# PHOTO IDENTIFICATION AND SKIN LESION PREVALENCE OF BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS)* IN THE NEW YORK-NEW JERSEY HARBOR ESTUARY

A Final Report of the Tibor T. Polgar Fellowship Program


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## ABSTRACT

Investigating species health helps scientists monitor their well-being within an environmental context. The health of sentinel species can reflect environmental stressors and be used to infer ecosystem health. Due to their life history traits, cetaceans can serve as sentinel species in marine environments. In cetaceans, one method for determining individual and population health is by examining skin conditions. For two decades, skin lesions have been increasingly documented in coastal populations of bottlenose dolphins (*Tursiops truncatus*) worldwide. Lesion presence indicates underlying disease or diminished health and can reflect environmental stressors. Here, lesion prevalence of bottlenose dolphins in the New York-New Jersey Harbor Estuary was documented during their seasonal presence from spring to fall. Photographs of distinct individuals sighted from May to October 2017-2020 were compiled into a catalog and skin lesions were categorized and counted. Annually, the lowest lesion prevalence was in 2018 (P = 0.28) and highest in 2017 (P = 0.48). By month, prevalence decreased from spring to fall. Overall lesion prevalence in this population was lower than reported estimates for North Carolina, South Carolina, and Georgia, and roughly equivalent to Florida. The most common lesion types observed have been associated with viral infections and may be exacerbated by environmental stressors. This research establishes an important baseline for further studies into bottlenose dolphin population health in the New York-New Jersey Harbor Estuary and surrounding waters. Understanding the health of the bottlenose dolphin population in this heavily human dominated area is particularly important in the face of continued expansion of anthropogenic activities, including those related to forthcoming offshore wind development.

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# INTRODUCTION

There is currently worldwide concern about the health of the oceans (Borja et al. 2020) as the effects of climate change and environmental degradations become apparent across the globe (Bossart 2010). In order to better understand marine ecosystem health and the potential impacts of environmental stressors, a range of species have been selected based on their life history traits to serve as sentinels (Fossi and Panti 2017). These sentinel species can signal when there is cause for concern for wildlife and humans alike, which can subsequently inform management efforts (Fossi and Panti 2017). In marine systems, bottlenose dolphins (*Tursiops truncatus*) can be considered sentinel species for coastal ecosystems, as they are long-lived, easily-observed apex predators that are accessible for monitoring, and they are known to concentrate contaminants from the environment with potential health consequences (Wells et al. 2004; Bossart 2010; Fossi and Panti 2017). By understanding the health of this species within the context of their environment, inferences can be made regarding the health of the habitat they are utilizing and conservation measures can be established (Wells et al. 2004; Fossi and Panti 2017). While there are many logistical challenges to assessing dolphin health in the wild, the presence of skin conditions or lesions provides a visible morphological indicator of potential underlying disease (Duignan et al. 2020).

Skin lesions have been documented in bottlenose dolphin populations worldwide for the past two decades (Wilson et al. 1999), yet little is known about the pattern of development and the distribution of lesions on individuals and across populations. Although typically nonlethal, skin lesions are considered to be an indicator of disease or diminished health, and have been found in association with unusual mortality events for inshore dolphins (Bearzi et al. 2009; Toms et al. 2020). Lesions may be viral, fungal, or bacterial in origin and their prevalence and severity can be influenced by environmental factors, such as sea surface temperature and salinity, and anthropogenic influences, including chemical pollutants (Wilson et al. 1999; Bearzi et al. 2009; Hart et al. 2012). Therefore, skin lesion prevalence may be an indicator of environmental or anthropogenic stressors in the ecosystem that may lead to individual and/or population level health concerns (Taylor et al. 2020; Toms et al. 2020). Furthermore, lesion types have varying etiologies (Toms et al. 2020). When considering bottlenose dolphins as sentinel species, it is important to consider the critical differences in development and spread across skin lesion types. Some lesion types appear to be more strongly correlated with environmental conditions than others; thus, inferences about population or ecosystem health may vary based on lesion types observed.

Due to the macroscopic qualities of skin lesions, photo-identification ("photo-ID") methods have been co-opted for analyzing lesions on bottlenose dolphin individuals and calculating prevalence of lesions across populations (Taylor et al. 2020). Photo-ID has been increasingly used to monitor marine mammal populations as it offers a cost-effective, non-invasive approach and can additionally be used as a baseline for comparing lesion prevalence across space and time (Urian et al. 2014; Toms et al. 2020). While photo-ID has limitations, including inaccessibility to certain parts of the dolphin's body and lack of a conclusive etiology, this method nonetheless provides a useful, straightforward approach for characterizing visible skin lesion types and calculating a minimum prevalence estimate (Taylor et al. 2020; Hart et al. 2012).

Bottlenose dolphins are present in the New York-New Jersey Harbor Estuary ("Harbor Estuary" throughout) from spring to fall, migrating south to North Carolina during the cold weather months where they overlap with other Atlantic stocks (Hayes et al. 2018). These bottlenose dolphins belong to the Western North Atlantic Northern Migratory Coastal Stock, which is estimated to have over 6,500 individuals (Hayes et al. 2018). Anecdotally, bottlenose dolphins have been observed both more frequently and for an extended period in and around the Harbor Estuary in recent years (Stinnette et al. 2018), potentially due to efforts to restore the habitat (Taillie et al. 2020); however, little is known about the population in the Harbor Estuary and how they interact with this habitat.

