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Beluga (*Delphinapterus leucas*) response to personal watercraft and motorized whale watching vessels in the Churchill River estuary

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As interest in tourism and conservation grows worldwide, whale-watching has become a popular means of educating the public about wildlife conservation. The short-term impact of ecotourism industries on observed species has been widely studied with findings that indicate responses are most often behavior alterations or avoidance. Close vessel interactions with beluga whales (*Delphinapterus leucas*) are a major draw for whale-watching ecotourism in Churchill, Manitoba, Canada. As the Churchill River estuary and surrounding waters are assessed for a Marine Protected Area, information on the response of belugas to vessels are needed to inform management. To assess this, an oblique time-lapse camera system with a 5-minute photo interval was set up overlooking a section of the Churchill River estuary that is shared by belugas and tourist vessels. Measurements calculated from photos were used to compare the distance between belugas and kayaks, paddleboards, motorboats, and Zodiac whale-watching vessels. These distances were compared to an expected distribution generated from locations of belugas in photos without the presence of vessels. We found evidence that belugas are attracted to kayaks, avoid paddleboards, and are neutral regarding motorboats and Zodiacs. This is the first study to quantify the behavioral response of cetaceans to tourist vessels using a camera system and a distance-based analysis. Results could inform the development of a site-specific management system that accounts for beluga-vessel relationships.

KEYWORDS

photogrammetry, whale-watching, ecotourism, time-lapse camera, beluga whale

Introduction

Whale-watching is known for increasing tourist investment in conservation, providing research opportunities, and creating economic possibilities (Gleason and Parsons, 2019). Intensity of tourism, vessel type (Pirootta et al., 2015), vessel maneuvering (Filby et al., 2014; Argüelles et al., 2016; Arias et al., 2018), management regulations (Tosi and Ferreira, 2009) and vessel compliance to regulations has been shown to affect cetacean response to whale-watching (Corkeron, 1995; Stamation et al., 2010; Hoarau et al., 2020). Tourism should therefore be closely monitored as energetic costs associated with whale behavioral reactions can affect the fitness of individuals and thus survival of a population (Bejder et al., 2006b; Lusseau et al., 2006; Williams et al., 2006; Lusseau and Bejder, 2007; Christiansen et al., 2013a; Christiansen et al., 2013b; Christiansen et al., 2014; Currie et al., 2021).

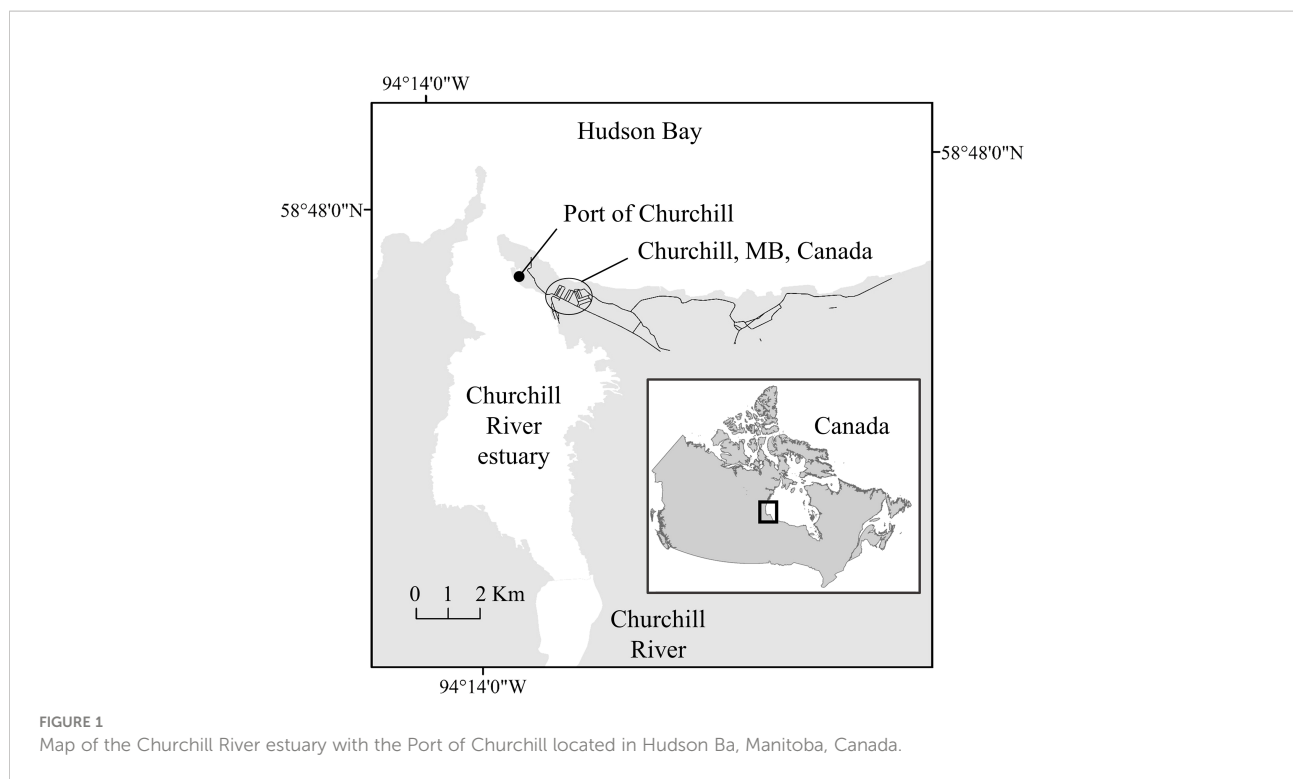
Studies on ecotourism worldwide have found that cetaceans respond to tourist vessels through behavior changes. Behavioral response is often recorded as changes in the time spent traveling, foraging, or resting in the presence of tourism vessels (Coscarella et al., 2003; Constantine et al., 2004; Williams et al., 2006; Stockin et al., 2008; Arcangeli and Crosti, 2009; Lusseau et al., 2009; Visser et al., 2011; Dans et al., 2012; Steckenreuter et al., 2012; Avila et al., 2015). Changes to respiration rate (Christiansen et al., 2014; Schuler et al., 2019), surfacing behaviors (Coscarella et al., 2003; Hastie et al., 2003; Lemon et al., 2006; Noren et al., 2009; Stamation et al., 2010), group size or dispersion (Bejder et al., 1999; Bejder et al., 2006a; Tosi and Ferreira, 2009; Steckenreuter et al., 2012) and increased erratic movements (Lusseau, 2006; Stensland and Berggren, 2007; Avila et al., 2015) have also been observed as a response to vessel presence. While the majority of whale-watching vessel interaction studies indicate impacts to cetaceans, responses vary by species, population (Senigaglia et al., 2016), age class composition (Magalhães et al., 2002; Stamation et al., 2010; Steckenreuter et al., 2012), sex (Williams et al., 2002; Lusseau, 2003b) and activity (Sousa-Lima and Clark, 2008; Arcangeli and Crosti, 2009; Williams et al., 2011; Dans et al., 2012; Vermeulen et al., 2012; Lundquist et al., 2013b; Argüelles et al., 2016).

