Social influence on vessel behaviour around cetaceans in the waters of Northeast Vancouver Island

by

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Abstract

When managing human behaviour around wildlife, regulations are often designed to mitigate disturbance to vulnerable species. Yet, patterns and drivers of compliance with such regulations are poorly understood. In partnership with the Marine Education and Research Society, we assessed local compliance rates and examined patterns underlying vessel-whale encounters by observing vessel behaviours around marine mammals. In the summers of 2022 and 2023 (n = 475 observation hours, 902 interactions between marine mammals and boats), we assessed motorized vessel compliance to Canada's Marine Mammal Regulations and examined a suite of boater behaviours relating to humpback (*Megaptera novaeangliae*) and killer whales (*Orcinus orca*) in Northeast Vancouver Island. Recreational and ecotour vessels had similar rates of compliance (85 and 87%, respectively), with the lowest compliance rates around killer whales (74%). Complementary modelling showed that closer distances between vessels and whales were associated with vessels that spent more time with an animal or that were idle. In contrast, greater distances from the whales were associated with interactions involving a higher number of vessels. Assessing other measures of potential disturbance, we found that the number of vessels surrounding an animal varied by study site and was higher in encounters after VHF radio communication about the focal whale compared to encounters without mention. Finally, the time a vessel spent with a whale was higher for vessels at idle and slow/medium speeds compared to vessels travelling at faster speeds. Results from this work can inform geographic and practical areas of focus for education, enforcement and policy development.

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Dedication

For my dad, whose encouragement inspired me to pursue this path many years ago. Your passion for discovery and support have been guiding lights throughout my journey. Though you are no longer here, you continue to inspire me. This work is dedicated to you, with all my love and gratitude.

Chapter One: Introduction

Conservation and wildlife management efforts in the past primarily focused on understanding and managing ecological systems and species. However, and increasingly common and more effective approach to conservation involves managing human behaviour through the integration of social sciences (Bennett et al., 2016). This integration requires not only knowledge of wildlife and their habitats but also an understanding of human-environment relationships and dynamics (Bennett et al., 2016; Peterson et al., 2010).

Examining the dynamics of human-environment relationships and the patterns that motivate decision-making are crucial for effective management (St. John et al., 2011). The field of social psychology can provide insights into pro-environmental decision-making, thereby strengthening wildlife conservation (Farrow et al., 2017). Understanding human perceptions of different species can inform management efforts. For example, fear of large predators can hinder efforts, but happiness when viewing esteemed species can spur positive attitudes toward their conservation (Castillo-Huitrón et al., 2020). The integration of social psychology into conservation is not a new concept (Beedell & Rehman, 2000; Cialdini et al., 1990; Farrow et al., 2017), and pro-environmental decision-making has been examined in various fields, such as recycling, energy efficiency, charitable donations, and wildlife tourism (Bergquist et al., 2020; Corrado et al., 2022; Mayer & Carter, 2024; Pan et al., 2024).

When human behaviour poses significant disturbance to wildlife, laws are often enacted, such as fishery closures or protected marine areas (Kriegl et al., 2021; Seary et al., 2022). To investigate adherence to these laws and the factors influencing non-compliant decision-making, we can integrate social psychology theories into ecology to examine the underlying patterns.

Understanding why regulations are not followed or where public confusion occurs is essential for wildlife conservation and the safety of human-wildlife interactions.

Human-wildlife interactions and the patterns underlying these relationships can vary based on context, region, and the laws and regulations governing these interactions. Place-based studies can illuminate these contexts, guiding local management and education while contributing to the literature on pro-environmental behavior and social theory in conservation. Our study contributed to these objectives by observing various vessel behaviors in a region with high levels of marine mammal activity and vessel traffic in British Columbia, Canada. We used these methods to 1) assess boater compliance with national regulations enforcing a minimum avoidance distance to whales and 2) identify potential social and context-specific factors influencing vessel behaviours around Humpback whales and killer whales. This project provides a much-needed basis for assessing boater knowledge of these regulations. It also identifies key behavioural measures influencing boater actions around whales. Additionally, this study offers important insights into social influence theory regarding pro-environmental decision-making and compliance.

Chapter Two: Motorized vessel behaviour and compliance to Marine Mammal Regulations in Northeast Vancouver Island

Introduction

Theory describing situational social influence (SSI) outlines how and why the behaviour of people can be strongly affected by that of others, providing key insight into successful implementation of pro-environmental behaviours. In essence, when formal guidance (i.e., laws, rules) is not readily available or known, people can often make rapid decisions by observing and mimicking the actions of others around them (Roy, 2021). Insight emerging from this body of work can be applied to education, regulation, and enforcement (Arlidge et al., 2023). Although theory and concepts related to social influence are well-known across several fields (White et al., 2011), rarely are the predictions from SSI tested quantitatively in a conservation context to examine how people's environmental decision-making might be influenced (Arlidge et al., 2023).

SSI can manifest through three processes. Behaviour can be influenced by the prospect of inappropriate behaviour being detected (instrumental-based motivation), as a result of enforcement and regulations (legitimacy-based motivation), or by the attitudes and actions of other people (normative-based motivation) (Oyanedel et al., 2020a). These processes are sometimes related. For example, management strategies can include regulations and guidelines to shape behaviour, but adherence to regulations is often unknown or have high levels of non-compliance (Cross et al., 2013; Woolasten et al., 2021). If the regulations are not well-known, normative-based motivations may be central to shaping behaviour (Oyanedel et al., 2020a). In this context, the probability of one person mimicking the behaviour of others can vary with multiple factors, depending on the context. These factors can include the geographic location and the number of people in the area, (Aldridge et al., 2023; Bond, 2005). Here, we use legitimacy- and normative-based processes as lenses to examine human behaviours in the presence of wildlife species sensitive to human disturbance.

Such SSI lenses provide insight into how human behaviour can be modified to reduce negative human-wildlife interactions. The social dynamics and the most effective ways to direct social norms around wildlife are complex and often contentious (Nesbitt et al., 2021; Jochum et al., 2014). Accordingly, understanding the patterns and potential motivations that result in the behaviours of interest comprise a key challenge. Examples of using a legitimacy-based motivation lens to elicit behavioural change include limiting fishing activity by enforcing a no-take zone in a marine protected area (Oyanedel, 2020b) or placing signs to manage tourist disturbance at a popular seal-watching site (Marschall et al., 2017). Lischka et al. (2018) outlined a case study in Durango, Colorado, where human-bear conflict was common. The city introduced a bylaw to seal garbage securely and provided bear-safe garbage containers. There was high variation in compliance from block to block despite regulations being consistent across the city. Lischka et al. proposed that observing the behaviour of immediate neighbours may guide an individual's behaviour more than regulations. These case studies provide insights into potential factors that may result in behavioural changes, but how behaviours 'spread' (positively or negatively), and the direction and strength of patterns in behaviour subject to social influence are largely unknown (Arlidge et al., 2023).

Such uncertainty is common within human-wildlife interactions in marine systems, particularly in the behaviour of boaters around marine wildlife, including large whales. Managing behaviour around large whale species poses ongoing challenges. Regulations and voluntary measures for operating vessels around cetaceans vary greatly on global, national, regional and temporal scales (Currie et al., 2021; Damato, 2024; Fraser et al., 2020; Fisheries and Oceans Canada, 2018; Fisheries and Oceans Canada, 2024a; Kessler & Harcourt, 2013; Schoemann et al., 2020; Seely et al., 2017; Silber et al., 2012; Transport Canada, 2024; Vanderlaan & Taggart, 2007; Wiley et al., 2008). Management efforts often include confusing policies, where the rates of adherence to regulations are not well known (Fraser et al., 2020; Burnham et al., 2021). This knowledge is urgently needed. Providing services that view cetacean species is now a multi-billion-dollar industry (Burnham et al., 2021). Additionally, recreational boaters frequently view whales (Seely et al., 2017). Although viewing cetaceans can yield positive outcomes for education and conservation (Jacobs & Harms, 2014), they also carry associated risks. These include vessel strikes, which can cause potentially lethal injuries to both humans and cetaceans, as well as vessel damage (Shoeman et al., 2020). Acoustic disturbance from boats can also negatively influence behaviour (Noren et al., 2009), foraging ability (Williams et al., 2006; Holt et al., 2021; Burnham et al. 2023) and acoustic communication (Holt et al., 2009; Burnham et al. 2023). The most common tool for management includes mitigating the threat of disturbance through regulations focused on vessel behaviour (Kessler & Harcourt, 2013), such as slow-down zones and distance regulations (Fisheries and Oceans Canada, 2024a; Silber et al., 2012). The adherence to these legitimacy-based motivations in the form of regulations, however, is often unknown or yields limited behavioural change (Silber et al., 2012; Kessler & Harcourt, 2013; Seely et al., 2017; Wiley et al., 2008). Moreover, the influence of normative-based motivations on vessel behaviour remains unclear.

