Migratory Bottlenose Dolphin Movements and Numbers Along the Mid-Atlantic Coast and Their Correlation with Remotely Sensed Chlorophyll-a and Sea Surface Temperatures

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Abstract— Along the Mid-Atlantic coast of the United States, there are different sub-populations, or stocks of bottlenose dolphins. The bottlenose dolphin, Tursiops truncatus, has both resident and migratory stocks. The focus of this study is the northern migratory population. This group of animals moves north and south along the coast in response to seasonal changes. The need for study arises from this mobile nature. Determination of the environmental cues that may be used to predict the presence or absence of these animals will aid in efforts to avoid disturbance to this protected species. This stock was also greatly affected during the 1987-1988 epizootic event that killed an estimated 50% of the migratory stock. This disease event was likely worsened by exposure to environmental toxins. The main areas of the field work, the lower James and Elizabeth Rivers of Virginia, are of interest due to their high toxin loads and frequent usage by bottlenose dolphins. The Elizabeth River is largely developed along its length. It also has a very high level of traffic: commercial, military and recreational.

Since this species represents the highest level on its food chain, our hypothesis is that the movement north represents can be correlated with the movements of their prey species. These prey species are known to be themselves migratory with temperature. As a surrogate for the in situ detection of the prey species, we feel that sea surface temperature (SST) and chlorophyll-a levels can be used. Both of these factors can be sensed remotely, removing the need for local observations. Sea surface temperature can serve to represent the movement of the prey species, and chlorophyll-a levels can be used to show the primary productivity, and thus the total food energy available in the ecosystem. The presence and absence data on these animals is then to be compared with the remotely sensed SST and chlorophyll-a data. These data were derived from a number of sources. MODIS-Aqua and AVHRR data was obtained from Goddard Space Flight Centers Ocean Color web archive. Additional AVHRR data was obtained from the Jet Propulsion Laboratory's PO.DAAC Ocean ESIP Tool (POET) website. Field observations were based on archives from the Christopher Newport University Dolphin Project, and from the Ocean Biogeographic Information System (OBIS) archive of Duke University.

The results of the correlations show that the critical temperature in determining the presence or absence of bottlenose dolphins is between 16° and 18° C. While there were two sightings below this temperature, there were 694 above. A t-test show that there was a significant ($p=0.003$) difference between the mean temperatures of sighting and non-sighting efforts. When compared to the numbers of animals sighted at the different temperatures, again the 16° and 18° critical temperatures showed up. There were only 2 animals sighted below 16°, while there were 5400 sighted above. An ANOVA analysis showed a significant ($p<0.01$) difference between the two temperature ranges when it came to group size. A t-test for the mean group size showed no significant difference in the sizes of groups between 18° and 28°. While there was some variation in the chlorophyll levels (measured in mg/m^3), a t-test showed no significant ($p>0.1$) difference between the means of sighting and non-sighting levels. In comparing chlorophyll-a levels with group size, there was a significant ($p<0.001$) difference, but this was likely due to the fact that coastal waters never drop below moderate chlorophyll-a levels. Based on these findings, it becomes clear that in determining the migratory movements of bottlenose dolphins sea surface temperature is the preferred environmental variable.

I. INTRODUCTION

Bottlenose dolphins, *Tursiops truncatus*, are the most commonly seen marine mammals in the world. Bottlenose dolphins are gray color on the dorsal surface of their bodies that fades to a light gray color on the sides with a soft gray color on the belly. The dorsal fin of the dolphin is tall and curves toward the rear of the animal. The fins of the tail are curved with a deep indentation in the middle, and the fins have a medium length and are pointed. This dolphin has a strong body with a short stubby beak which earned it the name "bottlenose." Bottlenose dolphins feed on fish, squid, and et al; they may hunt willingly, chase fish onto mud banks, and dig in the sand to uncover food items, or feed in association with fishing boats. Dolphins are very susceptible to ocean pollution and commercial fishing. Under the Marine Mammal Protection Act of 1972, all marine mammals are protected. Humans remain the biggest threat to dolphins because of accidental takes or by direct harassment. Dolphins along the Atlantic coast of the United States can be divided into four sub-populations, or stocks. The subject of this study is the northern migratory stock, which migrates seasonally north and south from North Carolina to New Jersey [1]. It is the environmental cues of these movements that will be investigated.

