Shorebird Report, BIO539 Final Project

Emily Hamel

April 26, 2021

INTRODUCTION

On the whole, shorebird habitat in the North Atlantic tends to occupy large expanses of beachfront - in shorelines for foraging, lower dune environment for nesting, and lower energy tidal marshes or mudflats for more expansive staging prior to migration events. Humans, as seen from experience living on the Northern Atlantic coast, are drawn to these large stretches of open beach (most notably barrier beaches) for recreation in the warmer, summer months. This overlap in human and bird use of these areas is important to understand, as a number of regulations are set in place in order to properly monitor and manage seabird and shorebird populations. In some cases these birds are heavily monitored due to a federal or state status as an endangered species - in these cases critical habitat is also delineated and set aside for essential breeding activities. While space is made for nesting shorebirds to lay their eggs and rear their young away from human activity, their interactions with humans, while limited, are often unavoidable. (Glover et al., 2011). In more populated areas, it is not uncommon to see nesting least terns "diving" at the heads of recreational beach-goers, or to hear the federally threatened Piping Plover peeping in some form of distress as people pass by. As mentioned, attempts are made to lessen this level of disturbance, but success is not guaranteed. In defending their nesting grounds and territories in this way, the birds are expending energy that would otherwise be reserved for foraging, chick rearing, and other necessary activities. This paper seeks to review a study on the relationship between anthropogenic disturbance and the energy budget of disrupted shorebirds.

This study was chosen due to its relevance to the issue of human disturbance and its impact on sensitive species. Conducted in 2019 on Dutch Wadden Sea island of Vlieland in the Netherlands, this study utilizes a field-based observational approach in order to quantify the immediate and long term spatial disturbance responses of roosting Eurasian Oystercatchers (*Haematopus ostralegus*). Although these disturbance tests were not conducted on breeding birds, which is arguably when individuals are most sensitive, the study site was situated in an area that is a notable food source for migrating and wintering individuals. This area is also subject to different levels of military, commercial, and recreational human use. In order to relate disturbance events and associated energy expenditure the research team quantified immediate displacement (in the form of short-term flight responses to different levels of disturbance) and distance traveled during an entire high tide period (as the longer-term measurement, through the use of light-weight GPS tracking devices). These responses and travel distances were then compared to average energy budgets of similar species of Oystercatchers, derived from the literature, in order to measure the energetic impact of anthropogenic disturbance on this particular species of roosting shorebirds. (Linssen, et al., 2019).

METHODS

As with most studies done in an ecological setting, the site selection of this research plays a large role in the outcome of the results. The chosen study site is described as a mudflat and sand dune system on a barrier island in the Wadden Sea. This island serves as a breeding ground, an important roosting and foraging site (as previously mentioned), and an active military base. This military base in the area has been used for air force training - such as flying and targeted shooting and bombing by jets - since 1948, and these activities prevent public use of the wildlife area on weekdays. This study was conducted over a 100 day observation period and categorized disturbance sources as those from the air field noise, from people walking past roosting birds, and from “non-anthropogenic”, which accounts for environmental factors or disturbance events originating from an unknown source. Lightweight GPS trackers were placed on twenty Oystercatchers determined to be over-wintering in the area in December and an additional twenty were tagged during the breeding season - of the forty fixed with trackers, twenty-one provided data for this study (it is unknown why the remaining trackers did not provide data, perhaps due to mechanical malfunction or the emigration or death of the birds). These GPS trackers were put in place in order to measure immediate disturbance in addition to individuals’ long term movements during one high tide cycle.