Here, we examine how situational social influence that may influence vessel behaviour around cetaceans. We considered the coast of Northeast Vancouver Island (Figure 1) as a context for examining vessel behaviour in an area with high densities of both whales and vessels. The

National Marine Mammal Regulations apply to this area, but rates of compliance with these Regulations are unknown. We focused on interactions between vessels and Humpback whales (*Megaptera novaeangliae*) and killer whales (Bigg's and Northern Resident; *Orcinus orca*). We used the following three distinct categories to describe vessel behaviour: vessel distance to a whale, the number of vessels around a whale, and the duration of time with a whale. Our objectives were to 1) assess boater compliance with national regulations that limit the vessel distance to whales – 100m for Humpbacks, 200m if they are resting or with a calf; 200m to killer whales (legitimacy-based process); and 2) identify potential factors that influence the categories of vessel behaviour around Humpback whales and killer whales, including those related to the behaviour of other vessels (normative-based processes). We hypothesized that compliance and general vessel behaviours around marine mammals would be influenced by social and context-specific factors or a combination of both. Context-specific factors were variables that were specific to the whales and/or site (i.e. whale species, whale behaviour, calf presence/absence, study site), while social factors were variables that focused on human characteristics (i.e. vessel type, radio communication, number of vessels in the area). We predicted that compliance with national regulations would be lower in vessels that may not know the existence of the regulations or the specifics of these regulations (recreational vessels), and/or in encounters with sought-after species (killer whales). For general vessel behaviours, we predicted that in conditions in which a boater has knowledge of the behaviour of others (social, normative-based processes, i.e. radio communication about whales, number of vessels) could elicit one of two (alternative) responses, either pro-environmental behaviour (further from the whale, fewer boats around a whale, less time spent with a whale) or the opposite. Additionally, we predicted that vessels that are more likely to intentionally view whales (ecotour vessels), encounters with sought-after species (killer whales) or behaviours (surface active behaviour) will result in closer vessel distances to a whale, a higher number of vessels around a whale, and a longer duration of time spent with a whale.

Methods

Study Area

Figure 1. Study sites with associated 2km rangefinder buffer, located off Northeast Vancouver Island, in the Johnstone Strait Region. Average elevation at each site depended on tidal height, and was 44.0m at Donegal Head, 4.0m at Blackfish Sound, and 3.7m at the Blackney Pass Site.

We conducted land-based monitoring scans off the coast of Northeast Vancouver Island, specifically Donegal Head (9U 653870 5610363), Blackfish Sound (9U 658374 5606607) and Blackney Pass (9U 661987 5605442; Figure 1). Field sites for this project were selected to be ecologically relevant and practical. Specifically, these general areas host high vessel activity, are known hotspot areas of Humpback whales and are within designated critical habitat for Northern Resident killer whales (Fisheries and Oceans Canada, 2018). The precise observational sites within these areas were those with good vantage points, where we could secure landowner permission to use for consecutive weeks. The Donegal Head site was on a cliff on a private residence on Malcolm Island with a 127° field of view, the Blackfish Sound site was located on a small islet approximately 1km off northwest Hanson Island that had a 184° field of view, and the Blackney Pass site was a rocky outcrop on northeast Hanson Island with a 212° field of view.

The original 1993 National Marine Mammal Distance Regulations (MMDR; Marine Mammal Regulations, SOR/93-56) were amended in 2018. We assessed compliance in the region based on these amended regulations. Minimum avoidance distances for each species are mandated, where vessels must stay 200m away from killer whales and 100m away from all other whale and dolphin species. There is an additional requirement for whale species (including Humpback whales) when they are with a calf or resting, where vessels must stay 200m away.

We limited data collection to a 2 km radius from each observation area. We reasoned that measurements would become unreliable beyond that distance, especially during poor weather and sea states. Distance from the researcher to each vessel or whale was measured using laser rangefinders (Safran Vectronix 21, Appendix A, Figure S1). Azimuth was also measured by the laser rangefinders, specifically, the bearing of the vessel or whale from Magnetic North (See Appendix A, Figure S1). The “slope distances” measured by the laser rangefinders account for elevation and horizontal distance (including eye height and tidal differences), creating a diagonal slope distance metric between the researcher and target (*i.e.,* whales, vessels). Within this 2 km buffer, accuracy tests of distance measurements were completed by taking slope distance and bearing estimated from study sites to a colleague's vessel. The "theoretical" location of the vessel was estimated with ArcGIS, using the researcher's location, slope distance and bearing. Comparisons of distance estimates with known location (vessel location measured with Raymarine Dragonfly-5 navigation system in the field) revealed high accuracy (+/- 15m).

Field Methods

We employed two main sampling protocols: 1) a combination of systematic timed scans; and 2) opportunistic focal sampling on individual marine mammals. Over two field seasons in 2022 and 2023, the research team sampled for 66 days (25 days in 2022, 41 days in 2023) and a total sampling time of 475 hours (150 hours in 2022, 325 hours in 2023).

The systematic timed scans complemented our methods by providing an overview of the entire observational area during a short period. We conducted scans at the start of each hour for 10 minutes, during which the researcher scanned the entire field of view for the presence of any vessels or marine mammals (Krogman et al., 1989; Mann, 1999). We recorded the distance and bearing from the researcher to each vessel and marine mammal sighted, as well as group composition of any marine mammal sighting (calf presence/absence), number of mammals in a group, vessel type and speed. We categorized the speed of each vessel as idle, slow/medium, or fast, based on whether the boat was on plane and the size of its wake (Vanderlaan & Taggart, 2007). We aggregated vessel types into 4 main categories: ecotour vessels, commercial vessels, recreational fishing, and recreational non-fishing (See Supplementary Materials: Appendix A). No specific identifiers of vessels or the boaters themselves were recorded. Ecotour presence was noted as yes/no to indicate whether there was an ecotour vessel present in a scan.

After each systematic scan, focal sampling was initiated to collect more detailed observations of the vessels encountered by an individual Humpback or killer whale. The length of focal scans depended on our ability to observe continuously. Due to the often erratic and unpredictable behaviour of the whales, as well as time spent underwater, we extended focal scans for as long as we could record consistent measurements from a single individual. We ended focal scans, however, at the top of every hour, when a new systematic scan commenced.

Focal sampling required reliably distinguishing among individuals. A focal individual (Humpback whale or killer whale) was chosen opportunistically, where the closest individual to the researcher was selected (Mann, 1999). When more than one whale was present in a group, we distinguished among them by continuously taking and reviewing photos (Nikon Z6II, 200-500mm lens) and observing through a spotting scope (Vortex® Diamondback® HD Angled - 20-60 x 85mm) to select and track an animal with identifiable features (Fraser et al., 2020). If the focal individual was no longer in view or we were uncertain if it was the same individual, a new focal individual was chosen, cueing the start of a new focal scan. Humpback whales can be identified by pigmentation, scars, and shape of the dorsal fin or fluke (Katona et al., 1979). Northern Resident and Bigg's killer whales can be identified through markings or the shape of the dorsal fin, and the varying size, shape and markings on the saddle patch (Hammond et al., 1990).

Focal sampling followed a schedule. We recorded observations on focal individuals every 2 minutes unless the focal individual was underwater. If the animal dove for longer than 2 minutes, the scanning schedule was paused until the animal resurfaced. At each observation, we recorded the distance of the focal individual to the researcher, along with behavioural state, calf presence/absence, and the individual's identity (if catalogued in the region or we noted newly observed individuals in the area) or other identifiable features.

We measured behaviour state following Lusseau et al., 2009. We defined four categories: travel, feeding, resting and surface activity (See Supplementary Materials, Appendix A). We used a point sampling approach, noting the behaviours of the whale in the 2 minutes before the observation. When behaviour during that period varied, we recorded the predominant behaviour, i.e., the one observed for the majority of the scan, termed "predominant activity sampling" (Mann, 1999).

We also recorded data on the vessels. We estimated the distance from the researcher to the vessel, the speed (idle, slow, medium, fast, very fast) of all vessels present, and the vessel type. If a vessel was present for multiple observations during the scan, we used the speed classification that the vessel was at for the longest duration. We indicated if there was radio communication about the focal whale (or generally about whales in our sampling area) on the VHF marine radio channel that is used by the local whale-watching community to communicate about whale sightings and marine mammal issues of concern. Vessels using the radio channel identify themselves to begin any correspondence (Fisheries and Oceans Canada; 2024b), so we could locate the vessel that was speaking and if they were in our sampling area. If they directly referenced the whale (using known 'names or identities of whales that are used in the area), or referenced a location, or specific behaviour that indicated the focal whale, we categorized this as present radio communication. If we located the vessel in our sampling area, and they referenced a whale's presence using a spatial reference (i.e. Donegal Head), and we could see the whale, we also categorized this as present radio communication. We classified this as a binary measure, where radio communication was present within each focal scan, or not. Additionally, we estimated the time each vessel spent with the focal whale by assigning arbitrary IDs to each vessel. The number of vessels around a whale was calculated by the number of individual vessel

IDs recorded during the focal sample, and the median number of vessels was calculated for each focal scan.

Before analyses, we assessed the reliability of our subjective measurements. Specifically, both researchers independently collected 24% of the dataset, and we compared estimates. We differed in assigning dominant behavioural states in 24 of 362 observations (6.7%), which we considered acceptable. For the original vessel speed categories, however, our inter-researcher error was 62 of 323 observations (19.2%). Accordingly, we collapsed the variables following Vanderlaan & Taggert (2007), into three categories: idle, slow/medium, and fast. We grouped the original measured variables of slow and medium into 'slow/medium', and fast and very fast into 'fast'. Following this recategorization, the inter-researcher error was 4.3%, which we considered acceptable.

