within Barnegat Bay and surrounding ocean waters (Safina and Burger 1985) long-term assessment of their populations in response to local land-use change will be useful in gauging the overall ecological health of the area. Examining the response of populations of common terns to urban land conversions over time can serve as an indicator the future success of common tern populations, as well as the fate of local ecosystem goods and services.

Threats to Common Tern Populations

The plume trade contributed to severe population declines in the late 1900s, but conservation efforts, including The Migratory Bird Treaty Act of 1918, legally protected the killing of terns for the use of their feathers for women's hats (Beans and Niles 2003). These efforts to protect terns allowed for a recovery until pesticide poisoning threatened populations in the 1970s (Nisbet 2002). Recently, increased infrastructure to support the demand of human populations in Barnegat Bay has threatened the livelihood of common terns. Many of the indirect and direct results of urbanization, recreation, and fisheries alter the nature of ecosystem processes, which affects common terns.

Populations of common terns are directly and indirectly threatened by human disturbances. When humans encroach upon seabird habitats, they disrupt breeding, courtship, nesting and parenting behavior (Burger and Gochfeld 1994). Also, debris and food litter discarded by humans can attract predator species, such as herring gulls and black-backed gulls, to common tern habits. Exploitation by humans of eggs, feathers and birds for food can also contribute to a decline in common tern species. Destruction of breeding habitats by humans may impede future populations of common terns.

Human fisheries-seabird conflicts have indirect and direct impacts on common tern populations. Direct negative effects on seabirds include mortality due to net kills or seabirds used as bait for fish (Duffy and Schneider 1994). Indirect effects include changes in reproductive health or to population dynamics resulting from food competition for species of fish and small invertebrates between humans and seabirds.

The success of breeding common terns is also dependent upon climate patterns. Eggs, chicks and fledglings are vulnerable to floods, as they may be washed into the bay or drown when sea level rises (Burger and Gochfeld 1991). Land-use intensification may shift global and regional climates and exacerbate natural disturbances, such as hurricanes, cyclones, tornadoes, storms and severe temperatures (Dale 1997). Deforestation and loss of vegetative species may decrease an ecosystem’s ability to sequester carbon emissions. Increasing large and small scale CO_2 emissions can contribute to extreme weather, such as high temperatures, flooding and heavy rain. Sea-level rising as a result of long-term global warming, affects nesting and foraging areas of seabirds (Burger and Gochfeld 1994). Since common tern nests are prone to flooding, they choose nesting sites on the highest point of an island or a shoreline, from 0-5 meters above sea level (Burger and Gochfeld 1991; Nisbet 2002). If flooding occurs in an established habitat before common tern chicks take flight, the likelihood of the survival of the chicks greatly diminishes.

Chapter III. METHODS

Introduction

For the purpose of relating changing urbanization to habitats of common terns and their populations within a spatial context, 4 data sets will be used in this research. Robust temporal data for common tern populations over the last 25 years was available through Rutgers University by Joanna Burger and her field assistants. Landsat satellite imagery was provided by the Center for Remote Sensing and Spatial Analysis (CRSSA) and the USDA Farm Service Agency. This satellite imagery was previously classified for land-use and landcover by CRSSA using GIS. NJDEP data will be used to link the islands to the land-use/landcover data processed by CRSSA. For this study, waypoints were collected using a global positioning system to crosscheck island names used while collecting bird census data and those collected by the NJDEP.

Avian Census Data

Common tern population survey data collected from islands in Barnegat Bay, NJ will be used for this research. Only those salt marsh islands that were consistently inhabited by common terns will be included in this study. Due to inter-colony movement of common terns, which feed in flocks to avoid predation (Burger and Gochfeld 1991) and share flyways and breeding habitats in close proximity, the islands were grouped for this study according to geographical proximity to create island groups (Figure 2).

