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UNIVERSITY OF CALIFORNIA SAN DIEGO

**Temporal and Spatial Variability of Pantropical Spotted Dolphin (*Stenella attenuata*)
Group Size in the Eastern Tropical Pacific**

A Thesis submitted in partial satisfaction of the requirements
for the degree Master of Science

in

Marine Biology

by

Pooja Balaji

Committee in charge:

Professor Frederick Archer, Chair
Professor Peter Franks, Co-Chair
Professor Brice Semmens

2023

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University of California San Diego

2023

DEDICATION

To my Stray Kids, you held my hand while I flew high into the sky, and with you by my side, I won't stop until the day I die. I'm rising up to the sun, and I call you my heart. Thank you for being my super board.

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LIST OF ABBREVIATIONS

ETP	Eastern Tropical Pacific
US MMPA	United States Marine Mammal Protection Act
STAR-LITE	Stenella Abundance Research Line Transect and Ecosystem
IATTC	Inter American Tropical Tuna Convention
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service

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To my parents and my brother, thank you for always believing in me, even when I didn't believe in myself. There isn't enough I can do to show my gratitude, but I will absolutely spend every moment of every day left trying my best.

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This thesis is currently being prepared for submission for publication of the material. Balaji, P; Archer, Frederick E.; Franks, Peter JS; Semmens, Brice X. The thesis author was the primary researcher and author of this material.

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ABSTRACT OF THE THESIS

**Temporal and Spatial Variability of Pantropical Spotted Dolphin (*Stenella attenuata*)
Group Size in the Eastern Tropical Pacific**

by

Pooja Balaji

Master of Science in Marine Biology

University of California San Diego, 2023

Professor Frederick Archer, Chair

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Tuna purse seine vessels fishing for *Thunnus albacares* was a cause for significant incidental bycatch of dolphins and subsequent depletion of their populations in the Eastern Tropical Pacific (ETP) in the 1960s and 1970s, until the establishment of the United States Marine Mammal Protection Act (US MMPA) in 1972. Some of the most heavily affected species are spotted dolphins (*Stenella attenuata*), the abundances of which have been

estimated to have been reduced by up to one-fifth of their size. Despite a marked decrease in dolphin mortality and incidental take post implementation of the US MMPA, populations have not been recovering at expected rates. One hypothesis for this is that repeated chase, encirclement, and release by purse seiners affects reproduction or population growth rates in ways other than directly observed mortality. Since these effects are related to how often a given dolphin is likely to interact with the fishery and the fishery is more likely to target large schools that carry large amounts of tuna, it is imperative to understand how schools of pelagic dolphins arrange themselves in the ETP. This study uses data from the Stenella Abundance Research Line Transect and Ecosystem (STAR-LITE) cruise from 2007 to determine how schools of different sizes are arrayed in space and time. We then illustrate how these results can improve estimates of indirect effects of purse seine fishing on the recovery of these depleted populations.

INTRODUCTION

The Eastern Tropical Pacific (ETP) is a region that supports a rich variety of megafauna. It is one of the most productive Yellowfin tuna (*Thunnus albacares*) fisheries in the world, with an estimated catch of 253,611 metric tons (IATTC, 2022) in 2021. This high catch in the ETP uses the “fishing on dolphin” method of purse-seine fishing, exploiting the association between *T. albacares* and two species of cetacean, pantropical spotted dolphins (*Stenella attenuata*) and spinner dolphins (*Stenella longirostris*).

“Fishing on dolphin” targets the dolphin school, surrounding it with a net to capture the dolphins and the associated tuna that are subsurface. This has caused significant incidental dolphin mortality in the region, especially in the 1960s and early 70s when the kill numbers ranged between 200,000 to 550,000 dolphins per year (Wade, 1995). The establishment of the Marine Mammal Protection Act in 1972 placed significant regulations on the purse-seine vessels, including setting quotas on the authorized number of takes, and the development of procedures by the fishers to reduce mortality as much as possible. These developments included the Medina panel, which is a panel with tighter crosshatched mesh placed in the area of the net that the dolphins most often come into contact with, in order to reduce the risk of entanglement; the ‘backdown procedure’, which involves reversing the boat after encirclement, causing the corkline of the net to sink and creating a space for the dolphins to escape through; and the use of rafts and provision of training to fishers to hand-release entangled dolphins. While these regulations did cause a marked decrease in mortality as reported by observers onboard the tuna vessels, abundance estimation surveys undertaken by the National Oceanic and Atmospheric

Administration (NOAA) and the National Marine Fisheries Service (NMFS) show that the affected dolphin populations are not recovering at expected rates (Gerodette et al., 2008).

The estimated annual exponential rate of change between 1986 and 2006 for the NE offshore stock of *Stenella attenuata* was 0.010 (Reilly and Barlow, 1986); considering the reported decrease in mortality of more than 95% per set between 1979 and 1995 (Gosliner, 1999), the rate of recovery for these stocks are insignificant. Recently revised abundance estimates (Gerodette et al. 2008) suggest that there is evidence of annual population growth rates between 1998 and 2006 close to the suggested maximum of 8-9% (Reilly & Barlow, 1986). However, these estimates are uncertain, and it cannot be taken for granted that these highly depleted stocks are showing signs of recovery at such a fast rate – especially considering the reproductive age parameters and calf/non-calf survival rate that is required to maintain an annual population increase of 8%.

There are a few proposed hypotheses for why these populations are not recovering as expected (Gerodette and Forcada, 2005), such as bycatch numbers being higher than currently reported, environmental changes impeding recovery, or unrealistic expectations of population recovery. None of these is mutually exclusive or more likely to occur than the other.

The purse seiners preferentially set on dolphin groups that are larger than average in the ETP (Perkins and Edwards, 1999), and while *S. attenuata* groups are known to be more ephemeral (Scott and Chivers, 2009), the calculation of the fisheries exposure index of an individual dolphin is influenced by sets of larger group size and spatial and temporal proximity

(Archer et al., 2010). The amount of fisheries interaction directly determines how much stress a dolphin experiences during the chase and capture process, the effects of this stress on its physiological health and reproductive success, and mortality caused by cryptic effects of the fishery, such as mortality of nursing females and unobserved mortality caused by their separation from unweaned calves (Archer et al., 2004).

It is important to have a fundamental understanding of dolphin school sizes and their dynamics, to better understand the potential for fishery-induced mortality and the indirect influences of the fishery on population-level dolphin recovery rates.

Here we quantify the diurnal fluctuations in school size and spatial distribution of pantropical spotted dolphins (*Stenella attenuata*) in the ETP. These analyses will help us understand the spatial and temporal variations in dolphin group size, and may lead to insights that will help minimize dolphin mortality in this fishery.

METHODS

Cruise Description

The data for this study comes from the Stenella Abundance Research Line Transect and Ecosystem (STAR-LITE) cruise, undertaken by NOAA in 2007. The study area was approximately 200 nm off the coast of Manzanillo, Mexico in the Eastern Tropical Pacific Ocean (ETP). One of the objectives of this cruise was to explore a new line-transect methodology; the surveys were conducted not with a traditional transect pattern but instead with a diamond-shaped transit pattern (Fig. 1).