Analysis

We used trigonometry on field data to estimate vessel distances to whales. In the field, laser rangefinders (Safran Vectronix 21) provided measurements of the distance from the researchers to vessels, and from researchers to whales (See Supplementary Materials, Appendix A). To convert these measurements to the distance between the vessels and a whale, we first calculated the angle between the vessel and the whale (i.e the difference between the bearing from the researcher to the vessel and from the researcher to the whale; A), and then we used the cosine formula to calculate the distance between them (B):

A: $\theta_{VW} = |((\theta_{RW} - \theta_{RV}) mod 360) - 180|$

B: VWD = $\sqrt{}((RWD^2 + RVD^2) - (2 \times RWD \times \; RVD \times \cos\theta_{VW})$.

where:

VWD = Vessel to Whale Distance

RVD = Researcher to Vessel Distance

RWD = Researcher to Whale Distance

θ_{VW}= Angle between Vessel and Whale

θ_{RV} = Angle between Researcher and Vessel

θ_{RW} = Angle between Researcher and Whale

Compliance in the Region

We summarized compliance with the minimum avoidance distances specified in the Marine Mammal Regulations by grouping all data from both scan types throughout 2022 and 2023, for both Humpbacks (n = 344) and killer whales (n = 61). To be comparable with a previous study assessing compliance in the Salish Sea (Fraser et al, 2020), we subset this data to only include vessel-whale interactions within 500m. When referencing compliance, encounters with vessels were defined within 500 m. Given that the minimum legal avoidance distances vary by species (100m for Humpbacks; 200m for Humpbacks that are resting or have a calf present; 200m for killer whales), we scaled to a “Distance to Compliance”, where we set the minimum avoidance distances at 0 for the appropriate species/context. This indicated the threshold to a non-compliant event. To account for accuracy with laser rangefinders, we included interactions within 15m of the regulation distance as non-compliant events. We visualized patterns with smooth density plots (ggplot2 package in R; Wickham, 2016). To compare rates of compliance between species and vessel type, we conducted a two-sample t-test.

Modelling - General Approach

To examine the characteristics of vessels and marine mammals that may influence vessel behaviours, we used several generalized linear mixed effects models (GLMMs). We started measuring the radio communication and vessel speed in 2023, and since the focal scan data gives the most information for vessel-whale interactions, we only used this dataset for the mixed effects modelling approach.

Our modelling approach tested predictions considering social and context-dependent variables. The response variables were used in subsequent analyses as predictor variables. We modelled how a vessel's distance to a whale, the number of vessels around a whale and a vessel's time spent around a whale varied based on characteristics of the vessel of interest, other vessels' behaviour, and the species involved. All continuous predictors were centred and scaled to a mean of 0 and a standard deviation of 1. Scans shorter than 2 minutes were excluded from analyses because these scans corresponded to instances where a whale was observed only once during the scan. Additionally, only whale-vessel interactions within 800 m were considered. Since the distribution of vessel distance had a plateau beyond 800 m, we reasoned that there would be no relationship with the predictors beyond this point. Thus, when referencing encounters or interactions with vessels in the modelling approach, these are defined within 800 m between a vessel and a whale. We also only included ecotour vessels and pooled recreational vessels in these models, as the sample of commercial vessels was small when we omitted interactions beyond 800m (n = 28). We created three candidate model sets (one for each response variable; Table 1, See Supplementary Materials Appendix B). We used the focal scan number as a random effect in all models (Table 1). Statistical analyses were carried out using R version 4.3.3 (R Core Team, 2024).

Table 1 Vessel and species metrics and covariate data for all model sets.

Type of Variable	Variable Name	Value	Model Set
Response Variable (Model Set)	Distance to Whale (m)	Continuous Numeric	
	Number of Vessels (median per scan)	Count	
	Time with Whale (mins)	Continuous Numeric	
Random Effect	Focal Follow Scan Assigned Number	Factor	Distance to Whale
Fixed Effect	Vessel Type	Categorical (Recreational, Ecotour)	Distance to Whale; Number of Vessels; Time with Whale
	Vessel Speed	Categorical (Idle, Slow/Medium, Fast)	Distance to Whale; Number of Vessels; Time with Whale
	Distance to Whale (m)	Continuous Numeric	Number of Vessels; Time with Whale
	Number of Vessels (median per scan)	Continuous Numeric	Distance to Whale; Time with Whale
	Time with Whale (mins)	Continuous Numeric	Distance to Whale; Number of Vessels

	Radio Communication	Categorical (yes/no)	Distance to Whale; Number of Vessels; Time with Whale
	Species	Categorical (humpback whale, killer Whale)	Distance to Whale; Number of Vessels; Time with Whale
	Behaviour State	Categorical (Resting, Travel, Foraging, Surface Behaviour)	Distance to Whale; Number of Vessels; Time with Whale
	Calf Present	Categorical (Yes/No)	Distance to Whale
	Ecotour Presence	Categorical (Yes/No)	Distance to Whale; Number of Vessels; Time with Whale
	Site	Categorical (Blackney Pass, Blackfish Sound, Donegal Head)	Number of Vessels
Interaction Term	Vessel Type : Species	Categorical	Distance to Whale; Number of Vessels; Time with Whale

Distance to Whale

The first response variable considered to model patterns in vessel behaviour was the minimum vessel distance to a whale during the focal scan. Since there were multiple observations of one boat in a focal scan if they were present for > 2 min, we pooled the data and used the minimum distance to the whale, rounded to the nearest metre. Due to significant variance exceeding the mean in distance to whale, we used the negative binomial distribution, specifically utilizing the quadratic parameterization of the negative binomial distribution (nbinom2), which handles overdispersion and zero-inflation (Stoklosa et al., 2022). Interactions between vessel type and species were included in all models, as we expected that human behaviour varies with wildlife species based on public perception, marketing efforts, and regional culture (Fraser et al., 2020; Seely et al., 2017; Di Minin et al., 2013).

Number of Vessels

The median number of vessels seen during a scan was the second response variable to represent vessel behaviour. As the instantaneous number of vessels present changes during a scan, we reasoned the median represented an accurate representation of the vessels present throughout the scan. Any decimals in the median were rounded to the nearest whole number. We used a Poisson distribution for the number of vessels, as this variable consisted of positive count data (Viti et al., 2015). We did not detect any overdispersion and checked with the Performance package in R (Lüdecke et al., 2021).

Time with Whale

The time a vessel spent within 800 m of a whale was the third and final response variable to represent vessel behaviour. Due to many vessels passing through the area, the distribution of time with the whale exhibited right-skewness, with many interactions lasting ~2 minutes. Given the detected overdispersion in this dataset, we used the quadratic parameterization of the negative binomial distribution (nbinom2; Dormann, 2016; Stoklosa et al., 2022). We detected no overdispersion using the Performance package in R (Lüdecke et al., 2021) after running the models with this distribution.

Model implementation, selection and relative variable importance estimates

To implement all models, we used the glmmTMB function within the glmmTMB package in R with "BFGS" optimization (Brooks et al., 2017). We compared models using the Akaike Information Criterion (AICc), and considered models that were within an AICc score of 2.0. We selected the top-performing model as the simplest model with the lowest AICc score (Bolker et al., 2009). We assessed the model fit with the DHARMA package in R (See Supplementary Materials; Hartig, 2022). We also calculated the relative variable importance (RVI) for each variable in each model set, standardized by the number of models including each variable (Kittle, 2008; Burnham and Anderson, 2002).

Interactions Included Post-Analysis

We considered several additional and possible important interactions after the analysis was completed. Specifically, these new models allowed us to consider possible influences of ecotour vessel presence in determining the relationship between another covariate and a response variable, thereby permitting testing of so-called "sentinel" and "magnet" effects, as well as some additional social influence hypotheses (Kessler & Harcourt, 2013; Shields, 2022). For distance to a whale as the response, the interaction term of ecotour presence and the number of vessels was added (Table S4) to test whether ecotourism vessels may attract other vessels around a whale, in turn influencing the distance to a whale (Shields, 2022). For the average number of vessels as a response variable, we added the interaction terms of radio communication and whale behaviour (Table S6). We posited that surface behaviour in whales may draw more vessels to the area, but only be important if called on the radio. For the time a vessel spent with a whale as the response variable, we included interactions of vessel type and distance to the whale, and also added the interaction between the presence of ecotour vessels and distance to the whale, also addressing sentinel vs magnet effects (Kessler & Harcourt, 2013; Shields, 2022; Table S8).

Results

Compliance in the region

Compliance of vessels to minimum avoidance distances from humpback (100 m; 200 m for resting whales or with a calf) and killer whales (200 m) was generally high at ~88% (n = 355 of 405 encounters) but varied depending on several important factors. Compliance rates were lower in 2022 (77%) compared with 2023 (88%). Compliance was significantly lower with killer whales (74%, n = 45 of 61, p-value = 1.1e-07; Figure 2D) than with humpback whales (88%, n = 301 of 344; Figure 2B). Compliance with minimum avoidance distances for when humpbacks are resting or with a calf (200 m) was significantly lower (68%, p-value = 1.7e-09, n = 41 of 60) than the 100m regulation (92%, n = 260 of 284), particularly among recreational vessels. Recreational vessels were generally compliant (85%, n =252 of 297) at a similar rate as commercial ecotour vessels (87%, p-value = 0.3, n = 94 of 108).

