



**NOAA Technical Memorandum NMFS-NE-251**

# Trends and Patterns of Seal Abundance at Haul-out Sites in a Gray Seal Recolonization Zone

**US DEPARTMENT OF COMMERCE  
National Oceanic and Atmospheric Administration  
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# Trends and Patterns of Seal Abundance at Haul-out Sites in a Gray Seal Recolonization Zone

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# TABLE OF CONTENTS

Abstract .....	1
Introduction.....	2
Methods.....	4
Analysis.....	4
Results.....	6
Gray Seals .....	6
Harbor Seals .....	6
Discussion.....	7
Acknowledgements.....	8
References Cited .....	9

# LIST OF FIGURES

Figure 1. General locations of haul out sites in our study area. Also depicted are boundaries for 10 area groups pooled to examine occupancy. ....	13
Figure 2. Species specific heat maps of counts of harbor ( <i>Phoca vitulina</i> ) (a) and gray seals ( <i>Halichoerus grypus</i> ) (b) observed during 2005-2015 at 10 areas in southern New England. ....	14
Figure 3. Expanding periodic fluctuation fit to counts of gray seals ( <i>Halichoerus grypus</i> ) observed during repeated surveys of areas in southern New England during 2005-2015.....	15
Figure 4. Observed counts and fitted growth functions (a) of the annual buildup of gray seals ( <i>Halichoerus grypus</i> ) using haul outs in areas in southern New England during 2005-2015. (b) A plot of estimated asymptotes to the growth curves and includes 95% credible regions.....	16
Figure 5. Observed counts of harbor seals ( <i>Phoca vitulina</i> ) during repeated surveys of areas in southern New England during 2005-2015. (a) Summed counts across haul-out sites for all surveys. (b) Peak counts together with fitted broken stick model to those data. ....	17

## ABSTRACT

Gray (*Halichoerus grypus*) and harbor seals (*Phoca vitulina*) were greatly reduced in numbers along maritime Canada and nearly extirpated from waters along the US Atlantic Coast by the mid1900s. Harbor seals were first to show substantial increases in US Atlantic waters. Expanding from a rapidly rebuilding residual population off Atlantic Canada, gray seals are recolonizing areas of southern New England. Although their abundance appears to vary seasonally, the presence of large numbers of gray seals raises questions about the potential for competitive exclusion of smaller harbor seals as well as public concern over resource conflicts. We counted gray and harbor seals hauled out on frequently used sites near the southern edge of a gray seal recolonization zone, primarily near Cape Cod, Massachusetts. Counts were made during periodic aerial surveys conducted during 2005-2015 to measure seal occupancy at haul outs and to gauge trends in abundance during that time period. We also used statistical models to characterize this variation. In particular, we characterized the annual cycle of gray seal abundance at haul outs with an expanding sinusoidal function and fit annually varying growth functions from year start to peak abundance to characterize the pattern of peak abundance change among years, relying on empirical Bayes methods to estimate parameters. We limited models of harbor seal counts to testing for change in the upward trend in peak counts. Gray seal peak abundance at haul outs occurred between 15 April and 13 May, and total abundance across surveyed sites increased from 10,847 in 2005 to 23,579 in 2015. Although peak abundance of gray seals in the study area more than doubled during our study, the rate of growth declined over time. Concomitant with increasing gray seal presence at haul outs, peak numbers of hauled out harbor seals detected in the study area increased for about half of the study period and then declined. Our study documents the fluctuating but increasing abundance of gray seals on haul-out sites at the edge of a gray seal recolonization zone during 2005-2015, and we provide further evidence that increasing gray seal populations may reduce use of the region by harbor seals. We did not measure total seal abundance in the region. Our work demonstrated that, despite a lack of knowledge about true availability and therefore total abundance, repeated surveys of haul outs can be informative about trends in seal abundance.

Keywords: abundance trend; *Halichoerus grypus*; gray seal; harbor seal; Northwest Atlantic; *Phoca vitulina*

# INTRODUCTION

Gray (*Halichoerus grypus*) and harbor seals (*Phoca vitulina*) were historically distributed along the northeast coast of the United States (US) and Canada (CAN) through the 17th century. Harbor and gray seals were considered a nuisance to commercial fishing and nearly extirpated by the mid-1900s via local and state bounty systems; some of which lasted well into the 20<sup>th</sup> century (Andrews and Mott 1967; Lelli et al. 2009). Since bounties ended, both species have recolonized parts of their former range (Gilbert et al. 2005; Wood et al. 2011). This area includes former pupping colonies of gray seals on islands off of the Northeastern United States, where breeding and pupping were first observed again in the late 1980s (Rough 1991) and have steadily increased in size (Rough 1991, 1992, 1993, 1995; Wood et al. 2011). The Canadian gray seal population off Nova Scotia has increased substantially since the 1960s (Hammill et al. 1998; Bowen et al. 2003b, 2007). Seals with tags and brands indicating they were born on Sable Island (CAN) have been observed at US sites (Wood et al. 2011). Genetic analyses of gray seals born at sites throughout the northwest Atlantic demonstrated little genetic differentiation among these sites (Wood et al. 2011), and thus, the Canadian population has served as a source for the recovering US population. The majority of the US Atlantic harbor seal population is found along the Maine coast, with a subset of animals moving south to Cape Cod (MA) to winter during September to May (Barlas 1999; Gilbert et al. 2005; Payne and Selzer 1989). Harbor seal pup monitoring along the Maine coast since the 1980s showed this population increasing (Gilbert et al. 2005). Little is known about harbor seal movement between Canadian and US sites.

