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Chapter 25
The Mismanagement of *Limulus polyphemus* in Long Island Sound, U.S.A.: What Are the Characteristics of a Population in Decline?

Mark A. Beekey and Jennifer H. Mattei

Abstract Over the past 15 years, horseshoe crabs in Connecticut have gone from being considered a nuisance species to a species of Greatest Conservation Need in 2015. This has happened through first, its discovery as an economically important species, second through research of its ecological role in coastal estuaries, and third, through education of the public concerning its role in the environment and their own health. To manage horseshoe crab populations successfully requires long term monitoring, research and education. The use of annual or biannual trawl data trends to assess the success of management decisions is limited due to the high variance of counts by location, season, and year, and is prone to misinterpretation. Trawling also damages the very habitat that the target species needs to survive. What is required to reach the goal of a sustainably managed population is the determination of local population dynamics and then modifying management practices to maximize reproductive success of the species. In Long Island Sound (LIS), these basic requirements for sustainable management have not been available until recently. The two states that manage horseshoe crabs in Long Island Sound (Connecticut and New York) have drastically different harvest regulations and management plans that are clearly not working. The LIS horseshoe crab population has declined and remains low as shown by both the long term trawl data and our long term mark-recapture data. After 13 years of a classic ecological study we found the Long Island Sound horseshoe crab population to be one discrete management unit where at least 3 % of the recaptures were found to cross the Sound. The LIS population is aging with low recruitment of newly molted adults and is reproducing well below its maximum rate. We observed very low spawning densities, increasing numbers of single females on the beach, and less than 6 % of polyandrous mating behavior. These basic population trends over the length of this study indicate the current harvest quotas and management techniques are not sustainable. We recommend at

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the very least the implementation of a unified management plan for Long Island Sound with one shared harvest quota for the entire LIS population. Second, we suggest that the number of no-harvest zones should be increased on both sides of the Sound and a ban of the harvest of spawning females should be added to existing harvest regulations. Ultimately, we would recommend the establishment of multiple Marine Protected Areas (MPAs) within LIS where the entire MPA is off limits to commercial or recreational fishing of any type.

Keywords Long Island Sound • Population dynamics • Mark-recapture data • Harvest regulations • Home range • Condition • Prosomal width • Operational sex ratios

25.1 Introduction

Historically, horseshoe crab (*Limulus polyphemus*) populations within US waters seemed boundless. With wide-ranging populations and very high fecundity, sustainable management plans were not deemed necessary. It was not until the 1990s that the *Limulus* populations experienced a notable decline, most rapidly in the mid-Atlantic region (Millard et al. 2015). Within Long Island Sound (LIS), the horseshoe crab had been harvested and used as bait for decades (Berkson and Shuster 1999). Harvest quotas of this species have been implemented in the states of Connecticut and New York, over the past 15 years, in compliance with the Atlantic States Marine Fisheries Commission (ASMFC) mandate to produce a Fishery Management Plan for *Limulus*. In Connecticut, the harvest quotas are rarely reached through the self-reporting system that has been implemented. Yet, the population in Long Island Sound continues to decline (Fig. 25.1).

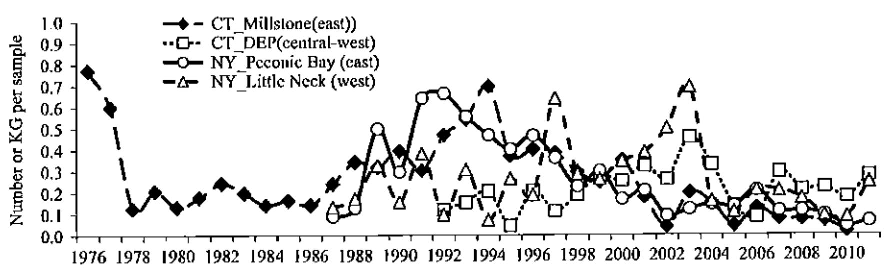

Fig. 25.1 Horseshoe crab indices of relative abundance in Long Island Sound (LIS). The number or kg of horseshoe crabs per sample (tow or seine) is plotted over time. The Millstone Power Station Trawl Monitoring Program (Dominion Nuclear Connecticut) records counts per tow and is conducted bi-weekly year round at fixed stations (total scheduled tows = 234–243) in the vicinity of the power station (Niantic River, Niantic Bay, and Jordon Cove) in eastern LIS. CT_DEP indices are based on central and western CTDEEP Long Island Sound Trawl Survey stations and represent kg/tow. NYSDEC Peconic Bay and Little Neck Bay indices are based on seine surveys and represent number horseshoe crabs per seine. Data obtained from Penny Howell, CTDEEP, Connecticut Compliance Report for Horseshoe Crab, March 2014

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It is more than likely that the legal harvest of horseshoe crabs is only one source of mortality in this population. Some of the greatest losses to these economically important populations are the illegal, unregulated, and unreported (IUU) take of horseshoe crabs (Vincent and Harris 2014). Thousands of horseshoe crabs can get caught in water intake pipes used to cool shoreline power plants and industrial complexes (Applied Biology 1980). They also become bycatch during bottom trawling operations. Bottom trawling and dredging for shellfish indiscriminately pulls up many of the organisms in the benthic area and destroys the habitat as it goes. The ASMFC supports trawling for "stock assessment" purposes, yet this very activity causes harm directly or indirectly to the species that are being sustainably managed and to many species that are not currently under a management plan but are clearly part of the food web. Other causes of horseshoe crab population decline would include the loss of eggs, young of the year and subsequent juvenile life stages (at least 8–10 years of development). Causes of mortality include predation and a long list of destructive human activities: e.g., habitat degradation, pollution, invasive species, and climate change to name the most damaging (Vincent and Harris 2014).

Successful fishery/wildlife management plans would include an understanding of horseshoe crab population dynamics and life history characteristics, which can vary depending on the local environment (Walls et al. 2002). A sustainable management plan would include regulations that will maximize reproductive output and juvenile survival as well as maintain ecological services that adult horseshoe crabs provide in estuaries. Previous studies have documented that the low density of horseshoe crab populations in Long Island Sound limits egg predation by shorebirds (Beekey et al. 2013) and contributes to changes in mating behavior such as a decline in polyandry and the presence of single females on the spawning beaches (Mattei et al. 2010).

Many questions remain unanswered about general life history and population characteristics of horseshoe crabs that reside in LIS that would aid management strategies:

1. Do horseshoe crabs exhibit site fidelity within and across spawning seasons; this is important in informing conservation decisions
2. Do horseshoe crabs have home ranges and if so what is their general size; this is important to know when establishing no-harvest zones
3. Do horseshoe crabs cross the Sound from Connecticut to the north shore of Long Island, NY; this knowledge would help define the size of the population management unit
4. Do LIS horseshoe crabs leave LIS and if so, where do they go; the rates of immigration and emigration are important in population analyses
5. What is the ratio of new recruits into the breeding population using shell condition; this is an indication of an expanding or declining population and survival rates of juvenile horseshoe crabs
6. Do LIS horseshoe crabs exhibit similar population characteristics to other populations of horseshoe crabs further north in New England or further south in Delaware Bay?

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Here, we present an analysis of a long-term data set collected by researchers and a large group of well-trained citizen-scientists associated with Project *Limulus* (www.projectlimulus.org) to provide answers for these general questions about the population characteristics of horseshoe crabs in Long Island Sound. We examine current management strategies and recommend changes based on the results of this long-term study. It is important for the Department of Energy and Environmental Protection and Department of Environmental Conservation agencies of Connecticut and New York State, respectively, to manage the Long Island Sound population of horseshoe crabs cooperatively to achieve a sustainable fishery; sustainably managing Atlantic coastal fisheries was the original vision of the ASMFC when it was established in the 1940s and remains its mission today.

25.1.1 Horseshoe Crab Management History

The Atlantic States Marine Fisheries Commission (ASMFC) was founded with the goal for the Atlantic states to cooperatively and sustainably manage their shared migratory fishery resources with assistance from a number of federal agencies.

> An Interstate Compact, ratified by the member states and approved by the U.S. Congress in 1942, affirmed the states' commitment to cooperative stewardship in promoting and protecting Atlantic coastal fishery resources. (asmfc.org)

Since 1998, representatives from ASMFC member states have overseen the management of the horseshoe crab fishery (ASMFC 1998). The ASMFC produced an interstate Fishery Management Plan (FMP) for horseshoe crabs with the long term goals of maintaining sustainable levels of spawning adults required to ensure the horseshoe crabs' continued role in the ecology of coastal ecosystems as well as providing for continued use by humans in the biomedical and bait industries. However, the horseshoe crab population data available to the ASMFC members was limited and flawed (Walls et al. 2002). Over the past 16 years, seven addendums have been added to the FMP for horseshoe crabs including state-by-state harvest quotas, monitoring requirements and management recommendations that in some cases recommended harvest closures. Recently, the ASMFC adopted an Adaptive Resource Management Framework (ARM) in 2012 (implemented in 2013) for horseshoe crabs originating in Delaware Bay. The ARM framework will utilize a suite of multispecies models including the status of *Limulus* and Red Knot (*Calidris canutus rufa*) populations to derive an annual allowable harvest that will be allocated among the four bay-area states (Delaware, New Jersey, Maryland, and Virginia; Millard et al. 2015). Obviously, the ARM model requires ongoing and accurate horseshoe crab stock assessments.

