USING AERIAL BEHAVIOR TO PREDICT REMORA PRESENCE IN HAWAI'I ISLAND ASSOCIATED SPINNER DOLPHINS (*STENELLA LONGIROSTRIS LONGIROSTRIS*)

by

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May 2014

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

2014

Abstract

Gray's spinner dolphin (*Stenella longirostris longirostris*) is a species of spinner dolphin associated with Hawai'i Island. This species has a unique 24-hour schedule involving traveling offshore to forage at night and then migrating back to shore to rest in bays during the day. While in these bays, spinner dolphins come in close proximity to humans. A factor in determining the impact of human interactions with dolphins in the bay is understanding the behavior of spinner dolphins. Spinner dolphins known for the aerial behavior of leaping in the air and spinning. There are several hypotheses as to the function, or functions, of this behavior such as communication or removal of remoras (*Remora australis*), which are hydrodynamic parasites that attach to the body of dolphins and negatively impact their health. This study used a generalized linear model (GLM) to assess if the aerial behavior of the spinning leap can predict remora presence on spinner dolphins off the coast of Hawai'i Island. The study found that the aerial behavior of spinning leaps is not statistically significant in determining remora presence on a spinner dolphin. This finding compliments other research suggesting that spinning is not used primarily for remora removal.

Introduction

Many species of cetaceans exhibit aerial behaviors such as porpoising, leaping, and breaching. These behaviors can be attributed to reducing energy costs of locomotion, socializing among individuals, acoustic communication, and removal of ectoparasites (Au and Weihs 1980; Norris et al. 1994; Weihs 2004). Spinner dolphins are named after an aerial behavior where the animal will leap into the air and revolve its body on its longitudinal axis up to seven times before reentering the water on its side (Figure 1) (Hester et al., 1963; Norris et al., 1994). There is an instance where an individual animal was observed exhibiting this spinning leap 14 consecutive times (Perrin, 2002). Approximately 1.25 seconds is spent in the air for each spinning leap (Hester et al. 1963).

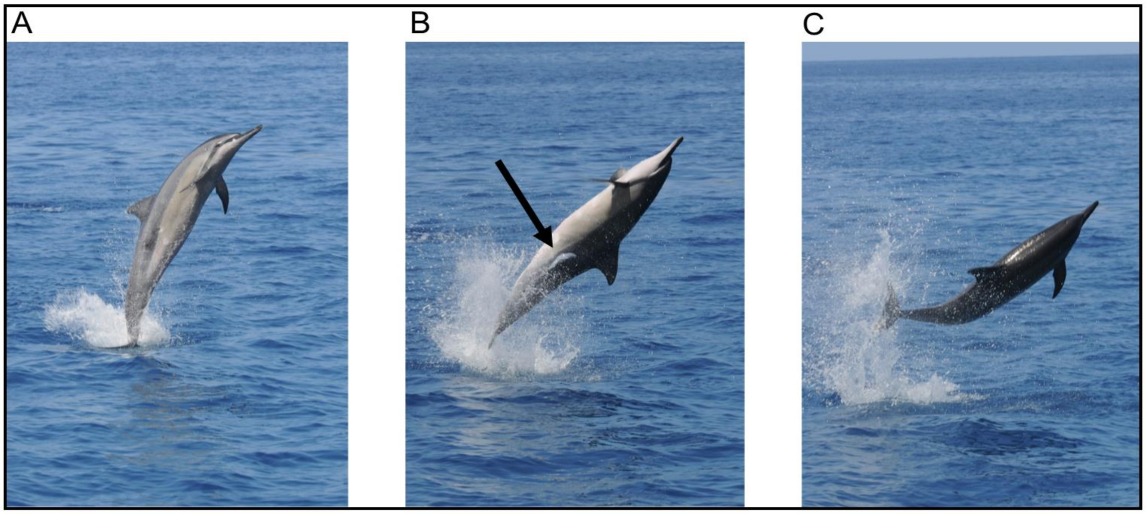

Figure 1. Photograph sequence of a spinner dolphin exhibiting the aerial behavior of the spinning leap. The dolphin emerges from the water (A) and rotates on a longitudinal axis (B) before reentering the water on its broadside (C). Attached remora is present on the side of the dolphin (B). (Photo Credit: SAPPHIRE Project under permit from NOAA)

There are a multitude of aerial behaviors that spinner dolphins can exhibit in addition to spinning. The most active behavior is the tail-over-head leap where an individual will throw its tail over its head during the leap (Norris et al. 1994). There is also the tail-over-head spin where an individual exhibits a tail-over-head leap while spinning (Norris et al. 1994). There is also the less active arcuate where an individual will leap a few meters into the air before reentering the water (Norris et al. 1994). An additional aerial behavior is the salmon; where an individual will leap into the air with a rigid body before reentering on its side (Norris et al. 1994).

