Observations of gray whales and other cetaceans in the vicinity of Naval Station Everett in North Puget Sound and gray whale's responses to vessel's presence

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Introduction

This report summarizes sightings and results from two different projects near Naval Station (NAVSTA) Everett: 1) a land-based project, conducted from March to May 2021, that tracked whales from shore and studied the potential impacts of boats on the behaviors of gray whales in North Puget Sound, WA, 2) sightings from boat-based surveys conducted by Cascadia Research Collective from 1991 to 2021 near Everett.

In 1990, the first gray whales were documented regularly using North Puget Sound (Weitkamp et al., 1992, Calambokidis et al., 2015). These individuals detour into Washington waters predominately in the spring, March to May, but they have been seen throughout the year, though most commonly with a few individuals arriving in February or staying into June, following the other members of the Eastern North Pacific stock to forage in Alaskan waters. The group of whales that return annually, some for over 30 years, have come to be called the Sounders, and as of 2022, include 15-20 individuals (Cascadia Research and Orca Network, 2023).

The Sounders take part in risky behavior in shallow waters to feed on ghost shrimp, also known as sand shrimp (Weitkamp et al., 1992, Pruitt & Donoghue, 2016). This strategy of feeding on the shrimp has been beneficial for the Sounders, and the number of gray whales utilizing the Puget Sound has increased in recent years, despite an unusual mortality event that has resulted in the death of over a third of the overall eastern North Pacific gray whale population (Eguchi et al., 2022, Stewart et al., In Press, Moore et al. 2022).

Methods

Land-Based Observations

For the land-based project, Hat Island, located in Possession Sound, provided an ideal location to observe boats, whales, and their interactions from shore (Pavlinovic, 2022). From March 15 to May 14, 2021, a Sokkia DT5A theodolite and visual observations were used to record locational data on boats and whales and whale's behavioral data (Pavlinovic, 2022). Additionally, weather data were recorded (Pavlinovic, 2022). Boats were categorized by whether they were whale-watching or not and based on their hull design and purpose (Pavlinovic, 2022). These data were captured and stored on a computer using Pythagoras software (v1.2). Before each tracking session began, the accuracy of the theodolite was checked using a known point. Additionally, theodolite accuracy was checked on one day using known distances. An individual on a research vessel recorded a GPS point; then, it would be compared to the land-based crew's data. This test gave us confidence in the equipment used for this research (Pavlinovic, 2022).

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The observation team ranged from two to four individuals (Pavlinovic, 2022). The theodolite operator (A. Pavlinovic) had extensive experience using and setting up this device. Before acting as spotters or recording data, the research assistants and volunteers were trained. Besides the theodolite operator, the roles were rotated every 30-60 minutes to keep the team fresh.

This study investigated the impact on whale's behaviors when boats were present within 1 km or less of a whale. Using the methods from Williams et al. 2002, the hypothesis was that boat presence would impact gray whale behaviors, specifically speed, direction indices (DI), deviation indices (DEV), and Inter Breath Intervals (IBI). To test this hypothesis, whale behaviors were recorded and divided into two categories: (1) when a boat was present within 1 km or less of the whale being tracked, and (2) when no boat was present within 1 km or less of the whale being tracked. During fieldwork, when boats were within 1 km of the whale, the boat presence were recorded. Also, details of the boats were recorded and divided into categories based on their hull design and purpose, and separated based on their uses of recreational, commercial, or research purposes. These data were gathered using a theodolite to track the whales and boats and a laptop to record the data running the software Pythagoras.

Using the gray whale location and timing of breath data, the variables of speed, DI, DEV, and IBI were calculated. The DEV and DI datasets were used to show the linearity and path predictability of a whale's path (Williams et al., 2002). For equations to calculate DI and DEV, please see the description of Figure 1 (Christiansen et al., 2013). Speed was calculated in kilometers per hour. The timing of the whale’s breath was recorded each time it surfaced, and the IBI was calculated as the amount of time between breaths (Pavlinovic, 2022).

Each time a whale surfaced, the location was determined using the theodolite (Pavlinovic, 2022). The location and timing of the whale’s breath were recorded using the laptop, along with Pectoral Fin Showing, Peduncle Showing, Fluke Up, Side Fluke Showing, and other singular behaviors (Pavlinovic, 2022). If this recording happened even a second late, a missed IBI would be recorded instead (Pavlinovic, 2022). After the field season, the data were cleaned (removed eccentric data points and errors) and organized into focal follows/tracking sessions (Pavlinovic, 2022). Focal follows were divided into two categories: boat presence or absence. If a whale was being tracked for 10-minutes and then a boat traveled to within 1 km of a whale, then this tracking would be separated into at least two focal follows. Also, if the team decided to start tracking another whale, then this change would mean the creation of another focal follow (Pavlinovic, 2022).

After the datasets were broken into two categories, boats present or not present within 1 km of a whale, each of those two categories were further divided into two subcategories. The first contained the movement metrics of Speed, DI, and DEV. For this subcategory, the whale’s locations were used to calculate these variables. The second subcategory contained IBI. For this subcategory, the timing of the whale’s breaths was used to calculate IBI. Due to the differences in data structure and using two separate Excel sheets to record the different subcategories, these two datasets were separated for analysis.

Movement Metrics

Over 151 focal follows, 2,868 fixes of a whale's locations (931 boat, 1,937 no boat), and 1,127 fixes of boats were recorded. First, all the movement metrics were tested for normality using the Shapiro-Wilk normality test in base R. None of the categories were normally distributed (Pavlinovic, 2022). Second, a Hotelling's T^2 test was used to analyze the movement metrics of gray whales as a group. The results indicated a significant difference between when boats were present within 1 km of a whale or not (Pavlinovic, 2022). Third, Welch's T-tests and Mann-Whitney U-tests showed that Speed, DI, and DEV were significantly different when boats were present within a km of a whale versus not (Pavlinovic, 2022). Fourth, to account for any correlation structure among the movement metrics and to calculate the effect of each movement metric in separating the two groups in the Hotelling's T^2 test, standardized discriminant coefficient function analysis was used. DEV appeared to have the most significant impact on separating the two groups (boat versus no boat), compared to Speed or DI, with DI showing the least impact (Pavlinovic, 2022).