To quantify the immediate response of the birds to different types of disturbance, researchers compared pre-disturbance measurements of response distance to the three levels of disturbance listed above. A Dunn’s statistical test was conducted to determine the significance of the bird’s repose to a stimulus when compared to its travel distance prior to disturbance. Additionally, the study describes an assessment of the birds’ total travel distance during a high tide window compared to the immediate displacement response, in order to understand if the initial disturbance results in additional or less movement following that event. Correlations between this high tide window travel distance and the total displacement distance were assessed through the use of a generalized linear mixed model, where positive results indicated additional movement following the immediate displacement and negative results suggest no additional movement at the roosting site. As mentioned previously, the goal of this study was to understand how disturbance impacts shorebirds’ energy budget. In order to make such an assessment the overall energetic cost of each disturbance type was quantified under the assumption that the birds fly at an average speed of 12 meters/second, and that flight expends 36 Jules/second. This calculation in conjunction with the estimation of daily energy expenditure resulting from disturbance in roosting areas (derived from the assumptions that an Oystercatcher’s daily energy requirement is 860 kiloJoules, the roost for 12 hours a day, and that the frequency of nighttime disturbance is equal to the frequency observed during in the day), were used to estimated extra foraging time needed to compensate for this additional energy expenditure. The timescale for foraging was based on the dry weight measurement of prey items, assuming that the birds consume prey at an average rate of 1 milligram/second and that the energy content is about 21.9 kiloJoules/dry gram.

For the purpose of this paper, it was the goal of this researcher to replicate the analysis and results of Lissen, et al. in order to assess the reproducibility of the research and to present a challenge relevant to personal, future research interests. Although the intention was to fully recreate the data analysis, it must be mentioned that some of the statistical tests and modeling involved fall outside *this* researcher’s realm of understanding. With that in mind, it was possible to create the relevant figures from the data provided and to gain a baseline analysis of the data (without the more complex modeling, the process of which is not described in detail in the literature). All four figures (as seen in the Results section) were created using the `ggplot()` function in R - all relevant graphical manipulation can be viewed in the “shorebird_analysis” file within this repository.

In order to analyze the data it was necessary to first run a Kruskal-Wallis rank sum test on the immediate displacement data set, these data were then tested further as pairwise comparisons using Wilcoxon rank sum exact test, with the intention of determining significance between disturbance categories. Linear models were also run to analyze Figures 2, 3, and 4, and a table was created of the birds’ energy budgeting in order to visualize the impact of disturbance. While this exact methodology differs from that outlined in the original study, it is the feeling of this researcher that, while recreation of the study is a primary goal, comprehension and digestibility of the results is paramount. In conducting the analysis in a this fashion, it becomes possible to see how the birds’ movements are significant compared to their movements prior to a disturbance event.

RESULTS

The results presented in this paper are the product of this researcher’s attempt to recreate a complex analysis of preexisting research. This section will display relevant figures and discuss the outcome of this analysis. Due to the incomplete nature of the source material’s description of their data processing, the results provided here will draw comparisons between the original study and this secondary, outside attempt to manipulate the available data in a similar fashion.

