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Creating an Interactive Visual Database of Piping Plovers (Charadrius melodus)

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Creating an Interactive Data Visualization of Piping Plovers (*Charadrius melodus*)

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Abstract

Piping plovers (*Charadrius melodus*) face many threats, substantially reducing their populations. Conservation strategies have included predator control and symbolic fencing, and complex records of plovers' reproductive success have been kept for many beaches. In creating an interactive visual database with data from Massachusetts, the data becomes more comprehensible and conclusions can be drawn on the implications of conservation techniques. This information can be used to influence decisions about future conservation efforts at other breeding locations.

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Introduction

Charadrius melodus, more commonly referred to as the piping plover, is a small shorebird found in various coastal systems across the North American continent (see Figure 1). Within the United States, there are two major subspecies; the *Charadrius melodus melodus* is the eastern/Atlantic coast breeding population while the *Charadrius melodus circumcinctus* refers to the population of piping plovers found in the Northern Great Plains region of the country (Miller et al. 2010). As a migratory species, piping plovers spend the colder months of September through March in southern states along the Gulf of Mexico, and migrate to the coastal regions of the Great Plains and New England for the breeding season.

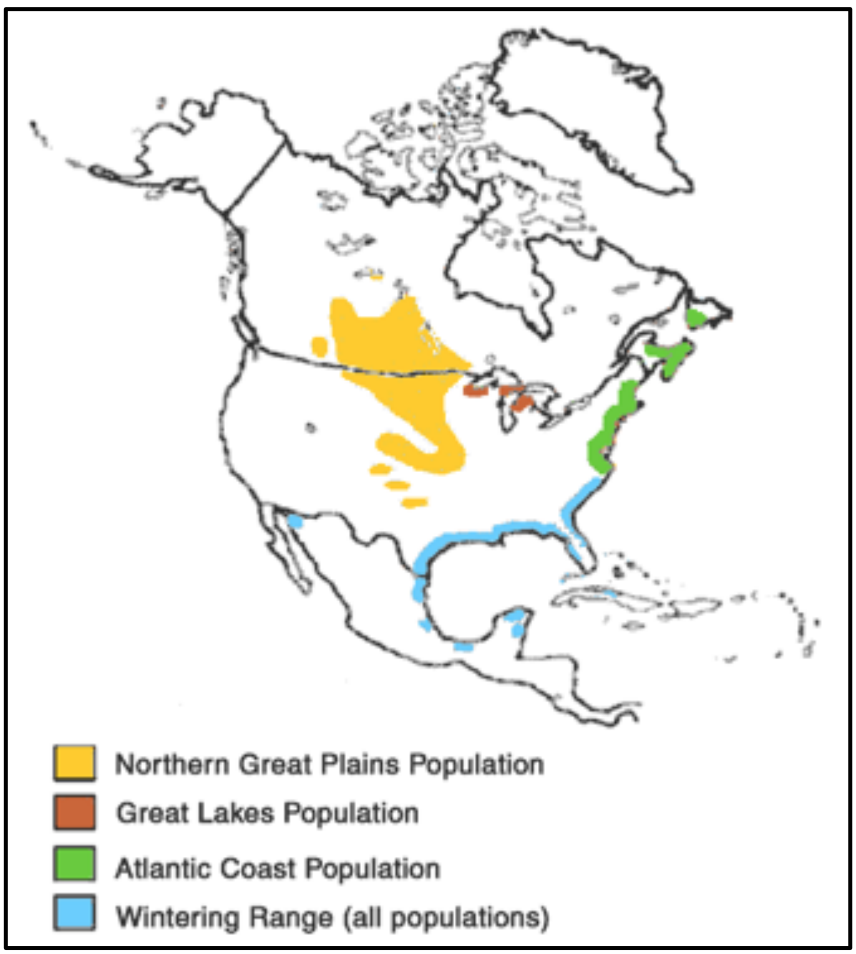

Figure 1- Piping plover distribution in North America (U.S. Fish and Wildlife Services, 2011)

For the purpose of this study, a focus was established on the eastern *Charadrius melodus melodus* subspecies, and particularly on those nesting in the Massachusetts region. In the Commonwealth of Massachusetts, the piping plover has been a protected species since 1986, and has been declared as a federally threatened species in the state. With increased management of the species, populations have subsequently increased across the state. However, the species is still below ideal population numbers in the state, and in other regions conservation efforts have yet to be as successful (Hecht et al. 1996). The total population for both subspecies is estimated to be at approximately 6,410 individuals (Massachusetts Division of Fisheries and Wildlife 2015). With such low numbers, many states, including Illinois, Indiana, Michigan, Minnesota, Nebraska, New York, New Jersey, Ohio, Pennsylvania, and Wisconsin, designated this species as endangered in 1986. In 2005, 475 total breeding pairs were recorded for the Atlantic coast subspecies, with most of those pairs breeding in Massachusetts (Massachusetts Division of Fisheries and Wildlife 2015). Therefore, if we are to increase the population of piping plovers, an ideal place to start the investigation is in the state with the most success. Understanding how efforts have worked in this state, as well as how they can be improved, has the potential to contribute valuable information to conservationists.

Appearance

At approximately 17 centimeters long, *Charadrius melodus* is a small, tan-colored shorebird species that feeds along the coastal sand and gravel beaches (Petersen & Meservey, 2003). The piping plover has a very specific plumage that stands as one of its best defense mechanisms. A distinguishing feature of the species is a white forehead, with the exception of a single black band across the forehead and between the eyes. They have a brown breast, sandy gray body, and white underside, which makes for exceptional camouflage in their sandy coastal environment (Figure 2). Males and females of the species are not easily identifiable by plumage, as female have a slightly duller, but not incredibly variant, plumage color. The bill is bright orange, with breeding males having a pronounced black tip and brighter color than females, aiding in the identification of the sex.

Breeding Behaviors

As a coastal species, piping plovers in Massachusetts are found in great numbers along the South Shore and on the beaches of Cape Cod (Petersen & Meservey, 2003). The breeding season for piping plovers begins in mid-April, although the males start claiming nesting territories as early as March. Males of the species arrive to the breeding grounds ahead of the females and immediately begin nest-scraping, or building a nest, to attract a mate. As a form of competition, the male with the most attractive nest and territory will have a far greater chance of attracting a mate than a male with a less than ideal territory, since a better nesting ground is a sign of fitness (Elliott-Smith and Haig, 2004). The species nest in open beach areas as well as in dune vegetation such as tall grasses (see Figures 2 and 3).

Figure 2- Piping plover nesting in dune vegetation (Maine Audubon, 2013)

Figure 3- Piping plover nesting in open beachfront (U.S. Fish and Wildlife Services, 2011)

The nests themselves are usually shallow scrapes in the sand, approximately 10 centimeters in length and 2 centimeters in depth, designed to blend in extremely well with the surrounding beach (U.S. Fish & Wildlife Service 2015). Males will often surround their nest with small stones and pebbles in an attempt to draw the attention of a potential mate (Elliott-Smith and Haig, 2004). Within a couple days of the female birds' arrival, breeding pairs have been established and distinguished territories have been claimed.

Once pairs have been established, breeding begins shortly thereafter. Under normal circumstances, a pair of piping plovers will produce a clutch of 4 eggs over the course of 4-6 days (U.S. Fish & Wildlife Service 2015). Once the eggs have been laid, the parent birds are defensive of their nest and the males, in particular, remain territorial. If a neighboring male is not paired, the male of the pair will increase his defense, specifically during copulation and egg-laying by the female plover, to avoid neighboring males attempting to mate with his female (Elliott-Smith and Haig, 2004). Both the male and female will incubate the eggs, as the eggs require constant incubation during the 28-day period. Within one day of hatching, piping plover young are capable of walking and soon begin foraging for their own food (U.S. Fish & Wildlife

Service 2015). A common foraging technique is known as "foot trembling", in which the bird will be observed to vibrate a single leg against the sand before pecking at the ground. This is most likely done in order to bring small invertebrates lying under the sand to the surface for easy consumption. Food sources of the piping plover include marine worms, crustaceans, insects, and other small marine animals (Elliott-Smith and Haig, 2004).

While the chicks are still brooding, parents will alternate between foraging for themselves and guarding their chicks while they forage. The males will maintain the territory using a behavior known as "parallel-run display" in which neighboring males will run back and forth from the nest to the shoreline with their necks stretched upwards and their breast feathers puffed. Young will fledge after 21-35 days, when they are able to fully care for themselves and are capable of flight. If successful in their first nesting attempt, pairs will rarely attempt a second brood, unless the first clutch of eggs or brood was completely unsuccessful. Plovers generally stop attempting to nest by late June, and rarely exhibit breeding behaviors in July. In Massachusetts, piping plovers depart from the breeding grounds by late August and head south, returning to the beaches along the Gulf of Mexico or the southern coast of the Atlantic Ocean by mid September. These birds are sometimes seen traveling in large species-specific flocks as they migrate, but a smaller flock of approximately 40 individuals is more common (Elliott-Smith and Haig, 2004).

Pressures Against Population Maintenance and Growth

Piping plovers are facing a number of threats in their ongoing struggle to maintain sufficient population numbers. Off-road vehicles (ORVs) and other human disturbances, erosion and habitat loss, and predation all result in a decrease in piping plover nest success (Melvin, 1994). By influencing the plovers' ability to mate, nest, and raise their young to adulthood, these threats hinder the species from successfully breeding, and overall contribute to the below-ideal population size seen in the species nationally.

