FROM SEA TO SHINING SEA

EXECUTIVE SUMMARY

Last year marked the 100th anniversary of the National Park Service (NPS). Today, the National Park system secures over 84 million acres in its 417 units. Designed to manage and protect the properties within the National Parks, the NPS must continually adapt its policies to best suit the needs of the visitors and the natural resources of each park.

The National Park Service is responsible for securing our greatest wildernesses from risk and must thus predict and adapt to change. Analyzing how climate might change over the next century, how the change might affect both the visitors and the land, and planning in accordance are important tasks of the NPS today. Our team was asked to develop models to assess the climate change, particularly how the change could affect sea levels, the vulnerability of parks to climate-related natural disasters, and how to appropriate funds based on the corresponding changes in visitor needs.

A general increase in global temperatures is expected to cause the mean sea level to rise. We were asked to evaluate how rising sea levels put selected coastal national parks at risk. We provided two curves for the increase of sea level over time from the National Water Level Observation Network site which were generalized to apply to the national parks. To quantify the risk that each park faces on account of rising sea levels, we estimated the proportion of area lost to the sea by identifying the length of each park's shoreline and that shoreline's average angle of inclination. Olympic National Park faced the least risk, while Cape Hatteras faced the most.

Next, we were asked how the changing climate might affect the vulnerability of each park to selected climate-related events (namely wildfires, hurricanes, and flooding). We manufactured metric from raw data and preexisting scales before implementing them to identify the risk of each event. To provide a general metric, we combined the metrics for the events for each park and divided the combined metrics by the maximum value of the combined metric. Padre Island had the highest vulnerability score in 2067 and Kenai Fjords the lowest.

Finally, we used our vulnerability scores and visitation data for the parks to calculate how visitation rates would change for each of the parks by 2067. We plotted our data and used trend line extensions to arrive at conclusions for 2067. In addition, we calculated a measure of confidence in each of those predictions by considering qualitative data that affects visitation numbers, including trail availability and presence of threatened and endangered species. Based on our results, we recommend funding Olympic National Park and defunding Padre Island National Shoreline.

Restatement of the Problem:

The problem asks us to do the following:

- Create a model that determines a risk level of high, medium, or low, relative to the increase in sea level that for Acadia NP, Cape Hatteras NS, Kenai Fjords NP, Olympic NP, and Padre Island NS
- Create a model that assigns a single climate vulnerability score to the national parks that can account for the likelihood and severity of climate-related events that might occur over the next 50 years
- Create a model that predicts long-term changes in park visitation and advise the NPS on where funding should go

Part I: Tides of Change

Restatement of the Problem:

Part I asked us to determine "a sea level change risk rating of high, medium, or low" for the following five parks: Acadia National Park, Cape Hatteras National Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore. We assumed that the park at highest risk was not the park with the highest water level at the shore, but actually the park that lost the greatest total land area due to the rising water level. This required us to find not only the net increase in sea levels, but also how much are would be lost under this higher water.

Assumptions:

- The selected national parks experience an equal rate of sea level change as local NOAA gauges
- The largest risk to national parks is projected percent of park land lost, not the projected average height of water
- Each park has an equal elevation 100 yards inland from the coastline
- The elevation from the current coastline to 100 yds inland changes at some constant rate
- Any park that experiences less than 1% area loss is at low risk, a park that experiences between 1 and 5% loss is at medium risk, and a park that experiences over 5% is at high risk

Part A:

To start, we defined "sea level change risk" as a factor determined by the portion of the park's total area engulfed by the sea (low, moderate, or high to be determined comparatively after determining range of values). This area is a can be determined by identifying l, the sea level rise at a specific time from the current sea level l_0 (Part A) and A, the corresponding land area below that elevation (Part B).

We first used the tide data provided to establish local trend lines for rate of sea level rise dl/dt; though the levels are generally equivalent, areas supporting large ice masses experience isostatic rebound that negates the sea level rise caused by the release of the water. Some areas have thus experienced falling net sea levels even as the sea level rises (Caffrey & Beavers, 2014). These trend lines, however, were poorly fitted (R^2 values of less than 0.5), so we turned to other cleaner sources of information.