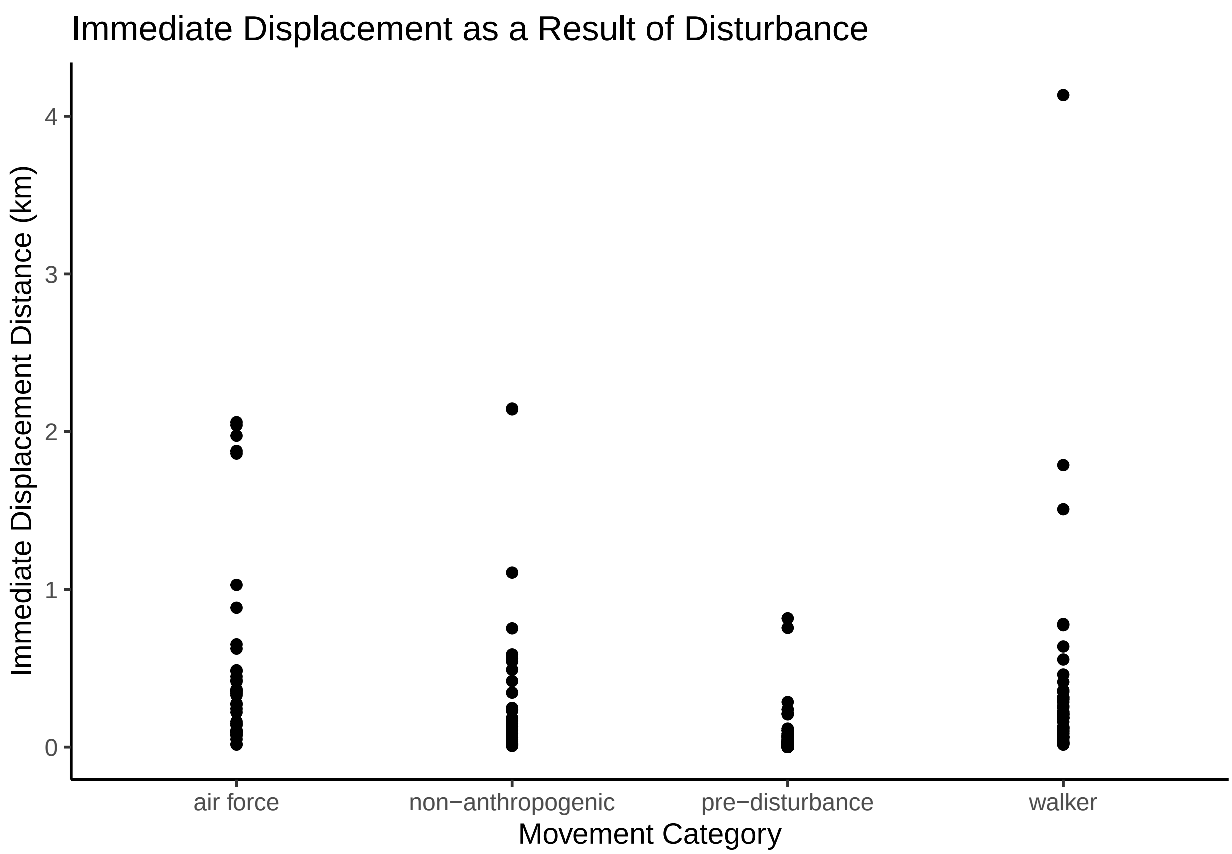

Figure 1: Depiction of immediate displacement resulting from different disturbance categories. The points are indicative of each displacement event of the 240 observations.

Figure 1 seeks to show the immediate displacement caused by disturbance events. The study outlines 240 observations of this kind, half of which being the "pre-disturbance" observation that is used to base the severity of the response from each of the three disturbance categories. The Kruskal-Wallis rank sum test of this data produces a p-value of $7.3555356 \times 10^{-29}$, indicating a strong, significant relationship between the immediate displacement distance and a disturbance event. Following this test, a pairwise test was conducted to analyze the relationship between pre-disturbance movements and each disturbance category. P-values were corrected through the holm method and are listed below:

```
non-anthropogenic = 2.2e-11
air force = 1.6e-15
walker = < 2e-16
```

These p-values indicate significant disturbance from non-anthropogenic events and air force activities, while displacement as a result of people walking past is not significant. Although the values are different, these same results were described by Linssen, et al. It is the belief of this researcher that this variation in results is due to the use of different statistical tests and the use of differing p-value adjustments by Linssen.

```
## ‘geom_smooth()‘ using formula ’y ~ x’
```

