Northeast Fisheries Science Center Reference Document 22-14

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Editorial Notes

Second Edition: We have issued a second edition of NOAA NEFSC CRD 22-14, "Gray seal (*Halichoerus grypus*) pupping trends and 2021 population estimates in U.S. waters." The second edition clarifies total counts of pups in Table 1 and the minimum population estimate. The total count of pups in Table 1 should be 6,469, and there should be a count of 163 for Noman's island. Using an Nbest of 27,911 and a default CV of 0.20, the minimum population estimate of gray seals in U.S. waters in 23,624. The second edition can be found here: https://doi.org/10.25923/9hjq-gb82.

ABSTRACT

The Northeast Fisheries Science Center (NEFSC) conducts aerial surveys of the Northwest Atlantic stock of gray seals approximately every 5 years to monitor the size, distribution, and rate of growth of the population in U.S waters. We flew aerial surveys in January 2021 to obtain updated information on gray seal (*Halichoerus grypus*) pupping in U.S. waters, relative to the previous survey flown in 2016. Nine known pupping sites were surveyed along with reconnaissance flights in Maine, New Hampshire, and New York to look for newly established sites. Two image processing approaches were taken: the first created layers of individual seals on a base-map satellite image of the islands, while the second marked individual seals on large, stitched images. We counted a total of 6,469 pups and 7,890 adults which produced a population estimate of 27,911 gray seals in U.S. waters and a minimum population estimate of 23,624. We also fit an autoregressive state-space model to calculate pup growth rates at 4 sites, 3 in Massachusetts (Monomoy Island, Muskeget Island, and Nomans Land) and 1 in Maine (Seal Island). All 4 sites had positive long-term growth rates although we found high variability among the sites and a pattern of rapid growth early in recolonization that then slowed over time.

INTRODUCTION

Gray seals were extirpated from the northeast U.S. coast by the mid-20th century due to local and statewide bounty systems (Andrews and Mott 1967; Lelli et al. 2009). Since the late 1980s, ground and aerial surveys have documented the recovery and recolonization of pupping sites in northeast U.S. waters (Wood et al. 2020). This recovery is due in large part to the protection provided by the Marine Mammal Protection Act (MMPA) of 1972.

Section 117 of the Marine Mammal Protection Act mandates the National Marine Fisheries Service (NMFS) to prepare stock assessment reports on a regular basis for each marine mammal species occurring in U.S. waters. These assessments must include a minimum population estimate and current population trend, among other estimates of mortality and habitat concerns, to evaluate whether a population is meeting recovery goals set forth by the MMPA. The Western North Atlantic stock of gray seals extends from Labrador, Canada, to New Jersey, U.S., and most of the stock is in Canadian waters (Hayes et al. 2020). The Northeast Fisheries Science Center (NEFSC) conducts aerial surveys of the Northwest Atlantic stock of gray seals approximately every 5 years to monitor the size, distribution, and rate of growth of the population in U.S. waters. The NEFSC flew aerial surveys in January 2021 to update estimates of gray seal population size and to revise models to estimate rates of change at the pupping colonies with longer time series. In this report, we also compare different approaches for processing and counting the aerial survey imagery.

METHODS

Aerial Surveys

The NEFSC conducted surveys on January 11, 12, and 13, 2021, in a de Havilland Twin Otter aircraft flown at 230m in altitude. We photographed pupping sites obliquely from the side window of the plane using a Canon EOS 6D camera with a 300mm lens. We chose survey times that would have the optimal daylight conditions. The surveys targeted the 9 established sites in Massachusetts (Muskeget, Monomoy, and Nomans Land islands, as well as Great Point at Nantucket Island) and Maine (Seal, Green, Mount Desert Rock, Wooden Ball, and Matinicus Rock islands) along with some reconnaissance in Maine, New Hampshire, and New York to look for expansion of pupping into new sites (Figure 1). Surveys of sites in Maine and New Hampshire took place on January 11; surveys of sites in Massachusetts and New York took place on January 12. Given platform availability and good survey weather, repeat surveys were flown over Massachusetts on 13 January. Repeat surveys can be used to assess variability in counts and may also provide better island coverage.

Image Processing

The first step of the image processing workflow was to combine overlapping images into manageable-sized chunks using Adobe Photoshop's photomerge function. We then georeferenced the merged images using ArcGIS Pro (v. 2.7.0) by overlaying them on satellite images of the islands (Figure 2). This step was useful for viewing island coverage and reducing double counting since multiple passes over sites using a handheld camera can yield a large quantity of confusing data. At smaller sites, individual images were used for counting. We counted adults, pups, and dead seals in the images (Table 1).

Two trained, experienced counters processed the images using 2 approaches. The first approach was a georeferenced counting technique using the georeferenced image composites, as well as some georeferenced individual images, and then using the "create features" tool in ESRI ArcGIS Pro (v. 2.7.0) to add a point on each seal, producing point layers for each of the different categories (pup, adult, dead; Figure 3). As image distortion was introduced in both the photomerge and the georeference steps, the original individual images were periodically referred to in order to categorize seals. The second approach was a Photoshop counting technique using Adobe Photoshop (v. 23.4.0) to visualize overlap among images and to count seals. Individual seals were marked on the images to create a record of the counts (Figure 4).