The area in which bottlenose dolphins are typically found in and around the Harbor Estuary also encompasses the largest port on the Eastern seaboard and is exposed to intense vessel traffic (Port Technology 2020). Other maritime industries found in the Harbor Estuary and surrounding waters include fishing, tourism, and planned offshore renewable energy (Pirani et al. 2018; BOEM 2020); therefore, there is considerable overlap between habitat use by bottlenose dolphins and human use of these waters. Though this ecosystem is exposed to high levels of anthropogenic disturbance, no previous analyses of skin lesion prevalence have been conducted on the bottlenose dolphins in the Harbor Estuary. The Harbor Estuary also experiences seasonal fluctuations in sea surface temperature (Balcom et al. 2008) and variations in salinity due to the oceanic flushing during tides and freshwater contributions from its many tributaries, including the mainstem Hudson River (Pirani et al. 2018). Both of these environmental characteristics have been previously linked to fluctuations in skin lesion prevalence in dolphins (Wilson et al. 1999).

Given the extent of bottlenose dolphin presence in the Harbor Estuary and the level of anthropogenic disturbance, the aim of this project was to gain a better understanding of population health in the bottlenose dolphins in the Harbor Estuary by characterizing the types of skin lesions present and variations in skin lesion prevalence by season. Given that the estuarine environment in this study experiences fluctuations in salinity and sea surface temperature, both of which are considered natural stressors that contribute to lesion development, their influence on lesion prevalence was also investigated (Wilson et al. 1999; Hart et al. 2012). Lastly, comparing skin lesion prevalence during and before the global COVID-19 pandemic provided a unique opportunity to investigate whether lesion prevalence may be correlated with a period of reduced marine traffic (March et al. 2020).

## METHODS

*Data Collection and Building a Photo-Identification Catalog of Individuals*

Non-systematic, vessel-based surveys were conducted in the Harbor Estuary from May to October in 2017-2020. Vessels ranged in size from 9-15 m, and maintained survey speeds of 13-17 knots during daylight hours and Beaufort sea states of δ3. Trained observers were stationed around the vessel such that a clear 360° view was maintained throughout the survey. Once bottlenose dolphins were sighted, they were approached to collect photographs (Figure 1). Photographs were collected using a Nikon D2700 digital camera with a Nikon AF-S Nikkor 70-200mm lens.

All photographs containing bottlenose dolphins were analyzed using Adobe Bridge and categorized based on photo quality and the distinctiveness of the individual. Photographs of insufficient quality (e.g. blurry or not suitable for identification) were excluded from the analysis and the remaining photographs were subsequently sorted by individual distinctiveness using natural markings (Urian et al. 2014). Because this population migrates across large distances, the probability of resighting an individual is reduced compared to smaller, resident populations (Urian et al. 2014). To ensure that resights were true positives, a high threshold for individual distinctiveness was used; only individuals with natural markings that were distinct enough to eliminate the potential for “twin” individuals were included (Urian et al. 2014). Each photo containing identifiable individuals was cropped to include just the body of the individual and the individual was given a unique ID. A catalog of unique individuals was built by comparing all the distinctive fins to one another; each distinctive fin was either matched to an individual in the catalog and noted as a resight or added to the catalog as a new individual.

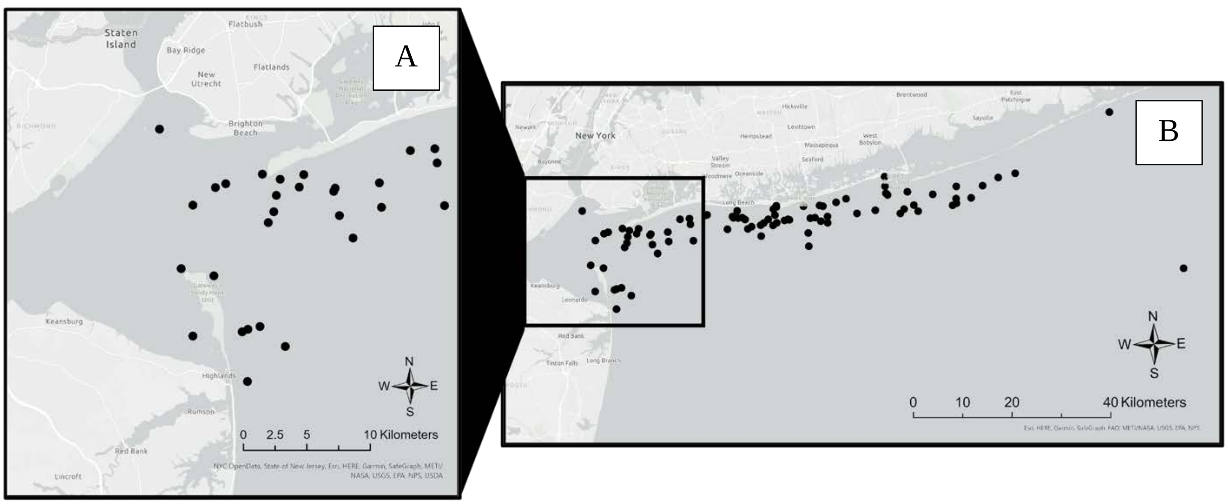


**Figure 1. Bottlenose dolphin sightings in the New York-New Jersey Harbor Estuary (A) and surrounding waters (B) from 2017-2020.**