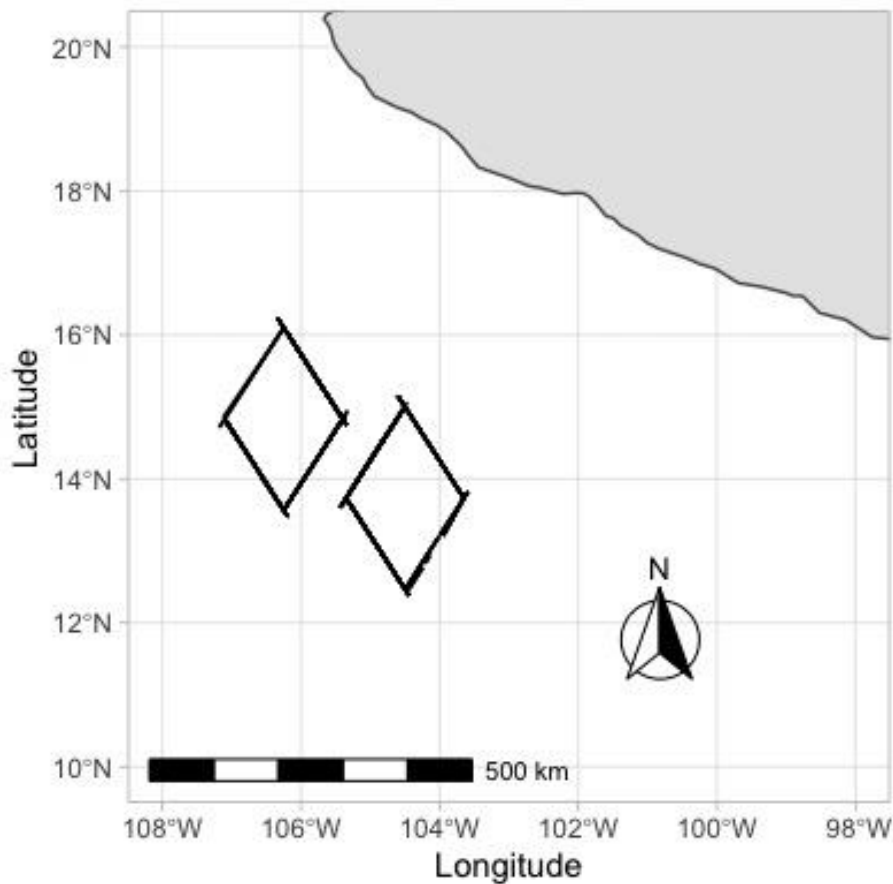


Figure 1: Map of the survey area.

Starting from the vertex of each diamond, each side, which is about 90 nm long, was surveyed twice, using two different survey modes. The first day was conducted in “passing mode”, which is when the ship traversed the trackline, and sightings would be recorded as they were made without the ship stopping or slowing down. There is no break in effort in order for the observers to better estimate school size or identify the species; they would continue until sunset or the ship reached the next vertex of the diamond. The ship would then travel back to the start point overnight and the same trackline would be completed the following day in “closing mode”. Closing mode is different from passing mode in that when a sighting was made, all observers go off effort, and the ship would “close” (travel off of the trackline towards the sighting) on the animals in order to better estimate group size, identify species, and take pictures for photo identification and biopsies. This way, each side of the diamond was repeated twice, and the 16 days it would take to cover both diamonds would make up one “leg”; the cruise lasted from 18th August to 29th November 2007 and was split into four legs.

“Sightings” refers to observations of one or more individuals of the target species in a group. Group size estimates were recorded for each sighting. Thus, a single sighting may represent multiple individuals.

The diamond patterns allow us to resolve sightings both spatially and temporally, i.e., sightings that are close in distance but far apart in time, and vice versa. This provides us with the necessary data to quantify the patchiness of dolphin schools across the entire time and distance parameter space resolved by the sampling.

Analysis

Of the 29 species recorded during the survey, we will only analyze data from *Stenella attenuata*. The observations were logged in space and time using the program WinCruz which writes data in the DAS format (Kinsey et al, 2000). The group size estimates were calculated following the methods detailed by Georodette and Forcada (2005).

It should be noted that Greenwich Mean Time ended on the 4th of November that year and also that the study area spans two time zones. Using the *swfscDAS* and *swfscMisc* packages, we processed the raw data (“DAS file”) and manually corrected some errors, namely in the GMT Offset and sighting date and time columns. The coordinates of the sightings themselves were calculated using the destination function in the *swfscMisc* package. The data frame of all sightings events was used in most of the analyses.

All analyses were performed in the software R.

Species ID confidence bias between modes

There is a marked difference both in the number of encounters and confidence in species identification between passing mode and closing mode (Schwarz et al, 2010). Using the packages *randomForest* and *rfPermute*, we ran a random forest model on our dataset to filter it for the highest possible species identification confidence. The model was trained on all confirmed sightings of a species and all sightings that possibly could have been that species but were unconfirmed. We used all the environmental factors recorded in our initial dataset as the

predictor variables in order to assess their effect on whether a sighting could be identified down to the species level. The predictor variables were group size, distance from sighting to the ship, perpendicular distance of sighting to the ship trackline, time, sea state, visibility, swell height, wind speed, presence of rain or fog, the horizontal angle of the sun and the vertical angle of the sun. The sample size was adjusted to be half of the number of unidentified sightings, and, as the sample size is small, the number of trees was set at a high value (24,000) and the model was run without replacement. The model performance was evaluated using class priors, and the model was used to predict which of our closing mode sightings would have been identified to species had it been made in passing mode, without the ship going off effort and closing on the sightings. The final filtered data frame was created by combining the predicted closing mode sightings and the confirmed species passing mode sightings.

Absolute group size

In order to center the hours of daylight across the time span of the cruise, the day was binned by the fraction of the diurnal period instead of by the actual time of day. The diurnal period fraction is calculated by dividing the number of hours elapsed between sunrise on that day and the time that the sighting was made by the number of hours of daylight (hours between sunrise to sunset) of that day.

To understand the effect of the time of day on the group size, we binned the diurnal period into quarters or thirds in order to compare the mean group size of the dolphins between different segments. Our sightings dataset was filtered separately for confirmed sightings of *S. attenuata*, then analyses were conducted separately for closing mode sightings and passing mode sightings. The group size was not normally distributed in any of the filtered variations, therefore

the means of the groups were compared using Kruskal-Wallis tests and Pairwise-Wilcox tests as a post hoc.

We also tested for a linear relationship between the diurnal period fraction values and group size. The raw diurnal period values are bounded between 0 and 1 and cannot be normally distributed. It was made symmetrical at zero by converting the values into the logarithm of their odds ratio (log odds) using the following formula:

$$pdl = \frac{\log p}{(1 - p)}$$

where p is the diurnal period fraction at which the sighting was made and pdl is the log odds of the diurnal period fraction. We then created a linear model of group size as a function of log odds of the diurnal period fraction:

$$\log_{10}(gs) \sim pdl$$

where gs is the best estimate of group size and pdl is the log odds of the diurnal period fraction.