We chose the Muskeget Island (12 January) and Seal Island (11 January) surveys to be processed by both counters because of the size and complexity of these colonies. The 12 January Muskeget survey was chosen instead of 13 January as it had better overall island coverage. Given large initial differences between the Nomans Land Island surveys on 12 and 13 January, the 13 January survey was also counted by both scientists. The smaller sites were counted once by 1 scientist.

If we found a difference in the 2 counts, we selected specific areas to reconcile. These areas were encompassed within large stitched images containing relatively high seal counts covering a large area of the island. We also selected areas of the island where multiple aerial survey tracks overlapped. We focused our attention on areas that were confusing and likely to have more counting mistakes.

Pup Trend Modeling

Sites with good-quality survey counts available for 8 or more years are Green, Monomoy, Muskeget, Nomans Land, and Seal islands (Table 2). The pup counts at Green Island were low, and their trajectory might have changed 1 or more times, making it unclear what kind of model might be an appropriate fit; consequently, we decided not to model pup counts at Green. While surveys at Monomoy began in 1990, that colony had small numbers of pups intermittently from 1990 to 2008 and then began growing in 2009 (Wood et al. 2020). Because of the different trajectories of the colony counts in the 2 time periods, we decided to model only the counts starting in 2009, representing the colony's recent trajectory. When the 2 counters produced substantially differing counts at a site for 2021, modeling was performed with each count and with their average.

The time series of counts at each site were modeled with an autoregressive state-space model using the MARSS package (Holmes et al. 2021a, 2021b; Holmes et al. 2012) in R (R Core Team 2020). MARSS implements a density-independent stochastic Gompertz exponential growth model and estimates process error and observation error separately. We considered whether to model the sites as multiple observations from a single population, i.e., sharing process error and potentially observation error. We decided instead to model each site individually because of different colony establishment dates and potential site-specific influences. The models are of the form:

$$x_t = x_{t-1} + u + w_t, w_t \sim N(0, q)$$

$$y_t = x_t + v_t, v_t \sim N(0, r)$$

where x_{t-1} and x_t are the natural logs of the (unobserved) true counts at times t-1 and t, u is the growth rate, w_t is the process noise at time t, q is the variance of the process noise, y_t is the natural log of the observed count at time t, v_t is the observation noise at time t, and r is the variance of the observation noise. The growth rate u is a single rate calculated over the entire time period modeled and thus does not necessarily reflect the growth in any single time step.

Because the Gompertz exponential growth model makes use of the log of the counts, zero counts in 1 year at Muskeget and 3 years at Monomoy were replaced with counts of 1 before taking the log. MARSS models were fit with 10 different random initial conditions to increase the chance of converging to a global maximum. The models were allowed to run up to 3000 iterations, and 0.01 was used as a convergence cutoff for the slope of the log parameter versus log iteration. The models had very similar log likelihoods and AICs across the different initial conditions. The MARSS model was not able to converge on an estimate for the observation variance for Monomoy, and in order to fit that model, we set the observation variance to 0.04, which is similar to the estimated observation variances at Muskeget and Seal.

To approximate the annual growth rates at Muskeget, Seal, and Monomoy, neglecting process noise and observation noise, we calculated the differences between consecutive time steps in the natural log pup counts. Figure 5 shows both the raw (a) and natural (b) log of pup counts over time at the 4 modeled sites. When counts were missing in 1 or more years, the log differences were divided by the number of years since the previous survey so that all changes are shown on an annual basis.

Population Size

We assumed that all pups had been born at the time of the surveys on January 11 and 12, based on results from the 2016 survey which was conducted around a similar date of January 17 (den Heyer et al. 2020). We increased the pup count by 3% based on the correction applied to the 2016 counts, which accounted for pup mortality prior to the survey based on Sable Island (den Heyer et al. 2020).

We estimated the total size (pups and adults) of the gray seal population in U.S. waters near the peak of the 2021 winter pupping season by multiplying the adjusted number of pups born at U.S. colonies by an expansion factor. This approach is often used to estimate the size of a pinniped population when the only measure of population size is the number of pups born (Kirkwood et al. 2005; Muto et al. 2021). We used an expansion factor of 4.19 based on the most current ratio of adults to pups in the Canadian portion of the stock (400,400:95,585; Rossi et al. 2021; den Heyer et al. 2020). There is no coefficient of variation (CV) around the expansion factor.

For stock assessment purposes, a minimum population estimate (N_{min}) is calculated from the best population estimate (N_{best}) and is defined as the 20th percentile of the log-normal distribution resulting from a point estimate of abundance and its CV (Wade and Angliss 1997). When the variance around an expansion factor is unknown, a default $CV(N_{best})$ of 0.20 has been used to calculate N_{min} (Muto et al. 2021), which is computed as:

$$N_{min} = \frac{N_{best}}{exp\left(0.842 \times \left(ln(1 + CV(N_{best})^2)\right)^{0.5}\right)}$$

RESULTS

Aerial Surveys and Counts

We counted a total of 6,469 pups and 7,890 adults over all sites surveyed (Table 1). Pupping occurred at all known, established sites, as well as at 1 new pupping site on Pumpkin Island, Maine, where there were 28 live pups. We also observed 1 dead pup at Little Gull Island, New York, where successful pupping has not yet been documented. At the largest site, Muskeget Island, pups and adults were distributed around the perimeter of the island, with the largest area of high relative pup density found on the eastern side of the island (Figure 6).

