INFERRING SURVIVAL AND MORTALITY OF STRANDED COMMON DOLPHINS OFF CAPE COD, MA USING SATELLITE TELEMETRY DATA

By

Audrey White
Dr. Andrew Read, Adviser
Dr. Patrick Halpin, Adviser
April 24, 2020

Masters project submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment of
Duke University

Introduction:

Cetacean strandings are a worldwide phenomenon, which makes research into this field of global importance. Live stranded cetaceans create intense public interest and concern due to the animal welfare considerations for the health of the marine mammals. Title IV of the Marine Mammal Protection Act (MMPA) deals primarily with the Stranding Response Program—an indication of the national importance of this issue. Cape Cod, Massachusetts is a hotspot of marine mammal stranding events, as its protruding hook shape, shallow sloping beaches, and large tidal fluxes contribute to frequent strandings (Wiley et al, 2001; Bogomolni et al, 2010; Sharp et al, 2016). The Marine Mammal Rescue and Research Team at the International Fund for Animal Welfare (IFAW) responds to on average 262 marine mammal strandings per year on Cape Cod and elsewhere in southeastern Massachusetts (www.ifaw.org). IFAW has improved response time and medical care in the field, resulting in an increase in survival rates of live stranded small cetaceans (dolphins and porpoises) from 14% (1999-2004) to 61% (2005-2012) (Sharp et al, 2016). After rescuing animals from their stranding location, the team transports these individuals to one of three primary release locations, chosen specifically for their quick access to deep water, giving the animals a better chance of reintegrating into the wild (Figure 1). In some circumstances, other, less ideal release locations have been used as well. The team also collects scientific data to better understand why marine mammals strand and how to better rescue them. Modern stranding protocols established by IFAW have led to a streamlined system of data collection and animal care procedures.

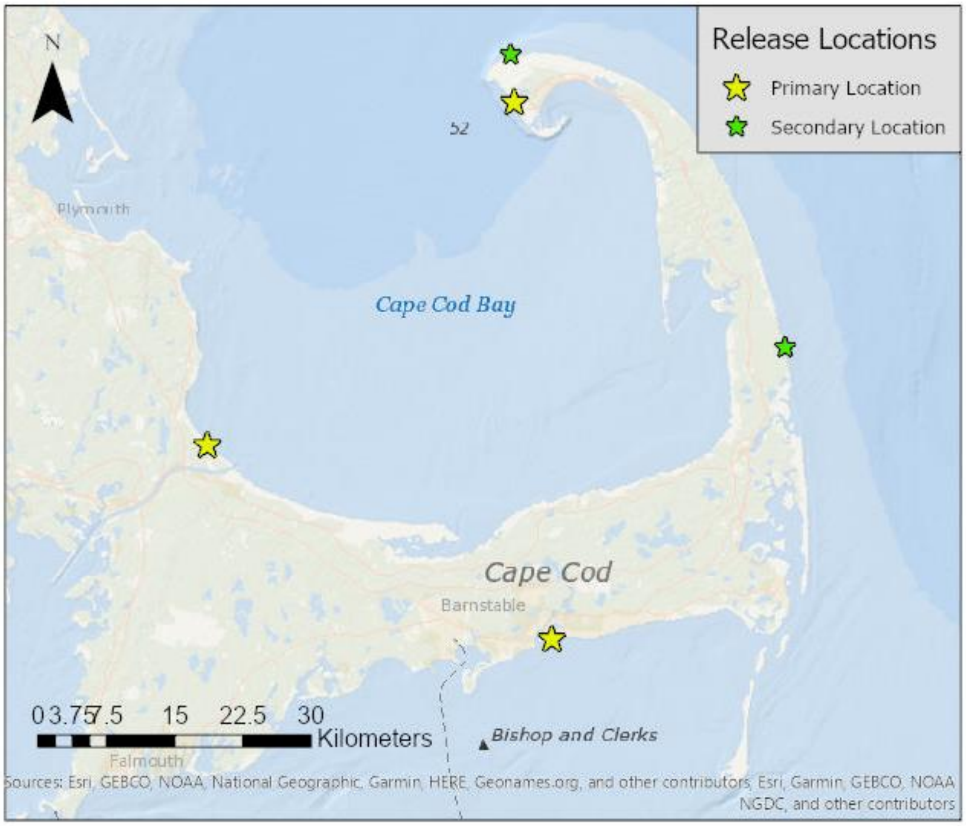

Figure 1. Release locations indicated by yellow star for stranded cetaceans on Cape Cod. Primary locations include Scusset Beach, Sagamore; West Dennis Beach, Dennis; and Herring Cove, Provincetown. Secondary locations include Coast Guard Beach, Truro; and Race Point, Provincetown.