Consecutive distance

We examined the distances between two consecutive sightings across the day separately for each survey mode. The diurnal period fraction was divided into three equal segments that ranged from 0-0.33, 0.33-0.67, and 0.67-1.0. Distances between sightings were only calculated for sightings that occurred on the same day.

The time between consecutive sightings in closing mode was the sum of the time that was spent on effort and the time that the ship spent off effort while closing on a sighting. Any pair of sightings that spent more than half the total time off effort was omitted, as observers could miss potential sightings and thus the sightings are unlikely to be truly consecutive.

This effort criterion is not necessary for passing mode, as the observers do not go off effort between sightings. However, there is a lower level of confidence in species identification when in passing mode, and thus, there is a potential for other “unidentified” species sightings to be our focal species. The passing mode dataset was thus filtered for any confirmed pairs of sightings that had unidentified sightings between them; these unidentified sightings could potentially be of the same species.

The two filtered datasets (closing mode and passing mode) were then combined in order to compare the distribution of consecutive distances across the day between modes.

RESULTS

Sightings

S. attenuata sightings were the most common (n=236) of all cetaceans species sighted on the cruise, with the number of sightings per day ranging from 1-11 with a mean of 4. *S. attenuata* were also sighted more frequently in the first half of the cruise (Fig. 2), with 63 and 88 sightings in the first two legs (08/26 to 09/12 and 09/19 to 10/04) and 36 and 49 sightings in the last two legs (10/13 to 10/29 and 11/05 to 11/23). The low number of sightings at the start of the first leg was attributed to bad weather days that affected survey conditions.

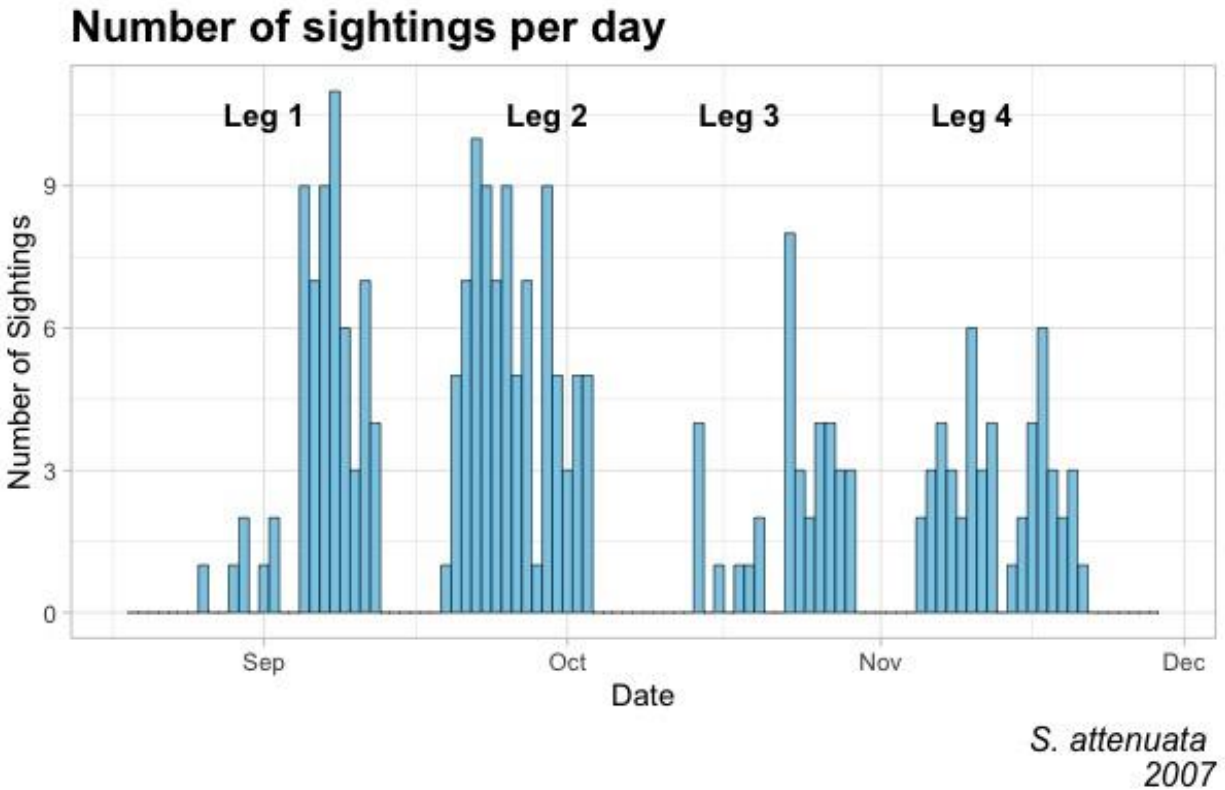


Figure 2: Number of sightings of *S. attenuata* per day over the course of the survey.

Group size

S. attenuata sightings tended to have group sizes smaller than 250 individuals with a median of 66, and a mean of 104 (Fig. 3). 55.93% of all *S. attenuata* sightings had groups with sizes of fewer than 100 individuals. Only 1.27% of pure *S. attenuata* groups had a group size greater than 300 individuals, and group sizes ranged between 2 and 362 dolphins. Sightings larger than 400 individuals were all mixed species sightings (usually with *S. longirostris*); the largest mixed species group size was estimated at 913 individuals.

