NICHOLAS PURAN

Effects of Lower Troposphere Temperature on Ice Phenology and the Pacific Walrus Population

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The effects of climate change on biotic communities and their environment have been one of the leading factors of recent population declines. This study investigated how climate change affected sea ice, a key component of the Pacific Walrus's habitat, and in turn how it can affect walrus populations. Lower troposphere temperatures along with sea ice retreat data were obtained between 1979–2014 for the Arctic Ocean and Chukchi Sea region, respectively. Concurrently, Pacific Walrus population estimates were obtained from the literature. We found a significant, negative relationship between sea ice retreat and temperature such that earlier retreat of sea ice was more common with warmer temperatures. Sea ice retreat and temperature were good predictors and highly correlated with population size. These results provide a possible link between climate change and walrus population decline, and future studies should include life history and sea ice traits to solidify this linkage.

Keywords: Arctic amplification, climate warming, haulout, ice phenology, sea ice retreat

INTRODUCTION

Climate warming is at the forefront of changing sea ice phenology (Serreze et al., 2000), most notably indicating a downward trend in sea ice extent (Chapman & Walsh, 1993). There has been a notable thinning of ice since 1988, attributed to greater air temperatures over the Arctic for spring, winter, and fall; shifts in the Arctic Oscillation and Pacific Decadal Oscillation; and Arctic amplification (Lindsay & Zhang, 2005). Kim et al. (2016) proposed three mechanisms that explain the acceleration of warming in the Arctic: water vapour feedback, albedo feedback, and insulation feedback. The most widely accepted mechanism, insulation feedback, refers to the warming of the lower troposphere via turbulent heat flux released from the ocean in the winter, if the ocean is free of ice. Overland and Wang (2007) suggest that by 2050 there will be at least 40% loss in sea ice area during the summer for marginal seas in the Arctic basin, and for some seas, at least 40% loss in sea ice area over the winter.

Sea ice has been retreating earlier in the year and forming later in the year (Cai et al., 2021). This loss in sea ice contributes to a positive feedback loop because more open water leads to greater warming of the lower troposphere. But how does such retreat and onset affect life? Kovacs et al. (2010) notes distribution shifts, declines in production/abundance, and reduced body condition as direct effects of sea ice retreat. More specifically, earlier seasonal sea-ice melt can cause direct effects such as earlier phytoplankton blooms, which disrupts primary production among top marine mammals (Post et al., 2013).

The Chukchi Sea is a region of the Arctic basin situated adjacent to the Beaufort Sea between Alaska and Russia, and above the Bering Sea. A recent study by Taylor et al. (2017) suggests Pacific Walrus populations have undergone a multidecadal decline with juvenile survival either decreasing or stabilized, but still below a rate of increase. This decrease in Pacific Walrus populations is attributed to the declining extent of summer sea ice that increases coastal haulouts and decreases productive offshore feeding areas (Udevitz et al., 2012). We aimed to find a correlation between temperature, sea ice phenology, and walrus survival. We hypothesized that warming temperatures correspond to earlier sea ice retreat, which subsequently causes a decrease in walrus population in the Chukchi Sea. We predicted temperature to have a significant effect on sea ice phenology based on previous literature, and in turn sea ice retreat to be significantly correlated with walrus decline.

METHODS

Average lower troposphere Arctic Ocean temperature anomalies for March–May were obtained from the National Oceanic and Atmospheric Administration (NOAA) website for 1979–2014. Walrus population data were obtained from a paper by Taylor et al. (2017). They used total population size estimates from five United States and Russian aerial surveys, which took place in 1975, 1980, 1985, 1990, and 2006, to construct a likelihood function that predicts population size from 1975–2015. We extracted population size estimates from a single figure using WebPlotDigitizer (Rohatgi, v4.2), and the data included both males and females. In addition, ice phenology data were extracted from Serreze et al. (2016) using WebPlotDigitizer. Day of sea ice retreat, or the Julian day in which sea ice starts to retreat to the shelf break of the Chukchi Sea, was the variable used to portray ice phenology. IBM SPSS Statistics (v26) and Minitab (v19) Statistical Software were used to conduct simple linear regressions, multiple linear regressions, and descriptive statistics. All assumptions were met, except normality for the dependent variable. No transformations corrected this, so this should be kept in mind. No outliers were reported. An alpha value of 0.05 was used for the significance threshold. Alpha is a predefined number that determines how likely it is for one variable to affect the other.

A p-value below 0.05 would indicate that there is at least a 95% probability that the results are not occurring by chance.

