

AN ANALYSIS OF GRAY AND HARBOR SEAL STRANDINGS IN CAPE COD, MASSACHUSETTS
FROM 1999 TO 2012

by

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ABSTRACT

In recent years, the number of gray seals, *Halichoerus grypus*, inhabiting Massachusetts has increased dramatically. In Canada and Scotland, similar increases in gray seal abundance have been accompanied by a concomitant decrease in numbers of sympatric harbor seals, *Phoca vitulina*. It has been hypothesized, although not confirmed, that interspecific competition between the two species led to a decrease in harbor seal populations. The present study addressed the question of whether gray seals and harbor seal populations are interacting in Cape Cod, MA by analyzing stranding data from Cape Cod in the period from 1999 to 2012, provided by the International Fund for Animal Welfare (IFAW). Gray seal strandings increased 2.9% annually from 1999 to 2012. Harbor seal strandings, on the other hand, increased 8.5% annually until 2004, after which the increased stopped and the number of strandings varied interannually. Strandings were best predicted by species, age class, and month, although age class only affected harbor seal seasonal stranding trends. Seasonal trends in the number of gray and harbor seal strandings caused by human interactions were significantly different. These differences in the stranding record suggest that the two species are interacting ecologically in Cape Cod.

INTRODUCTION

1. Harbor and gray seals are sympatric throughout most of their ranges in the North Atlantic (Figure 1).
2. Throughout their ranges, both harbor and gray seal populations were greatly reduced in both size and range by formal or informal culling programs.
3. In most areas of their ranges, such culls no longer occur, and, as a result, both species are increasing in abundance and range.
4. In both Scotland and eastern Canada, recent increases in gray seal populations have coincided with dramatic collapses of harbor seals, suggesting an ecological interaction between them (although no such linkage has yet been demonstrated).
5. My Master's Project is examining strandings of the two species on Cape Cod, MA to look for evidence of competition in the southern portion of their range in the NW Atlantic.

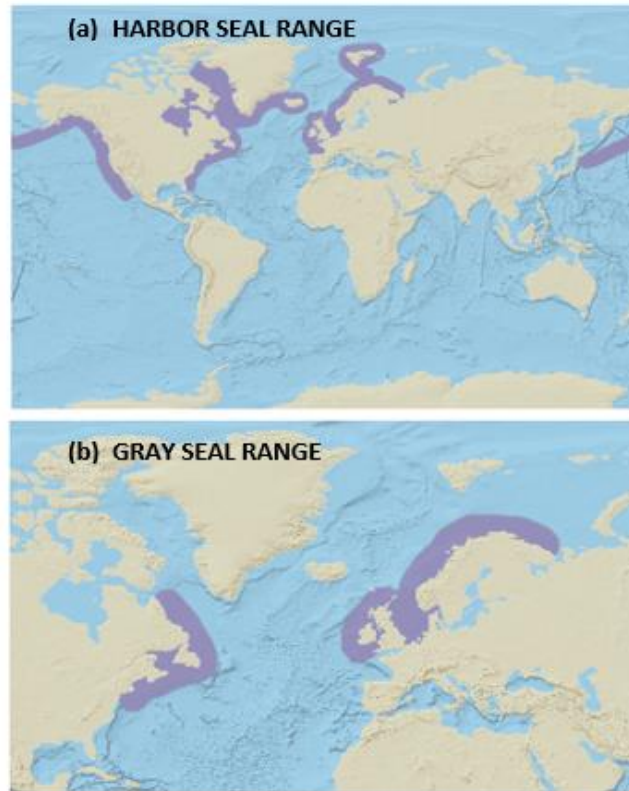


Figure 1. (a) "Common seal habitat map." Map. n.d. Marine animal encyclopedia: Common Seal *Phoca vitulina*. Oceana. Web. 23 April 2014. (b) "Gray seal habitat map." Map. n.d. Marine animal encyclopedia: gray Seal *Halichoerus grypus*. Oceana. Web. 23 April 2014.

The first occurrence of an increase in gray seal abundance and concomitant decrease in harbor seal abundance was seen in Sable Island, Canada. Sable Island supported the largest population of harbor seals in Eastern Canada in the 1980s (Bowen *et al.* 2003a). All components of the harbor seal population in Sable Island decreased during the 1990s (Figure 2), including a 95% decrease in pup production (Bowen *et al.* 2003a). Bowen *et al.* (2003a) suggest that interspecific competition with gray seals contributed to this decline. Gray seals in Sable Island have been exponentially growing (Figure 3) at a rate of 12.8% from 1962 to 2000 (Bowen *et al.* 2003b; Bowen & McMillan 2006). By 1997, Sable Island was the largest gray seal colony of the world (Bowen & McMillan 2006). This gray seal colony continued to grow until 2005, when the population began showing signs of density-dependence (Bowen & McMillan 2006, Trzcinski *et al.* 2006). By 2005, the rate of population increase declined and the females' age of primiparity increased, both signs of density-dependence (Bowen & McMillan 2006, Trzcinski *et al.* 2006).

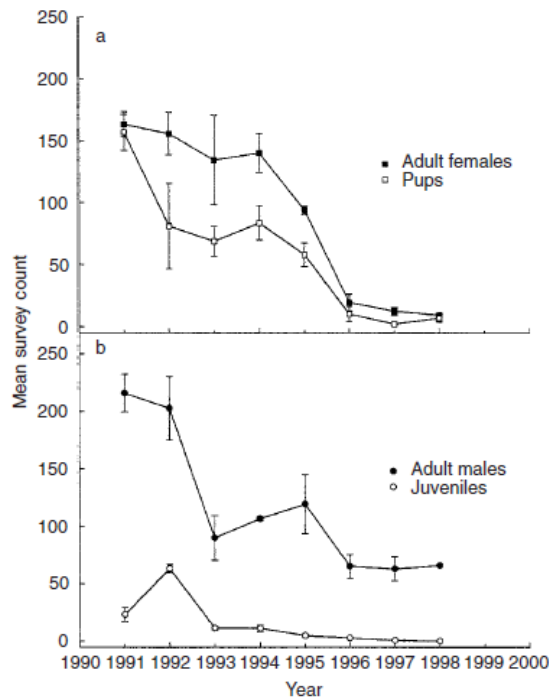


Figure 2. Mean number of harbor seals counted at a section of North Beach of Sable Island from 1991-1998: (a) adult females and pups; (b) adult males and juveniles. Adapted from "Maternal and newborn life-history traits during periods of contrasting population trends: implications for explaining the decline of harbour seals (*Phoca vitulina*), on Sable Island," by Bowen *et al.* (2003), *Journal of Zoology* 261,155-163.