The US Army Corps of Engineers provides three curves that project the sea level change at the locations of the National Oceanic and Atmospheric Administration's National Water Level Observation Network (NWLON) (US Army Corps of Engineers, 2014). These are a low curve based purely on historical data, an intermediate curve, and a high curve. The intermediate and high curves are based on a National Research Council report in 1987 that determined the global mean sea level to be:

$$E(t) = 0.0012t + bt^2,$$

in which t is time in years starting in 1986, b is a constant, and $E(t)$ is the eustatic change of sea level in meters. Adjusted for time, the current equation used by the Army Corps of Engineers is

$$E(t) = 0.0017t + bt^2.$$

The difference between the intermediate curve and high curve lies in the definition of the constant b. The intermediate curve defines b to be equal to $2.71e^{-5}$, while the high curve defines b to be equal to $1.13e^{-4}$ (US Army Corps of Engineers, 2013).

The NWLON sites determined to be closest to the selected national parks are as follows:

- Bar Harbor, Maine stands in for Acadia National Park
- Oregon Inlet Marina, North Carolina stands in for Cape Hatteras National Park
- Seward, Alaska stands in for Kenai Fjords National Park
- Port Angeles, Washington stands in for Olympic National Park
- Port Mansfield, Texas stands in for Padre Island National Seashore.

We assumed that the sea level in the specified parks will fall somewhere between the projections provided by the low curve and high curve. For each park, we found the low curve and high curve and subsequently evaluated each to find the minimum and maximum increases in sea level.

For Bar Harbor, NOAA low curve estimated the sea level changed by 0.00669 feet per year, so we interpreted the sea level rise from year to year would be

$$S(t) = 0.00669t_2 - 0.00669t_1,$$

in which t_2 is the second year, t_1 is the first year, and $S(t)$ is the net rise in sea level. Doing so from 2027 to 2017 yields a net change of 0.0669 feet. At 2037, the sea will have risen 0.1338 feet. By the year 2067, the sea will have risen by 0.3345 feet over the course of 50 years.

The high curve was given as chart of years past 1992 and the difference in sea level between the year and 1992. A line of best fit was used to plot the difference in sea level compared to years past 1992. The curve of best fit for Bar Harbor was determined to be

$$N(t) = 0.0004t^2 + 0.0076t - 0.0034,$$

in which t is the difference in the year in question and 1992 and $N(t)$ is the net difference in sea levels since 1992. This means the net difference in any year and 2017 would be

$$R(t) = N(t) - 0.4366,$$

where $R(t)$ is the change in sea levels to the year in question from 2017. This equation was evaluated at 35, 45, and 75 years to show the net sea level change from 2017 to 2027, 2037, and

2067, respectively. In 2027, *R(t)* = 0.316 feet; in 2037, *R(t)* = 0.712 feet; in 2067, *R(t)* = 2.38 feet.

We utilized this same method to evaluate the maximum and minimum net change in sea level in each of the four other locales.

For Seward, the low curve estimated the sea level as

$$S(t) = -0.00571t_2 + 0.00571t_1.$$

This yields a net decrease of the sea level of 0.0571 feet in 2027. Similarly, in 2037, the sea level decreases by 0.1142 feet. By 2067, the sea level would have a net decrease of the sea level of 0.2855 feet.

The high curve was drawn as a line of best fit that is equal to

$$N(t) = 0.0004t^2 - 0.0062t + 0.0078.$$

Subtracting the value of *N(25)* yields

$$R(t) = N(t) - 0.1028.$$

In 2027, *R(t)* = 0.178 feet; in 2037, *R(t)* = 0.436 feet; in 2067, *R(t)* = 1.69 feet.

For Oregon Inlet Marina, the low curve estimated the sea level as

$$S(t) = 0.00925t_2 - 0.00925t_1.\ 18.65725$$

In 2027, this curve projects that the sea level will rise by 0.0925 feet. The projection for 2037 is a rise of 0.185 feet. By 2067, the sea level will have risen by 0.4625 feet.

A line of best fit that approximates the high curve was given as

$$N(t) = 0.0004t^2 + 0.0098t - 0.005.$$

Subtracting the value of *N(25)* yields

$$R(t) = N(t) - 0.49.$$

Evaluating this curve projects that the sea level will rise by 0.338 feet over the next 10 years, 0.756 feet in the next 20, and 2.49 feet in the next 50.

For Port Angeles, the low curve was estimated as

$$S(t) = 0.00062t_2 - 0.00062t_1.$$

By 2027, the sea level will have risen in by 0.006199 feet. A rise of 0.012399 feet will have occurred in the next 20 years. A rise of 0.030999 feet will have occurred by 2067.