The most recent coast-wide stock assessment conducted in 2013 indicates that in general, horseshoe crab abundance has increased along the Delaware Bay and Southeastern US regions while declining across New England (Maine, New

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Hampshire, Massachusetts, Rhode Island) and New York regions (New York State and Connecticut, see Fig. 25.1). Declines in the New England region had been evident in the 2004 Stock Assessment and the 2013 Stock Assessment confirmed the continued decline (ASMFC 2013). Trends of the New York Region surveys are variable. In western Long Island Sound, there was evidence for increasing or stable trends, while in eastern Long Island Sound/Peconic Bay, there has been a steady decline from peak levels during the mid-1990s with current levels slightly lower than levels in the mid-1980s (Smith et al. 2009; CTDEEP 2014). Harvest regulations put in place as a result of the ASMFC management plan have been successful as evident from the increasing horseshoe crab population in Delaware Bay where regulations reduced harvest by 85 % from 2000 to 2006 (Smith et al. 2009). Additionally, horseshoe crab populations in Delaware Bay were protected by the establishment of the Carl N. Shuster, Jr. Horseshoe Crab Reserve in federal waters off the mouth of the Delaware Bay estuary where horseshoe crab harvest is prohibited.

However, reduced harvest in Delaware Bay was accompanied by an increase in harvest across other regions. The New England and New York region states along with the State of Virginia saw horseshoe crab landings increase significantly after 2005 (for review, see Smith et al. 2009). This pattern of redirected harvest has raised concerns for the sustainability of populations across New England and New York regions. Numerous studies have been carried out over recent years that have revealed the vulnerability of horseshoe crab populations across New England to over-harvesting (Gibson and Olszewski 2001; Carmichael et al. 2003, 2004; Rutecki et al. 2004; James-Pirri et al. 2005; Grady and Valiela 2006; James-Pirri 2010; Schaller et al. 2010). Taken together as an aggregate, one clear conclusion from these studies is that the New England region is composed of a series of coastal embayments that support horseshoe crab populations with different characteristics and limited dispersal of adults and larvae among them. These studies helped trigger more specific regulations at the local level. For example, harvesting horseshoe crabs for bait was prohibited in Pleasant Bay, MA, and harvesting was completely banned within the Monomoy National Wildlife Refuge and Cape Cod National Seashore. In Rhode Island, regulations were implemented that prohibited harvesting from 48 h preceding and following the full and new moons from May to July (Smith et al. 2009).

The horseshoe crab population in the Delaware Bay region is dominated by one large intermixing population and management is tailored to the inter-specific relationship between horseshoe crabs and migratory shorebirds (King et al. 2005; Swan 2005; Smith et al. 2009). In contrast, the New England region is comprised of many embayment-specific populations, and consequently management regulations are more localized as a result of embayment-specific population assessments. Regulations tailored to specific population and habitat characteristics are important as variation in these characteristics can affect recovery time of an overharvested population, and measures employed may need years of assessment before discovering what strategy will speed population recovery (Beekey et al. 2013).

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25.1.2 Management of Horseshoe Crabs in Long Island Sound

The Long Island Sound estuary (Fig. 25.2), with over 600 miles of coastline and 1,320 mile^2 of open water, is currently managed separately by the states of Connecticut (CT) and New York (NY). Their horseshoe crab management strategies and regulations are different although both states rely on self-reporting by harvesters. New York implemented an annual harvest quota of 150,000 horseshoe crabs in 2012, approximately 41 % of the quota allowed under ASMFC regulations (Table 25.1). From 2008 to 2013, NY harvested an average of 147,450 horseshoe crabs. This is the second largest average harvest among all states between 2008 and 2012, representing 48 % of the coastal harvest outside of the four Delaware Bay region states. The bulk of the harvest for NY occurs along the southern shore of Long Island (57.1 % in 2013; NYSDEC 2013). Harvesters are required to obtain permits and submit monthly harvesting reports to the New York State Department of Environmental Conservation (NYSDEC) from August through April. During

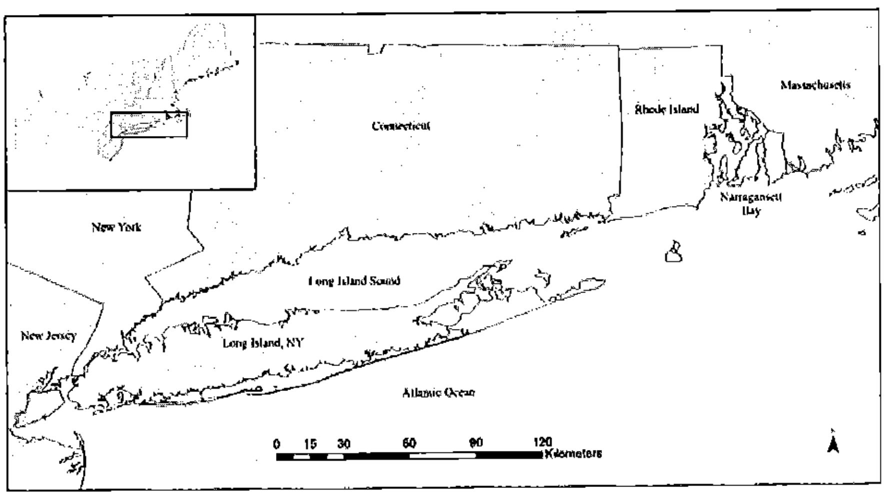

Fig. 25.2 *Inset*: Location of study area (*boxed*) within the northeastern United States. Our study area (*boxed*) includes the entire coast of Connecticut (CT), part of New York with coastline on Long Island Sound and the northern coast of Long Island, New York (NY)

Table 25.1 Reported commercial bait landings of horseshoe crabs for Connecticut and New York from 2008 to 2012

	Addendum IV quota	State quota 2012	2008	2009	2010	2011	2012	2013
CT	48,689	48,689	32,565	27,065	30,036	24,466	18,958	19,645
NY	366,272	150,000	148,719	123,653	124,808	146,995	178,899	161,623

Adapted from ASMFC (2013), CTDEEP (2014), NYDEC (2013)

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May, June, and July, permittees are required to submit harvesting reports on a weekly basis. Harvesting is permitted by hand harvest, pound net, trap net, gill net, otter trawl, seine or dredge. Dredges are not permitted in the Atlantic Ocean except during the months of September and October. Horseshoe crab harvesting is currently prohibited at two beaches on the north shore of Long Island at West Meadow Beach in Stony Brook and Cedar Beach in Mount Sinai as well as on the southern shore of Long Island within the Fire Island National Seashore managed by the National Park Service.

Connecticut's annual harvest quota is set by ASMFC at 48,689 animals, although their 6-year average harvest from 2008 to 2013 has been only 52 % of their allowed quota (Table 25.1) representing approximately 9 % of the coastal harvest not including the four Delaware Bay Region states (IUCN Red List Assessment, in review). In 2013, 66 % of harvested horseshoe crabs were collected west of the Connecticut River to the NY border (CTDEEP 2014). Connecticut prohibits all harvesting and landing from July 8 through May 21. During the open period from May 22 through July 7 harvest and landing is closed from 6:00 pm on any Friday through 6:00 pm on the following Sunday. Both a permit and an endorsement letter are required for harvest. Endorsement letters can only be obtained by those on record for possessing a harvest permit between 1999 and 2006. There is a 500-crab limit per 24-h period and harvesters are only allowed to hand-harvest spawning crabs up on beaches. In 2007, CT established three no harvest zones at Menunketesuck Island in Westbrook, Sandy Point in West Haven, and Milford Point, Milford, CT in order to maximize horseshoe crab egg availability for shorebirds utilizing those areas.

New York State and Connecticut clearly have differences between their horseshoe crab harvest regulations with respect to harvest quotas (3:1 difference), allowed manner of harvest (multiple methods vs. hand harvesting alone), harvesting pressure (NY – unevenly split between the southern and northern shore of Long Island versus 100 % of CT harvest within Long Island Sound), open seasons (year round vs. late May through July) although both States have started to implement similar management strategies with the establishment of protected areas. However, both states lack basic population data on horseshoe crabs within their boundaries. While numerous studies have been conducted in New England and Delaware Bay examining population trends (size, mating patterns, movement patterns, spawning densities, egg densities) that enhance management strategies (for review see Smith et al. 2009), various population indices for horseshoe crab populations in Long Island Sound are lacking. With recent stock assessments indicating declines in abundance of horseshoe crabs in the New York Region (ASMFC 2013), it is imperative that we assess the horseshoe crab populations in this region and determine whether the different management plans of CT and NY are sustainable over the long term.