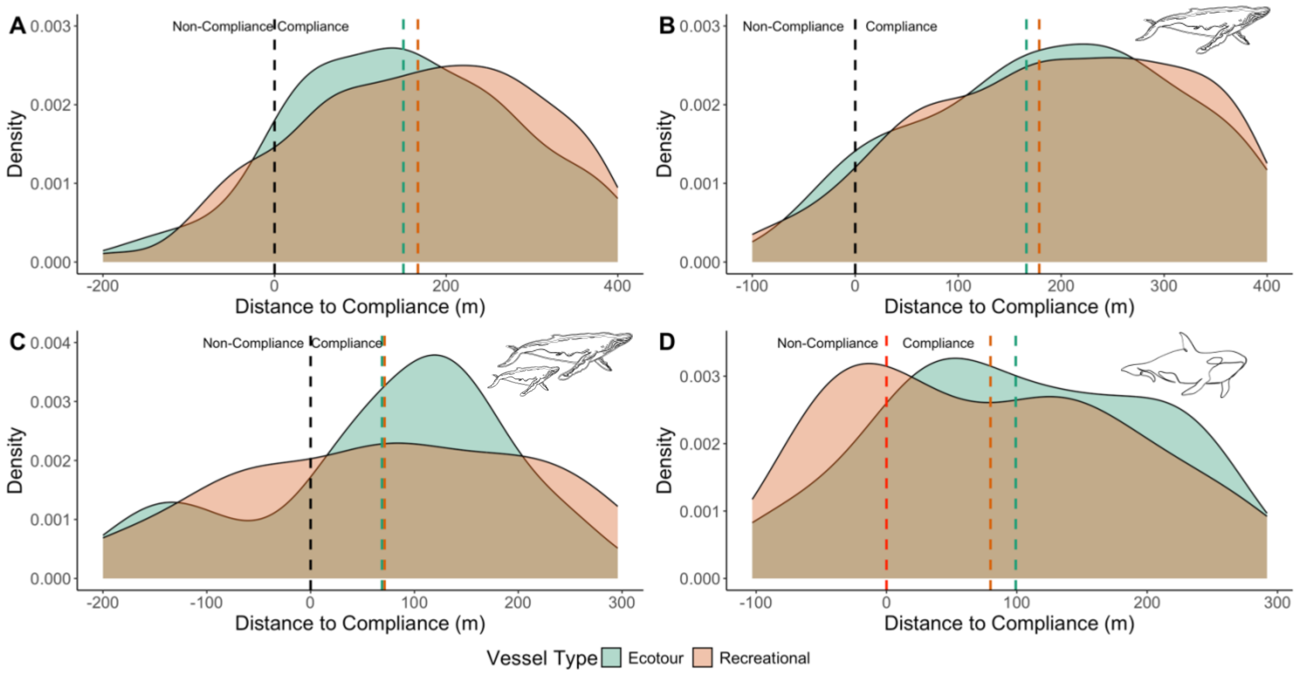

Figure 2. ***A)*** *Distance to compliance with national Marine Mammal Regulations (MMR) by ecotour and recreational vessels around killer whales and humpback whales;* ***B)*** *around humpback whales;* ***C****) around humpback whales that are resting and with a calf; and* ***D)*** *killer whales. The black dashed line denotes the MMR line, scaled for the minimum avoidance distance required in the presence of each species (100m for humpback whales; 200m for resting humpback and/or humpback with calf, and 200m for killer whales). Coloured lines denote the mean distance of recreational (blue) and ecotour (yellow) vessels.*

Modelling Approach

Vessel Distance to Whale

The top model from the 2023 focal scans (n = 300 vessel-whale encounters) explained 9% of the variation in the data, revealing that the median number of vessels present in a scan, the time each vessel spends with a whale and the vessel type influenced the vessel distance to a whale (Table 2; Figure 3A). Vessel distance increased by 7% as the median number of vessels within 1km of the focal whale increased by one (Figure 3A). There was a negative association between vessel time with a whale and vessel distance. Vessel distance decreased by 13.5% with every additional 10 minutes a vessel spent around a whale (Figure 3C). Finally, we observed that vessels travelling at fast or slow/medium speeds were significantly farther away than idle vessels. Specifically, fast vessels were predicted to be 89.3m ($\hat{y}$: 441.6; CI: 380.5m – 512.6m) farther than idle vessels, whereas vessels travelling at a slow/medium speed were 61m ($\hat{y}$: 423.14; CI: 372.1m – 479.9m) farther from a whale than idle vessels ($\hat{y}$: 362.3 ; CI: 324.2–404.9; Figure 3D).

All three predictor variables had a similar influence on vessel distance to a whale, with the average number of vessels and the time with a whale being 1.5x more important (RVI = 0.09, 0.08, respectively; Figure 3A) than the vessel speed (RVI = 0.06; Figure 3A).

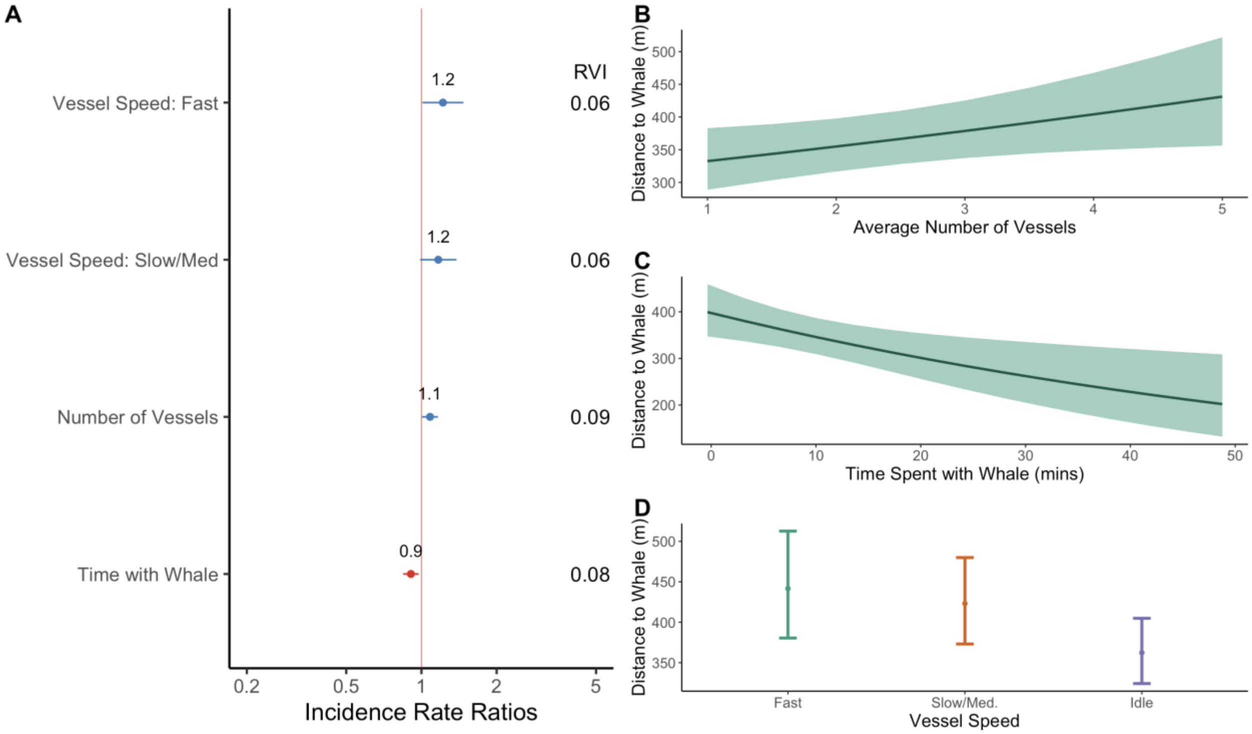

Figure 3. Focal scan top model predicting vessel distance to a whale: ***A)*** *parameter coefficients, and CIs for fixed effects. Dots represent the magnitude of effect on vessel distance, and the lines span 95% CI. Relative Variable Importance (RVI) shown on the right for each fixed effect;* ***B)*** *predicted vessel distance to whale as a function of the median number of vessels within 1km of a whale during a focal scan;* ***C)*** *predicted vessel distance to whale as a function of the time with a whale observed during the focal scan;* ***D)*** *predicted vessel distance to whale as a function of vessel speed during the focal scan. Shaded regions or coloured error bars in* ***B)*** *to* ***D)*** *represent 95% CIs, and the lines represent model predictions.*

Table 2. Ranked candidate set model predicting vessel distance to whale for 2023 focal scans (ΔAIC <4). The top model is indicated in italics, with corresponding delta AIC scores on the right. Full candidate set model in supplementary materials.

Model	**Δ AIC**
Vessel Speed + Number of Vessels + Time with Whale	0.0
Vessel Type + Vessel Speed + Number of Vessels + Time with Whale + Radio Communication	2.7
Vessel Type + Number of Vessels + Time with Whale + Ecotour Presence	2.8
Number of Vessels + Time with Whale + Ecotour Presence	3.3

Number of Vessels

Overall, the top model explained ~25% of the variation in the data (n = 300 vessel-whale encounters), with the fixed effects alone accounting for 7% of the variation in the number of vessels. The top model revealed that radio communication and study site influenced the number of vessels within 800m of a whale (Table 3, Figure 4). There was an average of 1.4x ($\hat{y}$: 3.1; CI: 2.3 – 4.2) more vessels within this distance when there was radio communication about the focal whale or other whales in the sampling area (Figure 3C). Finally, we observed more vessels within 800 m of whales at some study sites than others. Donegal Head had on average 1.6x ($\hat{y}$: 2.3; CI: 1.9 – 2.7) more vessels than Blackney Pass ($\hat{y}$:1.4 ; CI: 1.2– 1.8; Figure 4D). Blackfish Sound had on average 1.5x ($\hat{y}$: 2.1; CI: 1.6 – 2.8) more vessels than Blackney Pass (Figure 4D). Radio communication was 1.6x more important (RVI = 0.08; Figure 3A) than the study site (RVI = 0.05; Figure 4A).