The high curve was drawn as a line of best fit

$$N(t) = 0.0004t^2 + 0.0011t - 0.0106.$$

Subtracting the value of *N(25)* yields

$$R(t) = N(t) - 0.2669.$$

Evaluating the curve projects the sea level rising by 0.251 feet in the next 10 years, 0.582 feet in the next 20, and 2.055 feet in the next 50.

Finally, for Port Mansfield, the low curve was estimated as

$$S(t) = 0.00633t_2 - 0.00633t_1.$$

This provides an estimate of a rise of 0.0633 in the next 10 years, a rise of 0.1266 in the next 20, and a rise of 0.3165 feet in the next 50.

The high curve was drawn as a line of best fit

$$N(t) = 0.0004t^2 + 0.0068t - 0.0113.$$

Subtracting the value of *N(25)* yields

$$R(t) = N(t) - 0.4087.$$

Evaluating this curve approximates a rise of 0.308 feet in the next 10 years, a rise of 0.696 feet in the next 20, and 2.34 feet in the next 50.

Part B:

It was more difficult, however, to estimate the area affected by a rise of *l* in each of the parks, a value determined completely by the area's topography. We first found the length of each park's coastline (Fig. 1).

Park	Acadia NP	Cape Hatteras NS	Kenai Fjords NP	Olympic NP	Padre Island NS
Coastline (miles)	60	70	400	73	70

Fig. 1

We then attempted to establish rudimentary generalizations for the elevation profiles of each park (vertical cross-sections perpendicular to the coastline). To simplify the process, we made the assumption that the profiles could be roughly represented triangularly. Using Google Earth, we traced a path of 500 line segments 100 yards inland (example Fig. 2) from the shore of each national park and exported the elevation profile to Excel. We then averaged the values to establish the vertical dimension of our generalized profile.

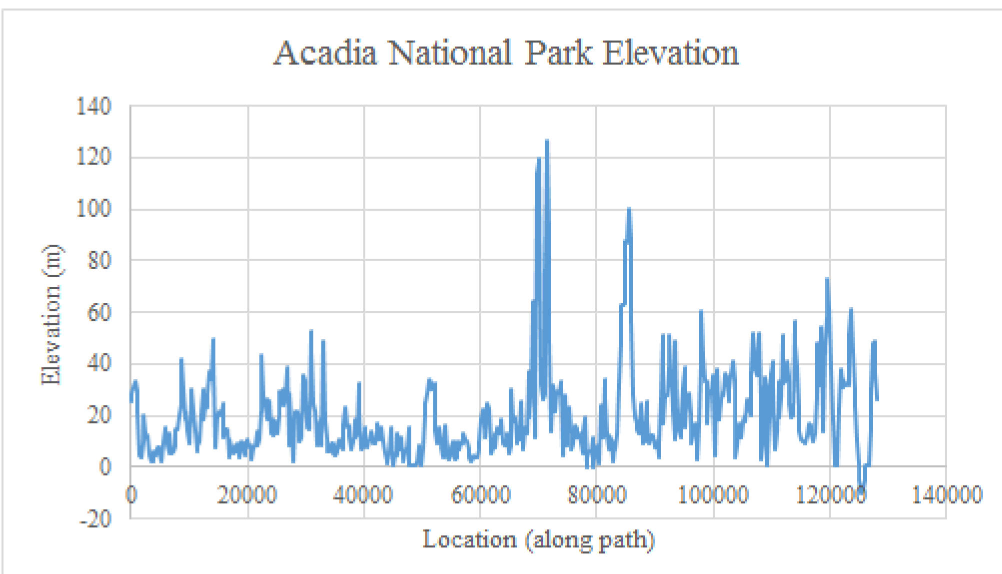
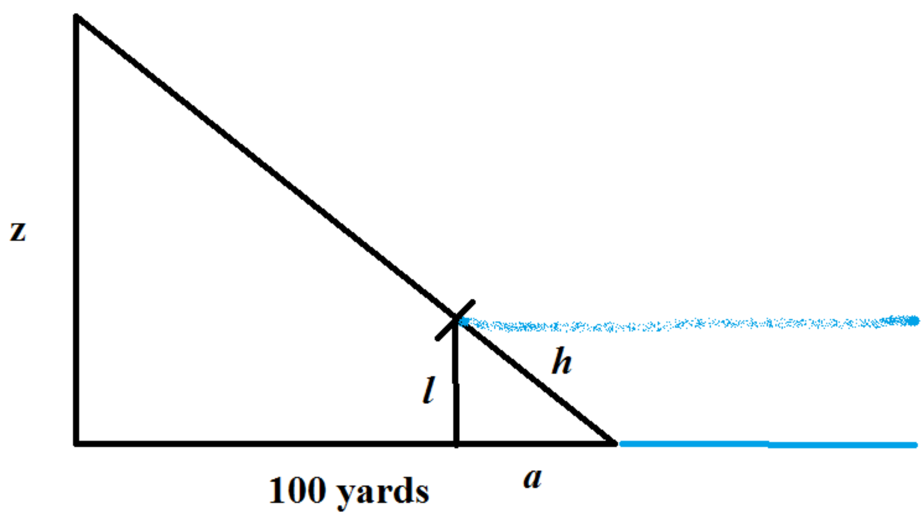