First, spatial-temporal data leading to knowledge of resource use and home range sizes are necessary for informing conservation efforts. Clearly, developing a sustainable horseshoe crab management plan for Long Island Sound is dependent upon understanding whether Long Island Sound is one large intermixed population similar to Delaware Bay or representative of the New England Region where horseshoe crabs are arranged in smaller, localized and separate management units. Second, it

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is important that we understand how the population is changing over time. Changes in various indices such as physical size, sex ratios, mating patterns, and condition of crabs can supply management agencies with crucial information that can help determine whether populations are being harvested in potentially damaging manners (e.g. selectively harvesting large females or taking every spawning pair off of the beaches). Also, if populations are rapidly aging with little or no recruitment of newly molted adults, and if population densities are low, as measured by beach spawning counts, or indicated by numbers of single females coming up to spawn but cannot find mates, then management regulations need to be changed to protect the long term viability of the species in a given region.

25.2 Methods

It is difficult to study migration patterns of horseshoe crabs in a body of water with over 600 miles of coastline. Following the lead of federal researchers in Delaware Bay who employed fishermen to tag adult horseshoe crabs caught in trawls and state biologists who trained volunteers to census spawning crabs, we started a community research program in 2000, Project *Limulus* (www.projectlimulus.org) to train and organize volunteers to help gather information along the coastline of the Sound. This education/research endeavor utilizes citizen scientists from non-profit environmental organizations, local aquariums and zoos, K-12 school groups, along with undergraduate/graduate research assistants to tag crabs and collect population data mainly along the coastline of Connecticut, but also in the Sound bordered by the States of New York and Rhode Island. All Project *Limulus* volunteers were trained to tag horseshoe crabs and record specific data for each horseshoe crab they tagged on a common data sheet that was returned to Sacred Heart University (SHU) via mail or e-mail. Individuals and/or groups of volunteers tagged crabs on private and public beaches depending upon access. For data quality control, every April or early May we would meet with group leaders and review the protocols, data sheets and data collection methods and distribute the tags. Each group or conservation organization therefore, had a trained group leader that was mainly responsible for training new volunteers on their beach and returning the data sheets. Members of our research team at SHU would also perform site visits periodically during the tagging season. Tagging commenced each year in May as soon as the crabs started arriving on shore to spawn and ended when all of the tags were utilized or when the crabs stopped spawning. Tagging occurred during day and night hours and on low and high tides. Typically all crabs encountered were tagged until the tags were used up or when volunteers ran out of time. The majority of beaches where tags were deployed had more than 100 horseshoe crabs tagged per season, therefore the samples of tagged individuals were a representative sample of the spawning population at each location. Volunteers were trained to tag animals as they were found regardless of sex or current mating status. From 2000 to 2006, we tagged horseshoe crabs using yellow Floy Cinch-tags (model FT-4, 8″: http://www.floytag.com) with

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unique identification numbers and a SHU phone number for reporting tag information. Cinch tags were attached to the crab using a #1 Yellow scratch awl (Challenge Sailcloth, Inc. Vernon-Rockville, CT) to make a hole through the lower right or left rear of the prosoma. The cinch tags were strung through the hole and cinched tightly across the posterior edge of the prosoma. In 2007, we started utilizing white disc tags issued by the U.S. Fish and Wildlife Service (USFWS). Disc tags were attached to the crab using a #2 Yellow scratch awl with a #8 stainless steel washer affixed to the awl to act as a stop to prevent the hole from getting too large. The awl was gently twisted into the lower rear of either the right or left posterior side of the prosoma. Once a hole was made, the tree pin of the disc tag was firmly inserted into the hole. Each disc tag has a unique tag number and is imprinted with a toll free number and mailing address to report recapture information to the USFWS office in Annapolis, Maryland. Mortality due to tagging is highly unlikely within and across spawning seasons (Mattei et al. 2011).

The tag number, date, sex (based on the morphology of the pedipalps), prosomal width (greatest width in cm), mating status, location of tagging and release, and any additional remarks (e.g. damage) were recorded for each tagged crab. Mating status was recorded for each crab as follows: single male, single female, pair (female and amplexed male), or F+N where F is equal to a female and N equals the total number of males mating with her including the amplexed male (e.g. F + 2 equals a female with one amplexed male and one satellite male). Starting in 2012, the condition for each tagged crab was determined based on previous studies (Brockmann and Penn 1992; Penn and Brockmann 1995; Brockmann 1996). Horseshoe crabs have a terminal molt between the ages of 8–10 years old and live approximately 18–20 years based on record tag returns. The carapace of *Limulus* erodes over time (Brockmann and Penn 1992), and the dorsal prosomal surface changes in color from a light tan with fringing hair in newly molted adults to black and hairless in older adults. We scored carapace condition based on a scale of 1–3, where:

- Condition 1 was for a newly molted, glossy prosoma, fringed with hairs;
- Condition 2 was for an intermediate prosoma (i.e., showing scratches and other signs of wear, very little fringing hair and with some gray areas), and;
- Condition 3 was for a heavily worn, no hair, mostly blackened and pitted prosoma.

For analysis of this data, we assumed Condition 1 animals to be from 0 to 3 years past their terminal molt, Condition 2 adults were 3–6 years past their final molt and Condition 3 adults were older than 6 years past their final molt. For the Chi-square analysis we assumed an expected distribution of age classes to be one-third each. A growing population would have relatively more Condition 1 crabs. We obtained recapture data from a variety of sources but the majority of recapture data was reported by individuals associated with Project *Limulus* during tagging sessions. Additional information on recaptured crabs was obtained through the general public who reported information throughout the years via phone, e-mail, or by reporting the tag information to the USFWS horseshoe crab tag database via the toll-free number.

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We report the results from Milford Pt. and Sandy Pt. because the data was gathered by researchers and their supervised students from these two locations. We also show results from the combined data from all beaches in CT that includes the data from trained volunteers. Not all recapture reports called in by the public were complete; however, whenever possible, the data was used to determine differences between tag and recapture location, determine straight-line distance traveled between release and recapture location, time between release and recapture. The data were analyzed using regression analysis and one-way analysis of variance (ANOVA) in SPSS software.

25.3 Results

25.3.1 Spatial and Temporal Patterns

A total of 84,432 crabs were tagged from 2000 to 2013. Over that same period, 18,525 crabs were recaptured (Fig. 25.3) of which 72 % were live recaptures, 13 % reported as dead and 15 % with no information on their status. Over 600 volunteers associated with Project *Limulus* placed the majority of the tags deployed from 2006 to 2013 on crabs. The decrease in number of tags placed on crabs in 2012 and 2013 represents a decrease in the number of tags allotted to Project *Limulus* by the USFWS, not a decrease in volunteer participation. At the conclusion of the 2013 tagging season, our overall recapture rate was 22 %. In all, tags were put out on 241 different beaches with 75 % of the beaches along Connecticut's coastline, 21 %

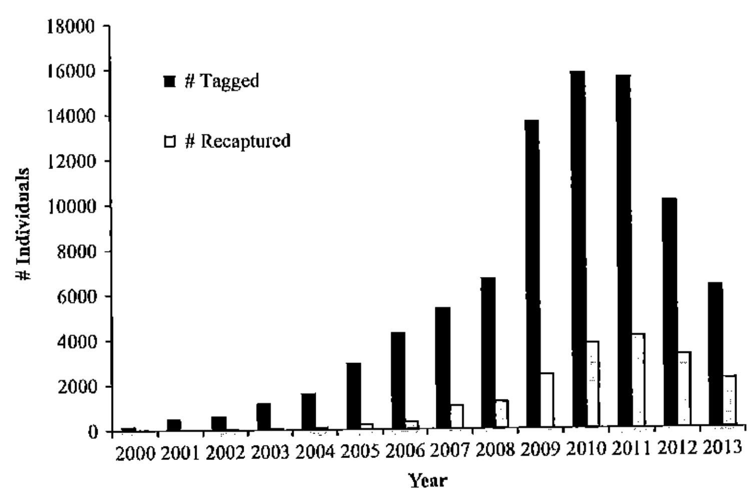

Fig. 25.3 Number of crabs tagged and recaptured by year from 2000 to 2013. Over 84,000 crabs were tagged during this time period, and over 18,000 recapture reports were generated

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along the mainland coastline of New York State and the north shore of Long Island, and 4 % of the sites within Rhode Island. Project *Limulus* stopped tagging along the north shore of Long Island in 2008 with the start of a cooperative tagging study jointly administered by NYSDEC and Cornell Cooperative Extension of Suffolk County; however, tagging has continued along New York State's western shoreline of Long Island Sound around the town of Rye in Westchester County (Table 25.2).