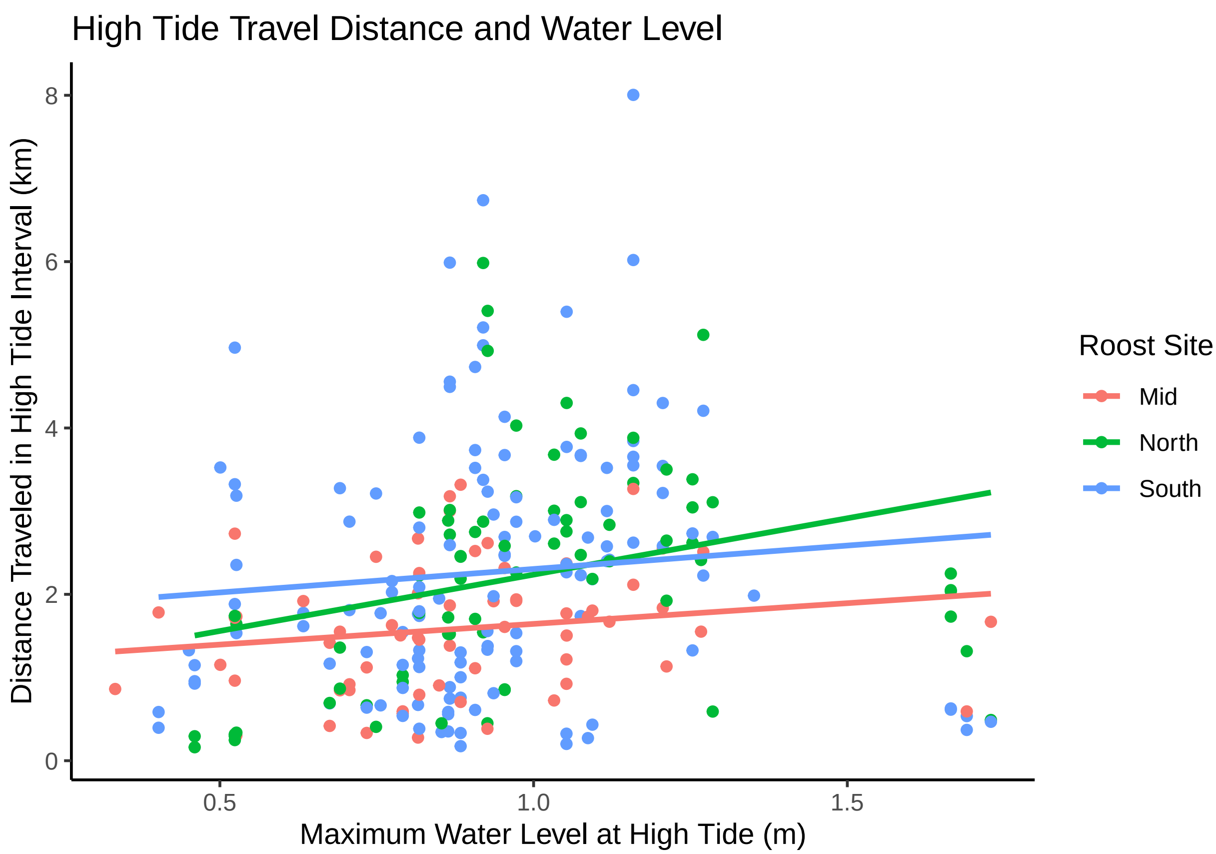

Figure 2: Relationship between the distance birds traveled during intervals of high tide and the maximum water level during these events. Data is divided between three relevant roosting sites: Mid, North, and South (shown in red, green, and blue - respectively)

From the analysis of immediate disturbance in Figure 1, Figure 2 was created to show the relationship between the birds travel distance during the high tide interval and the maximum water level during the same interval (due to the fact that the water level at high tide can differ, especially in the Northern latitudes of the Netherlands). The original study ran a generalized linear mixed model with a gamma response distribution and a log link function, but this researcher chose to run a linear regression model instead in order to produce a more accessible analysis.

The results of the linear model associated with Figure 2 show an overall p-value of 0.0033641, displaying a significant relationship between the water level and the distance the birds were likely to move during a given high tide interval. This makes logical sense considering the fact that the level of the high tide is not a static value and birds that forage at the shoreline will inevitably base their movements around the rising and falling of the tide. This model also produces an R^2 value of 0.0324692, indicating that the relationship between the water level and the birds' movements during a high tide cycle only accounts for about 3% of the variation in the data.

```
## `geom_smooth()` using formula 'y ~ x'
```