Cetacean response to tourism vessels at close range is complicated as both attraction and avoidance behaviors have been recorded. Avoidance includes both vertical distancing by diving (Lusseau, 2003b; Stamation et al., 2010), and horizontal distancing by moving away from vessels (Steckenreuter et al., 2012). Horizontal avoidance of vessels by cetaceans includes more changes in travel direction (Lemon et al., 2006; Richter et al., 2006; Amrein et al., 2020), increased swimming speed (Magalhães et al., 2002; Scheidat et al., 2004; Avila et al., 2015) and combinations of these behaviors (Kruse, 1991; Williams et al., 2002; Bejder et al., 2006a; Williams et al., 2009; Stamation et al., 2010; Schuler et al., 2019; Currie et al., 2021; Santos-Carvalho et al., 2021). Attraction, interaction, positive reactions,

and approach are terms that have been used to describe similar behaviors of cetaceans approaching vessels, traveling with vessels, and swimming around or underneath tourism vessels (Constantine, 2001; Gregory and Rowden, 2001; Arcangeli and Crosti, 2009; Stamation et al., 2010; Malcolm and Penner, 2011; Steckenreuter et al., 2012; Filby et al., 2014; Hoarau et al., 2020). For instance, dwarf minke whales (*Balaenoptera acutorostrata*) in Australia were observed more than expected within 60 m of swim-with-whale tourism boats indicating attraction (Mangott et al., 2011). Neutral (also called independent) reactions, described as no change in cetacean behavior in the presence of tourism vessels have been recorded along with attraction and avoidance (Constantine, 2001; Gregory and Rowden, 2001; Arcangeli and Crosti, 2009; Filby et al., 2014). Attraction behaviors and neutral responses to tourist vessels have been grouped together for humpback whales (*Megaptera novaeangliae*) to better understand avoidance rates in Reunion Island, and Vava'u, Kingdom of Tonga, finding avoidance 27.4% and 33.5% of the time, respectively (Fiori et al., 2019; Hoarau et al., 2020).

Churchill, Manitoba, Canada, is known for the unique whale-watching interactions with the Western Hudson Bay (WHB) population of beluga whales (*Delphinapterus leucas*) that occupy the Churchill River estuary from June to September every year. The WHB beluga population is classified as not at risk by the Committee on the Status of Endangered Wildlife in Canada and its size is estimated at 54,500 belugas (Matthews et al., 2017; COSEWIC, 2020). The return of beluga whales to the estuary each summer has been hypothesized to be related to matrilineally learned philopatry, or biological advantages associated with greater prey availability, optimal habitat for molting and predator protection (Sergeant and Brodie, 1969; Sergeant, 1973; Finley, 1982; St. Aubin et al., 1990; Smith, 2007; O'Corry-Crowe et al., 2020). In the Churchill River estuary, belugas interact closely with kayaks and Zodiac whale-watching tour boats in a way that is a major draw for ecotourism to the region (Malcolm and Penner, 2011). While Malcolm and Penner (2011) were able to record beluga behaviors near snorkeling activities, a passenger motorboat, and kayaks, the distributional response of belugas to whale-watching vessels has not been quantified. Additionally, responses to paddleboards were not recorded by Malcolm and Penner (2011) as this ecotourism activity started in 2015 after completion of their study. Quantifying beluga whale response would provide needed information for tourism management that would ideally meet the needs of tour operators and mitigate against harmful disturbance to the whales. Tourism vessels are currently limited to a 50 m approach distance for belugas in the Seal and Churchill River estuaries (Regulations Amending the Marine Mammal Regulations. SOR/2018-126, 2018).

In this paper, we used time-lapse photography to locate belugas in a section of the estuary and calculate the distances between belugas and tourist vessels. Through comparison of



beluga-vessel relationships to beluga location without vessel presence we determined whether belugas were closer to, farther from, or the same distance to vessels than would be expected. In other words, we can use the distance between belugas and vessels to determine if belugas are attracted to, avoid, or are neutral to different types of tourist vessels in the Churchill River estuary. Because of the experiences of the Churchill community and tour operators as well as relevant literature, we expected to find that belugas are attracted to tourist vessels in the Churchill River estuary (Malcolm and Penner, 2011; The Churchill Beluga Whale Tour Operators Association et al., 2015; Manitoba western Hudson Bay ad hoc beluga habitat sustainability plan committee, 2016).

Materials and methods

Study site

This study took place in the Churchill River estuary, a subarctic estuary connected to Hudson Bay (Figure 1), from 13–28 August 2020. During August, the difference between high and low tide was 4 m. Daily boating activity on the Churchill River estuary includes whale-watching, research, subsistence fishing, and local recreation. The vessel type and quantity on the estuary vary daily depending on tourist demand and weather. Larger groups of kayaks and paddleboards, as well as accompanying Zodiacs (inflatable, single motor, boats capable of

carrying multiple passengers) are present in the estuary at low tide when waters are calm. During falling, rising, and high tide, motorboats (solid hull motorized boats capable of carrying multiple passengers) and Zodiacs are the most frequent vessels. The year of this study was different from a typical year in that there were fewer international tourists due to travel restrictions from the COVID 19 pandemic.

Setup

A Harbotronics Cyclapse Pro-Glacier time-lapse camera system, with a Harbotronics Digisnap Pro time-lapse controller, and a Pentax K1 Mark II camera with Pentax HD PENTAX-D FA 28-105mm f/3.5-5.6 ED DC WR Lens was installed on the 2nd floor of the Port of Churchill Gallery (Figure 2). The camera faced west, and the lens was set to a focal length of 58 mm to capture the horizon and most of the estuary. To optimize photo quality in an outdoor setting with varying light, the ISO speed was set to 800, exposure to 1/1600 seconds, and f-stop to 11. Photos were taken every 5 minutes from 6:30 am to 8:30 pm every day.

To calibrate and test distance measurements from photos, 30 georeferencing points were taken during 17–23 August 2020 (Figure 2). A Garmin GPSMAP 64s was used to locate these georeferencing points, which has a 5-15 m error depending on satellite orientation¹. Georeferencing points were taken following Pavia et al. (2015) by maneuvering a boat into view

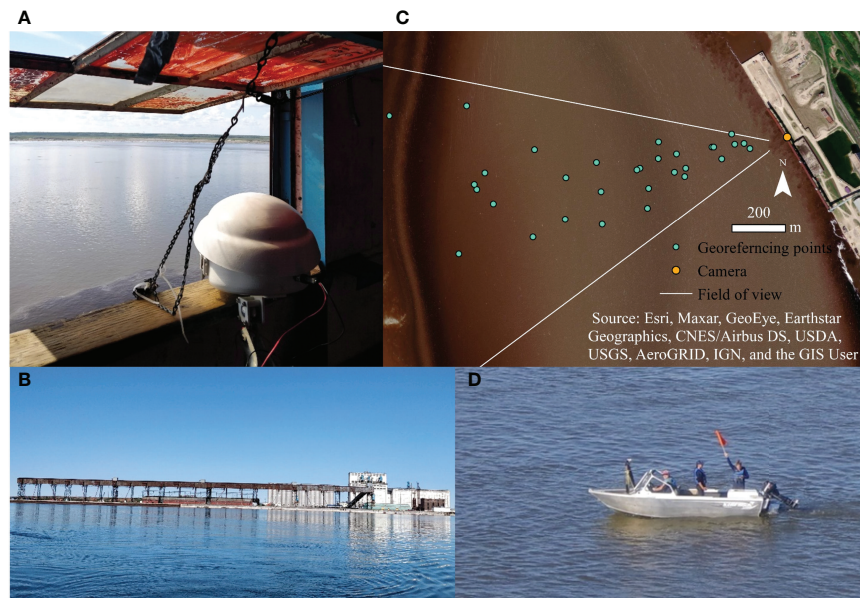


FIGURE 2

(A) Digisnap Pro Cyclapse system. The camera is under the white dome necessary to protect the camera from rain. (B) The Port of Churchill gallery (two-story structure) where the camera is located, as viewed from the estuary. (C) Location of georeferencing points on the estuary (white lines represent the field of view of the camera). (D) Image of a georeferencing point being recorded.

of the camera, with one individual in the boat holding up an orange flag and taking a simultaneous GPS point with the time-lapse camera photo (Paiva et al., 2015). Images were corrected for pincushion lens distortion using the Pentax filter in Photoshop 21.2.0.