Habitat loss is of great concern to maintaining piping plover populations. As the population of people living in a given beach communities increases, so does their need for more land. As a result, a substantial amount of beach habitat is lost to human development and infrastructure. Piping plovers require separate nesting areas, and will not nest in another individual's territory (Elliott-Smith and Haig, 2004). Therefore, sufficient habitat size is important to the success of a given population. There are several data supporting the idea that beach restoration efforts are actually hindering breeding. Research has been conducted on the effect of increased dune vegetation plantings that suggests beach restoration efforts may cause a decrease in snowy plover breeding by affecting site occupancy. Dune debris was also found to negatively affect plover success by decreasing occupancy, affecting foraging success, and overall deterring plovers from nesting. Such issues can also be thought to affect piping plovers, whose nesting behaviors are similar to those of the snowy plover (Webber, Heath, & Fischer, 2013).

Additionally, piping plovers face a loss of habitat as the result of erosion and washout as a result of storms. Particularly in the breeding grounds on Cape Cod, storms continue to drastically reduce beachfront, such as Sandy Neck Beach Park, a site of focus for this project, as it is a popular breeding ground for piping plovers. Sudden storms, such as nor'easters and hurricanes, not only destroy beachfront, but can also drown nests and young if breeding has already occurred. In this case, an entire season's worth of breeding in a particular area can be erased with a single storm (Talley 2003). However, recent studies have found data supporting the theory that washouts, or sudden erosions of soft soil as the result of heavy flooding, may actually provide more habitat for future generations by clearing the terrain to provide better nesting sites.

Therefore, washouts may in fact be ultimately beneficial, and the environment created from them may be highly sought after (Leal et al. 2013).

Piping plovers face difficulties resulting from other human interactions, in the form of both off-road vehicle (ORV) and foot traffic. If nests are not marked soon enough by conservation officials, or areas of beachfront are not closed off to ORV activities once nesting occurs, the vehicles may crush the nest, eggs, or piping plover young. Additionally, piping plover juveniles may become trapped in the deep tracks left behind by the vehicles and, unable to climb out, will eventually die due to exposure (Melvin, 1994). Human foot traffic also causes adverse effects, as people may not heed to nesting warnings, and will walk over nests as they blend so well with the surrounding environment. Furthermore, research has shown that male plovers see humans as a threat, and will abandon incubating the nest in order to display for the intruders. Piping plovers are known in particular for their use of the "broken wing display", a type of distraction display, in which they feign a broken wing in order to draw attention to themselves and away from their chicks for the duration of the nesting period (Gochfeld, 1984). In implementing these display tactics, plovers not only expend valuable energy, but also waste time that could be spent looking for food and consequently spend more time away from the nest, leaving their young vulnerable to predators (Burger, 1991).

A final threat hindering piping plover populations, and one faced by most species, is predation. Animals such as the red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), American crow (*Corvus brachyrhynchos*), and various species of gull such as the American herring gull (*Larus smithsonianus*) and ring-billed gull (*Larus delawarensis)* prey upon piping plovers as a main food source during breeding season, where the food source is readily available (Ivan and Murphy 2005). These species often experience population inflation due to the activities of humans; by feeding on trash other resource subsidies left by humans, more predators can be supported in a given area, and eventually shift to feeding on animals such as the piping plover. Additionally, these subsidies can act as an attractant, luring more predators to a beachfront as people leave their trash behind. Once the predators are aware of a new food source in the form of piping plover eggs and young, they often change their eating habits (Newsome, Dellinger, Pavey, Ripple, Shores, Wirsing, & Dickman, 2014).

Conservation Techniques

With such a variety of hazards being faced by the *Charadrius melodus,* an equally large variety of solutions have been tried and implemented in an attempt to protect the species from further decline. A commonly used tactic in protecting nesting grounds is to implement "symbolic fencing" (Beaulieu et al. 2014). In symbolic fencing, the fence itself provides no actual protection to the species, but serves as visual barrier, hindering accidental human traffic across the breeding grounds. Another type of fencing used is known as exclusion fencing. In exclusion fencing, stronger, more durable welded wire fencing is used to physically protect the nest from predators. In some cases, the fencing only covers the four sides, providing protection from predators such as raccoons and skunks, while in others there is a cover to protect from overhead predation by gulls, owls, and other avian species. There is much debate as to how effective exclusion fencing is in increasing piping plover population numbers. Many suggest that nest exclosures actually "advertise" the nest to predators by eliminating the natural camouflage, effectively causing an opposite effect of that which was intended (Beaulieu et al. 2014). A last technique implemented by conservation officials is predator control. By lowering the populations of predators through controlled shootings and other removal methods, the effects of predation are reduced. This is not considered a long-term solution to the problem, as conservationists are weary of protecting one species at the cost of another, as in the case of regulated coyote killings to save livestock (Edvenson, 1995). Herein lies the ultimate question: What is the best, most effective, and most cost-efficient method, or methods, with which to increase populations of piping plovers while causing the least harm to the rest of the environment?

NetLogo and Agent-Based Modeling

Growing in popularity is the idea of Agent-Based Modeling, or ABMs, as a means by which to predict the behaviors of a given population of individuals based on a predetermined set of characteristics and environmental factors. The main goal of ABM is to search for insight into the collective behavior of agents obeying simple rules, typically in natural systems. This differs slightly from Multi-Agent Simulation (MAS), in which agents are designed to solve a specific practical or engineering problem. Agent-Based Modeling provides a means by which to create a computer-generated environment, where individuals within the simulation act independently of each other while following basic rules established to coincide with reality (Kornhauser et al. 2004). For example, a bird agent will have rules designated to it so that it will only "breed" during a certain time of year. Created in 1999 by Dr. Uri Wilensky, one such frequently used ABM program is called NetLogo, and will be the focus of this project (Wilensky 1999).

NetLogo was designed by Dr. Wilensky as a means by which to make ABM accessible to a wide range of audiences; all programmers from high school-level to advanced computer experts can use this program in order to model system-wide phenomena in such fields as psychology, physics, chemistry, biology, and economics. Run on the computer coding language Java, NetLogo is a free program intended to give ABM access to anyone who desires it, in order to stimulate an interest in Agent-Based Modeling and computer programming (Gammack 2015).

NetLogo, and other such programs, are so useful because they allow the user to test a variety of hypotheses without the cost of conducting actual trials in the real world. In the realm of biological simulations, ABM can provide a means by which to understand how a given system works, as well as how changing certain factors can affect the population as a whole. One simulation, completed by K. Ringelman, tested the theory that conservation efforts to promote "nest clustering" in duck populations actually trap the fowl, providing easier access for predators (Ringelman, 2014). Ringelman coded the "smart" predators, foxes and skunks, with certain "foraging" behaviors, meaning that the agents moved around the environment in a method meant to find prey as efficiently as possible, with a certain degree of spatial memory. The animals would return to their dens at the end of the day, and would pick up foraging the following day, much like predators act in reality. If a predator agent was successful in finding prey, it would continue to forage in the same area, as would a live animal upon discovering an area dense in prey. Ringelman concluded that as the number of "smart predators" increased, clustering became a less advisable nesting technique for the ducks (Ringelman, 2014). In the case of this particular study, a biological simulation was useful because it was able to provide insight into a commonly implemented conservation technique, concluding when it is most advisable to use the technique versus when it may actually harm the species in question due to increased predation.

Interactive Visual Databases

In the case of this project, a program was implemented in NetLogo in order to create a meaningful and interactive database through which the user may view relevant information on a more visual interface. The previous organization of the data in question did not lend itself well to agent based modeling: it was disorganized, irregular, and difficult to interpret. If this data was ever to be utilized in a simulation, the first step needed to be to create a way for people to visualize and make sense of the data, before using that data to educate a biological simulation. Data supplied by the Massachusetts Division of Fisheries and Wildlife was at the core of this program, with the user being able to retrieve specific data points through the interactive database interface created. In particular, data on nest exclosures, predator control, and egg/chick mortality across multiple sites in the Massachusetts area were used within the program, allowing the user to retrieve useful information from across the state. This program was designed with the hope that future projects will be able to utilize this re-organized database system to infer trends in the data and suggest possible conservation efforts for the future.

A new method of conveying data, which shall be the focus of this project, is the idea of "interactive data visualization". Interactive data visualizations are representations of information that allow the user to interact with the data provided in a more meaningful and useful fashion. These visualizations allow the user to interact with the environment in which the data are presented, and through exploration of the data, the user is capable of making their own conclusions from the data. In the case of the piping plover data provided by the Division of Fisheries and Wildlife, multiple individual data sets are available, but in a way that does not make for easy comparison. In implementing the idea of interactive data visualizations, these various datasets were combined in a way that lets the average computer user access the data and draw meaningful conclusions and comparisons from the data.

Interactive data visualizations are useful across various fields of study, from ecology to linguistics. One great example of interactive data visualization is the "Languages of the World" interactive produced using DensityDesign, a type of data visualization program. This visualization allows the user to not only view the 2,678 different languages of the world, but interact with the world map to explore related language families, see where languages are spoken, and learn what words are borrowed from other languages and how that might have occurred (Girelli et al. 2014). The user can click within the environment of the visualization in order to gain more information, see additional data, and explore questions they may have.