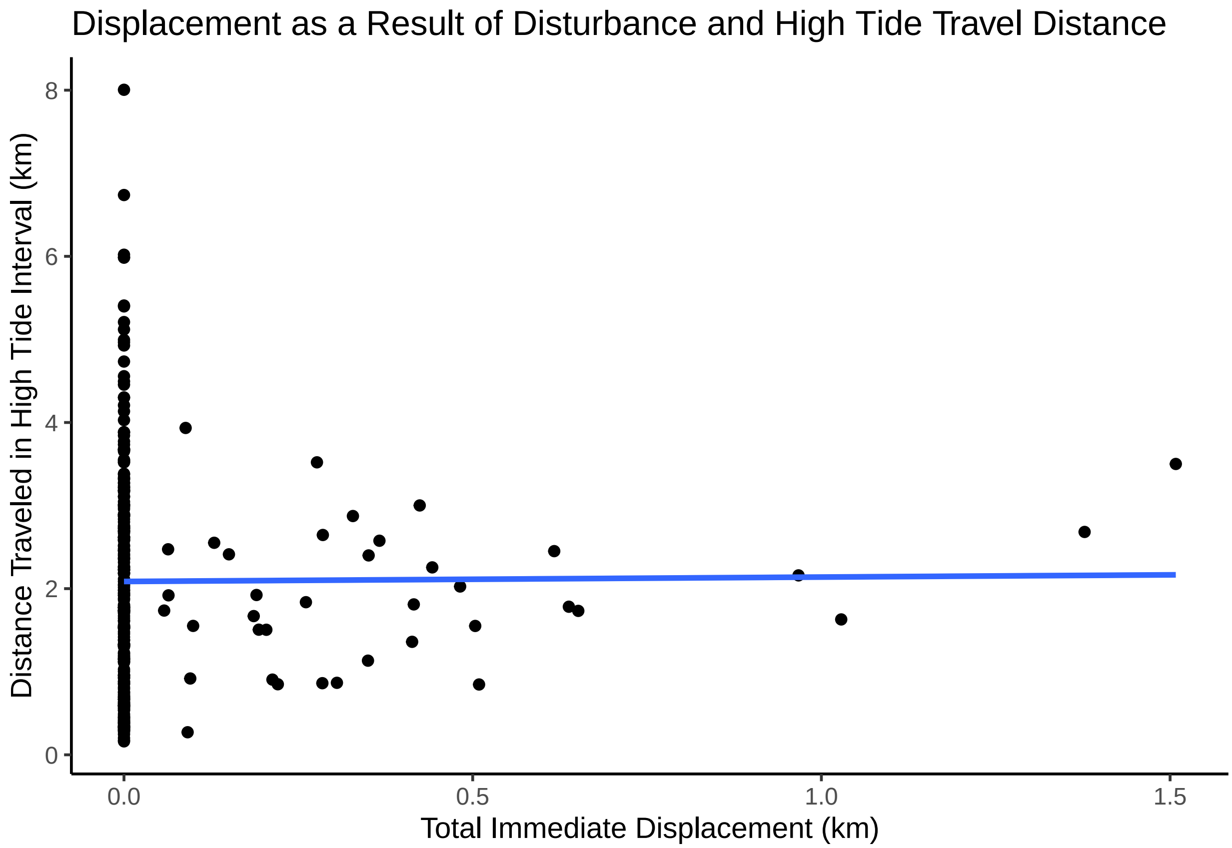

Figure 3: Relationship between the total distance traveled within the high tide period in kilometers (i.e. high tide travel distance) and the total distance traveled in responce to immediate disturbance within the high tide period in kilometers (calculated as the sum of the collected movements from GPS transmitters from disturbance, i.e. total immediate displacement).

The above figure (Figure 3) seeks to utilize the total distance individuals moved during a high tide cycle to understand the significance of their movements in response to disturbance. As was in case with the data in Figure 2, the original research ran more complicated models than was possible for this researcher to recreate, so the data in Figure 3 was analyzed using a linear model. This model produced a p-value of 0.9054663 and an R^2 value of 5.4139317×10^{-5}, indicating a lack of significance between these two variables.

```
## `geom_smooth()` using formula 'y ~ x'
```