Measurements

Photogrammetry of oblique imagery is characterized by the change of scale associated with increasing distance from the measurement device. To reference oblique imagery, surface elevation, the location of the camera, and the camera specifications are needed (Höhle, 2008). Height of the camera and of the port above the water's surface were measured using a weighted rope. Tide level measurements were obtained from the Canadian Hydrographic Service gauge (station 5010)² measured every 3 minutes. Tide level measurements were used to adjust for the height of the camera above the water's surface. The angle of the camera relative to vertical was approximately 79 degrees when measured during set up and removal using the Clinometer smartphone app from PixelProse SARL.

The area captured by a photo is determined by the distance of the object from the camera and lens angle of the camera, which is also called field of view (FOV). The focal length (f), the horizontal sensor length (s_h) and vertical sensor lengths (s_v) are camera specifications that are used to determine both horizontal field of view (θ_{HFOV}) and vertical field of view (θ_{VFOV}) using

equation (1) and (2) (Havens and Sharp, 2015). The Pentax K1 Mark 2 camera has a horizontal sensor length of 35.9 mm and a vertical sensor length of 24 mm.

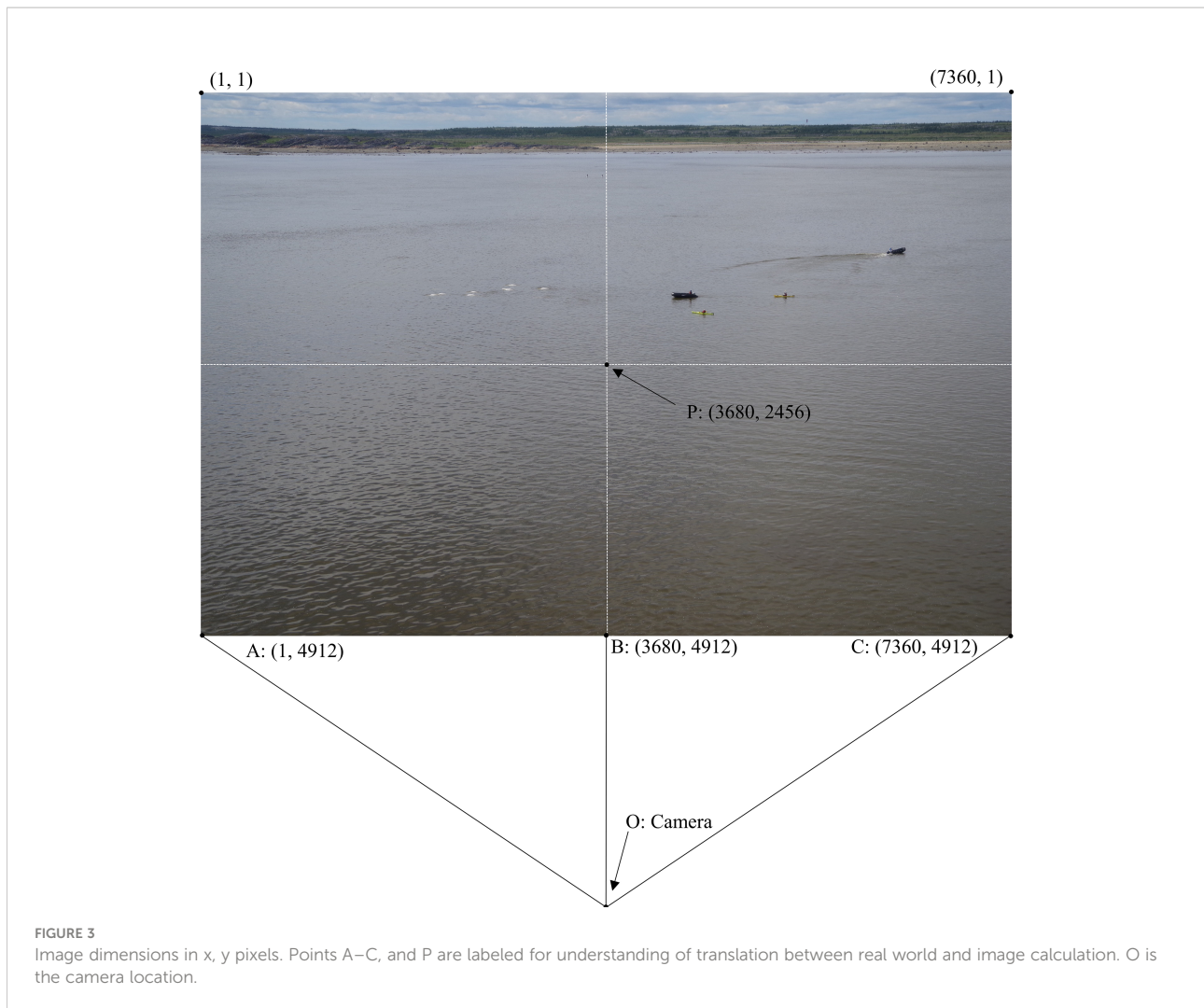
$$\theta_{HFOV} = 2 \tan^{-1}(s_h/2f) \quad (1)$$

$$\theta_{VFOV} = 2 \tan^{-1}(s_v/2f) \quad (2)$$

Measurements were obtained through calculations based on the pixel dimensions of the photos. Each 17.9 MB image contained 7360 by 4912 pixels (Figure 3). Horizontal pixels are considered as x pixels and vertical as y for the following calculations. The origin of the image at 1,1 is located at the top left corner. The center of the image, known as the principal point (P) is assumed to approximately represent $x = 3680$ and $y = 2546$. The limits of the horizontal field of view of the camera are at $x = 1$ and $x = 7360$. The real-world area of each pixel increases from $y = 4912$ at the bottom of the photo to $y = 1$ at the top, so the area between 1 and 7360 x pixels increases with distance from camera. A pixel location (x,y) on the photo will be represented by the point E, and E' in the real-world (Figure 4). An x pixel has an angle from the camera (O) subtended by the arc of the center line of the camera \overline{OB} to any given pixel location

1 <https://support.garmin.com/en-CA/?faq=aZc8RezeAb9LjCDpJpITY7>

2 <https://www.qc.dfo-mpo.gc.ca/tides/en/tide-and-water-level-station-data>



\overline{OE} (Figure 4). This angle (θ_x) can be determined if the distance between E at a given y pixel value and the vertical center line ($x = 3680$) is known in pixels. To achieve a representation of that distance, the horizontal field of view (θ_{HFOV}) and $\frac{1}{2}$ of the image width in x pixels $\overline{AB} = 3680$ were used in conjunction with trigonometric laws in the following formula (equation 3):

$$\overline{OB} = \frac{\overline{AB}}{\tan\left(\frac{\theta_{HFOV}}{2}\right)} \quad (3)$$

When the length of \overline{OB} is known, θ_x for any x pixel value can be calculated (equation 4). This angle (θ_x) remains the same for a given x-value and is not impacted by different y or increasing distance of real-world locations from the camera (equation 4).

$$\theta_x = \tan^{-1}\left(\frac{x - \overline{AB}}{\overline{OB}}\right) \quad (4)$$

The vertical dimension of the image in y pixels can be understood in the same way using vertical field of view (qVFOV)