Aerial behaviors can be used to assess the alertness level of a group of spinner dolphins. The more alert a group is correlates to an increase in aerial behaviors exhibited (Norris and Dohl 1980). It has been observed that spinner dolphins will increase aerial behaviors as individuals end the resting period and transition to the foraging period within the 24 hour cycle (Norris and Dohl 1980). An increase in aerial activity was also observed when individuals are widely dispersed and at night when visibility is limited (Norris and Dohl 1980). There are multiple hypotheses as to the function of aerial behaviors in spinner dolphins. A possible function of aerial behavior would be to emit noise amongst individuals within a group for communication purposes (Norris and Dohl 1980). However, the emitted noises do not transverse far distances and therefore communication can only be between nearby individuals (Norris and Dohl 1980).

Another possible function of aerial behaviors is to remove ectoparasites such as remoras (*Remora australis*). Remoras are hydrodynamic parasites that rely on hitchhiking to reduce the energy costs of locomotion, improve foraging and life history success, and for protection from predation (O'Toole 2002; Sazima et al. 2003; Silva-JR and Sazima 2006). Remoras attach to spinner dolphins through a disk located directly above the head containing transverse rows of modified spines (Moyle and Cech 1988). For a remora to attach to a host, the spines become rigid to produce a pressure cavity between the disk and the body of the host (Fulcher and Motta 2006). After attachment, the transverse position of the modified spines assist in creating enough friction to overcome the longitudinal drag force on the remora from the locomotion of the host; causing the remora to remain on the host (Weihs et al. 2007).

Remoras can remove smaller parasites from the host, which is most likely the only advantage the host receives from the relationship (Silva-JR and Sazima 2006). Other than removing small parasites, hosts are negatively impacted from associations with remoras. Remoras increase the drag force for their hosts while disrupting the water flow over the host's body; increasing the energy cost of locomotion (Moyle and Cech 1988). Since spinner dolphins possess highly sensitive skin, remoras can irritate the skin due to the modified spines within the disk (Fish et al. 2006). To eliminate the negative effects, spinner dolphins can utilize aerial behaviors to remove remoras from their bodies (Weihs et al. 2007). A computational model suggests the spinning during a leap and the reentry into the water will generate enough force on the remora to cause stress at the disk, further reducing resistance to dislodgement (Fish et al. 2006; Weihs et al. 2007). If the remora in a horizontal position when the dolphin lands on its broadside, the drag force on the remora will be parallel to the modified spines decreasing the friction between the disk and the dolphin's skin causing a dislodgement of the remora from the dolphin (Weihs et al. 2007).

Spinner dolphins exhibit aerial behaviors without remoras present on their bodies, suggesting that ectoparasite removal is not the primary function of the spinning leap. However, the spinning leap can produce enough force to dislodge a remora. Therefore, this study is designed to observe and better understand the functions served via the aerial behavior of spinning by looking at the details of this behavior found in wild spinner dolphin groups off the coast of Hawai'i Island. The prediction of this study is that if a spinner dolphin exhibits the aerial behavior of a spinning leap, then one or more remora will be observed attached the individual.

Materials and Methods

Study Area

All data was collected on the west coast of Hawai'i Island from August 2010 to June 2012. The waters in the study area were shallow with large drop-offs within a mile off the coastline. The majority of the pictures used in this study were taken from Kealakekua Bay, Honaunau Bay, Kauhako Bay and Makako Bay (Figure 2). These bays have large, sandy areas interspersed with coral reef. It is the shallow waters of these four bays that were historically and are presently used by spinner dolphins for rest. In some instances, the opportunity arose to photograph aerial behaviors outside of these four main bays in deep water, in other resting bays, or in the shallow waters as dolphins moved parallel the coast.

