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US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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2012 Population Estimate for the Harbor Seal (*Phoca vitulina concolor*) in New England Waters

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ABSTRACT

This survey was conducted to obtain an abundance estimate for the New England harbor seal (*Phoca vitulina concolor*) population, as the previous estimate (2001) was outdated for stock assessment purposes. Aerial photographic surveys and radio tracking of harbor seals on ledges along the Maine coast were conducted during the pupping period in late May 2012. Twenty-nine harbor seals (20 adults and 9 juveniles) were captured and radio-tagged prior to the aerial survey. Of these, 18 animals (6 adult males, 6 adult females, 2 juvenile males and 4 juvenile females) were available during the survey to develop a correction factor for the fraction of seals not observed. The estimate of harbor seal abundance in 2012 was 75,834 (11,625 standard deviation [sd]; 0.153 coefficient of variation [CV]). N_{min}, the lower 20% confidence limit, was 66,884. The 2012 point estimate is 24% lower than the 99,340 reported for 2001. Possible reasons for the lower estimate include changes in survey design, differences in the age/sex ratio of radio-tagged seals available for obtaining a correction factor, differences in harbor seal distribution between 2001 and 2012, and/or that the population has actually declined.

INTRODUCTION

NOAA's Northeast Fisheries Science Center is charged by the Marine Mammal Protection Act with monitoring marine mammal populations along the northeast Atlantic coast. Population estimates are required for each species and stock for management purposes; these are expected to be generated at a maximum of 8-yr intervals. In 2001, the harbor seal population (*Phoca vitulina concolor*) along the coast of Maine was estimated to be 99,340 (including 23,722 pups) (Gilbert et al. 2005), but since 2010 this estimate has been considered too outdated to be used for Potential Biological Removal (PBR) determinations in the stock assessment reports.

As part of the Atlantic Marine Mammal Assessment Program for Protected Species (AMAPPS), efforts were made in 2012 to obtain a current abundance estimate for harbor seals. These efforts included live seal captures and radio-tagging for the development of a correction factor (Hanan 1996; Huber et al. 2001; Pitcher and McAllister 1981; Stewart and Yochem 1985; Thompson and Harwood 1990; Withrow and Loughlin 1997; Yochem et al. 1987). The radio-tagging was followed by an aerial photography effort in sample areas along the coast of Maine during the May-June pupping season. Previous surveys had been confined to Maine coastal waters because all the population was presumed to be in that area during the pupping season.

METHODS

Capture and Tagging

Captures took place in 2012 in two locations: Chatham Harbor, Massachusetts and western Penobscot Bay, Maine (Figure 1; Table 1). Chatham operations were conducted during 24-30 March. Twenty-two harbor seals were captured, but 5 escaped during retrieval from the net. Capture work in western Penobscot Bay was conducted during 12-17 April 2012 (Figure 1; Table 1). Fifteen harbor seals were captured. Three seals escaped during retrieval from the capture net.

Harbor seal capture operations followed protocols used in prior NEFSC efforts (Gilbert et al. 2005; Waring et al. 2006), which are similar to procedures followed in other regions (Jeffries et al. 1993; Withrow and Loughlin 1997). Seals were captured by setting a nylon twine research gillnet (150 x 7.4 m) off specific haul-out locations (i.e., sand bars and beaches in Chatham Harbor or tidal ledges in western Penobscot Bay) during low tide periods (Waring et al. 2006). Seals typically flee into the water at the approach of the net boat, and some seals get entangled in the net. Once entangled, the seals were brought aboard boats and placed in hoop nets. After all seals were secured in hoop nets, they were moved to a designated handling site (e.g., beach or boat).

Each seal was tagged with both a flipper tag and a coded VHF transmitter (radio tag). Each radio tag transmitted an identifiable code on 1 of 4 frequencies at a signal rate of 60 BPM.