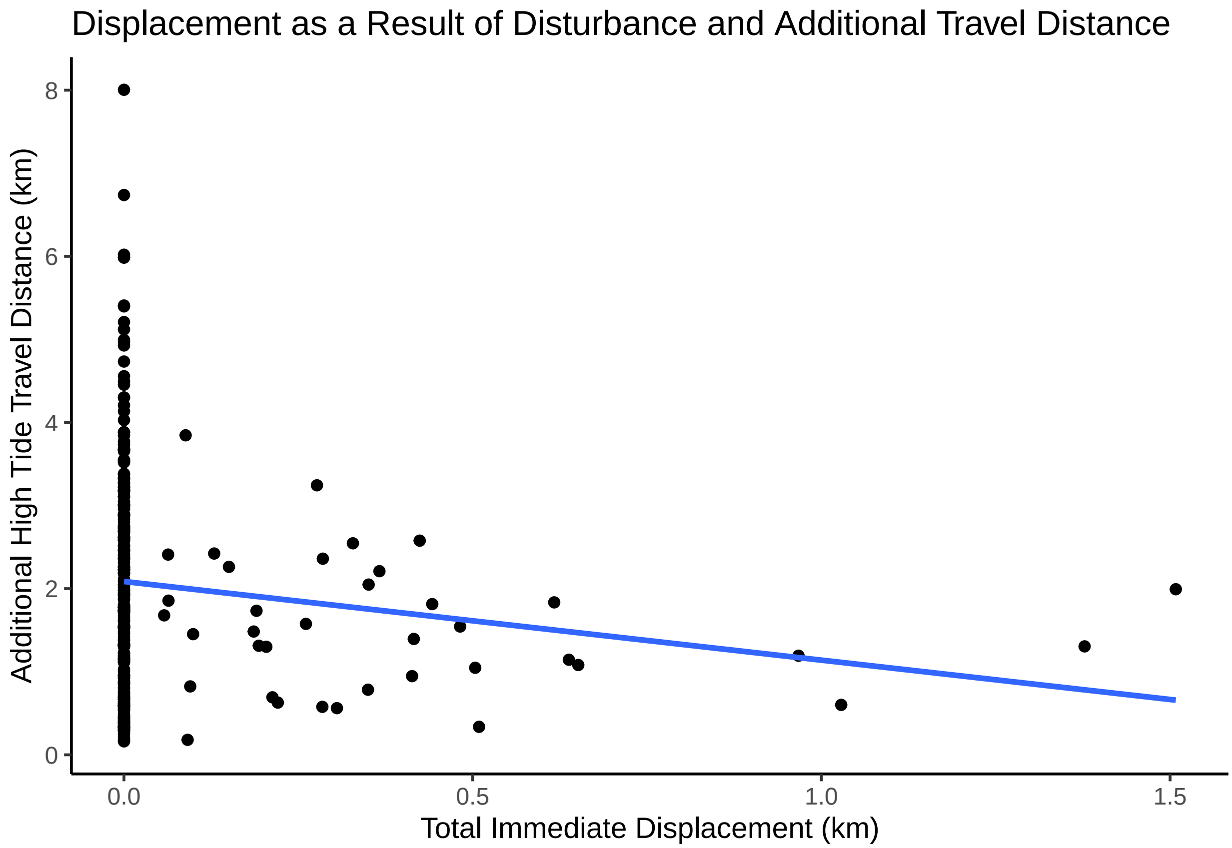

Figure 4: Depiction of the relationship bewteen the additional distance traveled during the high tide interval, measured in kilometers, and the total distance traveled in response to immediate disturbance events, also measured in kilometers.

The study moves one step further in order to understand if a relationship exists between the additional high tide travel distance (which was defined as the high tide travel distance minus total immediate displacement) and the total immediate displacement. This information is outlined above, in Figure 4. From the linear model in this figure one finds a p-value of 0.0349192 and a R^2 value of 0.0169341. This meaning that, while significant, this element of the data does not account for a substantial amount of the variation in this data.

Relevant Energy Budgeting Results

In order to understand how disturbance events impact the energy budget of the Oystercatchers in this roosting area, it was advantageous to create a table that displayed this information (Table 1).

Table 1: Visualization of the average distance birds were displaced as a result of the different disturbance categories and the energetic output required to move such a distance. This output is compared to the birds' daily energy requirement in Joules and kiloJoules, respectivley.