Coastal communities and conservationists have become embroiled in a debate about the apparent rapid recolonization and continued population growth of gray seals now inhabiting the waters off Cape Cod and the perceived impacts of seals on natural and recreational resources. Perceived impacts of a burgeoning gray seal population include consumption of commercial and recreational fish stocks, entanglement in commercial fishing gear, displacement of harbor seals, decreased water quality, and attraction of white sharks (*Carcharodon carcharias*), a seal predator, with resulting concerns regarding shark attacks and potential beach closures. What the debate lacks is adequate scientific basis to characterize these perceived impacts, particularly the lack of documentation of population numbers and haul-out use patterns that might better characterize trends in seal abundance.

Listed among the effects of a burgeoning gray seal population is the potential for displacement of harbor seals whether from physical interference at particular haul-out sites or from the general vicinity through competitive exclusion. Herreman et al. (2009) concluded that competition, primarily with a rapidly growing Stellar sea lion (*Eumetopias jubatus*) population, supported a competitive exclusion hypothesis to explain a decline in harbor seals in Prince William Sound and Glacier Bay. Physical displacement of harbor seals by gray seals is possible owing to the much larger size of gray seals, and predation of harbor seals by gray seals has been recorded in at least one area of sympatry (van Neer et al. 2015). The storied rapid growth of the population of gray seals that use Sable Island off Nova Scotia for pupping has been implicated along with shark predation as the primary drivers leading to declining harbor seal use and pupping of the area (Bowen et al. 2003a). Conservation mandates within the United States call for regular assessments of the status marine mammal populations. In instances of declines in abundance, it is important to document principal causes driving change to properly target management efforts.

Although both gray and harbor seals tend to aggregate and show some seasonal fidelity to beaches and ledges where they can haul out when not foraging, gray seal abundance at such sites

can be orders of magnitude larger than harbor seals. Gray and harbor seals often overlap in space and time along the Northeast US Coast. At some sites they can be observed hauled out in close proximity, but at other sites gray seals appear to have displaced harbor seals from areas that they formerly used. For example, surveys of Monomoy Island (MA) 1983 to 1987 documented a minimum of 1,000 harbor seals there annually (Payne and Selzer 1989) while surveys from 1998-1999 (Barlas 1999) and 2005-2015 found few to no harbor seals.

Seals present at haul-out sites during any brief period, such as during a survey, represent an unknown fraction of animals. Individual seals haul out based on physiological or environmental cues occurring simultaneously on daily and seasonal time scales. In particular, both species will spend more time hauled out during pupping and molting periods, which are strongly seasonally driven (Anderson et al. 1975; Gilbert et al. 2005). Pupping seasons in the northwest Atlantic are December to February and May to June for gray and harbor seals, respectively (Gilbert et al. 2005; Bowen et al. 2003, 2007). During the pupping season, gray seal adults of both sexes are hauled out at sites for up to 5 weeks (Anderson and Harwood 1985). Harbor seals haul out more often during the pupping season (especially mother/pup pairs), and their daily haul-out behavior is tidally driven and heavily influenced by weather (Gilbert et al. 2005; Skinner 2006). Animals haul out in higher proportions and for longer periods of time during their annual molting period (Boulva and McLaren 1979; Leoney et al. 2010; Reder et al 2003; Reeves et al. 1992). Gray seals in the northwest Atlantic molt annually from March through June (Katona et al. 1983; Stobo et al. 1990; Bowen and Siniff 1999; Beck et al. 2000), while harbor seals molt in July-August (Katona et al. 1983).

Outside of molting and pupping seasons, time spent hauled out is reduced and more variable. Both gray and harbor seals also spend time resting at sea (Russell et al 2015), reducing their need to haul out for rest. Yochem et al. (1987) found an average of 41% of radio-tagged seals hauled out each day. Russell et al. (2015) reported probabilities of resting on land, and therefore being available to aerial survey observations, at 0.18-0.38 and 0.10-0.33 for gray and harbor seals, respectively, which is quite small when compared to an availability rate of 0.60 estimated for harbor seals during the molting season in California (Lowry et al. 2008). Distances traveled from haul-out sites, and therefore time at sea, vary between the 2 species as well. For instance, tagged gray seals traveled as far as 258.8 km from Sable Island (Austin et al. 2004), and 2,100 km from sites in the UK (McConnell et al. 1999). Satellite tagged harbor seals have exhibited shorter trips (<50km), though individual seals have been observed traveling 100s of km from haul-out sites (McConnell et al. 1999; Lowry et al. 2001; Sharples et al. 2012). Harbor seals' movements also vary by month (Lowry et al. 2001). Certainly time at sea and movement of individuals among sites reduce an individual seal's availability to be counted at any particular haul-out site and likely influence public perception about total abundance. Regardless of the downward bias that counts of hauled-out seals represent relative to total abundance, if seasonal seal availability is consistent among years, the visible fraction of seals available to be surveyed can be characterized through time to depict trends in the population. In addition, it is this visible fraction that influences public perception and therefore warrants a characterization through time.

To test the idea that regular surveys could be used to characterize seasonal and interannual abundance patterns, we used counts of seals hauled out on frequently used sites surrounding Cape Cod that were made during periodic aerial surveys conducted during 2005-2015 to characterize changes in abundance. We were particularly interested whether or not this simple approach would allow us to discern trends in abundance in a part of the gray seal range currently under rapid recolonization.