The percentage of crabs recaptured within the same year as they were tagged ranged from a low of 25 % in 2001 to a high of 78.4 % in 2002 (Table 25.3). During 2010 and 2011 when the greatest number of crabs were tagged, 52.7 % and 60.3 % were recaptured within the same spawning season. Overall, 58.7 % of the 18,525 recaptured crabs were recaptured within the first year of release. This percentage decreased exponentially over time (Fig. 25.4). Nearly 98 % of all recaptured horseshoe crabs were found within 4 years from when they were first tagged. Only three individuals (0.02 %) were recaptured 8 years after they were tagged.

Within a single spawning season, 73 % of recaptured crabs (N = 10,650) were recaptured at the same beach as they were tagged; 85 % were recaptured within the same city (different beaches) as they were tagged; and 98 % were recaptured within the same state as they were tagged. On average, crabs were recaptured 2.64 ± 10.3 (S.D.) km away from their original tag site. After one spawning season, 22 % of recaptured crabs (N = 7,488) were reported from the same beach where they were tagged; 36 % were recaptured within the same city; and 83 % were recaptured within the same state. After the first spawning season had passed, crabs were recaptured on average 12.6 ± 22.6 (S.D.) km from where they were tagged. Twenty percent of the recaptured crabs after one season were more than 20 km from where they were originally tagged after the initial spawning season (Fig. 25.5).

For those crabs tagged in Milford (N = 1,073) and New Haven (N = 852), CT from 2000 to 2013, 84–87 % of crabs, respectively, were recaptured within 16–18 km of the tagging beach after the first spawning season (Fig. 25.6a, b). While separated from the northern shoreline of Long Island by up to 33 km, crabs tagged at Milford and New Haven, CT have been recaptured across the sound near Port Jefferson along the north shore of Long Island, NY (Fig. 25.6a, b). Close to 3.5 and 2 % of crabs tagged in Milford and New Haven, CT, respectively, were recaptured across the Sound. Three crabs originally tagged at Milford and only one crab originally tagged at New Haven were recaptured on the south shore (i.e. Atlantic Ocean side) of Long Island. No recaptures of crabs tagged at Milford or New Haven have been reported from Rhode Island or Massachusetts.

For horseshoe crabs originally tagged in Stamford and Greenwich, CT 67 % were recaptured within 16 km of their original tag site (Fig. 25.7a). Nearly 16 % of all crabs tagged in Greenwich/Stamford were recaptured in NY either along the north shore of Long Island or NY's southwestern shoreline of Long Island Sound (Fig. 25.7a). Approximately 30 % of recaptured horseshoe crabs (N = 1,424) originally tagged in Groton and Stonington, CT were found in Rhode Island and <1 % were recaptured in Massachusetts (Fig. 25.7b). On average, crabs were recaptured 8 km away from where they were tagged. Nearly 3 % of crabs tagged in either Groton or Stonington were recaptured on New York State's Fishers Island and close

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Table 25.2 Summary of the cumulative number of crabs tagged, cumulative number of recaptures, and recapture rate from 2000 to 2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Cumulative # crabs tagged	354	831	1,436	2,584	4,172	7,077	11,327	16,659	23,303	36,920	52,681	68,253	78,343	84,644
Cumulative # recaptures reported	7	12	49	112	208	431	751	1,762	2,956	5,347	9,123	13,207	16,464	18,651
Recapture rate (%)	2.0	1.4	3.4	4.3	5	6	6.6	10.6	12.7	14.5	17.3	19.4	21.0	22.0

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Table 25.3 Summary of the temporal distribution of recaptured crabs by year tagged

Year	# Tagged	Total Recaps	# Tagged individuals recaptured (percentage) by year													
			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2000	142	8	3	1	3						1					
			(37.5)	(12.5)	(37.5)						(12.5)					
2001	477	16		4	5	1	1	3	2							
				(25.0)	(31.3)	(6.3)	(6.3)	(18.8)	(12.5)							
2002	605	37			29	4	1	2	1							
					(78.4)	(10.8)	(2.7)	(5.4)	(2.7)							
2003	1,148	91				58	16	10	4	2		1				
						(63.7)	(17.6)	(11.0)	(4.4)	(2.2)		(1.1)				
2004	1,588	146					78	37	15	5	3	6			2	
							(53.4)	(25.3)	(10.3)	(3.4)	(2.1)	(4.1)			(1.4)	
2005	2,905	277						170	37	37	11	13	8		1	
								(61.4)	(13.4	(13.4)	(4.0)	(4.7)	(2.9)		(0.4)	
2006	4,250	408							259	75	29	18	19	6		2
									(63.5)	(18.4)	(7.1)	(4.4)	(4.7)	(1.5)		(0.5)
2007	5,332	1,163								892	134	53	54	15	14	1
										(76.7)	(11.5)	(4.6)	(4.6)	(1.3)	(1.2)	(0.1)
2008	6,644	1,827									1015	413	228	100	43	28
											(5.6)	(22.6)	(12.5)	(5.5)	(2.4)	(1.5)
2009	1,3617	4,072										1882	1130	561	310	188
												(46.2)	(27.8)	(13.8)	(7.6)	(4.6)

The total number of tags deployed each year of the study are presented along with the total number of recaptures from that tagging year grouped by the number of tagged individuals recaptured during the initial and subsequent years (percentage in parentheses)

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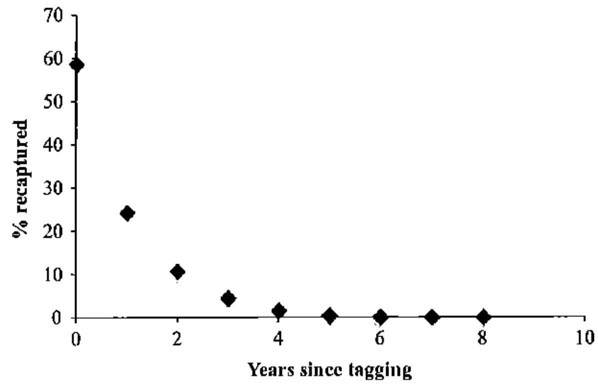

Fig. 25.4 Percentage of all crabs recaptured as a function of year since originally being tagged. The longest period of time elapsed from the date of tagging to recapture was a female crab tagged on 6/1/2000 and recaptured on 7/26/2008

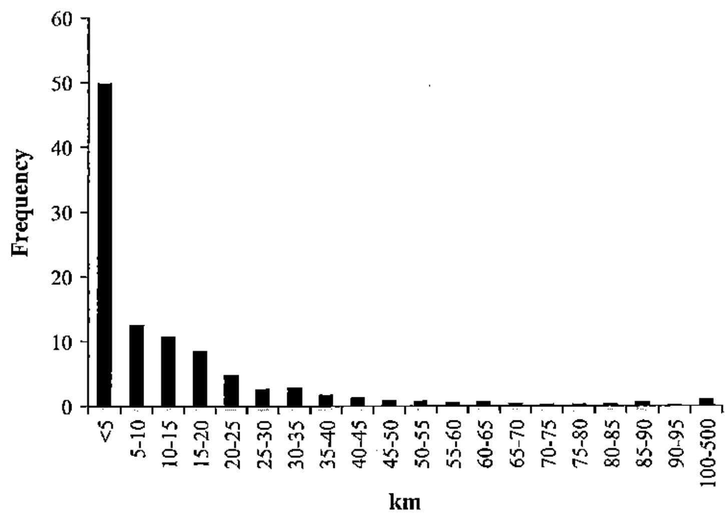

Fig. 25.5 The frequency of straight line distance (km) traveled by crabs tagged from 2000 to 2013 and recaptured after at least 1 year had passed since their initial tagging (N=7488)

to 1 % of the crabs were recaptured on the north shore of Long Island near Orient Point (northeasterly tip of Long Island).

