Whether the Parks can Weather out the Weather

Executive Summary:

Based on climate change, park visit, and economic research, we have modeled major problems that the NPS will face in its upcoming second century of stewardship based on five of its parks: Alaska's Kenai Fjords, Maine's Acadia, Texas' Padre Island, North Carolina's Cape Hatteras, and Washington's Olympic National Parks. We hope our models will help to further improve the efficiency of the National Park System and retain whatever parks possible for future Americans.

Our first model was meant to determine the risk of sea level change for each of the parks. This model considered park size, maximum elevation, profile, and historical rate of mean sea level change for each park and allowed us to determine which of them were at risk of being damaged due to changing sea levels. The model identified that Acadia, Kenai Fjords, and Olympic parks were all at low risk for the next century. Padre Island and Cape Hatteras were identified to be low-risk in the upcoming 10 years, medium-risk locations at the 20 and 50-year marks, and at high risk by the end of the century.

We also analyzed the effect that climate change has had on the probability of severe natural disasters on each park, and created an index that defined how high a risk of severe disasters each park faced over the next 50 years. Based on the severity scores we assigned to each location, it was determined that Kenai Fjords was at the lowest risk, Acadia the second lowest, Cape Hatteras the third, Olympic the second most, and Padre Island the highest risk of severe weather causing significant damage.

Using functions created to model estimated changing visitor statistics, deferred maintenance costs, and costs of recovering from disasters, we created a single model that represented the profitability of each park. From this model, we could determine how much money must be invested in each park to keep them operating into the coming decades. Although no park would yield positive profits at any point in the future, some would cost much more than others to maintain. In addition to risks for rising sea levels and severe weather threats, this cost could determine whether a park should be invested in by the NPS.

In analyzing each of the models describing sea level changes, vulnerability to natural disasters, changes in visiting rates, and overall park budget, we can prioritize which parks should be valued and invested in for the coming generations of Americans. Of the five parks analyzed, we recommend that parks be prioritized in this order: Kenai Fjords, Acadia, Cape Hatteras, Padre Island, and Olympic. Based on the risk for natural disaster, the cost of operation, loss of land to sea level changes, and visitor preferences, by investing in this order the NPS can do the most to preserve the land most precious to our country without wasting on lands that will not survive.

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Restating the Problem:

For the past 100 years, the National Park Service (NPS) has tirelessly dedicated itself to its ultimate mission to "preserve unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations." However, the world is a constantly changing place, and factors like the ever-evolving global climate have great implications on the 417 parks covered by the NPS, and especially the experiences that these parks can provide to visitors. With increasing climate change data becoming available, the NPS must now determine how its parks will be affected and create a path forward to maintain our parks for the next generations of Americans.

Background:

In the last 20 years, significant progress has been made in the area of data acquisition concerning how our climate has been evolving and affecting the nation, specifically our National Parks. Accurate measurements for the changing sea levels as well as the severity and frequency of natural disasters in many National Parks are now readily available, allowing for an analysis as to how the changing climate is reshaping the role and responsibility of the NPS in preserving the National Park System. Using this data, we can create models which give insight into how the NPS could most productively distribute its financial resources, and ensure that the second century of America's National Park System is as enjoyable, educational, and inspirational as its first.

<u>Tides of Change:</u>

Restating the Problem:

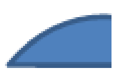
Coastal national parks have faced the threat of flooding since their incarnation, but the emergence of climate change research has enabled them to quantify their concerns. Using sea level trends collected for the past 2 decades, we are creating a function that will model the risk of sea level changes that certain parks face over time. The output of this function will tell us the remaining surface area after a certain amount of years as a percentage of the initial surface area. These outputs will then be categorized into low, medium, and high risk of damage, depending on the severity of the risk they describe, allowing the NPS to identify which parks in specific need the most attention and will potentially require the most financial investment through the upcoming century.

Assumptions Made:

- No major natural disaster, nor outlying weather trends will impact the overall sea level change of any park over another in the given time period
- The rate of sea level change will change at a constant rate equal to that of its average over the past 20 years
- No government will make any significant policy change in regard to climate change over the given time period

- Sea level today is referred to as $0m$, for the elevation of each park is determined from their current distance above sea level
- Each park can be simplified as a uniform geometric figure, by which the rate of change in sea level can mathematically be defined to cover a certain percentage of the park over a given time.
- An area of the park becomes unusable when the average sea level is above that area.

