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Maine Horseshoe Crab *(Limulus polyphemus)* Spawning Surveys, 2005

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Abstract

The Maine Horseshoe Crab Surveys completed its fifth successful season in 2005. The purpose of the surveys is to monitor Maine's horseshoe crab populations in the face of anecdotal reports of declining numbers. Horseshoe crabs are no longer found at some sites where they were previously reported including: Stover Cove (Harpswell), the Fore River and Back Cove (Portland), and marshes behind Brave Boat Harbor (York). Breeding populations have declined in some locations to the point that only a few solo animals have been sighted, such as Pleasant Cove on the lower Damariscotta River. The cause of these declines is unknown. (Born 1977, Schaller and Thayer 2003).

Spawning counts have been conducted to generate an index of relative abundance among sites. Optimal field conditions in 2005 appeared to contribute to higher counts at a number of sites. The most abundant remaining populations known are currently in Middle Bay (Harpswell/Brunswick), and at Thomas Point Beach (Brunswick). Healthy, but less abundant populations persist in Taunton Bay (Franklin/ Hancock/Sullivan) and on the Bagaduce River (Penobscot/Sedgwick/Brooksville). The status of the population in the Damariscotta River is unclear at this time. Local conditions at the Mills obscured visibility on some survey dates.

An intensive tagging study on Taunton Bay has accumulated five seasons of detailed population data. Optimal environmental conditions in 2005 may have facilitated recording the highest counts of any season to date, both for the number of observations (2549) and the number of individuals (1525). The number of individuals seen in 2005 was calculated to be 115% of the maximum seen previously in 2001. For animals tagged in 2005, and back to 2002, sex ratios have ranged between 1.6 and 2.0 males per female in the year in which they were initially tagged, and for the proportions of returning tagged animals. By contrast, the group of individuals tagged in 2001 had 2.8 males per female initially, and generally continues to document lower numbers of returning females. For all five years, a total of 4454 tagged individuals have been seen an average of 1.96 times (8725 observations). Referral to the results from the tagging data is recommended as a guide to understanding data from the transect counts at all other sites. Use of observation data without the knowledge provided by individually numbered tags would lead to an inflated estimate of the number of animals present in a watershed.

Introduction

The Maine Horseshoe Crab Surveys completed its fifth successful season in 2005. Horseshoe crab populations occur intermittently in Maine, and are relatively sparse where they can be found. The purpose of the surveys is to monitor Maine's populations in the face of anecdotal reports of declining numbers. Horseshoe crabs are no longer found at some sites where they were previously reported including: Stover Cove in Harpswell; the Fore River and Back Cove in Portland; and marshes behind Brave Boat Harbor in York. At some sites, breeding populations have declined to the point that only a few solo animals have been sighted, such as Pleasant Cove on the lower Damariscotta River. The cause of these declines is unknown. There is a documented history of horseshoe crab harvest in the Damariscotta River, but it is not the case at all locations. (Born 1977, Schaller and Thayer 2003).

With the help of dozens of volunteers over the past five years, spawning counts have been conducted in accordance with an established methodology to generate an index of relative abundance among sites. The most abundant remaining populations known are currently in Middle Bay (Harpswell/Brunswick), and at Thomas Point Beach (Brunswick). Healthy, but less abundant populations persist in Taunton Bay (Franklin/ Hancock/Sullivan) and on the Bagaduce River (Penobscot/Sedgwick/Brooksville). The status of the population in the Damariscotta River is unclear at this time.

An intensive tagging study on Taunton Bay has accumulated five seasons of detailed population data. This data is used not only to generate counts of the number of animals observed each day, but also to identify individual animals using (individually) numbered tags. This data distinguishes between actual changes in the population over time (changes in the number of individual males and females) from the apparent changes in the population (variation in the number of observations from year to year).

Biological Background

Horseshoe crabs range intermittently from Maine to Mexico's Yucatan Peninsula (Shuster 1982). Taunton Bay, the innermost portion of Frenchman's Bay (Hancock County) is the northernmost known spawning site of the species (Born 1977, Schaller et al. 2002, 2005).

Spawning occurs in late spring when adult horseshoe crabs move ashore on the rising tide. Mates are located visually and horseshoe crabs have an impressive array of primitive eyes, compound eyes and light sensing organs (Barlow et al., 1982; Barlow and Powers 2003). Spawning occurs on both the daytime and nighttime tides. On Cape Cod, Barlow et al. (1986) found a preference for the higher of the two daily tides, qualified by a delay of several days when tidal inequality reverses.

During spawning, females move to the upper intertidal zone to lay eggs, typically arriving with a male clasped piggyback in amplexus; pairs may be joined by unpaired (satellite) males. At or near the high tide line, females burrow into the bottom and deposit a cluster of hundreds to thousand of eggs (Rudloe, 1980). Eggs are fertilized externally, so satellite males also contribute to paternity (Brockmann et al. 1994).

Eggs hatch 2 or more weeks after spawning (Shuster 1990). Development may be slowed by low salinity, low temperatures, or low levels of dissolved oxygen (Jegla and Costlow 1982; Penn and Brockmann 1994). Within a few days of emergence, larvae settle to the bottom where they feed on small invertebrates and plant material they encounter, either while burrowing through sediments or by moving over the bottom (Shuster 1950, 1990; SS, PT).

Juveniles are believed to stay in shallow waters up to 12' deep, through their first winter (Shuster, 1990; Brady and Schrading, 1977). Sexual maturity is reached after 9-10 years and 15-17 molts, respectively, for males and females (Shuster 1982). Movement into deeper waters as the young grow is evidenced by the fact that most adults have been found at depths of 100' or less. Animals are occasionally found at greater depths, including one which was photographed by a robotic submarine at 1097m. (Botton & Ropes 1987)

Spawning habitat in Maine is characterized by protected shorelines in estuaries where the reach of open water is 1.5 miles or less (Schaller, based on spawning sites documented by Born, 1977; Banner and Schaller, 2001). Optimal sites offer a substrate of sand, gravel, or shell hash that the females can excavate with their feet (Shuster 1990), and which are free of underlying anoxic sediments (Botton et al. 1988). The eggs are protected during development by wet sand which collapses into the depression as the female departs the spawning site (Shuster 1990).

Methodology

The methodology developed in 2001 is still followed (Schaller et al, 2002). For the survey sites, each crew counts horseshoe crabs seen along a transect at the water's edge. Counts are conducted on daylight high tides only, and start approximately 20-30 minutes before high tide in order to finish close to high tide and before the water begins to ebb noticeably. On Maine's relatively steep shorelines, horseshoe crabs leave for deeper water soon after the tide begins to ebb.

Transects used for the counts are a minimum of 100m in length and data are recorded by the number of animals seen within each 10m segment. Additionally, animals observed within 1m of the water's edge are tabulated in one column, and animals observed beyond that distance are tabulated in a second column. To minimize observation bias, only data for animals seen within 1m of the water's edge are considered for comparisons among sites, and the data are standardized to a uniform 100m length.

Tagging is conducted at only one site (Shipyard Point in Taunton Bay). Tagging protocols were established in accordance with the current best recommended practices to minimize interference with the study species (Nietfeld et al. 1994). Tag location was determined so that a tag would not interfere with spawning behavior or alter typical patterns of survival and mortality. Although adult horseshoe crabs are believed to molt rarely if at all, the presence of a few large individuals in the population suggests that molting occurs occasionally after sexual maturity has been reached. In the event of molting, the numbered tag would remain on the shed shell. It is expected that an animal which had molted out of a tagged shell might show a small notch on the genal angle of the new shell. Tags are attached close enough to the tip of the genal angle (edge of the shell) that they would tear out in the event of entanglement, resulting in the loss of the tag but saving the animal.

Tags used on this project are standard fish marking tags, FD-94 by Floy Tag and Manufacturing, Seattle, Washington. A small hole is drilled in either the left or right genal angle— one of the bony points on either side of the trailing edge of the prosoma (the rounded portion of the shell). The bony point is typically an empty cavity, and the animals show no more aversion to the tagging process than they do to being handled and laid flat on a fish board for measuring. The tags are individually numbered on one side with a message that reads: "Report number XXXXX", where XXXXX represents an individual number, and "HORSESHOECRABS@ AOL.COM" on the other side. The drill bit is dipped in 5% Povidone-Iodine solution between animals to prevent cross contamination.

Morphometric data are collected when animals are tagged, using a fish board to measure prosomal width. Males are identified by the presence of claspers on their anterior pair of legs whereas females have undifferentiated walking legs on their anterior pair. Males are regularly found missing one or both claspers, but with their other legs intact. In those cases, their sex is confirmed by their typically smaller size (Schaller et al. 2002) and the absence of patterns of shell wear that develop on females.