Short-beaked common dolphins (*Delphinus delphis*) are a highly social, energetic species that is normally found in cool, offshore waters (NOAA Office of Protected Resources, 2017). The species is not endangered or threatened, but is protected under the MMPA. Due to their highly social behavior, mass strandings (involving two or more individuals, excluding mother-calf pairs) contribute more stranding numbers than single strandings (Wiley et al, 2001; Bogomolni et al, 2010; Sharp et al, 2016). Most mass strandings of this species occur in Massachusetts, although their range extends from

Nova Scotia to Cape Hatteras (NOAA Office of Protected Resources, 2017). Of the 13 species that IFAW responds to, common dolphins are the most frequent cetacean species to strand in their range (Sharp et al, 2016). IFAW's commitment to improving the survival of these stranded animals has lead them to using new and innovative technologies to track and analyze the behavior of these animals in the wild after release.

Satellite-linked tags have become a common tool in marine mammal research because they allow researchers to track marine mammals over long periods of space and time from the comfort of their office (Mate and Lagerquist, 2007; Balmer et al, 2014; Nowacek et al, 2016). IFAW has been attaching satellite tags to live-stranded, released cetaceans since 2010 and has amassed a large set of data from over 100 pinnipeds and cetaceans monitored in this fashion. This technology can lead to insight into the behavior and habitat use of these animals, although a pervasive problem of this technology is the failure of transmitters, often for unknown reasons (Hays et al, 2007; Balmer et al 2014; Nowacek et al, 2016). Some theories as to why tags are failing include the tag pulling out of the dorsal fin due to fast currents or conspecifics, a fouling of the conductivity sensor so that the tag is no longer able to detect when the dolphin breaks the surface of the water, a broken antenna, running out of battery life, or because the animal died (Hays et al, 2007).

The tags that IFAW has deployed on common dolphins have all transmitted for fewer than 67 days, with an average transmission duration of only 18 days (maximum transmission duration: 66.9 days; minimum transmission duration: 2.5 hours). The question of why these tags are failing (presumably before their battery life runs out) is of particular concern to IFAW, who spend a significant amount of time and resources rescuing and studying these animals. The premature cessation of messages from these tags leads to the question of whether the tags are failing or the stranded, rescued animals are dying after release considering that strandings are particularly stressful events for marine mammals (Hays et al, 2007; Bogomolni et al, 2010; Sharp et al, 2014). Stranded cetaceans, in particular, are susceptible to capture myopathy, which occurs when an animal is physically restrained or put under considerable stress (Rojas-Bracho et al, 2019). This syndrome can lead to muscle damage and in certain cases, death (Rojas-Bracho et al, 2019). Additionally, stranded animals may possess preexisting health conditions that contributed to their stranding in the first place (Bogomolni et al, 2010; Sampson et al, 2012; Sharp et al, 2014).

A previous study of satellite tagged stranded and released common dolphins in Cape Cod by Sharp, et al (2016) found that animals that transmitted longer than 21 days post-release were likely to survive and reintegrate into wild populations. However, in this study, a large number of tagged animals transmitted for less than 21 days and were never seen again (n=27/66). A number of different scenarios could cause the satellite tag to fail, which complicates the problem of assessing whether a dolphin died as a result of the stranding (Hays et al, 2007).

In my project, I used a consistent signal from satellite telemetry data from stranded common dolphins to indicate likely mortality. In particular, I identified three behavioral parameters (swim speed, turning angle and number of messages received per day) as potential indicators. In my dataset of 66 satellite tagged common dolphins, three individuals transmitted for six days or less and their carcasses were recovered on shore. I used the behavior of these animals to describe a consistent pattern that leads to mortality. I hope that my work will help to improve our ability to distinguish between equipment failure and animal death and thus improve rescue and release protocols for stranded cetaceans on Cape Cod and elsewhere.

Methods:

Data Acquisition and Filtering

Telemetry data were obtained *via* Service Argos (CLS America, Inc., Largo, MD) and stored at the IFAW International Operations Center in Yarmouth Port, MA. Service Argos provides a location class (LC) for each estimated position based on the number of messages received by each satellite, the number of satellites receiving the messages from the tag, and the length of time between messages received on each satellite pass. Service Argos reports that the best LCs (LC 3 and 2) have a positional error estimate of 350 m or less.