Fig. 2

We can then use data generated for *l* from Part A (Fig. 3) to determine area lost.

Park	Acadia NP	Cape Hatteras NS	Kenai Fjords NP	Olympic NP	Padre Island NS
Average Elevation (ft)	66.31	3.63	1101.64	255.80	2.67
10 yr Low l Estimate (ft)	0.0669	0.0925	0.0571	0.006199	0.0633
10 yr High l Estimate (ft)	0.316	0.338	0.178	0.0633	0.308
20 yr Low l Estimate (ft)	0.1338	0.185	0.1142	0.012399	0.1266
20 yr High l Estimate (ft)	0.712	0.756	0.436	0.251	0.696
50 yr Low l Estimate (ft)	0.3345	0.4625	0.2855	0.030999	0.3165
50 yr High l Estimate (ft)	2.38	2.49	1.69	0.582	2.34

Fig. 3



$$\frac{z}{300} = \frac{l}{a}$$

$$A_L = shoreline\ length * \sqrt{(l^2 + a^2)}$$

Total Area of Each Park

Park	Acadia NP	Cape Hatteras NS	Kenai Fjords NP	Olympic NP	Padre Island NS
Total Area* (square miles)	76.65	47.42	1046.85	1441.63	203.80

Fig. 4

Land Lost (as percentage of total area)

Park	Acadia NP	Cape Hatteras NS	Kenai Fjords NP	Olympic NP	Padre Island NS
10 yr Low	0.004595	0.213742	0.000428	0.000009	0.046269
10 yr High	0.021707	0.781026	0.001335	0.000094	0.225132
20 yr Low	0.009191	0.427485	0.000857	0.000018	0.092538
20 yr High	0.048909	1.746911	0.00327	0.000371	0.508741
50 yr Low	0.022977	1.068712	0.002141	0.000046	0.231345
50 yr High	0.163487	5.753715	0.012675	0.00086	1.710421

Key

Key
Low (less than 1%)
Medium (1% to 5%)
High (greater than 5%)

Fig. 5

*See references of source National Park Service for each park for total area data

Using the profile of each park, we calculated the slant height h for each sea level rise l and found the product, A with the park's shoreline length. Finally, we determined the percentage of park consumed by the sea (Fig. 5) by dividing A by the park's total area (Fig. 4) to find A_L, area lost.

Our model provides a range of possibilities and is thus can flexibly accommodate complexities that may periodically skew the data over 100 years, but it fails to account for rise because of changes in the water column's density due to temperature changes (Earth has been warming for years but only recently has enough of that energy been transferred to the water to cause significant changes in density) and the more rapid rise of sea level produced by the widespread fragmentation--and therefore faster dissolution--of arctic ice shelves. Our model's range of validity, however, is largely inclusive as it is designed to encompass the factors that contributed to large sea level rise historically.

Model Assessment:

Using a range of sea level heights provided a range of data points that could serve as a useful reference for the National Park Service when it assesses the risk of coastlines to increases in mean sea level. However, this range does not provide a concrete risk value for which the National Park Service can use as a basis for action. We opted to use the minimum and maximum projected values for the functionality of the range instead of providing a possibly less accurate model.