In allowing the user to have interaction with and explore the data sets, they have the opportunity to learn in a new way, and come to conclusions using their own intuition, which can be extremely useful when there are unanswered questions in the scientific community. Other key research has been completed by Pham et al. in examining the use of a "Diversity Map" which "facilitates the visual inspection of the distribution, abundance, and covariates of large multi data sets using an interactive web-based visual interface" with regards to moth populations (Pham et al. 2011). In completing this research, it is the hope of these ecologists that further collaboration among scientists will expand this program and make ecological interactive data visualization a new and useful tool. If successful, this type of data visualization, and others like it, may be implemented for the purpose of identifying important ecological patterns and trends in biological systems.

Pham completed further studies in 2013, in which he and his team presented *Ecological Distributions and Trends Explorer (EcoDATE),* a web-based visual tool used for exploratory analysis of long-term ecological data. In this program, the user is able to review long-term data in the form of charts, graphs, and other useful visual formats. The user can view multiple histograms and line charts and filter data based on the desired focus of study, allowing them to direct their analysis at as specific or broad of a range as wanted. In doing so, the user is capable of easily finding visual trends in the data, educating them and impacting the hypotheses they wish to further explore. For example, an ecologist exploring forest structure data can view data on several species in the area of interest, construct charts based on the data, produce summary data as educated by the charts, and gain insight into the given area of study.

An important design feature of *EcoDATE* is its "user-centered design", in which a team of ecologists was brought into the design process in order to educate the builders on what the needs and limitations were of the intended user. In doing so, the program was designed to give ecologists the most useful data interpretations in the most user-friendly format obtainable (Pham, Jones, Metoyer, Swanson and Pabst 2013).

Goals

Interactive data visualization is a great resource for researchers and amateurs alike. While the programs can be used to gain insight into ecological patterns and animal behaviors, it is also a great way to make once overwhelming data accessible to wildlife management and conservationists. In creating an interactive data visualization with the available piping plover data, it was the goal of this project to both aid in the research of state ornithologists and also to make piping plover data more comprehensible, interactive, and accessible to the typical citizen by organizing and displaying the data in a more cohesive manner. In doing so, researchers can easily analyze conservation techniques, and new hypotheses can be explored.

Overall, the intent of this project was to compile and organize data provided by the Massachusetts Division of Fisheries and Wildlife on the 2015 breeding season, before using it within a visual database for exploratory analysis. We selected the specific data to include based on its relevance to the topic of nest success, including such topics of interest as number of eggs laid, chicks fledged, predation and overall nest success. The data was planned to be time oriented, allowing the user to visually observe the nesting behaviors of the plovers throughout the season, as well as to view overall trends via summary graphs.

Once the data was organized into the visual database, preliminary analyses were conducted to not only test the potential of the program, but also to gain insight into piping plover populations and the success of current conservation efforts. Based on these preliminary analyses, hypotheses were formulated and further analyzed using tools of the interactive visual database. In doing so, it was the goal to identify key issues that could be further studied through agent based modeling in the future.

Methods/Design

Initially, the desire for this project was to create a biological simulation in order to model the behavior of the species and predict future successes with changes to conservation efforts. However, once we received the data from MassWildlife, it was determined that the first step would be to first organize the data into a way that could be readily interpreted and hypothesized on. Therefore, it was concluded that a visual database would be built using the data provided, with the intent of using this information and the insight gained from exploratory analysis to build a biological agent-based modeling simulation in the future.

Before creating the Netlogo program, a file was compiled of all the data of interest. Using this data, 15 beaches of interest along the coast of Cape Cod and the Islands, the North Shore, and the South Shore were selected for study, and the data for these sites was compiled into an individual file. While data for a large number of beaches exists, we chose to focus on 15 beaches of interest, due to time constraints. These 15 files were selected based on their differing uses of predator control, size, location, and the detail of data available for the. This Excel file was then converted to a single csv file, a type of file that can be read by Netlogo; the entirety of the data was transferred into this single file. The data in each of these files included: latitude and longitude of each nest, number of eggs laid at each nest, number of chicks fledged from each nest, date the clutch was completed, the date each nest hatched or failed, the number of eggs lost (if any), the date of egg loss, and predation activity. Dates were often provided in ranges, as conservationists do not monitor the nests daily. Therefore, the median date was used and converted to Julian date. In some instances, no date was provided for when the clutch was completed; in these instances a backcount was conducted from the date when the nest hatched, accounting for the average 28 day long incubation period for a piping plover egg. In other instances, a range of values was given for the number of eggs laid and the number of chicks fledged. In order to determine an actual value, the average for the entire site was calculated and used in place of the missing data. If no data was available to help educate on any of these aforementioned problems, the data for that nest was removed.

Netlogo was implemented for this project to create an interactive visual database, as opposed to the typical agent based modeling application it is most well known for. To create this database, code was written to store the csv file as a list of information; each row of data, indicative of a particular nesting attempt, is stored as a line of data in the program. Upon initial setup, a map of the coast of Massachusetts is generated from a file provided by the user. In order to guarantee correct placement of latitude and longitude points, a formula is implemented to translate latitude and longitude points into x and y coordinates, using data input on the maximum and minimum latitude and longitude points for the given image. These points were determined using Google Earth © to mark the corner points of an area before capturing an image of the area and documenting the latitude and longitude of the corners. The latitude and longitude of the corner points were necessary in order to determine the maximum and minimum latitude and longitude included in the image, so that all points would then be included within the image. The formula then used this information in order to determine the overall size of the image and translate these latitude and longitudes into x and y coordinates. Then, all latitude and longitude points were plotted using the corner points as reference. A small circle is plotted in the location of each of the beach sites in order for the user to understand the possible sites for study.

Once the user has decided on a beach to study, they can use the Image-chooser drop down menu to select a beach for study. From here, an image of the chosen beach is generated from a file. Using the slider provided on the interface, the user is able to go to a certain date and view the populations present at that time. Each successful nest is shown as a yellow plant, each failed nest as a red plant, each hatched egg as a white sphere, each failed egg as a black sphere, and each plover as a brown bird agent icon. As the user manipulates the visualization, a chart plots the population numbers of the plovers in the various stages of development versus time. The program also outputs the number of different predator control efforts implemented at the given beach, such as toxic eggs, coyote removals, box traps, and exclosures. For more information on the design of the program, please refer to Appendix I.

Results

In creating this interactive visual database, the data compiled by the Massachusetts Division of Fisheries and Wildlife was transformed into a visualization that can be manipulated in order to gain new insights into piping plover nest success across Massachusetts beaches. A simple user interface was created, and several outputs were made in order for the user to draw conclusions through the data calculations, as well as through the visual output.

Resolving Issues in Data Entry

In various instances, missing data required using either estimates or averages in order to fill in the blank cells. Unfortunately, there were also several cases in which not enough data existed to make an educated guess regarding the missing pieces, and therefore the entire line of data for a given nest had to be removed from the data set. However, this was not done very often, and rarely more than once per beach. Therefore, the summary data for a given beach, as well as the conclusions drawn from certain patterns in the data, can be thought to be relatively unchanged with these deletions.

User Interface

In order to make the interface as simple and easy to use as possible, the goal was to limit the amount of user input required, while maximizing output and still allowing for user manipulation. The interface is shown in Figure 4 with "Map" selected to give the user a brief overview of each beach, so that they may be more informed before selecting a beach to further study. Additionally, each input and output created is shown.