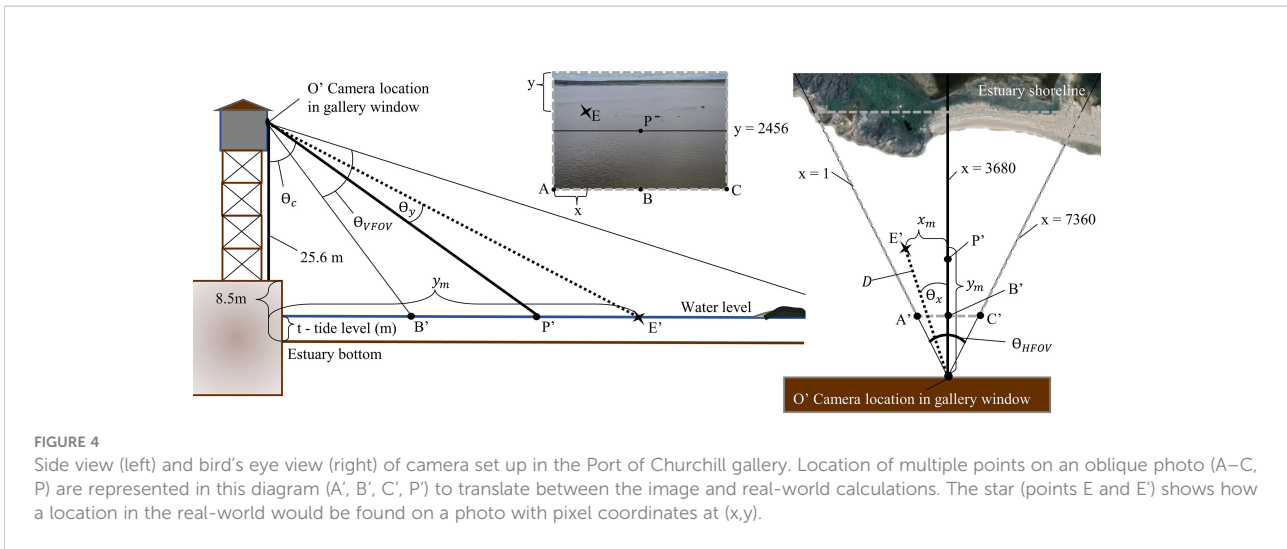
(Figure 4). The distance from the camera to the principal point (\overline{OP}) (equation 5) is used to determine the angle from the camera subtended by pixel y at E (\overline{OE}) and \overline{OP} (equation 6).

$$\overline{OP} = \frac{\overline{BP}}{\tan\left(\frac{\theta_{VFOV}}{2}\right)} \quad (5)$$

$$\theta_y = \tan^{-1}\left(\frac{\overline{BP} - y}{\overline{OP}}\right) \quad (6)$$

These calculations allow for the angle from camera between the principal point (P) of the image to both the x pixel (θ_x) and y pixel (θ_y), to be determined (Figure 4).

The height of the camera above water level (h) is the sum of the height of the camera in the gallery above the port floor (25.62 m) and the distance from the port floor to the bottom of the estuary (8.51 m) subtracting the estuary water level (equation 7). Using the above angles (θ_x , θ_y), the height of the camera above estuary water level (equation 7), and the angle of the



camera from nadir (θ_c), distances to and between pixels can be calculated (Figure 4). The right angle subtended by the intersection of the vertical line at $x = 3680$ pixels and any horizontal line at a y pixel value allows for distance calculations between the camera and real-world locations using the Pythagorean theorem. Distance in meters between the y pixel of the real-world object at $x = 3680$ (y_m) is calculated using equation 8. The distance in meters from $x = 3680$ to the real world value of x uses y_m and θ_x in equation 9, and the distance from the real world object at a pixel (x,y) to the camera (D) location represented at the same elevation as the tide level is then calculated using equation 10. The law of cosines can then be used to determine the real-world distance between two pixels (equation 11).

$$h=25.62+(8.51-\text{water level}) \quad (7)$$

$$y_m=h*\tan(\theta_c+\theta_y) \quad (8)$$

$$x_m=y_m*\tan(\theta_x) \quad (9)$$

$$D=\sqrt{y_m^2+x_m^2} \quad (10)$$

$$\text{distance between points}=\sqrt{D_1^2+D_2^2-(2 * D_1 * D_2 * \cos(|\theta\chi_1-\theta\chi_2|))} \quad (11)$$

The exact camera angle at the time georeferencing points were taken was not known due to shifts in the camera position resulting from system errors. The vertical angle of the camera (θ_c) was determined by splitting the georeferencing points into training and testing groups. Evaluation of the accuracy in determining pixel distances from the camera and visual inspection of images resulted in a cut-off line at $y = 700$ pixels, above which belugas can be identified and calculations of

distances are accurate. Of the 30 georeferencing points, 17 were located over 700 y pixels and these were split into 10 training and 7 testing. GPS locations were entered into ArcGIS and the NEAR tool calculated each distance to the camera location and to other GPS points. The camera angle was determined to be 79.41 degrees using the 10 training georeferencing points by comparing between calculations using equation 10 and GPS distances to the camera. The mean difference in distance to camera between the 7 testing GPS and calculated georeferencing points was 6.6 meters (between 1.7 and 10.0 m). Calculation accuracy was verified by comparing the distances between the GPS locations for the 7 testing georeferencing points and the calculated distance using equation 11 (Figure 5). For the 20 distances root mean square error was 4.2 meters. This error can likely be attributed to GPS error, and boat movement with tide as the photo and georeferencing point were taken.

Photo analysis

Belugas and tourist vessels were identified in photos by searching in five horizontal bands of 1,000 y pixels to ensure no objects were missed. For each beluga and vessel, the center location was recorded in x and y pixels. Tide for each photo was assigned to the nearest three-minute Canadian Hydrographic Service tide gauge measurements. Photos were also categorized by tide category, which was determined through equal division in time between minimum and maximum tide as recorded by the Canadian Hydrographic Service gauge. This resulted in tide categories for High, Falling, Low, and Rising tide of approximately 3 hours each. If belugas were in a group, defined as swimming in the same direction within approximately two body lengths of each other, one beluga was selected for each group to avoid pseudoreplication (Hurlbert, 1984). All other belugas were considered individual beluga. Each

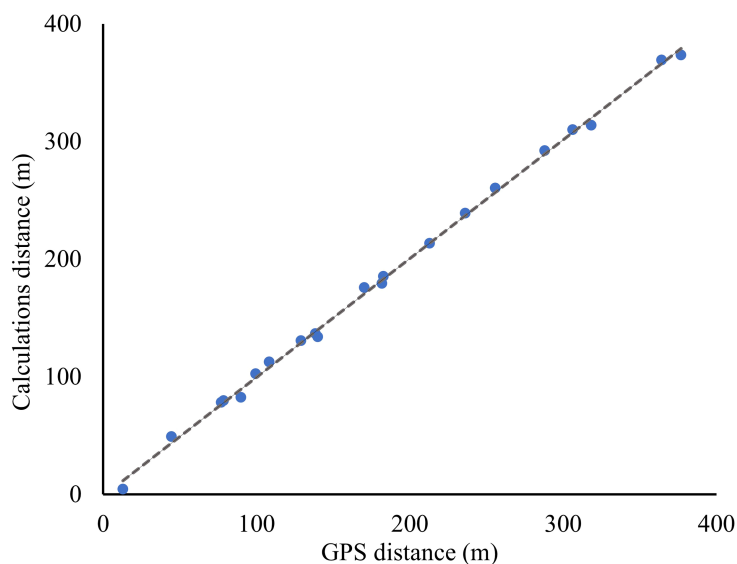


FIGURE 5

The distances between georeferencing points (m) as determined by inputting GPS locations into ArcMap (x) and by calculating using equations described in this paper (y).

tourist vessel was identified as a kayak, paddleboard, motorboat, or Zodiac. Unique cases such as canoes were also identified, but not included for consideration in this study as there were few occurrences ($n = 3$). See [Supplementary Materials](#) for additional information and photos describing how camera errors and edge impacts were addressed.