Defining Variables:

We simplified each of the national parks into two distinct categories based on their shape. The two national seashores, Cape Hatteras and Padre Island, are long and narrow strips of land, with elevations of zero on the shore and rising to a peak elevation in the middle. Therefore, they can be treated as horizontal cylindrical segments; i.e. their cross section can be visualized as a region of a circle bounded by a chord and arc, like shown: . The width and height of this cross-section can be determined via the average width of each seashore and its maximum elevation. A function can be created from these values and the length of the island to describe the total surface area of the seashore. Further, a similar function can be determined to find the area of the island at any time after rising sea levels decrease its height. By dividing the surface area of this function, which is the area left after a given time of sea levels rising or lowering, by the original surface area, we could find the percentage of the park remaining. In the case of Kenai Fjords, the entire park is not such a horizontal cylindrical segment, but rather like half of one, as the coast is at an elevation of zero and the borders cut off when the highest mountains of the park are reached, like so: . As the surface area of such a shape would always be half that of that above, and the final surface area is divided by the initial, the ½ is cancelled out. Thus, the same equation can be used to define all three of these parks. This equation can be made using the constants of *w,* the average width of the park, *h*, the highest elevation of the park, and *r,* the average rate at which the sea level at the park is rising or dropping. Thus, the independent variable, *t,* the number of years elapsed since today, determines how much of the park remains.

Acadia National Park and Olympic National Park are different from the geometric forms of the other three parks in that they more closely resemble a dome than an elongated prism of near-constant width, both having a central mountain gradually sloping down in all directions to the sea. Thus, their cross-sections can still be modeled by the diagram , but their surface area would be found by revolving the figure rather than elongating it by a found length. Both these parks are circular when viewed from above, so the variable *w* in their case represents their diameters, and the variable *h* now represents the elevation of the mountain peak central to both of the parks. The variables *r* and *t* remain as defined above, and by subtracting the change in MSL as determined by our observed trends from the initial elevation, we can find the new effective height of each park, which we can then use in our model to find percentage of the park remaining after *t* years.

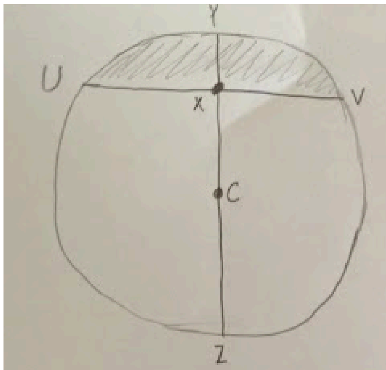
However, not all of the parks are completely surrounded by water as Padre Island, Acadia, and Cape Hatteras are. Only about half of Kenai Fjords and Olympic National Parks are exposed to the coast. Therefore, as twice the amount of water rising would be necessary for these two parks to be affected in the same way as Padre Island, Acadia, and Cape Hatteras, their rate of change must be divided by two. This was considered and incorporated when recording their average rate of sea level change.

Developing the Model:

The functions for change in surface area will rely on the parks' peak elevations, widths, and the rates at which their sea level is changing. Peak elevations and widths can be found from the National Parks Service[1], and sea level change rates from the National Oceanic and Atmospheric Administration[2].

Park	**Type of Geometric Figure**	**Peak Elevation (m)**	**Effective Average Sea Level Change (m/year)**	**Average Width (m)**
Acadia	Dome	466m	0.002178	16093m
Kenai Fjords	Half-Horizontal Cylindrical Segment	1996m	-0.0013098	19302.1m
Olympic	Dome	2389m	0.00007002	91249.8m
Padre Island	Horizontal Cylindrical Segment	2m	0.00348	3000m
Cape Hatteras	Horizontal Cylindrical Segment	2m	0.00384	2494.5m

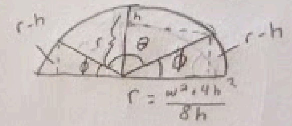
For the parks categorized as horizontal cylindrical segments, the initial surface area can be defined in the following manner:



$XY = h$, max elevation
$UV = w$, width of park

Via the Intersecting Chords Theorem:

$$XY \cdot XZ = UX \cdot XV$$
$$\Rightarrow h \cdot XZ = \frac{w}{2} \cdot \frac{w}{2} = \frac{w^2}{4}$$
$$\Rightarrow XZ = \frac{w^2}{4h}$$
$$d = ZY = XZ + h = \frac{w^2+4h^2}{4h} = 2r$$
$$\Rightarrow r = \frac{w^2+4h^2}{8h} = \text{radius}$$



Formula for Arc Length: $\frac{2\pi r\theta}{360}$

$$\theta = 180 - 2\phi$$
$$r\sin\phi = r-h \Rightarrow \arcsin\frac{r-h}{r} = \phi$$
$$\Rightarrow \theta = 180 - 2\arcsin\frac{r-h}{r}$$
$$\Rightarrow \frac{2\pi r\theta}{360} = \frac{\pi r\left(90 - \arcsin\frac{r-h}{r}\right)}{90} = \frac{\pi(w^2+4h^2)\left(90 - \arcsin\frac{\frac{w^2+4h^2-8h^2}{8h}}{\frac{w^2+4h^2}{8h}}\right)}{720h}$$
$$= \frac{\pi(w^2+4h^2)\left(90 - \arcsin\frac{w^2-4h^2}{w^2+4h^2}\right)}{720h}$$

$$\text{Surface Area} = \ell(\text{arc length}) = \frac{\pi\ell(w^2+4h^2)\left(90 - \arcsin\frac{w^2-4h^2}{w^2+4h^2}\right)}{720h}$$

Additionally, a function can be defined which gives the area of the park after a given number of years, in terms of the same constants.