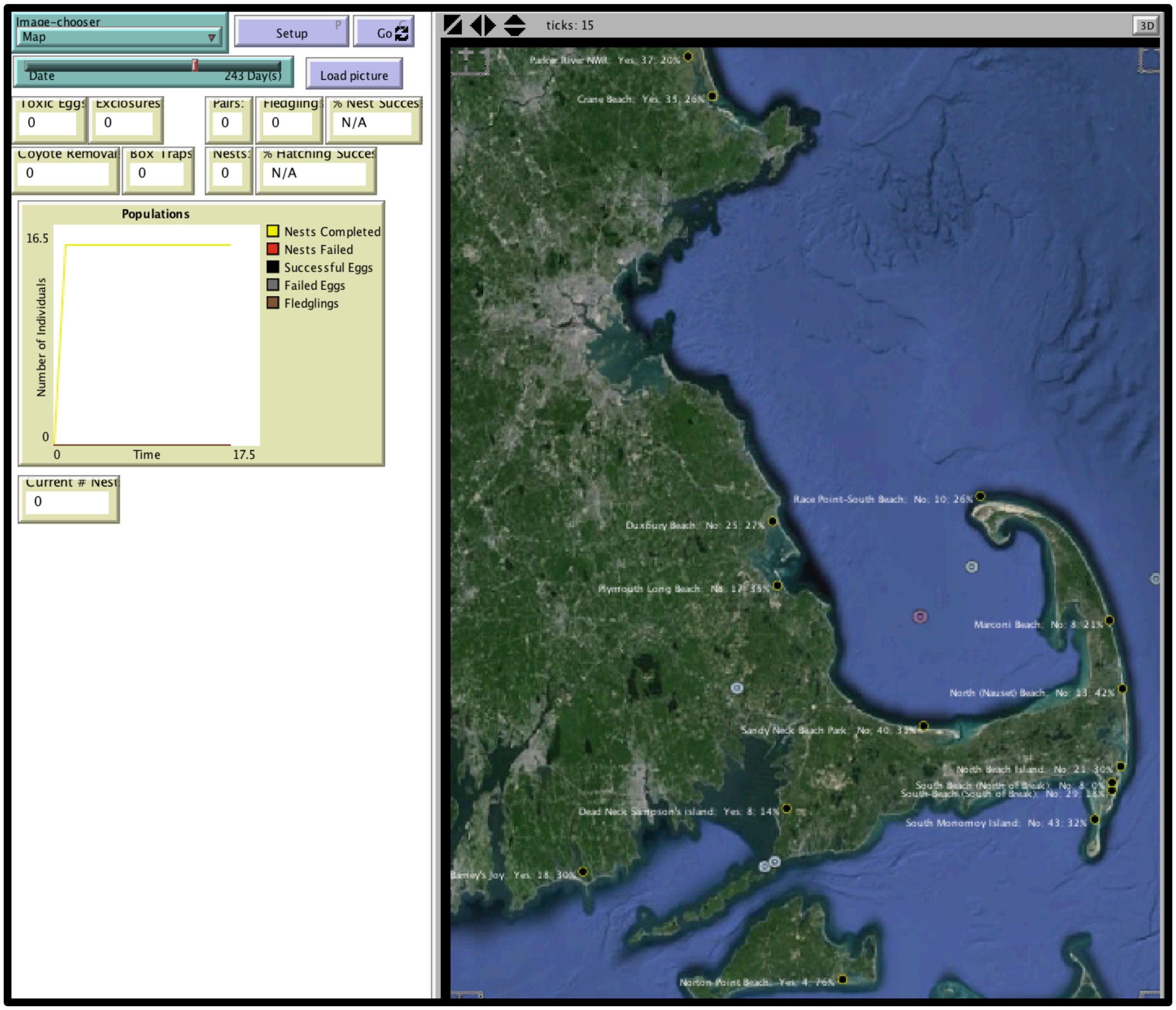

Figure 4- Complete user interface and map of the coast of Massachusetts provided by data output in program
Each beach is marked with a black point and is labeled with the following information: name, use of predator control, number of breeding pairs, and percent hatching success. User input (Image-chooser, Date-slider) and data output (predator control output, population trackers, graph) is also shown.

Another visualization provided by this program is the main visualization of the beach. The program loads an image for any given beach in the directory, and agents are generated on that image in the corresponding latitude and longitude (see Figure 5). This provides a great piece of data output and visualization, as the user can see at a glance if techniques were implemented at a site (using the data output), and with what degree of success.

Figure 5- Visualization rendered by program of Sandy Neck Beach Park; Barnstable, MA
Agents generated on this image include hatched nests (yellow plant), failed nests (red plant), successful eggs (white sphere), failed eggs (black sphere) and fledglings (brown birds). Inset shows an enlarged section of the beach.

As can be seen above in Figure 5, the agents created a great representation of the activity on a given beach. For example, each nest created is shown in yellow, while those that fail become red.

In order to allow the correct image and data to be generated, a user input was required: a drop-down chooser for the image and data (See Figure 6). The drop down menu is responsible for allowing the user to select the image and which beach they want to study, using this input to generate a list of data for that particular beach. Initially, the "Setup" button is implemented in order to load all the data from the csv file titled "allbeachdata.csv" into the database.

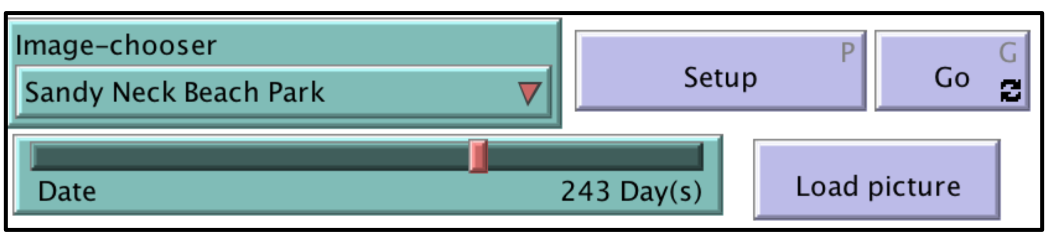

Figure 6- User Input controls for NetLogo program.
Input controls include: Image-chooser to select beach, "Setup", "Load picture", and "Go" buttons, and a slider to control the data being viewed.

Once the data are loaded and the beach is selected, the data can be plotted onto the generated image using the "Load picture" button. This loads the image for the particular beach and creates a subset of the data for just that beach. Initially, agents are created for nests, eggs, fledglings, but are "hidden" to the user. Once the button "Go" is toggled, the agents are made visible to the user when the correct date as specified by the beach data subset is reached. In order to achieve this, a slider was created, spanning from 1 to 365 days (Jan 1 to Dec 31). As the user moves the slider, it reflects the date in the program. When a given date is reached, agents appear in accordance with their data. For example, nests and eggs stay hidden until the date in the program is greater than or equal to the date in the file specified as the nestHatched date. Therefore, the user only sees a given agent if it was present on the beach at that particular date. This feature created a great user interface option, as the user has the ability to go back and forth in time and view the beach as it would have appeared on the given day, complete with nests, eggs, fledglings, and predator controls.

Data Output

In order for the user to gain the insight required of a true interactive visual database, the data output provided by the program needed to be clear, accurate, and informative. To achieve this, it was decided to incorporate graphs and numerical output into the final design. Using the date slider feature implemented in the user interface, a graph was created to plot the populations of each age group present at the given date (see Figure 7). If the user slowly pulls the date slider from beginning to end, a plot is created which tracks the populations over the entire season. If the user goes backwards, the graph erases all previous data and re-plots starting at the date specified on the slider.

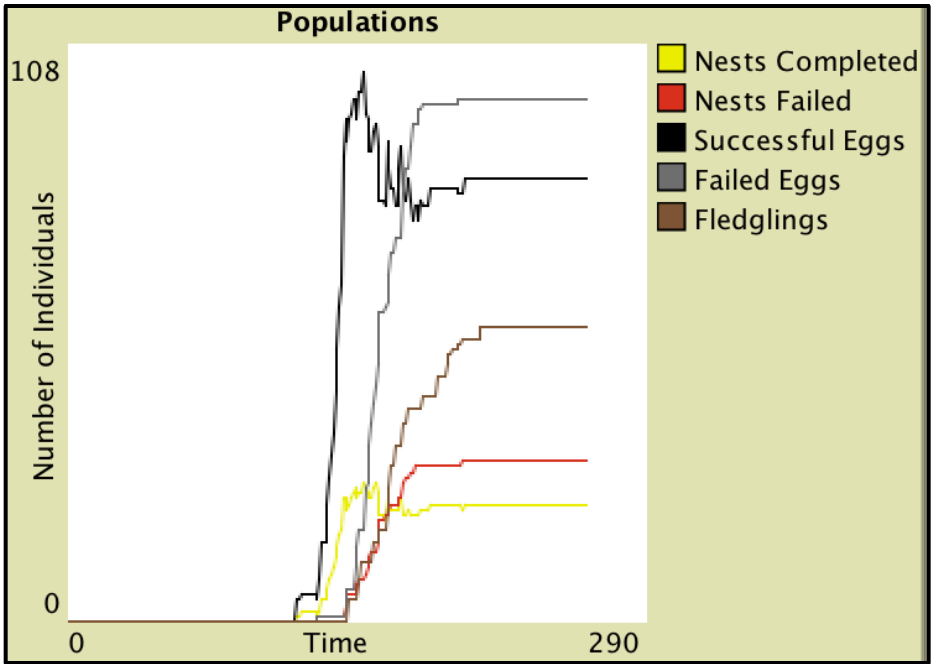

Figure 7- Plot output of agent populations (Sandy Neck Beach Park)

The population numbers of each agent are plotted against time, and can move back and forth with the manipulation of the date slider.

This plot seen above in Figure 6 keeps a running total of the number of completed nests, failed nests, successful eggs, failed eggs, and fledglings to be produced at the particular beach site.

In addition to the plot, numerical outputs are provided, reflecting the number of uses of various predator control techniques at the given location. These numbers are generated at the beginning of the program when the user loads a particular beach, and provide a quick overview of some of the conservation techniques used at the particular beach. It was a main goal to provide valuable information on conservation techniques, and this output provides a method for doing so (See Figure 8).

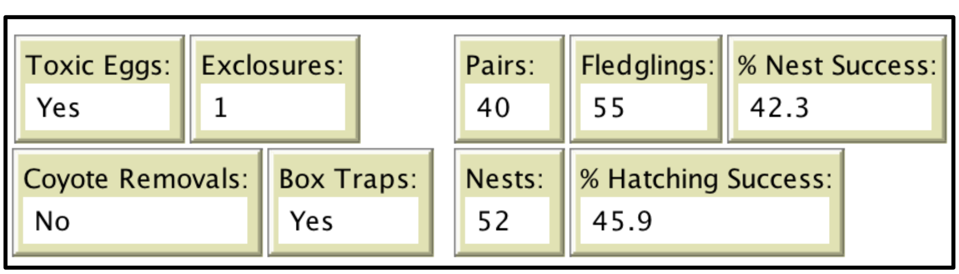

Figure 8- Numerical output data provided by program (data for Sandy Neck Beach Park)
Output values include the use of predator control, exclosures, number of pairs, number of nests, number of fledglings, percent nest success (percent of nests producing at least one hatchling), and percent hatching success (percent of eggs that hatch overall on that beach)

Overview of Beach Data Rendered from Database

In order to conduct all investigations and tests for hypothesis testing, a large quantity of data for each beach needed to be available. Below is a summary of all data compiled and available for study of a particular beach as a result of the construction of the database as well as the re-organization of the data files.