Results of Surveys

In 2005, horseshoe crab spawning counts were conducted at ten sites in four watersheds. In Casco Bay four sites were surveyed at Wildwood, Cumberland; Middle Bay, Harpswell/Brunswick; Thomas Point Beach, Brunswick; two sites on the Damariscotta River -- Days Cove (a.k.a. Hospital Cove) in Damariscotta and at Damariscotta Mills in Nobleboro; three sites on the Bagaduce River in Sedgwick; and two sites on Taunton Bay in Franklin and Sullivan. Tagging continued at the Taunton Bay site in Franklin. Tagging results will be covered in more detail later. Geo-referenced locations are provided in Table 1 below.

The onset of spawning appears to be influenced by a number of factors including lunar phase (Barlow et al 1986), minimum water temperature (Schaller et al. 2001), and to some extent by the current weather, which may be a function of light and temperature (Schaller et al.. 2005). Spawning in Maine begins within a day or two of the lunar phase (full or new moon) at the end or May, provided that water temperatures have attained a minimum of 12 degrees C, and more commonly 14 degrees C. If water temperatures have not warmed sufficiently, the onset of spawning is delayed two weeks until the next lunar phase.

Once spawning has begun, activity occurs on both daytime and nighttime tides. Maine surveys have only been conducted during daylight tides for reasons of safely and staffing. Data from 2004 and 2005 suggested that once the spawning season had begun, the daytime levels of spawning activity were higher during fair weather, or improving weather than when conditions were rainy or deteriorating.

Table 1: 2005 Horseshoe Crab Spawning Survey Sites, Georeferenced by Datum

Town	Site Description	2003 Survey Name	WGS84 N	WGS84 W	NAD83 N	NAD83 W
Cumberland	Wildwood Park Beach	Cousin's Island	43.7590357	-701949804	43 45 32.51	70 11 41.91
Yarmouth	Sandy Pt at Snodgrass Bridge	new in 2004	43.7733140	-70.1443200	43 46 24.83	70 08 39.88
Yarmouth	cove sw of Blaney Point	Cousin's Island	43.7743429	-70.1302621	43 46 27.62	70 07 48.93
Freeport	Winslow Memorial Park, seaward	new in 2004	43.8034806	-70.1104267	43 48 12.52	70 06 37.52
Freeport	Winslow Memorial Park, Staples Cove	new in 2004	43.8034806	-70.1104267	43 48 20.33	70 06 42.74
Freeport	Sandy Beach off Cushing Briggs Road	new in 2004	43.8309308	-70.0974228	43 49 51.34	70 05 50.71
Brunswick	Middle Bay, eastern cove	Middle Bay	43.8593299	-69.9447254	43 51 33.57	69 56 41.00
Brunswick	Thomas Point Beach	Thomas Pt. Beach	43.8939318	-69.8909125	43 53 38.14	69 53 27.27
Wiscasset	Eaton Farm on Back River	Bailey Cove	43.9491529	-69.7011517	43 56 56.94	69 42 04.13
Damariscotta	Day's Cove, shoreline behind hospital	Days Cove	44.0245795	-69.5325076	44 01 28.47	69 31 57.01
Nobleboro	Salt Bay, Damariscotta Mills sewer filter	Damariscotta Mills	44.0614377	-69.5225716	44 03 41.16	69 31 21.24
Sedgwick	behind Bagaduce Lunch	Bagaduce River	44.3985850	-68.7027723	44 23 54.89	68 42 09.97
Sedgwick	upstream of Bagaduce falls, s of point	Rhodora	44.3646796	-68.6773836	44 21 53.17	68 40 40.30
Sedgwick	upstream of Bagaduce falls, n of point	Quiet Cove	44.3650245	-068.6760905	44 21 54.23	68 40 35.99
Franklin	Shipyard Point, start of tagging transect	Taunton Bay (tag site)	44.5817858	-68.230541	44 34 54.41	68 13 49.93
Franklin	Shipyard Point, end of tagging transect	Taunton Bay (tag site)	44.5831980	-68.2319333	44 34 59.50	68 13 54.95
East Franklin	South Bay Rd at Hog Bay	Taunton Bay, So.Bay Rd	44.5711586	-68.2248982	44 34 16.16	68 13 29.62

Water temperatures were slow to warm in 2005 and although tagging work began in May at Taunton Bay, no horseshoe crabs were seen until June. This was anticipated and the counts at all other sites were delayed until June 6th through June 18th. The new moon of June 6th coincided with optimal environmental conditions and was followed by week-long period of clear, fair weather. The highest spawning counts for any season to date were recorded at four of nine sites surveyed in prior years—Wildwood, Thomas Point Beach, the Bagaduce River and Taunton Bay at Shipyard Point. It is noteworthy that elevated counts were seen in three of four watersheds at one or more sites. Only the Damariscotta River watershed failed to record higher counts. Local conditions at the Mills obscured visibility and may have contributed to the lower numbers.

The results of the 2005 counts are shown in Table 2, standardized to a 100 by 1 meter transect. (Raw data are shown in Appendix A.) Water clarity varies among sites (influenced by wind, silt and shoreline slope), so only the number animals observed within 1 meter of the water's edge are used to compare among sites. To smooth out day to day variation in the counts, daily results are combined for the five highest consecutive days for each site (for observations within 1m of the water's edge) in the Index of Relative Abundance.

The Index of Relative Abundance is shown in Table 3 for 2005 and prior years During 2005, higher counts were seen in Casco Bay at Wildwood (42 in 2005; 4 in 2004), and at Thomas Point Beach (2005 in 2005 and 1482 in 2004). Counts at Sandy Beach (Freeport) were 63% (24 versus 38) of the numbers seen in 2004 (the first full season for Sandy Beach). Middle Bay counts in 2005 were 79% of the 2004 numbers (581 versus 736).

On the Bagaduce River, combined five day counts totaling 654 were seen downstream of the falls– more than three times the number seen in 2004. An enthusiastic crew of volunteers stepped forward to support the addition of a new survey site upstream of the falls. Multiple additional sites were scouted; one site was selected and added to the surveys with peak totals of 302 horseshoe crabs seen.

Counts at the Taunton Bay tagging site on Shipyard Point were the highest seen to date—even exceeding the previous high count of 2001. Counts were lower on the south shore of Hog Bay, but may have reflected delays in the crew getting to the site because of extended work times at Shipyard Point. Members of the tagging crew conduct counts on the south shore of Hog Bay after tagging work is completed. On all days this means that the Hog Bay counts are conducted after the tide has started to fall. The shoreline on the south shore of Hog Bay is nearly flat and the ebbing tide is not apparent until several hours after high, so animals stay later.

Table 2 Daily Survey Counts, Standardized to 100 x 1 meter Transect

Watershed-->	Casco Bay				Damariscotta River	
Transects standardized to 100 x 1 M	Middle Bay	Wildwood	Sandy Beach	Thomas Point Be.	Damaris. Mills	Days Cove
	Low Tide	High Tide	High Tide	High Tide	High Tide	High Tide
Originally-->	14 sections	20 sxns	10 sxns	12 sxns	10 sxns	10 sxns
6/6/2005	95.7	0.0		24.2	0	0
6/7/2005	47.9	0.5	3.0	182.5	0	0
6/8/2005	67.1	1.0		**385.8**	0	3
6/9/2005	73.6	**3.0**	5	**382.5**	0	5
6/10/2005	121.4	**3.0**	**1**	**460.8**	**0**	**8**
6/11/2005	69.3	**4.0**	**6**	**476.7**	**0**	**20**
6/12/2005		**5.5**	**4**	**299.2**	**0**	**16**
6/13/2005	**146.4**	**5.5**	**6**	212.5	**37**	**46**
6/14/2005	**231.4**	0.0	**7**	0.8	**1**	**8**
6/15/2005	**141.4**	0.0	0	0.0	0	0
6/16/2005	**40.0**	0.0	0		0	1
6/17/2005	**22.1**	0.0	0		0	0
6/18/2005	12.9	0.0	0	3.3	0	0
6/19/2005		0.0	0			
6/20/2005		2.0	0	23.3	0	
6/21/2005		0.0	6	93.3		
6/22/2005		0.0	12			
6/23/2005		0.0		70.8		
6/24/2005						
6/25/2005	72.9				**36**	**59**
6/26/2005	71.4					
6/27/2005						
5 days total	814.0	21.0	24	2005.0	38	98
	Middle Bay	**Wildwood**	**Sandy Beach**	**Thomas Point Be.**	**Damaris. Mills**	**Days Cove**