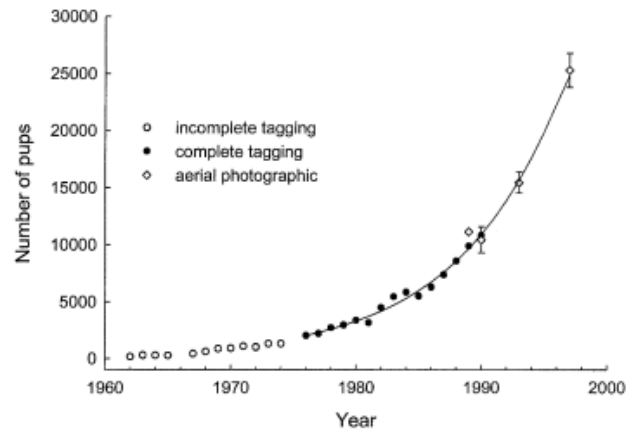


Figure 3. Gray seal abundance in Sable Island, Canada from 1962- 1997. Adapted from "Reduced population growth of gray seals at Sable Island: evidence from pup production and age of primiparity," by Bowen WD & McMillan JI (2006), *Marine Mammal Science* 23.1: 48-64.

A second occurrence of this suggested ecological interaction between gray and harbor seals occurred in Scotland. The Orkney Islands, off the north coast of Scotland, once held the largest harbor seal population in Europe (Thompson *et al.* 2010). Between 2001 and 2010, the Orkney Islands' harbor seal population declined at a rate of 13% annually (Hanson *et al.* 2013; Lonergan *et al.* 2013). Since 2000, other declines in harbor seal abundances were observed throughout Scotland including Shetland, Outer Hebrides, Moray Firth, and Firth of Tay (NERC 2011). As these harbor seal populations declined, gray seal population increases were observed. Beginning in 1984, gray seal colonies in the Orkney Islands, Inner and Outer Hebrides, and the North Sea exhibited a period of exponential growth (Figure 4) in pup production (Lonergan *et al.* 2011). Currently, more than 20,000 gray seals breed in the North Sea region, which includes the eastern coasts of Scotland and England, and this population continues to increase exponentially (Lonergan *et al.* 2011). The Orkney and Hebrides gray seals, however, have experienced a slight decrease (Figure 4) in their annual growth rates (Lonergan *et al.* 2011). This decrease in population growth suggests density-dependence effects, as seen in Sable Island.

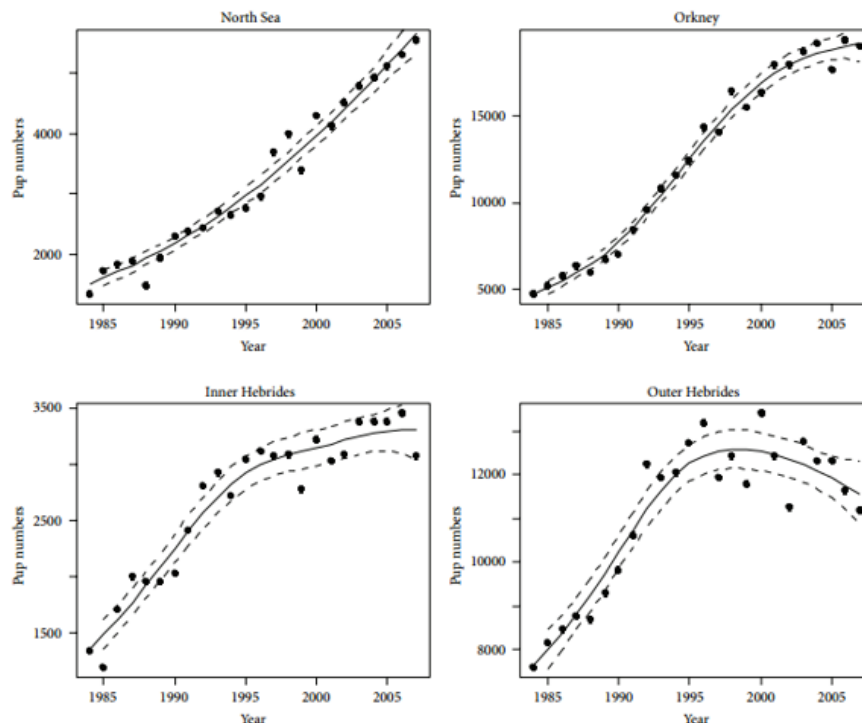


Figure 4. Pup production estimates for four regions in Scotland from 1984- 2007. Reprinted from “An approximate Bayesian method applied to estimating the trajectories of four British grey seal (*Halichoerus grypus*) populations from pup counts” by Lonergan *et al.* (2011) *Journal of Marine Biology* 2011.

The third occurrence of potential interactions between harbor and gray seals may be currently taking place in Massachusetts. In the past, seals were viewed as predators of commercially valuable fish species in the state and their populations were controlled by town or state bounties from 1888 to 1962 (Payne and Selzer 1989). These bounties were not species specific, targeting both harbor seal and gray seal populations (Wood LaFond 2009). As a result of the bounty programs, the harbor seal population was greatly reduced and the gray seal population was virtually extirpated from Massachusetts. It was not until the Marine Mammal Protection Act was enacted in 1972 that both harbor and gray seal populations began to recover. The harbor seal population in Southern New England doubled by the mid-1980s and by 1988, gray seals began to recolonize Massachusetts (Payne and Selzer 1989; Wood *et al.* 2007).

Current estimates of gray and harbor seal abundance in eastern United States suggest gray seals are increasing and harbor seals are decreasing. Gray seals are estimated to have a maximum abundance of 15,756 individuals in southeastern Massachusetts waters and this portion of the gray seal population continues to increase at a rate hypothesized to be around 8.6 percent (Waring *et al.* 2012). Harbor seal abundance in eastern US, however, has decreased in the last ten years (NMFS unpublished). Aerial surveys conducted in Maine suggest the 2012 harbor seal estimate is 29.3% lower than the 2001 estimate (Waring *et al.*, in prep). This poses the question whether interspecific competition between gray seals and harbor seals is occurring and if so, whether it will lead to a decrease in harbor seals and their eventual eradication from Massachusetts.