Analysis

The relationship between belugas and vessels was investigated through measurements of the distance between them. These relationships may be influenced by tide level or vessel type (kayak, paddleboard, motorboat, Zodiac), so differences were assessed using a Kruskal-Wallis chi-squared test to determine if beluga-vessel distances differed by vessel type, or vessel type at different tides. A Monte Carlo analysis was performed to generate an expected distribution of distances that would occur if vessels had no effect on beluga distribution. This analysis allowed for a large random sample to be created and for analysis to be iterated multiple times to ensure accuracy. By comparing observed distances to the expected distances between belugas and vessels, each observed distance relationship was classified as closer to, farther from, or neither (i.e., independent or neutral) of vessels.

In photos of both vessels and belugas, the distances between their locations were measured as the observed sample. Each beluga in a photo was treated as an independent individual as the 5-minute photo interval did not allow for tracking of individual

beluga movements through time. In the 5-minute interval, there was a large change in photo composition, and we assume that different belugas were seen in consecutive photos. Beluga locations in photos without vessels were compiled and categorized by tide category to determine the expected locations for comparison with locations with vessels. This was done for two reasons. First, belugas select habitat within the Churchill River estuary based on tide, prey movement and other related environmental variables (Hansen, 1988; Caron and Smith, 1990; Chernetsky et al., 2011). By randomly sampling belugas in photographs, the expected distribution represents locations that belugas occupy without vessels present, which allows for more meaningful comparison. Second, there is a detection function associated with correctly identifying belugas in the oblique photographs (Rowcliffe et al., 2011). Belugas further from the camera are less likely to be correctly identified and recorded than those closer to the camera. Randomly sampling belugas for comparison minimizes detection bias.

To test for tide category and vessel type differences in the distance between vessels and belugas, a Kruskal-Wallis chi-squared test was used. For each photo, 100 expected locations were chosen with replacement. Monte Carlo simulations were used to find the expected distribution of distances between belugas and vessels that, due to high numbers of generated points, is close to what should be expected without vessels. The distances between each expected location and all vessel locations were compared to observed distances between belugas and all vessel locations captured in a photo (Figure 6). These distances

were differentiated by vessel type: kayak, paddleboard, motorboat, or Zodiac. The null hypothesis that observed distances between belugas and vessels were greater than or less than expected distances between belugas and vessels was tested. We chose to categorize beluga behavior as attraction if belugas were found closer to vessels than expected avoidance if belugas are found further from vessels than expected, and neutral if belugas were not closer to or farther from vessels than expected.

Analysis was completed in R (version 4.1.1) using the `tidyr` and `ggplot2` packages (Wickham, 2016; Wickham, 2021; R Core

Team, 2021). The code used for this analysis is available upon request. One-sided non-parametric Wilcoxon Rank sum tests were used to test if observed distances were greater, or less than expected distances, with a significant p-value of 0.05. This test was selected as distances were not normally distributed. A neutral response occurred if one sided tests showed observed and expected values were not significantly different. This analysis was iterated 100 times, each time determining if belugas show attraction, avoidance, or are neutral to kayaks, paddleboards, motorboats, and Zodiacs. Results from this analysis were verified



FIGURE 6

(A) Distances for Monte Carlo analysis collected between belugas and all vessels in a photo (white lines). (B) An example of 100 expected locations (white x), of which the distance between each point and all vessels is used to determine the expected distribution.

by testing for edge effects. Details on edge effect testing are covered in the [supplementary materials](#). The raw data supporting the conclusions of this article will be made available upon request.

Results

Between 13 and 28 August 2020, 2,303 georeferenced photos were taken of the Churchill River estuary. Of these photos, 164 contained vessels and belugas, 910 contained only belugas, and 98 contained only vessels (Figure 7). Belugas were photographed at all tides, with a total of 2,261 belugas recorded. After removing photos with canoes and miscellaneous vessels, there was a total of 162 photos that captured belugas at the same time as kayaks, paddleboards, motorboats, and/or Zodiacs. These photos contained a total of 329 belugas, 29 groups of belugas, 320 kayaks, 392 paddleboards, 43 motorboats, and 119 Zodiacs. Belugas were found to be distributed between 3.6 and 744.6 m from all vessels, with a median observed distance of 227.8 m and a mean of 268.3 m (n = 2,005, sd = 164.5) (Figure 8). Kruskal-Wallis tests of observed distances between vessels and belugas showed significant differences by vessel type (p-value = <0.01, chi-squared = 35.26, df = 3) (Figure 9). When testing distances for the effect of the different tide cycles by each vessel type

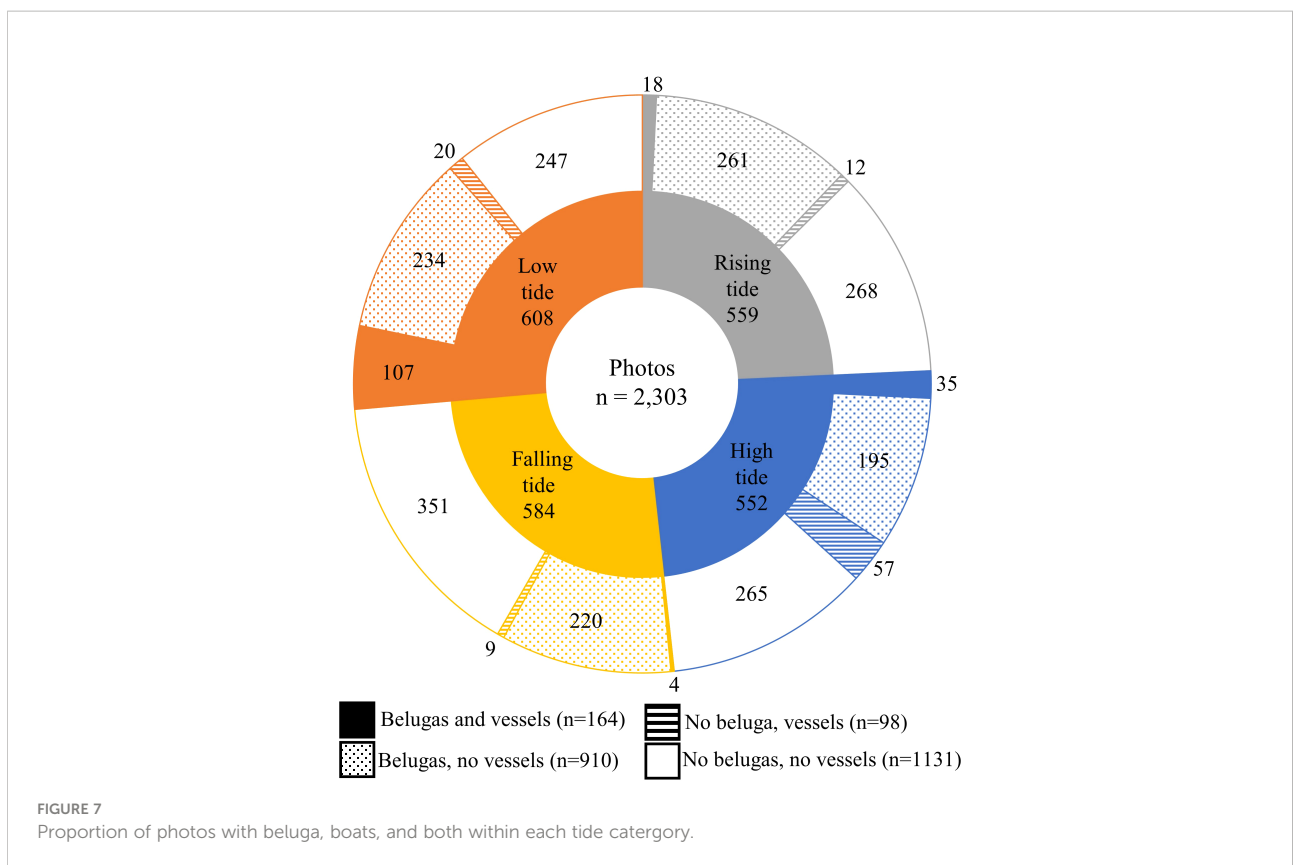
separately, only paddleboards significantly differed between rising (n = 12) and low (n = 920) tide.