Height after given time: $h - rt$

$\boxed{r \text{ now} = \text{rate of sea level change}}$

Width after a given time:

$$\frac{w_1^2 + 4(h-rt)^2}{8(h-rt)} = \text{radius} = \frac{w^2+4h^2}{8h} \Rightarrow w_1^2 + 4(h-rt)^2 = \frac{(w^2+4h^2)(8(h-rt))}{8h} \Rightarrow w_1^2 = \frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h}$$

Area Remaining after a given time:

$$\frac{\pi\ell\left(\left(\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h}\right) + 4h^2\right)\left(90 - \arcsin\frac{\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} - 4h^2}{\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} + 4h^2}\right)}{720h}$$

Finally, in order to find the percent remaining of the park after a given number of years, this function can be divided by the function of initial surface area, yielding this equation:

$$\text{Percentage Remaining} = \frac{\text{Area Remaining}}{\text{Initial Area}} \cdot 100$$

$$= \frac{\pi\ell\left(\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} + 4h^2\right)\left(90 - \arcsin\frac{\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} - 4h^2}{\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} + 4h^2}\right)(720)}{720\left(\pi\ell(w^2+4h^2)\right)\left(90-\arcsin\frac{w^2-4h^2}{w^2+4h^2}\right)} \cdot 100$$

$$\boxed{= \frac{\left(\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} + 4h^2\right)\left(90 - \arcsin\frac{\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} - 4h^2}{\frac{(w^2+4h^2)(8(h-rt)) - 32h(h-rt)^2}{8h} + 4h^2}\right)}{(w^2+4h^2)\left(90-\arcsin\frac{w^2-4h^2}{w^2+4h^2}\right)} \cdot 100}$$

For Acadia and Olympic National Parks, we assumed the shape of a spherical dome. In doing so, we could calculate the percentage of the park remaining to be represented by the following function, in terms of the rate of the sea level changing, the maximum elevation of the park, and the number of years from today.

Via the Same Intersecting Chord Theorem:

$$r = \frac{\ell^2+4h^2}{4h}$$

Area of a Spherical Dome: $A = 2\pi r h = \frac{2\pi(\ell^2+4h^2)h}{4h}$

Height after a given time: $h - rt$

Area Remaining: $\frac{2\pi(\ell^2+4h^2)(h-rt)}{4h}$

Percentage Area Remaining: $\frac{\text{Area Remaining}}{\text{Initial Area}} = \frac{\cancel{2\pi(\ell^2+4h^2)}(h-rt)}{\cancel{4h}} \cdot \frac{\cancel{4h}}{\cancel{2\pi(\ell^2+4h^2)}h} \cdot 100$

$$= \frac{(h-rt)}{h} \cdot 100$$

The risk rating for each of the parks will be determined based on this percentage of land area that still remains after 10, 20, and 50 years. As few park resources are located around its outer 1%, a park will be considered at low risk if it retains over 99% of its land over a period of time. As flooding progresses beyond this amount, the chance for damage to infrastructure and to a significant amount of useful land becomes greater. However, up until around 5% of land has been lost due to increasing sea levels, it is unlikely that vital parts of the camp (headquarters, trails, housing) will be made unusable. Therefore, a park which retains between 99 and 95% of land area is considered to be at a medium risk. When any park retains less than 95% of its land area, it will likely have lost a great amount of vital infrastructure, transportation routes, and desirable land. Therefore, any park which has lost more than 5% of its land area will be categorized as being at a high risk.

Testing the Model:
After entering values obtained for width, height, and rate of sea level change into our model, the following values were determined for the percentage of park land remaining (rounded to the nearest hundredth of a percent):

	Percent Remaining After Given Time			
Park	10 Years	20 Years	50 Years	100 Years
Acadia	100%	99.99%	99.98%	99.95%
Kenai Fjords	100%	100%	100%	100.04%
Olympic	100%	100%	100%	100%
Padre Island	99.13%	98.24%	95.56%	90.88%
Cape Hatteras	99.04%	98.06%	95.08%	89.89%

Therefore, none of Acadia, Kenai Fjords, nor Olympic National Parks will ever, at any point in time over the next 100 years, be categorized as being above a low risk to sea level changes. Within the next ten years, both Padre Island and Cape Hatteras can also be classified as low risk. However, at the 20 and 50 year marks, Padre Island and Cape Hatteras will be at a medium risk of significant damage from sea level changes.