25.3.2 Population Characteristics

Female horseshoe crabs averaged 25.4 ± 2.4 cm SD (N = 14,020) in prosomal width. Prosomal width of males averaged 19.6 ± 1.8 cm SD (N=24,050). Overall there has been no significant change in prosomal width for females (R^2=0.03, p>0.05) since 2000. However, male prosomal width has decreased significantly since 2000

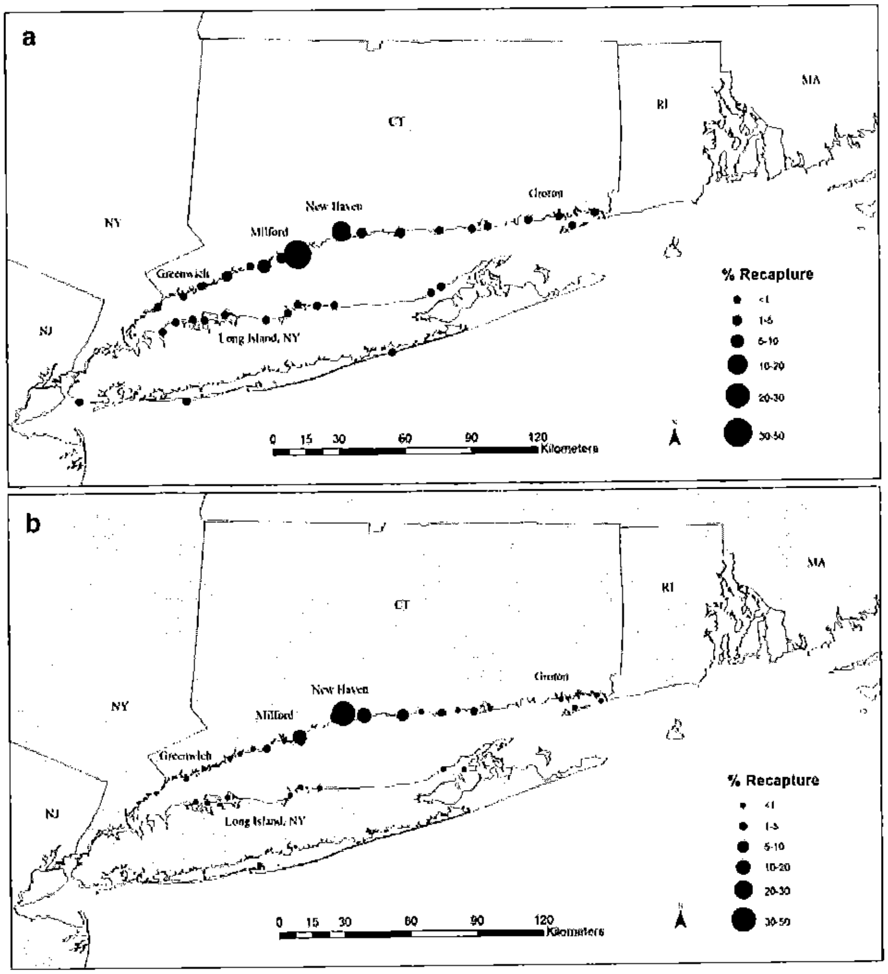

Fig. 25.6 Recapture location and frequency (%) of crabs originally tagged at (a) Milford, CT (*top*) and (b) New Haven, CT (*bottom*) and recaptured. The most eastern point–Stonington, western–Rye, NY and across the Sound on eight beaches of the North Shore of Long Island, NY

($R^2=0.296$, $p<0.05$) (Fig. 25.8). Male to female sex ratios on beaches where crabs are tagged decreased on average from 2006 to 2013 although not significantly ($R^2=0.062$, $p>0.05$) (Fig. 25.9a). At our two main research sites (Milford Point, MP and Sandy Point, SP) where we have focused our research efforts using research assistants, operational sex ratios on spawning beaches, while not significant, have decreased on average over time (MP, $R^2=0.045$, $p>0.05$; SP, $R^2=0.081$, $p>0.05$) (Fig. 25.9b).

Mating status data collected while tagging from 2007 to 2013 indicates the number of single females observed on beaches across CT generally increased ($R^2=0.436$, $p>0.05$) while the number of females with one male (paired females)

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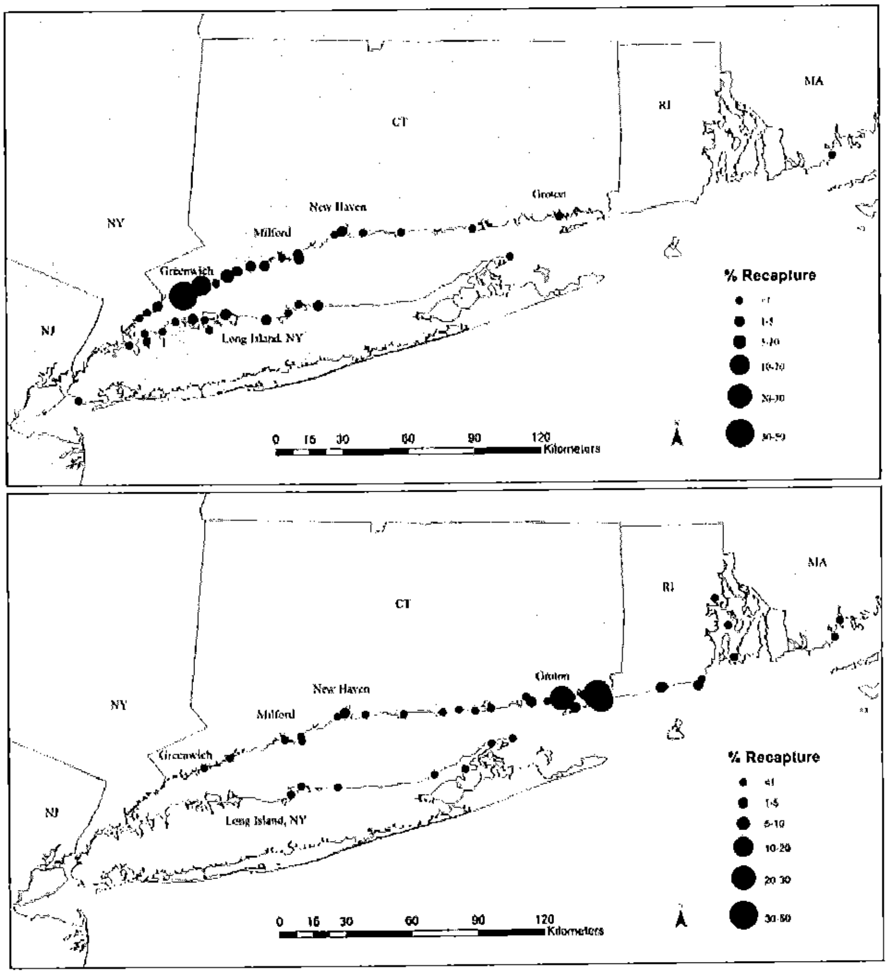

Fig. 25.7 Recapture location and frequency (%) of crabs originally tagged at (a) Greenwich/Stamford, CT (*top*) and (b) Groton/Stonington, CT (*bottom*)

($R^2=0.382$, $p>0.05$) and females with multiple males (one amplexed male and one or more satellite males) ($R^2=0.205$, $p>0.05$) decreased (Fig. 25.10a). At Milford Point (Fig. 25.10b), the number of single females has risen steadily since 2007 ($R^2=0.522$, $p>0.05$) while the number of paired females ($R^2=0.586$, $p<0.05$) and females with multiple males ($R^2=0.205$, $p>0.05$) have decreased. In contrast, the number of single females at Sandy Point has decreased slightly since 2007 ($R^2=0.097$, $p>0.05$), while the number of females with multiple mates has slightly increased ($R^2=0.441$, $p>0.05$). Paired females have remained relatively stable ($R^2=0.098$, $p>0.05$) (Fig. 25.10c).

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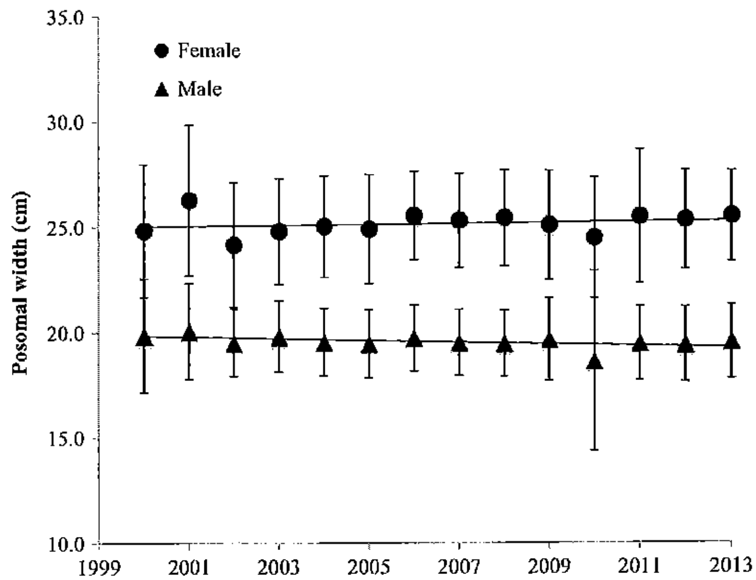

Fig. 25.8 Prosomal width (cm) by sex and year from 2000 to 2013. Regression equations as follows: Females: $y = 0.02x - 18.41$, $R^2 = 0.030$, $p > 0.05$; Males: $y = -0.04x + 104.07$, $R^2 = 0.296$, $p < 0.05$

Condition data was collected in 2012 and 2013 on a sample of adult spawning horseshoe crabs (N=9,908, N=6,165, respectively). Overall, for the combined sexes Condition 1 (newly molted adults) were significantly less abundant than Condition 2 and 3 in both years, 2012 (Fig. 25.11a, $\chi^2 = 1923.9$ $p < 0.00001$) and for 2013 (Fig. 25.11b, N=6,165, $\chi^2 = 977.6$, $p < 0.00001$). Condition 1 females without any mating scar across the opisthosoma were never observed. The number of Condition 1 females and males (new recruits) remained relatively stable from 2012 to 2013 while the number of Condition 2 ("middle aged") females and males decreased by 2.5 % and 4.3 % respectively (Fig. 25.12a). Condition 3 females and males increased on average by 2.4 %. There were fewer Condition 1 males than females in both 2012 and 2013. While the percentage of Condition 1 females and males is higher at Milford Point than the overall pattern, the decrease in the percentage of condition 2 females and males was higher than the overall average at 9.5 % and 23.7 %, respectively (Fig. 25.12b). The increase in number of Condition 3 females and males at Milford Point from 2012 to 2013 was also greater compared with the pattern observed overall in LIS. The percentage of Condition 1 females at Sandy Point was higher than the overall pattern in 2012 and 2013 (Fig. 25.12c). Also, the percentage of Condition 3 males at Sandy Point decreased from 2012 to 2013.