Last, generalized least squares model analysis was used to assess the possible impacts of boat presence on the whale's movement metrics while accounting for the limited number of focal follows (151) and the location from which the observations took place, also known as OPs (F15, M27, W18). DI was excluded from this analysis because these data could not be transformed to deal with heterogeneity issues. Thus, it violated the assumptions needed for the models and would not produce accurate results. Even after accounting for the correlation among focal follows by adding focal follows as the auto-correlation structure, these impacts were still present for Speed and DEV (Pavlinovic, 2022). Also, for some of the variables, the location (OPs) from which the observations took place likely had an impact on the variables (Pavlinovic, 2022). Further details on the statistical analysis can be found in Appendix A.

IBI

From the initial fieldwork, 6,222 focal behaviors were recorded. From this dataset, 4,355 surfacings or missed surfacings (1,816 boat, no boat 2,539) were recorded over 193 focal follows. First, IBI data were tested for normality using the Shapiro-Wilk normality test, and were not found to be normally distributed (Pavlinovic, 2022). Second, using Welch's T-tests and Mann-Whitney U-tests, IBI data were shown to be significantly different when boats were present within 1 km of a whale versus not (Pavlinovic, 2022).

Last, generalized least squares model analysis was used to assess the possible impacts of boat presence on the whale's IBIs, while accounting for the limited number of focal follows (193) and the location from which the observations took place, also known as OPs. Even after accounting for the correlation among focal follows by adding focal follows as the auto-correlation structure, these impacts were still present for IBI (Pavlinovic, 2022). Also, the location (OPs) from which the observations took place had an impact on IBI (Pavlinovic, 2022).

Cascadia Vessel Surveys

We drew from 140 surveys conducted by Cascadia Research and collaborators from 1991 to 2021 in the north Puget Sound Region (CRC, 2022). These surveys were opportunistic and were primarily designed to search and identify gray whales in and around Possession Sound, Port Susan, and Saratoga Passage. They were conducted primarily from March to June (the period of primary gray whale occurrence), with a few surveys in other months. We identified 350 gray whale sightings (out of 652 marine mammal sightings) made during these surveys.

Surveys were primarily conducted with Cascadia Rigid-Hull Inflatables launched from Everett during the period from February to June.

Mapping

ArcGIS maps were created using ArcGIS online software. These maps can be divided into two distinct groups of boat-based and land-based data. First, for the boat-based data, there were 354 observations of whales (350 of only gray whales) used to create these maps. These data were recorded from 1990-2021 and included information on gray whales, humpback whales, and minke whales. These sightings were recorded almost exclusively from surveys conducted from research vessels where we endeavored to search the broad region. While additional sightings were available from whale-watch vessels, these were not included since the areas of coverage were not as extensive or documented. For this category of data, the location is for the vessel when it was close to the whale and not the exact location of the whale. Also, for the heat maps, the estimated best size of the group was considered, which made the heat map a better representation of gray whales observed in Puget Sound.

Second, from the land-based effort, 157 GPS points were used to produce the two heat maps. These observations represent the location of gray whales, as recorded by the theodolite (Pavlinovic, 2022). All these points were within the study area defined during the research proposal and had to be visible from the observation locations on Hat Island. Whales were tracked for as long as possible, some for over an hour (Pavlinovic, 2022). Over that time frame, up to 50 locations of a whale could be recorded. For each focal follow, if the duration was under an hour, only the first location recorded was used for the map. If the focal follow went beyond an hour, another location was used as close as possible to the 1 hour and 1-minute mark.

Results & Discussion

Sighting & Heat Maps

Evaluation of the boat-based heat maps needs to take into account our survey coverage. Figure 2 shows the tracks from 61 Cascadia Research surveys conducted 2005-2021 which had detailed tracks (not all surveys had available detailed tracks including none of those prior to 2005). These provide a representation of our overall survey coverage. Most of the boat-based surveys started out of the Port of Everett, and while we attempted to cover all of Port Susan, Saratoga Passage, and Possession Sound, that was not always possible. The most consistently surveyed portion of the study area was the area around Hat Island and the Snohomish River Delta, which could have accentuated this area of concentration.

With that being said, from the boat-based data, three maps were created: Figure 3 shows the locations and whale species found during the surveys in the study area, Figure 4 shows a heat map for the gray whale sightings during the surveys, and Figure 5 shows both the gray whale heat map, and gray whale sighting locations. Sightings of gray whales were concentrated most densely immediately southeast of Hat Island and extending over to the western portion of the Snohomish River Delta. There was also a concentration of sightings in the northern portion of Port Susan and secondary concentrations of sightings just south of Possession Point and along the southwestern shore of Camano Island.

From the land-based data, two maps were created. The heat map in Figure 6 shows the densities of gray whales during 2021. The heat map in Figure 7 shows the density of gray whales in the defined study area and the points used to create the heat map during 2021. Similar to the boat-based sightings, these showed the greatest concentration of gray whale sightings between Hat Island and the Snohomish River Delta. The more limited range that could be observed from the Hat Island locations is useful for looking at finer scale distribution in that area but did not allow coverage of more distant areas where whales were present, such as Port Susan, Saratoga Passage, or Possession Bar. The three observation locations from which the observations were made also did not cover the areas approximately west or southwest of Hat Island.

Interpreting Movement Metrics & IBI Data Analysis

After running the statistical tests, there was a high level of confidence that whale metrics of Speed, DEV, and IBI recorded when boats were present within 1 km significantly differed from when boats were absent (Pavlinovic, 2022).

Over 76.5 hours of observations resulted in 151 movement metrics, and 193 IBI durations focal follows, made up of 2,799 estimates of movement metrics and 4,072 estimates of IBI durations. In the presence of boats, gray whales were likely to speed up. According to DEV, gray whales were likely to travel in a more linear path in the presence of boats. According to IBI, whales were likely to have shorter IBI durations in the presence of vessels.

Depending on the boat size and activity (for example, noise level or engine condition), different boats could have significantly different impacts on whale behavior. These variables were not analyzed to simplify the analysis. Also, given that there were less than 15 Sounders and around 191 focal follows, the same whales have likely been tracked multiple times, which could lead to bias in study results because there was a possibility that different whales responded differently to the presence of boats. However, the fact that observations were significant indicates the impact of confounding variables is relatively small. Still, further analysis of these other variables would be a valuable area for future research, with potential policy implications.