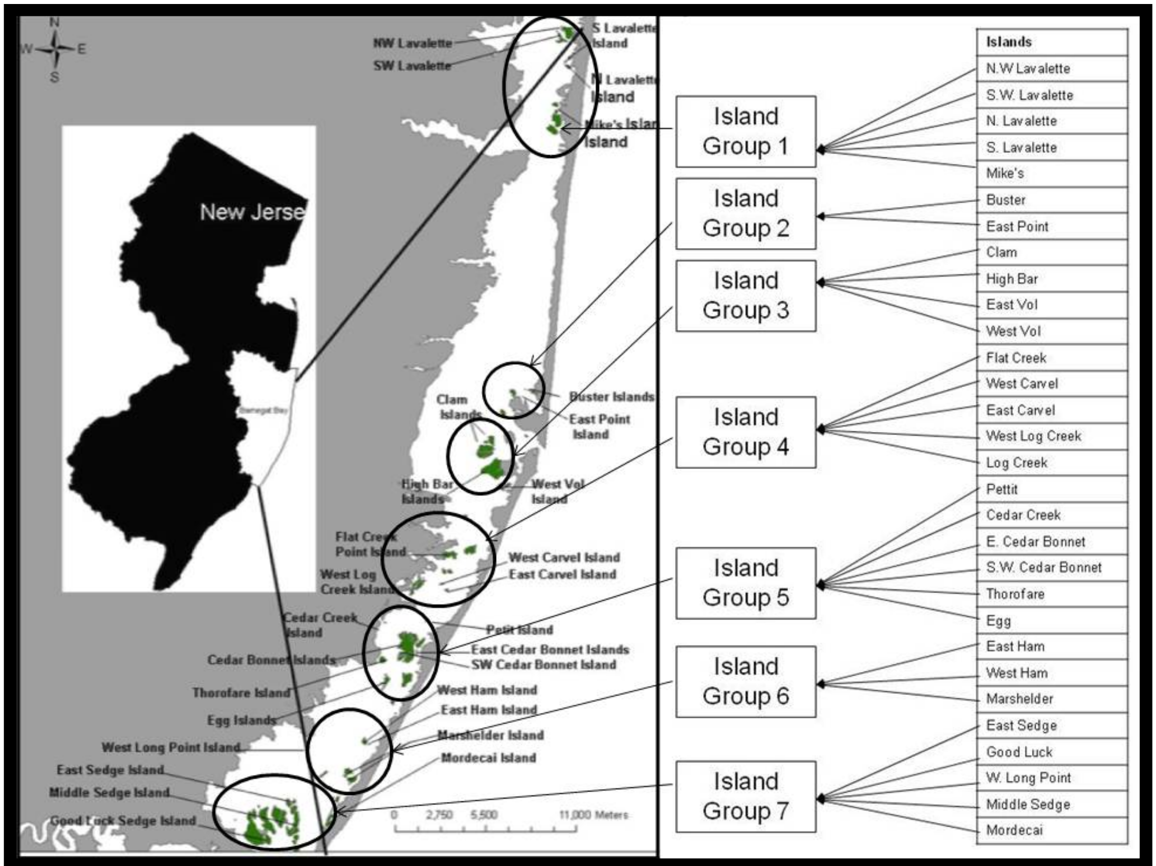

Figure 2. Map and diagram showing island groupings used in this study.

Since 1972, common tern populations have been recorded by Joanna Burger, in association with Fred Lesser and Michael Gochfeld in Barnegat Bay from several salt marsh islands. I participated in population data collection from 2002-2007. Due to low resolution of the available satellite imagery collected before 1984, 80x80 meter pixels in 1976, population data that corresponded to imagery with 30x30 meters or greater were used in this study. This finer resolution was available between the following years: 1984-2006. Population counts were made 6 or more times per year from June 1 – August 30, using a motor boat to slowly approach each island. Counts were either made from the boat when all birds flushed, from the edge of the colony when all birds flushed or from within the colony. Once the birds were flushed, careful estimates are made. Only islands with significant numbers of terns reported were used in this study. The entire data set was used, except for a very few colonies that were occupied only once by 5 or fewer birds.

Spatial Data for Islands

Two sets of spatial data for islands inhabited by common tern colonies in Barnegat Bay were used in this study. For one set of data, waypoints were collected in 2007 using a global positioning system (GPS), which were spatially cataloged and imported into map form using GIS. Preexisting shape files or vector data files containing salt marsh islands in Barnegat Bay, provided by the NJDEP, were also used in this study. These two sets of data were cross checked to ensure consistency amongst islands, as some islands may now be submerged underwater, eroded or identified differently by various scientists or organizations.

Landsat Satellite Imagery Data

Satellite imagery data of Barnegat Bay were collected by a Landsat Thematic Mapper 5 in 1984, 1995, and Landsat Enhanced Thematic Mapper 7 in 2001. These data were acquired by the Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University. The 2006 land-use data for this research were previously used by CRSSA for a special project using satellite data collected by the USDA Farm Service Agency and integrated with data from the New Jersey Department of Environmental Protection (NJDEP).

These data were classified by land cover or land-use by CRSSA for 4 years of data: 1984, 1995, 2001, and 2006.

> "A combination of unsupervised clustering, supervised training and spectral mixture modeling, GIS rules-based and on-screen digitizing approaches were used to classify the corrected Landsat TM image using the ERDAS image processing software (Lathrop 2000)." Unsupervised cluster busting aggregates pixels or creates clusters with similar spectral bands, thus creating several separate land cover classes. Classes are removed and the remaining classes are aggregated into fewer classes, which are broken or "busted" into more classes, yielding more classes. These new spectral classes were matched to land cover information from the original data by visual on-screen interpretation using GIS (Lathrop 2000).

Alternatively, supervised training requires the user to train the computer to identify land types based on existing maps provided by the following within GIS: U.S. Fish and Wildlife Service National Wetland Inventory (NWI), New Jersey Department of Environmental Protection (NJDEP) Freshwater Wetlands, NJDEP Integrated Terrain Unit (ITU) and U.S. Geological Survey Land Use/Land Cover (Lathrop 2000). For spectral clusters that were more difficult to distinguish, i.e., spectral clusters containing a mixture of forest landcovers, spectral mixture modeling was used. A simple linear model was conducted using ERDAS IMAGINE software, along with the supervised classification to estimate the relative proportions of the spectral outcome to determine the predominant landcover classes (Lathrop 2000). For accuracy, a GIS rules-based classification was used. This involves visually interpreting and digitizing masked Landsat images and assigning spectral values to each landcover using the Spatial Modeler in IMAGINE (Lathrop 2000).

For the years 1984, 1995 and 2001, the land cover data had a 30x30 pixel resolution, and the 2006 land use data had a 10x10 resolution. The 2006 data pixels were converted from 10x10 to 30x30 using Spatial Analyst in GIS to homogenize the resolution for each image to compare change in urbanization only. The Spatial Analyst tool in ArcGIS was used to perform this conversion.

This study used 25 years of population data and the years of this study were grouped into 4 separate year categories that corresponded to the available satellite imagery years: 1984, 1995, 2001 and 2006. In ecological research, it is common to use year groups to develop a better overall understanding of long-term dynamics.

Once these island habitats were grouped (Figure 2), the mean population was calculated for each group of islands for each year group, which resulted in a mean population for each group of islands for each year group. These results were compared to changes in urbanized land for each of the images satellite images, which were recoded (Figures 3 and 4) to illustrate developed or undeveloped land, to examine proximity to urbanization and its relationship to population declines.