The radio tag (Lotek[1] model RMMT-4) was attached to the pelage on the seal's upper back using 5-minute epoxy (Fedak et al. 1983). A numbered and labeled orange tag (Destron Fearing[1] sheep and goat) was attached to 1 hind flipper of each seal.

The full sampling protocol included external examination, morphometric measurement, sex and age class determination, ultrasound, blood draw, and collection of a genetic sample (tissue collected by flipper tag punch). However, the complete sampling protocol was not conducted for each animal due to logistics, handling time constraints, and animal activity level.

Tag Relocation

For this survey, a NOAA Twin Otter airplane was used to photograph seals on ledges and a USFWS Kodiak was used for radio tracking. The Kodiak was equipped with wing-mounted omnidirectional antennas that were cabled to a Lotek[1] receiver (model SRX400) to scan for transmissions from radio-tagged seals. In addition, a single omnidirectional antenna was mounted in the belly port of the Twin Otter and connected to an auto-logging receiver. Both receivers were configured to scan 1 frequency for 7 seconds then move to the next frequency in the series. One complete scan of all frequencies would take 28 seconds. Aerial operations for both aircraft were conducted during the 4 hours surrounding low tide (time of low tide ± 2 hr), excluding transit times from/to airport. The FWS Kodiak searched for radio-tagged seals by flying a loop, altitude of 300 m, extending from Cape Elizabeth to Frenchman's Bay as weather permitted. No radio-tagged seals were located east of Frenchman's Bay.

Aerial Photography

The Twin Otter surveyed seal haul-out ledges at an altitude of 225 m, and oblique photographs were taken from a left side rear pop-out window using a Canon 7D and 300 mm stabilized lens. Initial photography also used a 1.4x extender that was discontinued as unnecessary.

Given our experience with navigation and weather from the previous aerial surveys, we decided to conduct counts of sample areas rather than attempt to survey the entire coast. In 2001, we used 2 single-engine aircraft to count the entire coast, with some areas sampled twice (Gilbert et al. 2005). However, in planning the 2012 effort, we were limited to 1 twin-engine aircraft for photographing and we were not confident that the aircraft could complete a count of the entire coast within the 8-day time window dictated by midday low tides and peak of pupping season.

Previous harbor seal abundance estimate data were totaled by individual geographical areas or "Bay-Units." We used these codes to designate the sample areas with a couple of modifications. The previous distinction between Casco Bay and Upper Casco Bay was arbitrary; these 2 areas were combined. Previously, the numbers of seals on Pumpkin Island Ledges and

[1] Reference to brand names does not imply endorsement by **NOAA** Fisheries.

Seguin Island and Ledges often equaled that of other entire sample areas; therefore these sites were separated from the Boothbay-Sheepscot sample area, and considered a separate sample area.

Sample units were selected for counting with probability proportional to the relative number of adult harbor seals estimated for the unit in 2001 (Table 2). Counting the aerial images involved visual inspection, determination of species, age class and image overlap, and manual marking of seals in photo editing software. Marked images were archived. Blind duplicate counts of most of the larger haul-out sites were completed by a second counter for quality control. A total of 2,656 images were reviewed. Raw counts by sample unit are presented in Table 4.

Estimation

The Hanson-Horvitz estimator (Thompson 2012, p 67-69) was selected because of its appropriateness and flexibility with variable sampling designs. This design allowed us to select sample units with probability proportional to the fraction of adult seals observed in the unit in 2001. This estimator requires sampling units with replacement; thus, some sample units were selected more than once. Each unit was counted only once, but the resultant count was included in the estimate the number of times a unit was selected as a sample.

The estimate of the total number of seals available to be counted, $\boldsymbol{T}$, is estimated as

$$\hat{T} = \frac{1}{n}\sum\frac{T_i}{p_i}, \text{ i = 1, n} \qquad (1)$$

where $\boldsymbol{n}$ is the number of samples selected with replacement; $\boldsymbol{T_i}$ is the total count in sample $\boldsymbol{i}$, and $\boldsymbol{p_i}$ is the probability of selecting sample $\boldsymbol{i}$.