Also, we assumed that the coastline was of equal elevation 100 yards from the coastline. Not only is this an assumption that could provide variability in data, but the method used to calculate area lost (which assumed that elevation was gained at a constant rate over that 100 yds) also is not necessarily true on coastlines that have been subject to weathering for millions of years.

Utilizing percent of area lost to increasing sea levels might negatively affect the reliability of this model for parks with a large area that is not coastline. Any large park that does not have much coastline might rapidly lose that coastline, but is subsequently not losing much total area.

Conclusions:

Noting both the high and low projected area loss over the next 10, 20, and 50 years, Cape Hatteras National Shoreline is the most at risk of the 5 parks. Even though it only falls in the high risk category for the high prediction in 50 years, it is clearly the most at risk of the selected parks. The park at least risk is Olympia National Park, falling below one thousandth of a percent even in the high prediction for 50 years.

Part II: The Coast is Clear?

Restatement of the Problem:

Part II asked us to assess the effects of climate-related events on the five national parks. Generally, we defined "climate-related events" as wildfires, hurricanes, and floods. Hurricanes are expected to decline in number over the course over the 21st century, however the intensity is expected to increase. With the increase in global temperature, models suggest that hurricanes will be more intense, causing a 30% increase in damage (Geophysical Fluid Dynamics Laboratory, 2016). Climate change, especially its hastening of the snowmelt, is attributed to a greater number and intensity of wildfires in the West (Center for Climate and Energy Solutions, n.d.). Flooding is also associated with global warming through the greater amount of rain and raised sea level caused (Natural Resources Defense Council, 2017). To assess the vulnerability of each park to one type of event, it was necessary to find both the probability of these events occurring and the severity of these events if they were to occur. Combining the vulnerability scores for each park across events provided one metric to easily compare the five parks.

Wildfires

Assumptions:

- Kenai Fjords lacks fire data because data there is a not a significant number of fires within the park
- All fires that occurred on park grounds are included in the data provided by the Challenge
- The projected difference between the Haines Index of 2054 and that of 2007 is somewhat comparable to the difference between the Haines Index of 2067 and 2017

Every park, except Kenai Fjords, was assigned an average size rating, *Z*. To compute the value of *Z*, every size class (A to G) was renamed on a scale from 1 to 7, respectively. The average *Z* value for each park is as follows:

- Acadia = 1.26
- Cape Hatteras = 1.40
- Padre Island = 3.43
- Olympic = 1.22.

Factored in with the Haines Index, a measurement of atmospheric stability and the probability it will aggravate wildfires, we used *Z* to calculate a function that assesses the probability severity of fires.

$$S = Z * H$$

where *S* is the severity of the fire, *Z* is the average fire size, and *H* is the Haines Index.

The Wildland Fire Assessment System (2017) provides a general Haines Index value for each park:

- Acadia = 4
- Cape Hatteras = 4
- Padre Island = 3
- Olympic = 3.

This function *S* provides a minimum score of 0, which would indicate that there is little probability of any fire occurring, and a maximum score of 42 which would indicate that there is a high chance of a fire propagating and eventually consuming over 5,000 acres of land. Evaluating *S* with the current values for H yields:

- Acadia = 5.04
- Cape Hatteras = 5.6
- Padre Island = 10.29
- Olympic = 3.66

Given a map of the current Haines Index for the United States and a map of the projected Haines Index difference between 2007 and 2054 (Winkler & Potter, 2007), we found *H* for 2067 to be:

- Acadia = 4
- Cape Hatteras = 3.9
- Padre Island = 2.9
- Olympic = 3.3.

Evaluating *S* for each location in 2067 gives us the following values:

- Acadia = 5.04
- Cape Hatteras = 5.46
- Padre Island = 9.95
- Olympic = 4.03.

Hurricanes

Assumptions:

- The parks of Olympia and Kenai Fjords will not have hurricanes
- Any storm that has occurred at a park has been recorded and provided by the Challenge
- Acadia National Park has only experienced extratropical storms; these storms are assumed to be comparable in damage and wind speed to tropical depressions
- Since the intensity of hurricanes is expected to increase 30% over the next 100 years (Geophysical Fluid Dynamics Laboratory, 2016), the intensity of hurricanes will be 15% greater in the next 50.
- Since the number of hurricanes is expected to decrease by 25% over the course of the 21st century, the number of hurricanes will have decreased by 8.25% by 2050.