Watershed-->	Bagaduce River:			Taunton Bay:	
Transects standardized to 100 x 1 M	Bagaduce Falls	Rhodora	Quiet Cove	Hog Bay south shore	Shipyard Point
	High Tide	High Tide	High Tide	High Tide	High Tide
Originally-->	14 sxns	10 sxns	10 sxns	11 sxnx	38 sxns
6/6/2005	3.6	0			2.1
6/7/2005	6.4	0		9.1	0.8
6/8/2005	12.1	0		1.8	23.7
6/9/2005	**100.0**	**0**		0.0	38.2
6/10/2005	**132.1**	**0**	8	0.0	**53.7**
6/11/2005	**150.0**	**0**	7	**0.0**	**66.3**
6/12/2005	**161.4**	**0**	16	**0.0**	**98.9**
6/13/2005	**110.0**	**0**	1	**0.0**	**103.9**
6/14/2005	36.4	0	0	**7.3**	**59.5**
6/15/2005	7.9	0	0	**3.6**	4.7
6/16/2005	5.7	0	0	0.0	0.0
6/17/2005		0	0	0.0	1.1
6/18/2005		0	0	0.0	0.0
6/19/2005		0	0		2.1
6/20/2005		0	5		6.6
6/21/2005		0	56		15.8
6/22/2005			**35**		20.0
6/23/2005			**53**		23.4
6/24/2005			**34**		10.3
6/25/2005			**88**		7.6
6/26/2005			**92**		5.0
6/27/2005			6		
5 days total	653.6	0	302	10.9	543.7
	Bagaduce Falls	**Bagaduce Rhodora**	**Bagaduce Quiet Cv**	**Hog Bay south shore**	**Shipyard Point**

Table 3 **2005 Spawning Surveys Index of Relative Abundance** (combined counts for 5 highest consecutive days)

Watershed	Town	Site Name	2005	2004	2003	2002	2001
Casco Bay							
	Cumberland	**Wildwood**	**42**	4			
	Yarmouth	Cousin's Isl - bridge		0			
	Yarmouth	Cousin's Isl - Blaney		2	3		
	Freeport	Winslow Mem'l Park		0			
	Freeport	**Sandy Beach Freeport**	**24**	38			
	Harpswell	**Middle Bay** (Low Tide)	**581**	736	93	422	282
	Brunswick	**Thomas Point Beach**	**2005**	1482	2248	1865	171
Damariscotta River							
	Nobleboro	**Days Cove**	**98**	290	65	178	* 76
	Damariscotta	**Damariscotta Mills**	**38**	219	209	* 403	606
Bagaduce River							
	Sedgwick	**Bagaduce Falls**	**654**	192	23	50	25
	Sedgwick	**Bagaduce Upstream**	**302**				
Taunton Bay							
	Franklin	**Shipyard Point**	**544**	163	67	104	176
	Sullivan	**Hog Bay, south shore**	**12**	94	32	32	

Spawning counts, per 100m x 1m transect, conducted at high tide, except as noted at Middle Bay.
* Asterisks denote incomplete data series during periods of peak spawning activity.

Data for the Damariscotta River are difficult to interpret. Volunteers noted in 2005 that animals may have been present, but on most days there was high turbidity with debris and foam obscuring visibility, to the point that no animals were observed. It is likely that more animals were present but were undercounted due to conditions; whether the populations is stable or not remains unknown. Numbers at Day's Cove for the season tallied 98 observations where 290 were seen in 2004, 54 in 2003 and 178 in 2002. Both of the Damariscotta River sites have had a season of incomplete data as well.

It is known that there was commercial harvest of horseshoe crabs in the Damariscotta River. Horseshoe crabs take ten or more years to reach sexual maturity (Shuster 1982), and harvest focuses on removing adult animals solely. It is impossible to determine how fishing may or may not have impacted populations in the Damariscotta. It is logical that with continued closure and favorable conditions numbers should increase, barring any environmental disturbances.

Tagging Results

2005 was the fifth successful season for the tagging study, and the most demanding of any season yet for the tagging crew. Daily surveys at the tagging site began on May 23rd, following the full moon of the day before, and were conducted daily at high tide until June 30th, for a total of 39 days. Cold water temperatures delayed the onset of spawning. The first horseshoe crab was seen on June 3rd when the water temperature reached 14 degrees C, and daily counts increased rapidly thereafter.

A record number of 2549 observations on 1525 horseshoe crabs were logged at the tagging site, in spite of the delayed season. This represented 115% of the maximum number of individuals seen previously (in 2001). Table 4 summarizes the tagging results for all five seasons; Table 5 tracks the number of individuals newly tagged each season and the number of each tag-year-class returning in subsequent seasons. (Raw data for the tagging site are shown in Appendix B.)

The number of individual animals seen each season at the tagging site has varied widely. The Taunton Bay site is effectively 'closed' to immigration and emigration (by horseshoe crabs) by its physical configuration. In addition, there is no known history of fishing for horseshoe crabs in the Bay, so the variation seen in Table

3 reflects natural fluctuation in numbers. There is some bias in the data due to the fact that work is only conducted on daylight tides, but it remains the most detailed dataset for a single site in that all animals encountered each day are tagged.

Among tagged individuals, 2.8 males per female were observed in 2001. Sex ratios among returning individuals (from the tag-year class of 2001) have ranged from 1.6 to 1.9 (M:F), suggesting that females were underrepresented in the 2001 tag-year class. Counts on overnight tides, in addition to daylight tides, would provide useful information but such is beyond the scope of this project at this time.

Table 4: Tagging Study Summary Statistics for Years 2001 - 2005

Obs Year	Number of Observations			Number of Individuals			Males per Female
	Males	Females	Total	Males	Females	Total	
2005	1688	861	2549 (104%)	998	527	1525 (115%)	1.9
2004	877	507	1384 (57%)	592	323	915 (69%)	1.8
2003	758	494	1252 (51%)	556	338	894 (67%)	1.6
2002	696	411	1107 (45%)	465	276	741 (56%)	1.7
2001	1774	659	2433 (100%)	982	351	1333 (100%)	2.8
Overall:	5793	2932	8725				

Data on returning animals are given in Table 5. Animals seen for the first time in any season become the tagging-year-class, and are tabulated below according to the number (of each tag-year-class) seen in subsequent seasons. All year classes recorded their highest percentages of returning individuals in 2005; 17% of animals tagged in 2004 returned and 13%, 9%, and 11% , of animals tagged in 2003, 2002 and 2001, respectively. These represented unusually high numbers since returns in previous years (of any one tag-year class) ranged from 5.7% to 8.5%.

Table 5: Return Rates Relative to Original Tag Year

Observation Year	Tag Year	Number of Individuals			Year Class Composition			M / F Sex Ratio
		Female	Male	Total	Female	Male	Total	
Tagged in 2001	***2001***	***351***	***982***	***1333***	***26.3%***	***73.7%***	***100.0%***	***2.8***
Returned in 2002		33	83	116	2.5%	6.2%	8.7%	2.5
Returned in 2003		37	76	113	2.8%	5.7%	8.5%	2.1
Returned in 2004		13	87	100	1.0%	6.5%	7.5%	6.7
Returned in 2005		25	121	146	1.9%	9.1%	11.0%	4.8
Tagged in 2002	***2002***	***243***	***382***	***625***	***38.9%***	***61.1%***	***100.0%***	***1.6***
Returned in 2003		22	41	63	3.0%	5.5%	8.5%	1.9
Returned in 2004		14	28	42	1.9%	3.8%	5.7%	2.0
Returned in 2005		21	38	59	3.4%	6.1%	9.4%	1.8
Tagged in 2003	***2003***	***278***	***438***	***716***	***38.8%***	***61.2%***	***100.0%***	***1.6***
Returned in 2004		35	39	74	3.9%	4.4%	8.3%	1.1
Returned in 2005		45	54	99	6.3%	7.5%	13.8%	1.2
Tagged in 2004	***2004***	***255***	***432***	***687***	***37.1%***	***62.9%***	***100.0%***	***1.7***
Returned in 2005		47	75	122	6.8%	10.9%	17.8%	1.6
Tagged in 2005	***2005***	***386***	***707***	***1093***	***35.3%***	***64.7%***	***100.0%***	***1.8***
Total individuals tagged:		*1513*	*2941*	*4454*	*33.5%*	*66.5%*	*100.0%*	*2.0*

Sex ratios for horseshoe crabs tagged in 2001 appear to have been skewed (2.8 males per female), relative to subsequent year classes which have ranged from 1.6 to 1.8 males per female. In 2004 and 2005, proportionately more males than females were seen from the 2001 tag year class (6.7 males per female in 2004 and 4.8 males per female in 2005). The reason for the declining number of retuning females is unknown at this time.

Possibilities include mortality that is skewed towards females (i.e. occurring earlier for females). Other possibilities include molting by adult horseshoe crabs—an unanswered question in the life history of this species—or that females molt rarely as adults and that males do molt or molt even less frequently as adults.

A few tags have been lost but the losses were evenly distributed between males and females; therefore tag loss does not account for the lower numbers of returning females from animals tagged in 2001. Occasionally tags get entangled in eel grass or debris and are pulled out, pulled apart, or cause the edge of the shell to break off, freeing the animal (alive) in each case. There have been 3 known deaths due to entanglement out of 4454 tagged horseshoe crabs, and tag placement is conducted carefully to limit such losses.

It is important to note that each tagged individual has been seen an average of 1.96 times over the five years of this study (8725 total observations – Table 4 / 4454 tagged individuals – Table 5). Use of observation data without the knowledge provided by individually numbered tags would lead to an inflated estimate of the number of animals present in a watershed.