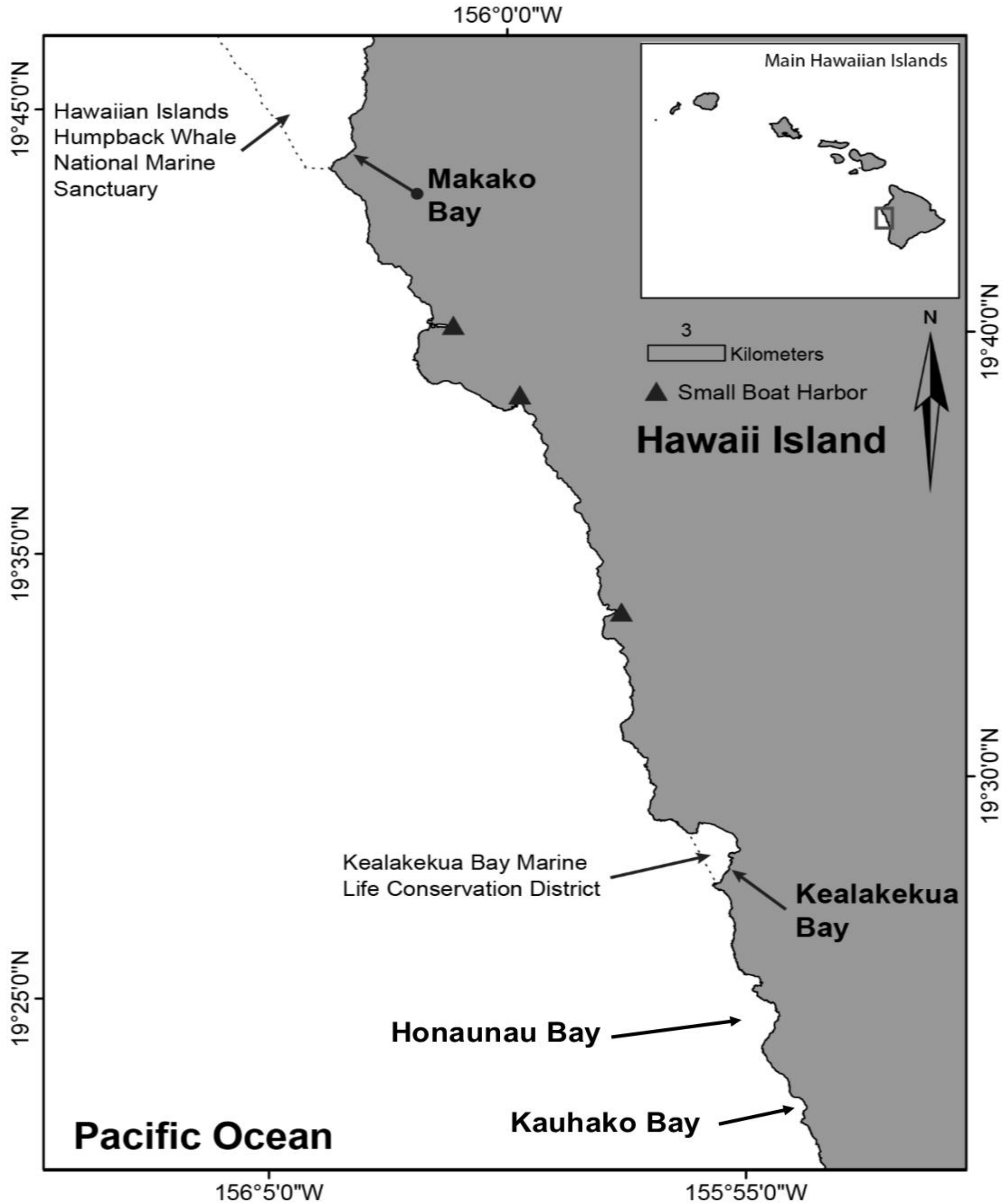

Figure 2. Map of the west coast of Hawai'i Island detailing the study area. Study occurred in four primary spinner dolphin resting bays, during focal follows between bays, and, exceptionally, outside of the bays. The four main resting bays from north to south are Makako Bay, Kealakekua Bay, Honaunau Bay, and Kauhako Bay.

Data Collection

All pictures were taken with group size and activity state not influencing data collection. With a few exceptions, the majority of aerial pictures were taken while dolphins were in the resting part of their daily routine. The exceptions were when viable pictures were taken in the travel and transition periods of a group's day. Pictures were taken with Nikon D300 and D300S. Multiple cameras were used to ensure the maximum amount of data was obtained. Both cameras shot independent of each other. Each photographer began shooting a continuous burst of photographs (6 frames per second for the D300 and 7 frames per second for the D300S) when an aerial behavior was observed until the behavior finished. This protocol captured the maximum visible surface area of the dolphin's body when above the water during an aerial behavior.

Data Analysis

Analysis of the photos began by separating the aerial behaviors by individual. One aerial behavior series for an individual per day was represented as one data point. If there were multiple series of aerial pictures per individual, the series capturing the highest percentage of dolphin surface area was used. Pictures of individuals were primarily matched by body scars and individual differences in pigmentation. Any series of pictures where it was impossible to differentiate an individual from other individuals found on the same day was discarded.