Raw location data were filtered using the Douglas Argos Filter (Douglas et al., 2012) to remove implausible location estimates, based on movement rates, distances, turning angles, and location quality. Locations were retained if they were within 5 km of the previous retained point, as this was considered a redundant location in the Douglas Filtering algorithm. In this study, all LCs 2 and 3 were retained automatically, a distance of 5 km was used as the maximum redundant distance, and 15 km/h was used as the maximum potential rate of travel. After applying the Douglas Filter, approximately 10%

of point locations in all tracks were filtered out and the remaining locations were used in subsequent analyses. Example tracks from each transmission duration group are shown in Figure 2.

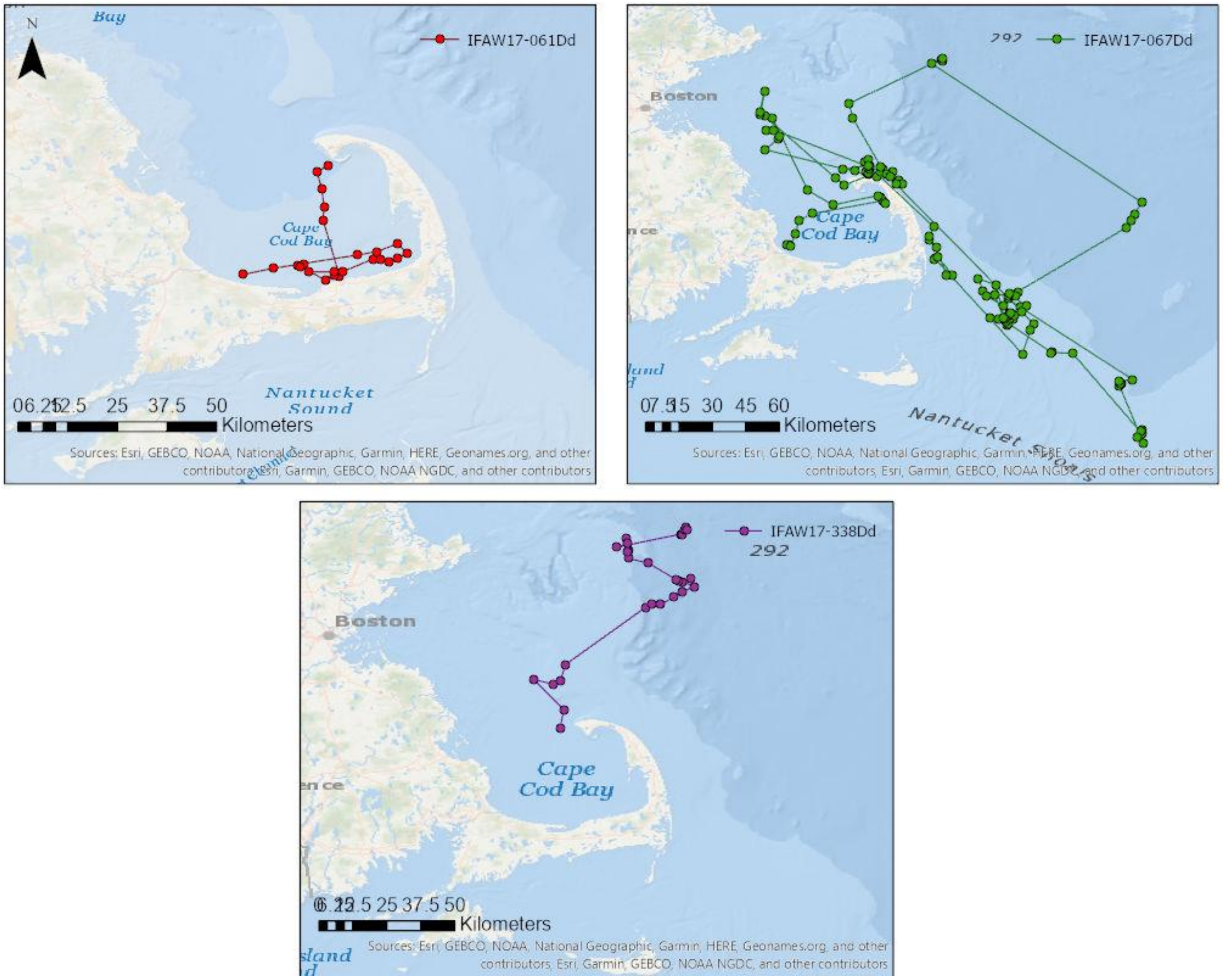

Figure 2. Example tracks from filtered locations for animals in each analysis group. Animal IFAW17-061Dd, shown in red, was confirmed to have died after its carcass was recovered on shore. Animal IFAW170067Dd, shown in green, transmitted for longer than 21 days and therefore had “survived”. Animal IFAW17-338Dd, shown in purple, transmitted for less than 21 days and was not seen again.