Since direct monitoring of the environmental cues which may be used by the animals in migration can only be done for specific locations and for the time of monitoring, indirect methods were used. Plankton, which contains substantial amounts of chlorophyll, is at the base of the food chain. High levels of chlorophyll show a greater amount of energy available throughout the food chain. Our working hypothesis is that if there is a high level of chlorophyll in an area the chances of seeing dolphins are higher. The temperature of the water is similarly relevant. Many of the fish that the dolphins eat migrate with changes in water temperature, so the dolphins should follow.

Remote sensing is the measurement of data and information on objects and or material by a recording device that is not in physical, close contact with the elements under observation. Sea Surface Temperature (SST) is an important factor in understanding the oceans interacting physical, biological, chemical and geological systems. It is defined as the temperature of the first meter of the sea's surface. Satellites measure radiance from the surface of the earth and that data is converted into the geophysical temperature. The SST of the oceans is subject to seasonal and yearly variation. Calculating an accurate Sea Surface Temperature is done in two ways. The raw satellite signals from the Advanced Very High Resolution Radiometer (AVHRR) are mathematically converted into calibrated radiances. This stage handles any in-flight changes in sensor calibration such as jumps or sensor drift. Then the radiances are converted into a bulk SST by the application of an algorithm. The algorithms derived by National Oceanic Atmospheric Administration are from global comparisons between SST buoys and the satellite values. The accuracy of satellite sea surface temperature observations depends on the ability of the satellite sensors to view the sea with little error introduced by the atmosphere [modis].

Chlorophyll-a levels are also measured by remote sensing. Ocean color sensors in the visible spectrum sense radiance from chlorophyll in oceanic plankton. The raw radiance data is processed in a manner similar to that of SST to correct for errors, georeferenced and converted to chlorophyll-a concentrations through the use of algorithms.

The results of sea surface temperature and chlorophyll-a data are presented as a color-coded graphic, with the color representing the level of the variable in question. Alternately, the data may also be presented as numeric data for a specific location or time[carder].

When viewing oceanic water remotely, there are two conditions: Case 1 and Case 2. The classification of Case 1 and Case 2 waters was made by Morel and Prieur [2]. These terms are commonly used to classify the two different types of waters. Case 1 water is found in the open ocean and is nearly as transparent as glass. In this type of water, all of the visual properties are determined by the concentration of phytoplankton and its association with chlorophyll. Because Case 1 water's concentration of phytoplankton and chlorophyll are usually low, the optical properties are comparatively easy to analyze, and fairly easy to model. Case 2 waters are heaving lush green waters loaded with chlorophyll and mixed with mud from the sea bottom. This type of water is found in coastal upwelling zones, the mouths of rivers, or where hurricane winds have pushed sediments offshore into a neighboring deep ocean. Case 2 waters are more significant and more productive than Case 1 waters. The production phytoplankton is enhanced by the nutrients delivered by the river water or contained in the upwelling deep water. This increased productivity in Case 2 water makes it important; this water can mislead the algorithms that are used to calculate chlorophyll concentration. Case 2 waters reflect more light than Case 1 waters, with this increased radiance can exceed the limits where the algorithms are most accurate. If there is not an alternative approach for just calculating phytoplankton in Case 2 waters, the algorithms may return erroneous overestimates of the chlorophyll concentration of the plankton [ioccg].

Our hypothesis is that both SST and chlorophyll-a levels may be used as surrogates for direct monitoring of the movements of the dolphins or their prey [rushton].

II. METHODS

A. *Remote Sensing*

The Jet Propulsion Laboratory Physical Oceanography DAAC Ocean ESIP Tool (POET) [poet] provided the data to evaluate sea surface temperatures. The AVHRR (Advanced Very High Resolution Radiometer, MODIS- Aqua (Moderate Resolution Imaging Spectroradiometer) Reynolds/NCEP dataset (compromised of AVHRR data interpolated with in situ data) was taken from the PODAAC POET website.