Kayaks

Kayaks occurred during low tide and at the beginning of rising tides. Kayaks were present in the estuary in general but occurred in larger numbers as a part of tourist groups that also included paddleboards and Zodiacs. The largest number of kayaks was 15 in one photo. The closest beluga to a kayak was 4.5 m. There were 32,000 expected distances between belugas and kayaks in each of the 100 iterations. In 94 out of 100 iterations the distance between belugas and kayaks was significantly less than the expected distances generated in a Monte Carlo Simulation indicating that belugas were attracted to kayaks (Table 1).

Paddleboards

Paddleboards occupied the estuary during low and rising tides, only as part of larger tourist groups, with a maximum number of 11 in one photo. Paddleboards were generally distributed near the center of the estuary between 500 and 800 meters from the camera.



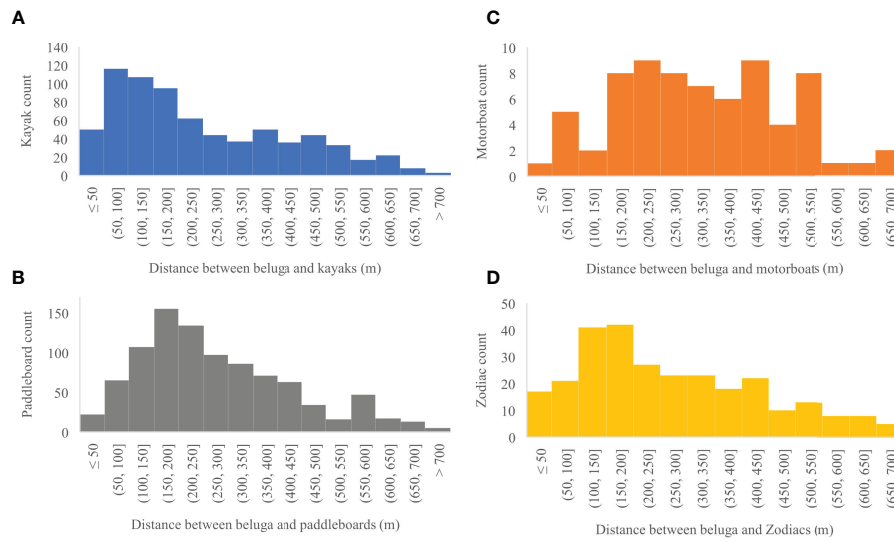


FIGURE 8 (A) Distribution of distances in meters between belugas and all kayaks (n = 724), (B) paddleboards (n = 932), (C) motorboats (n = 71), and (D) Zodiacs (n = 278) captured in a photo.

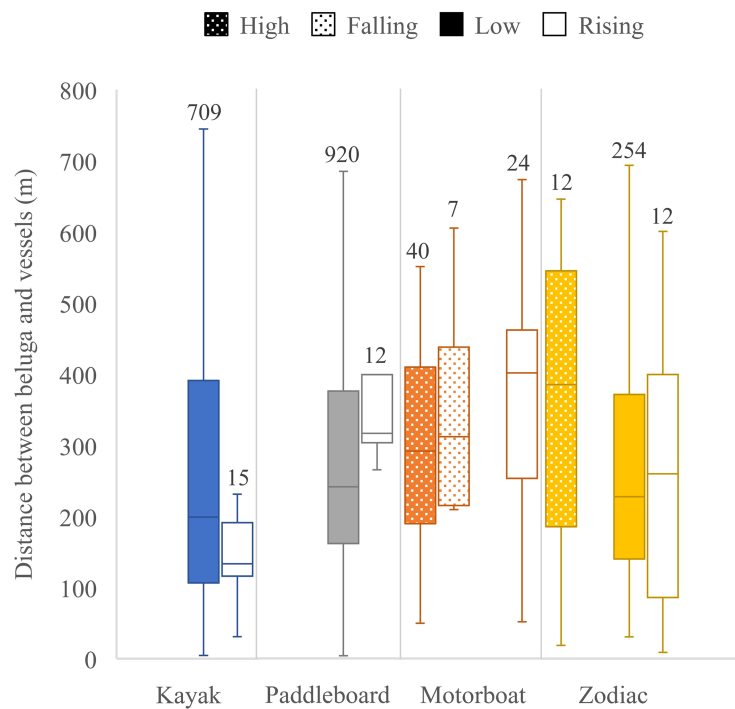


FIGURE 9 Distance between belugas and vessels by vessel type and tide. Quartiles calculated using inclusive median shown at edges of the box, center line of the box and ends of the tails. Sample sizes are given on top of each box.

TABLE 1 Attraction, avoidance and neutral results from one-sided Wilcoxon Rank sum tests out of 100 iterations for beluga distance relationships to kayaks, paddleboards, motorboats, and Zodiacs.

	Attraction	Avoidance	Neutral	Observed mean distance (m)	Expected mean distance (m)
Kayak	94	–	6	250.6	261.2
Paddleboard	–	100	–	277.2	258.2
Motorboat	–	–	100	327.0	308.9
Zodiac	–	–	100	269.8	266.1

The mean observed and the modal mean of the expected distances based on 100 iterations.

The closest beluga to a paddleboard was 3.6 m, which was the closest distance between a beluga and any vessel. There were 39,200 expected distances between belugas and paddleboards in each of the 100 iterations. In all 100 iterations of the Monte Carlo analysis the distance between observed belugas and paddleboards was significantly greater than expected indicating belugas avoided paddleboards (Table 1).

Motorboats

Motorboats occurred during all tide categories, except low tide. No more than one motorboat was present in a photo. The closest beluga to a motorboat was 49.6 m. There were 4,300 expected distances between belugas and motorboats in each of the 100 iterations. The distance between belugas and motorboats was the same as the expected distances generated in all Monte Carlo simulation iterations, indicating that belugas were neither attracted to nor avoiding motorboats and were therefore neutral (Table 1).

Zodiacs

Zodiacs occurred in the estuary at all tide categories, except falling tides. At low and rising tide, Zodiacs were used by tour leaders for supervision of kayaks and paddleboards. Of the 83 photos with Zodiacs and belugas, only 9 included Zodiacs as the sole vessel. The closest beluga to a Zodiac was 8.5 m. There were 11,900 expected distances between belugas and Zodiacs in each of the 100 iterations. The distance between belugas and Zodiacs was the same as the expected distances generated in 100 out of 100 Monte Carlo iterations indicating that belugas were neither attracted to nor avoiding Zodiacs and were therefore neutral (Table 1).