After the behavioral series for an individual was found, behavior type was classified in the category of spinning leap, arcuate leap, salmon leap, tail-over-head spin, and tail-over-head leap. The abundance and spatial placement of remora on the aerial active spinner were quantified and noted. Sex of each individual was determined for every series that had the genital region of the dolphin clearly photographed. Age of each individual was determined by body size relative to an adult spinner dolphin.

Statistical Analysis

A generalized linear model (GLM) was used to determine if the presence or absence of remoras on a spinner dolphin could be predicted by the dolphin exhibiting the aerial behavior of spinning leap. For this analysis, the response variable Remora Presence was collapsed into a binomial variable of Present or Absent (Table 1). Supplementary models were run to include additional predictor variables that could statistically determine remora presence. All model parameters were as follows: Remora Presence, Aerial Behavior Type, Year, Month, Time of Day, Location, Sex, and Age (Table 1). All analyses were conducted using R 3.0.2 which uses a binomial sampling distribution within the GLM function. The best fit model was selected through comparing Akaike's information criterion (AIC) values of multiple analyses with different combinations of model parameters; the best fit model is the model with the lowest AIC value (Burnham and Anderson 2002).

Table 1. Model parameters used to determine remora presence in spinner dolphins.

Parameter	Type	Units
Year	Class (3)	2010, 2011, 2012
Month	Class (12)	January, February, March, April, May, June, July, August, September, October, November, December
Time of Day	Class (3)	Morning, Afternoon, Unknown
Location	Class (6)	Focal Follow, Honaunau Bay, Kauhako Bay, Kealakekua Bay, Makako Bay, Opportunistic
Aerial Behavior	Class (5)	Arcuate, Salmon, Spin, Tail overhead leap, Tail overhead spin
Sex	Class (3)	Female, Male, Unknown
Age	Class (4)	Adult, Neonate, Unknown, Young of the year
Remora Presence	Class (2)	Absent, Present

Results

From August 2010 to June 2012, a total of 373 viable data points were collected off of the west coast of Hawai'i Island and used in the analysis. In total, there were 140 data points with remoras absent and 233 data points with remoras present. In addition, all five aerial behaviors - arcuate, salmon, tail overhead leap, tail overhead spin, and spinning leap - were observed throughout the data points.

The first fitted GLM, where aerial behavior type was the predictor variable, indicated that none of the five aerial behaviors were significant in predicting remora presence (Table 2). Comparison of a range of fitted GLMs with additional predictor variables resulted in the selection of a model possessing only aerial behavior type, sex of individual, age of individual (Table 3). The selected model indicated aerial behavior as not significant while sex and age were significant factors in predicting remora presence (Table 3).

Table 2. Summary of results from the GLM model with Aerial Behavior Type as the predictor variable. The model indicates that none of the Aerial Behavior Type variables are statistically-significant predictors in determining remora presence.

Coefficients:				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.0422	0.4944	0.085	0.932
Aerial Behavior Type				
Tail Over Head Spin	0.168	0.6522	0.258	0.797
Arcuate	-1.0267	0.6532	-1.572	0.116
Salmon	0.5852	0.5909	0.99	0.322
Spin	0.6149	0.5078	1.211	0.226

Table 3. Summary of results from the selected GLM model with Aerial Behavior Type, Sex, and Age as predictor variables. The model indicates that Aerial Behavior is not a significant predictor in remora presence. Per the model, both Sex and Age are significant predictors in remora presence with Female and Adult being significant variables.

Coefficients:				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.50544	0.73483	0.688	0.49156
Aerial Behavior Type				
Tail Over Head Spin	0.22462	0.72886	0.308	0.75795
Arcuate	-0.67532	0.72545	-0.931	0.35191
Salmon	0.07083	0.65657	0.108	0.91409
Spin	0.58282	0.56918	1.024	0.30585
Sex				
Unknown	-0.28357	0.34974	-0.811	0.41747
Female	1.53877	5.18100	-0.026	2.21E-07
Age				
Unknown	-0.35636	0.48674	-0.732	0.46408
Neonate	-3.46184	1.78622	-1.938	0.05261
Adult	-1.48430	0.43651	-3.400	6.73E-04

For the sex variable, female (n = 207) was a significant predictor of remora presence ($p < 0.001$) while male (n = 80) and unknown (n = 86) were not significant variables (Table 3). For the age variable, adult (n = 254) was a significant predictor of remora presence ($p < 0.001$) while neonate (n = 2), young of the year (n = 39), and unknown (n = 78) were not significant variables (Table 3). Within the 207 female data points, there was a total of 44 females with remoras absent and 163 females with remoras present (Table 4). Of the 254 adult data points, 111 adults had remoras absent and 143 had remoras present (Table 4).