Data was gathered from MODIS-Aqua and AVHRR datasets (satellites) on the Ocean Color website [ocjpl] located at the NASA Goddard Space Flight Center. Due to the area that our research was conducted (Case II waters) a correction factor was needed due to the sediment located in the water. Our original intent was to use a corrective algorithm on two spectral bands (this would allow derivation of just the chlorophyll levels and not both the chlorophyll and other remains located in the water) to get better chlorophyll data [ruddick]. However, we were unsuccessful with this method because it is not possible to obtain local data for just two out of the thirty spectral bands from the global dataset. The alternative was to derive and use corrective approximation. A set of ground-truthed data from the NOAA Chesapeake Bay Office website [cbo] had an archive for a number of years that coincided with views available from the satellites for chlorophyll-a data. The data taken from an aerial scan of the Chesapeake Bay chlorophyll-a levels that had been corrected for actual local conditions. This allowed comparison of the true values versus the satellite values and so a conversion chart was made that could correct the values taken from MODIS and AVHRR. This approximation gives us values that are closer to the actual levels rather than using raw data from the satellites.

For both ocean color and SST data, eight-day means were used. This is due to the incomplete nature of the data derived on a daily basis, generally due to cloud cover obscuring the surface, but also due occasionally to signal interference, dropouts of data, poor angle-of-view and other losses of primary data. Research by Loftus, et al. [] showed the utility of the eight-day mean values, while retaining enough specificity of the data to remain valid.

B. *Field Work*

In order to correlate the presence and absence probabilities with the remotely sensed data, field data on the presence of the animals was required. The field work data was taken from two sources. We conducted our field work in the Lower Chesapeake Bay and near shore off the coast of Virginia. Data was also taken from the archives of the Christopher Newport University Dolphin Project that covered the area for several years. This data included both effort expended and sighting data, which could be compiled to produce a probability of sighting.

C. *OBIS*

In order to extend the geographic and temporal range beyond the CNU archives, data was obtained from the Duke University Oceanic Biogeographic Information System website. [obis]This data was compiled from numerous researchers from different institutions, and represents a source of data available for researchers on numerous species. This information can be narrowed down by species, time span and location. Since the population of interest was migratory, the data was taken from a box bounded by 34° N to 42° N and 70° W to 77° W. Sightings from greater than 20 miles from shore showed the oceanic population, and were not considered. This data showed presences and numbers of animals sighted. As this data only represented presence data, absence data was needed so direct comparisons of the two datasets could be made. [read]Using a recent technique, pseudoabsence data was derived. This data was generated randomly to represent the effort made, so probabilities of sighting could be made. The random data was made modeled using the CNU archive data as a model[engler][zaniewski].

D. *Correlations*

The data for presence/absence and numbers were then entered into Microsoft Excel and aligned with the conditions found through remote sensing. The conditions found were then sorted along with the presence/absence and number data to provide the correlations. For both data sets, ANOVA tests were made to determine the significance of any differences in the data. For the presence/absence data, a t-test of the means of the temperatures for the presence and absence data sets was made to determine if the difference between the temperature for sightings and absences was significant.

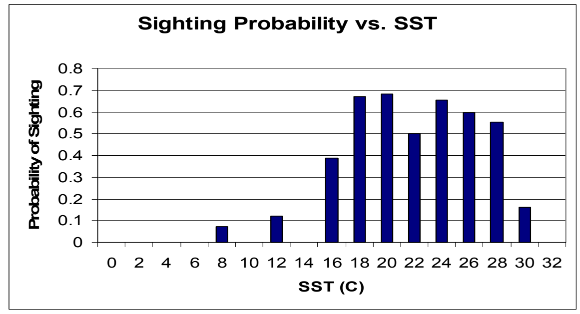

Figure 1. Sighting probability as related to SST.

III. RESULTS

SST was compared against the probability of sighting animals. The resulting plot is seen in Fig. 1.