Gray and harbor seals share many ecological characteristics. In Massachusetts, gray and harbor seals both prefer to haul out on the intertidal zones of sandy beaches. Both species occur at haul out sites such as Jeremy Point, Chatham Harbor, and Nantucket Sound (Murray 2008; Wood *et al.* 2007). In Canada, the competition for space at haul out sites has led to aggressive confrontations between the two species and gray seals have been suggested to competitively exclude harbor seals (Lesage *et al.* 1995). However, it is unknown whether gray seals are excluding harbor seals from haul out sites in Cape Cod. Murray (2008) documented harbor and gray seals sharing haul out sites, but did not observe aggressive interactions and concluded that competition between the two species was unlikely. Harbor and gray seals can forage up to 60 km from their haul-out sites (Thompson *et al.* 1997). If gray seals and harbor seals are sharing haul out sites, then they may also be foraging in the same areas. These species feed primarily feed on fish, such as herring, sandlance, and flatfishes (Payne and Selzer 1989; Mansfield and Beck 1977; Bowen *et al.* 2003a). It is unknown whether gray seals and harbor seals feed on the same fish species in Massachusetts.

The objective of my study is to analyze trends in gray and harbor seal strandings in Cape Cod from 1999-2012. I examined interannual trends in stranding numbers, seasonality of strandings, age classes of seal strandings, and strandings with human interactions. In my analysis, I assume that stranding data reflect the relative abundances of these two pinniped species in the ecological community (Pyenson 2011). Therefore, an analysis of these stranding data should provide insight into the dynamics of gray seal and harbor seal populations in Cape Cod, Massachusetts. I hypothesize that an increase in gray seal strandings combined with a decline in those of harbor seals, reflects competitive interaction between the two species.

METHODS

Stranding data of gray and harbor seals in Cape Cod from 1999-2011 were obtained from the Marine Mammal Rescue and Research team of the International Fund for Animal Welfare (IFAW) and the Cape Cod Stranding Network (Figure 5). The Cape Cod Stranding Network merged with IFAW in 2007. IFAW is a part of the National Marine Fisheries Service (NMFS) Northeast Regional Stranding Network and is responsible for responding to strandings throughout Cape Cod, Massachusetts.



Figure 5. Map of strandings of harbor and gray seals from IFAW 1999-2012.

The following data fields were recorded for every stranding: species; field number; location; date; indication of human interaction; sex; and length. Human interaction cases (HI) are those strandings with physical evidence that the animal had experienced harassment, bullet wounds, fishery or vessel interactions, or entanglement in fishing gear or marine debris (Bogomolni et al. 2010; Geraci and Lounsbury 1993). Every stranding is scored as HI positive (HI+), HI negative (HI-), or CBD (it could not be determined). Estimates of standard length were available for each stranded gray or harbor seal. However, some of these estimates were derived from photographs rather than actual measurements. Due to this level of imprecision, I used length estimates to identify the age class (juvenile or adult) of the stranded seal. For harbor seals, individuals less than 145 cm were classified as juveniles and those

greater than 145 cm were classified as adults (Sjare *et al.* 2005). Data was obtained from Dussault *et al.* (unpublished) to determine which lengths of gray seals were juveniles. Year-old gray seals had a mean length of 143.96 ± 10.197 , so I used one standard deviation (SD) above the mean, 154 cm, as the largest length of a juvenile gray seal. All gray seals larger than 154 cm were classified as adults.

To analyze differences in stranding rates among years and seasons, strandings were fit to linear and nonlinear regressions (JMP Statistics Software, version 10, SAS, Cary, NC). Strandings were also analyzed using generalized linear models (GLMs) (RStudio 0.97.551). All strandings from 1999-2012 were in the form of count data and modeled with a Poisson distribution. HI strandings from 1999-2012 were modeled using a binomial distribution because there was only one of two outcomes, HI+ or HI-. Model selection was determined by Akaike's Information Criterion (AIC); the model with the lowest AIC value best represents the data.

RESULTS

Interannual Trends

Interannual trends for gray seal and harbor seal strandings are presented in Figures 6 and 7. Gray seals strandings increased from 1999 to 2011. A linear regression fit to gray seal strandings resulted in a R-square value of 0.67 and a highly significant p-value of 0.0003 (Figure 6). Gray seal strandings increased throughout the time frame of this study at a rate of 2.91 percent.

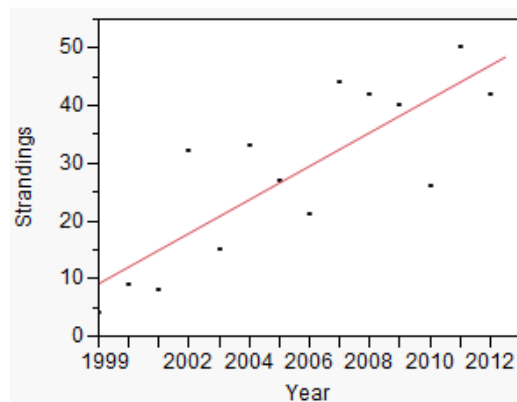


Figure 6. Gray Seal Strandings from 1999-2012

A logistic curve provided the best fit to harbor seal stranding data and resulted in a R-square value of 0.5148 (Figure 7). This curve is described by equation 1.

$$\frac{c}{[1+\text{Exp}(-a*(\text{year}-b))]} \quad [1]$$

$$a = \text{growth rate} = 1.217$$

$$b = \text{inflection point} = 2000.094$$

$$c = \text{asymptote} = 40.606$$

The logistic curve (Figure 7) shows that the number of harbor seal strandings increased linearly from 1999 to 2002. After this point, the increase in strandings ends and numbers vary throughout the rest of the time period. Further analysis of the harbor seal strandings concluded that the increase in harbor seal strandings actually ended in 2004. A linear regression was fit for harbor seal strandings from 1999 to 2004 (Figure 8) and exhibited an extremely high R-square value of 0.98 and a highly significant p-value of < 0.0001. This linear regression indicates that harbor seal strandings were increasing at a rate of 8.51% from 1999 to 2004.