## METHODS

Twenty-four locales, centered around Cape Cod and nearby islands of coastal Massachusetts, were identified as potential areas where seals might haul out (Figure 1). Haul-out sites were over flown using either a de Havilland Twin Otter (2005-2011) or Cessna Skymaster (2014-2015), and a series of spatially overlapping oblique photographs were taken to ensure complete coverage of the site. Surveys were flown at 230 m with a ground speed of approximately 185 km/h to maintain consistency with previous surveys (Scott and Gilbert 1982; CETAP 1982). The survey team usually consisted of a pilot, copilot, and an observer, but in some cases an additional recorder was present. Dates of surveys varied among years depending on aircraft availability, weather, and budget. All haul-out sites were observed during every survey, but photographs were only taken when seals were present, and the data analyzed herein excluded gray seal pupping seasons.

Digital images were organized to account for overlap and avoid double counting animals. Seals were assigned to species (gray seal, harbor seal, unknown harbor or gray, and other, such as the occasional harp seal); scanned for entanglements, tags, brands and other individually-identifiable markings; and counted using a paint-dot technique with standard image processing software (Corel PaintShop Pro Photo X2®). Most images were counted by a single individual, and a subset of those counted by others was crosschecked for consistency with the primary counter.

## Analysis

We were interested in characterizing both within year and among year trends in abundance at haul outs within the study area. To examine area-specific occupancy, we pooled nearby sites into 10 focal areas (Figure 1). We then arrayed counts as an area by time heat map to coarsely depict dynamics in hauled out numbers among areas. To avoid issues of heterogeneity in periodic use of geographically close areas and because our interest was on overall abundance for the region, we used the summed counts across all haul outs as data for additional analysis. Because all haul-out sites were photographed on the same day during any survey, there was an extremely low chance of double counting seals.

We fitted mathematical models to seal count data to characterize their variation and used empirical Bayes methods to estimate model parameters. Estimation was completed using Markov Chain Monte Carlo (MCMC) simulation implemented in JAGS 4.0 (Plummer 2015) by using the package R2jags in the R statistical computing environment (R Core Team 2013). First, we used a periodically varying function fit to seal count data to characterize the complete time series of counts. The model took the form:

$$Y[i] = (\gamma + \beta * rTime[i]) * (1 + \alpha * \sin((rTime[i] - \mu)/\tau)) \quad (1)$$

where  $\gamma$ ,  $\beta$ ,  $\alpha$ , and  $\mu$  were parameters to be estimated. The value for  $\tau$  was fixed a  $1/(2*\pi)$  to represent an annual cycle. Values  $Y[i]$  and  $rTime[i]$  are the summed counts and time expressed as years (including fractions) since 1 January 2004 for the  $i$ th survey, respectively. The model was fit assuming observed counts were Poisson random variables with means  $\lambda[i]$  and using an MCMC procedure with minimally informative priors:  $\gamma \sim \text{uniform}(1000, 40000)$ ,  $\beta \sim \text{uniform}(100, 1000)$ ,  $\alpha \sim \text{uniform}(0, 5)$ ,  $\mu \sim \text{uniform}(0, 12)$ .



Because we were interested in possible trends in peak use of haul outs among years, we also fitted a hierarchical model to gray seal counts conducted during day of year (DOY) 0-150, a period that captured the highest observed counts of gray seals. These models use Richards' growth function (Richards 1959) to characterize the change in abundance within a year, while constraining trends among year minima and maxima to linear and power functional forms, respectively. That is, we modeled the log of seal counts by using the following relationships:

$$\begin{aligned}
 Y[j,k] &\sim \text{dpois}(\lambda[j,k]) \\
 \log(\lambda[j,k]) &= \delta[j] + (\gamma[j] - \delta[j]) / (1 + \xi[j] * \exp(\beta[j] * (\tau[j] - \text{DOY}[j,k]))) / \xi[j] \\
 \delta[j] &= a + b * \text{yearct}[j] \\
 \gamma[j] &= m + n * \text{yearct}[j]^p
 \end{aligned}$$

where  $Y[j,k]$  and  $\text{DOY}[j,k]$  are respectively the counts and Day of Year for the  $j$ th year and  $k$ th occasion of a survey within the  $j$ th year;  $\xi[j]$ ,  $\beta[j]$ ,  $\tau[j]$  are year-specific shape parameters associated with Richard's growth function;  $\delta[j]$  are the annual minima fit by a linear function with parameters  $a$  and  $b$ ; and  $\gamma[j]$  are

$$\begin{aligned}
 a &\sim \text{normal}(0, 0.01), \text{ the common intercept for min} \\
 b &\sim \text{normal}(0, 0.01), \text{ the common slope for D, the lower asymptote} \\
 m &\sim \text{normal}(0, 0.01), \text{ the common intercept for G, the upper asymptote} \\
 n &\sim \text{normal}(0, 0.01), \text{ the common slope for G, the upper asymptote} \\
 p &\sim \text{uniform}(0, 1), \text{ the common power for G, the upper asymptote} \\
 \xi[j] &\sim \text{uniform}(0.01, 10), \text{ priors for unique H values among Years} \\
 \beta[j] &\sim \text{normal}(0, 0.01), \text{ prior on values among unique B Years} \\
 \tau[j] &\sim \text{normal}(0, 0.01)
 \end{aligned}$$

and normal distributions were specified by using precision = 1/standard deviation. In both simulations, we provided random starting points from within the range of priors, used an adaptation + burn-in sample of 5,000 iterations, and a final sample size of 10,000 iterations for estimation.