Environmental Variables

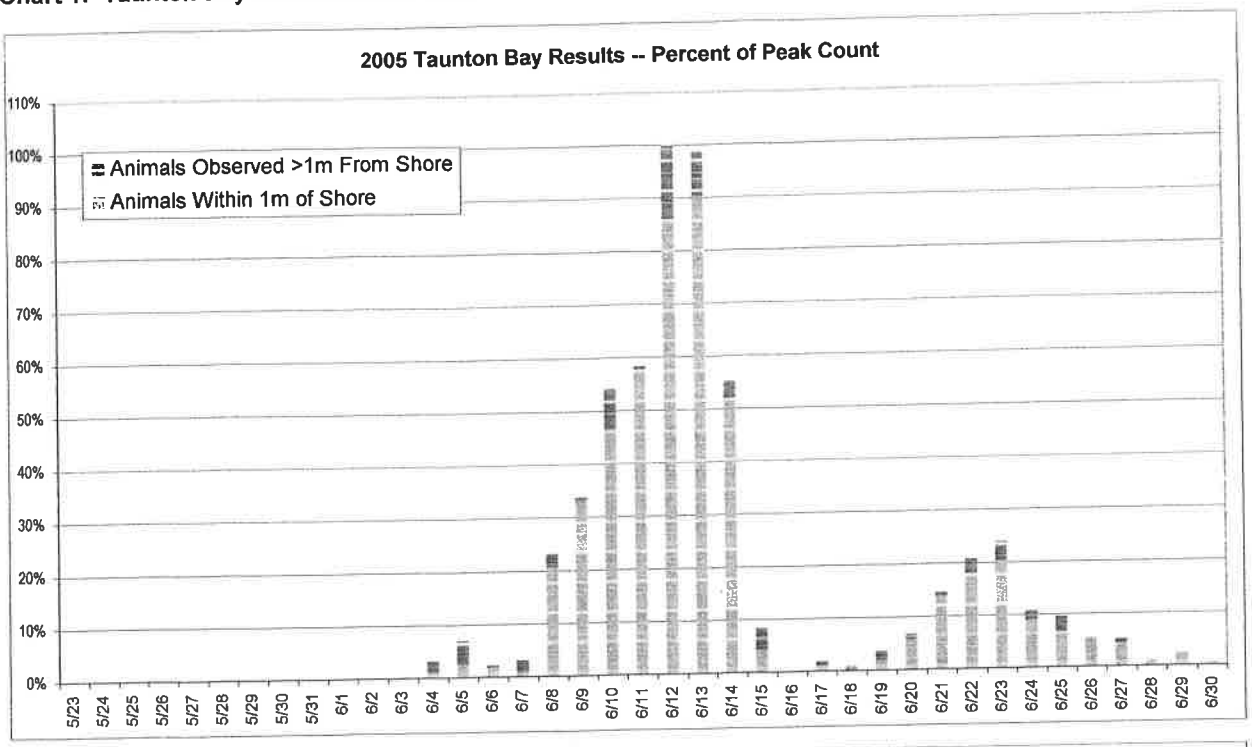
Tagging results for all five seasons are shown in Charts 1 through 5 as a percent-of -peak counts for that season, accompanied by graphs of the lunar phases, water temperatures, tidal amplitude, and the local weather conditions (2003- 2005). Seasonality, lunar phase, water temperatures and tidal amplitudes are all believed to influence spawning, but the influence of each of these parameters has been difficult to understand, making it difficult to predict periods of peak spawning activity and use volunteer crews with maximum effectiveness. Several patterns have emerged from the first four seasons of data that made spawning activity more predictable in 2005, and were confirmed by conditions in 2005.

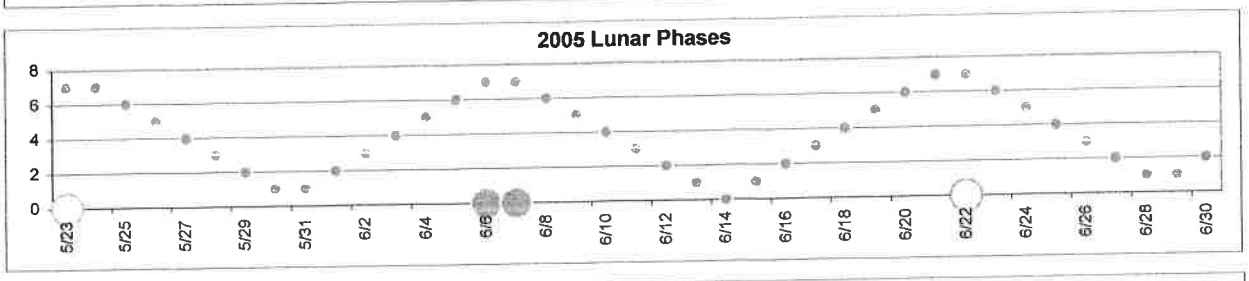
Seasonal changes in day length, temperature and lunar phase appear to be the key environmental factors that predict the onset of spawning. First, water temperatures need to attain a minimum of 12 degrees C, and more typically 14 degrees C. Once this has occurred, the onset of spawning immediately follows the next full moon or new moon, whichever occurs first.

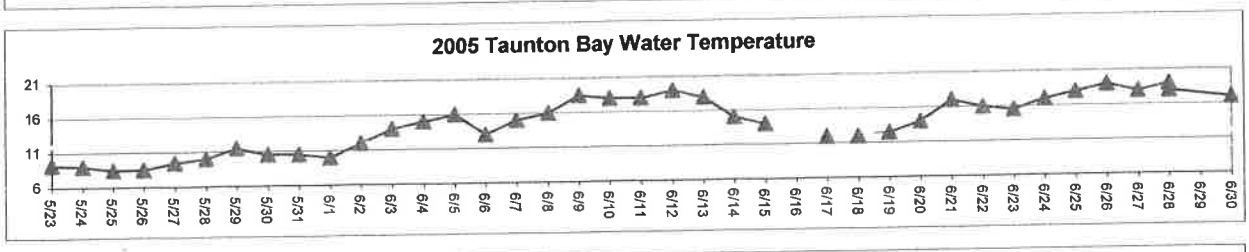
Second, the days with the highest of the high tides do not record the highest levels of spawning activity, although a few animals may be present. For Taunton Bay, the highest tides typically exceed 13', and on these days very few horseshoe crabs come to spawn. Third, once spawning has begun, bright, sunny days with higher temperatures coincide with elevated levels of activity. Further analysis is warranted, and arguably these variables are auto-correlated, but data from 2004 and 2005 suggest that these factors contribute to activity levels.

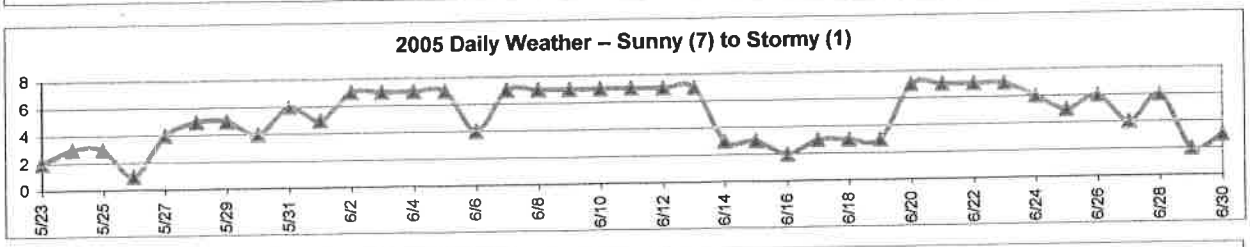
The highest counts for any season of tagging were documented in 2005. The progression of environmental conditions included water temperature reaching 14 degrees C on June 3rd, and a new moon on June 6th which coincided with the first of seven consecutive days of bright, sunshine and cloudless skies. Spawning typically slows after the first 7-10 days, and numbers decline, as they did in 2005, coincident with 6 days of overcast or rainy weather and declining water temperatures. The last of the 2005 season saw numbers increase again as the weather cleared, with counts dropping off at the end of the month. This was consistent with a small increase in activity that has been seen toward the end of each season, which does not correspond directly to the lunar phase. The onset of spawning activity appears to be regulated initially by seasonality, water temperature and lunar phase. Favorable local weather conditions appear to foster higher levels of activity. Horseshoe crabs avoid spawning during stormy weather and in waves which might tumble them (Schaller, personal observation; Shuster, 1990).