Beach	Latitude	Longitude	First Clutch Completion Date	Number of Nests	Number of Pairs	Number of Fledglings	% Hatching Success	% Nest Success	Predator Control Used	Exclosures Used
Barney's Joy	41.511771	-71.014762	122	24	18	28	46.8%	54.2%	Toxic Eggs	0
Crane Beach	42.685461	-70.756247	122	45	25	43	67.5%	64.4%	Toxic Eggs	1
Dead Neck Sampson's Island	41.607332	-70.607332	122	16	8	6	34.0%	44.4%	Toxic Eggs	0
Duxbury Beach	42.04177	-70.635591	118	28	25	30	68.5%	78.6%	Toxic Eggs	0
Marconi Beach	41.891773	-69.961131	131	15	8	10	35.4%	33.3%	Toxic Eggs	2
North (Nauset) Beach	41.788456	-69.935298	129	14	13	23	52.7%	50.0%	Toxic Eggs	0
North Beach Island	41.670861	-69.938811	133	21	21	19	63.7%	57.1%	Toxic Eggs	0
Norton Point Beach	41.348181	-70.495257	140	5	4	12	100.0%	80.0%	Toxic Eggs; Box trap	4
Parker River NWR	42.745474	-70.804741	115	65	37	45	30.6%	29.2%	Toxic Eggs; Coyote Removal	0
Plymouth Long Beach	41.944693	-70.625583	119	23	17	32	56.7%	60.9%	None	1
Race Point-South Beach	42.079942	-70.219717	129	18	10	18	40.3%	38.9%	Toxic Eggs	5
Sandy Neck Beach Park	41.732075	-70.333093	113	52	40	55	45.9%	42.3%	None	1
South Beach (North of Break)	41.646486	-69.956109	127	17	37	30	21.4%	17.6%	None	0
South Beach (South of Break)	41.634695	-69.956337	130	36	29	24	47.1%	44.4%	None	0
South Monomoy Island	41.59083	-69.99056	115	49	43	58	57.1%	71.4%	None	0

Table 1- Data compiled from each beach using the interactive database
All the data that can be collected exclusively using the database, including beach name, latitude and longitude, clutch completion date, number of nests, number of pairs, number of fledglings, percent hatching success, percent nest success, predator control use, and exclosure use

Table 1 displays all of the data that can be gathered about a given beach when using the database outputs. In addition to the data shown, other information can be concluded using these data to compute averages.

Hypothesis Testing- Predator Control Effectiveness

In order to determine the effectiveness of the program, and to gain insight into the success of predator control, a series of trials were run. In these trials, the program was implemented to determine the percent hatching success, mean fledglings per pair, and percent nest success for predator control beaches and non-predator control beaches. Predator control beaches were defined as those implementing toxic eggs, coyote removals, and box traps. In these techniques, toxic eggs are used to deter predators from eating actual plover eggs, poisoning them in the process. Coyote removals describe the process by which a coyote is removed via targeted hunt, while box traps refer to trapping and re-homing smaller predators. One of the data output values provided by the program is a percentage of hatched eggs compared to the total number of eggs produced from the beach (percent hatching success), providing easy analysis. An additional data output is the percent nest success, or the percent of nests that produce hatchlings when compared to all nests. The average number of fledglings per pair was computed using the raw data from the compiled csv file.

Averages for beaches either using or not using predator control were computed using the output data for each beach. These values were then used to create a chart (See Figures 9, 10, 11). The H_0 being examined through these trials was as follows: There is no significant difference in the given parameter of interest at beaches where predator control was implemented compared to those at beaches where it was not implemented. Three separate t tests were conducted in order to determine the significance between the two types of beaches with percent hatching success, mean fledglings per pair, and percent nest success. These three parameters were selected for study because they reflect accurately on the success of the site. Percent nest success demonstrates the affluence with which birds are able to nest and produce eggs, while percent-hatching success reflects on the safety of the beach in order to raise an egg to hatching. Mean fledgling per pair reflects on the success of a given pair, and how easy it is for them to raise multiple young in an environment.

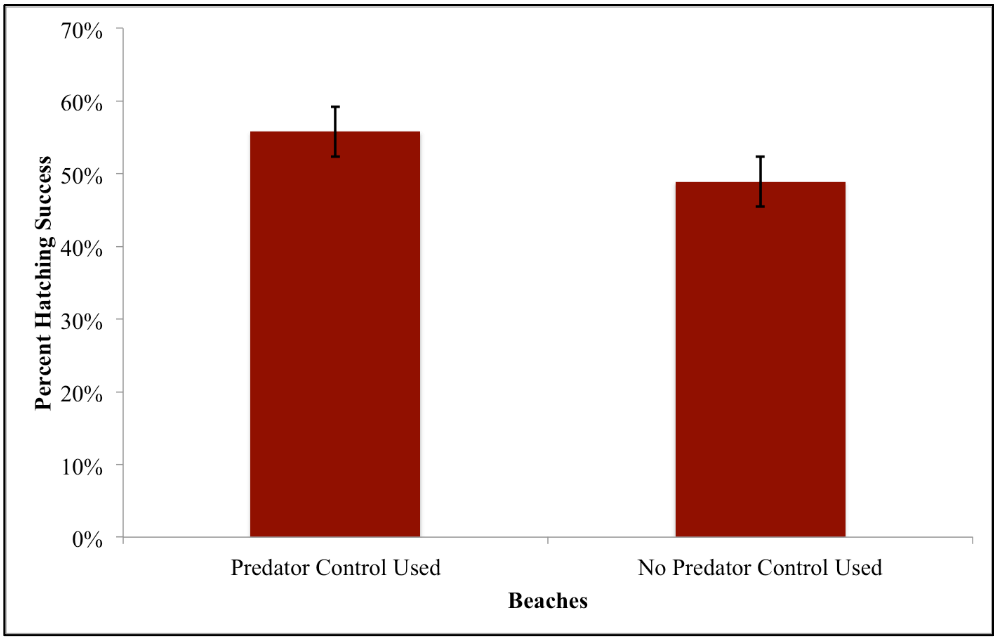

Figure 9- Chart comparing mean hatching success of nests at beaches either using or not using predator control
No significant difference was observed between groups (T-test: p = 0. 757)

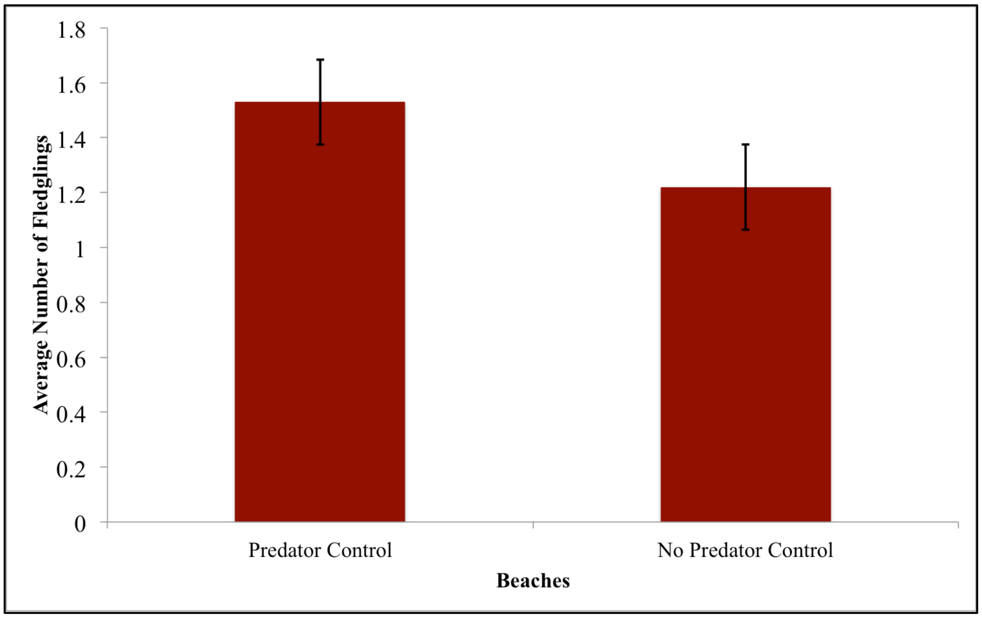

Figure 10- Chart comparing mean fledglings per pair at beaches using and not using predator control
No significant difference was observed between groups (T-test: p = 0. 256)