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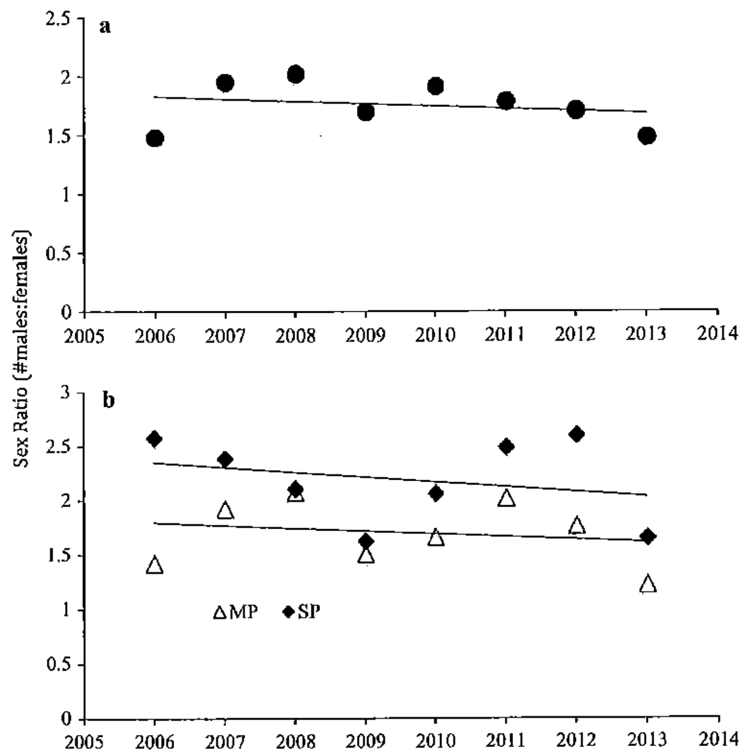

Fig. 25.9 Sex ratio (number males:females) by year from 2006 to 2013. (**a**) Overall sex ratios ($y = -0.02x + 43.58$, $R^2=0.062$, $p=0.552$) (*top panel*), (**b**) Sex ratios for Milford (MP) ($y = -0.03x + 54.33$, $R^2=0.045$, $p=0.613$) and Sandy Point (SP) ($y = -0.05 + 93.26$, $R^2=0.081$, $p=0.495$) (*bottom panel*)

25.4 Discussion

25.4.1 Spatial and Temporal Patterns

Discernable patterns obtained from recapture data are largely due to the amount of temporal and spatial surveillance that occurs post tagging as well as accessibility to various beaches where horseshoe crabs spawn. Immediate recaptures or recaptures within a few days are more likely to occur given that volunteers are actively tagging during the initial period of the spawning season until they run out of tags. This creates a bias in favor of short-term recoveries. However, even this short term recapture data is important because it demonstrates the idea that females come to shore multiple times to lay eggs and males do also. The data reveals that some females make their nests across several beaches in a particular area during one spawning season. Accessibility creates a bias with respect to the ability to detect movement patterns since volunteers and the general public are not searching every kilometer of

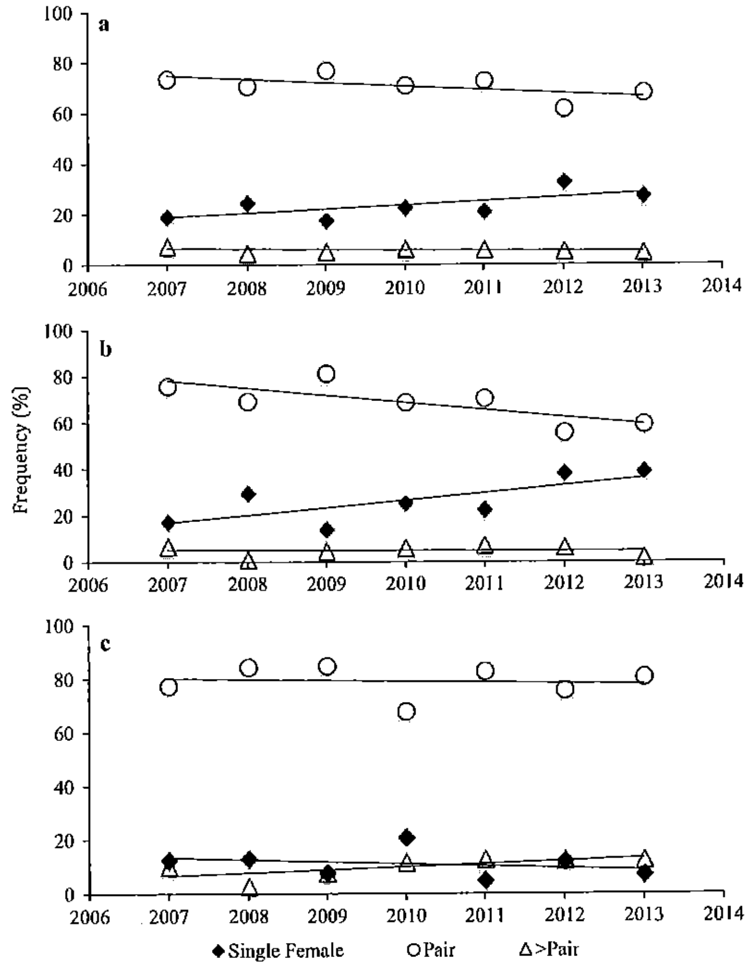

Fig. 25.10 Mating patterns for females tagged from 2007 to 2013. Paired females (P) (*circle*), single females (SF) (*diamond*), and females with multiple mates including amplexed male and additional satellite males (FM) (*triangles*) are plotted for (**a**) Females tagged at all sites ($P: y = -1.39x + 2862.5$, $R^2 = 0.38$, $p > 0.05$; $SF: 1.59x - 3167.4$, $R^2 = 0.43$, $p > 0.05$; $FM: y = -0.1985x + 404.86$, $R^2 = 0.205$, $p > 0.05$); (**b**) Females tagged at Milford Point ($P: y = -3.1423x + 6384.7$, $R^2 = 0.586$, $p < 0.05$; $SF: 3.2191x - 6443.9$, $R^2 = 0.52$, $p > 0.05$; $FM: y = -0.0768x + 159.16$, $R^2 = 0.004$, $p > 0.05$); and (**c**) Females tagged at Sandy Point, New Haven ($P: y = -0.3499x + 782.4$, $R^2 = 0.015$, $p > 0.05$; $SF: -0.7661x + 1550.9$, $R^2 = 0.097$, $p > 0.05$; $FM: y = 1.116x - 2233.3$, $R^2 = 0.440$, $p > 0.05$)

the coastline where crabs can reappear after initial tagging. However, even with these biases, mark- recapture data can provide general information on spatial and temporal patterns with respect to horseshoe crab movement, particularly when large numbers of tags are deployed over a 10–14 year study period.

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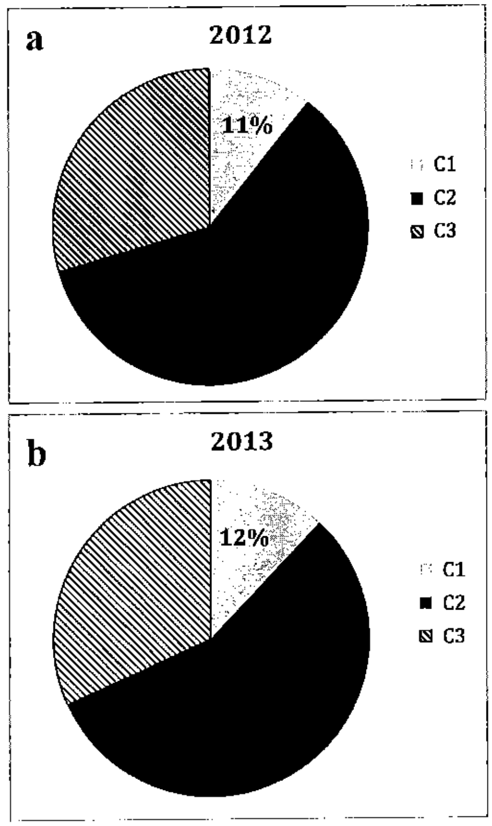

Fig. 25.11 Total frequency (%) of Condition 1, 2 and 3 for (**a**) 2012 (N = 9,908, χ^2 = 1923.9 p < 0.00001) and (**b**) 2013 (N = 6,165, χ^2 = 977.6, p < 0.00001)

1) Do horseshoe crabs exhibit site fidelity within and across spawning seasons; this is important in informing conservation decisions?