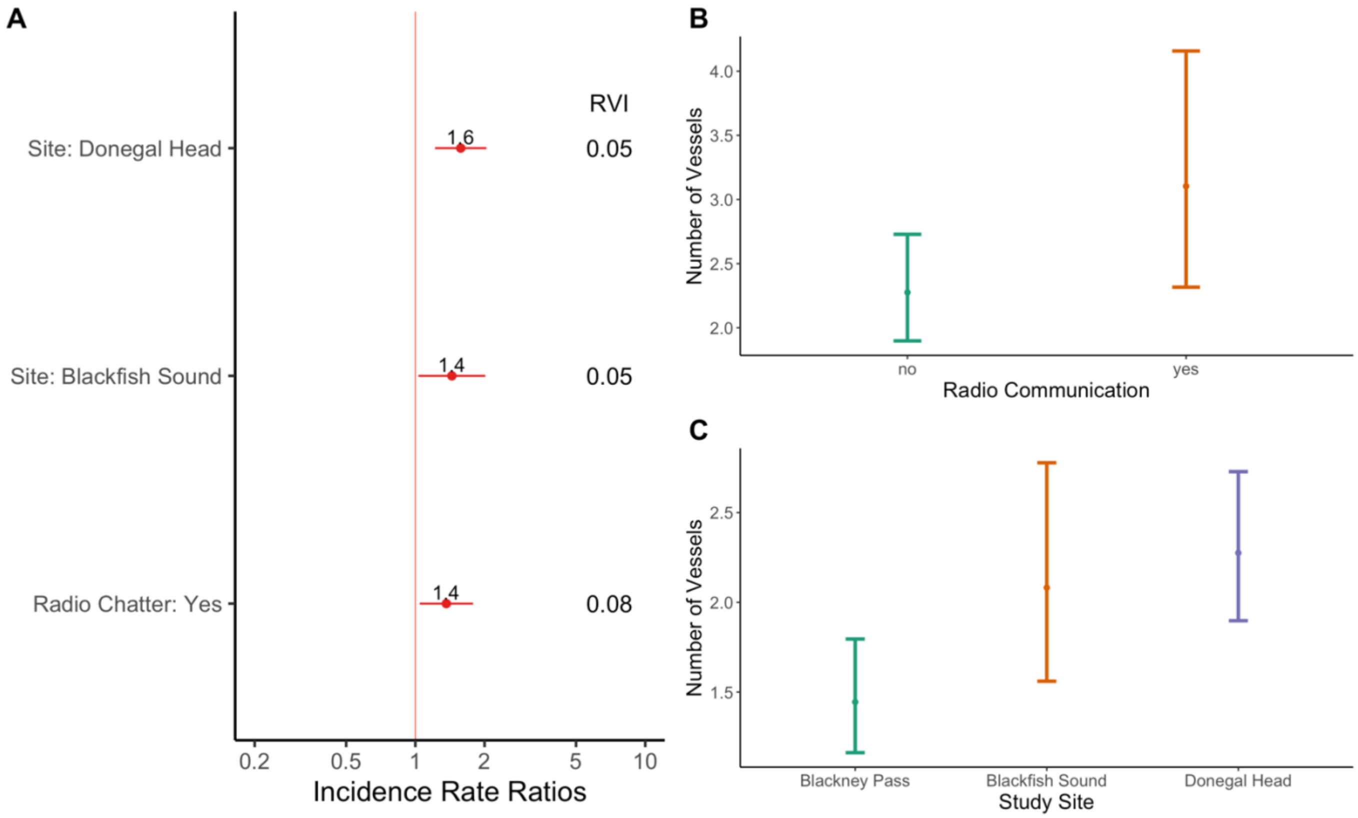

*Figure 4***.** *Focal scan top model predicting the number of vessels within 800m of a whale as response:* ***A)*** *parameter coefficients, and CIs for fixed effects. Dots represent the magnitude of effect on the number of vessels, and the lines span 95% CI. Relative Variable Importance (RVI) shown on the right for each fixed effect;* ***B)*** *predicted number of vessels as a function of a whale's behaviour state during a scan;* ***C)*** *predicted number of vessels as a function of radio communication about the focal whale during a scan. Coloured error bars in* ***B)*** *and* ***C)*** *represent 95% CIs, and the dots represent model predictions.*

Table 3. Ranked candidate set model for 2023 focal scans (Δ AIC < 4). The top model is indicated in italics, with corresponding delta AIC scores on the right. Full candidate set model found in supplementary materials.

Model	**Δ AIC**
Study Site + Radio Communication	0.0
Study Site + Radio Communication + Vessel Type	2.0
Study Site + Vessel Type + Ecotour Presence	3.3

Time with Whale

Overall, the top model explained ~37% of the variation in the data (n = 300), with the fixed effects alone accounting for 23% of the variation in the time a vessel spent with a whale. The top model revealed that the vessel speed and vessel distance to the whale influenced the time vessels spent with a whale (Table 4, Figure 5). Idle vessels spent 2.2x ($\hat{y}$ = 7.0; CI: 6.0 – 8.2) more time with a whale than vessels that were travelling fast ($\hat{y}$ = 3.2; CI: 2.6 – 3.9; Figure 5B). Vessels travelling at slow/medium speeds spent ~1.9x ($\hat{y}$= 6.0; CI: 5.0 – 7.2) more time within 800m of a whale than fast vessels (Figure 5B). We observed a negative association between the vessel distance to a whale and the time vessels spent with a whale. Every 50m increase in the vessel distance to the whale revealed a ~5% decrease in the time that they spent with the whale (Figure 5D).

A vessel’s distance to a whale and the vessel speed had similar effects on the time a vessel spent around a whale, with vessel speed being ~1.2x more important (RVI = 0.17) than distance to a whale (RVI = 0.14; Figure 5A).

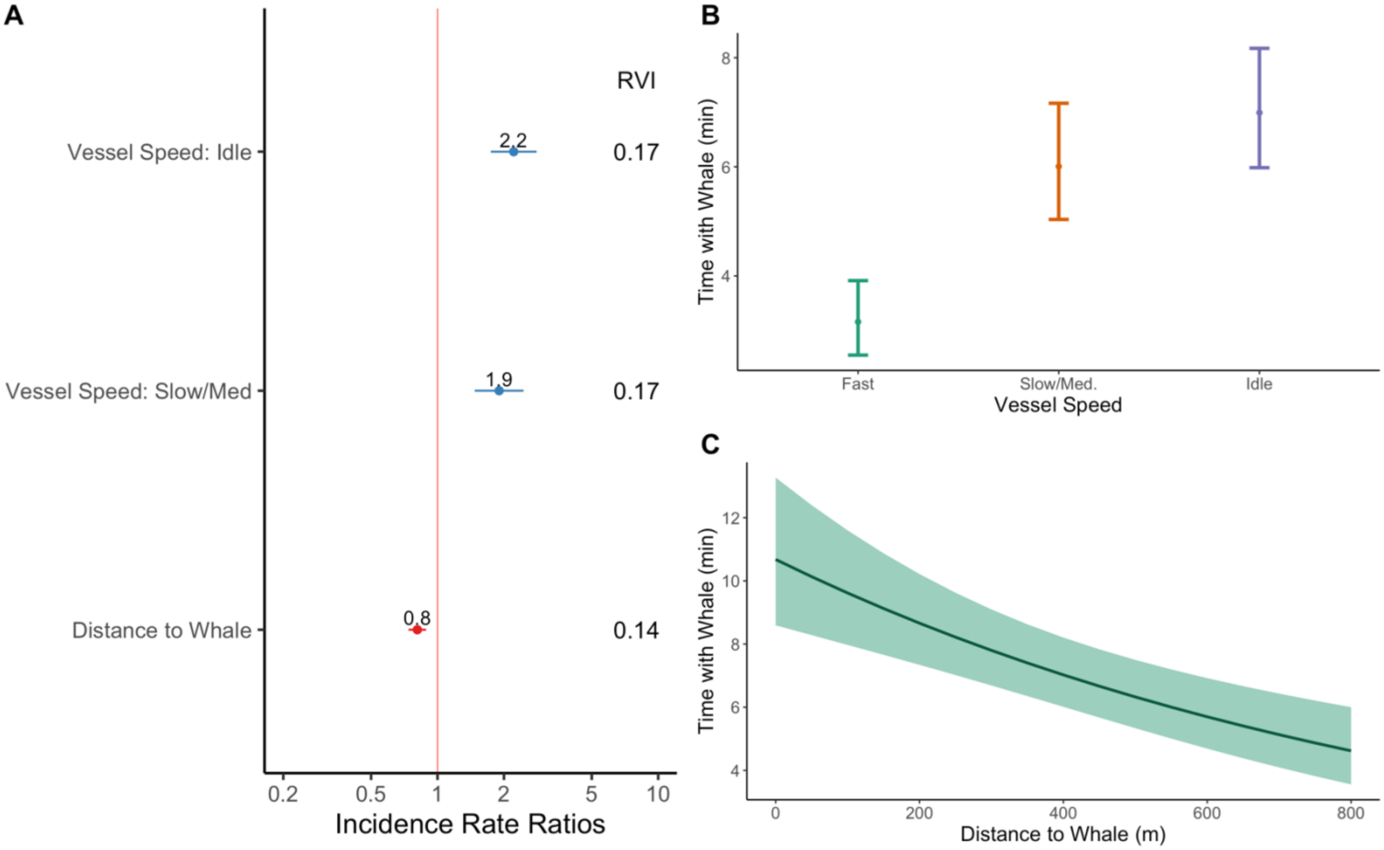

Figure 5. Focal scan top model predicting the time a vessel spends within 1km of a whale as the response: ***A)*** *parameter coefficients, and CIs for fixed effects. Dots represent the magnitude of effect on the number of vessels, and the lines span 95% CI. Relative Variable Importance (RVI) shown on the right for each fixed effect;* ***B)*** *predicted time with whale as a function of the vessel speed during a scan;* ***C)*** *predicted time with whale as a function of the vessel's distance to the whale during a scan; Coloured error bars in* ***B)*** *and* ***C)*** *represent 95% CIs, and the dots represent model predictions.*