Discussion

This study found belugas in the Churchill River estuary were attracted to kayaks, avoided paddleboards, and were neutral in their response to motorboats and Zodiacs. To our knowledge, this is the first study to quantify an attraction to kayaks by

cetaceans using the measured distances between them. While [Malcolm and Penner \(2011\)](#) described interactive behavior of belugas to kayaks, that study was not quantitative. Unlike offshore waters near other Arctic communities within Hudson Bay, there are only few reports of belugas being hunted within the Churchill River estuary. Beluga hunting, which is a traditional right for Inuit and Cree Peoples, has been observed to result in avoidance by beluga of motorboats historically within Churchill and in other communities around Hudson Bay ([Idle, 1989](#); [Caron and Smith, 1990](#); [Tyrrell, 2007](#); [Malcolm and Penner, 2011](#)).

Our results support findings by [Malcolm and Penner \(2011\)](#), which suggest that belugas are attracted to kayaks. However, our findings that belugas are neutral in their behavior regarding motorboats and Zodiacs contradict their results. [Malcolm and Penner \(2011\)](#) used vessel-based observers to classify beluga behavior within distance categories from a passenger motorboat (0 to greater than 150 m by 25 m increments), kayaks (within 100 m), and snorkeling activities (within 100 m). They investigated the proportion of time groups of belugas spent in the different behavioral categories at different distances from vessels to assess the potential vessel impact. They found that the most common behavior type of belugas within 25 m of the passenger motorboat was “interaction” and concluded that regardless of vessel type belugas show attraction to tourist vessels.

Several factors may contribute to the different results of these two studies. Our camera system was able to monitor a larger area of the estuary, allowing for all distances between belugas and vessels to be recorded up to 744.6 m. The methods of [Malcolm and Penner \(2011\)](#) may have observed behaviors of closer belugas interacting with vessels more than belugas at farther distances that may have been avoiding vessels. Additionally, by using locations of belugas in photos without boats, our study design allowed us to control for environmental variability such as prey availability and influence of tide.

The response of Churchill River estuary belugas to whale watching vessels is distinct. Belugas in the St. Lawrence River estuary, for example, have been observed to avoid motorboats by increasing swimming speed, bunching into groups, changing travel direction, and increasing diving intervals ([Blane and Jackson, 1994](#); [Lesage et al., 1999](#)). Vessel avoidance displayed by these belugas could be a result of

higher traffic from ferries and shipping vessels that occurs there. The St. Lawrence River population status is Endangered (COSEWIC, 2014) and high shipping traffic in this region may be a contributing factor in their status. Quantity, speed, approach distance, and regulation of tourist vessels have been shown to impact the behavioral response of belugas (Blane and Jaakson, 1994; Krasnova et al., 2020). Current management of beluga ecotourism does not allow approaches to be closer than 400 m for belugas in the St. Lawrence estuary, or closer than 50 m distance for belugas in the Seal and Churchill River estuaries (Regulations Amending the Marine Mammal Regulations. SOR/2018-126, 2018).

Some studies have reported behavior changes in response to kayaks, including horizontal avoidance (Jelinski et al., 2002; Lusseau, 2003a; Lusseau, 2006; Timmel et al., 2008; Noren et al., 2009; Fandel et al., 2015; Sullivan and Torres, 2018), while other studies have found no changes in observed cetacean behaviors (Steckenreuter et al., 2012; Heenehan et al., 2017). Multiple factors could differentiate the attraction behavior found in our study to response of other cetaceans to kayaks. Kayaks produce minimal noise and may surprise cetaceans by getting close before they are detected resulting in avoidance behaviors in whales (Gregory and Rowden, 2001; Sullivan and Torres, 2018). Williams et al. (2011) found that southern resident killer whales (*Orcinus orca*) reduced feeding and increased traveling behaviors when kayaks were present. Of the cetacean populations studied with respect to response to kayaks, difference in behavioral responses could be related to population health, population size, or the degree of sociality of the species. While the Western Hudson Bay beluga population is classified as not at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) the southern resident killer whale population is classified as endangered (COSEWIC, 2008; COSEWIC, 2020).

Behavioral responses by whales to vessels can change over time. After a decade, Burrunan dolphins (*Tursiops australis*) increased both avoidance (10.8% to 56.5%) and approach (3.3% to 10%) behaviors to vessels (Filby et al., 2014). Reduced behavioral response over time is generally classified as habituation, but in extreme circumstances could also be caused by reduced ability to respond due to decreased fitness (Lusseau and Bejder, 2007). For instance, if tourism activities overlap with essential feeding grounds for cetaceans, the cost of avoidance or fleeing the area over consistent occurrences could be too high for whales to continue exhibiting the same behaviors (Bejder et al., 2006a; Lusseau and Bejder, 2007). Fewer observations of belugas fleeing or diving to avoid tourist vessels over a 16 year period may be evidence of habituation to vessel presence in the White Sea, Russia (Krasnova et al., 2020). Whale-watching with kayaks, motorboats, and Zodiacs has been ongoing in the Churchill River estuary for decades (Malcolm and Penner, 2011), however paddleboards were added as a personal watercraft whale-watching option in 2015³. Beluga

avoidance to paddleboards in the estuary may be because there has not been time for habituation to occur.

To our knowledge, this is the first paper to record interactions between paddleboards and belugas. When observing dolphin reactions to recreational activities including paddleboards, Fandel et al. (2015) recorded neutral responses 61.93% of the time. Even though the closest distance between a beluga and a paddleboard in our study was 4.6 m, the overall response of belugas to paddleboards was avoidance. Paddleboards are less mobile than kayaks and more difficult to maneuver, which limits their ability to approach belugas. It is possible the differences between the physical and acoustic characteristics of kayaks and paddleboards contributed to the difference in beluga response. Paddleboards used in the Churchill River estuary were grey, while kayaks used for tourism in the Churchill estuary were lighter colors of bright yellow or green. While kayakers remain seated, paddleboarders are standing resulting in a higher profile which might affect the way belugas perceive the paddleboard. Paddleboards are not able to move as quickly as kayaks and may make less splashing noises as they have one paddle opposed to two. It is not clear how well belugas can see outside of the water, but the visual cues including color and vessel profile, may result in a similarity between paddleboards and killer whales. These factors in addition to movement patterns of personal watercraft could contribute to beluga response in the Churchill River estuary.

One alternative explanation for avoidance to paddleboards found in the Churchill River estuary may be related to the large number of paddleboards found in close proximity to each other. Greater intensity of behavioral responses with increasing numbers of vessels has been observed in humpback whales (Schuler et al., 2019; Amrein et al., 2020), killer whales (Williams et al., 2009), Risso's dolphins (*Grampus griseus*) (Visser et al., 2011), Hawaiian spinner dolphins (*Stenella longirostris*) (Timmel et al., 2008), dusky dolphins (*Lagenorhynchus obscurus*) (Lundquist et al., 2013a) and bottlenose dolphins (*Tursiops* spp.) (Constantine et al., 2004; Stensland and Berggren, 2007; Steckenreuter et al., 2012; Pirota et al., 2015). Paddleboards in the Churchill River estuary are often in clumped groups likely due to their limited mobility. Kayaks are also found in larger groups; however, kayaks are not avoided by belugas. Large numbers of vessels occur because personal watercraft tour operators take advantage of the 3-hour low tide period when currents are calmer in the Churchill River estuary. As large groups of vessels are often present in the Churchill River estuary during low tides, variation in beluga response with increasing numbers of vessels should be further investigated. The year this study was conducted was a light tourism year due to COVID 19 restrictions, therefore it is

³ <http://www.sup-north.com/about>

expected that vessel numbers will be higher in the future and results may differ.