Chart 1: Taunton Bay Environmental Data 2005









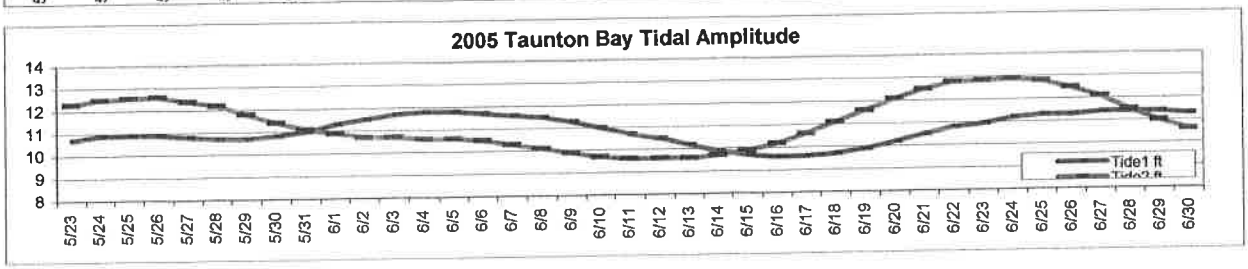
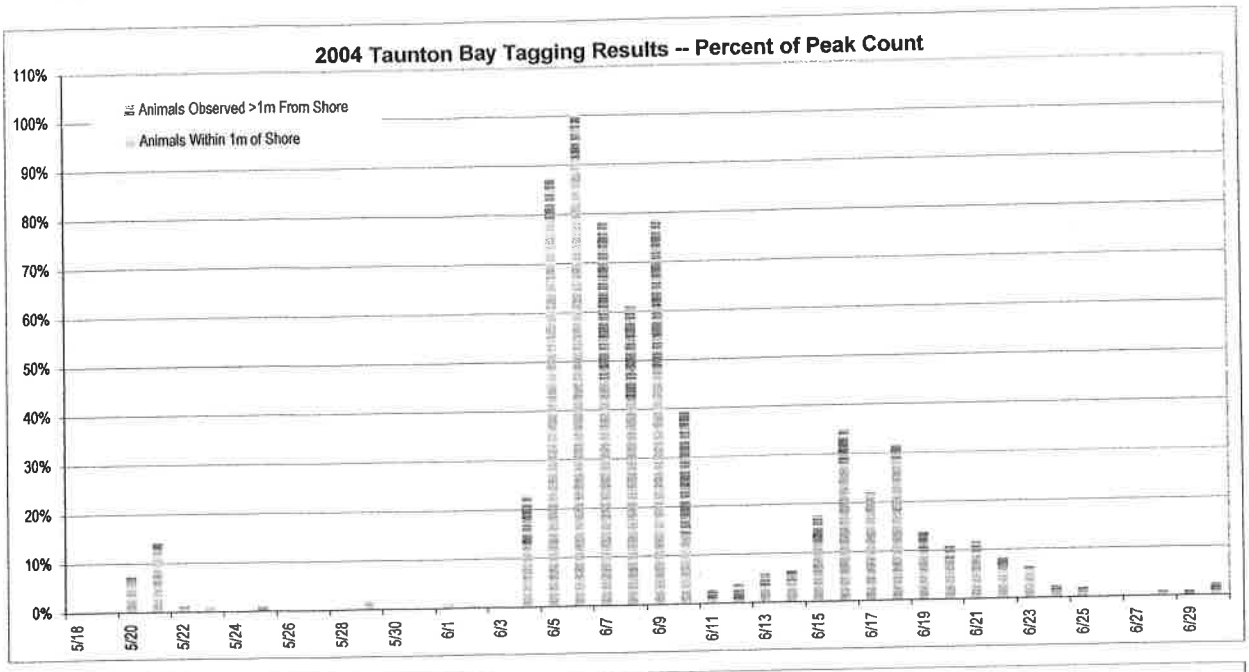
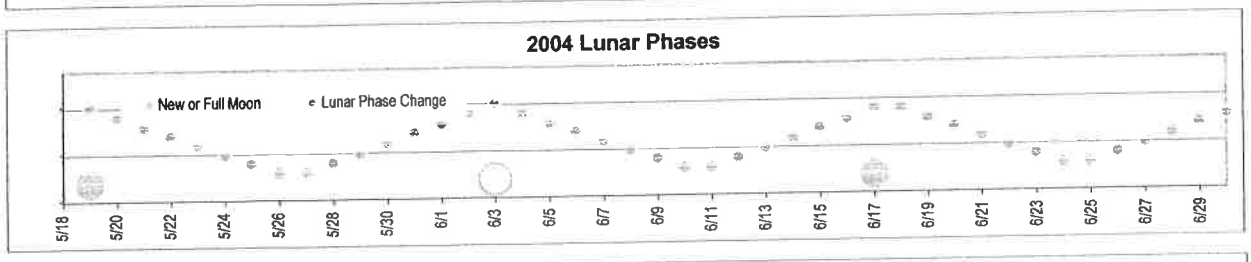
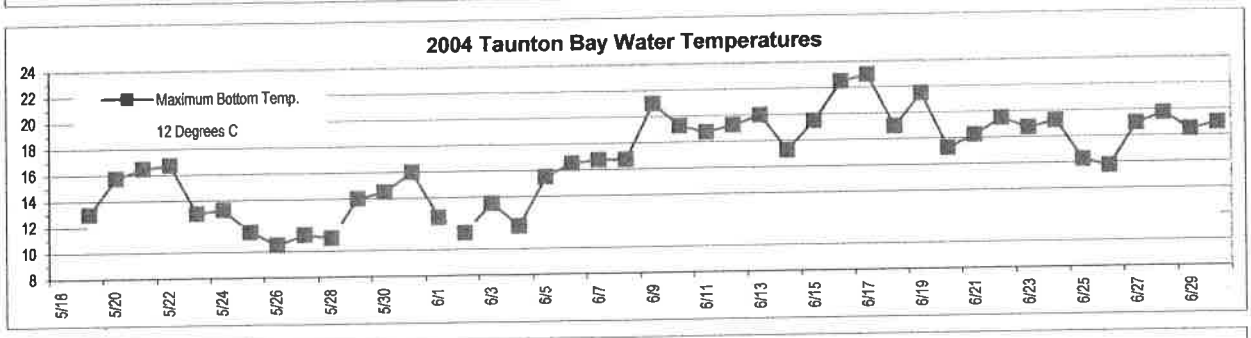
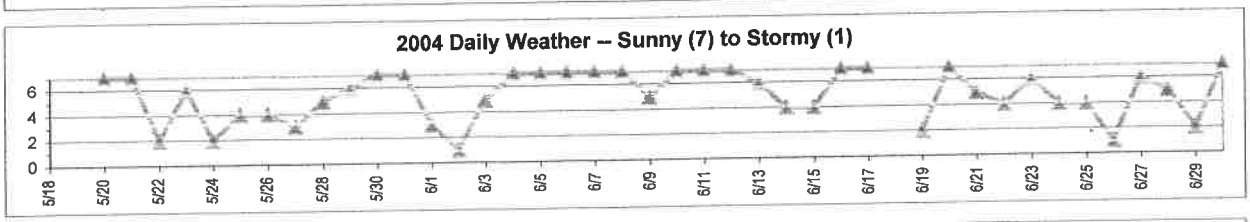