Generally, the Photoshop counting technique produced higher seal numbers than the georeferenced counting technique. During the reconciliation process, numbers generated by the Photoshop technique were reduced and changed to a larger degree compared to those from the georeferenced counting technique. The overcounting was a result of the counter using the Photoshop technique not identifying areas of overlap (double counting). That counter also preferred to assign unidentifiable objects to “unknown.”

Pup Trend Model

The estimated annual growth rates, confidence bounds around the growth rate, and process and observation variances are given in Table 2. Muskeget, Monomoy, Seal and Nomans Land islands all had positive growth over the periods examined. Nomans Land had the highest average long-term rate of increase at 44%. The annualized growth rates calculated from observations at Muskeget are presented in Figure 7a, which shows that the annualized pup count growth rates from 1991-1994 ranged from 71-90% and then generally fell until 2004. From 2005-2011, the growth rate was highly variable, from -13% to 67%. Since 2011, the growth rate at Muskeget has been slower and less variable, ranging between an 11% increase and an 11% decrease. At Seal (Figure 7b), after a period of varying growth from 2000-2006, the growth rate has overall fallen from 42% in 2007 to -2% in 2021. At Monomoy (Figure 7c), there were 10 or fewer pups in every survey up to 2008, leading to relatively large percent changes that may be within the range of uncertainty of such small counts. Since 2010, the annualized growth rate at Monomoy has generally decreased from 82% in 2010 to -22% in 2021. At Nomans Land (Figure 7d), the annualized growth rate has continued to increase since 2015.

Population Size

Applying a 3% correction to the observed pup count of 6,469 resulted in an adjusted count of 6663 pups. The best estimate (N_{best}) for the total number of gray seals in U.S. waters during the 2021 pupping season is 27,911 animals (6,663 * 4.19). Using an N_{best} of 27,911 and a default CV of 0.20, the minimum population estimate of gray seals in U.S. waters is 23,624.

DISCUSSION

Future Survey and Image Processing Recommendations

We have processed both oblique and nadir images of the U.S. gray seal pupping sites over the last 30 plus years (Wood et al. 2022). The challenges created by having to overlay many obliquely photographed images are drastically reduced when nadir images are taken with a belly-mounted camera system, and we strongly recommend using this type of system for all future seal surveys. Nadir images also expedite georeferencing of seal locations.

When considering the 2 counting techniques used in this study, the georeferenced counting technique is the preferred method for several reasons. As all seals were plotted on a basemap of the island, there was a lower chance of double-counting (overcounting). This plotting approach also meant less time was spent looking for overlap among different flight paths/transects. The final product is a visual depiction of both the spatial distribution and seal density on the islands, with each seal having a geographic position. The georeferenced counting technique also showed that referring to individual (non-stitched) images can increase seal category determination (i.e., reduce the number of unknowns).

A further advantage to using the georeferencing technique is that the resulting fine-scale spatial information generated for seal distribution lends itself to further analysis, such as spatial analyses correlating distribution with habitat characteristics, and examining distributional changes over time. Some ideas to explore include using mother/pup spacing or pup/adult ratios to develop a proxy for molt-staging for determining the timing of the pupping cycle, and looking at preferred habitat zones and the phenology of which areas are colonized first.

Rates of Increase and Population Size

All sites modeled had positive long-term growth rates although we found high variability among sites. The time since pupping re-establishment varies from 10 years to 33 years; pupping has been observed on Muskeget since 1988 while pupping on Nomans Land has only been observed since 2011. Generally, we observed a high growth rate early in recolonization that slows over time. This means the annualized growth rates presented here for well-established colonies (e.g., Muskeget and Seal) were driven by early, rapid growth with rates after 2015 being much lower (Figure 7). Based on these observations, as well as similar growth patterns documented in other gray seal pupping recolonization events (Gaggiotti et al. 2002; den Heyer et al. 2020), we might expect to observe a similar pattern at new U.S. colonies.

Both the 2021 and 2016 surveys of gray seal pups in U.S. waters took place at roughly the same date that the Department of Fisheries and Oceans (DFO) Canada flew surveys to estimate gray seal pup production in Canadian waters. In the United States, the total number of pups observed in 2021 (6,469) was similar to that observed in 2016 (6,308; Wood et al. 2020). Total pup production in Canada in 2021 was 98,200 (95% CI = 86,800 – 109,700; DFO 2022) and did not significantly differ from pup production estimates in 2016 (den Heyer et al. 2020).

The 2021 U.S. population size reported here relies on the assumption that vital rates (juvenile and adult survival, fecundity) of animals in the United States are the same as those in Canada. Variations in these rates, due perhaps to different drivers of mortality on the age classes or different proportions of sexually mature animals in each region, will influence the ratio of total population size to pup production (Harwood and Prime 1978). For gray seal population assessments in Canada, uncertainty in juvenile survival rates has a large impact on population estimates and has been a major factor in recent revisions of estimates of gray seal abundance (DFO 2022). In the United States, fishery bycatch mainly occurs of young-of-the-year animals; the level of gray seal bycatch in the New England sink gillnet fishery in 2019 was 30% (Precoda and Orphanides 2022) of the number of pups born in 2021. If juvenile survival rates in the United States are not comparable to those in Canada, there is uncertainty in the U.S. total population estimate derived from the Canadian total population size to pup production ratio.