*Skin Lesion Categorization*

Only catalogued individuals were analyzed for skin lesion prevalence in order to reduce the potential for repeat sampling of the same individual. If a catalogued individual was resighted within the same year, only the first high quality photograph of the individual from the year was included in the analysis. Catalog photos were also excluded from the lesion analysis if the surface of the skin was not visible due to poor lighting conditions or if only the dorsal fin was visible above the water line. Each of the remaining photographs were visually screened and coded for the presence (1) or absence (0) of visible lesions. If present, lesion types were categorized according to Toms et al. 2020, and an additional “other” category. The categories included black amorphous, dark spots, lunar, white amorphous, cloudy white spots, white freckles, dark fringe, white fringe, tattoo, spotted, vesicular, mottled, orange hue, orange patches, discolored head, pathogenic rake mark-associated lesions, non-pathogenic rake mark-associated lesions, and other (Figure 2). Rake marks are caused by aggressive contact between one dolphin’s teeth and another’s body, usually resulting in long, thin parallel lines on the surface of the skin (Scott et al. 2005). All rake mark-associated lesions were excluded from the study, as previous lesion analyses do not include them. The number of lesion types of for each individual dolphin was calculated and the most common skin lesion type was determined for each year and for the full study period.

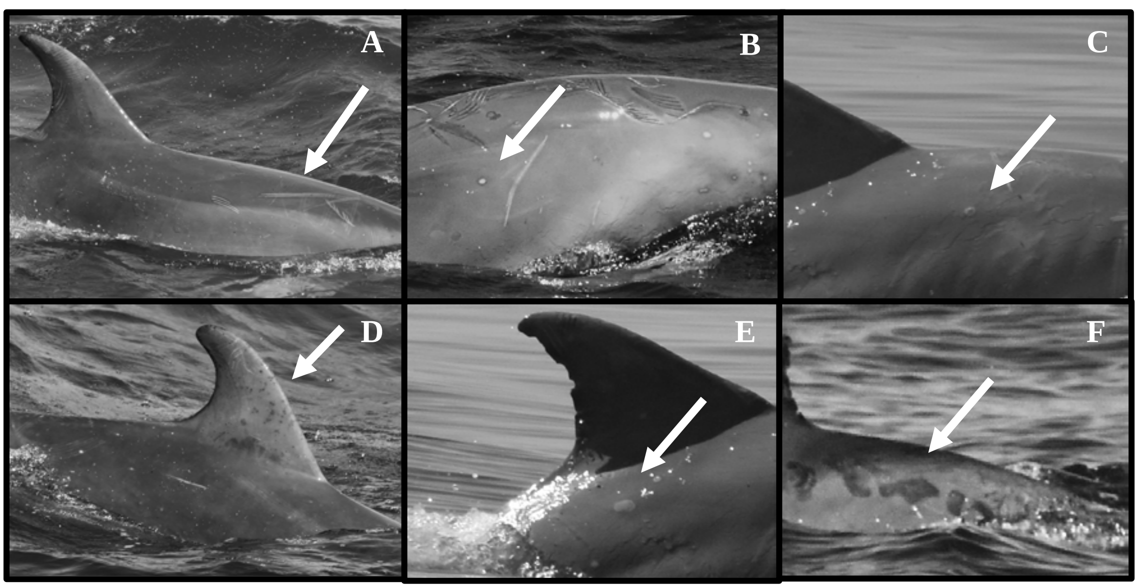


**Figure 2. Bottlenose dolphins exhibiting various lesion types, including a) non-pathogenic rake marks, b) dark-fringe lesions, c) white-fringe lesions, d) dark spot lesions, e) cloudy white spots, and f) black amorphous lesions.**

*Spatial and Temporal Variations in Skin Lesion Prevalence*

Overall prevalence for skin lesions in the Harbor Estuary was calculated and compared to reported overall prevalence estimates for other sites along the Atlantic Coast, including populations in North Carolina, South Carolina, Florida, and Georgia (Hart et al. 2012; Taylor et al. 2020; Toms et al. 2020; Table 1, Equation 1). To investigate temporal variations, annual and monthly prevalence were calculated (Taylor et al. 2020; Toms et al. 2020; Table 1, Equations 2 and 3). Because there was only one sighting in May, monthly prevalence was calculated from June to October.

**Table 1. Equations for calculating overall, annual, and monthly prevalence based on Taylor et al. 2020.**

| Equations for Calculating Prevalence | |
|---|---|
| Equation 1: Overall Prevalence | $P_{overall} = \frac{\#\ of\ individuals\ with\ at\ least\ one\ lesion\ (2017-2020)}{total\ \#\ of\ individuals\ screened\ (2017-2020)}$ |
| Equation 2: Annual Prevalence | $P_{annual} = \frac{\#\ of\ individuals\ with\ at\ least\ one\ lesion\ during\ a\ particular\ year}{total\ \#\ of\ individuals\ screened\ during\ a\ particular\ year}$ |
| Equation 3: Monthly Prevalence | $P_{monthly} = \frac{\#\ of\ individuals\ with\ at\ least\ one\ lesion\ during\ a\ particular\ month}{total\ \#\ of\ individuals\ screened\ during\ a\ particular\ month}$ |

*Skin Lesion Prevalence and Environmental Variables*

Each bottlenose dolphin sighting in the catalog was matched with the Julian day in which it was observed. The time period during which bottlenose dolphins were sighted in the Harbor Estuary was partitioned into 22 weeks from May 31 to October 31. For each bottlenose dolphin sighting, sea surface temperature (°C) was found using the OSTIA L4 SST analysis dataset from the UK Met Office and sea surface salinity (PSU) was determined using the SMOS/MIRAS L3 daily sea surface salinity dataset from NOAA. For each week, the proportion of individuals with lesions, mean sea surface temperature, and mean salinity were calculated. Generalized linear models were built in R (v. 3.4.3, R Core Team 2020) to explore how the weekly proportion of lesions correlated with temporal and environmental characteristics. Akaike Information Criterion (AIC) scores were used to determine the optimal model fit. The models used a log-link function and weeks were weighted by the number of days included. Akaike Information Criterion (AIC) scores were used to determine the optimal model fit (Wagenmakers and Farrell 2004). The model with the lowest AIC score was used (Bursac et al. 2008), and for models with comparative AICs, the one with the fewest terms was selected (Harrison et al. 2018). Figures were produced in R using the package ggplot2 (Wickham 2016).