*Table 4***.** *Ranked candidate set model for 2023 focal scans (AIC < 4). The top model is indicated in italics, with corresponding delta AIC scores on the right. Full candidate set model found in supplementary materials.*

Model	**AIC Score**
Vessel Speed + Distance to Whale	0.0
Vessel Speed + Distance to Whale + Vessel Type	2.0

Interactions Included Post-Analysis

We included interaction terms post-analysis to consider sentinel or magnet effects that may occur with the presence of ecotour vessels. Most interaction terms occurred in models that were not competitive with the original top models (Table S4, Table S6). In contrast, an interaction between ecotour presence and vessel distance to a whale was added to the time spent with a whale model set and had a AICc score of 1.6 (Table S8). Neither ecotour presence as a fixed variable alone nor its interaction with vessel distance, however, were significant within the model (Figure S5A).

Discussion

Our results revealed complex patterns in whale-vessel interactions. We found that compliance with national minimum avoidance distance regulations was relatively high at ~88%, and varied significantly with the type of species, and type of regulation. Additionally, compliance in Northeast Vancouver Island was found to be higher than in the Salish Sea (Fraser et al., 2020). By measuring several vessel behaviours, we found support for our predictions of normative social influence, and that normative-based processes appeared to strongly influence vessel behaviour to increase well beyond the minimum legal requirements. When the median number of vessels within a scan was higher, we observed pro-environmental behaviour in which vessels were farther away from the focal whale. On the other hand, we observed that if there was radio communication about the focal whale, the median number of vessels around the whale was higher compared with contexts in which there was no radio communication. Collectively, such patterns suggest that, although recent literature has emphasized how social influence can foster poor environmental behaviour, including non-compliance with regulations (Roy 2021; Arlidge et al., 2023), social influence can also support pro-environmental behaviour, even beyond legal compliance. We found conflicting support for our hypothesis that context-specific variables would influence compliance and general vessel behaviour. When assessing compliance rates, there were significant differences in response to different species. However, when examining further vessel behaviours (and distances beyond legal compliance), we did not detect effects related to vessel types, species, species behaviour, or group composition (calf presence/absence). As we detail below, insights from this work can inform education and management.

Limitations and Caveats

We acknowledge several limitations. For example, owing to the inclusion of more variables after a pilot year of data collection, we used only the 2023 data for our primary analyses. A comprehensive analysis, however, which includes both years and variables common to both, shows similar patterns (Appendix C). Additionally, we note that Northern Resident killer whale sightings in the Johnstone Strait region were abnormally low during our study, which likely explains the modest sample size of scans with killer whales (n = 31 scans in 475 sampling hours; systematic timed and focal scans), thereby limiting our inference into vessel-killer whale interactions (83 of 664 vessel-whale encounters within 800m). Third, we did not account for when a whale approaches closer to the vessel, rather than a vessel approaching a whale, particularly for idle vessels. As we were measuring the closest distance between a vessel and a whale, we did not incorporate distance over time within an encounter. We suggest further research can be completed by examining interactions between vessels and whales throughout an encounter.

Additionally, we acknowledge that our metric of radio communication does not incorporate all forms of on-the-water communication, which can also originate from other radio channels, designated cell phone applications and personal texts. Our metric of radio communication using the channel that is used by the local whale-watching community to communicate about whale sightings and marine mammal issues was readily and publicly available and is used as vessels are out on the water. As our focal scans were centred around an individual whale, we also recognized there may be a lagging effect in radio communication. For example, suppose there was radio communication present in one focal scan, and we began another scan 10 minutes later with a different focal whale. In that case, vessels may have continued to respond to the original radio communication without subsequent calls.

Our additional analyses generally failed to provide new inferences. Specifically, with distance to whale and number of vessels response variables, no additional models were competitive enough to consider interactions between ecotour presence and the number of vessels, along with radio communication and whale behaviour. With the time spent with a whale response variable, however, we considered a competitive model (dAIC = 1.6, Table S8) but inspection of coefficients suggested no significant associations between ecotour presence alone or its interaction with distance with the time vessels spend with a whale (Figure S5A). Thus, we retained our preference for inference from the top model (i.e., lowest AICc score was selected as the top-performing model; Figure 5). This interaction indicated that ecotour presence may have some influence for the time that other vessels spend with a whale, but the evidence is limited. The relationship shows that when vessels are closer and there is an ecotour vessel present, vessels may spend more time with a whale, suggesting a potential magnet effect (Figure S5B). This interaction term requires further consideration and be included in subsequent research.

Finally, our analysis assumed that boaters at the scale of observation (800m) were aware of whales and other vessels. We consider this assumption reasonable, given that basic vessel operation requires such observational abilities. Also, several visible reminders (e.g., signs or postings at marinas, wharves, online) alert boaters to slow down and be vigilant for whales within 1km, and to stay aware of other vessels in the area (Be Whale Wise, 2024; Government of Canada, 2023).

Compliance in the region

With these limitations in mind, our assessment of compliance with minimum distance regulations revealed differences between species and results found in past studies. Compared to a compliance assessment completed in 2018 and 2019 in the Salish Sea (Fraser et al., 2020), the overall compliance rates were moderately higher in our Northeast Vancouver Island study area (88% compared to 79%; Figure 1). When we considered the regulation specifying a 200 m minimum avoidance distance for humpback whales that are resting or with a calf, we found higher levels of non-compliance compared to the 100 m avoidance distance, specifically among recreational vessels (Figure 1). In our study region, vessels were also less compliant around killer whales than humpback whales (Figure 1), a pattern also observed in the Salish Sea (Fraser et al., 2020). Despite killer whales being a focal species for conservation, management and education, almost 25% of encounters were non-compliant across both recreational and ecotour vessel types in our study. Finally, although Fraser et al. (2020) found that ecotour boats showed higher compliance than recreational boats, we did not observe differences between vessel types, but higher compliance among both. Past studies have suggested that commercial ecotour companies may be more likely to comply with regulations, owing to the reality that they economically benefit from healthy whale populations, whereas recreational vessels do not, and may be less aware of the regulations (Fraser et al., 2020; Seely et al., 2017). However, with our findings, recreational boaters are found to be as compliant as ecotour vessels, suggesting more public awareness of regulations. There are distinct regional differences between Northeast Vancouver Island and the Salish Sea, namely, regulatory complexity. There is considerably higher vessel density in the Salish Sea (Fraser et al., 2020; Seely et al., 2017), and the area is subject to additional distance laws and speed restriction zones, with minimum avoidance distances changing when entering the United States (Fisheries and Oceans Canada, 2024a, Washington Department of Fish and Wildlife, 2024). These factors may explain why compliance is lower in the Salish Sea. We observed this association between increased regulatory complexity (legitimacy-based process) and lower compliance rates as recreational boaters exhibited lower compliance to the regulation specifying a 200 m minimum avoidance distance from Humpbacks that are resting or have a calf. Past studies have illuminated this association in complex, evolving regulations where public confusion is common (Roy, 2021; Weaver, 2013; Williams, 2009).

There are trade-offs in considering the simplest (and most conservative, i.e. largest and uniform distance to each species) regulatory framework. On one hand, a uniform distance would reduce public confusion and be the most cautious form of management. On the other hand, should the possibility that such longer distance (400 or 1000m) be biologically unrealistic, such a regulation would unnecessarily restrict the abilities of ecotour and other vessels from viewing whales at closer distances, which has been found increase enjoyment, education and conservation efforts when done ethically (De la Cruz-Modino & Cosentino, 2022; Stamation et al., 2007; Tkaczynski et al., 2022). There is a delicate balance in considering biological relevance to different species, possible limitations for vessel operators, and managing public confusion with complex regulations. Further research on compliance and more conservative or complex regulations around sensitive wildlife needs to be considered.

Distribution of vessels under theoretical regulatory frameworks

We also examined how observed distances would interact with a suite of theoretical minimum avoidance distance thresholds. For instance, we observed that 26% of vessels were within 200 m of humpback whales under current regulations. If a minimum avoidance distance of 200 meters for humpback whales under all states (i.e., without calf or showing any specific behaviours) were introduced, this illustrates how much boater behaviour would need to be altered if the regulations changed. Regulatory changes are ultimately at the discretion of policymakers but need insight provided by evidence-based research (Sutherland et al., 2004; Adams & Sandbrook, 2013; Christie et al., 2021; Sabo et al., 2024). We note that previous studies have shown that humpback whale behaviour is significantly altered well beyond the current 100 m threshold, up to 400 m (Currie et al., 2021).