Lastly, the population size reflects only the portion of the population in U.S. waters during winter and does not reflect seasonal changes in abundance as animals move around to forage. Outside of the pupping season, animals move between U.S. and Canada waters (Nowak et al. 2020, Murray et al. 2021), although the percent of time animals spend in each region is not known for a representative portion of the combined population. Increased tagging and/or seasonal abundance surveys would help inform what percentage of the Northwest Atlantic population uses U.S. waters and how migration and immigration varies throughout the year.

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TABLES AND FIGURES

Table 1. Pup, adult, and dead seal counts for all islands surveyed in January 2021. Sites with replicate counts include the smaller and larger counts in parentheses.

Colony	Survey Date	Pups	Adults	Dead
Boone Island NH	11 January	0	130	0
Fuller Rock ME	11 January	0	0	0
Great Gull NY	12 January	0	14	0
Great Point MA	12 January	12	972	1
Green Island ME	11 January	12	14	0
Isles of Shoals NH	11 January	0	7	0
Little Duck ME	11 January	0	0	0
Little Gull NY	12 January	0	235	1
Machias Seal ME	11 January	0	0	0
Matinicus Rock ME	11 January	158	189	1
Monomoy MA	12 January	772	1445	23
Mt Desert Rock ME	11 January	0	513	0
Muskeget MA	12 January	3898 (3741, 4054)	2217	64
Nomans Land MA	13 January	163	875	4
Pumpkin ME	11 January	28	67	0
Seal Island ME	11 January	819 (806, 831)	632	6
Sequin ME	11 January	0	0	0
Tuckernuck MA	12 January	2	104	0
Wooden Ball ME	11 January	605	476	3
Total Counts		**6469**	**7890**	**103**

Table 2. Rates of increase, confidence bounds on the rates of increase, and process and observation variances for the 4 data-rich sites. The model was not able to converge on an estimate for the observation variance for Monomoy, and it was therefore set to 0.04, a value similar to the estimates at Muskeget and Seal.

Site	Years Covered	# of Years Included	Rate of Increase (Confidence Bound)	Process Variance	Observation Variance
Monomoy	2009-2021	9	0.199 (-0.001–0.398)	0.113	0.04 (fixed, not estimated)

Site	Years Covered	# of Years Included	Rate of Increase (Confidence Bound)	Process Variance	Observation Variance
Muskeget	1988-2021	26	0.209 (0.058–0.361)	0.195	0.0348
Nomans Land	2011-2021	8	0.441 (0.281–0.602)	0	0.276
Seal	2000-2021	11	0.115 (0.037–0.192)	0.254	0.0536