If our model could accurately predict sea level changes over the next century, it would show that Padre Island and Cape Hatteras would continue to lose land area at an alarming rate. Each would lose approximately 10% of its land area within this time frame.

Analyzing the Model:

Our model is effective in creating two single functions that can reasonably define the change in land area for any coastal national park. Through our model, this can be done with knowledge of only the elevation, width, and rate of sea level change for each park. It also seems to yield fairly accurate data for the change in land area for each park; those parks which are substantially above sea level will likely not see a noticeable effect in changing sea levels within the next century, which our model indicates. It is also reasonable that, within a century, Padre Island and Cape Hatteras will lose a tenth of their land, being that they are so exposed to the changing sea level and are extremely flat, allowing for the rising sea to cover their land area. Therefore, we believe that this model can reasonably predict the effect of sea level change on land loss in one hundred years.

However, our model is oversimplified in that no park can be effectively categorized into risk categories simply based on the percent of land lost, nor visualized as a purely uniform geometrical shape. Though we defined a park as being under "high risk" if it lost more than 5% of its land, this number can be arbitrary depending on the layout of the park. For example, some parks, especially National Seashores such as Cape Hatteras and Padre Island, are intensely focused on the coast, with most of their buildings and infrastructure directly adjacent to the beach. In these parks, a 5% loss of land would cause much more damage than to parks such as Olympic, which is headquartered in mountainous regions. Finally, these models are only as accurate as the rate of change data applied to them. As our data for this rate of change was recorded for only a 20-year period, with significant standard deviations, the models may not be entirely accurate.

Reporting the Results:

After plugging in all of the data into our equations, the Acadia, Kenai Fjords, and Olympic parks were all categorized as low-risk parks for all time periods. They did not show any signs of being in danger of high sea levels within the foreseeable future. The Padre Island and Cape Hatteras parks were at low-risk for the first 10 years, but for the 20 and 50 year marks they fell into the medium risk category, losing more than 1% of their land area to rising sea levels. At the 100 year mark, our model predicted the Padre Island and Cape Hatteras parks to be in the high risk category, losing more than 5% of their total land area.

The Coast is Clear?:

Restating the Problem:

With sea-levels rising, evidence that climate change is occurring is abundant and foreseeable. However, sea levels rising are not the only consequence to warmer climates, and in order to protect our coastal park units, we must take into account all the effects of climate change. So that the NPS can better understand the direct threat of climate change to these coastal park units, we are tasked with creating a mathematical model that accounts for the possibility of several climate-related disasters, the severity of the event with respect to itself, and the severity of the event with respect to other events, in order to assess and assign a single climate vulnerability score in a coastal region over the next 50 years.

Assumptions Made:

Since the data demonstrates no previous increase (or decrease) in hurricane strength, it is unlikely that the next 50 years will experience a significant change in average hurricane strength.

- The frequency of hurricanes will remain at the same rate as the last 20 years, as with the data recorded over the past twenty years, the hurricane events were infrequent, and did not show any clear positive or negative correlation.
- The air quality in each of the national parks will not be harmful at any point in time because there has been a generally negative correlation between time and poor air quality over the past twenty years.
- For the next 50 years, the climate change that will take place will not be nearly significant enough to result in earthquakes, so this natural disaster will not be included as a climate change-related event.
- The rising sea-level will result in marginal change in coastal surface area- about a 5% decrease at most. This is not a significant percent and thus would not constitute a natural disaster. Additionally, this change will be gradual over the 50 years, and the park will have plenty of time to adjust to the changing circumstances.
- The severity of a storm increases exponentially as its categorization increases. For example, a tropical depression may cause only a quarter of the damage as an H1 hurricane and only a tiny fraction of the damage of a category G wildfire. Therefore, we used a square rule to relate the categorization of a natural disaster to its severity.

Developing the Model:

In order to compare the effects of wildfires and hurricanes, we can weight their impacts relative to each other. Hurricanes are measured based on the strength of their winds as defined by the Saffir-Simpson Hurricane Wind Scale[3], while wildfires by how many acres they damage, as classified by the National Wildfire Coordinating Group[4]. Although a weak hurricane may impact a vastly large region, its impact on the region will be much less severe than a wildfire. As each is measured on its own scale, we created this table in comparison:

Hurricane Strength	Wildfire Severity	Severity Level	Severity Multiplier (Severity Level Squared)
ET and TD	B	1	1
TS and H1	C	2	4
H2	D	3	9
H3	E	4	16
H4	F	5	25
H5	G	6	36

Per data from the National Oceanic and Atmospheric Administration[5] and the National Wildfire Coordinating Association[4], the following number of events per each severity multiplier occurred over the past twenty years:

	Number of Events per Severity Multiplier						Total
Park	**1**	**4**	**9**	**16**	**25**	**36**	**--**
Acadia	16	3	1	0	0	0	37
Cape Hatteras	34	16	8	0	1	0	140
Kenai Fjords	0	0	0	0	0	0	0
Olympic	39	6	3	7	3	0	277
Padre Island	15	14	4	7	4	4	463

Testing the Model:

After using the determined values for events of a certain severity, we divided each number by the data set timeframe of 20 years. We then multiplied this value by 50 years in order to create a score that represents the severity of disasters that will affect the parks in the 50 year time period.