## RESULTS

### *Characteristics of Identified Individuals*

Photographs of bottlenose dolphins were collected during the months of May to October in 2017-2020. In the final photo-ID catalog, there were 221 unique individuals. Out of these, 7% (n = 16) were resighted and 3% (n = 7) were resighted within the same year (Figure 3). Once within-year resights and catalog photos with poor lighting or only the dorsal visible were excluded, the 203 remaining photographs were analyzed for lesions.

**Figure 3. Photographs of individual U071, sighted on September 20, 2018 (left) and again on May 31, 2019 (right) with a new lesion to the left of the dorsal fin.**

*Skin Lesion Categorization*

The number of lesion types per individual ranged from 0-4, with a mean of 0.57 ± 0.03 types. In this population, 59% of individuals lacked visible lesions, while 30% had one lesion type, and 11% had two or more types of lesions (Figure 4). The five most common lesion types overall were cloudy white spots (n = 24, 12% of individuals), white amorphous lesions (20, 10%), mottled lesions (15, 7%), tattoo lesions (11, 5%), and dark-fringe lesions (9, 4%). Cloudy white spots were the most common lesion type in 2017 (5, 16%), 2019 (13, 13%), and 2020 (5, 16%), while in 2018 mottled lesions were most common (3, 8%); therefore, it appears that certain lesion types remain prevalent across years.

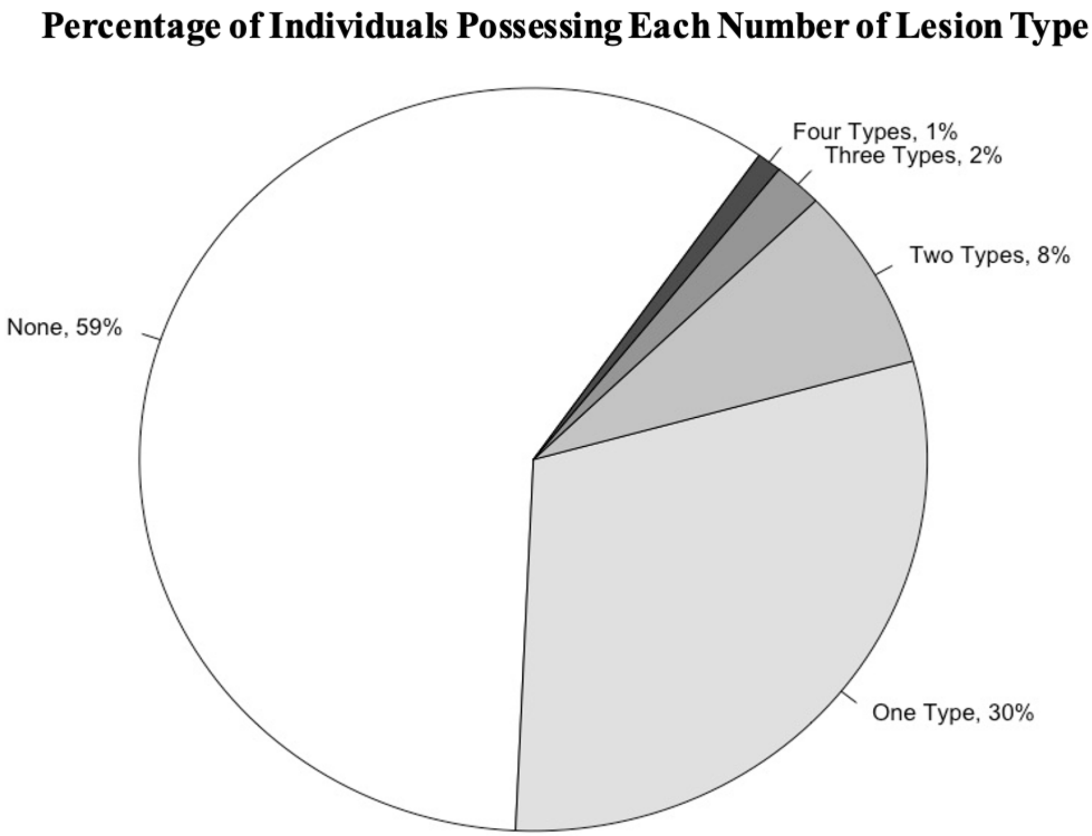


**Figure 4.** **Percentage of individuals with none, one, two, three or four types of lesions present.**

*Spatial and Temporal Variations in Skin Lesion Prevalence*

Skin lesion prevalence in the Harbor Estuary varied annually, with the highest prevalence observed in 2017 and the lowest in 2018 (Table 2). Although 2019 had a larger sample size compared to other years, skin lesion prevalence was moderate. 2020 had a similar sample size to 2017 and 2018, and had the second lowest lesion prevalence estimate. Skin lesion prevalence in the Harbor Estuary also varied by month. The highest prevalence was found in June ($P = 0.68 \pm 0.10$), with lower prevalence during July ($P = 0.36 \pm 0.069$), August ($P = 0.30 \pm 0.081$), and October ($P = 0.37 \pm 0.070$), and a spike in September ($P = 0.46 \pm 0.073$; Figure 5). From June to July, prevalence decreased by 32%. Overall skin lesion prevalence in the Harbor Estuary (n =