Research Implications

While these gray whales were in Puget Sound, they interacted with several boat-based whale-watching operations and large numbers of recreational and commercial vessels. The results showed that presence of boats likely impacted gray whales. With the Sounders and the number of gray whales utilizing the Puget Sound increasing and individual whales staying longer, this feeding area is becoming more critical to the Eastern North Pacific Stock of gray whales (CRC, 2022). In the future, further protections may be needed, such as larger standoff distances.

The most recent unusual mortality event for the Eastern North Pacific population of gray whales started in 2019 (NMFS, 2022). From that year until present time, it is estimated that a third of the approximately 20,000 whales in the population died, which would equal approximately 1,667 whales dying each year (CRC, 2022). To put this into perspective, the average mortality for the 18 years before this UME for the Eastern North Pacific population of gray whales was 29 whales stranded yearly (NMFS, 2021). As this population was already under pressure, limiting the stress put on this population may be critical for preventing further losses.

The Hat Island land-based study fits in well with previous research on the impacts of boats on cetaceans and can be applied to other research projects studying anthropogenic effects on cetaceans (Christiansen et al., 2013; Senigaglia et al., 2016; Williams et al., 2002). Williams et al. (2002) used the same methods and indices as the Hat Island study and found that the presence of vessels correlated with changes in the killer whale behaviors. Similar results have also been found with minke whales (Christiansen et al., 2013) and many other cetacean species (Senigaglia et al., 2016). Senigaglia et al. (2016) presents a meta-analysis studying the impacts of boat presence on whales, with the results indicating that the issue is not whether the whales were disturbed by the presence of boats, but rather how they would they respond. According to Senigaglia et al. (2016), these effects were dependent on the species, location, and methods. This study on gray whales showed boat presence impacted them in three of the five categories of DEV, IBI, and Speed.

Few studies have investigated anthropogenic effects on gray whales. Therefore, we mainly rely on similar studies on other cetaceans. In most studies, researchers concluded that the presence of boats adversely affects whales, but this was not consistent across all species and regions (Senigaglia et al., 2016). Some of these disturbances resulted in fasting and increased erratic movement, which combined to cause calorie deficits (Senigaglia et al., 2016). The acoustic impacts of boats have been shown to alter gray whale and humpback whale communications (Burnham & Duffus, 2019; Fournet et al., 2018). For Northern Resident killer whales, both males and females showed avoidance tactics when boats approached them (Williams et al., 2002). In Iceland, minke whales responded to the presence of boats by decreasing their IBI and increasing their sinuous movements (Christiansen et al., 2013). Cumulatively, these disturbances can cause whales to avoid and abandon high-disruption areas (Lusseau & Bejder, 2007)

Management Implications

At the time of the research, the required separation distance between boats and gray whales was 100 m/y (NMFS, 2020), but the cutoff used in this study was much further, at 1,000 m. Even at this distance, changes were observed. Among other marine mammals, killer whales had special and increased protection from boaters of at least 200 m and up to 400 m of distance (NMFS, 2020), but even this distance between the boats and gray whales was relatively near. This research and further research could be used to better inform managers of the appropriate separation distances for boats, and therefore improve protections for this species.

Previous studies have shown that the Sounders were more sensitive to boat presence when foraging, and that if a boat approached a foraging whale, it would likely stop foraging (CRC, 2022). With a short window of high tide for the whales to forage, interruptions of this critical time could cause large changes in whale's caloric intake and, thus, overall health. This information suggested that a "one distance fits all" approach may not be sufficient protection for the whales in some of these areas that see heavy use for foraging. Future research comparing different locations, such as the different observation posts used in this study, could shed light on optimal management strategies.

Conclusions

Primary conclusions from the work we summarize here include:

- Gray whales were heavily sighted around Hat Island, especially along the east side between Hat Island and the Snohomish River Delta.

- Even after accounting for the limited number of focal follows, when boats were within 1 km of a gray whale, the whale usually sped up, traveled in a more linear path, and had greater variation in IBIs.

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Terms

Boat – This term means that a boat was present within 1 km, when the data on the whale was recorded.
DEV - Deviation Indices. This measurement ranged from 0°-180°, with 0° being a straight path and 180° being a change in the whale's path to the opposite direction (Figure 1). For the equation to calculate DEV, see the description of Figure 1 (Christiansen et al., 2013).
DI - Direction Indices. This measurement ranged from 0-1, with 1 showing the whale traveled in a straight line and 0 indicating that the whale traveled in the opposite direction. For the equation to calculate DI, see the description of Figure 1 (Christiansen et al., 2013).
GLS - Generalized Least Squares. This multivariate statistical analysis allows the user to account for multiple variables' impact on one.
GPS - Global Positioning System
IBI - Inter-Breath Intervals. The time calculated, in seconds, between whale's blows.
M - Meters.
No Boat – This term means that there was not a boat present within 1 km, when the data on the whale was recorded.
NPS - North Puget Sound.
OPs - Observation Posts. The corresponding housing plot from which the whales were observed. Three different observations posts were used F15, M27, and W18.
RHIB - Ridged Hull Inflatable Boat.
Speed - The rate in which the whale traveled in kilometers per hour.

Bibliography

Burnham, R., & Duffus, D. (2019). *Gray Whale Calling Response To Altered Soundscapes Driven By Whale Watching Activities In A Foraging Area*. 23.

Calambokidis, J., J.D. Darling, V. Deecke, P. Gearin, M. Gosho, W. Megill, C.M. Tombach, D. Goley, C. Toropova, and B. Gisborne. 2002. Abundance, Range and Movements of a Feeding Aggregation of Gray Whales (Eschrichtius robustus) from California to Southeastern Alaska in 1998. Journal of Cetacean Research and Management 4(3): 267-276.

Calambokidis, J., G.H. Steiger, C. Curtice, J. Harrison, M.C. Ferguson, E. Becker, M. DeAngelis, and S.M. Van Parijs. 2015. Biologically Important Areas for Selected Cetaceans Within U.S. Waters – West Coast Region. Aquatic Mammals 41(1): 39-53.

Cascadia Research Collective [CRC]. (2022). Unpublished Information and Data Regarding Gray Whales and the Sounders [Personal communication].Cascadia Research Collective and Orca Network. 2023. A Guide to the Gray Whales of North Puget Sound "The Sounders". Self-published by Cascadia Research Collective and Orca Network.