The variance of the estimator is:

$$(\widehat{var})\hat{T} = \frac{1}{n(n-1)}\sum_{i=1}^{n}\left(\frac{y_i}{p_i} - \hat{T}\right)^2 \qquad (2)$$

The above formula estimates the total number of seals available to be counted. To correct this number for those not available required information from the availability of radio-tagged seals. We monitored radio-tagged seals during the aerial surveys. For each seal, we know the number of days the seal was exposed to detection (a seal-day) and the number of days it was detected; therefore we can calculate the probability of each seal being detected during the survey. Because the seal is monitored during the survey, this probability reflects its actual probability and therefore has no variance. An average probability of a seal being detected is calculated from the unweighted average probability of all seals being detected. If $\boldsymbol{f_i}$ is the fraction of survey days the $\boldsymbol{i^{th}}$ seal was detected, then the average probability of detecting a seal is:

$$\hat{f} = \frac{1}{n}\sum f_i \qquad (3)$$

with variance:

$$\widehat{var}(f) = \frac{(\hat{f}(1-\hat{f})}{m-1}$$, where $\boldsymbol{m}$ is the number of radio-tagged seals. (4)

The estimated number of harbor seals, $\boldsymbol{N}$, is

$$\hat{N} = \hat{T}/\hat{f} \quad (5)$$

with variance (Thompson 2012, p 224)

$$\widehat{var}(N) = \frac{\widehat{var}(\hat{T})}{\hat{f}^2} + \frac{\hat{T}^2}{\hat{f}^4}\widehat{var}(\hat{f}),$$ and (6)

$$N_{min} = \frac{N}{exp\left(z\sqrt{ln(1+CV(N)^2)}\right)},$$ where (7)

$$CV(N) = \frac{\sqrt{var(N)}}{N}$$

RESULTS

In Chatham Harbor 17 harbor seals (9 males and 8 females) were flipper and radio tagged (Table 2), and in western Penobscot Bay 12 harbor seals (6 males and 6 females) were flipper and radio tagged (Table 1). Of these, 20 were adults and 9 were juveniles. Nine seals tagged near Chatham and 9 in Penobscot Bay were in the study area during the survey period. The other 11 radio-tagged seals were never detected in the survey units and were presumed to be absent from the survey area. Attempts were made to relocate the radio-tagged seals on each of the 6 survey days. However, on some days the weather precluded searching some areas where certain radio-tagged seals were located (Table 3). Seals were detected on 42 of 95 seal-days (Table 3). Individual seals were detected between 0.167 and 0.833 of the times available.

Because only 18 seals were monitored for between 3 and 6 days, the fractions of times individual radio-tagged seals were available for counting were not distributed as a binomial (Table 3). We therefore used a bootstrap procedure to estimate the correction factor and its variance. The bootstrap estimate of the fraction of seals available to be counted ($\boldsymbol{f}$) was 0.429 with a coefficient of variation [CV] = 0.128).

Thirty-one samples representing 13 unique sample areas were selected from 22 possible areas (Table 2). Using the Hanson-Horowitz estimator (equation 1), we estimated that the available number of seals throughout the study area was 32,533 (2732 sd). Hanson-Horwitz estimate of the numbers of seals available and the bootstrap estimate of the fraction of seals out of the water were combined to estimate harbor seal abundance in 2012 as 75,834 (11,625 sd; 0.153 CV). N_{min}, the lower 20% confidence limit, was 66,884.

DISCUSSION

The 2012 population estimate of 75,834 is not significantly different from the 99,340 reported for 2001 (Gilbert et al. 2005). In addition, the CV of the 2012 estimate is 0.153 compared to 0.091 in 2001.