Within a spawning season, horseshoe crabs generally remain at the initial spawning beach where they were tagged over the course of successive tides. For instance, one female tagged at Milford Point on May 26th, 2005 was repeatedly sighted at the same beach over the next 6 days before disappearing. Horseshoe crabs that were recaptured at different beaches from where they were originally tagged within a spawning season were typically found within 2 km. This is likely because spawning horseshoe crabs never leave the shore zone to any great distance (Swan 2005). This within spawning season movement pattern has been observed in other populations along the Atlantic coast (Plum Island Sound, MA – Baptist et al. 1957; Cape Cod, MA – Widener and Barlow 1999; James-Pirri et al. 2005; Delaware Bay – Swan 2005; Great Bay Estuary, ME – Schaller et al. 2010). Thus within a spawning season there is strong evidence for moderate site fidelity.

2) Do horseshoe crabs have home ranges and if so what is their general size; this is important to know when establishing no-harvest zones?

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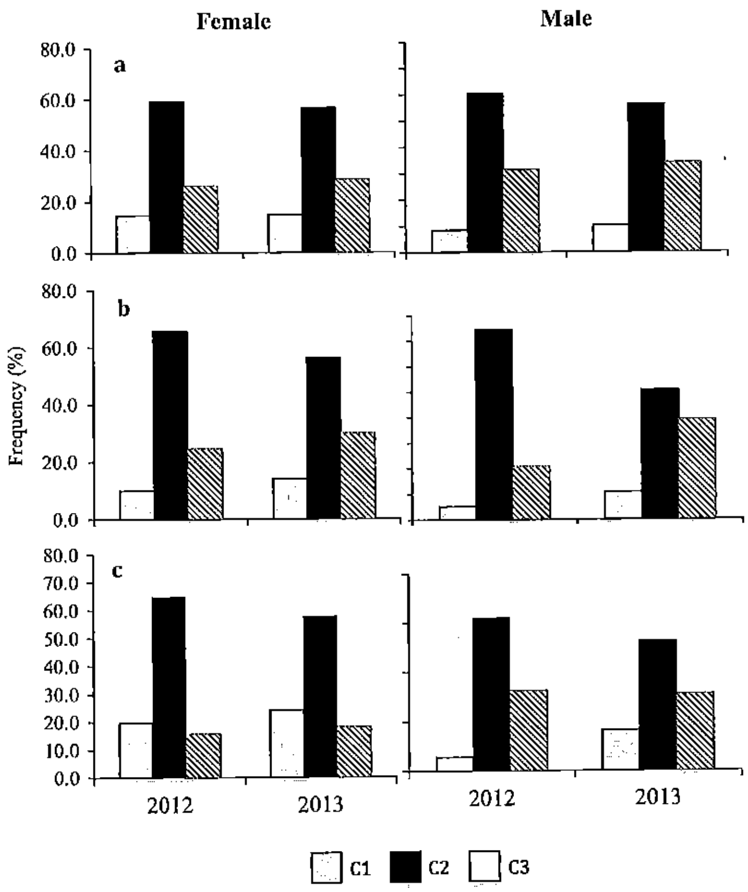

Fig. 25.12 Frequency (%) of crab conditions (1, 2, and 3) of tagged female and male crabs from (a) all tagging sites, (b) Milford Point, and (c) Sandy Point

After one season, horseshoe crabs in Long Island Sound (LIS) disperse more widely and are frequently recaptured on beaches other than the one they were originally tagged on. Of all crabs recaptured in subsequent spawning seasons (N=7,488), only 22 % were recaptured on the same beach as they were tagged compared to 73 % within a single spawning season. Thirty six percent of all recaptured crabs were resighted within the city limits of their original tagging location (approx. 3 km) compared to 85 % of crabs within a spawning season. However, given the differences in dispersal distances across spawning seasons, long distance dispersal was not common.

3) Do horseshoe crabs cross the Sound from Connecticut to the north shore of Long Island, NY; this knowledge would help define the size of the population management unit?

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Of the 17,086 recaptured crabs originally tagged along the CT coastline, only 2.2 % were recaptured on the northern shoreline of Long Island, New York indicating that they had crossed the Sound. Three percent (N = 541) were recaptured outside of Long Island Sound. The majority of these crabs were recaptured along the coastline of Narragansett Bay, Rhode Island (N = 511) or the southeastern coastline of Massachusetts (N = 12). Only 12 of the crabs originally tagged in CT were recaptured along the southern shore of Long Island, New York. Three crabs were reported from the Atlantic coastline of New Jersey, and one crab tagged in CT was recaptured along the Atlantic coastline of Maryland near Ocean City. On average, crabs were recaptured within 12 km of their original spawning site over subsequent spawning seasons. Greenwich/Stamford crabs were routinely recaptured on the north shore of Long Island. Clearly, crabs in the narrower western portion of Long Island Sound move more readily between CT and NY than crabs in the wider central portion of LIS. While more extensive than within spawning season, these data again reinforce the notion that horseshoe crabs have localized home ranges. Over the long term, horseshoe crabs in Long Island Sound, like in Delaware Bay (Swan 2005), are one large and interbreeding population. In fact, a genetic study of horseshoe crabs in Long Island Sound found no evidence of subpopulation structure, no evidence of inbreeding depression and that the population was in Hardy-Weinberg equilibrium (Kasinak et al. 2011).

4) Do LIS horseshoe crabs leave LIS and if so, where do they go; the rates of immigration and emigration are important in population analyses?

The recapture data indicate that there is very limited dispersal between LIS horseshoe crabs and populations to the south (southern shore of New York's Long Island, New Jersey, and Delaware) as well as populations to the north around and above Cape Cod, Massachusetts. Narragansett Bay is the only embayment with which Long Island Sound crabs are likely to intermix with, and even then, the data suggests it is mostly a result of dispersal between crabs in the easternmost portion of Long Island Sound near Groton, CT (Fig. 25.6b).

Earlier studies have demonstrated that crabs could survive for up to 5 years after they started spawning (Shuster 1950; Baptist et al. 1957; Ropes 1961). Botton and Ropes (1988) later concluded that adult crabs could live up to at least 8 years after their terminal molt. While tag loss has been demonstrated to affect tag recovery over time (Butler 2012), tagging studies can offer insight into horseshoe crab life spans once they have undergone a terminal molt and reached sexual maturity. Swan's tagging study in the Delaware Bay recorded recaptures up to 10 years post tagging (2005). In this study, only 2 % of all recaptures were resighted 4 or more years after their initial tagging (Fig. 25.4). Three crabs were recaptured 8 years after their initial tagging (Table 25.3) indicating potential life spans as outlined in previous studies.

25.4.2 Population Characteristics

One concern that has arisen with the harvesting of horseshoe crabs is that large females are preferentially targeted. Harvesters prefer females for use as bait (ASMFC 1998) because they can be cut up to bait as many as four pots, whereas cut males

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typically bait one to two pots (Manion et al. 2000). Eel fishermen also prefer egg-laden females due to the presumed chemical attractants found in the eggs (Ferrari and Targett 2003). The biomedical industry preferentially harvests female crabs with the assumption that they furnish more lysate (USFWS 2002). Reductions in the harvest quotas for Delaware Bay have redirected harvest pressures from the Delaware Bay to other regions (Smith et al. 2009). If there were preferential harvest of females in Long Island Sound, one would expect to see a decrease in female size and/or an increase in the operational sex ratio during spawning season when the majority of the crabs were tagged. Our long-term size data collected since 2000 indicates no significant trend in female or male size since 2000 (Fig. 25.7). Mean female ($\bar{X} = 25.4$ cm, range 12–41 cm) and male ($\bar{X} = 19.6$ cm, range 10–32 cm) prosomal widths for LIS horseshoe crabs are within the range of widths reported for Delaware Bay (females: $\bar{X} = 26.7$ cm, range = 22.5–27.2 cm; males $\bar{X} = 20.7$ cm, range = 17.5–24.5 cm) but on average larger than crabs from Massachusetts (females: $\bar{X} = 25.3$ cm, range = 12.6–29.5 cm; males $\bar{X} = 17.5$ cm, range = 9.7–25.0 cm) females and Rhode Island (females: $\bar{X} = 24.0$ cm, range = 20.1–30.0 cm; males $\bar{X} = 18.6$ cm, range = 15.9–22.4 cm) (Graham et al. 2009).