Based on the historical data of hurricane activity in each of the parks for the past 20 years, each park was assigned an average storm severity score, *G*. This was evaluated as the average hurricane strength based on a scale where tropical depressions are 1, tropical storms are 2, and hurricane strength (H1 - H5) are 3 - 7. The *G* values for the parks are as follows:

- Acadia = 0.3
- Cape Hatteras = 2.27
- Padre Island = 1.18.

The metric *G*, which measures severity, must be combined with some kind of measurement of probability. Therefore, the average number of hurricanes per year, *n*, was found to be:

- Acadia = 0.3
- Cape Hatteras = 0.94
- Padre Island = 0.48.

Combining probability and severity show the average vulnerability of any park to a hurricane, where the maximum value at any park (assuming that each park has no more than one hurricane per year) is 7 (based on the assignment of the maximum hurricane strength as 7). This combined factor would be described as

$$V_0 = G * n.$$

Evaluating this formula for each park yields the current vulnerability metric (V_0) as the following:

- Acadia = 0.09
- Cape Hatteras = 2.13
- Padre Island = 0.57.

We assumed that the intensity of hurricanes would increase by 15% and the number of hurricanes per year would decrease by 8.25%. The vulnerability adjusted for these factors yields the equation

$$V_f = 1.15G * 0.9175n.$$

The adjusted vulnerability scores for each park are as follows:

- Acadia = 0.10
- Cape Hatteras = 2.25
- Padre Island = 0.29.

Flooding

Assumptions:

- The severity of flooding is directly proportional to the effect of rising sea level because both are a function of elevation
- Precipitation will reflect historical trends (US climate data, 2017) but surge (hurricane factors) will not
- The likelihood of storm surges is proportional to the likelihood of hurricanes because storm surges are caused by the high wind associated with tropical storms and hurricanes
- The severity of storm surges is proportional to the severity of hurricanes because storm surges are caused by high wind such that a class 7 corresponds with a 30 foot surge (historical average), a class 3 corresponds to a 5 foot surge, and a class 0 corresponds with a 0 foot surge (Judge, 2014).

The average precipitation p and storm surge factor s are compiled independently but are both mediated (or intensified by elevation E) such that the flooding factor

$$F = \frac{p + s}{E}$$

Precipitation is the average rainfall measured in feet (directly corresponds to flooding), storm surge factor the combined likelihood of a storm (see Hurricane section) and the average surge per in equivalent feet rainfall (see assumption). E ranges from 0 to 1 and is based on the previous data of average inland elevation. Thus, the parks rankings are currently:

- Acadia = 0.071
- Cape Hatteras = 2.031
- Padre Island = 1.144
- Olympic = 0.039
- Kenai = 0.005

and when adapted to a 8.25% decrease in number of hurricanes and 15% increase of their intensity:

- Acadia = 0.071
- Cape Hatteras = 2.208
- Padre Island = 1.176
- Olympic = 0.039 (unchanged because probability of a hurricane = 0)
- Kenai = 0.005 (unchanged because probability of a hurricane = 0).

Theoretically, the flooding factor could approach infinity when elevation approaches 0, but to create a general factor we had to establish a practical limit (as observed in the parks in this situation). Land need be at least 3 ft above sea level to escape the tides, and in North America, combined coastal rainfall and storm surge are greatest in the Northwest, where, though s is 0, p approaches 10 (US climate data, 2017). Thus, our practical maximum for $F \approx 3.33$.

Total Vulnerability Score

A condensed metric can be created by summing the existing scores of each park in each category of risk and dividing by total possible risk. We then converted to percent of total.
The total scores are currently as listed:

- Acadia = 9.938%
- Cape Hatteras = 18.652%
- Padre Island = 21.814%
- Olympic = 7.775%
- Kenai = 0.010%

And projected for 2067:

- Acadia = 9.967%
- Cape Hatteras = 18.952%
- Padre Island = 21.814%
- Olympic = 7.775%
- Kenai = 0.009%

Model Assessment:

Using percentages as we did to define a vulnerability score does not show any park is, at a glance, particularly vulnerable. The low values are primarily due to the high maximum value for the fire vulnerability score, which significantly (and disproportionately) raised the maximum total score. If the model was refined, a way to better quantify how likely one area is to catch on fire would be the best adaptation. Provided that the maximum value for S is 42 and that the highest S among parks is about 10, some smaller scale would better quantify the vulnerability of a park to fire.