There are at least 4 possible reasons for the difference between the estimated number of harbor seals in 2001 and 2012. The 2012 estimate may be biased by erroneous assumptions about seal distribution. The 2012 estimate was based on a sample of areas along part of the coast, while the 2001 estimate was based on counts along the entire coast. One reason for this was necessity, as a complete coastal count was not feasible. We also had information from previous surveys indicating that each sample unit had a relatively consistent fraction of the overall harbor seal count. We used this information to design a sampling regime for a Hanson-Horvitz estimator that relied on these consistent proportions. Our assumption of consistent fractions of seals in each sample unit did not hold; for example, the Casco Bay sampling unit was selected 6 times, and the count on that unit was significantly lower than expected from 2001 counts (Figure 2). However, bootstrap sampling indicated that both the estimate of seals available to be counted and its variability were reasonable. The Hanson-Horowitz estimate was 32,533 (2732 sd) compared to the bootstrap estimate of 30,030 (2277 sd). Because these estimates were not different, we accepted the Hanson-Horwitz estimator as unbiased.

A second possible reason the estimates differ is because the correction factor was different in the 2 surveys, being 2.54 in 2001 and 2.33 in 2012. The number of radio-tagged seals was nearly the same, but in 2001 we used information from 10 juveniles and 9 adults, while in 2012 we used information from 5 juveniles and 13 adults. We expect different haul-out behaviors between juveniles and adults during the pupping and mating seasons; however, the observed difference in the correction factors is not significant or sufficient to explain the difference in the 2001 and 2012 estimates.

A third possible reason the estimates differ is because not all seals were in the study area during the survey period. The percentage of pups in the surveys has increased from 6.4% in 1981 to 24% in 2001. In 2012 pups constituted 31.4% of the count. Populations of harp seals (*Pagophilus groenlandicus*) and gray seals (*Halichoerus grypus grypus*) are modelled by extrapolation from pup counts to a total estimate. In a variety of increasing and decreasing populations, estimates of the percent of pups in the population range from 18 to 22%. In some instances, counts of seal pups have been used to extrapolate to a total population estimate. Hammill et al. (2007) used a population model to convert gray seal pup counts on Sable Island to a total population estimate, with the pup counts varying between 18.2 and 19.3 percent of the total population estimates. Harp seal population estimates are also based on counts of pups (Sjare and Stenson 2010).

In this study, the conclusion that 31.4% observed harbor seals were pups is biologically unlikely even for an increasing population. The samples selected in 2012 were not significantly biased toward units with more pups. From the 2001 survey data the number of pups in the samples selected was 25%; in those not selected it was 21%.

The estimated number of harbor seal pups did not differ significantly between 2001 and 2012. In 2001 there were an estimated 23,722 (CV=0.096) pups in the study area (Gilbert et al. 2005); in 2012 there were an estimated 23,830 (CV=0.159) pups in the study area.

It is therefore likely that some part of the population was not available to be counted because it was not in the study area of Coastal Maine. A number of seals could have remained farther south in New England, more northerly in Canada, or offshore.

A final reason the estimates may differ is that the population is no longer growing and has, in fact, declined. Given that possibility, the ecological role of an increasing and spatially expanding US gray seal population (Wood et al. 2002; Wood LaFond 2009; Waring et al. 2015) needs to be evaluated. For example, the 1990s decline of the Sable Island harbor seal population (Lucas and Stobo 2000; Bowen et al. 2003; Hammill et al. 2010) has been attributed to both shark-inflicted mortality on pups and adult females and interspecific competition with the abundant gray seal for food resources. Similarly, inter-specific completion with gray seals has been identified as a potential cause in the decline of several local harbor seal populations in the United Kingdom since the late 1990s (Thompson et al. 2001; NERC 2012). In New England waters, major seal haul-out sites that were once dominated by harbor seals (Payne and Selzer 1989; Barlas 1999; Gilbert et al. 2005; Waring et al. 2010) are now designated as shared sites or dominated by gray seals. Similar observations have been made by the Riverhead Foundation at major eastern Long Island seasonal haul-out sites.