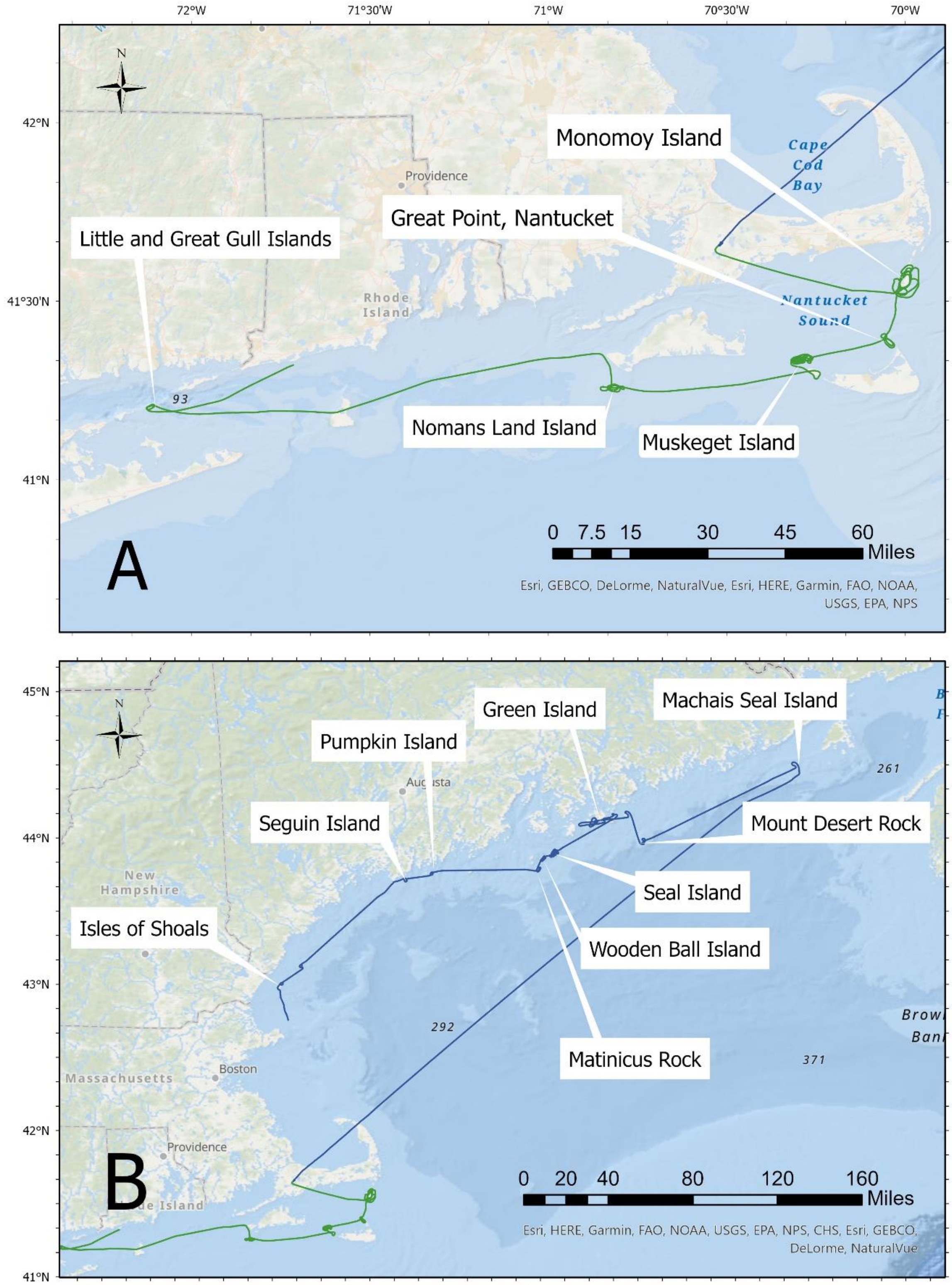


Figure 1. Aerial survey track line and pupping site locations.

Figure 2. Map of Muskeget Island showing the overlapping coverage of aerial transects. Each yellow polygon represents a stitched image.

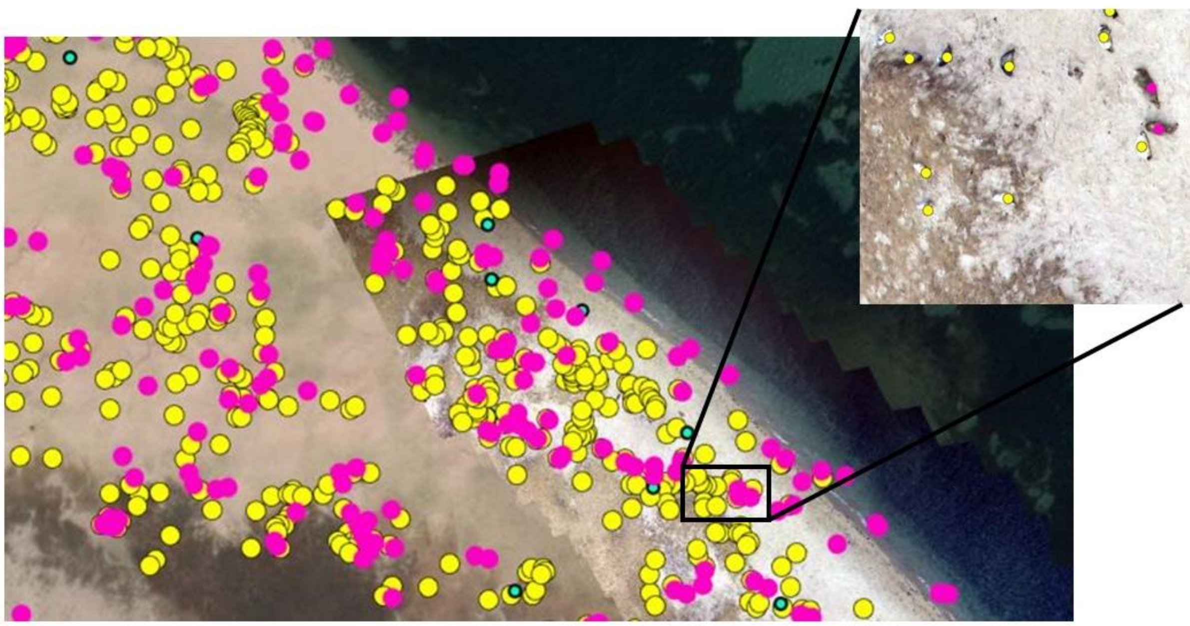


Figure 3. A stitched photo composite overlaid on a satellite imagery basemap in ArcGIS Pro, showing point layers added manually on individual seals. Yellow dots are gray seal pups, pink dots are adults, and green dots are dead pups.