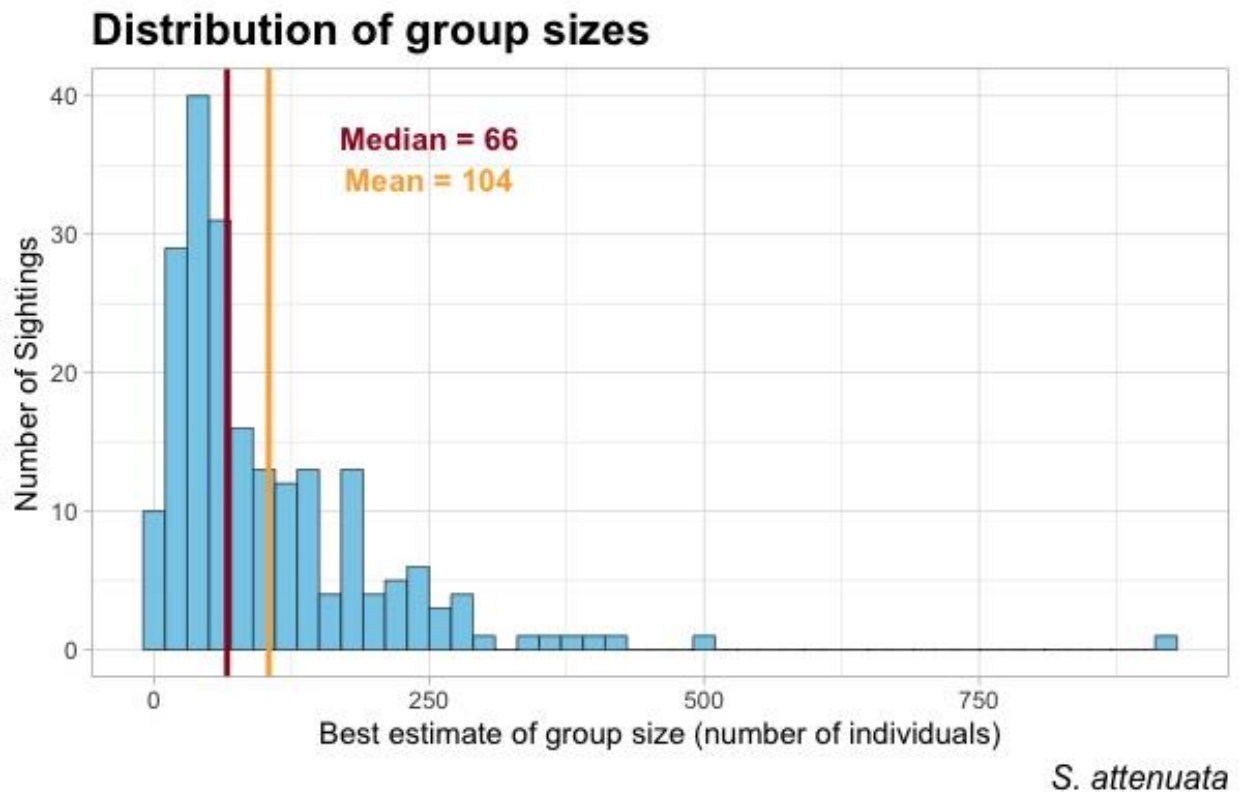


Figure 3: Histogram of the distribution of group sizes of all sightings of *S. attenuata*

Encounter frequency

The distribution of encounter frequency of *S. attenuata* was different between the two survey modes, with the greatest number of sightings in passing mode occurring in the second quarter of the diurnal period ($n = 46$), and in the last quarter of the diurnal period in closing mode ($n = 44$). There was a sharp decrease in sightings noted around 0.5-0.7 diurnal period in closing mode. The deficit in sightings between approximately 0.9-1.0 of the diurnal period is due to the ship reaching the end trackline waypoint sooner in passing mode than in closing mode due to continuous effort. However, in both survey modes, the fewest sightings were made in the first quarter of the diurnal period, with 17 and 16 sightings for passing and closing modes, respectively.

Table 1: The number of sightings and the mean group size across the quarters of the diurnal period, binned by survey mode.

	Fraction of diurnal period	0.25	0.5	0.75	1
Passing Mode	# of sightings	17	46	39	20
	Mean Group size	86.19	70.34	101.57	47.88
Closing Mode	# of sightings	16	30	24	44
	Mean Group size	131.69	174.65	121.06	92.25

For both survey modes, the mean group size was smallest in the last quarter of the diurnal period, i.e., close to sunset (Table 1). The mean group size was always smaller in passing mode than in closing mode, which is likely due to the limited amount of time the observers had to make their group-size estimates when compared to closing mode.

Number of sightings over a day in different modes

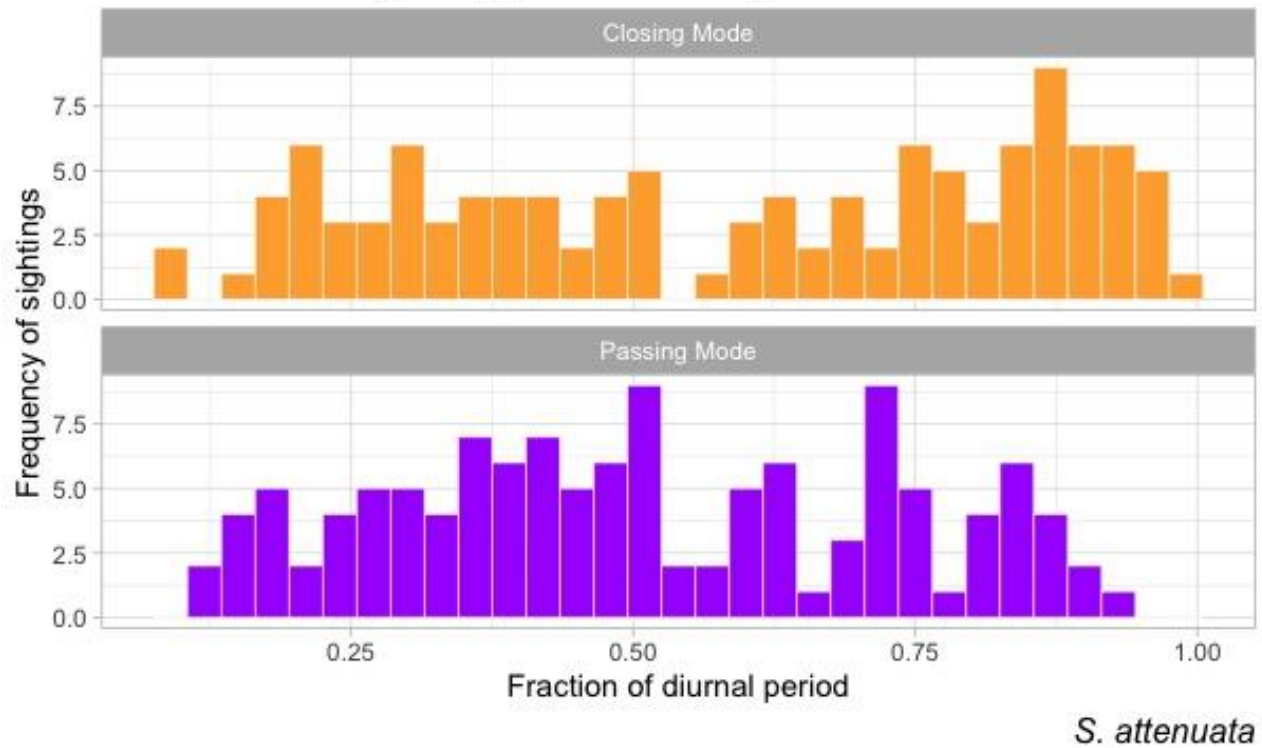


Figure 4: Histograms of the number of sightings as a function of the fraction of diurnal period for each survey mode.

The random forest model predicted that a total of 73 out of 114 sightings that were made in closing mode would have been identified down to the species level in passing mode (Percent correct = 74.4%, Class Priors p value = 7.182375e-02).

Does group size vary over the day?