Clayton, H., D.E. Cade, R. Burnham, J. Calambokidis, and J. Goldbogen. 2023. Acoustic Behavior of Gray Whales Tagged with Biologging Devices on Foraging Grounds. Frontiers in Marine Science 10: 1111666.

Christiansen, F., Rasmussen, M., & Lusseau, D. (2013). Whale watching disrupts feeding activities of minke whales on a feeding ground. *Marine Ecology Progress Series*, *478*, 239–251.

Eguchi, T., Lang, A.R. and Weller, D.W., 2022. Abundance and migratory phenology of eastern North Pacific gray whales 2021/2022.

Fearnbach, H., & Durban, J. (2022, April). *2022 Condition Assessment of "Sounders" gray whales*. SR3 Sealife Response, Rehabilitation, and Research Improving the Health of Marine Wildlife. https://www.sealifer3.org/news/2022-condition-assessment-of-sounders-gray-whales

Fournet, M., Matthews, L., Gabriele, C., Haver, S., Mellinger, D., & Klinck, H. (2018). Humpback whales Megaptera novaeangliae alter calling behavior in response to natural sounds and vessel noise. *Marine Ecology Progress Series*, *607*, 251–268.

Lumley, T., Diehr, P., Emerson, S., & Chen, L. (2002). The Importance of the Normality Assumption in Large Public Health Data Sets. *Annual Review of Public Health*, *23*(1), 151–169.

Lusseau, D., & Bejder, L. (2007). *The Long-term Consequences of Short-term Responses to Disturbance Experiences from Whalewatching Impact Assessment*. 10.

Moore, S.E., Clarke, J.T., Okkonen, S.R., Grebmeier, J.M., Berchok, C.L. and Stafford, K.M., 2022. Changes in gray whale phenology and distribution related to prey variability and ocean biophysics in the northern Bering and eastern Chukchi seas. Plos one, 17(4), p.e0265934.

National Marine Fisheries Service [NMFS]. (2020b, January 9). Marine Life Viewing Guidelines. NOAA.

National Marine Fisheries Service [NMFS]. (2022, June 3). *2019-2022 Gray Whale Unusual Mortality Event along the West Coast and Alaska*. NOAA.

National Marine Fisheries Service [NMFS]. (2021, December 7). *West Coast Gray Whales Declined During Unusual Mortality Event, Similar to Past Fluctuations in Numbers*. NOAA.

Pavlinovic, A. T. (2022). *Does boat presence affect the behavior of Sounders in inland waters? A study on gray whales (Eschrichtius robustus) in North Puget Sound.* [The Evergreen State College].

Pruitt, C., & Donoghue, C. (2016). *Ghost shrimp: Commercial harvest and gray whale feeding, North Puget Sound, Washington.* (p. 30) [Technical].

Senigaglia, V., Christiansen, F., Bejder, L., Gendron, D., Lundquist, D., Noren, D., Schaffar, A., Smith, J., Williams, R., Martinez, E., Stockin, K., & Lusseau, D. (2016). Meta-analyses of whale-watching impact studies: Comparisons of cetacean responses to disturbance. *Marine Ecology Progress Series*, *542*, 251–263.

Swartz, S. L., & Jones, M. L. (2016). Gray Whale (Eschrichtius robustus). In *Marine Mammal Encyclopedia* (3rd ed., p. 25). Academic Press, Inc.

Weitkamp, L., Wissmar R., Simenstad C., Fresh, K., & Odell J. (1992). Gray whale foraging on ghost shrimp (Callianassa californiensis) in littoral sand flats of Puget Sound, U.S.A. Can. J. Zoology Vol. 70:2275-2280

Williams, R., Trites, A. W., & Bain, D. E. (2002). Behavioural responses of killer whales (Orcinus orca) to whale-watching boats: Opportunistic observations and experimental approaches: Behavioural responses of killer whales to whale-watching. *Journal of Zoology*, *256*(2), 255–270.

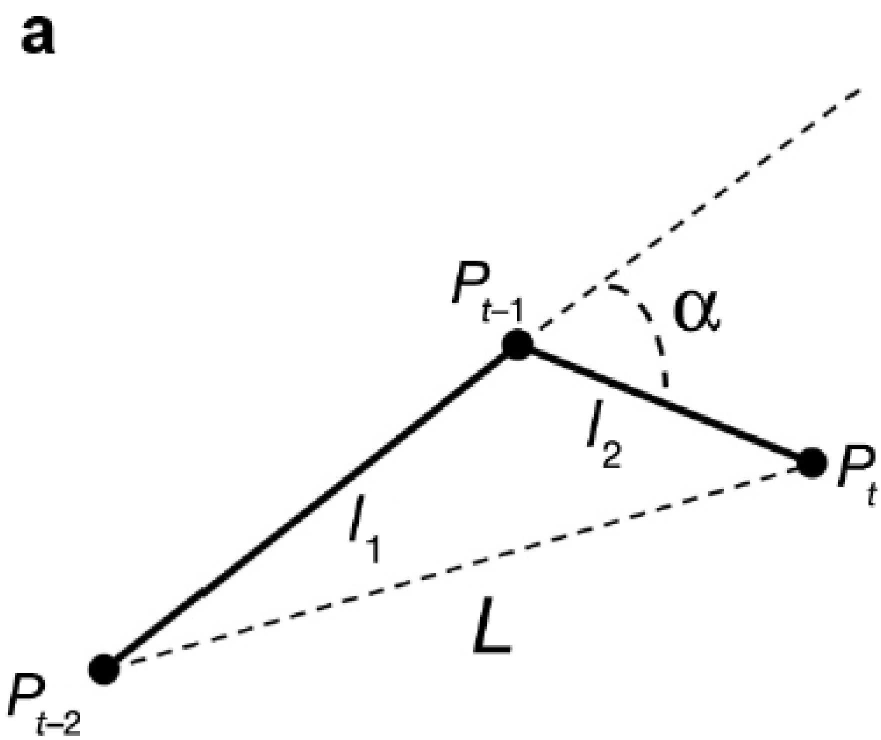


Figure 1. This image and description show how DEV, DI, and IBI were calculated, "Example of a movement track of a minke whale with 3 surfacings (Pt, Pt−1 and Pt−2) and 2 inter-breath intervals (IBI) (l1 and l2); Pt is the present position, Pt−1 the previous position, etc. and L is the net distance traveled between Pt and Pt−2. The deviation index for l2 is α. The directness index (DI) for l2 is calculated by DI = 100 · [L/(l1 + l2)]" from (Christiansen et al., 2013).