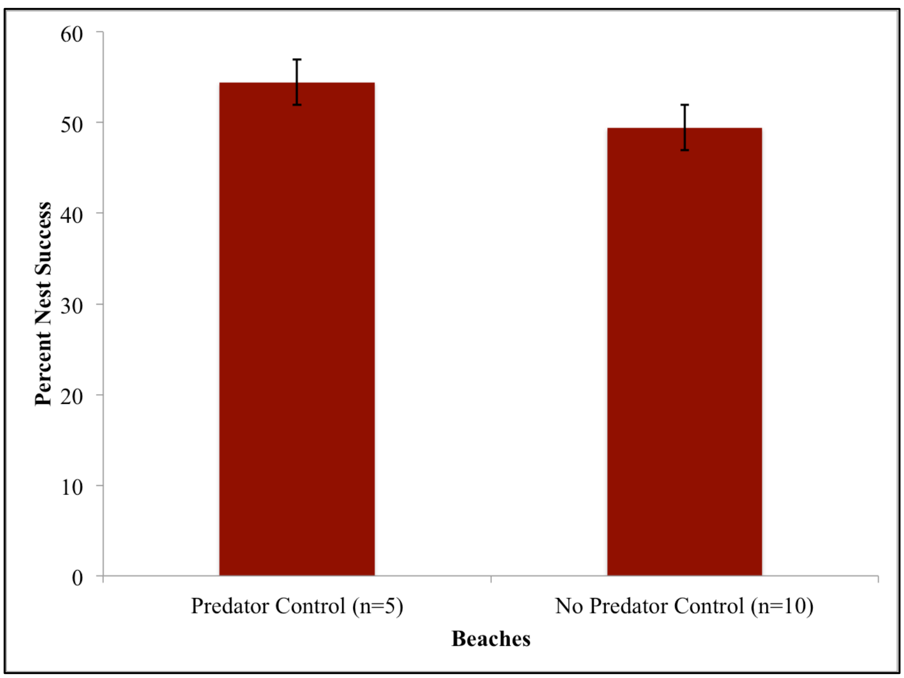

Figure 11- Chart comparing nest success at beaches using and not using predator control
No significant difference was observed between groups (T-test: p = 0. 994)

In order to determine the significance of the results seen in Figures 9, 10, and 11, a series of two-tailed T test were conducted, with no significant difference observed in any case (Figure 9: t_4=0.33289, P = 0.757; Figure 10: t_4= 1.3246, P = 0.256; Figure 11: t_4= 0.00837, P = 0.994).

Hypothesis Testing- Location of Selection

In the aim of further exploring the trends in success at different beaches, I wanted to investigate how location affected the success of a beach. First, the mean nest and hatching success of each beach were compared based on the latitude of the beach. This was done in order to observe if any trends exist between success and the location of the site.

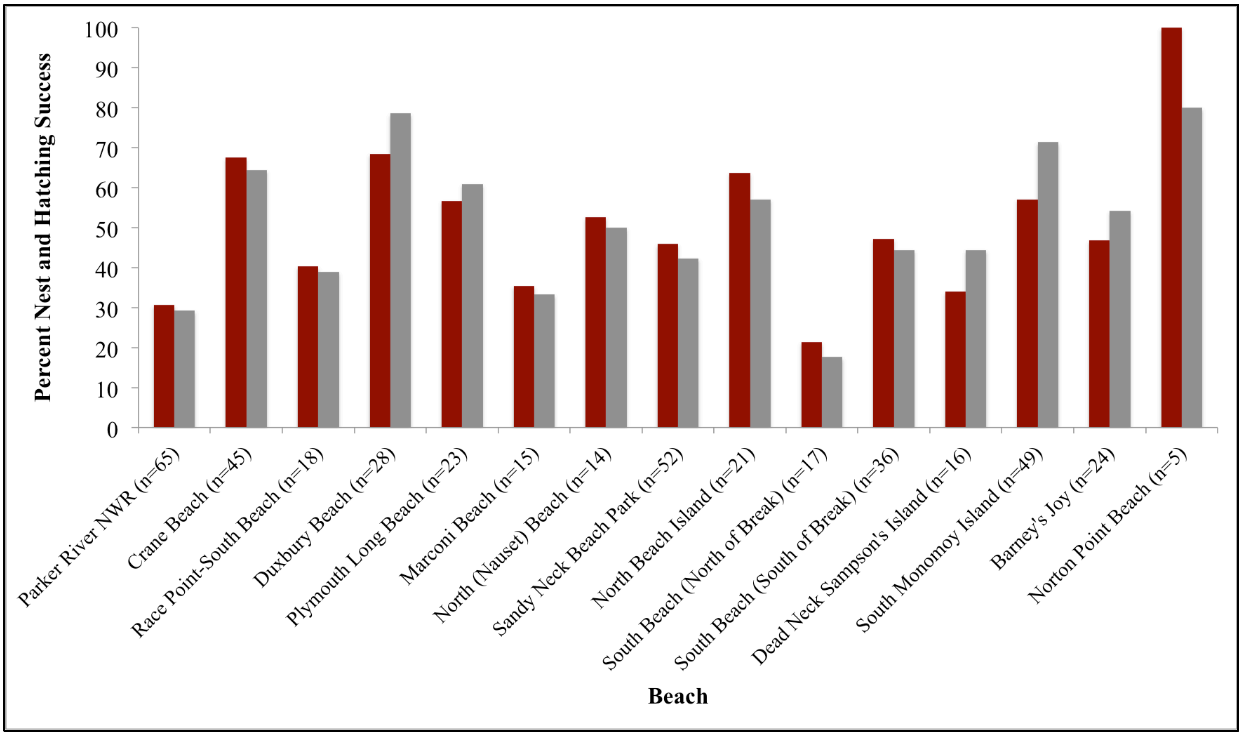

Figure 12- Graph showing the mean nest and hatching success for each beach
Beaches are arranged in order of northern-most location to southern-most location based on latitude. Red bar represents percent mean hatching success; gray bar represents percent mean nest success. Correlation p-value for hatching success versus latitude = 0.524; correlation p-value for nest success versus latitude = 0.554

A graph was created to observe any trends in the hatching and nest success when compared to the location of each beach. Each set of red and grey bars represents the hatching and nest successes of a beach, with the name of the beach and the n value shown below. The beaches are arranged on the graph so that the northern-most beach, Parker River NWR, is farthest to the left, while the southern-most beach, Norton Point, is to the right.

To continue investigation of location, the sites were next analyzed to see if there appeared to be any type of preference for location of nesting within a specific site. In order to do so, three sites were viewed at multiple times throughout the breeding season in order to gauge if any type of "clustering" appeared.

Figure 13- South Beach (South of Break) at day 139 (left) and day 230 (right)

Figure 14- Marconi Beach at day 136 (left) and day 221 (right)

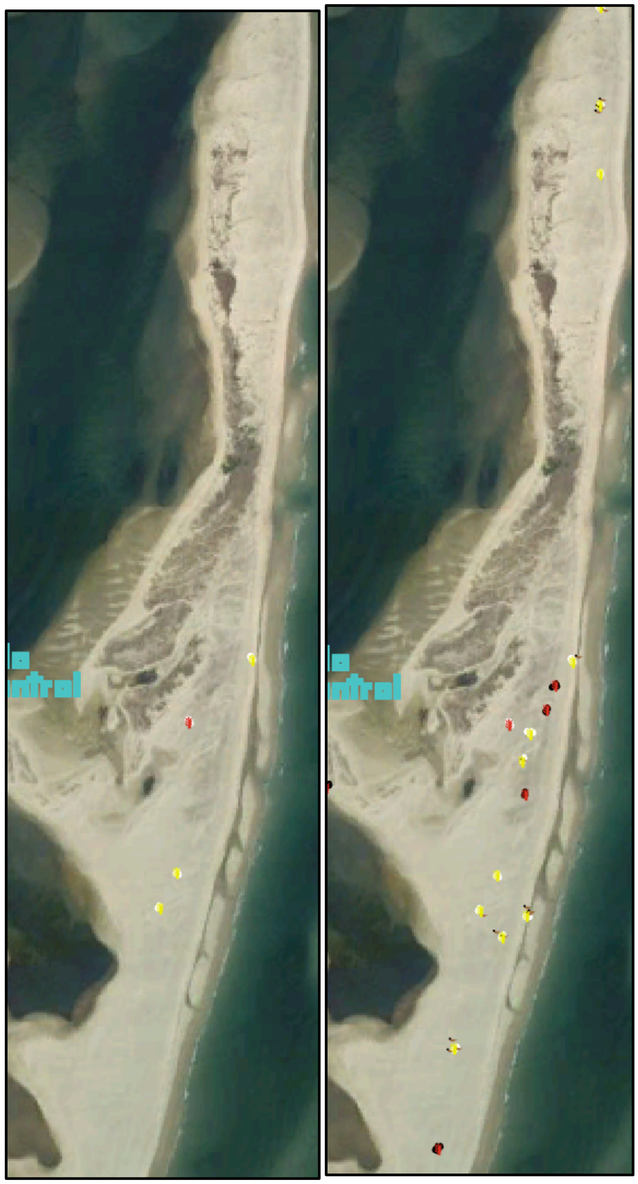

Figure 15- North Beach Island at day 131 (left) and day 224 (right)

In Figures 13-15 above, South Beach (South of Break), Marconi Beach, and North Beach Island were all observed at two different times during the breeding season. In the first image, the beach was observed early in the season, when 4-8 nests had been established. In the second image, each beach was observed once most nests had been established. No clustering was observed at South Beach (South of Break), but clustering was observed at Marconi Beach and North Beach Island.