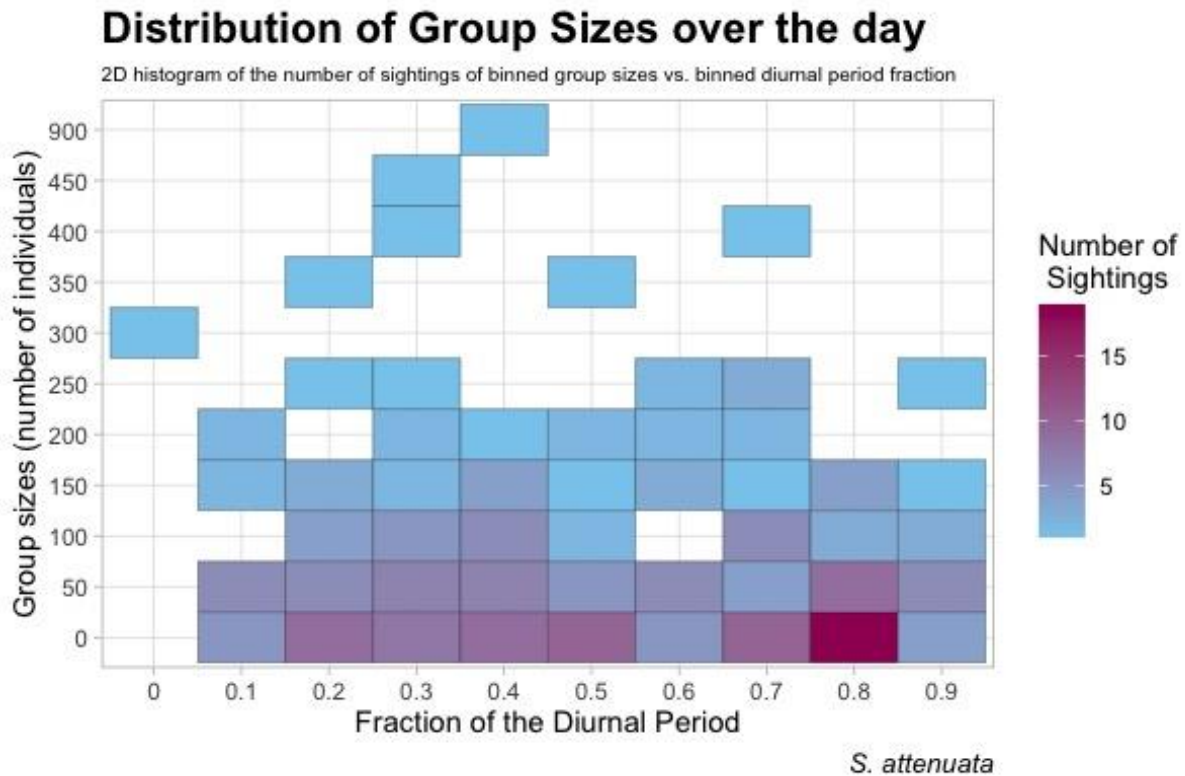


Figure 5: 2D histogram of the number of sightings of binned group sizes as a function of the binned fraction of the diurnal period.

Most of the largest groups (>250 individuals) were sighted in the middle of the diurnal period, while smaller groups (<100 individuals) were fairly evenly distributed throughout the diurnal period. The smallest groups (<25 individuals) were sighted the most frequently, with a peak frequency in sightings at a diurnal period fraction of 0.8. Mean group sizes were significantly different on closing-mode days vs passing-mode days (55 dolphins; Kruskal Wallis $p = 0.002575$), meaning that spotted dolphin groups sighted on closing mode days had, on average, 55 dolphins more than sightings made on passing mode days.

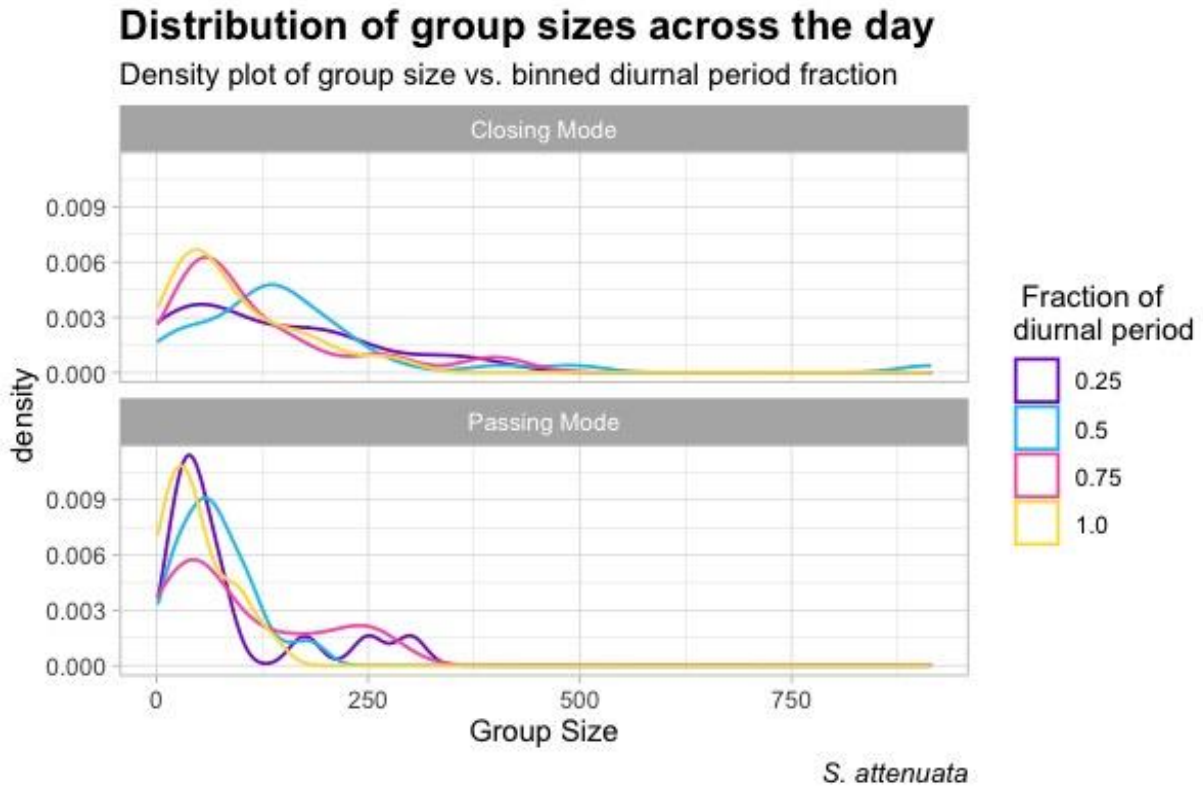


Figure 6: Density plot of the group sizes of sightings of *S. attenuata* binned by fraction of the diurnal period.

In closing mode, the mean group size was significantly different (Wilcox $p = 0.039$) between the second and last quarter of the diurnal period; i.e., the group size around midday, on average, was larger by 82 dolphins than at dusk. In closing mode, the density distributions were similar for 0.75 and 1.0 diurnal time periods, with pronounced peaks of 58 and 47 individual strong groups respectively, and relatively few larger groups. The 0.25 time period closing-mode distribution was flatter, indicating that there was a broader range of group sizes at that time. By the 0.5 time period, there was a pronounced mode at 135 individuals, with less frequent large and small groups than in other time periods. The passing-mode distributions showed much more pronounced modes than in closing mode, with fewer large groups; this was particularly noticeable at the 0.25 and 1.0 diurnal periods. The 0.5 period had the mode shifted to larger

group sizes (57 individuals), while the 0.75 period showed fewer small groups (<100 individuals) and more large groups (>200 individuals) than the other time periods.