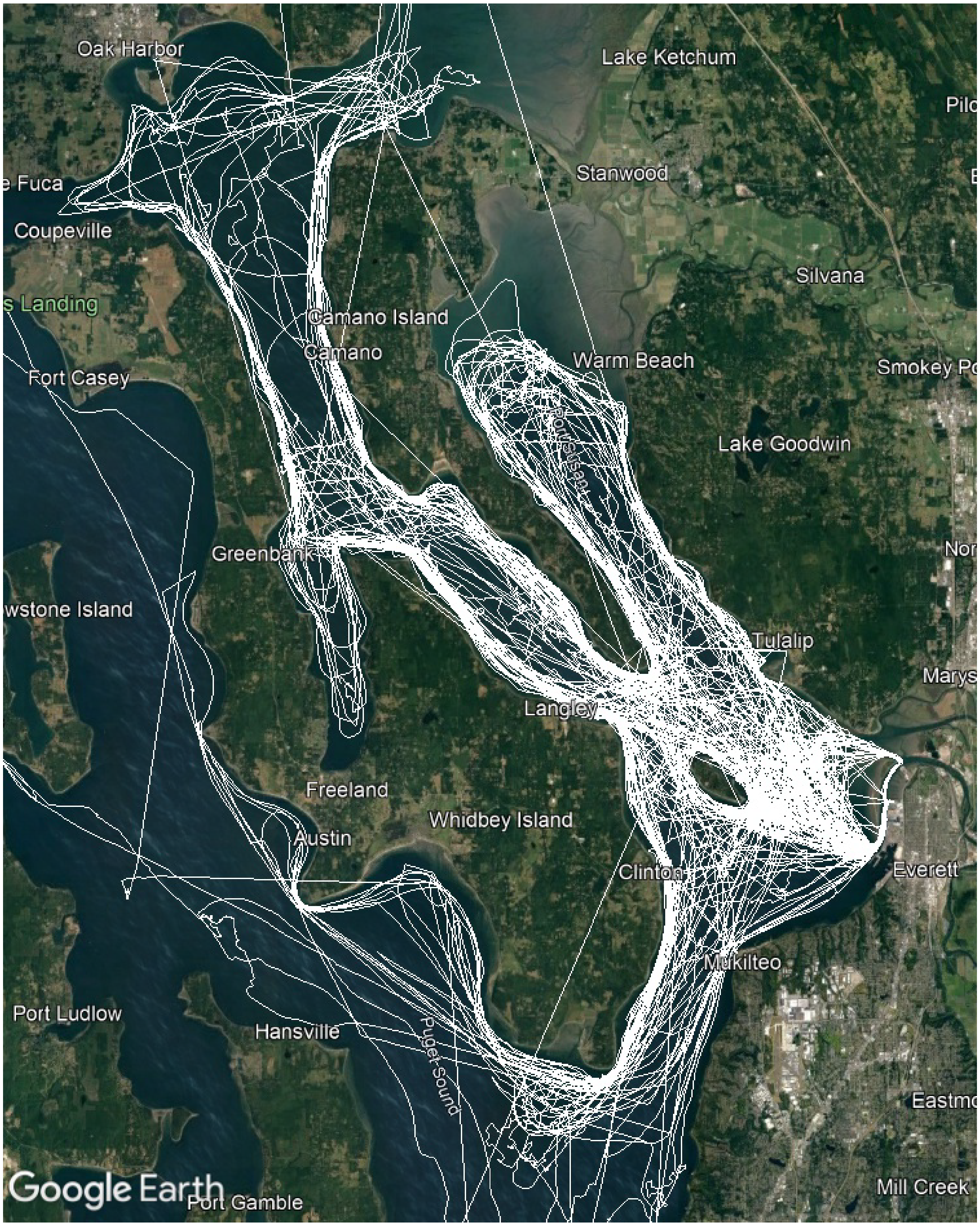


Figure 2. Tracks from 61 Cascadia Research surveys conducted 2005-2021. Not all surveys had available detailed tracks (none for surveys prior to 2005) but these provide a representation of our overall survey coverage. The few tracks over land are due to gaps in the GPS record and have been left unchanged.