Killer whales are known to be sensitive to disturbance (Williams et al., 2014; Stredulinsky et al., 2023; Murray et al., 2021; Williams et al., 2006). Our study found that 25% of boaters within 500 m of killer whales are within a 200 m threshold. A previous study has noted that Northern Resident killer whale (NRKW) behaviour can be altered from boats up to 400 m away, and if there are more vessels within a 400 m radius of the focal whale (Williams &

Ashe, 2006). Recent studies have shown lower prey capture rates and sex-linked behavioural differences in Southern Resident killer whales when vessels were an average distance of 366 m from a whale (Holt, 2021a; Holt 2021b). We also assessed how the observed distribution of distances compared with a theoretical regulation that matches the Interim management measures to protect Southern Resident killer whales in the Salish Sea (400m; Fisheries and Oceans Canada, 2024a). We observed that under current regulations (and considering vessel-whales encounters up to 500 m), 80% of vessels were within 400 m of killer whales in Northeast Vancouver Island. Additionally, Washington State will implement a 1000-yard (~1000 m) vessel exclusion zone between boats and Southern Resident killer whales in January 2025. (Washington Department of Fish and Wildlife, 2024). To determine distributions of vessels within 1000 m, we included vessel interactions of up to 2000 m and found that 81% of vessels were within 1000 m. As with Humpback scenarios, these distributions provide insight into what whales encounter within various distance buffers and illustrate how much boater behaviour would need to change if the regulatory landscape shifted.

Modelling Approach

Our modelling approach identified support for our prediction that vessel behaviour was influenced by the presence of other boaters, though the relationships through which this occurred were not fully anticipated. In addition, we found that with already high compliance rates, social norms influenced pro-environmental behaviour beyond the legal requirements. For example, we observed that vessels tended to maintain a greater distance from whales when more vessels were present. This pattern suggests a potential pro-environmental behaviour; we infer that boaters may be unwilling to approach whales closely when others may be observing their behaviour. Regardless of the reason, vessels maintaining a greater distance from whales can mitigate disturbances, for example, by reducing the risk of vessel strikes (Fraser et al., 2020) and minimizing noise (Stamation et al., 2010; Williams et al., 2002). Additionally, we found that idle vessels were closer to whales compared to those moving at fast or slow/medium speeds, which could also reflect pro-environmental behaviour, as vessels are expected to be idle near whales to avoid disturbance. Alternatively, this could reflect that slow/medium and fast vessels may be transiting through the area and are not viewing whales. Small, slow vessels pose perhaps the least risk to whales for noise disturbance (Lo et al., 2022) and vessel strikes (Redfern et al., 2024).

In contrast to pro-environmental behaviour, we also observed evidence that social influence can lead to a complex trade-off between awareness and increased disturbance to whales. Specifically, when there was radio communication about a whale during the scan, the number of vessels in the area tended to be higher. This pattern suggests that boaters are more likely to congregate in an area if they know a whale is present, elevating the levels of noise and potential disturbance experienced by the whale (Kessler & Harcourt, 2013). We note that the presence of radio communication might also be linked with the distance to a whale, given the observed relationship between the number of vessels (as a predictor) and distance (as a response) in a separate model. If this is the case, the effect of radio communication in terms of vessel number might be mitigated by a greater average distance between whales and boats. However, we are unable to infer causal relationships between radio communication and distance, as our three models (i.e. vessel behaviours) are independent of each other. We suggest further research be completed on the complex trade-offs being presented by common methods of communication such as VHF radio.

Finally, our results indicate that vessels, regardless of type, tend to get closer to the whale at some point if they spend more time observing it. This suggests that any social influence to maintain distance, which is positively mediated by the number of boats, might diminish the longer the interaction continues. In other words, social influence might be most pronounced during shorter interactions. Regardless of distance, vessels that spend more time with a whale may contribute to disturbance by eliciting changes in behaviour (Scarpaci et al., 2003), and increasing ambient noise (Lo et al., 2022).

Generally, our findings also suggest that the mere presence of others, regardless of their user group (i.e., vessel type), can promote pro-environmental actions. Previous research indicated that observing the non-compliance of others can prompt similar non-compliant behaviour (Arlidge et al., 2023). Arlidge et al. (2023) proposed that SSI is 'weakest' (focusing on influencing non-compliant behaviour) when an individual non-complier is observed by either a single researcher or a group. Our study now shows the opposite can also be true, where individual boaters may model pro-environmental behaviour and encourage similar behaviour. This aligns with general compliance literature, which shows that observing even a single individual's actions in uncertain situations can prompt others to imitate their behaviour (Roy, 2021; Gilovich, 1991; Loewenstein, 2001). These insights have significant implications for educational and management strategies.

Normative-based and simpler legitimacy-based processes shaping boater behaviour may be a valuable tool on the coast of British Columbia. Recent survey-based work has suggested this (Damato, 2024), and our study has illuminated the importance of social dynamics on the water through quantitative behavioural assessment. While regulatory strategies aim to reduce environmentally harmful behaviours through rules and laws (legitimacy-based processes), their effectiveness hinges on public awareness and understanding. We can see that in areas with more complex regulations (i.e. the Salish Sea), there is lower compliance present, particularly among recreational boaters. Additionally, social influence can be seen to affect behaviours that are not regulated (i.e. no legitimacy-based motivations present). This highlights the continued need for increased education on best practices and regulations to promote pro-environmental behaviour among boaters (Damato, 2024; Fraser et al., 2020; Seely et al., 2017). For example, our study showed that radio communication about a whale was associated with more vessels within 800m of the whale, suggesting that real-time communication could be an effective educational tool. The Cetus Research and Conservation Society and the Marine Education and Research Society can provide functional examples of using on-the-water education to modify and encourage pro-environmental behaviour for boaters exhibiting negative behaviours (Bent, 2022; Cetus Research and Conservation Society, n.d.; Marine Education and Research Society, 2023). Additional measures could include promoting educational materials that emphasize social influence. This might involve prompts encouraging boaters to adopt pro-environmental behaviours, and to model positive behaviour, inspiring others to do the same. Instilling a sense of responsibility in boaters has been associated with a greater willingness to act in a pro-environmental manner (Gifford & Nilsson, 2014). Consequently, a shift in culture and beliefs about acceptable behaviour in a community can be a powerful driver of behavioural change (Gifford & Nilsson, 2014). We propose that leveraging normative-based processes can strengthen regulatory frameworks and foster more sustainable boating practices.

Our results did not support the prediction that context-specific factors, or a combination of social and context-specific factors, would be associated with vessels being closer to whales, a higher number of vessels, or vessels spending more time around whales. Vessel type, species,

species' behaviour, and calf presence had no impact on any of our model results. This contrasts with our compliance analysis, which showed significant differences in boater responses to killer whales and Humpbacks. This suggests that species may influence compliance-related decision-making, but additional pro-environmental behaviours are observed due to social factors, particularly amongst behaviours where regulations are not present (number of vessels, time spent with a whale). Of note, past studies have suggested that the presence of ecotour vessels can model pro-environmental behaviour around whales, coined "the sentinel effect" (Kessler & Harcourt, 2013; Shields, 2022). Our findings indicate that the presence of any vessel is more important than the specific vessel type to influence the distance to a whale. We did include ecotour presence in our candidate model sets, but additional research should be completed on whether compliance of recreational vessels changes with ecotour presence/absence.

Education and Management Suggestions

Consistent with Fraser et al. (2020), we found minimal evidence of enforcement activity. Government agency vessels were observed only 5 times over 66 sampling days (475 sampling hours). This limited enforcement presence may signal to boaters that there are few consequences for noncompliance (Fraser et al., 2020). As such, increasing the presence of government or enforcement agency vessels may increase compliance rates.

The Marine Mammal Regulations rely heavily on boaters' knowledge about species, their behavior, whether a calf is present, coastal regions, and on their ability to estimate distances on the water. For example, boaters must maintain a 100 m distance from Humpback whales, but this distance increases to 200 m if the whale has a calf or is resting (Government of Canada, 2018). We found that while vessels largely complied with the 100-meter regulation for Humpback whales, adherence to the 200-meter requirement was lower, particularly among recreational boaters (Figure 2). The complexity of having different distance requirements for the same species and different regulations for different species can lead to confusion, especially among recreational boaters who may not be familiar with marine mammal identification and their behaviours. This is highlighted in areas with even more complex regulations, such as the Salish Sea (Fraser et al., 2020; Seely et al., 2017). Accordingly, we recommend, as others have, that regulations be standardized to a single distance for each species, potentially across coastal regions (Fraser et al., 2020), however, this needs to be carefully considered to account for biological relevance and need for each species.

Our observations shed light on factors influencing behaviours around whales beyond proximity to whales. We found, for example, that both the number of vessels and the time spent with a whale can influence how closely vessels approach whales (Figures 2B and C). As such, a broader policy should take these boater behaviours into account. Moreover, given our finding that marine radios can influence boater behaviour, (i.e., more boats, but potentially farther away; Figure 3B), we reason that they can be harnessed for pro-environmental behaviour. For example, encouraging organizations centred on conservation and education programming (e.g. Cetus Research and Conservation Society and the Marine Education and Research Society) should continue to use public chat channels to address and report disruptive behaviours by others. Protocols for doing so, however, need to be carefully developed. Additionally, we suggest that leveraging social influence and focusing on education - by encouraging boaters to model pro-environmental behaviour and share their knowledge - may have positive effects beyond their immediate recipients.