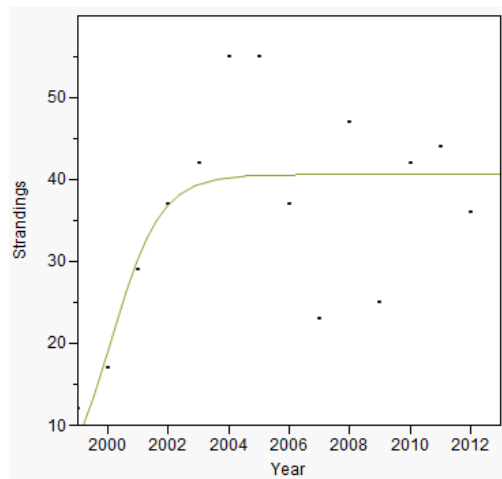


Figure 7. Harbor Seal Stranding from 1999-2012

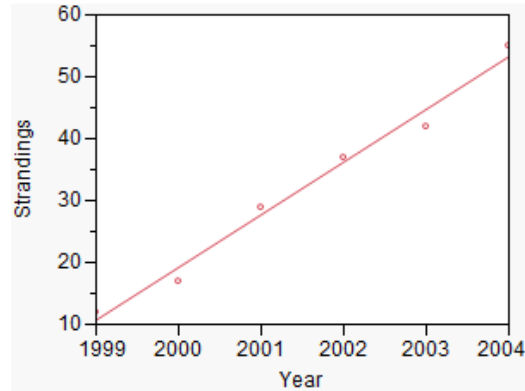


Figure 8. Harbor Seal Strandings from 1999-2004

Harbor Seal and Gray Seal Strandings as Response Variable

After analyzing various GLMs, the best fit model used species, month, and age class to predict harbor and gray seal strandings (Equation 2).

$$\text{Strandings} \sim \text{Species} * \text{Age} * \text{Month} \quad [2]$$

Juvenile and adult grey seal strandings followed a similar seasonal trend in which stranding numbers increased until a peak in May and then decreased for the rest of the year (Figure 9a). Juvenile harbor seals and adult harbor seals exhibited divergent seasonal trends (Figure 9b). Adult harbor seal strandings were low throughout the year, with a slight peak in May. Juvenile harbor seals stranded more frequently than adults throughout the year and stranded most often in October. A linear regression was fit ($R^2 = 0.54$) to juvenile harbor seal strandings (Figure 10) showing that juvenile harbor seal strandings generally increased throughout the year (although with an unexplained decline in August). A nonlinear regression was fit to adult harbor seal strandings. A Lorentzian Peak curve provided the best fit to this data and resulted in a R^2 value of 0.557. This curve is described by equation 3. The Lorentzian Peak curve (Figure 11) shows adult harbor seal strandings began increasing in March and strandings reached a maximum in May ($n=16$). In June, adult harbor seal strandings decreased and strandings remained low throughout the remaining months.

$$\frac{a \cdot b^2}{(\text{month} - c)^2 + b^2}$$

[3]

$a = \text{peak value} = 15.209$

$b = \text{growth rate} = 1.289$

$c = \text{critical point} = 4.969$

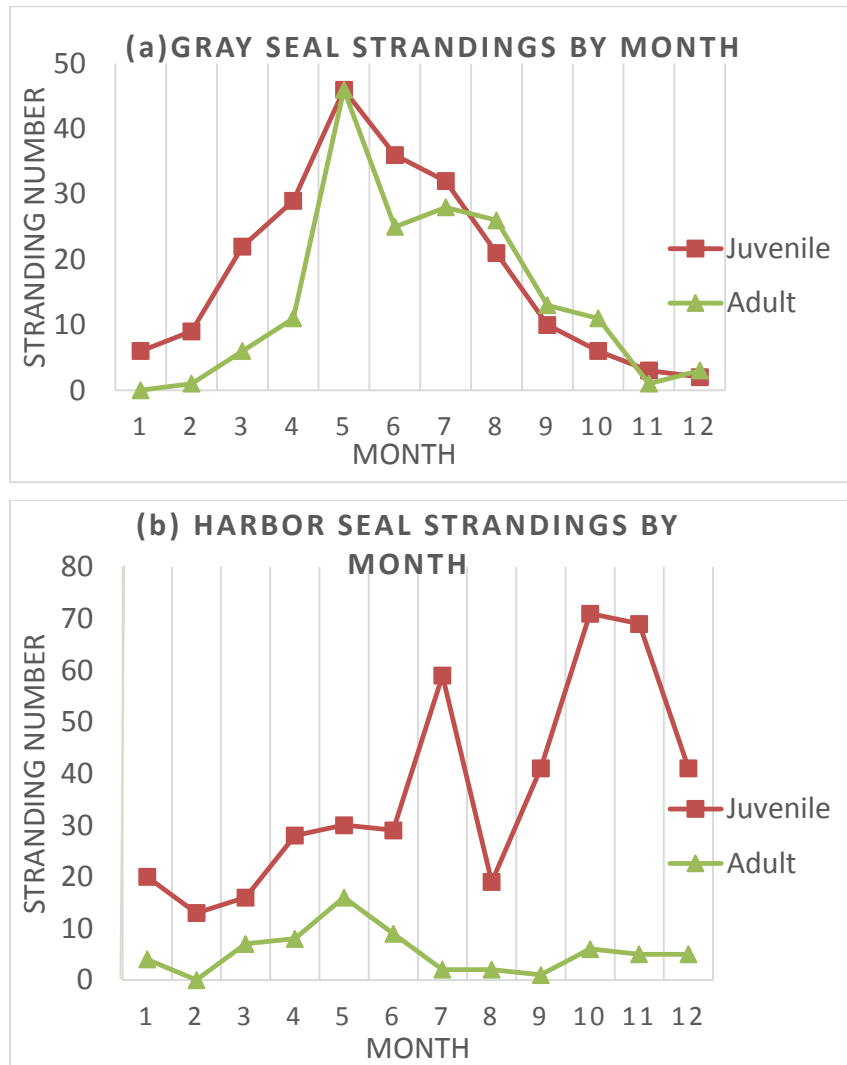


Figure 9. (a) Juvenile and adult gray seal strandings by month and (b) Juvenile and adult harbor seal strandings by month.