Since 2007, overall sex ratios (males:females) in Long Island Sound have decreased from 1:2 to 1:1.5 (Fig. 25.9). In Pleasant Bay, MA and Delaware Bay, the sex ratio of the entire population (not just while spawning) is skewed towards males (Carmichael et al. 2003; Smith et al. 2006). On spawning beaches, operational sex ratios are expected to be more skewed towards males due to their reproductive behavior and population demographics. Males typically spend more time on spawning beaches than females (Brockmann and Penn 1992). One male attaches to the female in amplexus while unattached satellite males surround the pair during fertilization in 40–50 % of the spawnings in Delaware Bay, while in LIS satellite behavior is only seen in 5–10 % of the spawning females depending on the beach (Mattei et al. 2010). In Cape Cod, typical spawning sex ratios range from one female to every two to three males (James-Pirri et al. 2005) while in Delaware Bay, spawning sex ratios ranged from 1:1.5 to 1:5 (Shuster and Botton 1985; Swan et al. 1996; Smith et al. 2002). Harvesting can increase the sex ratio (more males per female) on spawning beaches over time due to preferential selection of females (James-Pirri et al. 2005; Smith et al. 2009). In 2001 in Pleasant Bay, MA, an area exploited by the bait and biomedical fisheries, spawning sex ratios were 1:9 (F:M) (James-Pirri et al. 2005). Interestingly in Nauset Estuary, MA, a population that has not been exploited by harvesting, the spawning sex ratio was 1:1.6 (James-Pirri et al. 2005). Our data suggest that the number of males on spawning beaches is decreasing over time, which does not indicate preferential harvest of females. This decrease in males on spawning beaches corresponds with shifts in mating patterns we have also observed since 2007.

Since 2007, the frequency of single females observed on spawning beaches across the CT coastline of Long Island Sound has increased with a corresponding decrease in the number of females with one amplexed male and females with one amplexed male and one or more satellite male (Fig. 25.9). One might suggest that this pattern could be confounded by the types of females volunteers or researchers

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chose to tag (nesting or moving). However, all volunteers and researchers were instructed to tag every horseshoe crab they encountered whether nesting or moving. From 2007 to 2013, the overall percentage of females tagged that were paired with one male decreased from 73 % to 67 % while the number of single females on spawning beaches increased from 19 % to 27 %. We posit that this trend along with the decreasing sex ratios (F:M) is due to a gradual decrease in the number of males within the Long Island Sound population. Further evidence for this supposition comes from our recent assessments of crab condition.

5) What is the ratio of new recruits into the breeding population using shell condition; this is an indication of an expanding or declining population and evidence for survival rates of juvenile horseshoe crabs?

The condition data indicate that the recruitment of newly molted adults into the LIS population is low (11–12 %, Fig. 25.11a, b). This may indicate either egg and/or juvenile survivorship is very low in the Sound and that more research is needed in this area. This is yet another indication of a population in decline.

Female recruitment to the spawning population was higher than male recruitment over the past 2 years. The percentage of newly molted females (Condition 1, Fig. 25.12) was greater than the percentage of newly molted males in 2012 and 2013. In addition, the frequency of Condition 2 and 3 males is greater than the frequency of Condition 2 and 3 females. Based on these data, it appears that the male portion of the population is "aging" more rapidly than the female portion of the population, and it is not replacing itself. Previous studies have demonstrated that older males are less likely to pair with females (Brockman and Penn 1992; Penn and Brockmann 1995; Brockmann 2002; Duffy et al. 2006). Younger males (Condition 1) may be less likely to be covered with epibionts, less deterioration or fouling of the eyes, lighter and less pitted prosomas, less damage to claws used to clasp females thus, were more likely to pair and remain paired (Brockmann and Smith 2009). In a previous study, we explicitly examined male condition in relation to whether or not males were paired with a female or were a satellite male. Our data revealed that male condition played little role in determining whether a male was more likely to be found amplexed to a female or in a satellite position (Mattei et al. 2010). Interestingly, the percentage of unattached males in good condition was greater than the number of amplexed males. We attributed this behavior to low spawning density. Density plays an important role in determining alternative reproductive tactics in other species (see Courchamp et al. 1999; Stephens et al. 1999; Brockmann 2001; Gascoigne et al. 2009 for examples). We considered the presence of relatively high numbers of single females and the low level of polygynandrous behavior as evidence that horseshoe crabs along the CT coastline are not able to maximize their reproductive effort and have difficulty finding mates. This is yet more evidence of a population in decline.

6) Do LIS horseshoe crabs exhibit similar population characteristics to other populations of horseshoe crabs further north in New England or further south in Delaware Bay?

The population characteristics of horseshoe crabs in Long Island Sound are representative of both Delaware Bay and New England populations. Long Island

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Sound is similar to Delaware Bay in that it is one large interbreeding population. Yet this population is discrete like those in New England in that LIS horseshoe crabs do not readily migrate out of the Sound nor have we detected any significant migration into the Sound from other populations based on the USFWS horseshoe crab tagging Program (Sheila Eyler, USFWS, personal communication). Horseshoe crab prosomal widths are more similar to Delaware Bay than populations in the New England region. LIS spawning sex ratios are at odds with both Delaware Bay and more northerly populations. Mating patterns (frequency of pairs versus females with multiple satellites) in Long Island Sound are more similar to New England populations of horseshoe crabs compared to patterns observed in Delaware Bay (Mattei et al. 2010). Based on our tagging data, we conclude that while state and federal stock assessments (ASMFC 2013; CTDEEP 2014) have classified the western Long Island Sound horseshoe crab population as relatively stable, the population density is so low that we are beginning to see a serious shift in population characteristics that are indicative of significant population decline in the future. Further decreases in population density due to over-harvesting or habitat loss could push the LIS sound population over the threshold and start a long term decline in the horseshoe crab population where recovery would be a significant challenge. Continued decrease in the number of males within the population could significantly reduce reproductive success. Given the discreteness of this population in the sense that there is limited migration into and out of Long Island Sound, the likelihood of recovery based on adult dispersal from more robust populations to the south is unlikely. Recovery based on migration of individuals from more northern populations is even less likely given that these populations are even less dense than the Long Island Sound population (Mattei et al. 2010). Finally, recovery of depleted populations is further constrained by the limited dispersal abilities of horseshoe crab larvae as demonstrated by Botton and Loveland (2003).

25.5 Management Recommendations

While CT and NY share jurisdiction over Long Island Sound, their different horseshoe crab management strategies and regulations pose a conservation heresy. In 2013, Connecticut's reported harvest was 19,645 crabs (CTDEEP 2014), while New York State's harvest of horseshoe crabs from Long Island Sound waters was estimated around 69,336 individuals (NYSDEC 2013). The combined horseshoe crab harvest from Long Island Sound (89,000) in 2013 was 12 % less than the number of crabs harvested in Delaware Bay (100,255) (ASMFC FMP review 2013). Considering that Delaware Bay's reported spawning indices (# spawning females/ m^2) are up to 400 times greater than reported spawning indices in Long Island Sound (Mattei et al. 2010), we conclude that the current level of horseshoe crab harvest in Long Island Sound is not sustainable. Our data on population characteristics supports this conclusion in that we have observed an overall increase in the number of single females and a corresponding decrease in the number of paired

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females and females with multiple mates since 2007. Furthermore, the lack of recruitment into the spawning population (especially for males) does not bode well for the long-term success of the horseshoe crabs in LIS. If the ultimate goal is to increase horseshoe crab abundance in Long Island Sound, we suggest that (1) Connecticut and New York focus on a unified management plan for horseshoe crabs in LIS with consistent harvesting regulations, seasonal closures, and a reduction in the quota for allowable harvest of horseshoe crabs residing within the boundaries of the Sound; and (2) an increase in the number of protected areas where harvesting is prohibited at all times. Spacing of these protected areas could be matched to existing high quality spawning locales and placed no more than 16–18 km apart from each other to encompass the average home range of LIS horseshoe crabs. However, both of these suggestions would require long-term implementation to produce results. To increase horseshoe crab abundance to levels seen before the 1980s, we suggest implementing a ban on the take of females which would allow for an immediate increase in egg deposition, as seen in Delaware Bay and is the common and accepted management practice of other economically important species including lobster and blue crab (ASMFC 2013). Connecticut and New York should abide by the vision of the ASMFC and cooperatively manage this species as well as others by setting up at least two Marine Protected Areas that remain completely undisturbed on both sides of the Sound. The economic value and conservation success of MPAs is well known (Davies et al. 2012). Connecticut and New York State should take the lead on the sustainable management of their shared natural resources.

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