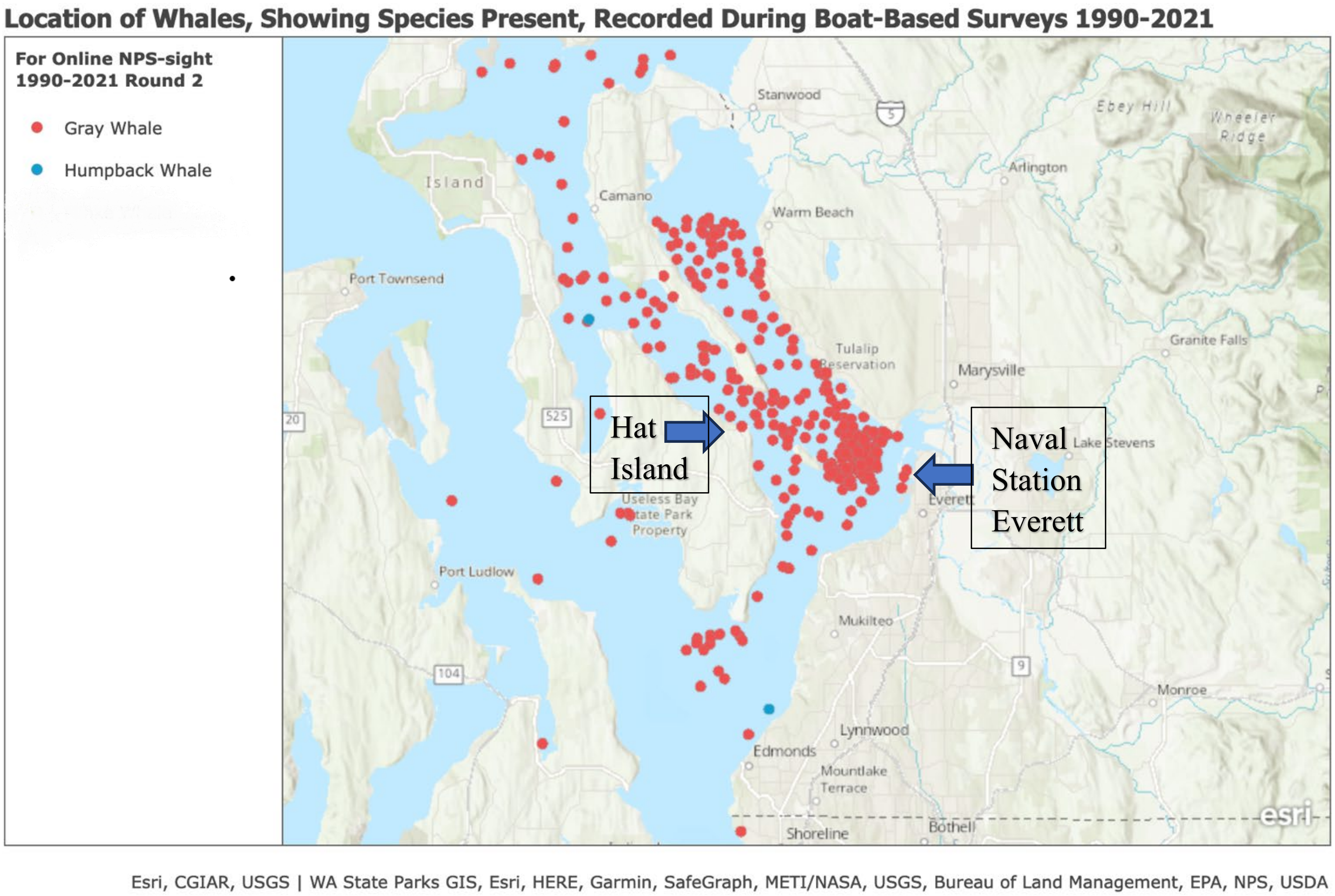


Figure 3. This map shows all the recorded locations in the defined study area of two different species of whales (humpback whales, gray whales), recorded between 1990-2021 using boat-based surveys.

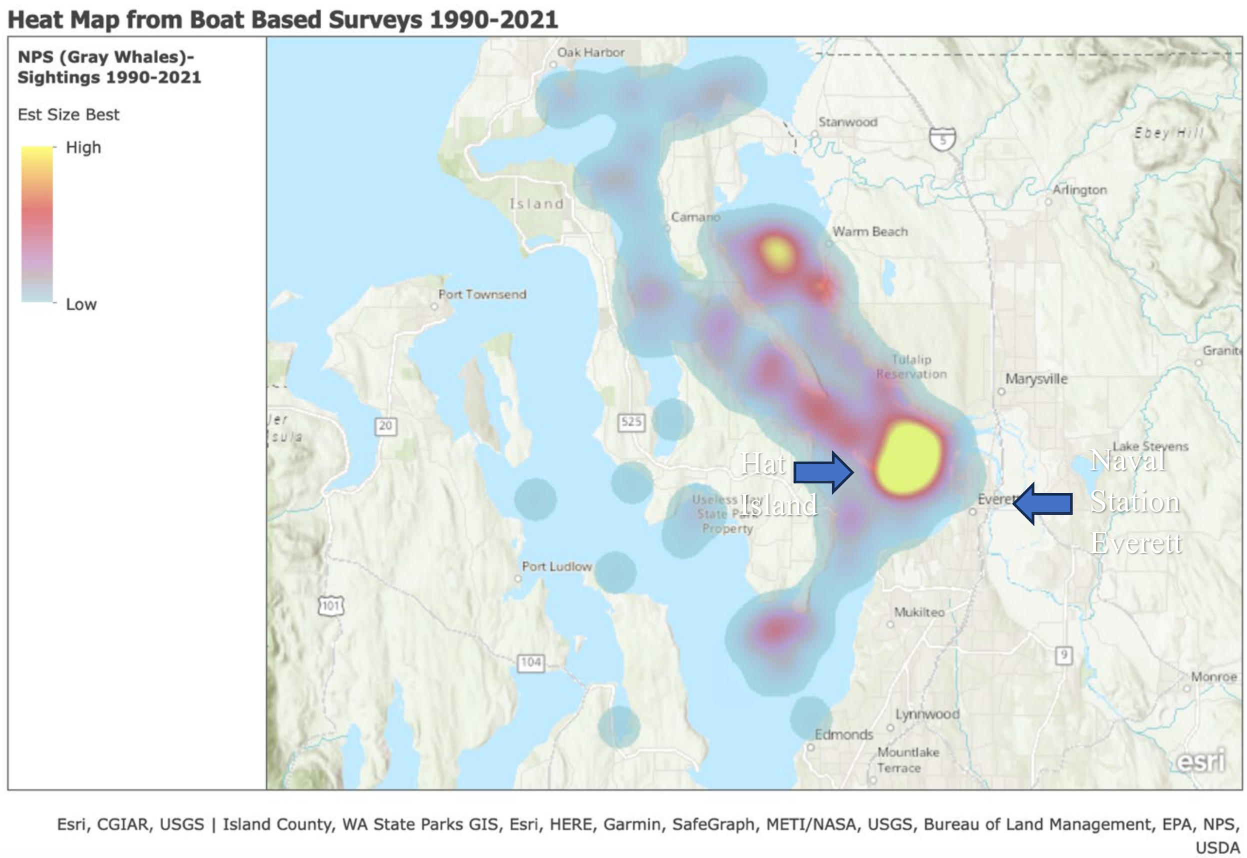


Figure 4. This heat map shows the densities of gray whales in the defined study area, recorded from 1990-2021 using boat-based surveys.