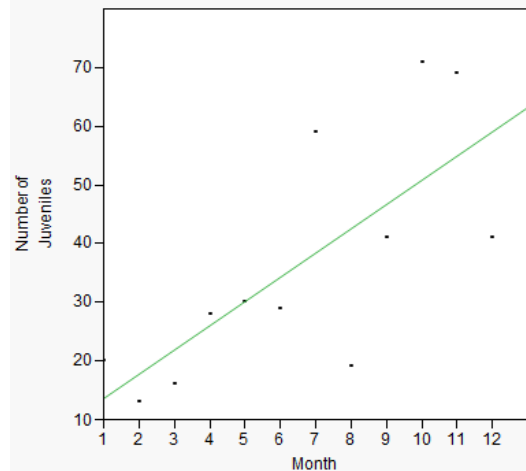


Figure 10. Linear regression for juvenile harbor seal strandings by month from 1999-2012.

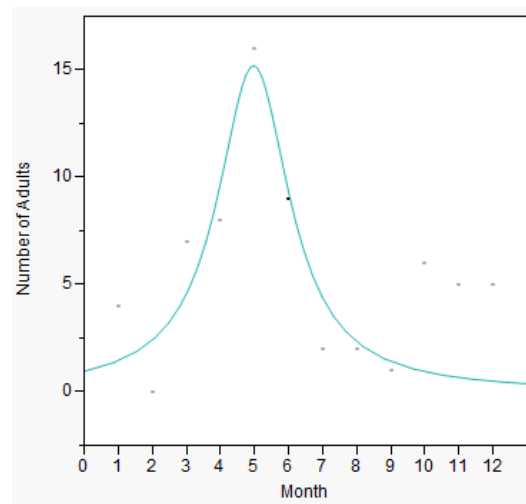


Figure 11. Nonlinear regression for adult harbor seal strandings by month from 1999-2012.

Strandings with Human Interaction

Of 374 stranding records scored HI+ or HI-, 133 were HI+ strandings. There were more HI+ strandings for gray seals than harbor seals (n=87:46) and more HI- strandings for harbor seals than gray seals (n=167:74). After analyzing various GLMs, two models were determined to best represent harbor and gray seal HI strandings (Equations 3 and 4).

Human Interaction ~ Species+ Month [3]

Human Interaction ~ Species+ Month+ Age [4]

The model of equation 4 had the lowest AIC (AIC= 391.29), but models with $\Delta\text{AIC} \leq 2$ are still considered reasonable models with good fit. The model of equation 3 had a ΔAIC of only 0.33. The only difference in the two equations is the presence of age class in equation 4. Thus age class had a slight influence on how likely harbor seals were likely to interact with humans.

The AIC of the two GLMs were so similar that I ran Bayesian GLMs on these two equations and resulting AIC and Bayesian Information Criterion values were used to determine the best model. These new AIC and BIC values established that equation 3 best predicted gray and harbor seal HI strandings.

The seasonal trends for HI strandings were found significantly different for gray and harbor seals ($p=1.26*10^{-6}$) and HI+ and HI- strandings did not follow similar seasonal trends for either species. For gray seals, most HI- strandings occurred in March and most HI+ strandings occurred in May (Figure 12a). There was a significant decrease in HI- strandings of gray seals seen in June ($p < 0.01$). For harbor seals, HI+ and HI- strandings followed a similar trend from March to August (Figure 12b), particularly with a peak seen in July and a large decrease seen in August. Beginning in September ($p < 0.05$), there was a clear deviation between harbor seal HI+ and HI- strandings. Harbor seal HI+ strandings remained low throughout fall and early winter while harbor seal HI- strandings drastically increased in the fall, reaching the maximum number of HI- strandings in October.

Harbor seal HI+ strandings occurred significantly less frequently (87 versus 46) than gray seal HI+ strandings (Figure 13). HI+ strandings occurred more frequently in the months of March, June, July ($p < 0.01$), May and September ($p < 0.05$). The greatest number of gray seal HI+ strandings occurred in May while the peak of harbor seal HI+ strandings occurred in July. Overall, gray seal HI+ strandings occurred more frequently throughout year (May to September), while harbor seals HI+ strandings remained low throughout the months, with the exception of a peak in July.

Gray seals strandings occurred mainly along Nantucket Sound while harbor seal strandings occurred primarily along the Cape Cod Bay areas (Figure 14). Harbor seal HI+ strandings were not as

concentrated as gray seal HI+ strandings. The majority of gray seal HI+ strandings occurred around Chatham, located at the southeast tip of Cape Cod.

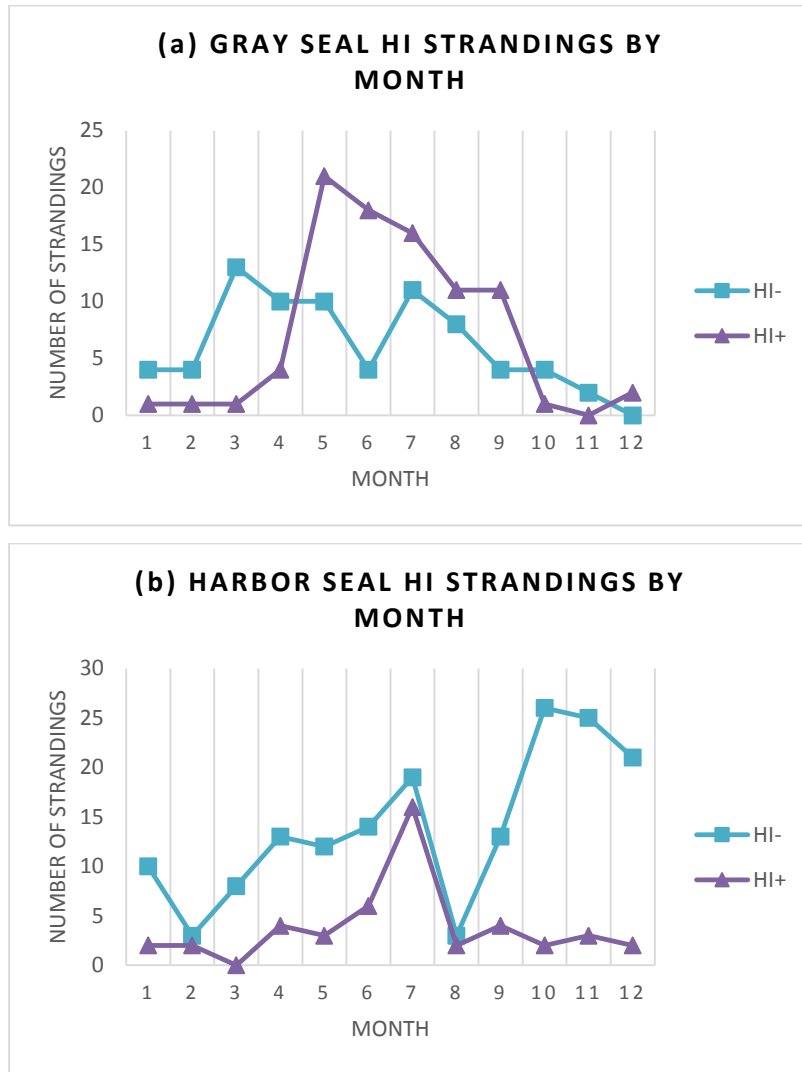


Figure 12. HI strandings of harbor and gray seals by month from 1999-2012.