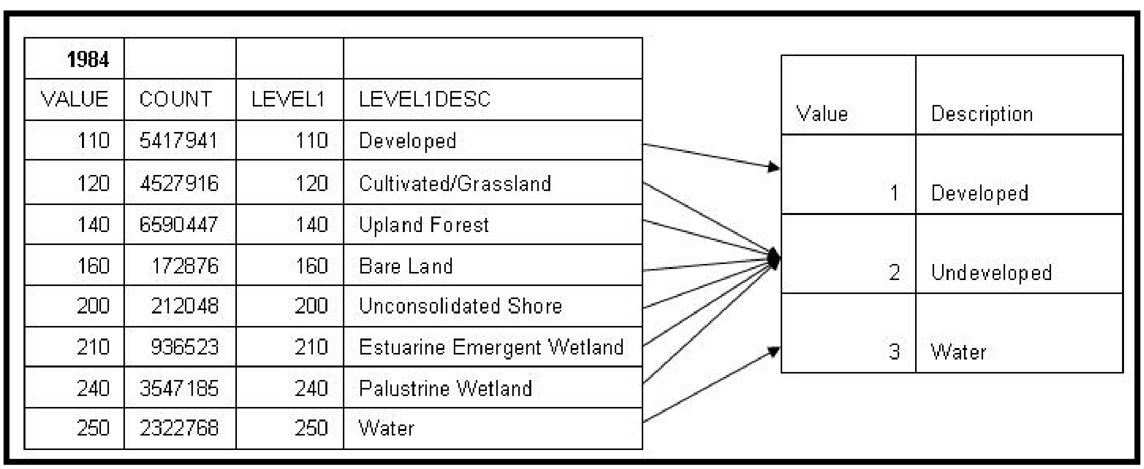

Figure 3.

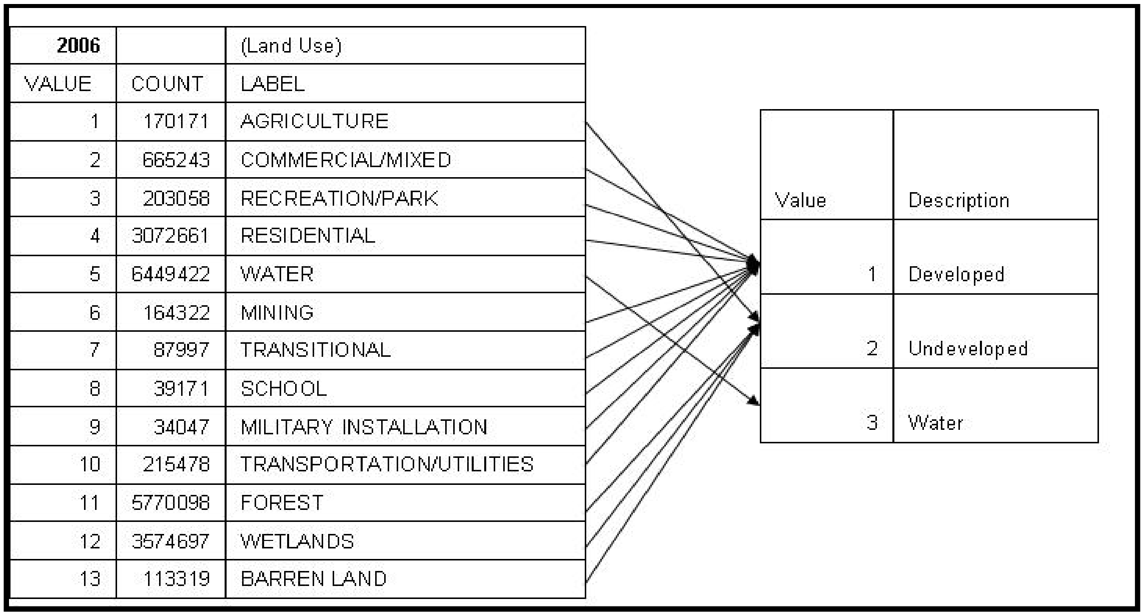

Figure 4.

Using ArcGIS, the straight line distance, or Euclidean distance, from the centroid, or center point of each island group, to the nearest area of development was calculated for each year group. Percent change to urbanization for each island group will then be calculated to determine which island group experienced the most change in distance from urbanization.

This percent change was compared to mean common tern populations for each island group. Each mean population within an island group for common terns, by year group, was categorized based on changing populations during the study period. If the populations increased and decreased over the study period and percent change in population was greater than 50% among island groups, then the island group was considered “highly variable”. If the mean population for each year group increased, then the island group was categorized as, “increasing”. Lastly, if the population decreased over the year group, then the island group was categorized as “declining”. These categories were compared to the percent changes in Euclidean distance from urbanization to determine if declining populations were linked to decreasing distances from urbanized land.

For the comparison of urbanized areas to common tern colonies in Barnegat Bay, the land-cover maps were recoded, or aggregated, in ArcGIS from several classes to 3 classes: developed, undeveloped and water. Land-cover classes were aggregated from 8 Anderson Level 1 classes to 3 classes for 1984. Anderson Level classification categorizes landcover with varying levels of detail, with the least amount of detail in Level 1 and the greatest in Level III. For instance, for developed land, Level I would only have "urban" listed, whereas Level II would list "residential', "commercial and services", "industrial and commercial complexes", "transportation, communications and utilities", "mixed urban or built-up land", and "other urban or built-up land" and for "residential" alone, Level III would list "Single-family units", "Multi-family units", "group quarters", "residential hotels", "mobile home parks", "transient lodging", and "other" (Anderson et al. 1976). The original Level 1 classes are as follows: developed, cultivated/grassland, upland forest, bare land, unconsolidated shore, estuarine emergent wetland, palustrine wetland and water. Developed land and water remained the same, while all other classes were grouped together and reclassified as "undeveloped". The 2006 land use data was also recoded from 13 categories to 3. The original categories are as follows: agriculture, commercial/mixed, recreation/park, residential, mining, transitional, school, military installation, transportation/utilities, forest, wetland and barren lands. The new "developed" class contained commercial/mixed, recreation/park, residential, mining, school, military installation and transportation/utilities, while the new “undeveloped” category contained agriculture, transitional, forest, wetland and barren lands. Water remained the same.