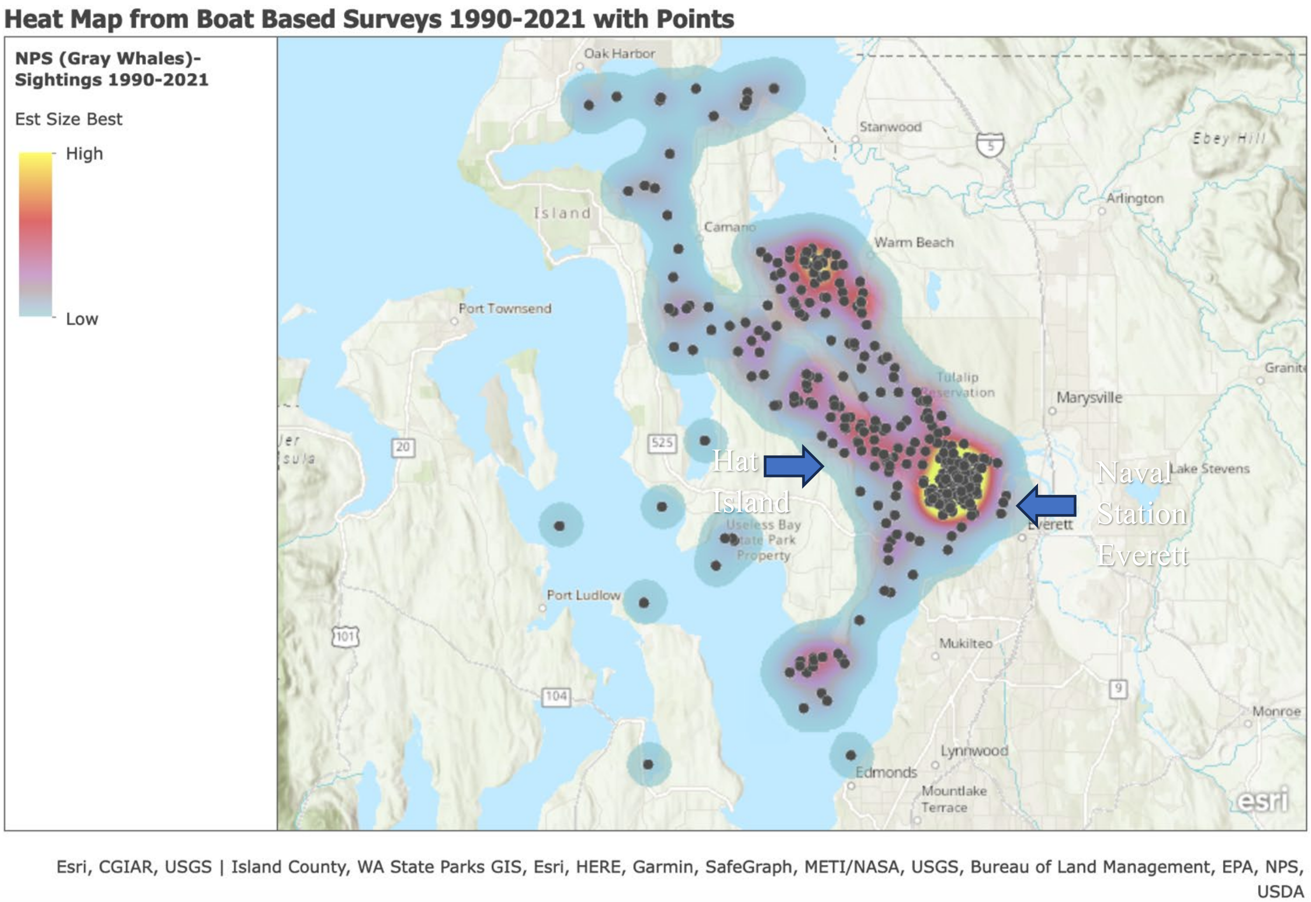
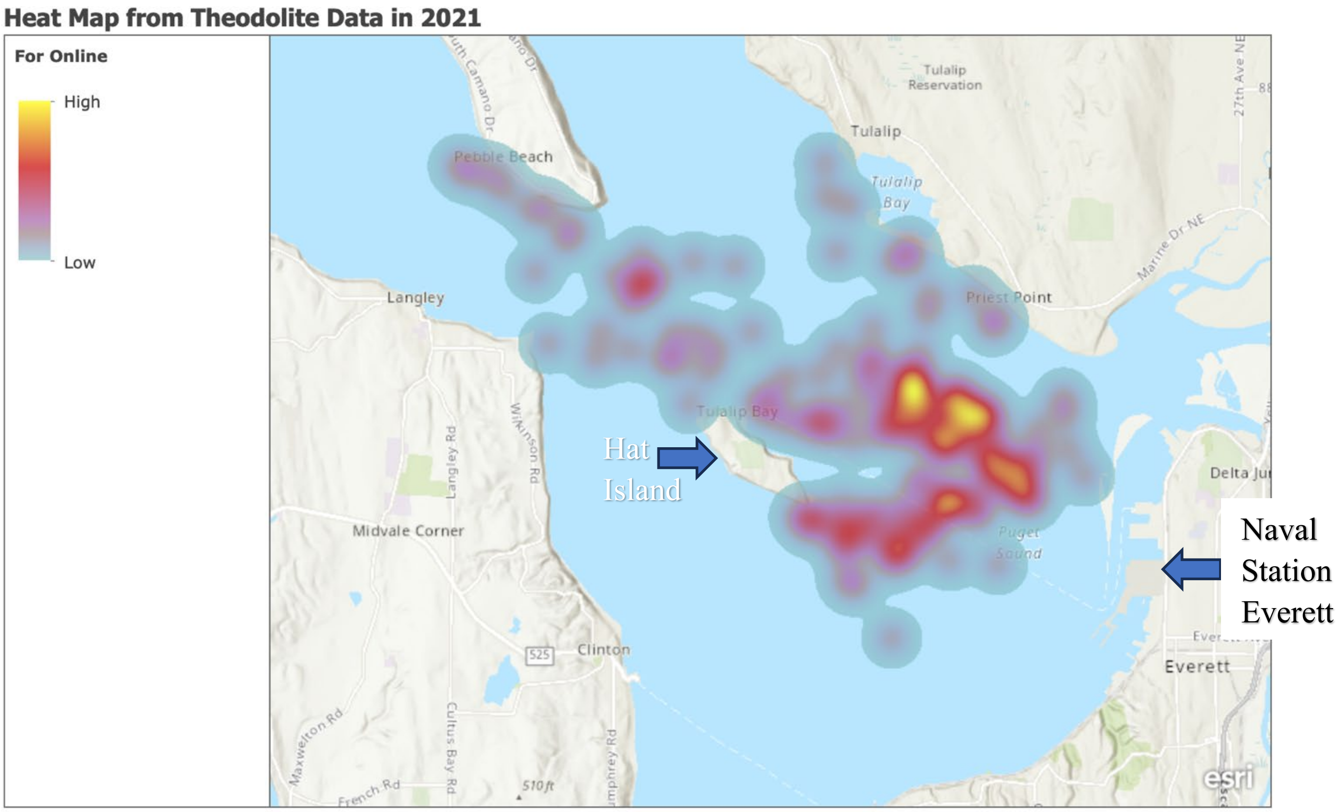
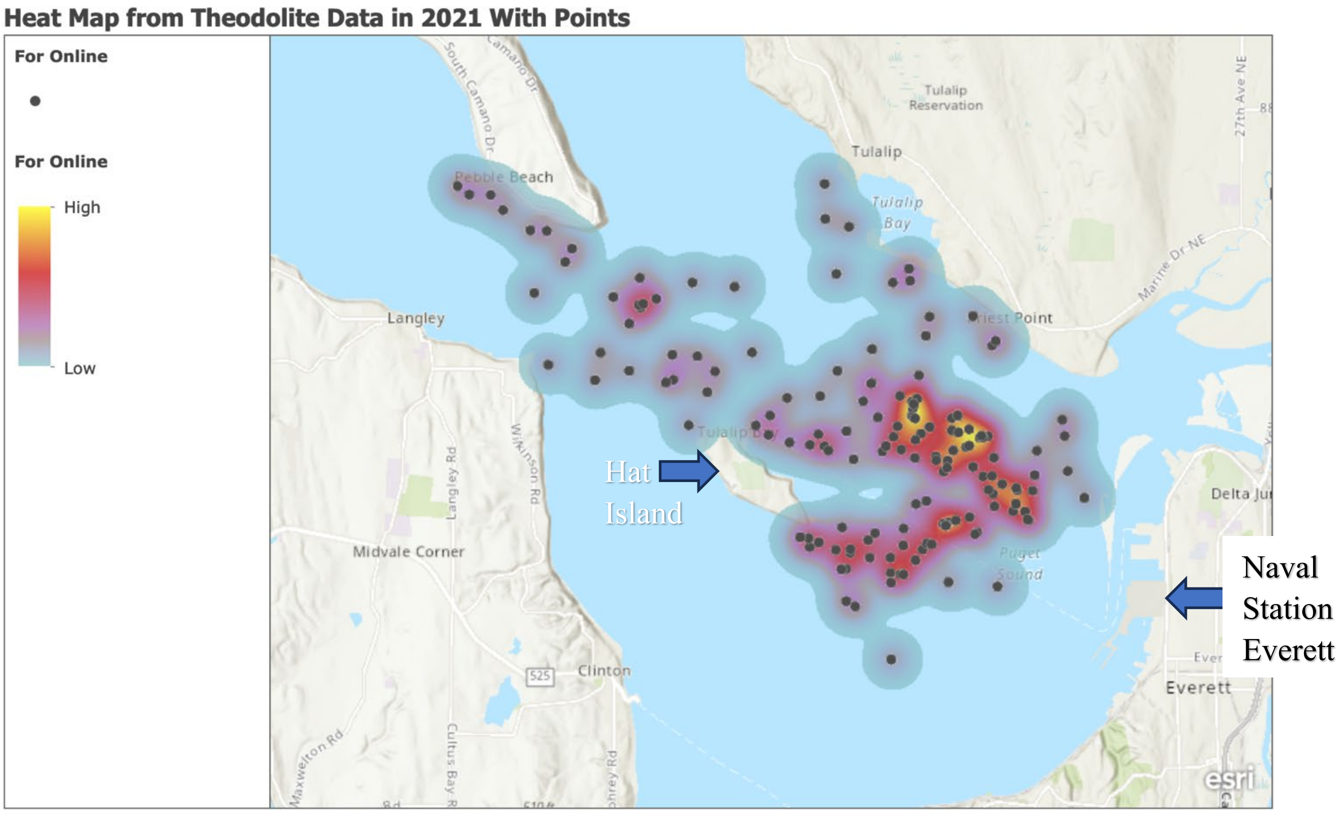