Estimation of Behavioral Parameters

Swim speed and *turning angle* were estimated from the filtered location estimates using their GPS coordinates. *Swim speed* was defined as the speed (straight-line distance calculated by the haversine formula divided by time elapsed) at which the animal moved between the locations of consecutive messages. *Turning angle* was defined as the difference between the heading of the current location and the heading of the previous location obtained from the satellite tag. Turning angles were always positive and fell between 0 and 180 degrees. It is important to note that these estimations were likely negatively biased as it is unlikely that any animal would move in a perfectly straight line. Position estimates more than 12 hours apart were removed, as they were considered too far apart in time to reasonably assume that the animal moved between them in a straight line. The *number of hits per day* was defined as the number of messages received by Argos satellites in a 24-hour period of time. All behavioral parameters were calculated in Microsoft Excel and R.

These behavioral parameters were used as proxies for an individual's well-being because as a dolphin's health begins to deteriorate it should start acting lethargically, swimming more slowly and turning less, just drifting with the current, as well as sending less messages per day because it should not be breaking the surface of the water as much as a healthy, energetic individual.

Unfortunately, satellite tags used on dolphins in 2012 were not programmed in the same manner as tags deployed in 2019. In particular, the duty cycle of tags deployed earlier in the data set were programmed to transmit for 12 hours and then turn off for 12 hours until the end of their battery life. In subsequent years, this duty cycle was changed to test whether or not the amount of data received could be increased.

Thus, my ability to test the hypothesis that fewer messages received per day was an indication of mortality was affected by this change in transmission programming. Therefore, tracks were split into groups based on their duty cycle. The programmed duty cycles were 12 hours on/12 hours off and 24 hours on. Due to a limitation in number of messages allowed per day, a large number of tags (n=27) transmitted the maximum number of messages in a short time period—around 3 hours—and then turned off for the remainder of the day. These tags were then analyzed as a separate group with a "duty cycle" of 3 hours on/21 hours off. Within each group distributions of number of messages received per day were computed for each individual track.

Statistical Analysis

After behavioral parameters were estimated for each individual, histograms of each parameter were created and then summed for the entire population. Separate frequency distributions were created for animals known to have died (n=3), those which were tracked for less than 21 days, and those tracked for more than 21 days. For number of messages per day, frequency distributions were created for these three strata within groups of different duty cycles. I compared these frequency distributions using a Kolmogorov-Smirnov test to assess significance of the difference in the distributions.

Results:

Average swim speed for individual dolphins ranged from 0.37 m/s to 4.46 m/s. The most frequent swim speeds ranged from 0.5-1.5 m/s for all dolphins. The swim speeds of animals known to have died was significantly lower than dolphins tracked for longer than 21 days (KS=0.270, p=0.000195, Figure 3).

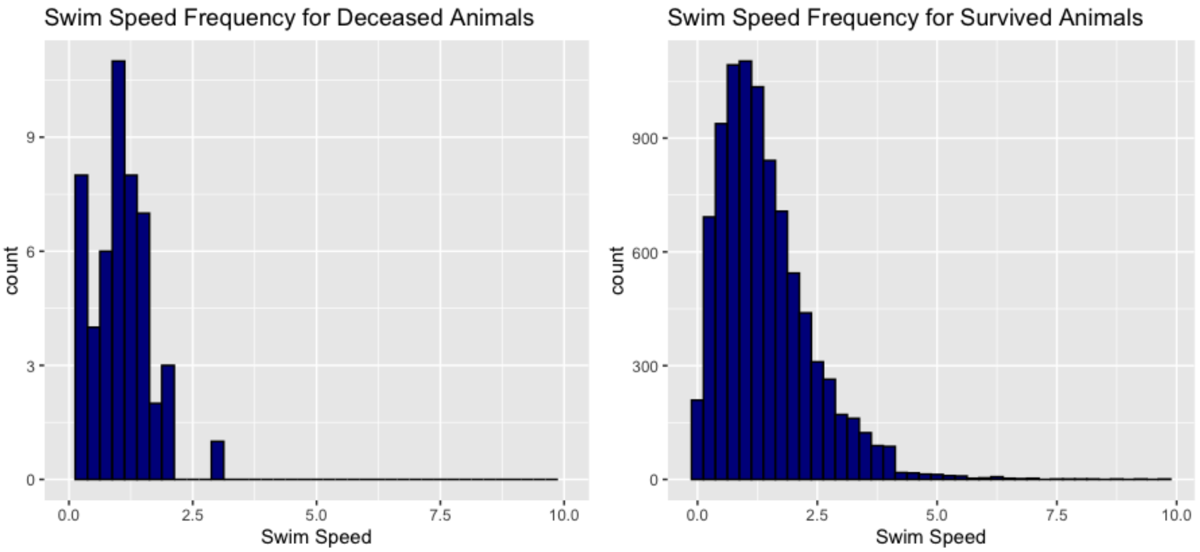

Figure 3. Histograms showing distributions of swim speeds for deceased animals (left) and survived animals (right).