New groups of years were created for periods of data collection by intervals of 4 or 5 years for the following years: 1984, 1995, 2001 and 2006 (Table 1). The aggregation of years in temporal studies is useful in ecological modeling to better understand the overall success within a community over time (Cottingham et al. 2008). For each year category, population data were combined for a total of 4 or 5 years, surrounding the satellite data collection year, to yield new categories consisting of 4 or 5 years. To correspond to the 1984 satellite data, the total number of birds reported for each group of study islands were grouped by year categories:1982-1986 were combined to correspond to the 1984 satellite image; for the satellite image for 1995, 1993-1997 populations were combined; the 2001 satellite image corresponded to the years 1999-2003, and for 2006, 2004-2007. The mean of the sum of common terns for each year group for each island was calculated (Table 1).

RESULTS

The study islands were then grouped according to location, nesting and flight patterns (Figure 2). The islands were grouped as follows and are listed from north to south: 1) Northwest Lavalette Island, Southwest Lavalette Island, North Lavalette Island, South Lavalette Island and Mike’s Island, 2) Buster Islands and East Point, 3) Clam Islands, High Bar Islands, and West Vol Island, 4) Flat Creek Point, West Log Creek Island, Log Creek Island, West Carvel Island, and East Carvel Island, 5) Petit Island, Cedar Creek Island, East Cedar Bonnet Island, Southwest Cedar Bonnet Island, Thorofare Island and Egg Island, 6) East Ham Island, West Ham Island, Marshelder Island and 7) East Sedge Island, Good Luck Sedge Island, West Long Point Island, Middle Sedge Island and Mordecai Island. Once the islands were grouped, the sum of each island group was determined and then the mean population of those totals for all year groups (Table 1).

Table 1. Given are the total numbers of common terns for each island group by year. Mean numbers of birds were calculated for each island group.

		Island Group						
		1	2	3	4	5	6	7
	Year	N.W. Lavalette S.W. Lavalette N. Lavalette S. Lavalette Mike's	Buster E. Point	Clam High Bar W. Vol	Flat Creek W. Log Creek Log Creek W. Carvel E. Carvel	Petit Cedar Creek E. Cedar Bonnet S.W. Cedar Bonnet Thorofare Egg	East Ham West Ham Marshelder	East Sedge Good Luck Sedge W. Long Point Middle Sedge Mordecai
Year Group 1	1982	700	33	67	98	456	62	49
	1983	625	0	35	50	478	80	38
	1984	700	33	67	98	456	62	48
	1985	1610	18	159	136	565	138	68
	1986	2150	65	103	60	142	300	126
Mean	**1982-1986**	**1157**	**29.8**	**86.2**	**88.4**	**419.4**	**128.4**	**65.8**
Year Group 2	1993	280	175	53	48	630	330	60
	1994	430	165	50	80	385	135	100
	1995	600	250	20	60	475	20	85
	1996	675	125	0	20	345	250	65
	1997	440	50	0	60	312	202	50
Mean	**1993-1997**	**485**	**153**	**24.6**	**53.6**	**429.4**	**187.4**	**72**
Year Group 3 2001 Map	1999	700	25	0	33	231	23	51
	2000	400	0	350	8	231	250	51
	2001	262	0	925	8	156	475	12
	2002	281	83	512	8	255	457	73
	2003	618	325	102	0	200	0	330
Mean	**1999-2003**	**452.2**	**86.6**	**377.8**	**11.4**	**214.6**	**241**	**103.4**
Year Group 4 2006 Map	2004	335	60	125	0	190	0	135
	2005	643	0	65	0	415	40	150
	2006	783	0	225	0	540	0	289
	2007	1161	0	1130	1	548	0	220
Mean	**2004-2007**	**730.5**	**15**	**386.25**	**0.25**	**423.25**	**10**	**198.5**

A trend category was created for each island group. Each island group was reclassified based on the percent change between year groups (Table 2).The center or centroid of each of these island groups was identified using ArcGIS in a new, distinct shape file containing all islands in each island group. The Euclidean distance tool in the Spatial Analyst function of ArcGIS was used to measure the distance from each centroid of each island group to closest point of development on the western main land of Barnegat Bay. The distance from the centroid of the island groups to the closest point of urbanization on the main land for each year was calculated to determine the percent change in urbanized land extending in the direction of common tern habitats.

Table 2. Population categories: highly variable (>50% change in periods), decline (overall decline) and increase (overall increase).

	Island Groups						
Year group	1	2	3	4	5	6	7
1982-1986	1157	29.8	86.2	88.4	419.4	128.4	65.8
1993-1997	485	153	24.6	53.6	429.4	187.4	72
1999-2003	452.2	86.6	377.8	11.4	214.6	241	103.4
2004-2007	730.5	15	386.25	0.25	423.25	10	198.5
Population Trend Category	Highly variable	Highly variable	Highly variable	Decline	Highly variable	Highly variable	Increase

The island group with an overall decline in common tern populations was island group 4, which had the highest percent decrease in distance to urbanized land on the mainland (Table 3). Island group 4 experienced a 40.6% change in distance to development, while island group 1 experienced a 10.9% change, and island group 7 experienced a 2.1% change. The other groups experienced no change.

Table 3. Percent change in distance from island group centroid to development calculated for 1984 and 2006.