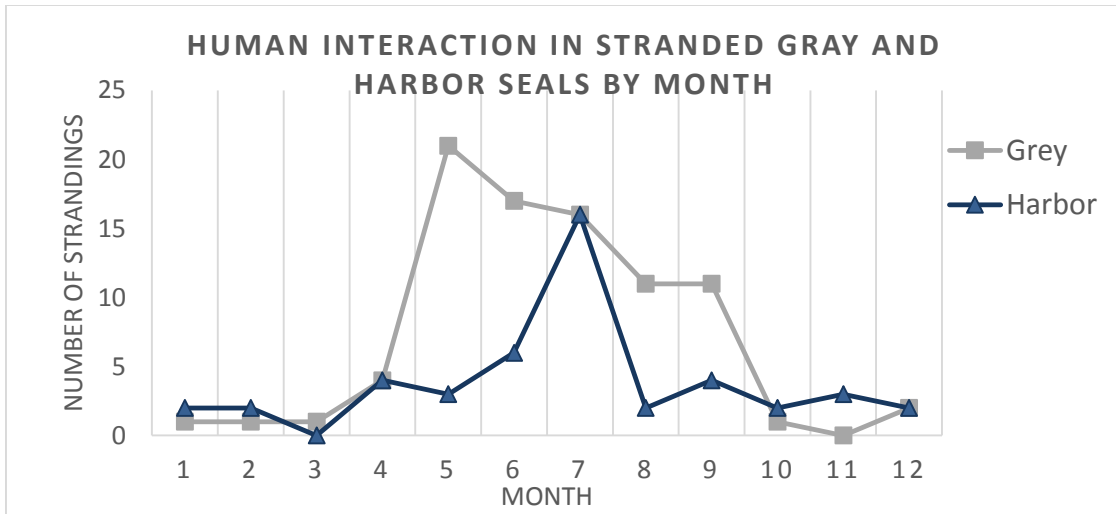


Figure 13. HI+ strandings for harbor and gray seals by month from 1999-2012.

Gray and Harbor Seal Strandings in Cape Cod, MA from 1999- 2012

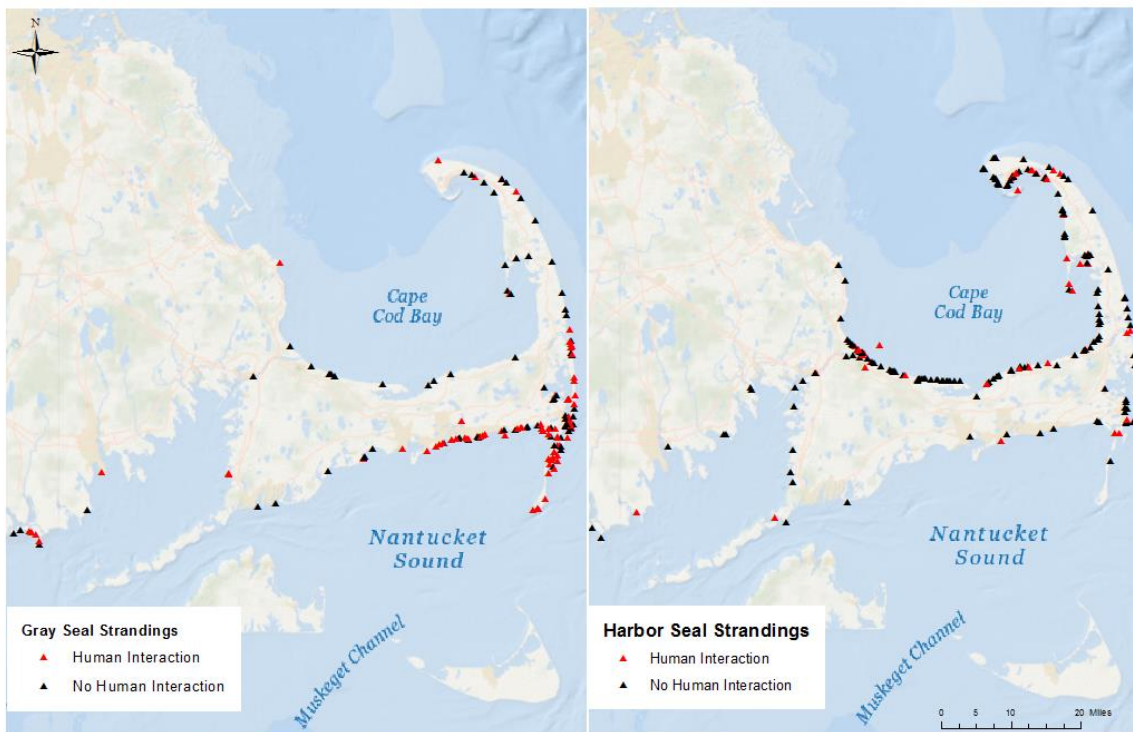


Figure 14. Map of harbor and gray seal strandings with and without human interaction.

DISCUSSION

My analysis of historical data in Cape Cod, MA from 1999-2012 show a clear difference between interannual trends of harbor and gray seal strandings. Gray seals strandings increased throughout the study period, while harbor seal strandings increased until 2004 and then leveled off. Prior to 2004, harbor seal strandings were increasing at a rate of 8.6% annually. After 2004, there was no clear trend in harbor seal strandings, as numbers increased and decreased sporadically throughout the rest of the period.