This shows that above the temperature 16° C, there is a much greater chance of sighting dolphins. There are two sightings below this temperature, but these are sightings of single animals, and thus don't represent the majority. There are only two sightings below 16°, and 694 above, so these represent rare events. There is also a decline in the sightings above 28°, which may represent the point where they begin to undergo thermal stress. A t-test showed that there was a significant (p=0.003) difference between the means temperatures where the animals were sighted and when they were not.

When the number of animals sighted was compared against SST, the graph in Fig. 2 resulted. This shows that again, there is a sharp drop-off of the number of animals sighted below 16°. Of the sightings where the number of animals was recorded, only one was at 16°, and two below that point. It should be noted that the two below represent sightings of single animals. So we have 2 animals sighted below 16°, and a total of 5400 at 16° and above. An ANOVA analysis was performed on the data, and this showed a significant difference (p<0.01) between the temperatures where they were found and where they were not. A t-test comparison of the mean values for the range of temperatures showed no, significant difference in the mean group size between 18° and 28°.

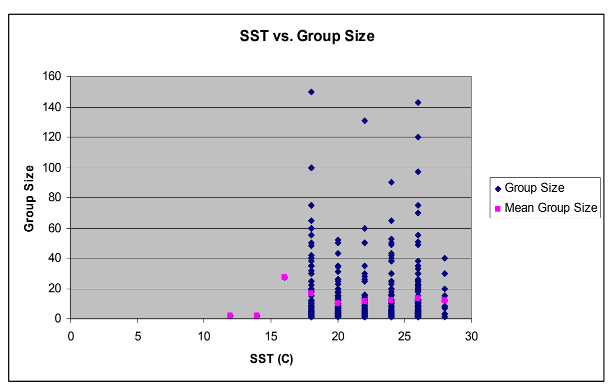

Figure 2. Group size and mean group size plotted against SST

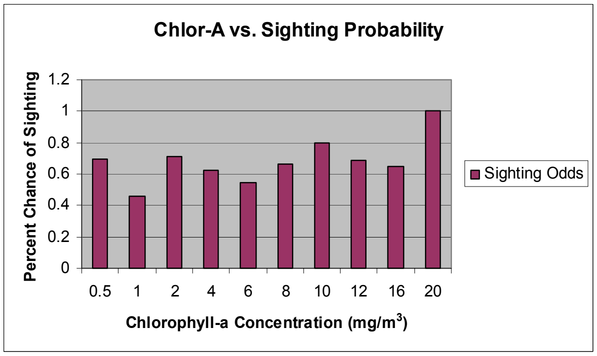

Figure 3. Sighting probabilities plotted against chlorophyll-a levels.

When the levels of chlorophyll were examined in the same ways, little correlation between the factors was found. The graph of the results may be seen in Fig. 3.

While there is some variation in the percent chance of sighting dolphins across the range of chlorophyll-a concentrations observed, a t-test showed no significant ($p>0.1$) difference between the means for the level where dolphins were sighted and where they were not.

A comparison between the level of chlorophyll-a and the number of animals sighted may be seen in Fig. 4. This data shows that there is a significant ($p<0.001$) difference in the mean group sizes, but this reflects the relatively high levels of chlorophyll-a found in coastal waters.

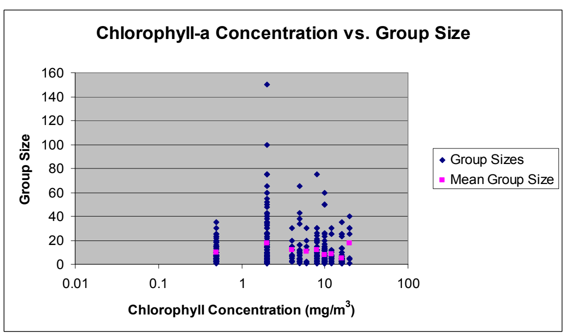

Figure 4. Group size plotted against Chlorophyll-a concentrations.

There was no real difference in the numbers of sightings at the different temperatures.