	Euclidean Distance to development 1984 (m)	Euclidean Distance to development 2006 (m)	Distance difference	Percent change in distance to development
Island Group 1	3180	2833	347	10.9
Island Group 2	5397	5397	0	0
Island Group 3	5024	5024	0	0
Island Group 4	3921	2330	1591	40.6
Island Group 5	989	989	0	0
Island Group 6	3875	3779	96	2.5
Island Group 7	4911	4810	101	2.1

Change in proximity of urbanization did not directly relate to changes in population of common terns for most island groups; however one group of islands that experienced an overall population decline experienced the highest decrease in distance to urbanization. The variability in the results may be due to disturbances and other indirect effects of intense land-use. Two main points are discussed in this section: 1) Indirect effects of urbanization that may affect common tern populations 2) Indications for of human health and 3) Future implications of this research.

DISCUSSION

Methods of Grouping

Methods of comparing study groups may have influenced the variability of these results. Year groups corresponding to satellite imagery may have affected the results, as all years in between years groups were excluded from the study. Also, inter-colony movement between island groups may have skewed results. Since there have been obvious declines in common terns over the years, yet no linear relationship found in this study, a comparison of percentages of the mean number of terns in each year group of the total number of terns within an island group were used to explore ratios of birds in contrast to absolute population numbers. The motivation for conducting this calculation was to test an alternate method of finding a linear relationship between terns, year groups and location (Table 4). Percentage comparisons showed stable or slightly varying results, which indicate that this method does not illustrate new, linear findings. These results do not represent the overall declines recorded over the study period and do not represent increases between year groups and exemplify how difficult it is to find clear trends by aggregating data.

Table 4. Percent mean of total common terns within each island group by year.

Year group	Island Group 1	Island Group 2	Island Group 3	Island Group 4	Island Group 5	Island Group 6	Island Group 7
1982-1986	20	20	20	20	20	20	20
1993-1997	20	20	20	20	20	52	20
1999-2003	20	20	20	20	20	20	20
2004-2007	25	25	25	25	25	25	25

Common Terns and Land-use

The long-term common tern population data used in this study did not show a linear decline or increase over the years, but fluctuated greatly from year to year. This variability of population responses suggests indirect effects of increasing urbanization. After exploring possible reasons for these extreme variations in bird counts, it appears that variability in tern populations may be attributed to dredging projects, climate change, human disturbances, and predation by other species of birds, along with the inability of the bay to flush itself of contaminants (BBEP 2000; Kennish 2001b; Kennish 1999).

Disturbances associated with dredging projects, which are performed to rebuild eroded salt marsh islands and beaches, as well as to maintain waterways in Barnegat Bay, may have contributed to the variability of common tern populations. Essink (1999) found that dredging and dumping of dredged sediment may increase turbidity of water, making foraging more difficult for visual predators, such as birds. Morson (2009) found that disturbances caused by dredging affect entire benthic communities. This disruption of fish spawning habitats may have limiting effects on food sources for common terns.

Land-use change on a global and regional level may induce climate change, and can impact the survival of common terns by flooding the salt marsh island habitats in Barnegat Bay. Over years of surveying the islands, washed-out eggs and chicks have been observed. Increased precipitation due to changes in atmospheric and water cycles and resulting from landcover change, contributes to sea level rise, and consequently, flooding of tern nests (Dale 1997; Burger and Gochfeld 1991). Elevated greenhouse gas emissions from changing land-use activities shift climate patterns on a regional and global scale (Dale 1997). Combustion of fossil fuel, agricultural land-use and other land-use activities emit carbon dioxide, nitrous oxide, methane and chlorofluorocarbons gases into the atmosphere which block excess heat radiation from leaving the earth and lead to higher average global temperatures (Grosvenor et al. 2004). This outcome of global warming melts glaciers, resulting in an overall sea-level rise and accelerated water cycles.

Declines of common tern colonies can also be attributed to the use of PWCs near nesting colonies in Barnegat Bay. Burger and Leonard (2000) monitored several islands in the bay and found that the close approach of high speed boaters and jet-skiers caused stressful responses in the birds, resulting in the failure of an entire common tern colony. With outcomes similar to dredging, PWCs stir up benthic and fish habits and interfere with spawning, which may affect food resources for terns. Kennish (2001b) found that marshlands were altered to create waterways for PWCs. Human land-use activities at marinas, docks, fueling stations and repair shops, spill fossil fuel, petroleum and debris into the bay and contribute to overfishing (Burger and Leonard 2000; National Parks 1996). The resulting contamination and competition for food may affect the success of common terns in Barnegat Bay.

When surveying common terns colonies on marsh islands, predatory avian species were also observed. Herring gulls, laughing gulls, black-backed gulls and ring-billed gulls, which predate on common terns and their eggs, often share habitats with terns. Several gull habitats were found interspersed within common tern nesting colonies. Injured or dead terns and predated eggs were presumably the result of foraging or aggression by gulls. In colonies with both nesting terns and gulls, O'Connell and Beck (2002) found significantly higher levels of disturbance to terns by herring gulls and black-backed gulls than in colonies without gulls nesting. Debris discarded by humans attracts gulls and it can be concluded that increasing urbanization near tern habitats may contribute to thriving gull populations that compete and predate on common terns.

Barnegat Bay, which is an estuary consisting of salt and fresh water, may be more susceptible to undesirable effects of pollution due to poor dilution and flushing capabilities of the bay. Because estuaries are slow flowing, excessive nutrients and contaminants do not dilute or flush away as rapidly as bodies of water with higher flow rates, such as oceans (BBEP 2000; Kennish 2001b). High concentrations of pollution in the bay due to land-use intensification negatively affect terns.

Indications for Human Health

It is imperative to assess the negative effects of urbanization on common tern populations, as there may be public health implications for residents of the Barnegat Bay area. If common terns are affected adversely by contaminants in air and water due to increasing urbanization in Barnegat Bay, questions about risks to public health begin to emerge about clean drinking water, contaminated fish and air quality. Impervious surfaces increase with infrastructure development and contribute to increased run-off of non-point source contamination and sedimentation. Groundwater, which is a source of drinking water, transports pollutants to Barnegat Bay and its tributaries. As tourist and local populations of personal watercraft users increase, high marina use contributes to significant amounts of oil and grease in the water. With increasing roads and numbers of motorists, gas stations and auto repair shops discharge more petroleum products and other automotive contaminants into the air, land and water. Bacteria, nutrients from household, pesticides and agricultural wastes also contribute to water contamination (BBEP 2000). Impacts include water pollution, loss of drinking water, loss of water recreation, and contamination of seafood.