203, P = 0.41, 95% CI = 0.35-0.48) was low relative to populations in North Carolina (n = 169, P = 0.49, 95% CI = 0.42-0.57), South Carolina (n = 351, P = 0.49, 95% CI = 0.43-0.54), and Georgia (n = 322, P = 0.59, 95% CI = 0.53-0.64), and roughly equivalent with populations in Florida (n = 266, P = 0.38, 95% CI = 0.32-0.44; Hart et al. 2012; Taylor et al. 2020).

**Table 2. Overall and annual minimum prevalence estimates for skin lesions.**

| Annual and Overall Skin Lesion Prevalence | | | | | |
|---|---|---|---|---|---|
| | **2017** | **2018** | **2019** | **2020** | **Overall** |
| **n** | 31 | 36 | 104 | 32 | 203 |
| **P** | 0.48 | 0.28 | 0.45 | 0.38 | 0.41 |
| **95% CI** | 0.31-0.66 | 0.13-0.43 | 0.36-0.55 | 0.21-0.55 | 0.35-0.48 |

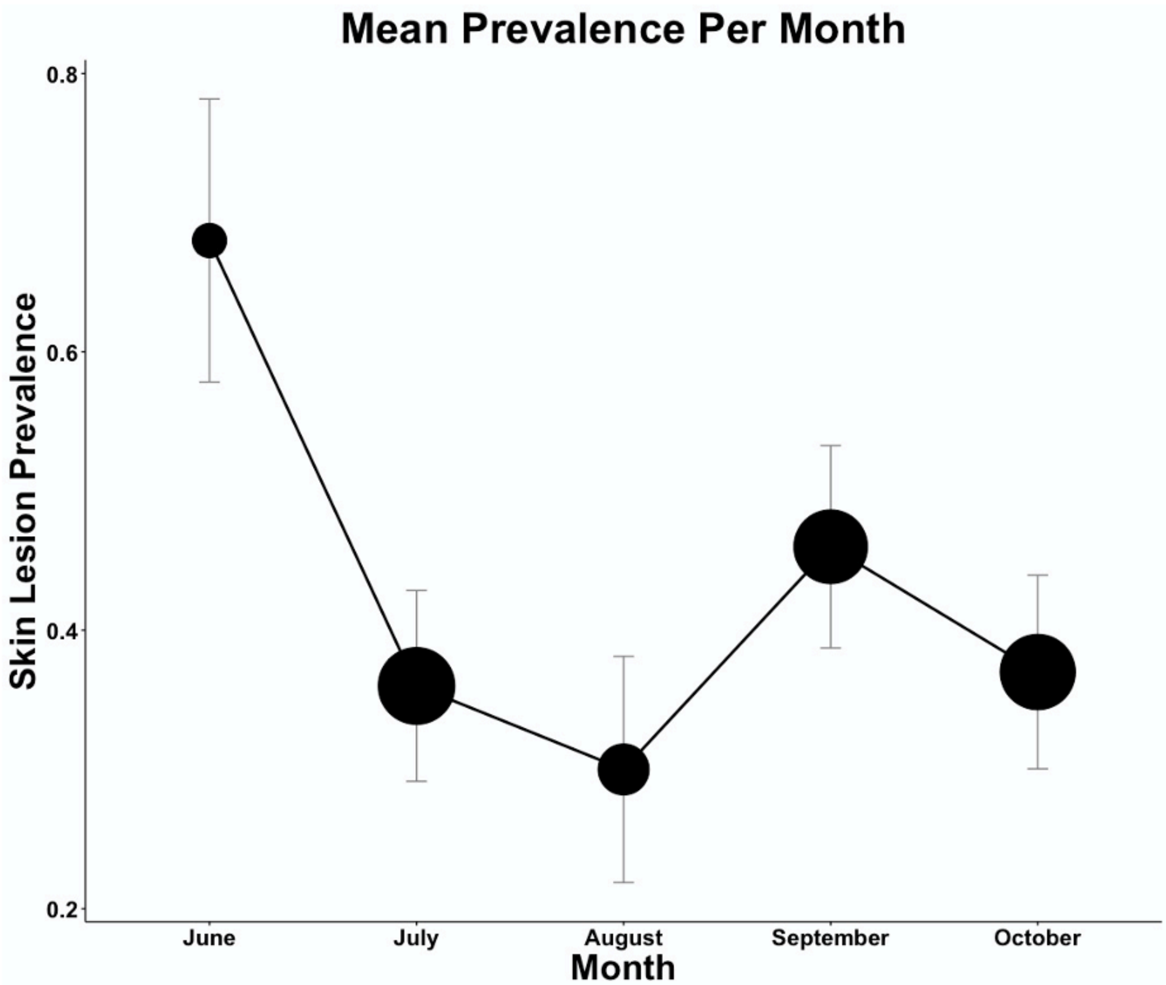


**Figure 5.** **Decrease in mean monthly prevalence of skin lesions from June to October. In September, a small spike in prevalence was observed. The size of the points reflects the number of individuals screened for each month across all years.**

*Skin Lesion Prevalence and Environmental Variables*

The optimal model included salinity and sea surface temperature as explanatory variables (Table 3). In this optimal model, both sea surface temperature (coefficient: -0.04°C, 95% CI: -0.08, -0.01, $p = 0.02$) and salinity (coefficient: -0.14 PSU, 95% CI: -0.23, -0.05, $p = 0.01$) significantly correlated with weekly skin lesion prevalence. Skin lesion prevalence was higher in colder and less saline waters (Figure 6).