Average turning angle for individual dolphins ranged from 38° to 123°, with average turning angle for deceased animals of 63° and average turning angle for survived animals of 79°. The most frequent turning angles were between 0 and 10 degrees. The comparison of turning angle distributions showed the same relationship as swim speeds, with animals known to have died exhibiting a significantly smaller turning angle than animals tracked for longer than 21 days (KS stat=0.195, p=0.00468, Figure 4).

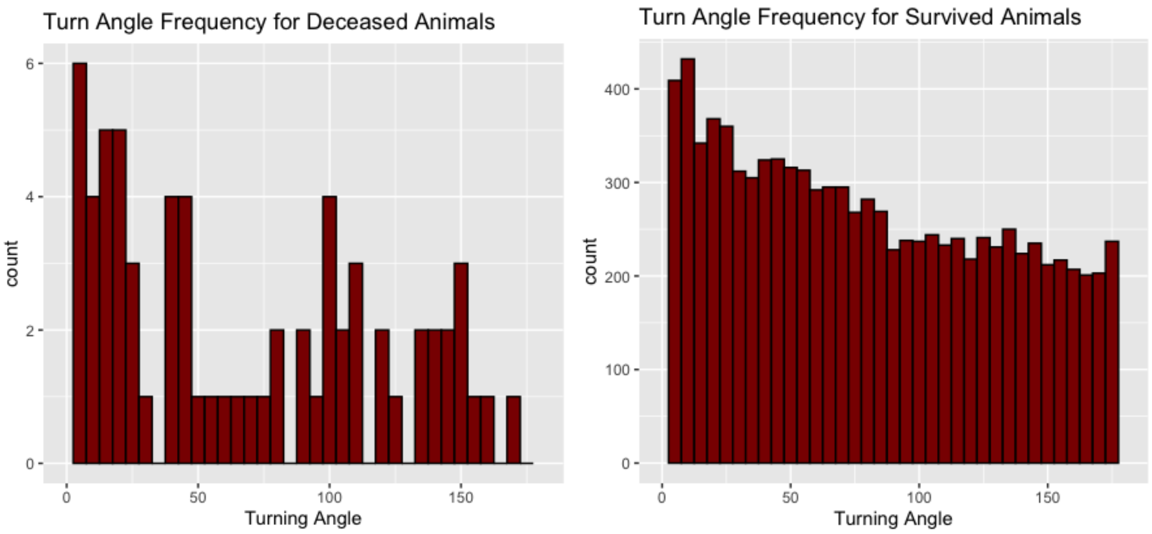

Figure 4. Histograms showing distributions of turning angles for deceased animals (left) and survived animals (right).

After separating tracks into groups based on duty cycle, only tracks that transmitted for duty cycles of 12 hours on/12 hours off and 3 hours on/21 hours off contained animals known to have died. The distributions of number of messages received per day were significantly different for the tracks of dolphins that had died than the tracks of dolphins that transmitted longer than 21 days for tags with a duty cycle of 3 hours on/21 hours off (3/21 duty cycle: KS stat=0.356, p=0.0151). For tags with a duty cycle of 12 hours on/12 hours off, the distributions of number of hits per day were not significantly different (12/12 duty cycle: KS stat=0.443, p=0.457). However, the “deceased” group for the 12/12 duty cycle only consisted of one animal. Additionally, this animal transmitted for a total of less than two days, making the data set too small to show any conclusive result (Figures 5 & 6).