Chart 2: 2004 Taunton Bay Tagging Results









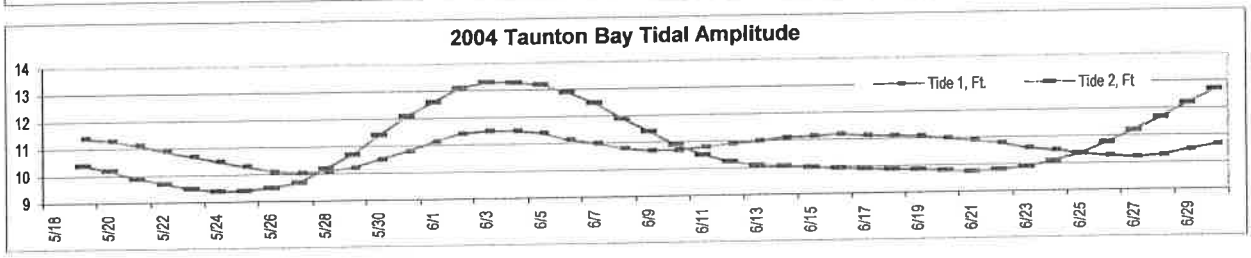


Chart 3: 2003 Taunton Bay Tagging Results

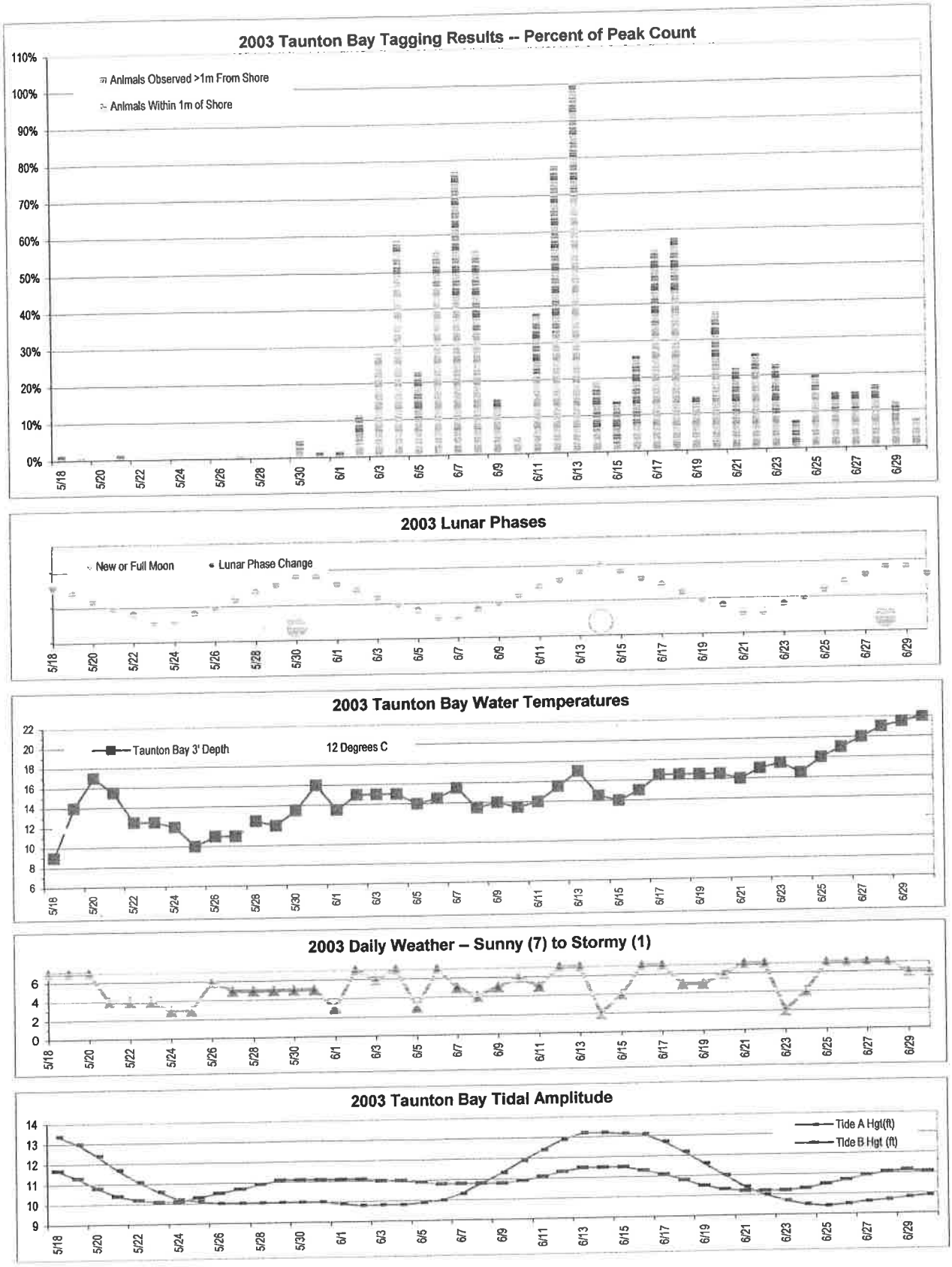
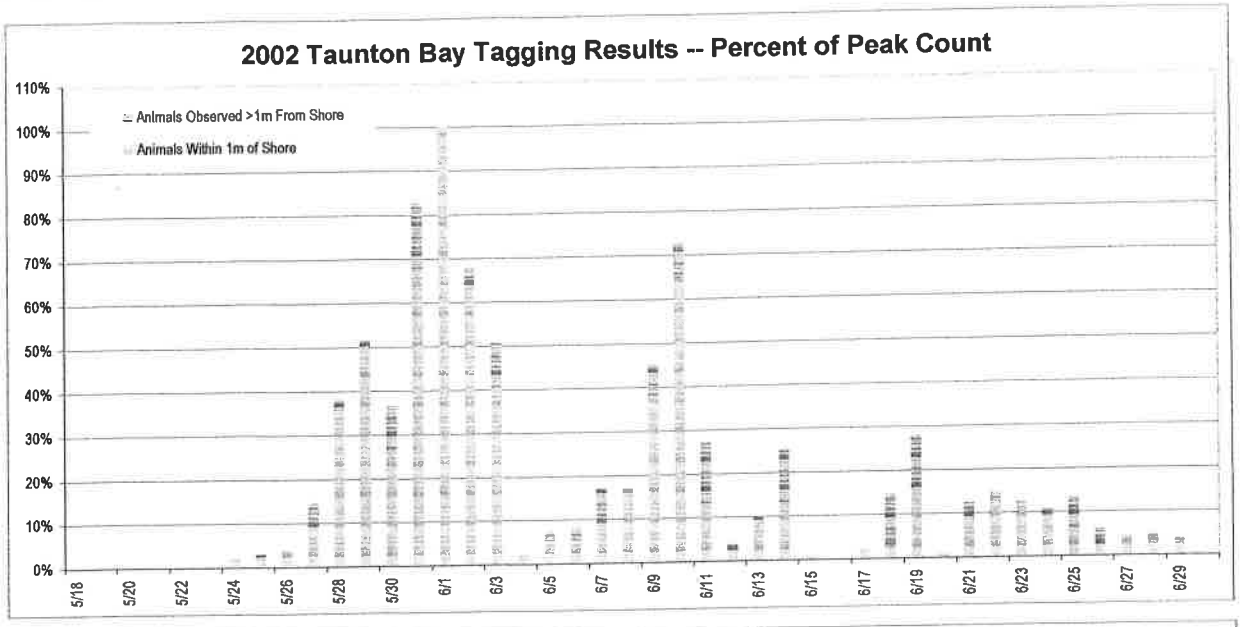
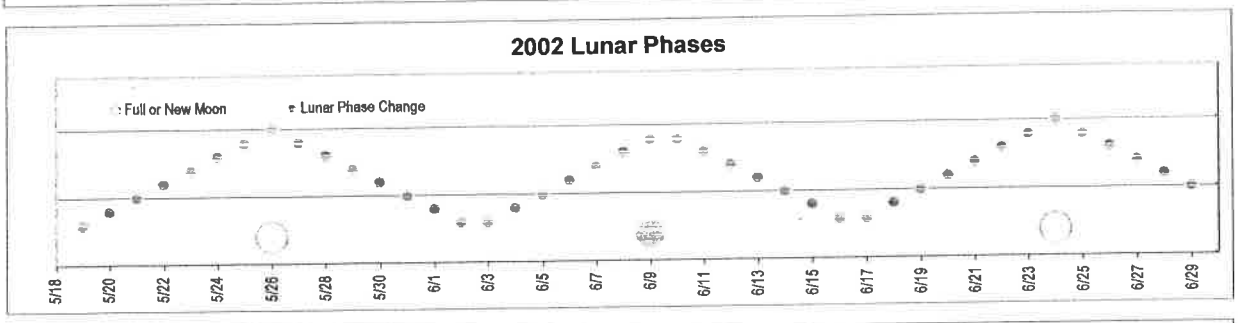
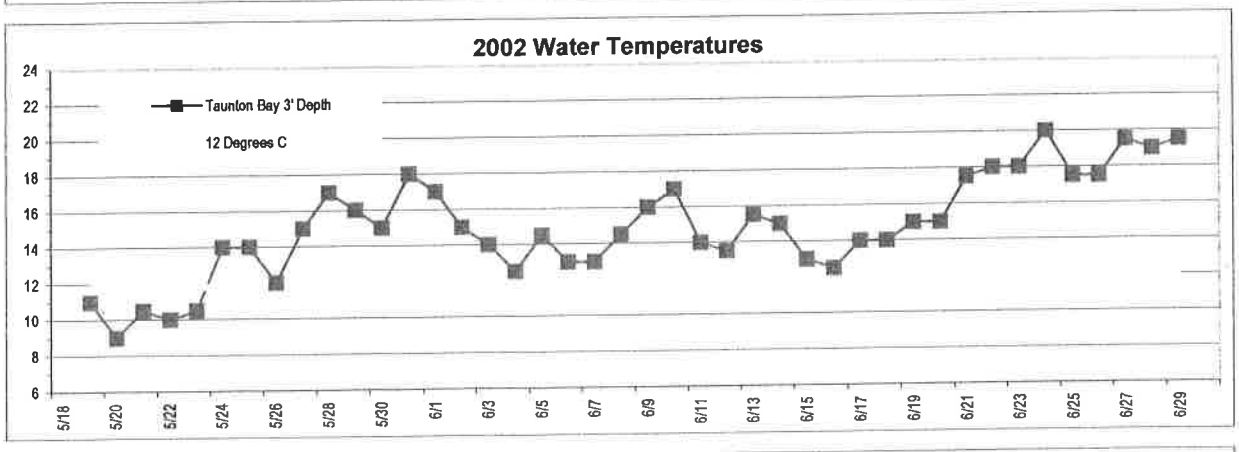