Finally, we modeled the time series of maximum spring harbor seal counts by using a broken stick or segmented regression model. That is, we allowed the maximum count for each year to vary linearly through time with a potential of two different slopes that change at some unknown time during the study period as in:

$$\begin{aligned}
 \text{Max(count)}[j] &\sim \text{dpois}(\lambda[j]) \\
 \log(\lambda[j]) &= \alpha + (\beta_1 * \xi[j] + \beta_2 * (1 - \xi[j])) * (\text{YEAR}[j] - \text{Year.change})
 \end{aligned}$$

where,  $\alpha$  is the intercept,  $\beta_1$  and  $\beta_2$  are slopes,  $\xi[j]$  is an indicator variable with value of 1 if  $\text{YEAR}[j] < \text{Year.change}$  and 0 otherwise, and  $\text{Year.change}$  is the point where the slope changes.

Parameters were estimated by using an MCMC procedure with minimally informative priors:  $\alpha \sim \text{normal}(0,0.01)$ ,  $\text{Year.change} \sim \text{uniform}(2,10)$ ,  $\beta_1 \sim \text{normal}(0,0.01)$ ,  $\beta_2 \sim \text{normal}(0,0.01)$ .

In all cases we used 3 chains and computed the Gelman-Rubin convergence statistic, which was  $<1.1$  for all model parameters, to determine when the algorithms had converged (Gelman and Rubin 1992).

## RESULTS

We conducted 78 surveys during 2005-2015 including 7, 7, 8, 9, 9, 7, 6, 0, 0, 13, and 12 in each year respectively. We counted seals on a total of 21,996 photos. Of these, 83% were counted by a single primary counter. Of the photographs counted by others, 814 (22%) were double counted to ensure consistency with the primary counter. Seal occupancy and abundance varied considerably among sites and across time and space (Figure 2). The general appearance of heat plots for both species indicated the following patterns in numbers of seals hauled out: (1) strong seasonal patterns of abundance existed among most areas; (2) a few areas dominated the abundance patterns, and the most highly used areas differed between species; (3) highest gray seal abundances at the areas of greatest use were an order of magnitude higher than harbor seal abundances in their areas of greatest use; and (4) relative overall abundance trends were apparent in both species, with gray seals increasing and harbor seals decreasing during the study period.

### Gray Seals

Highest cumulative counts among haul-out sites were observed between 15 April and 13 May and increased from 10,847 in 2005 to 23,579 in 2015. Two separate models of count data were useful in characterizing variation in counts within and among years. The complete time series of cumulative counts generally followed a cyclical pattern that was moderately well characterized with an expanding periodic regression (Figure 3). However, that model only weakly captured the growth in peak numbers through time. An alternative model primarily used to characterize the early seasonal growth in abundance to a peak while searching for evidence of interannual population growth had good convergence properties for all estimated parameters. Despite having only a few surveys per year, the evidence seemed strong that early abundance at haul outs was low and rose quite quickly to an apparent peak (Figure 4) that likely coincided with adult molt. Further, observed peaks seemed to support the idea that abundance increased dramatically during the study period, albeit at an ever decreasing rate (Figure 4). From 2005-2010 growth averaged roughly 5%, whereas from 2010-2015, peak abundance increased at an average of 2% per year.

### Harbor Seals

We had intended to characterize variation in seal counts for both species in a similar manner, that is to say with a mathematical model, but harbor seal counts lacked some of the consistency over time found in gray seal counts (Figure 5). In particular, data from 2005 were inconsistent with the 8 other years in that the maximum count occurred in the fall rather than spring. That particular inconsistency rendered a mathematical summary more tenuous than for gray seals. Other known factors made our harbor seal counts somewhat less patterned than the gray seal counts. Human disturbance at a well-used harbor seal haul-out area almost surely influenced a low count during our second survey in 2010 (Figure 5a). Despite these complications, inspection of annual counts revealed that peak numbers of harbor seals were observed at approximately the same time each year (between DOY 80 and 100). Further, the observed

maximum counts progressively increased from 1,978 to 3,778 during 2005-2009 and progressively declined in the 4 surveys after 2009 to the smallest peak abundance of 1,435 among all years observed in 2015.

## DISCUSSION

Strong and directional population dynamics were observed for 2 species of seals in New England during 2005-2015. The abundance of seals in the area and the fraction likely to be hauled out on any given day are 2 highly variable processes simultaneously influencing the summed counts of seals present at study area haul outs. However, the underlying dynamics were evident from our aerial surveys. For Cape Cod waters, the seasonal abundance of seals varies as the composition of seasonal migrants and possible year-round resident animals changes. Seals found in the study area also spend time in the waters off Nova Scotia, using areas in between to forage (Breed et al. 2006). During the pupping season, both male and female adult gray seals on Muskeget Island, MA, have been observed with brands indicating they had been born on Sable Island, Canada (Rough 1991, 1992, 1993, 1995; Wood et al. 2011), evidence that dispersal from Canada has played a role in the reestablishment of US pupping sites. This finding has been corroborated by genetic evidence; mitochondrial and microsatellite genetic analyses comparing gray seal pups born in the Gulf of St. Lawrence (CAN), Sable Island (CAN), Green Island (ME, USA) and Muskeget Island (MA, USA) showed no detectable population structure among these sites, indicating that both male and female seals are moving between these pupping sites (Wood et al. 2011).