The relationship between the log of group size and the logodds of fraction of diurnal period in closing mode was not strongly linear (p-value = 0.03386, F statistic = 4.615 on 1 & 112 df). It returns an adjusted R squared of 0.031, which indicates that the fraction of the diurnal period only accounts for 3.1% of the variation in group size. The model returns the linear equation:

$$\log(gs) = 1.954 - 0.059 \text{ } pdl ;$$

where *gs* is the group size of the sighting and *pdl* is the logodds of the fraction of the diurnal period. The predicted group size from this model at 0.5 of the diurnal period, i.e. when the log odds is 0, is 89 individuals and a 1 unit increase in the log odds corresponds to a 0.06 unit decrease in the log of school size.

Does consecutive distance vary over the day?

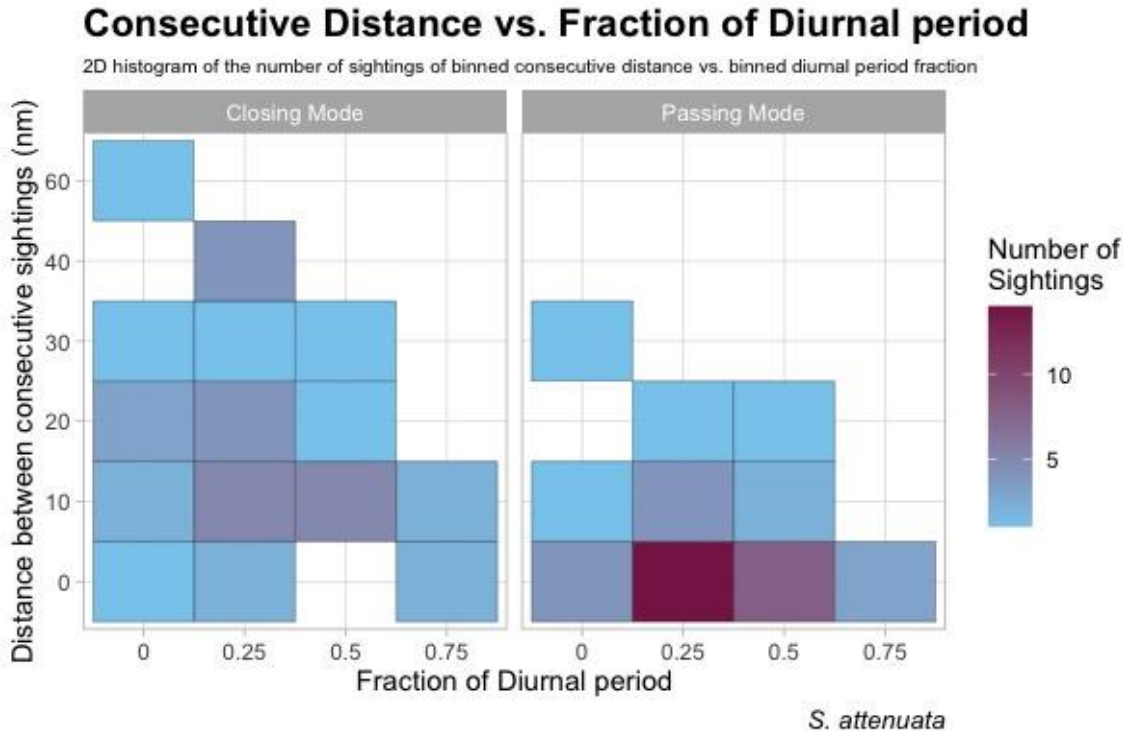


Figure 7: 2D histogram of the number of sightings of *S. attenuata* of the binned distances between consecutive sightings as a function of the binned diurnal fraction

The distance between consecutive sightings tended to be greater in closing mode than in passing mode for *S. attenuata*. The maximum potential distance between a pair of sightings is 90 nm, and there were no pairs of sightings with a distance greater than 40 nm between them on passing mode days. Passing mode also showed a higher density of sighting separations <20 nm than closing mode sightings. The mean consecutive distance between pairs of spotted dolphin sightings made on closing mode days was 13.95 nm greater than on passing mode days; this difference was significant (Kruskal Wallis $p = 1.338e-06$).

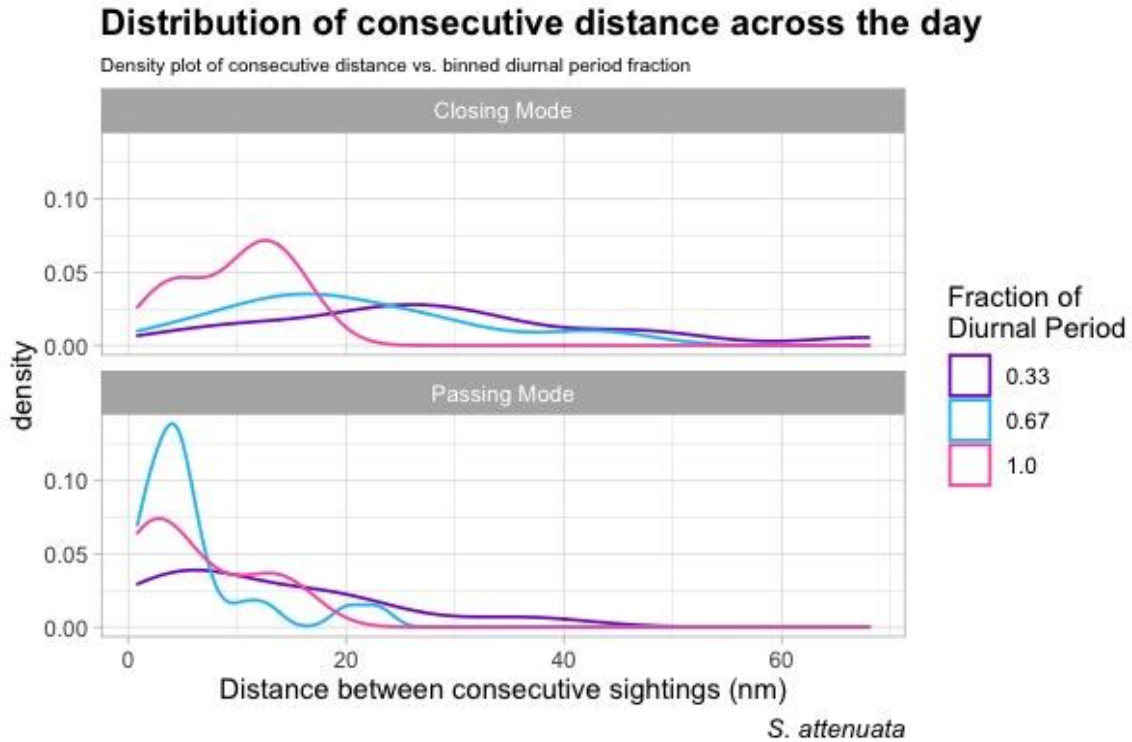


Figure 8: Density plot of the number of sightings of *S. attenuata* of the distances between consecutive sightings binned by the fraction of the diurnal period.

The mean distance between pairs of consecutive sightings made on closing mode days was significantly smaller in the first third of the diurnal period than the last third by 19.03 nm (Wilcox $p = 0.037$). It has to be noted that the sightings were binned considering only the diurnal fraction at which the first sighting of the pair was made. This means that in closing mode, a sighting made in the first third of the diurnal period would be, on average, 19.03 nautical miles farther away from the next sighting than a sighting made in the last third. The differences between the bins in passing mode were not statistically significant, and the relationship between the log of consecutive distance and the logodds of the fraction of diurnal period was not linear ($p = 0.086$, F statistic = 3.12 on 1 & 33df).