Hypothesis Testing- Time of Selection

In order to further test the program, as well as to gain more insight into piping plover behavior and success, a series of trials were conducted in order to determine the average first arrival time for piping plovers at the various beaches. It was noted that the arrival time differed at almost each site, varying from an average value of 121 to 134, with the earliest arrival date estimated at day 97, and the latest at day 152. These data were then compared to the hatching and nest successes calculated at those sites in order to determine if there was any significance between arrival time and success at a given beach. The hypothesis being tested was as follows: H_0= There is no significant difference in hatching and nest success based on mean arrival date at a beach.

In order to determine if any true trends existed, linear regressions were created in order to compare the hatching and nest success rates to the mean arrival time.

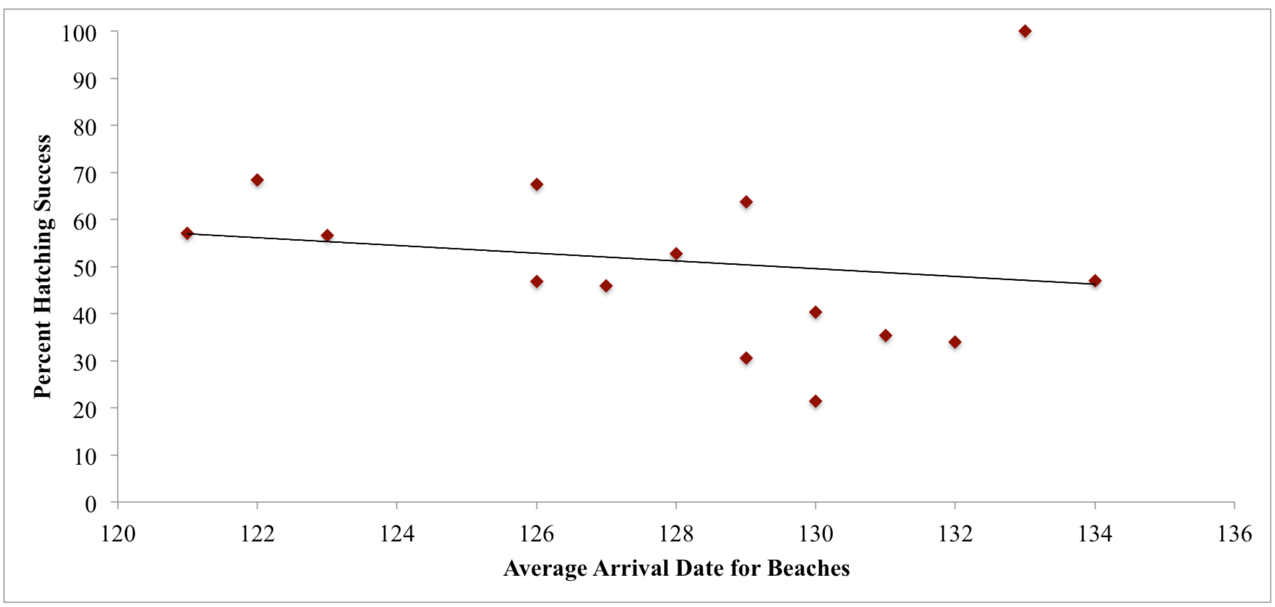

Figure 16- Linear regression for percent hatching success versus mean arrival date
Formula for regression line: y = -0.8253x + 156.87 with an R^2 value of 0.02809, P = 0.550

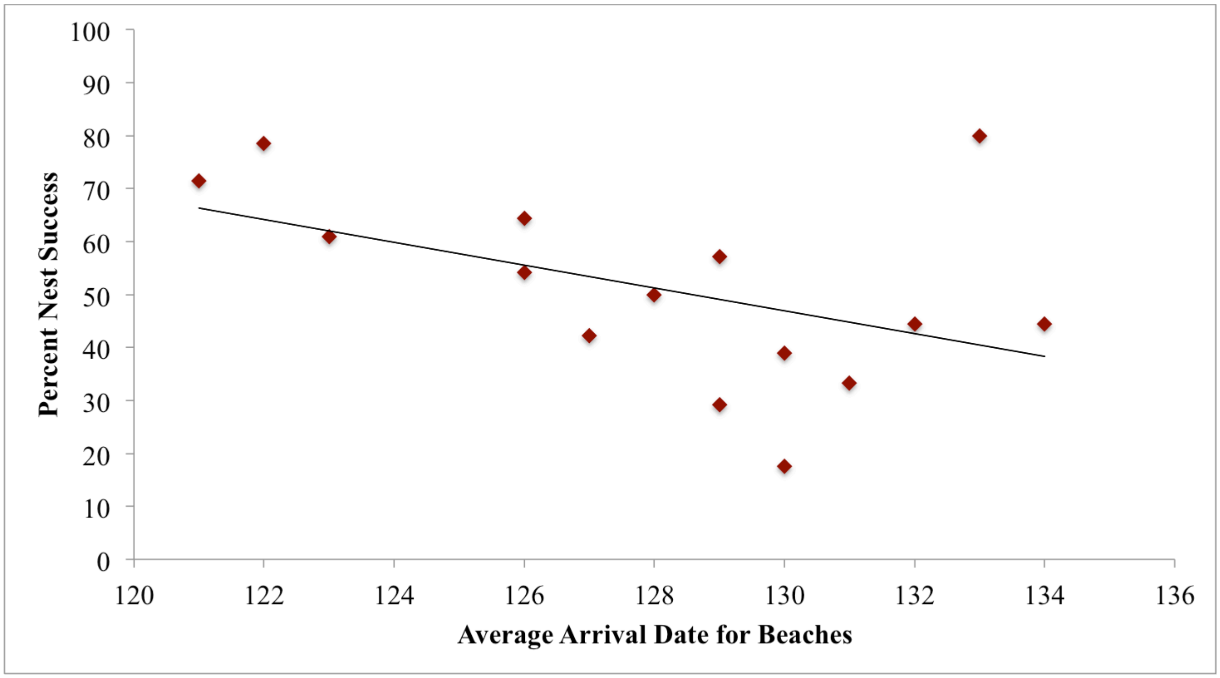

Figure 17- Linear regression for percent nest success versus mean arrival date
Formula for regression line: $y = -2.1556x + 327.18$ and a R^2 of 0.21911, $P = 0.0785$

As can been seen in Figure 16, the data appeared to show a downward trend, with a few outliers, but the trend was not statistically significant. In Figure 17, outliers were again present, but the trend appeared more linear than with Figure 16; the p-value for this regression is close to significance (p=0.07), suggesting that there may be a positive association between nest success and an early arrival date.

Discussion

This project resulted in the creation of an interactive data visualization of plover population data at 15 beaches on Cape Cod and the coast of Massachusetts. In order to test the ease and effectiveness of the program, a series of trials were conducted to determine the mean hatching success, mean fledglings per pair, and nest success between beaches using predator control, and those that are not. Using the program, data analysis was fast, and graphs of the results were constructed (see Figures 9, 10, and 11). While follow-up tests are necessary to confirm or reject any hypotheses, the quick analysis conducted fails to reject the null hypothesis, suggesting that there is no significant difference in success between beaches using predator control techniques, and those that do not. These observations support research conducted by Lavers, Wilcox, and Donlan (2010), in which predator removal alone was insufficient to reverse avian population decline in multiple species. In order to ensure a stable or increasing population, it is proposed that predator removal must be performed in conjunction with other conservation techniques. Therefore, it is my suggestion that further investigations be launched on the success of conservation techniques, in order to determine the effectiveness of not only predator control, but other conservation techniques as well. However, it is important to note that small sample size (n=5 and n=10), and a small data set (only existing for a year's worth of data) impede analysis. Further analyses with more data would be necessary to observe stronger trends and draw conclusions. But, although differences were not significant, the effects were positive in each case for predator control. So with larger sample sizes or more years of data, these effects might turn out to be real.

Observation of "clustering" of nests also provided insight into the behavior of the species at different locations. Of the three beaches observed, Marconi Beach and North Beach Island showed signs of clustering (see Figures 14 and 15), in which the birds appeared to prefer a certain area, and only moved to another area as the popular one reached occupancy. It's possible that these data are demonstrating behaviors studied by Maslo, Handel, and Pover (2010), where nest-site choice was hypothesized to depend on vegetative cover, percent shell and pebble cover, distance to nearest dunes, and distance to high tide line. In beaches where clustering occurred, it may be that ideal nest conditions were only within a small area whereas in South Beach- South of Break (see Figure 13), all of the beach front was of equal quality and therefore no clustering was seen. Further studies on this observation could prove useful: if the reason for this clustering can be determined, conservationists may be able to create more attractive sites, perhaps further from the danger of human interactions. This would also inform officials on how to improve the nesting sites currently in use, in order to potentially improve the population numbers (Maslo, Handel & Pover, 2010).

The experiments on time of selection versus hatching and nest success provided interesting results. Svensson (1997) found a direct selection for early breeding and large brood size in blue tits (*Parus caeruleus*) and also observed decreased fledging production in experimentally delayed breeding pairs. Work done by Janiszeski, Minias, and Wojciechowski (2013) also showed a pattern of breeding success when compared to time of arrival in white storks (*Ciconia ciconia*). When comparing percent hatching success to arrival date, a linear regression yielded a p-value too large to be considered significant (see Figure 16). This would suggest that there is no significant difference in percent hatching success when comparing beaches based on mean arrival date, and serve to contradict the work done by Janiszeski et al. (2013).