In addition, the assumption that hurricane intensity would increase and frequency would decrease linearly over time is probably not accurate. Adjusting the rates to the predicted increase of intensity and decrease of frequency did not significantly alter the data for 2067:

- Acadia = 0.09
- Cape Hatteras = 2.08
- Padre Island = 0.55.

Conclusions:

Comparing vulnerability scores tells us that, both currently and 50 years from now, Padre Island National Seashore is the most at-risk to the combination of climate-related events. Likewise, the Kenai Fjords are the least vulnerable both now and 50 years in the future.

Part III: Let Nature Take Its Course?

Restatement of the Problem:

To create a model predicting "long-term changes in visitors for each park," we began with a simple trend line extension of visitation data (1990 to 2016) that we collected from the National Park Service. However, a simple trend line is inaccurate over the course of more than five years in the future (Gramann, 2003), and qualitative data is more likely to give a reasonable projection, especially when used in combination with quantitative data. To this end, we considered the availability of maintained trail and the presence of threatened or endangered species as qualitative factors and the vulnerability scores from Part II to create a modifier for the conclusions we got from our trend line extensions. This modifier takes the form of a percent certainty that we can consider with our final predictions for 2067 visitor numbers in Acadia National Park, Cape Hatteras National Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore to give the National Park Service recommendations on where to focus its funds for maximum returns.

Assumptions

- Visitors to national parks find hiking trails more useful than driving trails.
- Visitors will be attracted to national parks by the chance to see threatened and endangered species.
- Endangered species will be a slightly stronger attraction to visitors than threatened species.

We plotted the National Park Service data of the percentage of visitors as compared to the total number of visitors to all National Park Service-run holdings for the five parks from 1990 to 2016 (National Park Service, 2017) to create a trend line for each park. We then extended the trend lines to predict visitation percentages fifty years into the future. From this trend line we found the following increases in share of visitors to all national parks for our sample parks:

Park	Share of Visitors, 2016	Share of Visitors, 2067	Percentage Increase (2016-2067)
Acadia NP	1.00	0.5036	-0.4937

Cape Hatteras NS	0.73	0.465	-0.265
Kenai Fjords NP	0.10	0.2152	+.1152
Olympic NP	1.02	0 .6636	-0.3564
Padre Island NS	0.19	0.011	-0.179

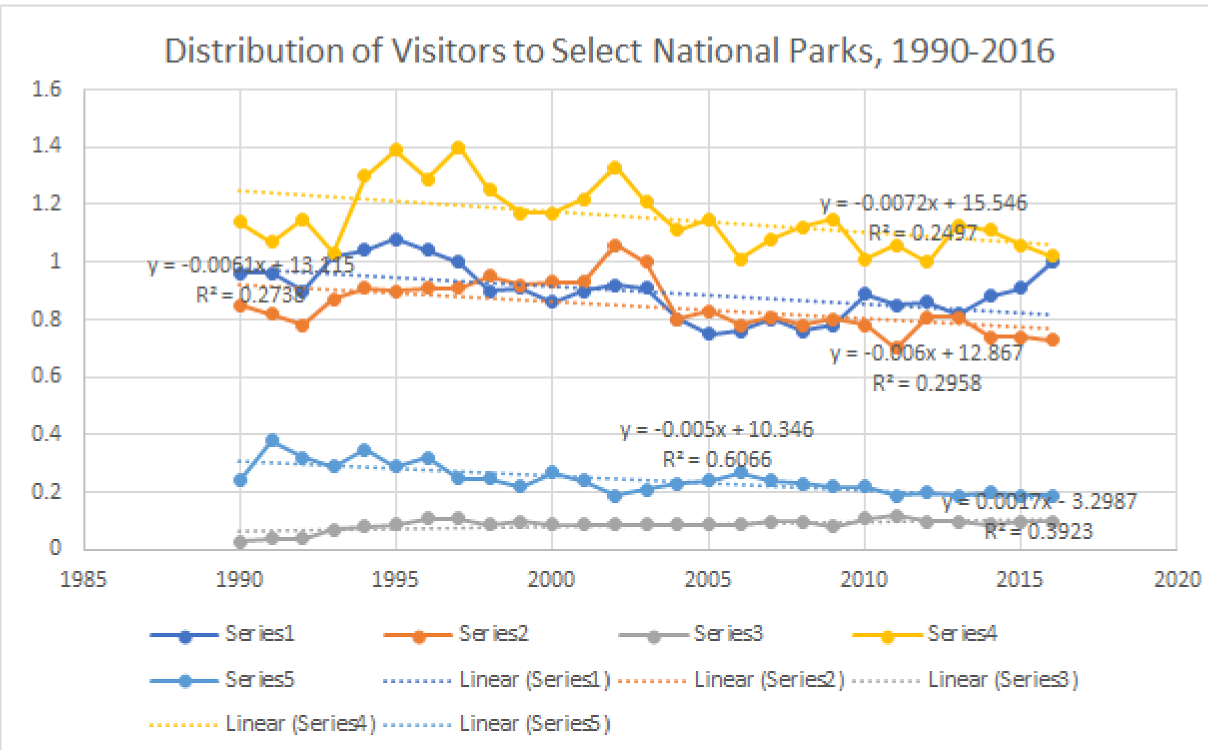
The plots and trend lines are shown on the graph below, with the legend as follows:

Series 1 refers to Acadia NP, with a trend line of $y = -0.0061x + 13.115$

Series 2 refers to Cape Hatteras NS, with a trend line of $y = -0.006x + 12.867$

Series 3 refers to Kenai Fjords NP, with a trend line of $y = 0.0017x - 3.2987$

Series 4 refers to Olympic NP, with a trend line of $y = -0.0072x + 15.546$



Series 5 refers to Padre Island NS, with a trend line of $y = -0.005x + 10.346$

Although the R^2 values are relatively low and could have been increased by using high-degree polynomials, we decided that linear trend lines were most appropriate to characterize a data range of merely twenty-six years.

Qualitative Modifiers

Trail Access

We decided that our first qualitative variable would be the ease of access or facilities at the park and that the best way to describe this in terms of a quantity was to use the miles of hiking trails compared to the miles of roadways and car trails. We assumed a 3:2 relationship of draw (in population) between hiking trails and the miles of roadways:

Park	Hiking Trails (mi)	Driving/Other Trails (mi)
Acadia	130	110
Cape Hatteras	6.0	70
Kenai	7.8	0
Olympic	>650	0
Padre	0	60

Threatened and Endangered Species

Our second qualitative variable was the abundance of threatened and endangered species in the parks, shown below (NPSpecies, 2017). Since we assumed that endangered species would be a slightly stronger attraction to visitors than threatened species, we weighted endangered species higher in our formula.

Park	Number of Threatened Species	Number of Endangered Species
Acadia	1	2
Cape Hatteras	5	7
Kenai	1	8
Olympic	6	7
Padre	2	12

Vulnerability Scores

We used the vulnerability scores we calculated earlier (see Part II).

Park	Vulnerability Score for 2067 (Decimal Form)
Acadia	0.09967

Cape Hatteras	0.18952
Padre Island	0.21814
Olympic	0.07775
Kenai	0.00009

Formula for Calculating Visitation Score

If *h* = miles of hiking trails, *d* = miles of driving trials, *e* = number of endangered species, *t* = number of threatened species, *v* = vulnerability score, and *c* is a percent certainty of our data based on our qualitative factors, then the formula we used to calculate our measure of certainty is as follows:

$$C = \frac{\left(\frac{3h + 2d}{2500} + \frac{3e + 2t}{5}\right)}{2} * 100$$

Park Name	Percent Certainty	Trend line Prediction for 2067
Acadia	15.2165	0.5036
Cape Hatteras	24.684	0.465
Kenai	26.4635	0.2152
Olympic	68.1125	0.6636
Padre	31.493	0.011

Model Assessment:

Using a linear trend line may not be the most accurate predictor of long-term visitation, but it was the model that had the best fit (via R^2 value) and predictions (some lines provided negative visitors).

Also, some modifiers used are somewhat arbitrary. While changing the value of these modifiers slightly would not affect the data too greatly, changing the value of these modifiers significantly would most likely affect the data significantly.

Although some percent certainty values for our model are low, the most popular and least popular parks are two of the most certain values for popularity predictions.

Conclusion

The high percent certainty of the highest prediction of visitors, leaves us confident that Olympic National Park is the best investment for the National Park Service’s funding. Continuing the same reasoning, a relatively high percent certainty of a very low percent of visitors leads us to recommend less funding for the Padre Island National Shoreline, which is consistently losing popularity.

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