Table 4. The distribution of remora absence and remora presence for the two statistically-significant predictors in determining remora presence.

Variable	Number With Remora Absent	Number With Remora Present
Sex		
Female	44	163
Male	41	39
Unknown	55	31
Age		
Adult	111	143
Young of the Year	8	31
Neonate	2	0
Unknown	19	59

Discussion

The results of this analysis suggest that aerial behavior does not predict remora presence on spinner dolphins. None of the five aerial behavior types, including spinning, were statistical significant in predicting if a spinner dolphin would have a remora present when the individual exhibits an aerial behavior. Supplementary GLMs indicated additional variables that were significant predictors in remora presence. The analysis found that female spinner dolphins had an interaction with remora presence; suggesting that females were more likely to have remoras present than males. Additionally, the model indicated that there was an interaction between adult spinner dolphins and remora presence. Adult spinner dolphins showed a statistically-significant interaction with remora presence when compared to other age groups.

Although the models did not support the hypothesis of the aerial behavior of spinning leap determining remora presence, the selected model predicted that female and adult variables influenced remora presence. The GLM indicated that female spinner dolphins were more likely to have remoras present when an aerial behavior was exhibited compared to males. In addition, adult spinner dolphins exhibiting an aerial behavior would be more likely to have a remora present than any other age group observed in this study. Since little is known about the species of remora found on cetaceans, this analysis can provide insight into remora distribution on spinner dolphins in Hawaiian waters (Silva-JR and Sazima 2006).

Even though the spinning aerial behavior can generate enough force to overcome the suction force of the remora on a dolphin's body, the GLM model suggests that spinning is not used solely as a means to remove remoras. It is suggested, from the analysis, that the spinning aerial behavior has other functions than the removal of remoras. Since spinning leaps can emit a localized omnidirectional sound, communication among individuals could be a function of spinning (Norris and Dohl 1980). An increase in spinning is observed when groups of spinner dolphins are dispersed, suggesting that the sound generated from this aerial behavior is a mechanism for communication (Norris and Dohl 1980). This study did not examine group size and dispersion when aerial behavior occurred. However, utilizing those variables combined with the aerial behavior variable could revel if there is a correlation between spinning and communication when individuals are dispersed.

Another function of aerial behaviors is determining the activity state of individuals and groups. The frequency of aerial behaviors directly corresponds to the activity state of a spinner dolphin group, with a higher rate of aerial behaviors indicating a more alert activity state (Norris and Dohl 1980). The alert activity state is an important factor when trying to determine the impact of human interaction on groups of spinner dolphins (Courbis and Timmel 2009, Lammers 2004, Timmel et al. 2008). With an increase in human interaction, there is also an increase in aerial behaviors, indicating a higher activity state within the group (Courbis and Timmel 2009). This change in dolphin activity state could have an impact on overall health and survivorship of the species (Lammers 2004).

Since this study suggests that aerial behavior is not indicative of remora presence and that spinning is not a significant factor in remora removal, a function of exhibiting aerial behaviors could be a response to increased human activity in the area. This study did not include variables such as the number of humans present in the area or anthropogenic activity occurring during an aerial behavior. However, quantitatively examining the link between human presence and aerial behavior displayed could provide better insight into the function of aerial behavior as well as the behavioral response spinner dolphins have to human activity.

This study statistically analyzed quantitative data on the aerial behavior of spinning leaps in spinner dolphins. These findings highlight the intricate role that aerial behaviors play in spinner dolphin life. Although there was no statistically-significant correlation between spinning leaps and remora presence, there are other variables - such as gender and age - which can affect the frequency of remora presence. Thus, these results suggest that remora dislodgement is not the primary function of spinning leaps. Therefore, to provide more insight into the behavior of spinner dolphins, further research should examine additional variables which potentially correlate with the function of aerial behaviors in this species.

Acknowledgements

Thank you to Dr. Dave Johnston, Dr. Lars Bejder, Julian Tyne, and Heather Heenehan and the entire SAPPHIRE Project field team for their hard work. Thank you to Kimberly New for the assistance in the data analysis and Kenady Wilson for the support in the statistical analysis. Without their time and effort this analysis would not be possible.

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