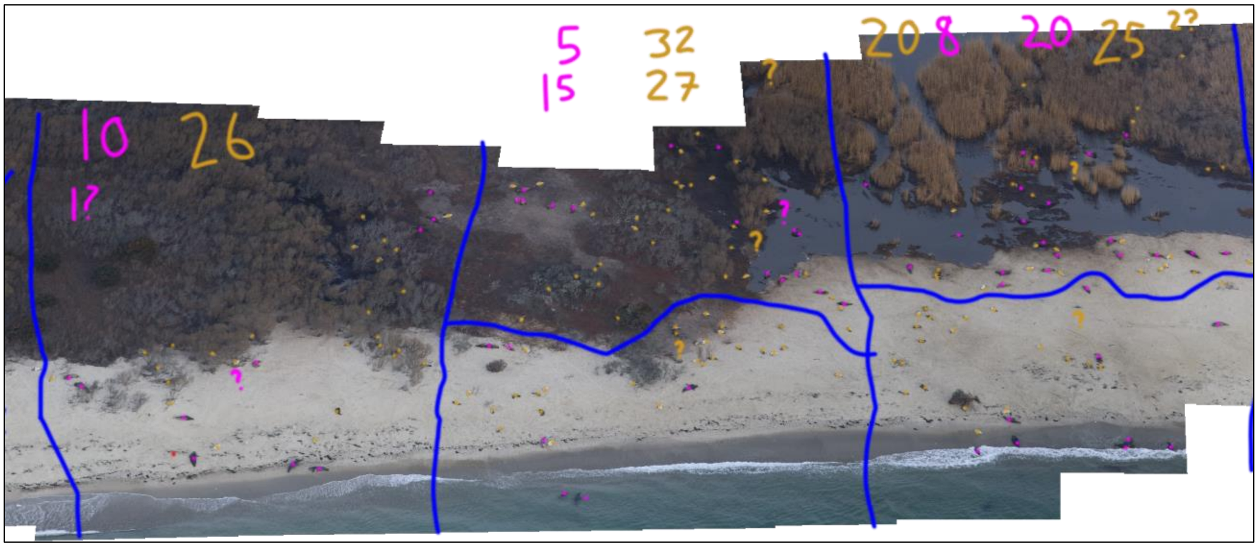


Figure 4. A stitched image with counted seals marked in Adobe Photoshop. Orange dots are pups, and pink dots are adults. The blue lines serve to divide up the larger stitched image for easier counting. The pink and orange numbers are seal counts for those areas.

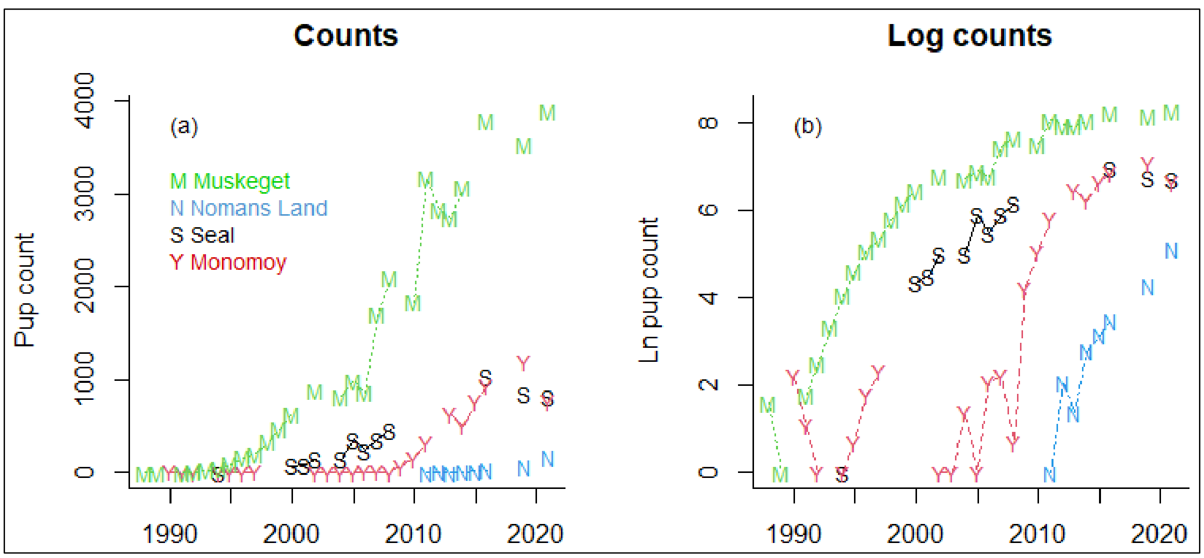


Figure 5. Pup counts at the 4 modeled sites: Monomoy, Muskeget, Nomans Land, and Seal. (a) represents absolute counts; (b) represents natural log counts.