Despite the many factors that tend to influence harbor seal use of haul outs (Cowles et al. 2013), environmental influences did not seem to obscure the major patterns of harbor seal abundance in our study area. That is, most harbor seals in our study area appear to be winter-only residents and likely go north to the many rocky ledges of Maine and Maritime Canada by late spring. This trend is in keeping with our observations from a small but informative telemetry study that included several animals tagged from monitored, haul-out areas (Waring et al. 2006). More surprising was the evidence from our data that the peak numbers available to be counted within our area declined toward the end of our study to less than half of the peak observed in 2009. Although not definitive evidence for a real decline in total abundance of harbor seals overwintering in this region, this observed decline agrees with the findings of Johnston et al. (2015) who found evidence that the numbers of by-caught harbor seals were on the decline in southern New England while gray seal by-caught numbers were increasing. Similar trend relationships between sympatric gray and harbor seal colonies have been observed in Canada (Bowen et al. 2003a) and Great Britain (Jones et al. 2015).

We demonstrated an increase in the minimum number of observed gray seals using haul-out sites around Cape Cod waters; however, this trend is increasing at a slower rate compared to a decade ago. This trend is similar to that observed on Sable Island off Nova Scotia, Canada, where the population size, estimated from a pup production model, increased at an exponential rate from 1962-1997 (Bowen et al. 2003b) but has since slowed (Bowen et al. 2011, 2007; den Heyer et al. 2014). The slowing of gray seal population growth in Canada has prompted investigation into density-dependent changes in vital rates as the population likely experiences resource limitations (Hammill et al. 2014, den Heyer et al. 2014). The number of pups born within our study appears to still be on the increase (Hayes et al. 2018).

Abundance levels reported here represent a minimum population estimate because we have made no assumptions about fractions of local populations being hauled out during our surveys.

We sought only to characterize the variability in observed seal presence at haul outs to understand trends in minimum abundance in southeastern Massachusetts and to inform future attempts at estimating seal abundance in the region. Other studies have quantified the percentage of time gray and harbor seals spend hauled out in order to adjust survey counts to account for animals not available to be seen at the time of the survey (Gilbert et al. 2005; Huber et al. 2001; Lonergan et al. 2011; Skinner 2006). These studies have reported adjustment range factors of 1.53 to 2.54, but these adjustments are not appropriate to use with our survey counts because haul-out behaviors are influenced by site-specific environmental conditions and seasonally varying physiological drives as well as age and sex structures within a population (Russell et al. 2015). Thus, a single multiplier will not work for a multiseasonal survey. Future studies may want to estimate detection rates of seals to calculate animal use days within the area which might be coupled with telemetry studies to elucidate the distribution of hauled out seals in principal foraging areas. This information, coupled with foraging data might help to better inform the public debate concerning gray seal influence on the region's food web. Until that work is completed, we believe that the frequent resurvey of haul outs provides useful information about trends in seal presence in the region.