Park	Severity Per Year	50-Year Severity Score
Acadia	1.85	92.5
Cape Hatteras	7	350
Kenai Fjords	0	0
Olympic	13.85	692.5
Padre Island	23.15	1157.5

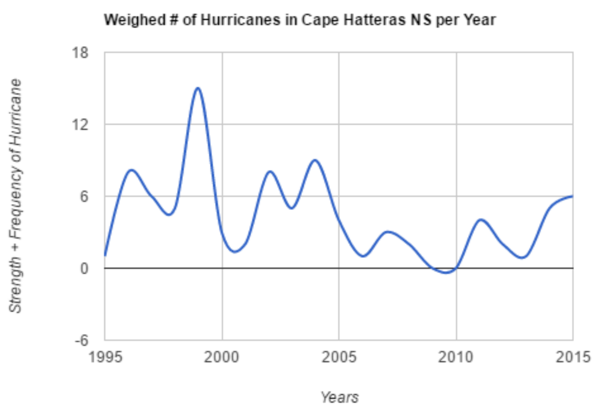
These numbers represent the projected "severity score" that each park will undergo in the next half-century. This means that this should approximate all of the severities of the climate-caused natural disasters which are summed in the next 50 years. For example, Cape Hatteras, with a severity score of 350, could undergo 350 category-1 severity events over this time period, or approximately 10 category-5 severity events.

Therefore, Kenai Fjords will face nearly no severe weather storms over the next fifty years. However, Acadia will be subject to the equivalent of 92.5 category-1 storms in this time frame. These data also show that Cape Hatteras will face approximately four times the severity of storms than that of Acadia, while Olympic National Park will face twice the severity of Olympic. Padre Island will be hit by the highest severity of storms in the coming decades, approximately twice that of Olympic.

Analyzing the Model:

This model is effective in that it can be used to determine how the severities of hundreds of small-scale events could be correlated to more easily understandable large-scale events. For example, though Acadia has faced many low-category events over the past 20 years, these can be more easily understood as facing about 2 category-5 events and one category-4 event. By making an effective comparison between different types and intensities of storms, we can also more easily compare two parks which differ in number of storms and severity.

However, our model may prove inaccurate in that it failed to account for any changes in frequencies or strength of natural disasters. This is largely due to a lack of data to display any strong correlation between climate change and the properties of the natural disasters (Fig. 1).



This proves that, to date, despite the evidence of increasing sea levels and climate change over the past few decades, there has been little to no correlation between climate change and increasing numbers of hurricanes. However, such a correlation may be proven to exist in the future, which would skew these values for severity scores.

Moreover, our model is inaccurate in its index of vulnerability for Kenai Fjords of 0, which indicates that there is no risk in the next 50 years for this Alaskan Park. As we had no wildfire data for the Kenai Fjord, this score is artificially lower than it should be. Since we also excluded earthquakes, avalanches, and other similar natural disasters from our data, this severity score has a significant chance of inaccuracy. However, it is a useful tool in giving a rough comparison of vulnerability between the five national parks.

Reporting the Results:

Acadia Park has a severity score of 92.5, Cape Hatteras of 350, Kenai Fjords of 0, Olympic National Park of 692.5, and Padre Island of 1157.5. These numbers predict the overall severity of events that will occur in the period of the next 50 years, meaning that South Padre will have the highest chance of experiencing high damage from natural disasters.

The 50-year sum severity, given by the table, indicates the total danger caused by an accumulation of natural disasters in each of the 5 national parks. Based on this model, Kenai Fjords has the lowest risk, Acadia the second lowest, Cape Hatteras the third, Olympic the second most, and Padre Island the highest risk of severe weather causing significant damage.

Let Nature Take its Course?:

Restating the Problem:

The National Park Service has limited funds with which to achieve its goals of investigating the causes of, and fighting back the effects of climate change in the National Park Systems it oversees. The primary way that the NPS can expand its limited funds is through visitors at their parks. In order to help the NPS be more efficient in its spending, we are modeling the effects of climate change on potential visitors, and how they can predict visitation at their parks and therefore their potential income.