RECOMMENDATIONS FOR FUTURE SURVEYS

With the increase in gray seal numbers, future surveys will have difficulty distinguishing gray seals from harbor seals. Gray seals have been observed in groups both separate from and mixed with harbor seals during the surveys. Aerial observers made notes when they recognized gray seals, and all images were counted by individuals with experience in photo-identification of harbor and gray seals. However, with increased observations of gray seals during the harbor seal surveys, distinction and separation of the two species on the images will be increasingly difficult.

We recommend not using coded VHF radio tags. In 2012 we used coded VHF tags to determine the fraction of seals hauled out of the water. Using coded tags reduced the number of frequencies we were required to monitor, but we found that the coded tags were not identifiable when the signal was weak. Often the signal was strong enough to detect at a frequency, but it was not identifiable to a particular code for an individual signal. As a consequence, the radio-tracking aircraft needed to be much closer to the seal for identification than was required in 2001 with uncoded radio tags.

We recommend using at least 2 aircraft for the next survey: 1 dedicated to locating the radio-tagged seals, and the other(s) dedicated to counting and photographing seals. This research effort was preceded by an attempted field season in 2011. In 2011 we attempted to use only 1 aircraft to both locate radio-tagged seals and photograph seals. Because the radio-tagged seals were not always where the survey sample area was located, we lost information that could have been obtained with 2 aircraft. Although 25 harbor seals were captured, tagged, and sampled in the spring of 2011, the aerial survey component was not completed due to unfavorable weather conditions.

As alternative to using VHF-radio tags, we recommend investing a major effort into satellite tagging (n=to be determined) during fall, winter, and spring to determine the covariates that influence haul-out fraction (Schneider and Payne 1983; Simpkins et al. 2003). Satellite tagging would preclude the need for a second aircraft to scan the area for active VHF tags during the survey. Further, given their longer operating life, the tags will provide data on the timing of the molt (Thompson and Rothery 1987); which we do not have for New England.

We do not recommend monitoring the harbor seal population by counting index sites, as suggested by the Atlantic Scientific Review Group in their 2013 Letter of Recommendations to the NMFS. Index sites have not been shown to be reliable indicators of population size in harbor seals, and as gray seals selectively displace harbor seals in the Northeast some index sites would likely be lost. The guidelines for stock assessments (NMFS 2005) require a population estimate for an estimate of potential biological removal (PBR), and index counts are insufficient.

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TABLES

Table 1. Information on locations and tagging of harbor seals (*Phoca vitulina concolor*) captured in New England waters in 2012.

Capture Location	Date	Flipper tag number	Age class	Sex	Radio Freq	Code
Chatham, MA	24-Mar-12	20	A	M	151.280	15
Chatham, MA	24-Mar-12	23	A	M	151.280	05
Chatham, MA	24-Mar-12	24	A	M	151.280	13
Chatham, MA	24-Mar-12	25	A	M	151.280	17
Chatham, MA	24-Mar-12	26	A	M	151.280	19
Chatham, MA	24-Mar-12	27	A	F	151.540	04
Chatham, MA	24-Mar-12	28	A	F	151.540	08
Chatham, MA	29-Mar-12	29	A	M	151.320	07
Chatham, MA	29-Mar-12	30	A	F	151.320	02
Chatham, MA	29-Mar-12	31	A	M	151.540	19
Chatham, MA	29-Mar-12	32	J	M	151.320	09
Chatham, MA	29-Mar-12	33	A	F	151.540	19
Chatham, MA	29-Mar-12	34	A	F	151.540	03
Chatham, MA	29-Mar-12	35	A	F	151.320	01
Chatham, MA	30-Mar-12	36	J	M	151.320	08
Chatham, MA	30-Mar-12	37	A	F	151.320	10
Chatham, MA	30-Mar-12	38	A	F	151.320	04
Rockland, ME	13-Apr-12	39	A	M	151.540	13
Rockland, ME	13-Apr-12	40	J	M	151.320	06
Rockland, ME	13-Apr-12	41	J	F	150.700	03
Rockland, ME	13-Apr-12	42	J	M	151.540	17
Rockland, ME	13-Apr-12	43	J	M	151.540	11
Rockland, ME	14-Apr-12	44	J	F	151.540	07
Rockland, ME	14-Apr-12	45	A	F	151.540	10
Rockland, ME	14-Apr-12	46	J	F	151.540	18
Rockland, ME	15-Apr-12	47	A	M	151.540	01
Rockland, ME	16-Apr-12	48	A	M	151.540	05
Rockland, ME	17-Apr-12	49	A	F	151.540	02
Rockland, ME	17-Apr-12	50	J	F	151.280	18