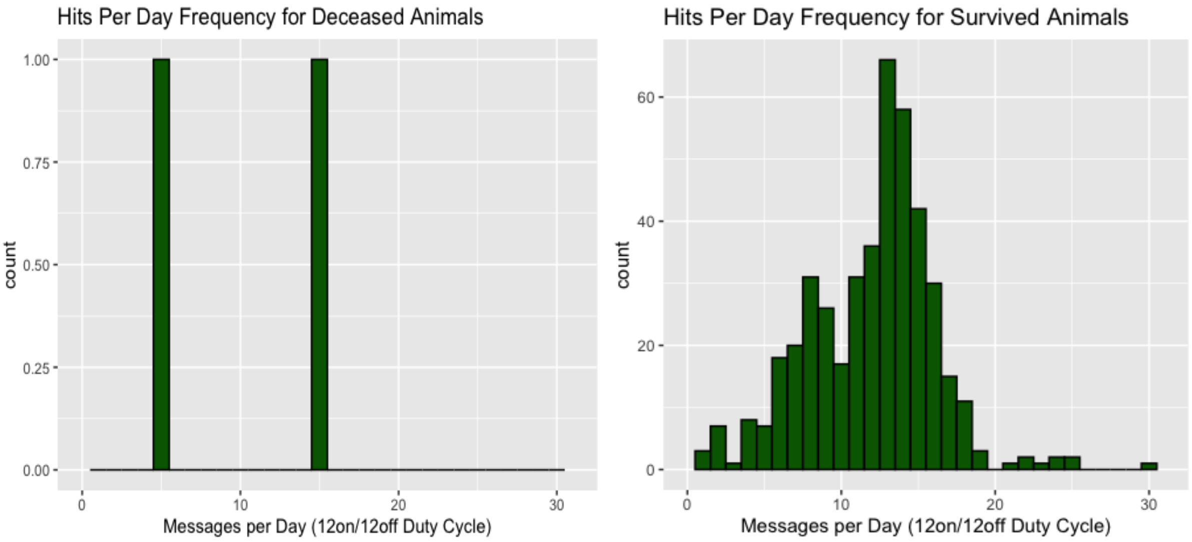

Figure 5. Histograms showing distributions of number of messages received per day for deceased animals (left) and survived animals (right) with duty cycles of 12 hours on/12 hours off.

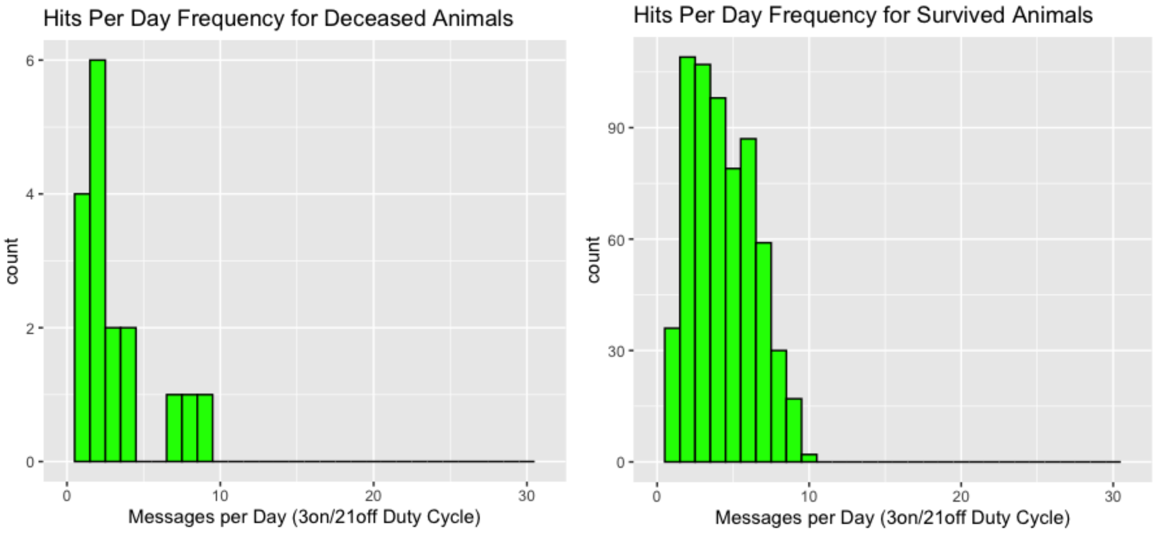

Figure 6. Histograms showing distributions of number of messages received per day for deceased animals (left) and survived animals (right) with duty cycles of 3 hours on/21 hours off.

With the remaining tracks of dolphins that transmitted less than 21 days, distributions from each individual track were compared with the distributions of behavioral parameters from both groups of deceased and survived animals. This analysis was meant to attempt to infer survival or mortality of individual animals, but generally these tracks did not contain enough data points to be able to conduct a robust analysis. Results of these analyses are given in a summary table in the appendix (Table 1, Appendix).

Discussion:

Stranded dolphins that died post-release exhibited a consistent behavioral pattern, which including slower swim speeds, lower turning angles, and possibly fewer location messages received per day. Slower swim speeds reflect the drain of an animal's energy reserves at the end of their lives. The turning angles should be lower for the same reason, as changing direction takes effort and these animals were likely just drifting with the current.