Movement Category	Average Displacement Distance (km)	Energy Used (J)	Energy Requirement Minus Loss (J)	Energy Requirement Minus Loss (kJ)
air force	0.5455881	1636.764	858363.2	858.3632

Movement Category	Average Displacement Distance (km)	Energy Used (J)	Energy Requirement Minus Loss (J)	Energy Requirement Minus Loss (kJ)
non-anthropogenic	0.3538641	1061.592	858938.4	858.9384
pre-disturbance	0.0343983	103.195	859896.8	859.8968
walker	0.3347655	1004.297	858995.7	858.9957

From Table 1 one can see that the energy used to move in response to disturbance, does not greatly diminish the 860 kJ of energy the birds require per day. In fact, the energy required to fly an average range of 0.3 - 0.5 km in response to disturbance hardly seems to have an impact on the required daily energy budget. From this information it is possible to predict that the amount of food that would be required to account for any energy loss due to disturbance is hardly significant. The authors of the original paper came to a similar conclusion. Regardless of this seemingly minimal impact, it is important to consider how this energetic loss could be more substantial/dire in areas with limited food availability, and prior to migration events or the breeding season - when energetic need is heightened. This study also fails to consider the impact of stress from disturbance events. While the short-term removal from a food source is, of course, important, stress response from anthropogenic activities can have additional negative impacts, such as nest abandonment.

In sum, one can observe a relationship between Oystercatcher movement as it relates to different levels of anthropogenic disturbance - with loud sounds from military training procedures resulting in the most significant level of movement. These relationships, while impacted by the tide cycle, are not an extremely significant representation of environmental factors. The purpose of the original study was to determine the impact of anthropogenic disturbance to the roosting birds' energy budget. This researcher was able to conduct a simple assessment of this impact to the birds, and, although it may not have been done to the same level of complexity as Linssen, et al., the analysis in this paper arrived at similar results.

DISCUSSION

First and foremost, it is the opinion of this researcher that the reader should understand this writer's limited knowledge of statistics. To speak frankly, this is my first semester of graduate school after years of working as a wildlife conservation technician. My current research is related to the impact of predation on nesting Piping Plovers in Rhode Island and the ability of shorebird monitors to accurately determine the source of this predation. I haven't been exposed to the level of statistics relevant to the Linssen, et al. research in a number of years and admit to a learning curve when it came to the analysis of their results. The goal of this project was to challenge myself and I believe that was accomplished in choosing a data set that involved statistics more complicated than I feel comfortable analyzing.

Although this study is not directly related to the research I am conducting for my major paper and I can admit to some of data analysis in this project to be over my head, it was my intention to stick with this project. As mentioned, I have been working in the wildlife conservation field for a number of years, primarily working in the monitoring and management of nesting seabirds and shorebirds. Throughout these experiences I have learned how human disturbance can act as a limiting factor in the nest success of these ground-nesting species. Oftentimes crowded beaches, dog-walking, and people passing by nesting sites can flush birds off their eggs and even have the potential to result in nest abandonment. I chose this study because I had not considered the similar impact this disturbance could have on the energy budget of these birds. Understanding these relationships remains an important element of managing coastal birds, which is something that I plan to to continue to base my career around as I exit this graduate program.

Overall, this project has exposed a personal struggle with statistics (and the relevant energy budgeting equation). I feel comfortable in the figures I have created for this project (which was my primary goal in taking this class), but it is clear that as I continue my work I need to expose myself to different statistical tests and analysis. It is my hope that the evaluation of this project is of the effort of the work involved rather than the specifics of the results. I hope to assure the reader that I invested a substantial amount of time and effort into this attempt and, although it is inherently flawed, it represents my best attempt to complete the required tasks. Perhaps it would have been more appropriate to have chosen a paper with a less complicated analytic requirement, but I maintain that this has been a solid first attempt and good practice for handling data in future projects.

LITERATURE CITED

Glover, H. K., Weston, M. A., Maguire, G. S., Miller, K. K., & Christie, B. A. (2011). Towards ecologically meaningful and socially acceptable buffers: response distances of shorebirds in Victoria, Australia, to human disturbance. *Landscape and Urban Planning*, 103(3-4), 326-334.

Linssen, H., Van De Pol, M., Allen, A. M., Jans, M., Ens, B. J., Krijgsveld, K. L., & Van der Kolk, H. J. (2019). Disturbance increases high tide travel distance of a roosting shorebird but only marginally affects daily energy expenditure. *Avian Research*, 10(1), 1-11. https://doi.org/10.1186/s40657-019-0171-8