Does group size vary with consecutive distance?

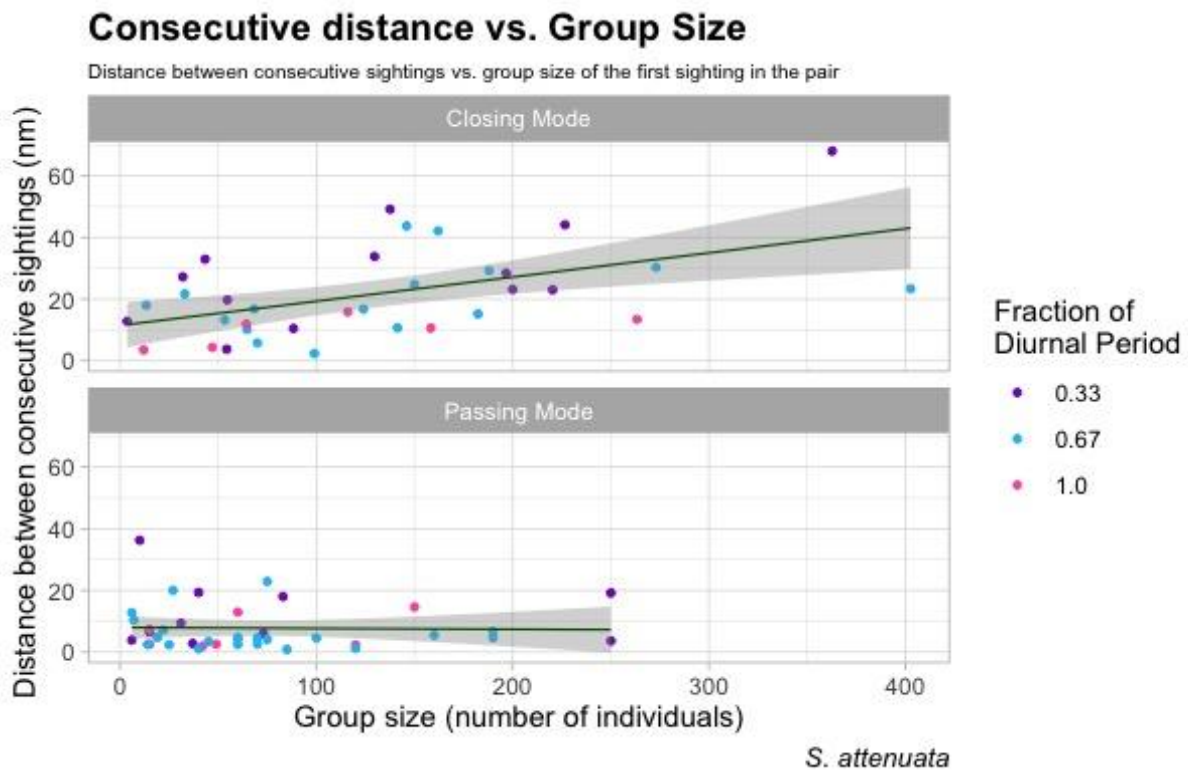


Figure 9: Scatter plot of the distances between pairs of consecutive sightings of *S. attenuata* against group size of the first sighting in the pair, binned by fraction of the diurnal period in which the first sighting was made.

In closing mode, there was a significant linear relationship between group size and consecutive distance (F statistic of 11.85 on 1 and 33 degrees of freedom and a p-value of 0.001587). The linear fit returns an adjusted R squared of 0.2419, indicating that group size accounts for 24.19% of the variation in distance between consecutive sightings. The model returns the linear equation,

$$cd = 11.47 + 0.078 gs ;$$

where cd is the distance between a pair of consecutive sightings and gs is the group size of the first sighting in the pair. Thus, for example, the predicted distance between a pair of consecutive

sightings is predicted to be 15.76 nm if the first sighting in the pair has a group size of 55 dolphins.

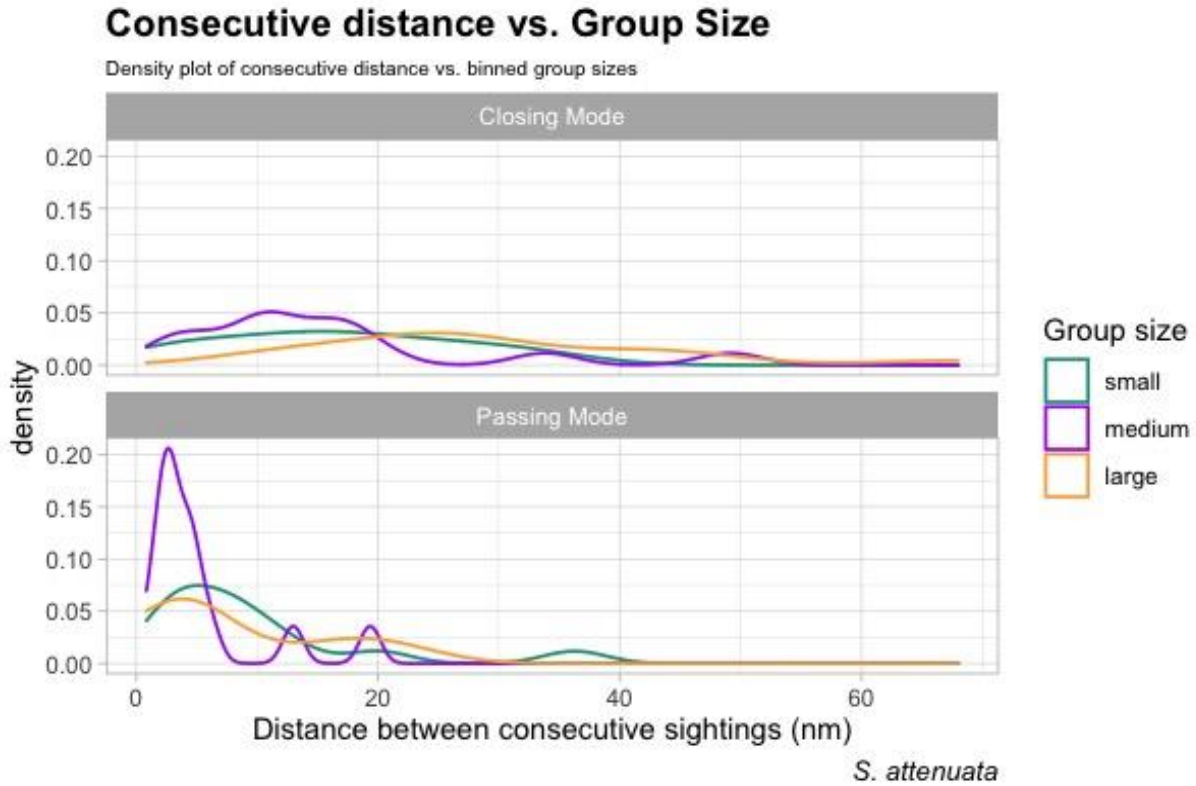


Figure 10: Density plot of the distance between consecutive sightings of *S. attenuata* binned by group size.