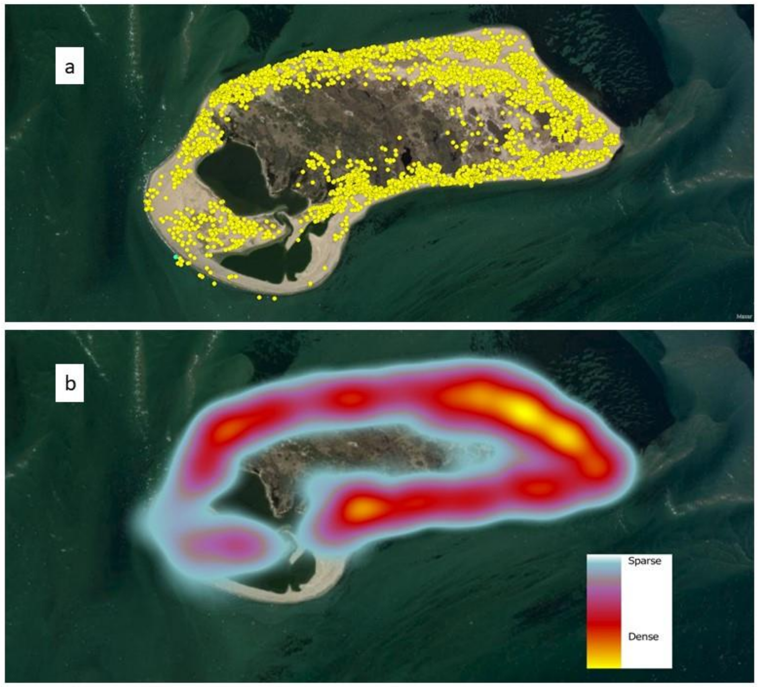
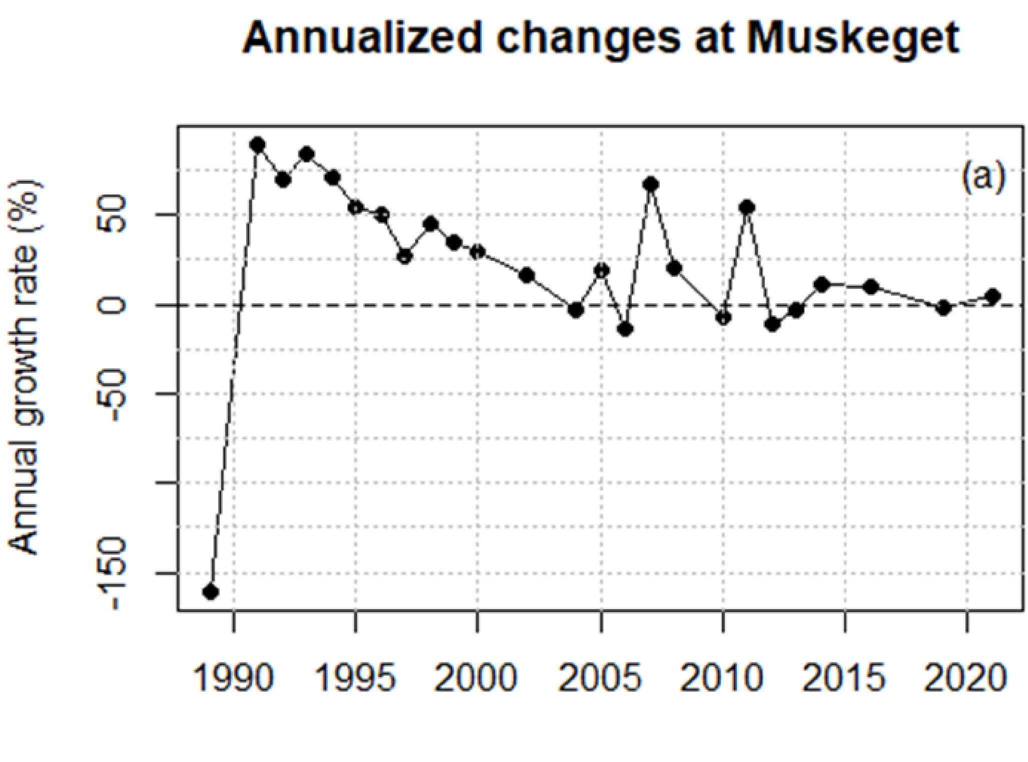
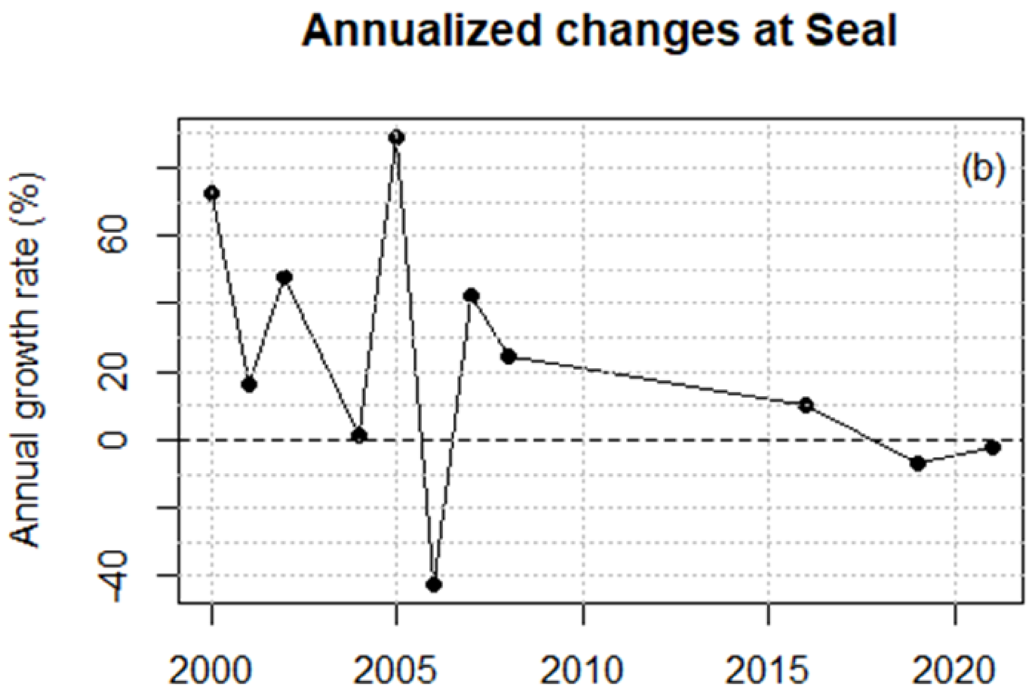
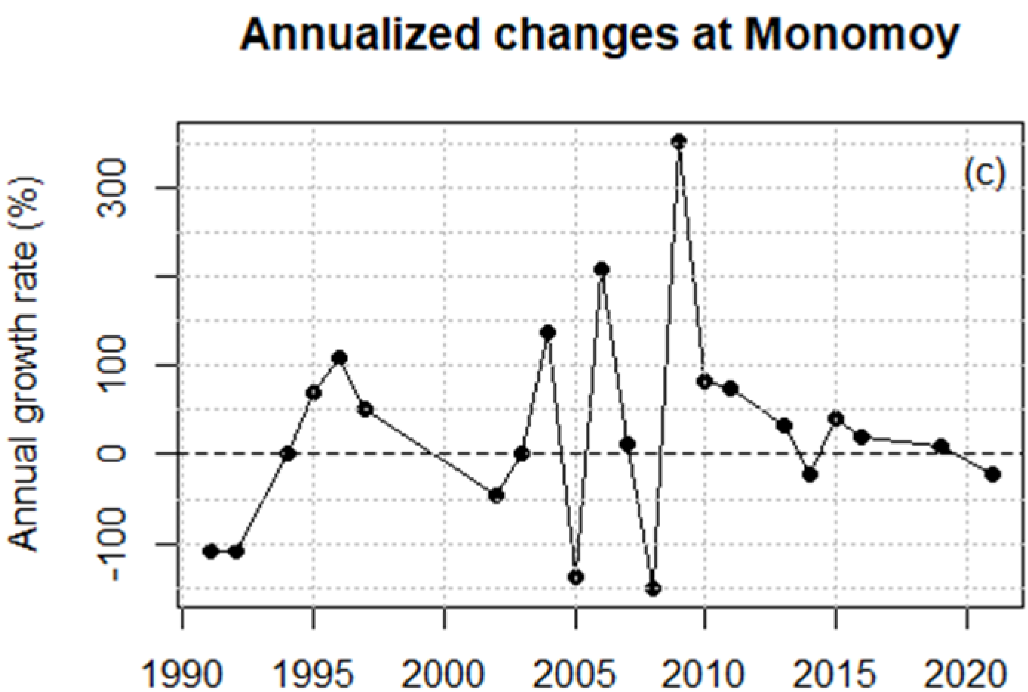