The trends I found in stranding data for these two species mirror those from elsewhere in New England. In Connecticut and Rhode Island, gray seal strandings increased from 1990 to 2011 (Smith 2013). Bycatch rates of harbor seals and gray seals presented in the NMFS Stock Assessment Reports also show a similar trend from 1990 to 2010 (Waring *et al.* 2012). Nonlinear regressions fit to this bycatch data show an increasing trend in gray seal bycatch consistent with the increase seen in my results (Figure 15a). Nonlinear regressions fit to harbor seal bycatches also show a similar trend as my results. The harbor seal bycatches increase until the late 1990s and then decrease (Figure 15b). However, my harbor seal stranding data showed an increase until 2004. This indicates that harbor seal bycatches stopped increasing almost five years prior to harbor seal strandings.

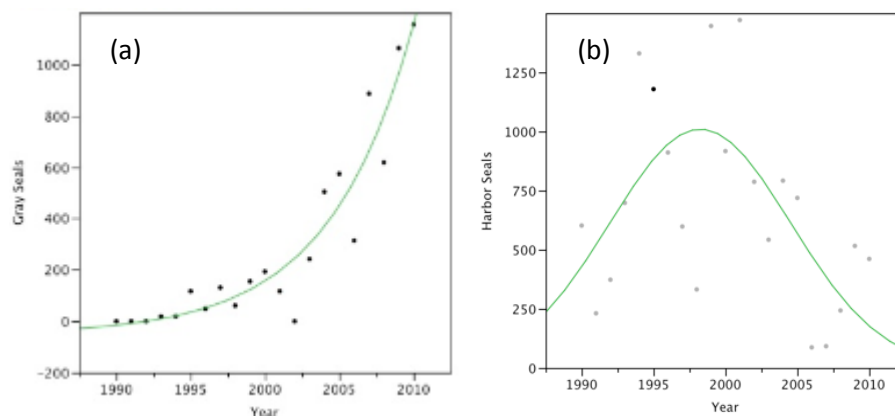


Figure 15. Bycatch data from NMFS Stock Assessment Reports for the (a) Northwest Atlantic gray seal and (b) Northwest Atlantic harbor seal stocks from 1990-2010.

The change in the stranding record for harbor seals following 2004 is a cause for concern. It is possible that competition with gray seals may have caused the change in harbor seal stranding numbers, although it is not possible to evaluate this proposition with the data at hand. Another possibility is climate events that differentially affect harbor seals. Severe winters can be particularly damaging to post-weaned pups (Hanson *et al.* 2013). In January 2004, Cape Cod experienced the lowest average temperature of all the years in our study (NOAA 2014). Furthermore, the average temperature of January to February was the lowest during the years of 2003, 2004, and 2005 (NOAA 2014).

First year seals are more likely to strand than all other age groups (Geraci and Lounsbury 1993), so it was not surprising that age class was an important predictor of gray and harbor seal strandings on Cape Cod. However, age class most noticeably influenced the seasonal trends for harbor seals. Seal pups are more vulnerable to disease and predation and commonly strand due to abandonment or separation from their mother (Geraci and St. Aubin 1979; Hanson *et al.* 2013). Both gray seals and harbor seals pup in Southern New England (Wood *et al.* 2007, Waring *et al.* 2012). For gray seals, pupping occurs in mid-December to mid-January, and for harbor seals pupping occurs in mid-May to June (D Johnston, Duke University, pers comm; Waring *et al.* 2012). Juvenile stranding rates increased after pups were weaned. Juvenile gray seals strandings decreased after a peak in May, although juvenile harbor seals continued to increase throughout the year. The high mortality of juvenile seals during winter may be attributed to their independence from their mothers and high thermoregulation needs during these months (Harding *et al.* 2013).

For gray and harbor seal HI strandings, age class was eliminated as a predictor because age class only slightly influenced the seasonal trends. Harbor seal HI+ and HI- strandings consisted primarily of juveniles ($n = 44:2$ HI+; $n = 153: 14$ HI-), so it was not expected that the best fit model of HI strandings did not include age class as a predictor. However, because most harbor seal HI strandings were juveniles, the overall seasonal trends for both HI+ and HI- followed the seasonal trend of the juvenile harbor seals and not the adult harbor seals. The large proportion of juvenile harbor seal HI+ strandings agree with previous work of Bjorge *et al.* (2002). Bjorge *et al.* (2002) found that harbor seals in Norway are “most vulnerable to incidental mortality in fishing gear during the first three months after birth” and remained at high risk until 10 months after birth.

My results showed that seasonal trends for gray seal strandings were significantly different than those of harbor seal strandings. Gray seal HI+ strandings occurred most frequently from May to September. Harbor seal HI+ strandings, however, remained low throughout the year, with the exception of July. Bogomolni *et al.* (2010) found that 45% of gray seal strandings in Cape Cod were caused by some form of human interaction. These HI+ strandings were mainly due to entanglement and predominately occurred in late spring and summer along the Southeast shores (Bogomolni *et al.* 2010). This coincides with the seasonal trends seen in my analysis of stranding data. The difference in seasonal trends of human interaction between the two species could be due to the two species interacting with different fisheries. This is supported by spatial differences in HI+ strandings of the two species (Figure 14). Harbor seals mostly stranded along the north shores of Cape Cod, in the areas surrounding Cape Cod Bay. This is consistent with 2013 marine mammal surveys that observed harbor seals most frequently present in the Cape Cod Bay and Stellwagen Bank areas (Wu 2014). Most gray seals HI strandings occurred along Nantucket Sound, particularly around the town of Chatham. Muskeget Island is located in Nantucket Sound and Chatham is home to the Monomoy National Wildlife Refuge. Both these areas are important haul out sites for gray seals. Muskeget Island produces 83% of the pups born in Cape Cod (Wood *et al.* 2007). The large population of gray seals hauling out at Monomoy and Muskeget likely contributes to the increased HI strandings present along Nantucket Sound.

This study assumes that the stranding data is reflective of the gray and harbor seal populations in Cape Cod; however, other factors, such as spatial and stranding effort, might influence the stranding data. IFAW's spatial effort might influence the stranding data because beaches that are frequently visited may be more likely to observe and report strandings than beaches that are barely visited. Spatial effort is not likely reflected in the stranding data because strandings were reported in most of the coastal areas of Cape Cod. Another possibility is that the stranding response team's effort was different prior to and after the 2007 merge of the Cape Cod Stranding Network and IFAW. The harbor and gray seal stranding data show no unusual stranding trends that begin in 2007. The interannual gray seal strandings follow a linear increase throughout the time period and harbor seal strandings experienced a change in interannual trends prior to 2007. Therefore, the merge of the Cape Cod Stranding Network and IFAW presumably did not change stranding effort.