While health effects of contaminants in wildlife have not been researched in depth, human health effects are numerous. Fox (2001) cited human health issues resulting from contaminant exposure as the following: “thyroid and endocrine disorders, metabolic diseases, altered immune function, reproductive impairment, developmental toxicity, genotoxicity, and cancer.” Burger and Gochfeld (2004) found significant levels of heavy metals including cadmium, chromium, lead, manganese, mercury and selenium in eggs of common terns, which Hu (2002) suggests can be inhaled by humans in the form of dust particles emitted from combustion of leaded gasoline or industrial fumes. Metal toxicity in humans includes the following, according to Hu (2002): brain and kidney disorders, cancer, weakness, headache and hypertension. Consumption of fish contaminated with high metal levels can lead to neurological, developmental and reproductive issues in humans (Burger et al. 2006).

Identification of areas sensitive to pollution may be useful for understanding impacts to public health. Conservationists and environmental land stewards may use this knowledge to gain public support for ecosystem conservation. This information may also be useful for policy makers to use in making decisions to protect ecosystems in the interest of public health.

Future Research

If hot spots of population decline can be identified using the methods in this research, there are options for future research. Small scale contaminant studies of water, fish and avian populations can be useful to model contaminants within the food chain. Tidal flow research may help understand which areas in the bay are less likely to naturally dilute or flush contaminants, and ultimately determine which areas are more suitable for development and those areas that should be preserved.

For future studies relating land-use change to bird declines, it may be better to choose species which inhabit primarily terrestrial areas to exclude the factors associated with water, e.g. sea level rise, contaminant flows and dredging projects. Avian species that nest, breed and forage on larger tracts of land, that are not surrounded by water, may be a better indication of how urbanized land affects populations through habitat fragmentation or loss of corridors, for instance.

For the successful conservation of the Barnegat Bay region and to protect common tern habitats, long-term studies of land-use change to predict the future of critical habitats would be beneficial. Other research to ensure the health of the Barnegat Bay's ecosystem should involve collaboration with cooperative management; land-use regulators, policy and zoning boards; conservation organizations; public participants; and citizen advisory boards.

LITERATURE CITED

Alan, J.D. and M.M. Castillo. 2007. Stream Ecology, The Structure and Function of Running Waters. Springer, Netherlands.

Anderson, J. R., E.E. Hardy, J. T. Roach and R. E. Witmer. 1976**.** A Land Use and Land Cover Classification System for Use with Remote Sensor Data. Geological Survey Professional Paper 964: A revision of the land use classification system as presented in U.S. Geological Survey Circular 671, United States Government Printing Office, Washington.

Barnegat Bay Estuary Program. 2000. Physical Characteristics and non-living resources. *In:* The Barnegat Bay Estuary Program Characteristization Report, (Ed.) M. Kennish http://www.bbep.org/Char_Rpt/Ch2/Chapter2.htm

Beans, B.E. and L. Niles. 2003. Endangered and Threatened Wildlife in New Jersey. Rutgers University Press, New Jersey, USA.

Berry, S. 2002. Myth and Reality in the Representation of Resorts. Sussex Archaeological Collections. 140:97–112.

Blaikie, P.M and H. C. Brookfield. 1987. Land Degradation and Society. London: Methuen.

Burger, J. 1982. Jamaica Bay Studies. I. Environmental determinants of abundance and distribution of Common Terns (Sterna hirundo) and Black Skimmers (Rynchops niger) at an East Coast Estuary. Colonial Waterbirds. 5:148-160.

Burger, J. and M. Gochfeld. 1991. The Common Tern: Its Breeding Biology and Behavior. Columbia University Press. 401 pp.

Burger, J. and M. Gochfeld. 1994. Predation and effects of humans on island-nesting seabirds. Birdlife Conservation Series. 1: 39-67.

Burger J., C.D. Jenkins, F. Lesser, and M. Gochfeld. 2001. Population trends of colonial nesting birds in Barnegat Bay. Journal of Coastal Research. 32:197-211.

Burger J. and J. Leonard. 2001. Conflict Resolution in Coastal Waters: the Case of Personal Watercraft. Marine Policy. 24: 61-67.

Burger, J. 2002. "Food chain differences affect heavy metals in bird eggs in Barnegat Bay, New Jersey." Environmental Research. 90(A): 33-39.

Burger, J. 2003. Assessing Perceptions about Ecosystem Health and Restoration Options in Three East Coast Estuaries. Environmental Monitoring and Assessment. 83:145-162.

Burger, J. and M. Gochfeld. 2003. Spatial and temporal patterns in metal levels in eggs of common terns (Sterna hirundo) in New Jersey." Science of the Total Environment, 311(1-3): 91-100.

Burger, J. and M. Gochfeld. 2005. Heavy Metals in Commercial Fish. Environmental Research. 99:403-412

Burger, J. 2006. Bioindicators: A Review of Their Use in the Environmental Literature 1970-2005. Environmental Bioindicators, 1:136-144.

Burger, J. 2006. Whispers in the Pines: A Naturalist in the Northeast. 345 pgs. Rivergate Books, USA.

Burger, J., C.Fossi, P.McClellan-Green and E. F. Orlando. 2006. Methodologies, bioindicators, and biomarkers for assessing gender-related differences in wildlife exposed to environmental chemicals. Environmental Research. 104(1):135-152.