Table 2. Sample allocation probabilities and number of times sampled during the 2012 harbor seal (*Phoca vitulina concolor*) abundance survey.

Sample Unit Code	Sample Unit	2001 Corrected Adult Number	Probability of Selection	Cumulative Probability of Selection	Times Sampled
COBSB	Cobscook Bay	837	0.01183	0.00000	0
MACHB	Machias Bay	4104	0.05805	0.01183	4
ENGB	Englishmans Bay	1554	0.02197	0.06988	0
EB	Eastern Bay	2690	0.03804	0.09185	2
WB	Western Bay	3419	0.04836	0.12990	0
PNDB	Pleasant, Narguagus & Denny Bays	3353	0.04743	0.17826	0
FB & MDI	Frenchman Bay & Mount Desert Is.	3335	0.04717	0.22568	2
BHBSI	Blue Hill Bay - Swans Island	1814	0.02565	0.27285	1
BHBMR	Blue Hill Bay - Merchants Row	5087	0.07195	0.29851	4
BHBIH	Blue Hill Bay - Isle au Haut	2741	0.03877	0.37046	3
BHBUP	Blue Hill Bay - Upper	2111	0.02986	0.40923	1
CELPT	Cape Elizabeth to Isles of Shoals	2993	0.04234	0.43909	0
CASB	Casco Bay	7807	0.11042	0.48143	6
BOSHB	Boothbay and Sheepscot Bay	3313	0.04685	0.59185	0
P&S	Pumpkin & Seguin	5559	0.07863	0.63870	0
MUSCB	Muscongus Bay	7156	0.10122	0.71733	3
OUTIS	Outer Islands	2186	0.03092	0.81854	0
PBEA	Penobscot Bay - Eastern	3510	0.04964	0.84946	1
PBVL	Penobscot Bay - Vinelhaven	894	0.01265	0.89911	2
PBUP	Penobscot Bay - Upper Bay	580	0.00820	0.91175	0
PBMW	Penobscot Bay - MidWest	2826	0.03998	0.91995	1
PBMC	Penobscot Bay - Muscle Channel	2833	0.04007	0.95993	1
	Totals	70702	1.00000	1.00000	31

Table 3. Radio tag detections by the Kodiak and NOAA Twin Otter during the 2012 harbor seal (*Phoca vitulina concolor*) abundance survey.

Flipper tag	May 27	May 28	May 30	May 31	June 1	June 2	Days Available	Signal Received	f
20	1	0	**x**	0	0	**x**	4	1	0.250
23	0	0	1	0	0	0	6	1	0.167
24	1	0	1	0	1	0	6	3	0.500
25	1	1	0	1	1	0	6	4	0.667
27	0	**x**	0	1	1	**x**	4	2	0.500
30	1	1	**x**	1	0	**x**	4	3	0.750
35	1	0	**x**	x	0	**x**	3	1	0.333
36	1	0	0	0	1	0	6	2	0.333
37	0	1	0	**x**	0	**x**	4	1	0.250
40	0	0	1	1	0	1	6	3	0.500
41	1	0	0	0	0	0	6	1	0.167
44	0	0	0	0	1	0	6	1	0.167
45	0	1	1	1	1	1	6	5	0.833
46	0	0	0	0	1	1	6	2	0.333
47	1	0	**x**	0	1	**x**	4	2	0.500
48	0	0	1	1	1	1	6	4	0.667
49	1	0	1	0	1	1	6	4	0.667
50	0	0	1	0	0	1	6	2	0.333
Totals	9	4	7	6	10	6	95	42	0.440

x = not available to either aircraft. If seal was available to Kodiak aircraft but not located on a particular day, any location from Twin Otter was not counted.