When binning pairs of sightings considering only the group size of the first one of the pair, the mean consecutive distance between sightings made in closing mode of small groups was 13.24 nm smaller than for large groups (Wilcox p-value = 0.053); medium-sized groups were 14.01 nm (Wilcox p-value = 0.023) closer together than large groups. This means that sightings of groups larger than 145 dolphins are, on average, 13.24 nm farther away from the next sighting than groups consisting of fewer than 55 dolphins, and 14.01 nm farther away from the next sighting than groups of between 55 - 145 dolphins.

DISCUSSION

In this study, we present an examination of the spatial and temporal distribution of spotted dolphin (*S. attenuata*) schools in the eastern Tropical Pacific (ETP). We detected non-random distributions of sightings of groups over the course of a day, as well as non-random distributions of group sizes across space and time.

This study was based on sightings made during the 2007 STARLITE cruise conducted by the Southwest Fisheries Science Center (Archer et al. 2008). The tracklines for this cruise were set to be within the core area of the Eastern Tropical Pacific (ETP), which is a region where the spotted dolphin is the most commonly occurring species (Polacheck 1987, Ballance and Pitman 1998, Perrin 2001). Although the ETP is a highly productive region, it also can experience high oceanographic variability, with concomitant changes in the distribution of *S. attenuata*, which prefers warmer and more stratified waters (Wyrтки 1965 and 1974, Reilly 1990, Fiedler and Lennert-Cody, 2019; Diaz Torres, 2022).

In this study, we saw a marked decrease in the sighting frequency of spotted dolphins during the last two legs (10/13 to 10/29 and 11/05 to 11/23). This is consistent with findings that *S. attenuata* exhibits a westward offshore movement along 10°N in the summer in tandem with the shoaling of the thermocline and a subsequent eastward onshore movement as the North Equatorial Current and Countercurrent weakens in winter (Wyrтки 1974; Perrin et al., 1979; Reilly, 1990; Fiedler and Reilly, 1994). It is hypothesized that the seasonal movement exhibited by *S. attenuata* is influenced by prey availability (Jones, 1981), as evidenced by the corresponding change in their diet compositions (Robertson and Chivers, 1997). There are more

records of their association with yellowfin tuna (*Thunnus albacares*) from the second and third quarters of the year, which is the more lucrative tuna fishing season (Alverson, 1959), and data from research cruises corroborates the existence of the “summer buildup” of *S. attenuata* and *T. albacares* (Au and Perryman, 1985). Warm water with a shallow thermocline and intermediate productivity leads to denser but patchily distributed aggregations of the prey species (Au and Pitman, 1988), and the stable thermocline of the ETP creates a characteristic thick oxygen minimum that restricts the movement of the tuna to the surface waters of the ETP (Prince and Goodyear, 2006; Scott et al., 2012), which is where the dolphins spend their time during the day. These create the optimal conditions for tuna-dolphin associations, and is why the warmer months of the year are more important for tuna fisheries.

S. attenuata tends towards larger group sizes during the day (Scott and Cattenach, 1998) and disperses into smaller groups beginning around sunset, as seen from the high concentration of small group size sightings at 0.8 of the diurnal period (Fig. 5), and the significantly smaller group sizes at the beginning and end of the day (Fig. 6). The diurnal group size pattern (Table 1) exhibited by *S. attenuata* has been attributed to schooling behavior of their prey species, which is also mirrored by the *T. albacares* schools that hunt their shared prey species in association with the dolphins (Scott and Cattanach, 1998). There is a strong overlap between the diets of these two species; the diet of *S. attenuata* is dominated by mesopelagic species of ommastrephid squid in the summer and myctophid fish in the winter (Robertson and Chivers, 1996; Perrin et al., 1973), which are known to undergo diel vertical migration (Roper and Young, 1975). However, *S. attenuata* food requirements compared to *T. albacares* are 5-10x higher per individual per day, and while *S. attenuata* do feed during the day in the multi-species aggregations (Perrin et. al,

1973), they rarely eat to fullness during associated feeding sessions (Edwards 1992) due to competition for limited prey availability. Nighttime dive behavior of *S. attenuata* shows slower travel and longer dives (Scott and Chivers, 2009) to feed on species that are vertically migrating in association with the rise of the deep scattering layer, with an increase in dive time in the fall and winter months. This is why *S. attenuata* (Robertson, 1997) and *T. albacares* (Buckley and Miller, 1994) can exhibit inverse stomach fullness indices across the diurnal period despite their mirrored group size pattern.

We found a fairly even distribution of sightings of small (<25 individuals) group sizes across the diurnal period in our study (Fig. 5). Previous group size estimates made using data primarily sourced from fisheries records are likely to be biased towards larger groups (Perkins and Edwards, 1999) due to preferential targeting by the fishers, so it is likely that smaller group sizes are more prevalent through the day than previously considered, especially during the fall and winter months when it is less advantageous for the association to occur.

Consecutive sightings were also found to be farther apart around dawn than around sunset (Fig. 8). Larger groups were found farther away from the nearest group than smaller groups (Fig. 9, Fig.10). This aligns with the diurnal fragmentation and nocturnal reformation of groups. This diurnal change in separation distance could be caused by smaller groups coalescing into large aggregations over the course of the day, or by small groups avoiding large groups in order to minimize competition for food. It is unlikely that these dynamics are fixed, and future work toward testing this hypothesis is recommended.

It can be difficult to discern whether signals in the data are ecological, or due to aspects of the data-collection process. The survey alternated passing and closing mode on successive days, and previous research has shown advantages and downfalls to using both. The continuous effort of passing mode days ensures that there is no underestimation in area surveyed and minimizes the amount of sightings missed, but results in poorer species identification and group size estimation, which is resolved in closing mode. The results of the random forest model predicted that only 64% of the sightings made in closing mode would have been correctly identified to a species level in passing mode.

The test results showed that there were no statistically significant differences between group size and distance through the day from the passing mode data, despite observing patterns in the distributions of the sightings (Table 1). There was a higher density of <20 nm distances between consecutive sightings (Fig. 7) and there were fewer large groups sighted (Fig. 6) in passing mode than in closing mode. This could be attributed to the lower confidence in species identification (Schwarz et al. 2010) that led to a lot of sighting pairs being filtered out in passing mode because of the presence of unidentified sightings, and to a more conservative approach to group size estimation (Georodette, Perryman and Barlow, 2002) in passing mode than closing mode, and the consequent small sample size of the passing mode data.

Future research comparing the present-day seasonal and diurnal group size trends of the ETP *Stenella attenuata* population to group size patterns of other populations could bring to light the influences of the tuna fishery on these dolphins. Low reproductive output due to stress from fisheries interaction is thought to be the primary reason for the non-recovery of ETP *S. attenuata*

populations (Wade et al., 2007; Cramer et al., 2008). Perkins and Edwards (1999) showed that the exposure of dolphins to the fishery was a function of the amount of time individuals spent in large schools. Therefore, it is imperative to continue to improve our understanding of the spatial and temporal distribution of these schools in order to contextualize the social interactions of these dolphins and the future impact of the fishery on them.

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