**Table 3.** **Table showing the five models with the lowest AIC scores. The optimal model is bolded.**

| Number | Model | df | AIC | AIC weight |
|---|---|---|---|---|
| **1** | **sea surface temperature + salinity** | **4** | **1.1** | **0.538** |
| 2 | sea surface temperature + salinity + week | 5 | 2.3 | 0.287 |
| 3 | salinity | 3 | 5.1 | 0.071 |
| 4 | salinity + week | 4 | 6.6 | 0.034 |
| 5 | sea surface temperature | 3 | 7.4 | 0.022 |

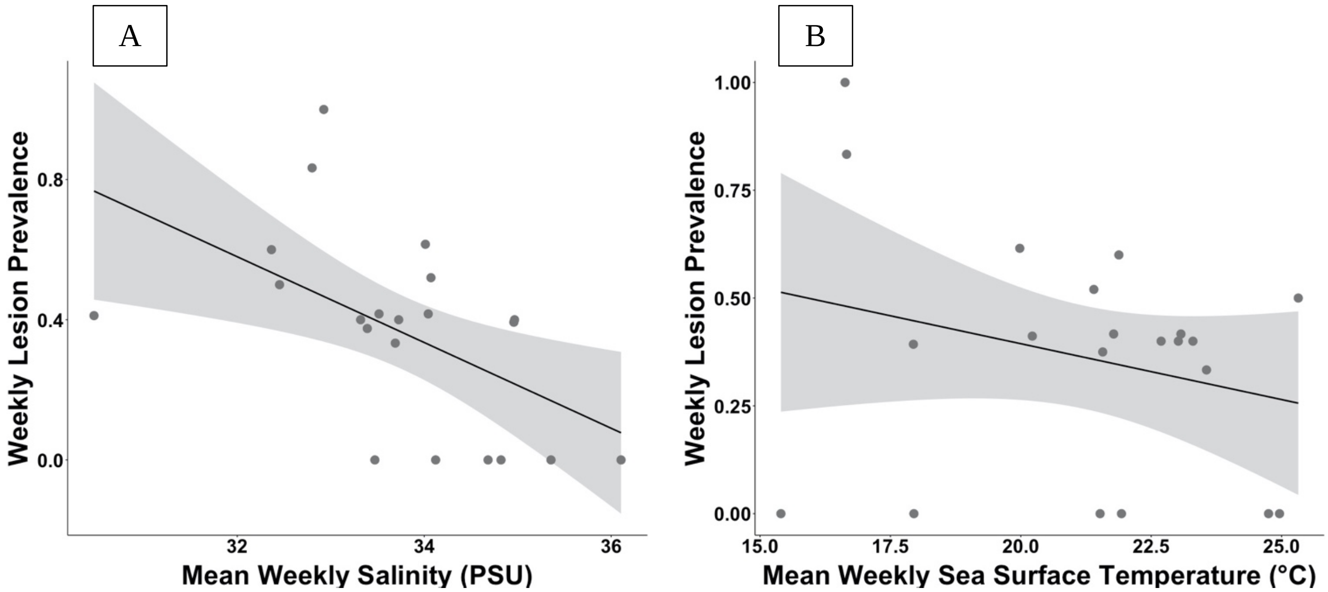


**Figure 6.** **Line graphs showing how salinity (A) and sea surface temperature (B) correlate with weekly lesion prevalence. Observed data are indicated by dark grey points and 95% confidence intervals indicated by the light grey shaded region.**

## DISCUSSION

Overall, skin lesion prevalence was not stable temporally within the New York-New Jersey Harbor Estuary, or spatially across the Atlantic coast. Approximately four out of every ten bottlenose dolphins in this study had at least one lesion and there were annual and monthly fluctuations observed that may reflect environmental stressors (Hart et al. 2012; Taylor et al. 2020).

*Spatial and Temporal Variations in Skin Lesion Prevalence*

Skin lesion prevalence fluctuated temporally at multiple scales. Annually, skin lesion prevalence varied by as much as 20% between years. Other West Atlantic populations have more stable prevalence estimates across years, with the largest annual difference being 11% (Taylor et al. 2020). Interestingly, 2020 was not the year with the lowest lesion prevalence, despite the reduction in maritime traffic during the COVID-19 global pandemic (March et al. 2020). The effects of this reduction may be delayed, masked by other factors, or vessel activity may not be a significant contributing factor to lesion development in this area, but further research is needed.

By month, there was an apparent negative trend from June to October. Other bottlenose dolphin populations show a similar trend, with prevalence highest in spring before decreasing over the summer months into the fall (Taylor et al. 2020; Hart et al. 2012). Although this study started at the onset of summer, the highest prevalence was observed in the earliest month, with lesion prevalence in June nearly double that of July. Prevalence subsequently decreased throughout the summer and fall months, with a small peak in September. This trend may reflect seasonal changes in environmental conditions that influence lesion development. For instance, the negative relationship between prevalence and salinity resembles the decrease in prevalence by month, potentially because the Harbor Estuary may have lower salinity during the spring as increased rainfall and melting snow may produce an influx of freshwater into the estuarine ecosystem. Alternatively, prevalence may be highest in spring when water temperatures are colder, and decrease as the water temperature increases over the summer and into the fall.