Figure 6. (a) Pup location points on Muskeget Island on 12 January 2021. (b) Heat map of point distribution.




Annualized changes at Seal
(b)
Annual growth rate (%)
-40
0
20
60
2000
2005
2010
2015
2020


Annualized changes at Monomoy
(c)
Annual growth rate (%)
-100
0
100
300
1990
1995
2000
2005
2010
2015
2020

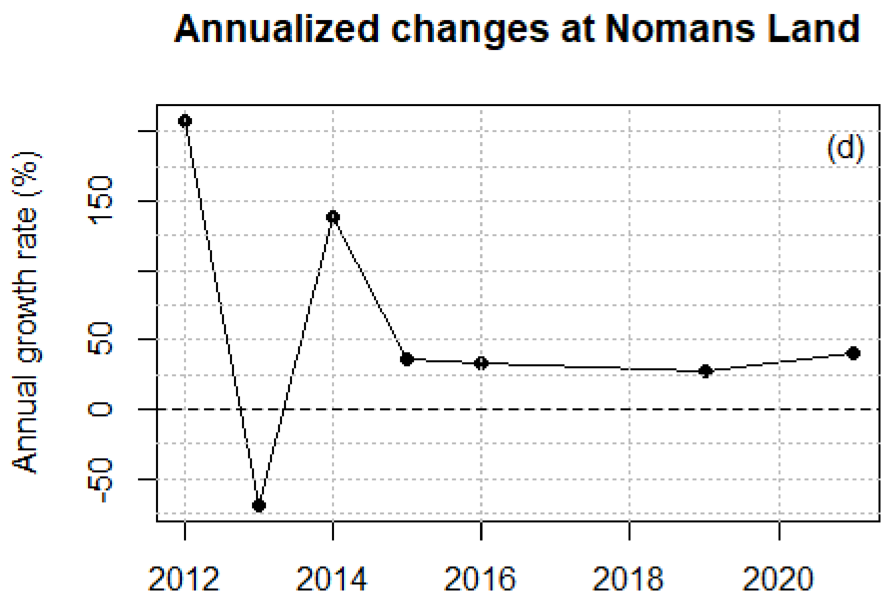


Figure 7. Annualized pup count growth rates at (a) Muskeget, (b) Seal, (c) Monomoy, and (d) Nomans. The growth rate at each survey time is calculated as 100 * [ln(survey count) - ln(previous survey count)] / (number of years between the 2 surveys).

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