The difference in trends of harbor and gray seal strandings in Cape Cod is a concern due to similar trends of the two species in Scotland and eastern Canada and because of the concordance between my finds

and those of Smith (2013) and the bycatch data described above. I have assumed that these strandings reflect trends in the abundance of harbor and gray seal populations in the Cape Cod area. The stranding data presented here imply that gray seals have been increasing in Cape Cod from 1999 to 2012 and that harbor seals increased only until 2004. If interactions between these two species follows the same trend as documented in Scotland and eastern Canada, we should expect a decline in the harbor seal population in the near future.

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LITERATURE CITED

Bjorge A, Oien N, Hartvedt S, and Bothun G (2002). Dispersal and bycatch mortality in gray, *Halichoerus grypus*, and harbor, *Phoca vitulina*, seals tagged at the Norwegian coast. *Marine Mammal Science* 18.4, 963-976.

Bogomolni AL, Pugliares KR, Sharp SM, Patchett K, Harry CT, LaRocque JM, Touhey KM, & Moore, M (2010). Mortality trends of stranded marine mammals on Cape Cod and southeastern Massachusetts, USA, 2000 to 2006. *Disease of Aquatic Organisms* 88, 143-155.

Bowen, WD, Ellis SL, Iverson SJ, & Boness DJ (2003a). Maternal and newborn life-history traits during periods of contrasting population trends: implications for explaining the decline of harbour seals (*Phoca vitulina*), on Sable Island. *Journal of Zoology* 261,155-163.

Bowen WD, McMillan J, & Mohn R (2003b). Sustained exponential population growth of grey seals at Sable Island, Nova Scotia. *ICES Journal of Marine Science* 60, 1265- 1274.

Bowen WD & McMillan JI (2006). Reduced population growth of gray seals at Sable Island: evidence from pup production and age of primiparity. *Marine Mammal Science* 23.1, 48-64.

Dussault H, Hammill MO, Barrette C, & Stobo WT. (unpublished) Age specific growth of the Northwest Atlantic grey seal: evidence for density-dependence?

Geraci JR & Lounsbury VJ (2005). Marine mammals ashore: a field guide for strandings. National Aquarium in Baltimore, Baltimore, MD.

Hanson N, Thompson D, Duck C, Moss S, Lonergan M (2013) Pup Mortality in a Rapidly Declining Harbour Seal (*Phoca vitulina*) Population. PLoS ONE 8.11: e80727.

Harding KC, Fujiwara M, Axberg Y, & Harkonen T (2005). Mass-dependent energetics and survival in harbour seal pups. *Functional Ecology*, 19.1, 129-135.

Lesage V, Hammill MO, & Kovacs KM (1995). Harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) abundance in the St Lawrence Estuary. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2307, 1-19.

Lonergan M, Thompson D, Thomas L, & Duck C (2011). An approximate Bayesian method applied to estimating the trajectories of four British grey seal (*Halichoerus grypus*) populations from pup counts. *Journal of Marine Biology* 2011.

Lonergan M, Duck C, Moss S, Morris C, & Thompson D (2013) Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. *Aquatic Conservation: Marine and Freshwater Ecosystems* 23, 135–144.

Mansfield AW & Beck B (1977). The gray seal in Eastern Canada. Technical Report No. 704. Department of Fisheries and the Environment.

Murray MJ (2008). Behavioral interactions between harbor seals (*Phoca vitulina*) and gray seals (*Halichoerus grypus*) on Cape Cod, Massachusetts (unpublished). MS Thesis. Northeastern University.

NMFS (unpublished). Draft U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments 2013. April 2013. Web. Assessed 23 April 2014. <http://www.nmfs.noaa.gov/pr/sars/pdf/ao2013_draft.pdf>.

NOAA National Climatic Data Center (2014). Climate at a glance. Web. Assessed 23 April 2014. <<http://www.ncdc.noaa.gov/cag/>>.

Payne PM & Selzer LA (1989). The distribution, abundance and selected prey of the harbor seal, *Phoca vitulina concolor*, in southern New England. *Marine Mammal Science* 5.2, 173- 192.

Pyenson ND (2011). The high fidelity of the cetacean stranding record: insights into measuring diversity by integrating taphonomy and macroecology. *Proceedings of the Royal Society B: Biological Sciences* 278.1724, 3608-3616.

Sjare, BL, Lebeuf M, Veinott G (2005). Harbour Seals in Newfoundland and Labrador, a Preliminary Summary of New Data on Aspects of Biology, Ecology and Contaminant Profiles. Canadian Science Advisory Secretariat= Secrétariat canadien de consultation scientifique.

Smith AF (2013). A geospatial analysis of mystic aquarium's marine animal stranding data. MEM Master's Project. Duke University.

NERC Sea Mammal Research Unit (2011). Scientific advice on the matters related to seal populations: 2011. Special Committee on Seals Report. University of St. Andrews.

Thompson D, Duck CD, & Lonergan ME (2010). The status of harbour seals (*Phoca vitulina*) in the United Kingdom. NAMMCO Scientific Publications 8, 117–128.

Trzcinski MK, Bowen WD, & Mohn R (2005). Estimation of grey seal population size and trends at Sable Island. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat.

Waring GT, Rossman MC, and Wenzel FW. in prep. Series injury determinations for small cetaceans and seals caught in commercial fisheries off the northeast US coast, 2007-2011.

Waring GT, Josephson E, Maze-Foley K, Rosel, PE, editors (2013). U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments 2012. NOAA Tech Memo NMFS NE 223; 419 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

Wells RS & Scott MD (1994). Incidence of gear entanglement for resident inshore bottlenose dolphins near Sarasota, Florida. In WF Perrin, GP Donovan, & J Barlow (Eds.), Gillnets and cetaceans: Report to the International Whaling Commission, Special Issue 15, 629.

Wood SA, Brault S, & Gilbert JR (2007). 2002 Aerial Surveys of Grey Seals in the Northeastern United States. NAMMCO Scientific Publications 6, 117-121.

Wood LaFond, S (2009). Dynamics of recolonization: a study of the gray seal (*Halichoerus grypus*) in the northeast US. Ph.D. Dissertation. University of Massachusetts, Boston.

Wu D (2014). Summary of marine mammal observations during 2013 surveys. Boston: Massachusetts Water Resources Authority. Report 2014-06. 15pp.