Figure 5. This heat map shows the densities of gray whales in the defined study area, recorded from 1990-2021 using boat-based surveys, and shows the points used to create the heat map.



Esri, NASA, NGA, USGS | WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

Figure 6. This heat map shows the densities of gray whales in the defined study area, recorded in 2021, using land-based surveys.



Esri, NASA, NGA, USGS | WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

Figure 7. This heat map shows the densities of gray whales in the defined study area, recorded in 2021, using land-based surveys, and shows the points used to create the heat map.

Appendix A

Further Statistical Analysis Explanation

For the movement metrics, the differences between the two groups were tested using multivariate and univariate statistics. A multivariate Hotelling's T^2 test was used to determine the possible impacts of ships on all three-movement metrics together. To account for any correlation structure among the movement metrics and to calculate the effect of each movement metric in separating the two groups of whales with and without boats present, standardized discriminant function coefficients were analyzed.

To assess the difference between individual movement metrics and IBI, both Welch's two-sample t-tests and Mann-Whitney U-tests were used. Two-sample t-tests were used, even though the distributions of the movement metrics were non-normal, because of the Central Limit Theorem (Lumley et al., 2002). Additionally, to compare the results of the t-test to a nonparametric test, our four metrics were analyzed using Mann-Whitney U-tests.

To account for the limited number of focal follows (movement metrics = 151, IBI =193) and the impacts of recording the metrics from different locations or OPs (F15, W18, M27), Generalized Least Squares (GLS) models were used. First, to deal with heterogeneity issues, the three datasets of IBI, DEV, and Speed were transformed using the log function. This transformation nor others made DI deal with heterogeneity requirements for GLS. So, it was not analyzed going forward. Second, to deal with independence issues and a limited number of focal follows, they were used as the correlation structure. Also, when the residuals were graphed, the residuals indicated that focal follows needed to be included in the model. To help with heterogeneity issues, a variance structure of boat*OP was added. Finally, to create the best-fit models for Speed, DEV, and IBI, many models with different variables were compared, and the model with the best fit for each metric was selected using AIC scores. These models were checked were checked for accuracy and passed. Although, the data at the beginning of the analyses nor the residuals at the end were normally distributed.