Coelho, J.P., M.E. Pereira, A.C. Duarte and M.A. Pardal. 2009. Contribution of primary producers to mercury trophic transfer in estuarine ecosystems: Possible effects of eutrophication. Marine Pollution Bulletin, 58(3): 358-365.

Charbonneau, R.B., and G.M. Kondolf. 1991. Land use conversion as a source of contaminants. Proceedings of the Conference on Protecting Drinking Water Quality at the Source. University of California Water Resources Center, Riverside.

Chizmadia, P.A., M. J. Kennish., and V.L. Ohori. 1984. Physical Description of Barnegat Bay. Ecology of Barnegat Bay. M. J. K. a. R. A. Lutz. New York, Berlin, Heidelberg Tokyo, Springer Verlag: 28.

Conway, T.M. 2001. Predicting the Impacts of Future Development on Water and Terrestrial Resource Using Landscape-Level Resource Indicators, in the Barnegat Bay Watershed. Masters of Science Thesis, Graduate School of New Brunswick, Rutgers, The State University.

Cottinham, K.L. K.L. Cottingham, B.L. Brown & J.T. Lennon. 2008. Biodiversity may regulate the temporal variability of ecological systems. Ecology Letters. 4(1):72-85.

Dale, V. H. 1997. The Relationship Between Land-Use Change and Climate Change. Ecological Applications. 7(3):753-769.

DeGraaf, R.M. and B.R. Payne. 1975. Economic values on non-game birds and some urban wildlife research needs. Transatlantic North American Wildlife and Natural Resources Conference. 40:281-287.

DeFries, R., G.P. Asner and R. Houghton. 2004. Trade-offs in Land-Use Decisions: Towards a Framework for Assessing Multiple Ecosystem Responses to Land-Use Change. Ecosystems and Land Use Change, Geophysical Monograph Series,153, American Geophysical Union.

Duffy, D.C. and D.C. Schneider. 1994. Seabird-fishery interactions: a manager's guide. Birdlife Conservation Series. 1:26-38.

Essink, K. 1999. Ecological effects of dumping of dredged sediments; options for management. Journal of Coastal Conservation. 5(1):69-80.

Forman, R.T.T. 1998. Pine Barrens: Ecosystem and Landscape. Rutgers University Press. New Jersey, USA.

Foster, D.R., D.H. Knight, and J.F. Frankin. 1998. Landscape Patterns and Legacies Resulting from Large, Infrequent Forest Disturbances**.** Ecosystems. 1 (6):497-510.

Fox, G.A. 2001. Wildlife as Sentinals of Human Health Effects in the Great Lakes. St. Lawrence Basin. Environmental Health Perspectives. 109 (6), 853-861.

Grosvenor, A., Roble, W. and M. de Castro. 2004. Global Warming and Glacial Melting.The Traprock. 3:16-19.

Hasse, John E., 2004. A Geospatial Approach to Measuring New Development Tracts for Characteristics of Rural Sprawl, Landscape Journal: Design, Planning and Management of the Land. 23:1-04.

Hu, H. 2002. Human Health and Heavy Metal Exposure. A chapter in "Life Support: The Environment and Human Health." Michael McCally, MIT press, USA.

Irwin, E. and J. Geoghegan. (2001). Theory, data, methods: developing spatially explicit economic models of land use change. Agriculture, Ecosystems and Environment. 85:7-23.

Jennings, S. 2004. Coastal tourism and shoreline management. Annals of Tourism Research. 39(4):899-922.

Jing, S., Jiupai, N., W. Chaofu and X. Deti. 2005. Land use change and its corresponding ecological responses: A review. Journal of Geographical Sciences. 15(3):305-338.

Kennish, M. J. 1999. Estuary Restoration and Maintenance: The National Estuary Program. Boca Raton, FL., CRC press.

Kennish, M. J. 2001a. "Characterization of the Barnegat Bay- Little Egg Harbor and

Estuary and Watershed." Journal of Coastal Research 32: 3-12.

Kennish, M. J. 2001b. "Physical Description of the Barnegat Bay-Little egg Harbor Estuarine System." Journal of Coastal Research 32: 13-27.

Kinzig, A,P, J. Antle, W. Ascher, W. Brock, S. Carpenter, F. S. Chapin III, R. Costanza, K. L. Cottingham, M. Dove, H. Dowlatabadi, E. Elliot, K. Ewel, A. Fisher, P. Gober, N. Grimm, T. Groves, S. Hanna, G. Heal, K. Lee, S. Levin, J. Lubchenco, D. Ludwig, J. Martinez-Alier, W. Murdoch, R. Naylor, R. Norgaard, M. Oppenheimer, A. Pfaff, S. Pickett, S. Polasky, H. R. Pulliam, C, Redman, J. P. Rodriguez, T. Root, S. Schneider, R. Schuler, T. Scudder, K. Segersen, M. R. Shaw, D. Simpson, A. A. Small, D. Starrett, P. Taylor, S. van der Leeuw, D. H. Wall, M. Wilson. 2000. Nature and Society: An Imperative for Integrated Environmental Research. A report from a workshop Held June of 2000, Report issued 1 November 2000.

Kroeger, T. and F. Casey. 2007. An assessment of market-based approaches to providing ecosystem services on agricultural lands. Ecological Economics. 64:321-332.

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J. Imbernon, R. Leemans, Li XiuBin, Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., Skånes, H., Steffen, W., Stone, G. D., Svedin, U., T. A. Veldkamp, C. Vogel, Xu

JianChu. 2001. The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change 11: 261–269.

Lathrop, R.G. and J. A. Bognar. 1997. A Barnegat Bay Gap Analysis: A Geographic Approach to Evaluating Coastal Habitat Protection. Center for Remote Sensing and Spatial Analysis, Rutgers University, New Brunswick, NJ.

Lathrop, R.G. 2000. New Jersey Land Cover Change Analyses Project. Report from the Grant F. Walton Center for Remote Sensing and Spatial Analysis. 1-38.