Chart 4: 2002 Tagging Counts and Environmental Data







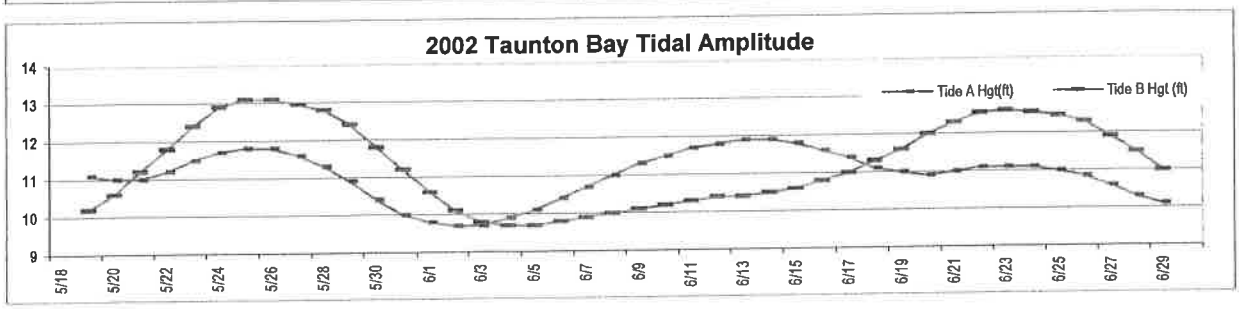
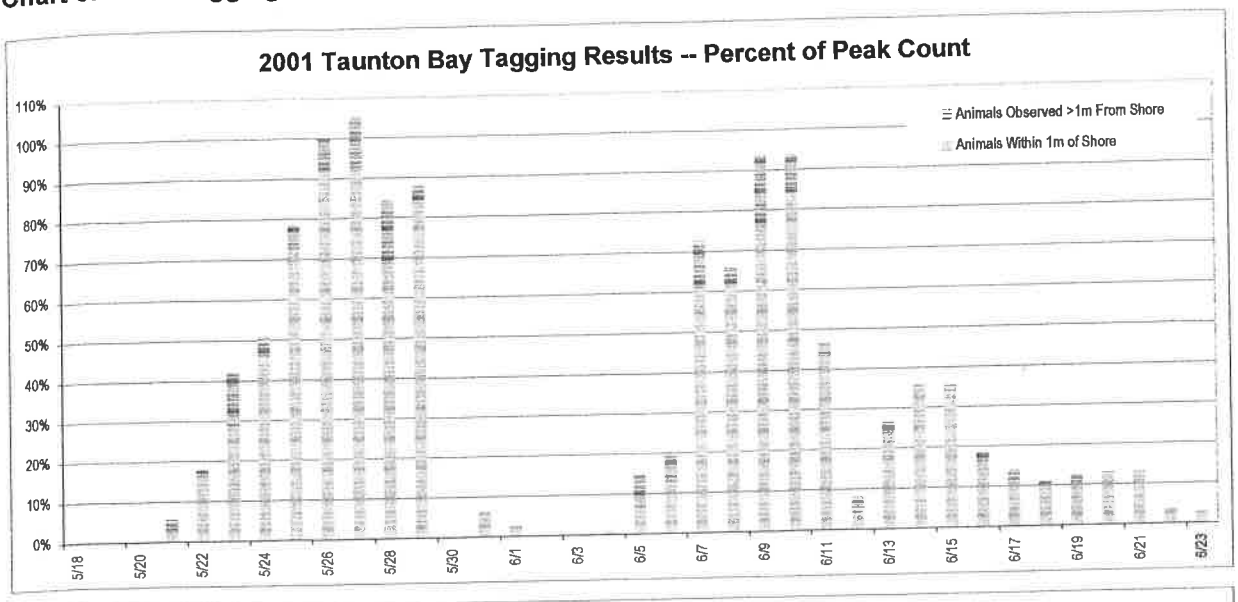
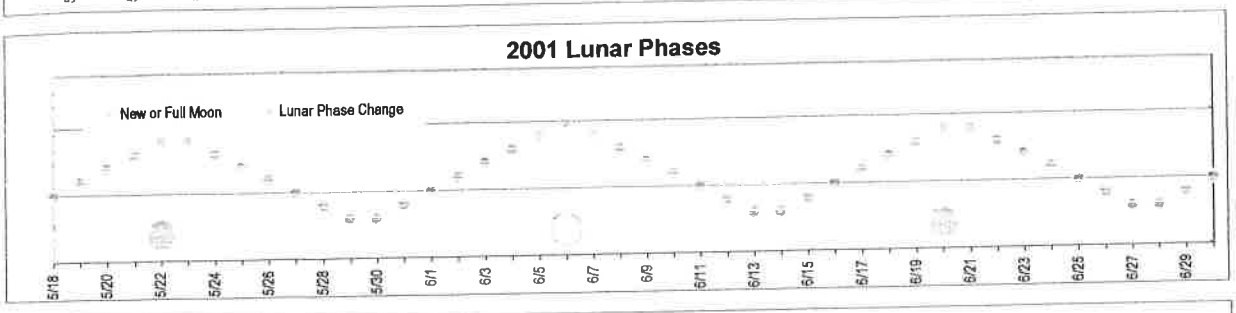
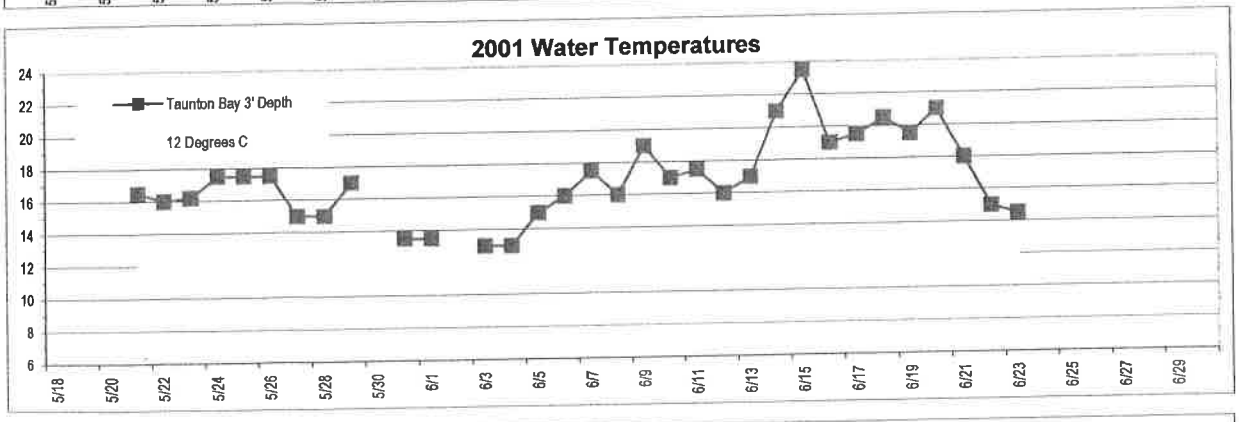
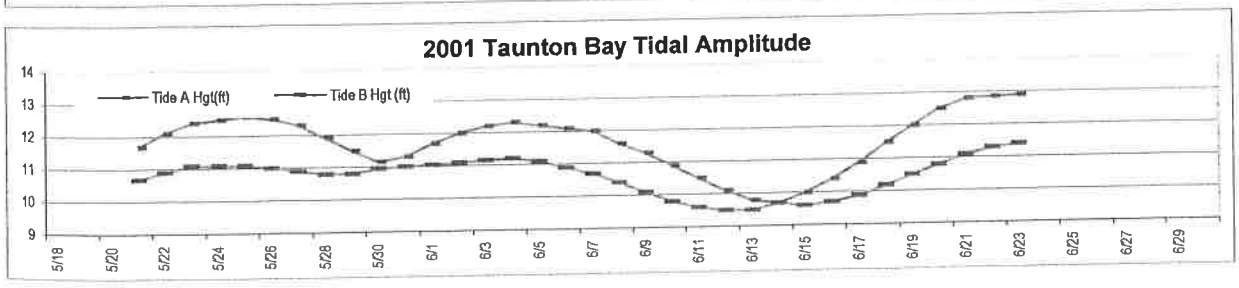


Chart 5: 2001 Tagging Counts and Environmental Data









Scouting Surveys

Limited scouting surveys were conducted during the spawning season and field notes are included in Appendix C. There were fewer opportunities for scouting due to time spent locating an upstream survey site on the Bagaduce. Six different shoreline sites were scouted upstream of the falls. Two sites were chosen for surveys and one, on the south east shore of Snow Cove (and called Quiet Cove by the property owners) was found to host spawning. (Georeferenced in Table 1) Mid-June scouting at a site off Schooner Point Road (on the Bagaduce) found seventeen horseshoe crabs. The owner was agreeable to surveys but the Quiet Cove location hosted more activity.

Horseshoe crabs were reported at Spirit Pond, Phippsburg, but when scouted only a single female was found. Pleasant Cove and Lower Dodge Cove, both in the Damariscotta River were scouted. No live animals were seen at the former site; just one dead female. At Lower Dodge Cove a mating pair and five solo males were found. Both sites in the Damariscotta were identified in the mid-1970's (Born 1977) as active spawning sites.