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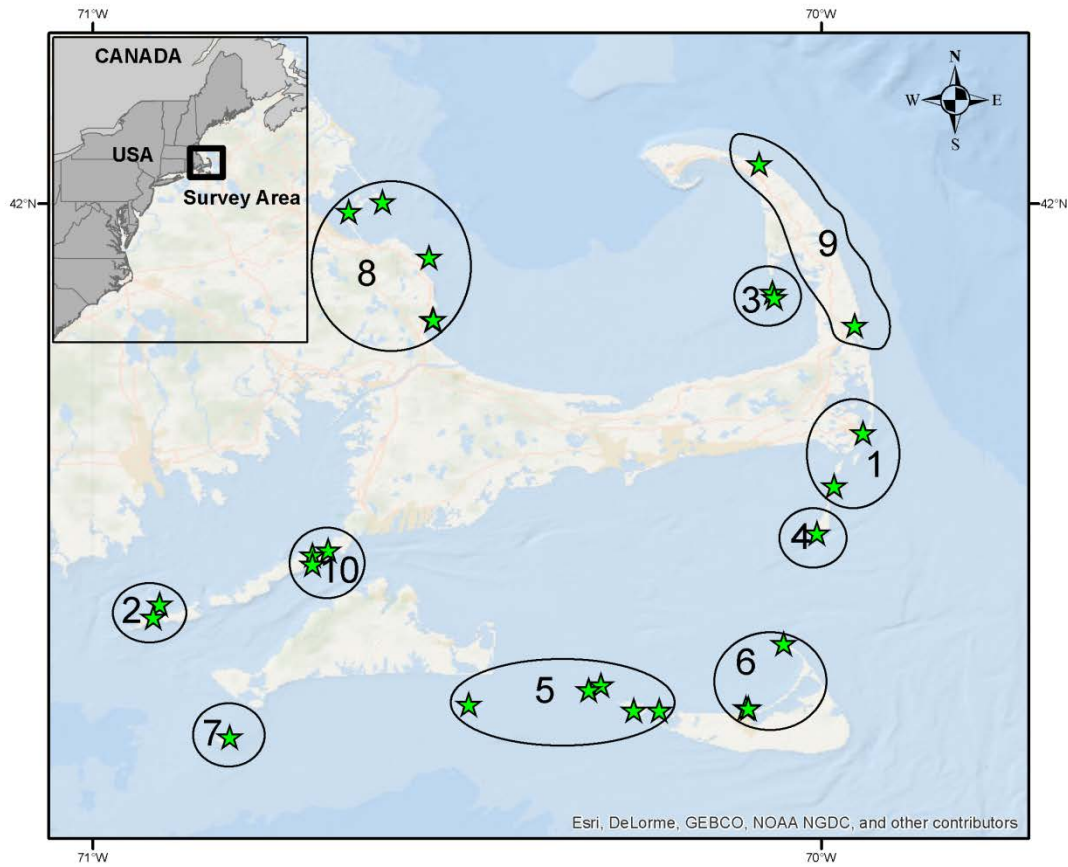
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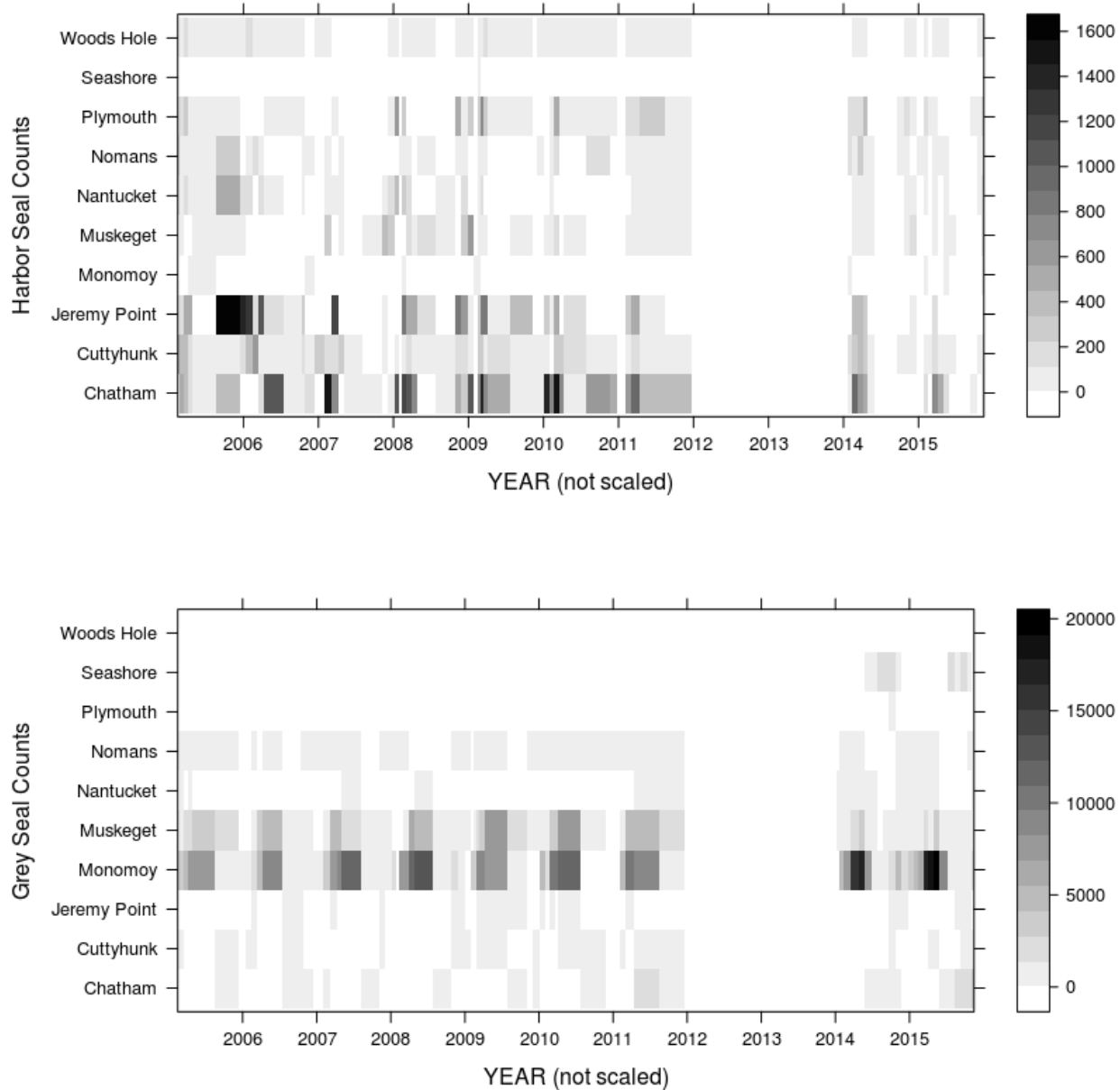
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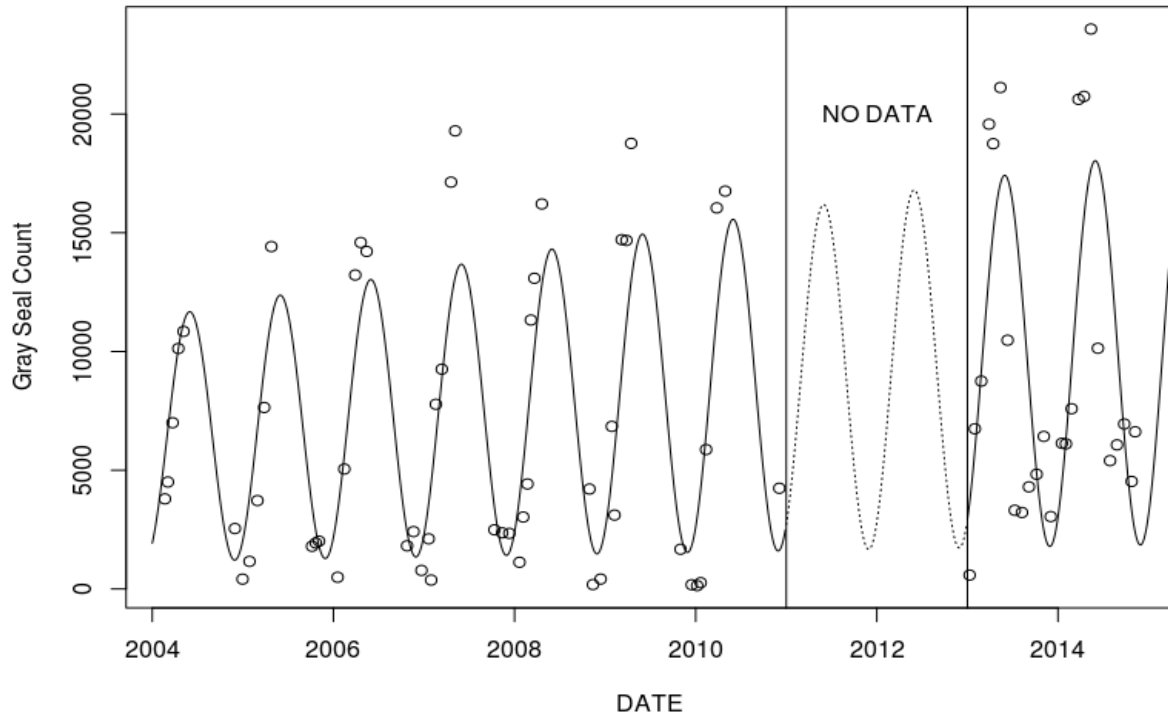