Description of Analyses

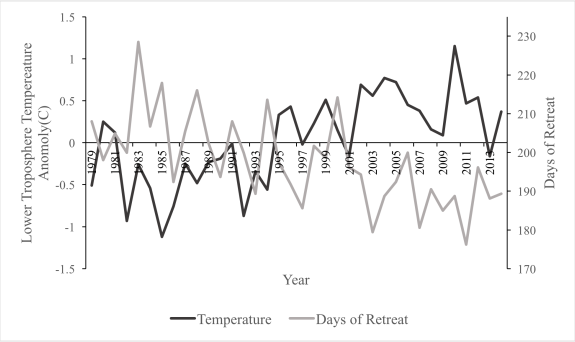
Regression analyses use test statistics such as F-value and adjusted R^2 to estimate the result of one variable based on the influence of others. As determined by the p-value, a significant F-value indicates that at least one of the explanatory variables can predict the response variable. R^2 indicates the percentage of the variance in the response variable that the predictor variables explain collectively on a scale of 0 to 1. Adjusted R^2 differs from R^2 in that adjusted R^2 considers the number of predictor variables used for predicting the response variable. R^2 does not decrease if new, possibly redundant predictor variables are added, but adjusted R^2 factors this in. For Pearson's correlation, a coefficient of 1 indicates a strong positive relationship, whereas a coefficient of -1 represents a strong negative correlation. For every increase in one variable, there is a fixed increase/decrease of fixed proportion in the other.

RESULTS

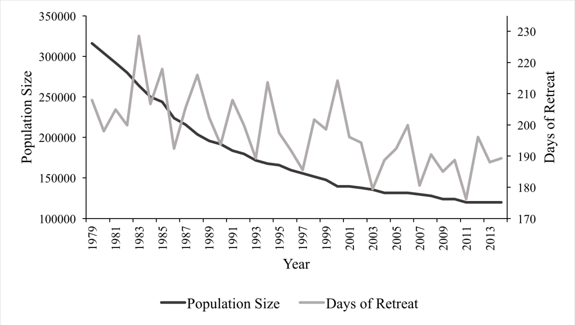
Notable downward trends were seen in walrus population and date of retreat, whereas an upward trend was seen for lower troposphere temperature (Figure 1). Furthermore, earlier sea ice retreat and warmer temperatures had a significant effect on population size (Analysis of Variance [ANOVA] of multiple regression: $F(2, 33) = 13.82$, $p < .05$) and explained a moderate amount of variation in population size as well (adjusted $R^2 = 42.3\%$). Warmer temperatures were a good predictor of date of sea ice retreat (ANOVA of simple regression: $F(1, 34) = 11.99$, $p < .05$; adjusted $R^2 = 0.26$). All three variables were significantly, highly correlated with each other (Table 1). Thus, there is sufficient evidence to conclude that all variables interact significantly with each other, along with trends in the raw data that support our hypothesis (See Appendix; Table A1).

Figure 1. Time Series from 1979-2014 for (A) Lower Troposphere Temperature Anomalies and Days of Retreat and (B) Walrus Population Size and Day of Retreat

(A)



(B)



Note. A large decrease in day of retreat and large increase in temperature is seen around 1995.

Table 1. Pearson Correlation Coefficients for Population Size, Day of Retreat, and Temperature

Variable	Population Size	Days of Retreat
Days of Retreat	0.574	-
P-value	<0.0001	-
Temperature	-0.598	-0.511
P-value	<0.0001	0.001

Note. This coefficient shows the linear relationship between two sets of data. The first cell content is the coefficient, and the second cell content is the *p*-value.

DISCUSSION

It is known that marine mammals are directly affected by climate change, however the processes by which they are affected are very complex. Here, we connect the influence of higher lower troposphere temperature to earlier days of ice retreat, and finally to declining walrus population numbers. Our findings stand in line with current literature that suggests that walrus life history traits and population demographics may be negatively influenced by climate change (Udevitz et al., 2017). We found that in the Chukchi Sea, ice phenology was influenced by lower troposphere temperatures in the Arctic, and walrus populations were negatively correlated with day of retreat and temperature.