Lathrop, R.G., J.A. Bognar, A.C. Hendrickson.1999. Data synthesis effort for the Barnegat Bay Estuary Program: Habitat Loss and Alteration in the Barnegat Bay Region. Technical Report, Barnegat Bay Estuary Program, Toms River, New Jersey.

Lathrop, R. G. and J. A. Bognar 2001. "Habitat Loss and Alteration in the Barnegat Bay Region." Journal of Coastal Research. 32: 212-228.

Lathrop, R.G. and S. Haag, 2007. Assessment of Land Use Change and Riparian Zone Status in the Barnegat Bay and Little Egg Harbor Watershed: 1995-2002-2006. Report from the Grant F. Walton Center for Remote Sensing and Spatial Analysis.

Lee, J.A. 1998. Unintentional experiments with terrestrial ecosystems: ecological effects of sulphur and nitrogen pollutants. Journal of Ecology 86: 1–12.

Mailman, R.B. 1980. Heavy metals. In, “Introduction to Environmental Toxicology”. J.J. Perry, Ed.), pp. 34-43. Elsevier, New York.

Milligan, J., T. O’Riordan, S.A. Nicholson-Cole, and A.R. Watkinson. Nature conservation for future sustainable shorelines: Lessons from seeking to involve the public. Land Use Policy 26: 203–213.

Morson, E.M. 2009. Impact on biodiversity of scallop dredging in San Matias Gulf, northern Patagonia (Argentina). Hydrobiologia. 619:167-180.

Munoz Del Viejo, A., X. Vega, M. A. Gonzalez and J. M. Sanchez. 2004. Disturbance sources, human predation and reproductive success of seabirds in tropical coastal ecosystems of Sinaloa State, Mexico. Bird Conservation. 14:191-202.

National Parks.1996. Use of personal watercraft banned. National Parks. 70(1):23-28.

National Research Council. 1999. Our Common Journey:A Transition Towards Sustainability. National Academy Press: Washington, D.C.

New Jersey’s Landscape Project (NJLP). 2008. NJ Department of Environmental Protection, Division of Fish and Wildlife, Endangered and Nongame Species Program Wildlife habitat mapping for community land-use planning and endangered species conservation.

Nilsson, C. J. E. Pizzuto, G. E. Moglen, M. A. Palmer, E.H. Stanley, N. E. Bockstael, and L.C. Thompson. 2003. Ecological Forecasting and the Urbanization of Stream Ecosystems: Challenges for Economists, Hydrologists, Geomorphologists, and Ecologists. Ecosystems. 6:659-674.

Nisbet, I. C. T. 2002. Common Tern (*Sterna hirundo*). The Birds of North America, No. 618 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

O'Connell, T. and R. A. Beck. 2002. Gull predation limits nesting success of terns and skimmers on the Virginia barrier islands. Journal of Field Ornithology. 74(1):66–73.

Poole, S.1996. "The United States National Estuary Program." Ocean and Coastal Management. 30(1): 63-67.

Randhir, T.O. and A.G. Hawes. 2009. Watershed land use and aquatic ecosystem response: Ecohydrologic approach to conservation policy. Journal of Hydrology. 364, 182-199.

Riebsame, W.E., W.J. Parton, K.A. Galvin, I.C. Burke, L. Bohre, R. Young, and E. Knop. 1994. Integrating modeling of land use and cover change. Biosciences. 44:350-356.

Rindfuss, R.R., Walsh, S.J., Turner II, B.L., Fox, J. and V. Mishra. 2004. Developing a science of land change: Challenges and methodological issues. Proceedings of the National Academy of Sciences. 101 (39): 1-6.

Safina, C and J. Burger. 1985. Effects of Human Disturbance on Reproductive Success in the Black Skimmer. Condor. 85:164-171.

Schmidt, P.L. 2009. Companion Animals as Sentinels for Public Health. Veterinary Clinics of North America: Small Animal Practice. 39 (2): 241-250.

Scott, J.M., F. Davis, B. Csut, R. Noss, B. Bulterfield, C. Groves, H. Anderson, S. Caicco, F.O.Erchia, T.C. Edwards, Jr., J. Ulliman, and R.G. Wright. 1993. GAP analysis: a geographic approach to protection of biological diversity. Wildlife Monographs. 123:1-41.

Turner, L., and J. Ash. 1975. The Golden Hordes: International Tourism and the Pleasure Periphery.London: Constable.

Turner II, B.L., E. Moran and R. Rindfuss. 2004. Integrated Land-Change Science and Its Relevance to the Human Sciences. Land Change Science. Part V: 431-447.

Turner II, B. L. E. F. Lambin, and A. Reenberg. 2007. The emergence of land change science for global environmental change and sustainability. Proceedings of the National Academy of Sciences (PNAS). 105(7):20666-20671.

United States Army Corps. Of Engineers (U.S.A.C.E.). 2000. Barnegat Bay Feasibility Study, Fish Ladders at Lake Pohatcong and Manahawkin Lake., Philadelphia, PA.

US Census. 1990. Census of Population and Housing, Historical Population Counts and STF-1A (Profile 1).

US Census, 2001. U.S. Census 2000, General Demographic Profiles.

U.S. Environmental Protection Agency, Region 2 Estuary Programs. http://www.epa.gov/region02/water/nep/

van der Muelen, F. and H.A. Udo de Haes. 1996. Nature conservation and integrated coastal zone management in Europe: present and future. Landscape and Urban Planning, 34: 401-410.

Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger and D. Tilman.1997. Human alteration of the global nitrogen cycle: Sources and consequences. Ecological Applications **7**:737–750.

Wolch, J. and Zhang, J. 2004. Beach recreation, cultural diversity and attitudes toward nature. Journal of Leisure Research. 36(3):414-443.