Conclusion

Spawning surveys continue to offer the best opportunity to identify horseshoe crab populations. Dedicated volunteers have been critical to the success of this work by making it possible to survey ten sites on the same tide for multiple days in succession. Scheduling is always a challenge in that volunteers are needed at different times, each day. High tide often varies between sites within a watershed, so even within a watershed surveyed sites have different schedules. We thank the volunteers who have made this project a success, and the many volunteers that have returned from season to season.

After five years of surveys we know that populations persist in Casco Bay, the Damariscotta and Bagaduce Rivers and in Taunton Bay. Combined five day counts suggest that there may be more horseshoe crabs in some of these sites than would be expected based on an average day's count, but data from the tagging study have shown that the same individuals are observed on multiple days throughout the season. Accordingly, repeated observation data without information on the actual number of individuals seen on recurring visits would provide an inflated estimate of population abundance. Continued closure of the fishery to harvest is a valuable safeguard to assure that this species is perpetuated in Maine's marine ecosystems.

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Appendix A

2005 Raw Data Counts from Survey Sites

2005	**Middle Bay** Low Tide **140 M**	**Sandy Beach In 100m**	Sandy Beach Out 100m	**Wildwood In 200m**	Wild-wood Out 200m	**Thomas Pt. Be. In 120m**	Thomas Pt. Be. Out 120m	# sxns Th pt Be	**Dam. Mills In 100m**	Dam. Mills Out 100m
5/16						0	17			
5/17						4	3			
5/18										
5/26										
5/27	0									
5/28	0									
5/29			814							
5/30										
5/31	0									
6/1	0									
6/2										
6/3										
6/4				8	15					
6/5										
6/6	134			0	0	29	179	13	0	0
6/7	67	3	0	1	5	219	107	12	0	0
6/8	94			2	4	**463**	671	**12**	0	4
6/9	103	5	5	**6**	11	**459**	562	**12**	0	17
6/10	170	**1**	18	**6**	28	**553**	394	**12**	**0**	0
6/11	97	**6**	0	**8**	62	**572**	322	**12**	**0**	0
6/12		**4**	15	**11**	92	**359**	403	**12**	**0**	5
6/13	**205**	**6**	8	**11**	25	255	366	12	**37**	13
6/14	**324**	**7**	0	0	0	1	29	13	**1**	3
6/15	**198**	0	0	0	0	0	15	13	0	6
6/16	**56**	0	1	0	0			13	0	0
6/17	**31**	0	4	0	0			13	0	0
6/18	18	0	0	0	0	4	1		0	0
6/19		0	0	0	0					
6/20		0	2	4	2	28	69	12	0	0
6/21		6	7	0	0	112	138	12		
6/22		12	2	0	1					
6/23				0	0	85	106	12		
6/24										
6/25	102								**36**	12
6/26	100									
5 day high	**814**	24		42		2406			38	
per 100m	**581**	**24**		**21**		**2005**			**38**	

2005 Raw Data Counts from Survey Sites

2005	**Days Cove In 100m**	Days Cove Out 100m	**Bagaduce Falls In 140m**	Bagad. Falls Out 140m	Upper Bagaduce **In 100m**	Upper B Out 100m	**Quiet Cove In 100m**	Quite Cove Out 100m	**Hog Bay In 110m**	Hog Bay Out 110m
5/16									11	
5/17										
5/18										
5/26										
5/27										
5/28										
5/29										
5/30										
5/31										
6/1										
6/2										
6/3										
6/4										
6/5										
6/6	0	0	5	2	0	0				
6/7	0	1	9	4	0	0			**10**	2
6/8	3	5	17	12	0	0			**2**	5
6/9	5	18	**140**	25	**0**	0			**0**	22
6/10	**8**	23	**185**	44	**0**	0	8	10	**0**	14
6/11	**20**	5	**210**	66	**0**	0	7	5	**0**	24
6/12	**16**	15	**226**	80	**0**	0	16	9	0	31
6/13	**46**	17	**154**	71	**0**	0	1	3	0	0
6/14	**8**	8	51	91	0	0	0	0	8	0
6/15	0	0	11	25	0	0	0	0	4	0
6/16	1	0	8	3	0	0	0	0	0	0
6/17	0	1			0	0	0	0	0	1
6/18	0	0			0	0	0	0	0	0
6/19					0	0	0	0		
6/20					0	0	5	1		
6/21					0	0	56	19		
6/22							**35**	4		
6/23							**53**	0		
6/24							**34**	4		
6/25	**59**	0					**88**	8		
6/26							**92**	0		
							6	0		
5 day high	98		915		0		302		12	
per 100m	**98**		**654**		**0**		**302**		**1**	

Appendix B

2005 Taunton Bay Daily Observations (380m transect)

ObsDate	In F	In M	Out F	Out M	Total
5/23/2005					0
5/24/2005					0
5/25/2005					0
5/26/2005					0
5/27/2005					0
5/28/2005					0
5/29/2005					0
5/30/2005					0
5/31/2005					0
6/1/2005					0
6/2/2005					0
6/3/2005				1	1
6/4/2005	2	2	2	8	14
6/5/2005	3	8	6	14	31
6/6/2005	3	5	1	1	10
6/7/2005	1	2	5	6	14
6/8/2005	32	58	3	9	102
6/9/2005	42	103	1	2	148
6/10/2005	58	146	8	25	237
6/11/2005	75	177	1	2	255
6/12/2005	130	246	15	46	437
6/13/2005	123	272	11	26	432
6/14/2005	78	148	4	12	242
6/15/2005	7	11	9	10	37
6/16/2005	0	0	0	0	0
6/17/2005	1	3	2	2	8
6/18/2005			2	2	4
6/19/2005	4	4	4	4	16
6/20/2005	11	14	2	3	30
6/21/2005	27	33	1	3	64
6/22/2005	28	48	5	10	91
6/23/2005	38	51	6	10	105
6/24/2005	16	23	4	4	47
6/25/2005	12	17	6	7	42
6/26/2005	9	15			24
6/27/2005	8	11	2	2	23
6/28/2005	1	4			5
6/29/2005	6	5			11
6/30/2005	1	1			2
	716	1407	100	209	**2432**

Appendix C

Horseshoe Crab Locations - Scouting Notes '05
Pete Thayer

5/27/05 Snow ("Quiet") Cove, Sedgwick (from northeast tip of Bagaduce Lane.) Mud/rocky shoreline. Large boulders/difficult walking in places. No crabs seen. Eventually selected as second Bagaduce River site, when crabs appeared in June.

5/27/05 Bagaduce River ("Rhodora"), Sedgwick (from northwest side of Bagaduce Lane.) Walked two 100-m segments separated by small rocky point. Easy access – grass field. Easy shoreline for volunteer survey; sand/mud sediment. No crabs seen. Two transects established 6/6/05, but later abandoned in favor of Quiet Cove due to few crabs.

5/27/05 Sis Porter Cove, Sedgwick (from Rt. 176 bridge) Not accessible for scouting – water level high from extended heavy rains.

5/27/05 Camp Stream Point, Bagaduce R., Sedgwick (from left fork of Camp Stream Point Lane.) Walked ~ 200m shorefront perimeter of dwelling, mostly steep banking, potentially difficult for volunteers. Water shallow at base; sand/mud sediment. No crabs seen. Owners agreeable to surveys.

6/7/05 Spirit Pond, Phippsburg (starting at northwestern side of pond, from point of blue blaze trail access, off Rt. 209). Water 15.0 C.; 23 ppt. Walked app. 0.75 mi. transect SW along western shore of pond, to dam and then due west into Morse River marsh system. Mostly marshgrass/bank (0.5 – 1m ht.) at edge of sand/mud substrate. Visibility poor (due to wind) in river below the dam/pool; otherwise, good in pond, pool, and in marsh creeks. Found 1 large female, with large barnacle on carapace, in small creek at the initial pond/trail intersection. Walked easterly from intersection up into pond head, app. 500m; no crabs, no shells.

6/8/05 Pleasant Cove, Damariscotta R. (northwest shoreline of cove). Walked 6-700m transect southward from point of land at house at end of access driveway. Mostly marshgrass/bank at edge of mud. Water temp. 15.5 C., 28 ppt., at north end of transect. No live HSCs seen; found one dead female. At small mud/sand pocket beach at north end of transect (next to the house), saw no spawning depressions in sediment.

6/8/05 Lower Dodge Cove, Damariscotta R. Water temp 16.5 C; 24 ppt. Walked northerly app. 400m to marshgrass/point. One long-dead female; one recently dead male, large (18cm). In and around small cove at north end – five males; one mating pair. Not a great volunteer survey site.

6/14/05 Bluff Head, Bagaduce R., Sedgwick (from house at end of Rope Ferry Rd.) Walked ~ 100m in front of house. Tall grass, rocks along shoreline. Two crabs seen. Not a good transect site. Sand/mud sediment.

6/15/05 Schooner Point, Bagaduce R., Sedgwick (from house at end of Schooner Pt. Rd.) Walked ~150m, 1-2 hours after high tide, rainy and getting dark. Sand/mud sediment. 17 crabs seen. Good accessibility/shoreline; owner agreeable to surveys.