In addition to fluctuations in prevalence over time, there were spatial variations. Skin lesion prevalence around the Harbor Estuary was within the range of prevalence estimates for populations inhabiting different regions across the Atlantic Coast of the United States, but was relatively lower than most of the comparison sites (Taylor et al. 2020; Hart et al. 2012). Moreover, skin lesion prevalence estimates for Atlantic coast populations (P = 0.38-0.59) are much lower than those reported for other parts of the globe (P = 0.63-1.0; Hart et al. 2012; Wilson et al. 1999). Differences in prevalence across sites may be attributed to varying methodology, environmental conditions, and population demographics (Fury and Reif 2012).

*Skin Lesion Prevalence and Environmental Variables*

In the Harbor Estuary, salinity was significantly and negatively correlated with lesion prevalence. A similar trend has been found in other populations, with more lesions observed in fresher waters (Fury and Reif 2012; Wilson et al. 1999). Skin lesion prevalence was also significantly higher during colder water temperatures in the Harbor Estuary, similarly to other locations (Hart et al. 2012; Wilson et al. 1999). Given that the majority of photographs were collected from June to October, the strength of the relationship between sea surface temperature and lesion prevalence might be influenced by data collection bias during warmer months. Once more data has been collected across a broader temporal range, the relationship between prevalence and environmental variables can be further explored.

*Potential Health Risks Associated with Lesions*

Four of the five most common lesion types identified on bottlenose dolphins in this study have been previously associated with viral infections. Cloudy white spots have been associated with herpesvirus, while white amorphous lesions have been associated with herpesvirus in addition to a number of other potential causes, including healing after trauma, ectoparasite attachment, previous viral infection, and inflammation (Hart et al. 2012; Toms et al. 2020). Mottled lesions have an unknown origin, and both tattoo lesions and dark-fringe lesions have been associated with poxvirus (Toms et al. 2020; Hart et al. 2012). Neither herpesvirus nor poxvirus appear to be fatal in bottlenose dolphins, but may have sublethal effects that ultimately contribute to reduced population health (Bossart and Duignan 2018; van Elk et al. 2009). The causes and effects of these viruses are important to understand, particularly given the level of anthropogenic disturbance that bottlenose dolphins are exposed to in the Harbor Estuary which may directly contribute to population health decline or exacerbate the effect of natural stressors.

Herpesvirus is hypothesized to spread through sexual contact of free-ranging bottlenose dolphins (van Elk et al. 2009). Though typically nonlethal, dolphin herpesviruses are associated with minor mucosal or epidermal lesions and have occasionally been found in relation to fatal infections of the nervous system (Bossart and Duignan 2018). Because the distribution and development are hypothesized to be socially driven and the genetic make-up of the herpesvirus can reflect the geographic origin of the dolphin, there may be implications for determining the directionality of the spread within and across populations (van Elk et al. 2009). This is particularly relevant for this population considering that during cold water months the bottlenose dolphin population in this study overlaps spatially and temporally with other populations that have higher lesion prevalence, such as the North Carolina population, suggesting that herpesvirus may be dispersing into the study population during the winter season.

Whereas herpesvirus spread is socially driven, development of poxvirus lesions has been correlated with environmental conditions (Flom and Houk 1979; Powell et al. 2018). Typically, poxvirus lesion prevalence increases as salinity and sea surface temperature decrease (Hart et al. 2012; Fury and Reif 2012). In addition to these natural stressors, differential prevalence of poxvirus expression may be associated with chemical pollutants in the water, which may have immunosuppressive effects and contribute to lesion development (Bossart and Duignan 2018).

Lastly, depressed immune systems can be caused by stress, which could ultimately lead to an increased prevalence of poxvirus lesions (Fury and Reif 2012). Poxvirus lesions have been found with varying prevalence in the Atlantic and Pacific Oceans, as well as the North, Mediterranean and Tasman Seas, suggesting that there are either common environmental stressors in these different areas or that many different stressors can contribute to poxvirus lesion development (Maldini et al. 2010; Fury and Reif 2012).

Given that bottlenose dolphins exhibit lesions when there are stressors in the environment, it has been suggested that lesion prevalence can be used as an indication of population health and ecosystem degradation (Powell et al. 2018; Bossart and Duignan 2018). When considering bottlenose dolphins as sentinel species, it is important to consider the critical differences in development and spread across lesion types, because some types appear to be more strongly correlated with environmental conditions than others; inferences about population or ecosystem health may vary based on lesion types observed. For instance, poxvirus lesions, including dark-fringe and tattoo lesions, have been highly correlated with environmental conditions whereas the development and distribution of herpesvirus-related lesions, including cloudy white spots and white amorphous lesions, are more likely socially driven (Fury and Reif 2012; Flom and Houk 1979; Powell et al. 2018; van Elk et al. 2009). Therefore, the presence of dark-fringe and tattoo lesions are more reliable indicators of environmental stressors than cloudy white spots or white amorphous lesions. As further monitoring occurs for the Harbor Estuary population of bottlenose dolphins, tracking fluctuations in poxvirus lesions would be beneficial to assess potential underlying environmental stressors to provide insight on ecosystem health.