It has been hypothesized that cetaceans avoid motorized boats due to their noise production, which can mask calls and interfere with communication or feeding (Lesage et al., 1999; Scarpaci et al., 2000; Erbe, 2002; Nowacek et al., 2007; Holt et al., 2009; Pirota et al., 2015). The neutral response of belugas to motorboats and Zodiacs observed in this study, however, appears contrary to this hypothesis. The closest beluga to a motorboat was 49.6 m, and the closest beluga to a Zodiac was 8.5 m. Only 3 belugas were within 25 m of a Zodiac and 17 were within 50 m. Of the 43 motorboats in photos with belugas, 8 were of our science vessel taking georeferencing points, 2 were of the same smaller motorboat that appears to be operated by Churchill residents, and 33 were the Polar Bears International (PBI) vessel, recording beluga whale video footage for beluga research⁴. When the PBI vessel was in the estuary the operator would drive the motorboat to one end of the estuary then turn off the engine and float to the other end with the tide. It is possible that the neutral response of belugas to motorboats is related to lack of noise from motorboats with the engine off, which is common in the estuary. This may also be a contributing factor to the response to Zodiacs, as most Zodiacs were in the estuary to supervise kayaks and paddleboards and would spend most of the time with their engine off.

Of 2,005 vessel-beluga distances recorded 90 (4.5%) were located within the 50 m approach distance to belugas allowed by Marine Mammal Regulations in the Churchill River estuary (Regulations Amending the Marine Mammal Regulations. SOR/2018-126, 2018). There is evidence that increased proximity of vessels to whales may result in increased negative behavioral reactions (Steckenreuter et al., 2012; Schaffar et al., 2013; Currie et al., 2021). With decreasing distance to vessels, southern resident killer whales showed increases in respiration interval and path deviation as well as exhibiting more surface behaviors (Noren et al., 2009; Williams et al., 2009). Within 100 m of vessels, humpback whales were more likely to exhibit avoidance behaviors (Stamation et al., 2010). In the White Sea, less behavioral changes were noted when vessels were further away from belugas (Krasnova et al., 2020). The Churchill River estuary is a popular ecotourism and research destination, with projected increases in visitors over time for the unique opportunities (Malcolm and Penner, 2011). With this in mind, impacts of proximity and quantity of vessels in the estuary are important factors to consider with respect to beluga response as well as population health.

Results from this paper show responses of belugas differ by vessel type in the Churchill River estuary. This is different from conclusions drawn by Malcolm and Penner (2011) who found that belugas are 'interactive' with tourist vessels regardless of

type, based on findings that beluga observed in close proximity to vessels (<25 m to motorboats, within 100 m for kayaks and snorkeling vessels) displayed behaviors such as moving towards the vessels, swimming alongside vessels, investigating vessels or blowing bubbles. Responses to different vessel types have been varied in gray whales (*Eschrichtius robustus*) in Oregon, relative to feeding behavior with distance from kayaks and distance from motorboats (Sullivan and Torres, 2018). Southern resident killer whales also differed in responses to whale-watching depending on vessel type and approach distances (Noren et al., 2009; Williams et al., 2009). Bottlenose dolphins (*Tursiops truncatus*) in West Wales exhibited attraction, avoidance, and neutral behavior in different proportions depending on vessel type (kayak, speeding boat, fishing boat, sailing boat) (Gregory and Rowden, 2001).

Determining the population level impact of whale watching is complicated because the relationship between short-term behavioral responses and fitness is unknown (New et al., 2015). We documented attraction and avoidance by belugas with respect to kayaks and paddleboards. Avoidance could cause stress (Orams, 2004; New et al., 2015), and may be similar to predator avoidance (Frid and Dill, 2002; Williams et al., 2002; Lusseau, 2003b). Higher respiration rate in addition to other behaviors that accompany avoidance could negatively impact whale energy reserves (Christiansen et al., 2014). By avoiding paddleboards, belugas may also lose opportunities to access habitat benefits hypothesized for estuary occupation, including access to prey. Reduced feeding is often recorded as a cetacean response to vessels (Williams et al., 2006; Stockin et al., 2008; Arcangeli and Crosti, 2009; Lusseau et al., 2009; Williams et al., 2011; Dans et al., 2012; Steckenreuter et al., 2012; Christiansen et al., 2013b; Pirota et al., 2015), which can reduce energy intake, especially if vessels are occupying areas that are necessary for feeding (Senigaglia et al., 2016).

Conclusion

Using a time-lapse camera system, we were able to photograph 2,261 belugas in 16 days on the Churchill River estuary. The use of georeferencing points and trigonometric equations allowed us to determine the distance between belugas and vessels. We found that belugas were located closer to kayaks (attraction), further from paddleboards (avoidance), and no closer or further from motorboats and Zodiacs (neutral) than would be expected. Considering these results in beluga response to vessels, and numerous observations of belugas approaching vessels to interact by Malcolm and Penner (2011), distance-based restrictions for whale-watching management in the Churchill estuary may not be the most appropriate management approach. Instead, we suggest that zones with different levels of protection be defined during the establishment of a National Marine Conservation Area (Villa

⁴ <https://explore.org/livecams/beluga-whales>

et al., 2002; Ashe et al., 2010; Gray et al., 2010; Manitoba western Hudson Bay ad hoc beluga habitat sustainability plan committee, 2016; Giakoumi et al., 2018; Ménard et al., 2022). These zones would limit vessel traffic (number or time present) in areas of critical beluga habitat. Studies will be required to define critical beluga habitat as this was not considered in our study. The economic and ecological benefits of enhanced beluga-human interaction should also be considered.

Issues of whale conservation and management require clear defensible scientific data upon which policies and procedures can be developed. Climate variability and change and other pressures on Arctic flora and fauna can also affect relationships measured here. We suggest additional monitoring of whale-vessel interactions to support species management in this unique sub-Arctic estuary. The beluga tourism industry in Churchill, Manitoba has many stakeholders. As such, it is important to consider the impact of this industry on the health of the beluga population, the local economy, and the tourists themselves. The ecotourism and whale-watching industry is an important source of jobs and income in Churchill, Manitoba. The estimated economic impact of beluga tourism was \$1,344,052 CAD for Northern Manitoba in 2014, with 60 direct full and part time jobs for residents (*The Churchill Beluga Whale Tour Operators Association et al., 2015*). Ecotourism can be a tool to educate participants about whale conservation (*García-Cegarra and Pacheco, 2017; Cárdenas et al., 2021*), and the uniqueness of this sub-Arctic environment could increase awareness on how climate change affects iconic species. Tourism vessel impacts on belugas in the Churchill River estuary will be an important factor for decisions with respect to the establishment of a National Marine Conservation Area. We also recommend monitoring the relationships found in this study to ascertain their stability with changes in numbers and types of vessels through time.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the animal study because data on whales was collected using photography from shore only, which has no disturbance effects on the whales and no impacts on whale habitat.

Author contributions

EA, MM, and DB contributed to the conceptualization and design of the study. EA collected data, reviewed photos, and

developed the equations for distance measurements. EA and WC explored oblique photo measurements, and calibrated distance measurement equations. EA wrote the first draft of the manuscript. MM and DB supervised the project. All authors contributed to manuscript revision and reviewed and approved the submitted version. DB and MM acquired funding for the project.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2022.837425/full#supplementary-material>

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