Table 4. Counts of harbor seal (*Phoca vitulina concolor*) adults and pups and gray seals (*Halichoerus grypus grypus*) by sample area during the 2012 New England harbor seal abundance survey.

Sample Unit	Harbor Seal Adults	Harbor Seal Pups	Harbor Seals Unknown[1]	Harbor Seals Total	Gray Seals
BHBIH	1448	525	2	1777	16
BHBSI	709	357	20	1086	5
BHBUP	942	474	6	1422	0
CASCB	970	420	10	1400	8
EB	1121	720	2	1843	0
FBMDI	1072	325	5	1402	497
MACHB	863	345	6	1214	7
MUSCB	1492	621	4	2117	5
PBMC	1278	589	26	1893	1
PBMW	567	262	6	835	1
BHBMR	2069	1069	3	2478	6
PBEA	1047	730	34	1811	0
PBVL	453	218	10	681	3
Total	14,031	6655	134	19,959	549

[1] Unknown harbor seals could not be distinguished as adults or pups.

FIGURES

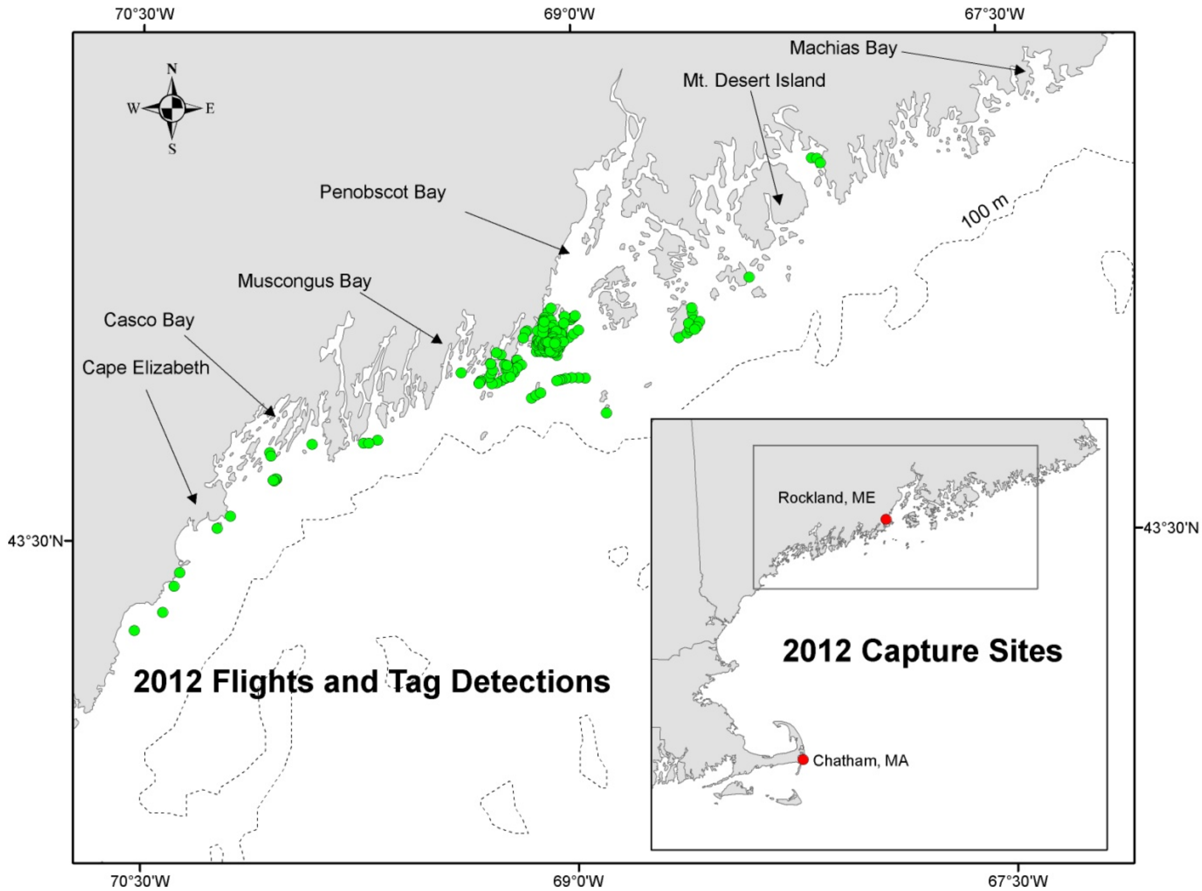

Figure 1. Harbor seals (*Phoca vitulina concolor*) were captured and radio-tagged in Chatham MA and Rockland ME during the 2012 New England harbor seal abundance survey. The green dot indicates each location of the radio-tagged seals (9 captured in Chatham and 9 captured in Rockland) during the survey days.

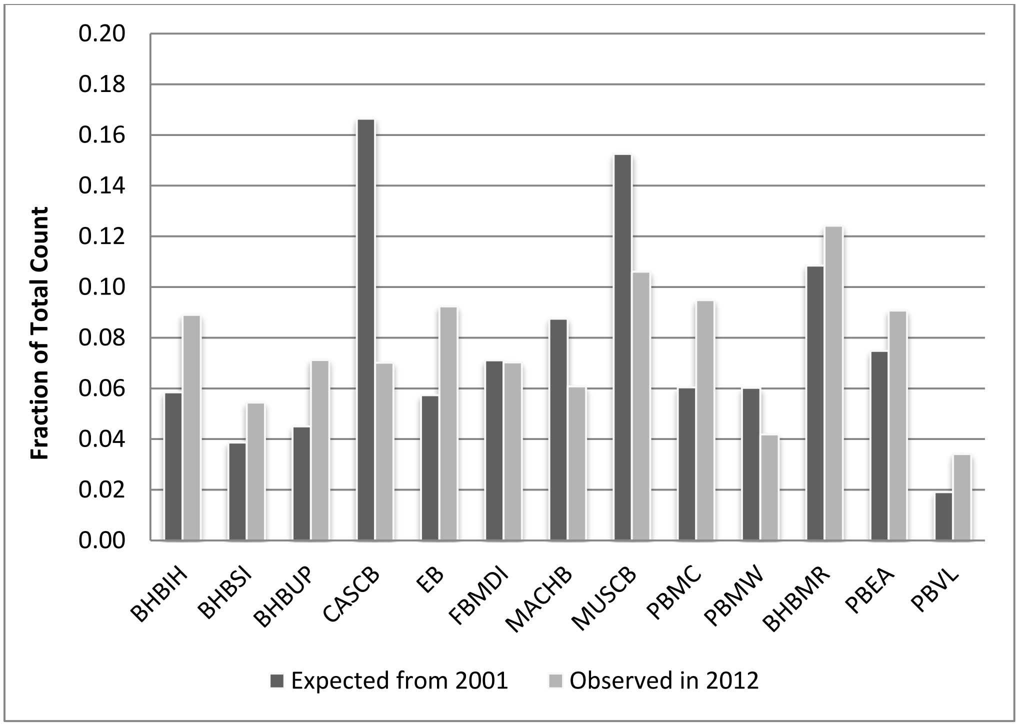

Figure 2. Expected and observed fraction of harbor seals (*Phoca vitulina concolor*) in each of the sample units during the 2012 New England harbor seal abundance survey. Expected fractions were proportional to the relative number of adult seals in each sample unit in 2001.

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