In the Harbor Estuary, bottlenose dolphins may be developing poxvirus lesions for a variety of reasons. In addition to natural stressors, there are multiple contaminants of concern found in the Harbor Estuary, including polychlorinated biphenyls (PCBs), mercury, dioxins and furans, pesticides and polyaromatic hydrocarbons (Lodge et al. 2015). Contaminants have been found in high concentrations in fish tissues in the Harbor Estuary (Lodge et al. 2015), and as bottlenose dolphins consume these fish, they may bioaccumulate contaminants. In turn, these contaminants may reduce immune functioning and contribute to lesion development (Bossart and Duignan 2018). It is possible that lesion prevalence is highest in spring because storm water runoff moves contaminants from tributaries into and throughout the Harbor Estuary system, where dolphins are found (Lodge et al. 2015). Furthermore, bottlenose dolphins in the Harbor Estuary may experience high levels of stress due to the intense anthropogenic disturbance in this region that may ultimately contribute to depressed immune systems and increased susceptibility to diseases (Fury and Reif 2012). While poxvirus, like herpesvirus, has a low mortality rate in odontocetes it may still indicate poor health and can factor into calf mortality (Powell et al. 2018; Bossart and Duignan 2018); therefore, the presence of poxvirus lesions in bottlenose dolphins in the Harbor Estuary is cause for concern and further research into the causes and effects of these lesions is needed.

*Limitations of the Data*

Photographic identification of individual animals offers a cost-effective and noninvasive way to explore the potential variation in skin lesion prevalence which can then be supplemented by other methods such as capture and release (Taylor et al. 2020; Bossart et al. 2019; Hart et al. 2012). Photographic identification is limited by photo quality, visible parts of the dolphin's body, and variation in methods of photographic assessment across studies (Fury and Reif 2012). Photographic analysis and visual screening of lesions are subject to some degree of observer bias (Toms et al. 2020; Urian et al. 2014). Additionally, standards for lesion categorization have not been solidified, and there is variation in both the number and type of categories included in analyses of lesion prevalence (Toms et al. 2020); however, despite these limitations, this method provides valuable data for inferring population health and making comparisons across time and space, as well as providing insight into the health of the underlying ecosystem (Toms et al. 2020; Fossi and Panti 2017).

*Future Directions and Conclusions*

Continuing to use photo-ID to expand the catalog and monitor the population of bottlenose dolphins in the Harbor Estuary will increase the sample size for resighted individuals, which can then be analyzed for longitudinal patterns in skin lesions for individuals in addition to the population as a whole.  This would allow for demographic analyses of skin lesion prevalence. At other locations, immature bottlenose dolphins demonstrate significantly higher prevalence of poxvirus-associated lesions than mature individuals, suggesting that this lesion type is not distributed evenly throughout the population (Van Bressem et al. 2003; Powell et al. 2018). Demographic information of the catalogued individuals from the Harbor Estuary is not yet readily available due to the relatively recent undertaking of photo-ID analysis in this region; however, as the catalog expands and the understanding of this population improves, it will be possible to analyze variation in lesion prevalence based on individual characteristics, such as age.  This will provide more nuanced insights on how bottlenose dolphins may be affected by stressors in this environment, which could be taken into consideration when drawing inferences about the underlying ecosystem health.

Future studies should also incorporate other methods of assessing disease prevalence in this bottlenose dolphin population, such as tissue analyses.  Integrating multiple approaches for assessing health contributes to a comprehensive understanding of the development and spread of lesions in Atlantic populations of bottlenose dolphins. For instance, information on the origin and persistence of lesions on the skin surface could indicate whether lesion presence reflects environmental stressors in the current habitat or previous habitats throughout the migration route. Additionally, by understanding the etiology of the lesions, it might be possible to consolidate lesion types based on the causal agent. Currently, if the macroscopic qualities of a lesion change drastically throughout the development of an infection, it could be categorized in multiple ways at different stages. By linking observable characteristics of an infection to the causal agent, those categories could be grouped by etiology and stage of development, which would aid in the standardization of skin lesion categories and allow for more accurate comparisons across study sites.

While this study included two environmental variables commonly associated with skin lesions, sea surface temperature and salinity, future studies on this population should include other anthropogenic stressors in the environment, such as chemical pollutants. Moreover, if there are multiple stressors in an area, the population may be more susceptible to the development of lesions, with consequences to fitness or survival (Powell et al. 2018). For instance, if there are chemical pollutants with immunosuppressive effects in an environment with low salinity, lesion development may be more likely, potentially contributing to higher rates of calf mortality. Therefore, possible cumulative and interactive effects between multiple stressors and the potential consequences of those effects should be further investigated, especially given that the study population migrates across large distances and is potentially exposed to many stressors throughout their migration.

In summary, 41% of the bottlenose dolphins in this study had at least one visible skin lesion and 11% had multiple lesion types, indicating that diseased individuals are common in this population. Temporal fluctuations of lesion prevalence in the Harbor Estuary demonstrate that prevalence is dynamic in this population, potentially reflecting variations in environmental stressors. Further research is needed to supplement and build upon this data to better understand the interactions between bottlenose dolphins and the natural and anthropogenic features of the Harbor Estuary. This study provides a straightforward framework for the continued monitoring of this bottlenose dolphin population during their seasonal presence, which is particularly important given forthcoming developments planned in this region. As sentinel species, understanding the health of these bottlenose dolphins can provide insight on the health of the underlying ecosystem with potential implications for coastal management and conservation efforts. This is particularly important given the continued expansion of anthropogenic activity in this heavily human dominated region. Monitoring environmental stressors and their impacts on bottlenose dolphin health as these developments occur can signal when there may be cause for concern for humans and wildlife alike.

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