IV. Conclusion

The results clearly show that when modeling the movement of bottlenose dolphins of the northern migratory stock, SST is a much better predictor. This is likely due to the temperature-dependent nature of the dominant prey species of the dolphins, and not a temperature constraint on the dolphins themselves. There does seem to be an upper limit on the tolerable water temperature for this stock, as the insulative qualities of the blubber reduce the amount of internal heat that can be shed to the water. Animals in other areas, notably Scotland, thrive in colder waters than this stock, but these are a separate population that is non-migratory and have a resident prey. For both presence probability and number of animals sighted, there were two outliers. In both cases, these represented sightings of single animals in water generally considered too cold for them, and probably represent rare events. The fact that there were only two sightings of single animals below 16° and 694 sightings of 5400 animals above this temperature shows a marked significance to this temperature. Therefore, for anyone finding themselves in the range of the migratory population, the water temperature can be used as a gauge of the likelihood of encountering dolphins.

Chlorophyll-a is shown to not be a useful predictor for migratory movements. This is likely due to the ephemeral nature of very high chlorophyll levels from algal blooms, the latency period between changes in the base of the food chain and its cascade effect to the upper levels where the dolphins are found, and to the fact that with high nutrient loads from riverine runoff the level of plankton in near shore water remains much higher than in oceanic ones. When modeling the migration of the northern migratory stock of bottlenose dolphins, chlorophyll-a levels may be disregarded, and SST can be used as a reliable surrogate for the likely presence of these animals.

References

[1] Barco, S, W. Swingle, W. McLellan, R.Harris, A. Pabst 1997 'Local Abundance and Distribution of Bottlenose Dolphins (*Tursiops truncatus*) in the Nearshore Waters of Virginia Beach, Virginia' Marine Mammal Science, 15(2) 394-408

[2]MODIS Website – modis.gsfc.nasa.gov

[3]Carder, K, R Steward, J Paul, G Vargo 1986 "Relationships Between Chlorophyll and Ocean Color Constituents as they Affect Remote Sensing Reflectance Models" Limnology and Oceanography 31(2) 403-413

[4]Morel, A and L Prieur 1977 "Analysis of Variations in Ocean Color" Limnology and Oceanography 22(4) 709-722

[5]International Ocean Color Coordinating Group 2000 "Remote Sensing of Ocean Color in Coastal and Other Optically-Complex Waters" Reports of IOCCG, Ispra, Italy 14-18 June, 1999

[6]Rushton, S, S Ormerod, G Kerby 2004 "New Paradigms for Modelling Species Distributions?" J. Appl. Ecol. 41, 193-200

[7]POET Website – poet.jpl.nasa.gov

[8]Ocean Color Data Browser Website – oceancolor.gsfc.nasa.gov/cgi/level3.pl

[9]Ruddick, K, H Gons, H Rijkeboer, G Tilstone 2001 "Optical Remote Sensing of Chlorophyll-a in Case 2 Waters by Use of an Adaptive Two-Band Algorithm with Optimal Error Properties" Applied Optics 40(21) 3575- 3585

[10]NOAA Chesapeake Bay Office Remote Sensing Website noaa.chesapeakebay.net/odas_sas.html

[11]Loftus, C, T Norris, P Fiedler, G Armstrong "Satellite Oceanographic Data Versus In-Situ Data as Inputs for Predictive Models of Marine Mammal Occurrence." Unpublished.

[12] OBIS SEAMAP Website – www.iobis.org

[13] Read, A 2005 "OBIS-SEAMAP" Ecological Consequences of Underwater Sound Symposium, Crystal City, Virginia, 3/16-18/05

[14]Engler, R, A Guisan, L Reichsteiner 2004 “An Improved Approach for Predicting the Distribution of Rare and Endangered Species From Occurrence and Pseudo-absence Data” J. Appl. Ecol. 41(2)

[15]Zaniewski, A, A Lehmann, J Overton 2002 “Predicting Species Spatial Distribution Using Presence Only Data: A Case Study of Native New Zealand Ferns” Ecol. Mod. 157 261-280