The investigation into nest success versus mean arrival date provided interesting, and perhaps significant, results. As can be seen in Figure 17, a p-value of 0.0785 was calculated for the regression comparing percent nest success to mean arrival date. While slightly above the accepted $p < 0.05$ for significance, this data more strongly argues that there is a difference in nest success based on mean arrival date, and therefore perhaps a selection for it (Velmala et al., 2015). Furthermore, these results support work done by Robinson & Dindo (2011) on an additional avian species, the brown pelican (*Pelecanus occidentalis*). In their work, they found a significant relatedness between early arrival date and both egg and hatching success. While my results do not support the relatedness of hatching success, they may support the relatedness of egg success. It is possible that males who arrive earlier to a breeding ground have the choice of the most optimal nest-sites, which therefore leads to higher nest success (Robinson & Dindo, 2011). While my results may not be statistically significant, they could be biologically significant based on how small the p-value is. Considering that this sample size consisted of only 15 beaches, and was only for the 2015 breeding season, a stronger significance could be obtained if further research is conducted with a larger dataset. If a strong relatedness is discovered, it could prove opportune to investigate the differences between various piping plover nesting sites based on the mean arrival date. Those sites experiencing earlier arrival dates could potentially provide a better nesting environment; if conservationists are able to determine the benefits provided by certain beaches, they could use this information to provide better nesting grounds at another locations.

Limitations and Suggestions

No project is without challenges and setbacks. The main challenges associated with this project came in the form of inconsistencies in data entry. The system by which individuals report data on a given beach is not entirely uniform, and therefore some assumptions had to be made when determining the exact meaning of some entries. Additionally, some data entries had to be eliminated entirely due to incomplete record keeping. Therefore, a key step for furthering this project would be to ensure a uniform system by which to record data observation in the field. If this is achieved, further coding and building of the program would be simplified immensely, and presumably better conclusions could be drawn from the data.

Additionally, this project was limited by the size of the dataset. Due to time and labor constraints, the dataset was limited to 15 beaches. While 15 sites do provide a great deal of valuable insight, more sites would provide additional data and therefore could serve to further support or refute hypotheses being tested. It is my suggestion that if further work is done on this program, more beaches should be incorporated to provide stronger trends in the data, as well as to better serve the conservationists of Massachusetts for whom this program was designed.

While this database houses a large variety of data, it is suggested that more detailed information be incorporated if this project is to continue. Details such as beach size and weather conditions have a huge impact on the success of a species, and so should be included in order to accurately represent all factors affecting the species from site to site. If a large storm interrupted the breeding season at a particular location, it would be useful to have this information in order to understand the change in populations. Additionally, the size of the beach would also be convenient to know, as it would affect the maximum occupancy of the site. If these features were taken into consideration for another generation of the database, a significant larger amount of information would be available and stronger conclusions could be drawn.

Implications on Further Studies

With regards to the hypothesis testing done in this project, it may be beneficial to use the results obtained to influence further study and future conservation techniques. No significant difference was observed between predator control and non-predator control beaches in the tests performed using the program. These results could be used to influence conservation efforts, or may inspire further research and tests on the effectiveness of predator control as a tactic to preserve piping plover populations. Likewise, further testing and research could be done on the topic of time of arrival for the species. Initial tests showed no significance in arrival time when compared to percent hatching and nest success, and these results could be used for future tests in order to determine how a site is selected and why arrival times vary.

The work done for this project has the potential to affect the way research on piping plover conservation is conducted. With all of the data organized by beach, it is simple to observe trends across a single beach. This data can be further analyzed due to the data output allowed by the program, and can be used to educate hypotheses across a single beach, or across the entire coast. Using this new investigative tool, it is possible to create a biological simulation using agent-based modeling; integrating the data gathered for this project and allowing the observations made to inspire the specific hypotheses to be tested, an agent based modeling of the system can be created to predict the future success of the species with the manipulation of certain conservation techniques.

Implications for Conservation Management

The information gained through this project has the potential to influence the ways in which conservation management function. While further studies on predator control are necessary, it is certainly worth exploring the potential effect of discontinuing predator control at certain locations, based on the results obtained from our testing. Additionally, testing on selection of location as well as clustering could prove extremely useful to management officials as they continually attempt to learn more about the behaviors of the birds as well as their preference for breeding grounds. In recognizing patterns in nesting, officials may further explore these precedents to gain information on how they can better suit their conservation efforts to support the species.

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Appendix I- ODD for NetLogo Program

ODD of NetLogo Implementation of Interactive Visual Database

Created on: April 7, 2016

Overview

Purpose

The purpose of this model is to provide a clear, interactive visual display of piping plover (*Charadrius melodus*) data collected by the Massachusetts Division of Fisheries and Wildlife during the breeding season (March-September) in order to allow for exploration and hypothesis testing. In interacting with this model, the user is able to observe data from various sites over the course of time, and select for certain variables such as nest success and fledgling numbers in order to manipulate the model and test hypotheses. This model provides an opportunity to investigate species success with a low cost, less invasive method of virtual data visualization.

Entities, state variables, and scales

Each agent represents a single nest attempt on a particular beach in the Massachusetts area. Each nest is based on real 2015 data, including nest attempts, eggs laid, young hatched, and chicks fledged. The agents are created on particular patches of the model, corresponding to latitude and longitude data points collected in the field. Therefore, the agents arise on the background satellite image of a given beach, in the specific location they were actually observed.

Process overview and scheduling

This model operates on a daily schedule, in which the nest agent produces a given number of eggs, which then age accordingly before either hatching, or failing, depending on the field data for that particular nest. If successful, the young plovers then age as the model progresses until they either become adults or die. All of the actions of the agents depend upon the data provided from field reporters for the MA Division of Fisheries and Wildlife, as this model is designed to be a visual recreation of the data collected in the field. This model is designed to process a year's worth of data, with the future potential to process multiple years in order to observe trends over the course of several breeding seasons.

Design Concepts

Basic principles:

Agents move in accordance with the data provided through input. The basic premise of this model is to provide a way to visually represent the data collected on the piping plovers' breeding season.

Emergence:

Emergence does not occur, as agents do change and no new traits or actions should emerge.

Adaptation:

Agents do not have any adaptive traits, as they are programmed only to appear and move as input data is given. The agents do not interact with the world.

Objectives:

The objective of this program is to model the data inputted exactly, and produce graphs displaying the results of that data over time. No other objectives exist.

Learning:

As previously discussed, agents do not possess any adaptive traits, and therefore are not capable of learning. Agents follow strict rules based on the data provided.

Prediction:

The agents are not capable of prediction, as they have no adaptive traits and therefore cannot learn from experiences within the program.

Sensing:

Time is sensed by the agents, and used in accordance with the input data in order to change and create new agents. No further decisions are influenced by state variables.

Interaction:

Agents do no interact directly. Each agent acts independently in accordance with the input data.

Stochasticity:

This model is completely predictable as it is the product of specific data input, and therefore lacks stochasticity.

Collectives:

Collectives are not implemented in this program.

Observation:

This model is designed for observation and hypothesis testing. Information on population numbers (nests, eggs, young, adults, predators) is collected in order to produce summary graphs.

Details

Initialization

Upon initialization of the program, a satellite image of the Massachusetts' coastline is produced on the screen. Points are created at the location of each beach in the database. Directly besides these points are labels providing information about the beach, including its name, the number of pairs of birds at the beach, if predator control was used, and the percent hatching success for the beach. This information is provided to help the user decide what beach they wish to explore. Once they have made a decision, they can use the Image-chooser dropdown menu in order to select a beach to study. Once this has been done, the program generates an image of the beach and creates a subset of data for the beach. As time elapses, agents appear in accordance with the data provided.

Input Data

A number of files are imported with input data. Input data provides information on nest success and locations. The following data files are imported:

CC1.jpeg
This file provides the background satellite image of the Massachusetts coastline

capemapdata.csv
This csv file contains all of the data for mapping the beaches onto the image of the coast of Massachusetts. The data includes the size of the image, the latitude and longitude of the corner points, and the latitude and longitude of each beach.

Allbeach.csv
This csv file contains all of the data for each beach in the directory. It includes the latitude and longitude points necessary to create a properly scaled image of the beach. The order of the columns of data are as follows: nestID, siteYearID, pair number, nestAttempt, latitude, longitude, nestHatchedorFailed, numberofEggsLaid, numberofChicksFledged, dateClutchCompleted, dateNestHatchedOrFailed, foudAfterHatching, numberofEggsLost, dateofEggLoss, PredatorControl?, TypeofControl, max x coordinate for image, min x coordinate for image, max y coordinate for image, min y coordinate for image

NNDATE.txt
This file contains the latitude and longitude of each beach to be used when the map of the Massachusetts coastline is generated.

"beach".jpeg
A number of files can be generated at any given time using the user input. A file exists for each of the fifteen beaches in the directory, each with the name of the beach as the file name.

In addition to the input files, user input controls are also implemented in this program.

Image-chooser

This drop-down menu allows the user to select which beach they want to view. This calls up an image of the given beach, as well as a subset of the data for the particular beach

Date-slider

This slider allows the user to manipulate the date in the program. By changing this date, the agents will appear as they correspond to the date in the csv file.