The inconsistent results for number of messages received per day reflects the small data set of confirmed dead animals. Only one confirmed dead animal had a 12hrs on/12hrs off duty cycle, which made the number of data points to compare with the "survival" group very small. The particular animal also transmitted for less than two days in total, which makes the distribution of hits per day only two numbers. Less than five data points is generally accepted as being too small show significant differences and therefore this result should be seen as inconclusive. The two deceased animals in the 3hrs on/21hrs off duty cycle transmitted for longer and had a slightly larger data set.

This comparison seems to indicate that fewer messages were sent per day, but the small data set complicates the findings, thus results should be seen as inconclusive. With a larger data set of confirmed dead animals this parameter could be a useful indication of mortality, but with just three animals, this analysis did not show consistent and conclusive results.

It is important to note that three of these animals were repeat strandings, meaning they had stranded more than once in a short time period, though none of these animals were confirmed to have died. This kind of stress on the animals can greatly increase their chance of death (Bogomolni et al, 2010), but because the purpose of this study was to determine an indication of mortality based solely on the behavior of the animals post-release, this factor should not have affected the results presented here. Perhaps future studies may be able to look into whether a repeat stranding indicates a highly likelihood of mortality post-release using the behavioral parameters found in this study.

The three individuals confirmed to have died ceased transmitting within the first week of tracking, therefore the first week should be seen as a critical time period in which as much data as possible should be collected. Duty cycling can extend the life of a satellite tag but, in this case, it hampered our ability to infer the survival or mortality of the animals that ceased transmission before the 21 day survival cutoff. For that reason, I recommend that tags be programmed to transmit for 24 hours a day, with no limit to the number of messages received per day, for at least the first week, to indicate short-term survival or mortality.

As more data are collected, it may be possible to determine the causes of post-release mortality, but the first step in later analyses must be confirming which animals do not survive. The determination of survival or mortality through analysis of satellite telemetry data is extremely important for this species because it is unlikely that animals will be observed again after their release (Sharp et al, 2016). It is also important to improve our ability to discriminate between animals that failed to survive and those whose tags stopped transmitting because of the loss or failure of the satellite tag. Slightly less than half of the dolphins analyzed here did not pass the survival cutoff (n=27/66), so the fate of these dolphins is still unknown. A more robust analysis of these animals is needed to determine the true rate of mortality and the frequency of failure of satellite tags. This could lead to better uses of satellite tags and an increase in the quality of data, ultimately helping rescuers make better decisions for the wellbeing of the animals.

Previous studies have analyzed satellite-linked stranded and released dolphins for indications that dolphins had survived and reintegrated into wild populations (Sampson et al, 2012; Wells et al, 2013; Sharp et al, 2016). These studies analyzed the movements of stranded dolphins to determine if they were behaving normally post-release and could be assumed to have been “successful” rescues. Other studies have tracked stranded and rehabilitated cetaceans or wild-caught marine mammals (Freitas et al, 2008; Schorr et al, 2009; Wells et al, 2009; Baird et al, 2011; Pulis et al, 2018). Again, these studies attempted to show that the marine mammals being studied had survived a stranding or entanglement. Others attempted to quantify what “normal” behavior looks like for a species. The analysis of satellite movements of marine mammals is improving and being used more frequently, but our ability to differentiate between mortality and transmitter failure is still imperfect. We know that dolphins can survive these strandings, but the survival of many released dolphins is still uncertain. My study attempts to lessen this uncertainty by determining predictors of dolphin mortality from satellite tag data.

Future studies should improve the indications of mortality described here. In particular, it would be helpful to deploy tags that not only track location, but also transmit records of dive behavior. This would provide another behavioral parameter to analyze and create a more robust indication of mortality. Future studies should also seek to determine the recovery timeline for common dolphins post-release. The dolphins known to have died in this study transmitted less than one week. The 21 day survival cutoff may be too conservative for this species and the surviving group could have included more animals, leading to a more robust analysis. If we knew either when animals died after a stranding or when their behavior returned to “normal” then a more refined survival timeline could be determined. All of these studies can help to improve the critically important work that IFAW and other marine mammal rescue groups are conducting to help protect and conserve the marine mammals of the world.

Acknowledgements:

This project would not have been possible without the hard work and dedication of the staff of the Marine Mammal Rescue and Research team at IFAW. They have put significant time and money into their satellite tag program and have generously allowed me to use their data in this project. I would like to thank Kathryn Rose and Sarah Sharp in particular for their edits and their support throughout this project. I would also like to thank my advisors, Dr. Andrew Read and Dr. Patrick Halpin, for their guidance in making this the best project it could be. Thank you finally, to the Edna B. Sussman Fund for granting me funding so that I could focus on this project during the summer of 2019.