Assumptions Made:

- Park admission fees will be recorded from the admission fee for a single vehicle. Each vehicle will be assumed to carry 3 visitors. This is reasonable because visitors to national parks tend to be families rather than individuals, and admission fees into parks are paid by vehicle count, not visitor count. We based the 3 visitor/car on National Parks Service Report showing 2.99 visitors per car entering Padre Island in 2016[7].
- The consumer price index has increased by 1% since 2014[8], according to the Federal Reserve Bank of Minneapolis. As the National Parks Service's deferred maintenance balance has increased by 5% since 2014, we will assume that the real cost for parks' deferred maintenance is increasing 2% annually. Thus, we are assuming that the federal government will not allocate more funds to the NPS, nor will the inflation rate change.
- The rate at which the number of visitors to each park each year is changing is constant, and is proportional to that observed over the previous 28 years.
- The percentage of land remaining usable after a natural disaster will directly affect the percentage of visitors of a projected visitor population for that year.

Defining Variables:

The vehicle entrance costs are based on fee data provided by the National Parks Service. Also, we found the number of vehicles that would be entering a national park at any given year by the vehicles per year function, which is derived from comparing population entering the park in a year and dividing it by the years away from 2016, with 2016 being year 0. Years in this function is represented by the variable t. To show that year 2016 starts at 0, we made every year going backwards from 2016, making 2015 hold the year value of -1.

The deferred maintenance is increasing at an average rate of 2% annually, so given that the rate will be 1.02, we can create the function of cost in a given year after 2016 is (cost in 2016)$(1.02)^{\text{\# of years after 2016}}$.

Developing the Model:

We created a raw function for vehicles entering each park from data of visitors provided by the National Parks Service[10], assuming cars contained 3 people. By finding a linear best fit of a plot of year vs. number of visitors per year for each park, we could determine the average change in number of visitors per year.

The vulnerability cost is based on the average cost per severity of an event, found from the cost per acre of fighting wildfires from the U.S. Forest Service in 2004 and adjusted for inflation[9]. The cost accounted for by each severity event is based upon how many average acres a wildfire in that category would burn. Thus, a category 1 event would destroy 5 acres, a category 2 50 acres, 3 200 acres, 4 1500 acres, 5 2500 acres, and 6 10,000 acres, as shown by data from the National Wildfire Coordinating Association[4]. Thus, as Acadia faced 16 category 1, 3 category 2, and 1 category 3 events in 20 years, and in Maine wildfires cost on average $184 per acre to fight, its cost over 20 years could be calculated to be 184(16*5+3*50+1*200). These values were then divided by 20 to find a cost per year that each park will spend recovering from natural disasters.

Park	**Vehicles per Year as Function of Year After 2016**	**Vehicle Entrance Cost**	**Deferred Maintenance Costs in 2016**	**Cost Per Acre of Wildfire**	**Annual Vulnerability Cost**
Acadia	-12769t + 720276	$25	$68,250,049	$184	$3,956
Kenai Fjords	3010.4t + 118481	$10	$4,148,151	N/A	$0
Olympic	7281.67t +1000000	$25	$139,821,329	$2513	$2,399,126
Cape Hatteras	7493.6t + 848670	$10	$61,485,934	$388	$98, 358
Padre Island	-1183.2t +202126	$10	$13,169,044	$388	$1,204,255

The percentage of land remaining after a natural disaster can be found by first finding the amount of land rendered unusable due to natural disasters each year. This was accomplished by multiplying the number of instances of each severity classification of disaster by the average amount of acres destroyed by each respective severity classification, and then taking a total sum. For instance, if looking at Olympic National Park, the equation for total damage would be (39*5+6*50+3*200+7*1500+3*2500). This number was then divided by 20 to get a yearly average amount of acreage lost. From this, the total percentage of the park remaining available to visitors each year could be found. Based on the assumption that the percentage of visitors from the value determined by our model is directly related to the percentage of land still available, we then applied the percentage we found as a coefficient to the visitor number equation to find the actual number of visitors we predict to visit each park each year beyond 2016.

Park	Acreage	Acres Damaged	Percent Remaining	New Visitor Equation
Acadia	49,052	430	99.12%	0.9912(-12769t + 720276)
Kenai Fjords	670,080	0	100%	3010.4t + 118481
Olympic	922,880	19,095	97.93%	0.9793(7281.67t +1000000)
Cape Hatteras	24,470	3,678	84.97%	0.8497(7493t+848670)
Padre Island	130,434	62,075	52.41%	.5241(-1183.2t +202126)