**Figure 1. General locations of haul out sites in our study area. Also depicted are boundaries for 10 area groups pooled to examine occupancy: (1) Chatham; (2) Cuttyhunk; (3) Cape Cod National Seashore, Jeremy Point; (4) Monomoy; (5) Muskeget; (6) Nantucket; (7) Nomans; (8) Plymouth; (9) Cape Cod National Seashore, Atlantic coast ("Seashore"); and (10) Woods Hole.**

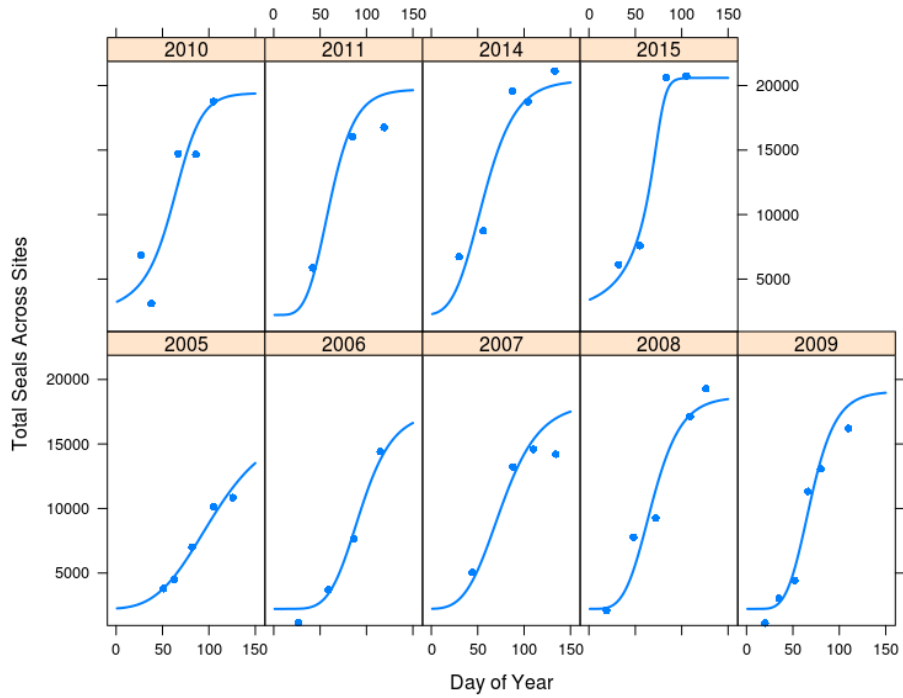


**Figure 2. Species specific heat maps of counts of harbor (*Phoca vitulina*) (a) and gray seals (*Halichoerus grypus*) (b) observed during 2005-2015 at 10 areas in southern New England (see Figure 1). Note that length of a grid square along the x-axis differs among years and represents the time between surveys. Also note that Y-axes and color schemes differ between species.**