Many studies have investigated top-down effects of the atmosphere on sea ice variability, and more recently bottom-up effects of sea ice on the atmosphere (Hopsch et al., 2012). The last 40 years of sea ice decline (retreat and thickness) is heavily attributed to Arctic amplification. Furthermore, this positive feedback mechanism leaves sea ice more vulnerable to other outside forces, such as downward longwave radiation, which is associated with climatic variability (Francis et al., 2005). This study simply provides more evidence for the consequential impacts of Arctic amplification on sea ice. As for walrus demographics, to date, there are no definitive answers as to why populations have been declining (MacCracken et al., 2017). Taylor and Udevitz (2014) suggest harvests are to blame for the declines of the 1980s and 1990s, but ecosystem changes which affect feeding sources may also be a factor. Nonetheless, this is not the first study to identify a link between retreating ice, temperature, and population declines (Siddon et al., 2020). Our study excelled at aligning and identifying trends in three key variables; however, the data are limited as average lower troposphere temperature data were presented as anomalies and for the entire Arctic Ocean, which is not indicative of the Chukchi Sea. Additional data such as juvenile survival rates and/or birth rates for the season of sea ice retreat would provide insights on life history traits. Furthermore, the inclusion of additional sea ice features, such as ice thickness and day of sea ice advance, would have strengthened the findings.

It is important to note that atmospheric and oceanic heat fluxes, along with advection from winds and currents, contribute to changing sea ice properties (Lu et al., 2020). In particular, the Chukchi shelf summer temperature is affected by three oceanic heat fluxes: winter water, Bering Sea water, and melt water. Oceanic heat flux in the Chukchi Sea accounts for over 70% of the heat budget allotted to melting ice along the ice edge and ice zone. While this paper was written with the intent to discuss atmospheric heat flux (that is, atmospheric heating at the surface of the ice), it should be viewed as inclusive towards both heat fluxes, as ultimately oceanic heat is affected by atmospheric temperatures, albeit indirectly.

Ice melts. Since the time this paper was written, recent research has indicated that the recent record-lows of winter and spring sea-ice cover from 2014–2018 in the Chukchi and Northern Bering seas are correlated with increased spring absorption of solar radiation, reduced springtime albedo, and elevated water column heat content (Danielson et al., 2020). By now, the topic in question is not whether sea ice retreat and a warming climate are related, and not necessarily if such sea ice retreat has ecological consequences, but rather the severity of such changes.

Management strategies for this particular field are hopeful, but not reality as of yet. Solving the global climate crisis would largely improve Arctic sea ice conditions, though this may not be practical in the short term. Two geoengineering strategies, carbon capture and sequestration (CCS) and solar radiation management (SRM), are promising technologies (Vaughan & Lenton, 2011). Further, restoring sea ice extent in the summer can be done most effectively by creating more sea ice in the winter through Arctic Ice Management (Zampieri & Goessling, 2019). This would be particularly useful in the Chukchi Sea as summer sea ice is marginal here (Desch et al., 2017). Regardless, mitigating greenhouse emissions and the climate crisis would effectively restore sea ice and the Pacific Walrus population.

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APPENDIX

Table A1. Troposphere Temperature, Population Size, and Day of Retreat 1979-2014

Year	Temperature	Population Size	Days of Retreat
1979	-0.51	315911.0169	208
1980	0.25	303898.3051	198
1981	0.12	291885.5932	204.9
1982	-0.93	279872.8814	199.9
1983	-0.26	263855.9322	228.5
1984	-0.54	249841.1017	206.7
1985	-1.12	243834.7458	217.9
1986	-0.76	223813.5593	192.4
1987	-0.25	215805.0847	205.5
1988	-0.48	203792.3729	216
1989	-0.23	195783.8983	202.4
1990	-0.19	191779.661	193.7
1991	-0.01	183771.1864	208
1992	-0.87	179766.9492	199.9
1993	-0.34	171758.4746	189.3
1994	-0.56	167754.2373	213.6
1995	0.33	165752.1186	197.4
1996	0.43	159745.7627	191.8
1997	-0.02	155741.5254	185.6
1998	0.23	151737.2881	201.7
1999	0.51	147733.0508	198.6
2000	0.15	139724.5763	214.2
2001	-0.16	139724.5763	196.1
2002	0.69	137722.4576	194.3
2003	0.56	135720.339	179.4
2004	0.77	131716.1017	188.7
2005	0.72	131716.1017	192.4
2006	0.45	131716.1017	199.9
2007	0.38	129713.9831	180.6
2008	0.16	127711.8644	190.5
2009	0.09	123707.6271	185
2010	1.15	123707.6271	188.7
2011	0.47	119703.3898	176.2
2012	0.54	119703.3898	196.1
2013	-0.16	119703.3898	188.1
2014	0.37	119703.3898	189.3

Note. Day of retreat refers to how many days into the year ice starts to retreat.