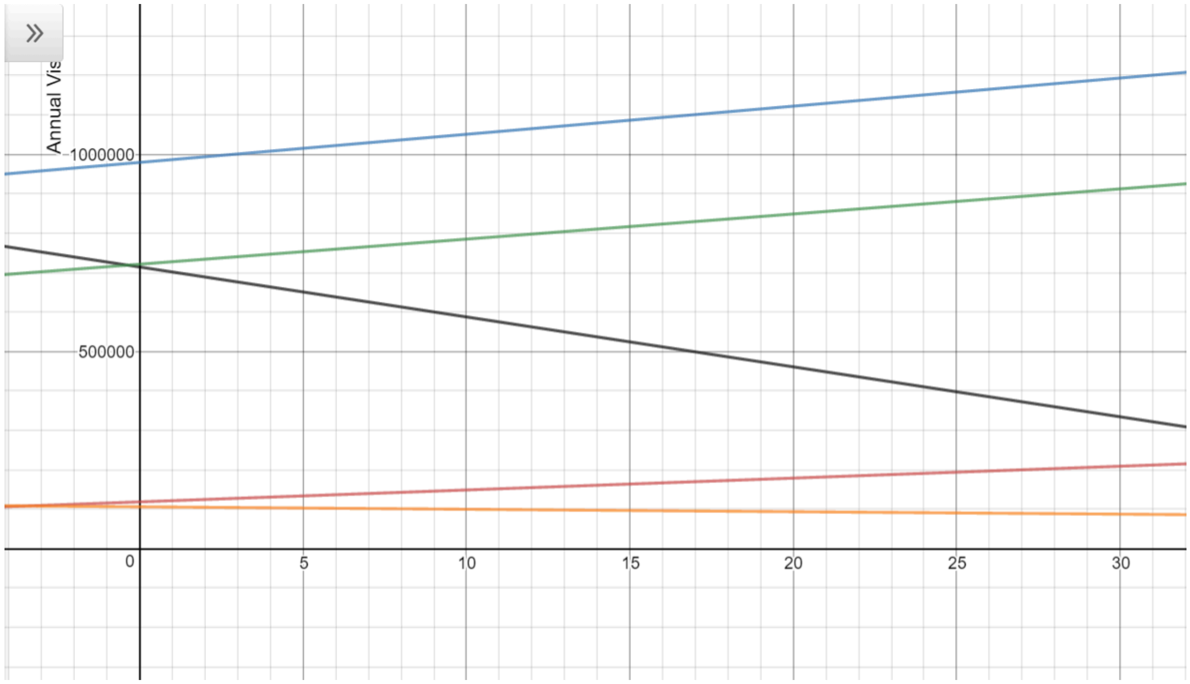
By combining the elements of vehicles per year, cost per vehicle, deferred maintenance, and annual vulnerability costs, we could create a formula for the yearly balance of each park in terms of the number of years after 2016.

Park	**Yearly Balance ($)**
Acadia	$25(0.9912)(-12{,}769t + 720276)-(68{,}250{,}049)(1.02)^t-3{,}956$
Kenai Fjords	$10(3010.4t+118481)-(4{,}148{,}151)(1.02)^t-0$
Olympic	$25(0.9793)(7281.67t +1000000)-(139{,}821{,}329)(1.02)^t-2{,}399{,}126$
Cape Hatteras	$10(0.8497)(7493.6t + 848670)-(61{,}485{,}934)(1.02)^t-98{,}358$
Padre Island	$10(.5241)(-1183.2t +202126)-(13{,}169{,}044)(1.02)^t-1{,}204{,}255$

By graphing these functions, we can observe at what points in time the parks will be in debt. We can also determine whether certain parks are financially feasible in the long term.

Testing the Model:

The following graph relates the year after 2016 to the number of visitors that will visit each park:

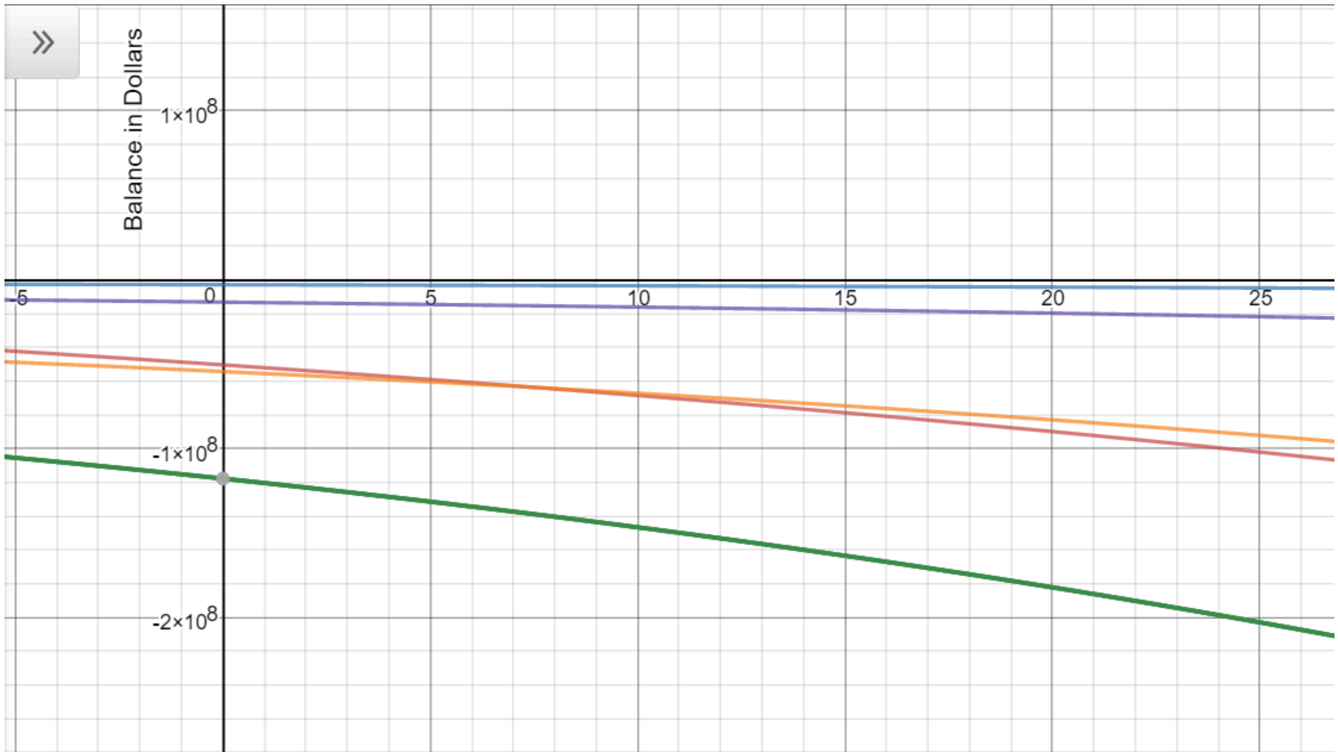


The x-axis represents the number of years after 2016.

Light Blue--------Kenai Fjords
Purple-------------Padre Island
Orange------------Cape Hatteras
Red----------------Acadia
Green--------------Olympic

This graph shows how visitor statistics and natural disaster vulnerability will describe the amount of annual visitors in future years. For example, though in the past 30 years Cape Hatteras National Park is gaining an average of about 7,500 visitors per year, because natural disasters are likely to cause damage to a significant percentage of the park, it will only increase at an estimated rate of 6,500 visitors per year in our model.

The following graph displays how this projected change in visitors over the next few decades, along with the rising interest of maintenance costs and costs of repairing natural disasters, will affect the overall budget of each park.



The x-axis represents the number of years after 2016.

Light Blue--------Kenai Fjords
Purple-------------Padre Island
Orange------------Cape Hatteras
Red----------------Acadia
Green--------------Olympic

In following this model, we determined that no park will ever be profitable within 25 years, and that all have a negative slope for all years after 2016. However, of the parks, Kenai Fjords will at all years after 2016 have the greatest budget, due to its vulnerability cost of zero and low maintenance deficit. Though Padre Island faces the greatest threat of storms, due to its relatively low maintenance deficit and increasing number in visitors, it is the second most profitable. The curves for Cape Hatteras and Acadia are relatively similar, and happen to intersect. After 7.563 years, Cape Hatteras will become more profitable than Acadia. At all points on the graph, Olympic is by far the least profitable, due to its massive maintenance deficit and high threat of natural disaster.

Analyzing the Model:

The model seems reasonably accurate and fairly simple, though it takes into account a variety of factors, from inflation to lost visitors due to natural disasters. The fact that every park has a negative budget is reasonable, for the federal government itself is in a budget deficit and the NPS is a federal service. However, through private donors and government funding not accounted for by this model, the parks can continue to operate. This model was not meant to determine how much money each park would produce for the NPS, but how much must be invested into each to keep them operating. Thus, we could prioritize the parks and advise the NPS how to diversify its monies for the maximum benefits of its parks.

Since the visitor data was influenced directly by natural disasters determined earlier through the index of vulnerability, this model does carry some of the inherent disadvantages of such an index. As our vulnerability multipliers were somewhat arbitrary, so are these values. Moreover, some of our assumptions may not hold true over many decades. For example, inflation may drastically increase, the government may invest more in parks, or visitors may gain incentives to travel to parks. Therefore, there is room for error in the assumptions made. But the model is effective in that it takes advantage of financial statistics to provide a basic framework for ranking these national parks.

Conclusion:

Through our models representing the effect of changing sea levels on parks, their vulnerability to natural disasters, and the estimated budget for each park over the next decades, we can prioritize the five parks analyzed in the following order to the NPS: Kenai Fjords, Acadia, Cape Hatteras, Padre Island, and Olympic. Kenai Fjords costs less to maintain than the other parks, is increasing in visitors, faces little threat of disasters, and is increasing in area as sea levels change. Therefore, it is the wisest investment of the five. Padre Island, though it seems to be the second most financially sound park, has high safety risks with the greatest vulnerability score and is prone to great loss of area over the next few decades. Acadia and Cape Hatteras are similar in terms of profitability, but because Cape Hatteras will lose significant land area in the coming years, it is less lasting than Acadia. Finally, though Olympic will not face a threat from sea levels rising, its high vulnerability score and massive maintenance deficit makes it a hard upkeep for the National Parks Service.

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