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Appendix

Table 1. Summary of results for individual tracks transmitting less than 21 days. D is the Kolmogorov-Smirnov statistic. A p-value of less than 0.05 indicates that the individual track's distribution is significantly different from the distribution it is being compared to. A result of significantly different ($p<=0.05$) from the "survival" groups and not different ($p>0.05$) from the "deceased" groups would indicate that a single individual had died.

Animal Number	Comparison to "Deceased Swim Speed"	Comparison to "Survived Swim Speed"	Comparison to "Deceased Turn Angle"	Comparison to "Survived Turn Angle"
IFAW12-003Dd	D=0.17, p=0.18	D=0.13, p=0.07	D=0.13, p=0.42	D=0.10, p=0.24
IFAW12-020Dd	D=0.14, p=0.41	D=0.23, p=4.7e-06	D=0.19, p=0.05	D=0.05, p=0.87
IFAW12-027Dd	D=0.38, p=0.17	D=0.28, p=0.49	D=0.19, p=0.92	D=0.27, p=0.59
IFAW12-126Dd	D=0.29, p=0.17	D=0.37, p=0.02	D=0.14, p=0.94	D=0.22, p=0.45
IFAW12-172Dd	D=0.25, p=0.01	D=0.06, p=0.57	D=0.10, p=0.64	D=0.12, p=0.009
IFAW12-214Dd	D=0.23, p=0.02	D=0.07, p=0.46	D=0.14, p=0.29	D=0.12, p=0.03
IFAW12-218Dd	D=0.4, p=0.09	D=0.55, p=0.005	D=0.38, p=0.17	D=0.32, p=0.30
IFAW12-221Dd	D=0.31,p= 0.001	D=0.11, p=0.21	D=0.10, p=0.73	D=0.12, p=0.11
IFAW12-226Dd	D=0.27, p=0.03	D=0.12, p=0.38	D=0.14, p=0.47	D=0.16, p=0.06
IFAW12-289Dd	D=0.19,p= 0.07	D=0.13, p=0.01	D=0.28, p=0.0008	D=0.17, p=6.2e-05
IFAW12-341Dd	D=0.22, p=0.03	D=0.14, p=0.006	D=0.15, p=0.18	D=0.05, p=0.88
IFAW12-348Dd	D=0.25, p=0.37	D=0.33, p=0.06	D=0.36, p=0.06	D=0.27, p=0.23
IFAW12-375Dd	D=0.3, p=0.91	D=0.43, p=0.63	D=0.32, p=0.75	D=0.26, p=0.96
IFAW13-169Dd	D=0.27, p=0.004	D=0.06, p=0.57	D=0.19, p=0.05	D=0.05, p=0.85
IFAW13-173Dd	D=0.21, p=0.05	D=0.3, p=4.01e-14	D=0.1, p=0.68	D=0.14, p=0.002
IFAW14-001Dd	D=0.38, p=0.43	D=0.55, p=0.09	D=0.56, p=0.13	D=0.47, p=0.35
IFAW14-163Dd	D=0.15, p=0.26	D=0.16, p=8.3e-08	D=0.20, p=0.02	D=0.04, p=0.59
IFAW15-002Dd	D=0.29, p=0.62	D=0.40, p=0.22	D=0.32, p=0.54	D=0.33, p=0.54
IFAW15-019Dd	D=0.37, p=0.19	D=0.49, p=0.03	D=0.18, p=0.95	D=0.27, p=0.60
IFAW15-229Dd	D=0.36, p=0.02	D=0.47, p=2.8e-05	D=0.26, p=0.15	D=0.18, p=0.39
IFAW16-245Dd	D=0.14, p=0.5	D=0.21, p=0.001	D=0.14, p=0.39	D=0.07, p=0.78
IFAW17-047Dd	D=0.50, p=0.03	D=0.64, p=0.0006	D=0.40, p=0.20	D=0.35, p=0.35
IFAW17-116Dd	D=0.25, p=0.38	D=0.20, p=0.58	D=0.21, p=0.38	D=0.13, p=0.87
IFAW17-129Dd	D=0.21, p=0.86	D=0.38, p=0.19	D=0.30, p=0.29	D=0.40, p=0.05
IFAW17-338Dd	D=0.41, p=0.01	D=0.24, p=0.24	D=0.11, p=0.95	D=0.21, p=0.28
IFAW17-380Dd	D=0.20, p=0.50	D=0.27, p=0.09	D=0.15, p=0.62	D=0.11, p=0.76
IFAW18-233Dd	D=0.26, p=0.84	D=0.26, p=0.87	D=0.53, p=0.17	D=0.45, p=0.40