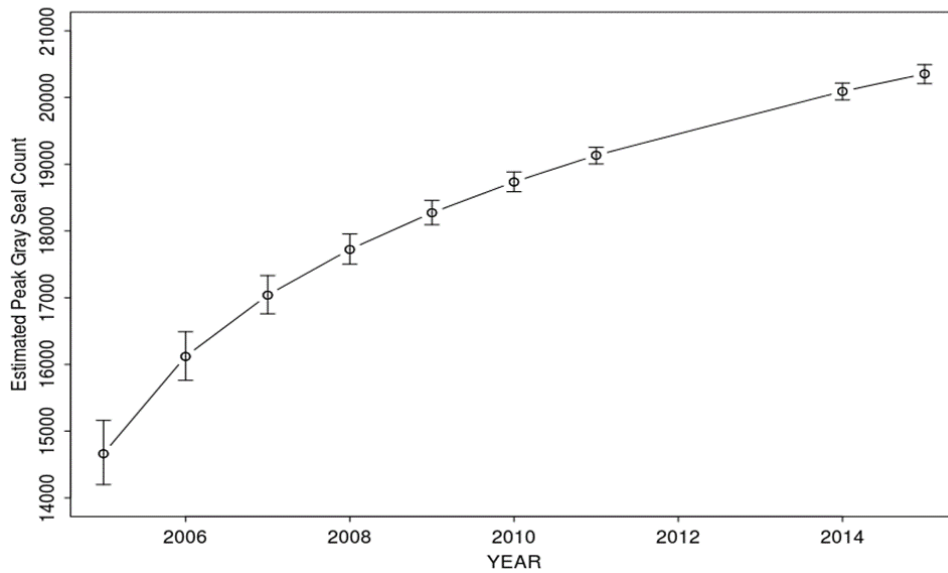


**Figure 3. Expanding periodic fluctuation fit to counts of gray seals (*Halichoerus grypus*) observed during repeated surveys of areas in southern New England during 2005-2015.**

(a)

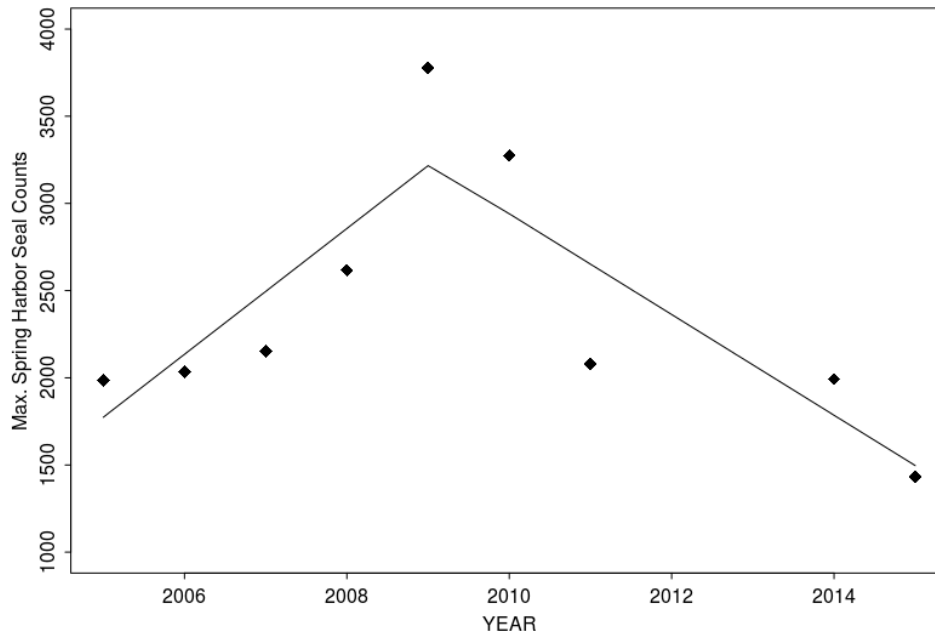


(b)



**Figure 4. Observed counts and fitted growth functions (a) of the annual buildup of gray seals (*Halichoerus grypus*) using haul outs in areas in southern New England during 2005-2015. (b) A plot of estimated asymptotes to the growth curves, including 95% credible regions.**

(a)



(b)

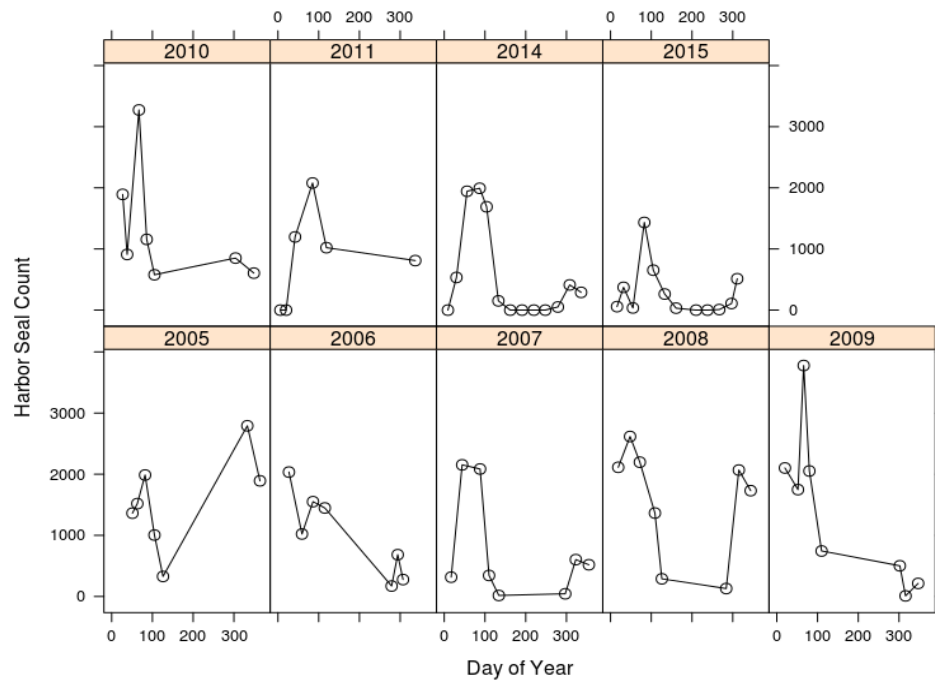


Figure 5. Observed counts of harbor seals (*Phoca vitulina*) during repeated surveys of areas in southern New England during 2005-2015. (a) Summed counts across haul-out sites for all surveys. (b) Peak counts together with fitted broken stick model to those data.

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