Chapter Three: Conclusion

Our study revealed a high rate of compliance to minimum avoidance distances specified in national Marine Mammal Regulations among both ecotour and recreational boaters in Northeast Vancouver Island. We found that compliance exceeds the minimum requirements and is more likely to do so under conditions of normative social influence. To assess regional compliance and the underlying patterns, we first observed vessel behaviours and then conducted a multivariate modelling approach on three distinct metrics of vessel behaviours. We found that species and regulatory complexity were important to compliance rates. However, social factors - such as radio communication, number of vessels around a whale and vessel speed - are important predictors for vessels beyond the regulated distance, and for behaviours that are not currently regulated. With this knowledge, researchers can expand on these findings to elucidate the trade-offs present in these complex and connected behaviours.

Our study also highlights an aspect of situational social influence that emphasizes the positive effect of pro-environmental behaviour. Arlidge et al. (2023) found that witnessing non-compliance can lead to bystanders acting in non-compliance, whereas alternatively we found that the presence of others around a boater can lead to behaviours associated with higher compliance, such as vessels staying farther away from a whale. Although similar findings have been found in other disciplines such as waste management and illegal harvest of resources (Cialdini et al., 1990; Walker et al., 2007); we suggest further research on the positive and spreading impacts of pro-environmental behaviour in human-wildlife encounters.

Within the broader context of social influence, both legitimacy and normative-based motivations can be leveraged for effective conservation of threatened species. Practically, this includes leveraging enforcement, education, and social responsibility within a community to mitigate human-caused threats. Overall, our findings provide insight into the complex relationships and patterns underlying human-wildlife interactions, as well as the role of different motivations in social theory aimed at conservation. Together, these findings contribute to the growing interdisciplinary body of social theory and conservation, which will critically inform effective environmental policy and management to protect threatened species and systems.

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Supplementary Materials

Appendix A.

Table S1. Classification of vessel types and criteria.

Final Categories	Field Classification	Description
Commercial Vessels	Commercial Vessels	1. Cruise Ships 2. Commercial Fishing Vessels 3. Cargo Shipping Vessels 4. Tugboats 5. Water Taxi Operators (no animal watching)
Ecotour Vessels	Ecotour	1. Commercial Whale Watching Vessels 2. Commercial Ecotour Vessels (e.g. nature tours, grizzly bear tours, etc.)
Recreational Vessels	Recreational Non-Fishing Vessels	1. Speed boats/small, motorized vessels 2. Yachts 3. Sailing Vessels

		4. Jet Skis
	Recreational Fishing Vessels	5. Any recreational vessel actively fishing or had clearly visible fishing gear

Table S2. Classification of killer whale and Humpback whale Behaviour States. Behaviour classified from local expertise and Lusseau et al. (2009).

Categories	
Travel	Rolling motion at the surface, regular breathing and relatively straightforward travel line
Resting	Sustained surfacing in contrast to rolling motion observed while travelling. • Do not progress or very slow through the water (i.e. resting line for killer whales and logging behaviour in Humpback whales)
Foraging	Characterized by milling, feeding, or direct pursuit of prey.

	• Northern Resident killer whales: Travelling in smaller subgroups; foraging in a directional manner; or milling where foraging involves frequent change of direction • Bigg’s (Transient) killer whales: Direct pursuit of marine mammals, splashing, frequent change of direction • HumpbackWhales: Milling with frequent dives; surface feeding behaviour (i.e; lunge feeding, trap feeding).
Surface Behaviour	Surface behaviour not associated with foraging (i.e., breaching, tail slaps, pectoral fin slaps, chin slaps, etc.)

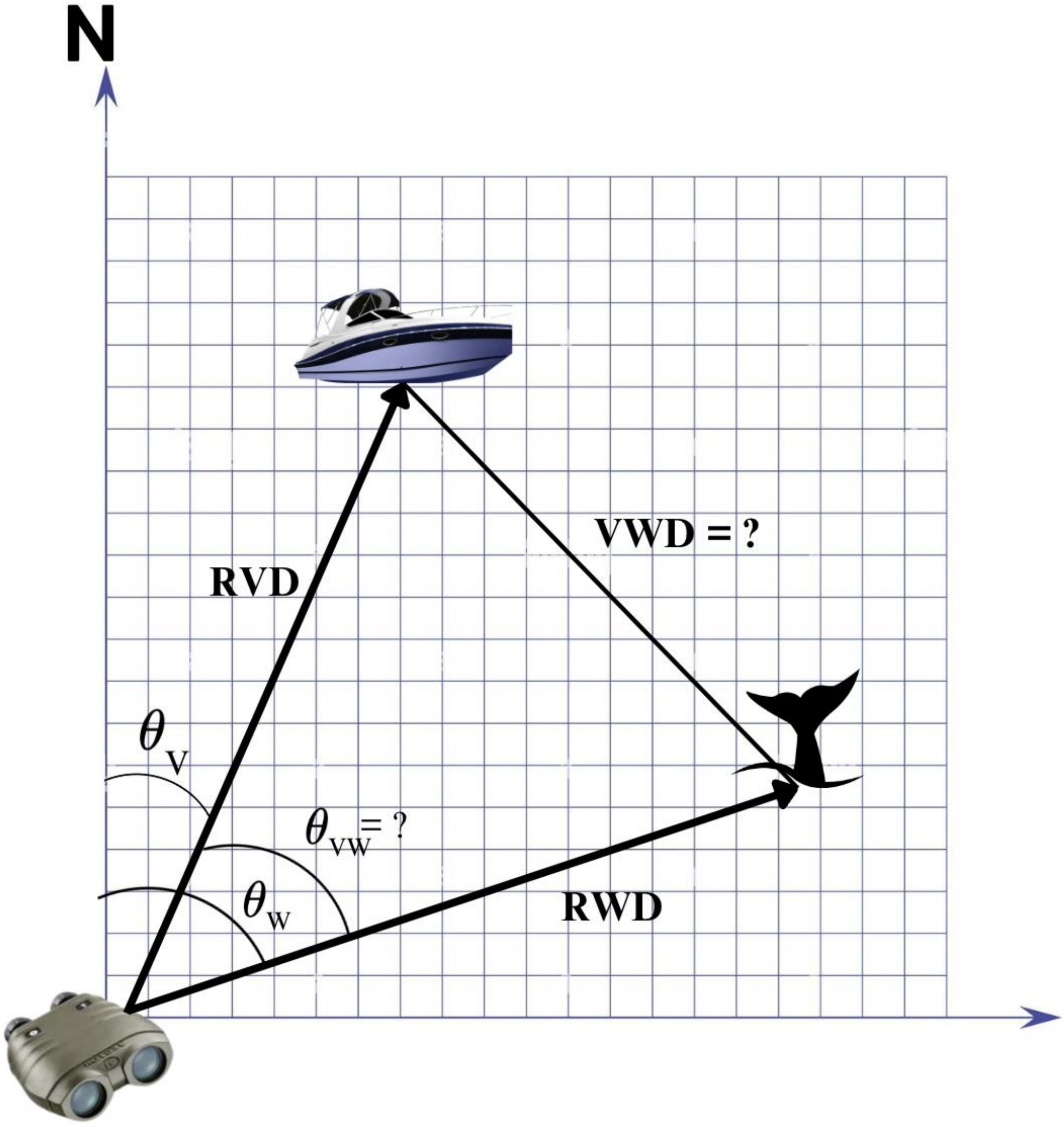

Figure S1. Visualization of calculating the bearing (Θ_{VW}) distance between the focal whale and the vessel (VWD) from the vessel bearing (Θ_V), whale bearing (Θ_W), the distance from researcher to vessel (RVD), and the distance from research to whale (RWD). Full equations in the Methods section.

Appendix B

Distance to Whale

Table S3. Candidate set model for 2023 focal scans (n = 25) with Distance to whale as response variable. All models have the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right. Vessel Type:Species denoted interaction term.

Null Model		**dsymbolAIC**
M1	1|focal scan number	20.9
Social Influence Factors		
M2	Vessel Speed + Number of Vessels	7.7
M3	Time with whale + Radio Communication	9.9
M5	Number of Vessels + Time with Whale + Ecotour Presence	4.9
M5	Vessel Speed + Time with Whale + Radio Communication	6.8
M6	*Vessel Speed + Number of Vessels + Time with Whale*	0.0
Context-Specific Factors		
M7	Vessel Type	18.7
M8	Species	22.1
M9	Species + Behaviour	22.3
M10	Species + Behaviour + Calf Present	23.8
M11	Vessel Type + Species + Whale Behaviour + Calf Present + Vessel Type:Species	19.7

M12	Vessel Type + Vessel Speed + Species + Whale Behaviour + Calf Present + Vessel Type:Species	15.1
Social Influence and Context-Specific Factors		
M13	Vessel Type + Ecotour Presence	9.8
M14	Vessel Type + Vessel Speed	12.0
M15	Number of Vessels + Vessel Speed + Vessel Type	7.9
M16	Number of Vessels+ Time with Whale + Vessel Type + Ecotour Presence	4.0
M17	Vessel Type + Vessel Speed + Number of Vessels + Time with Whale + Radio Communication	2.7
M18	Vessel Type + Species + Vessel Type:Species + Ecotour Presence	19.9
M19	Time with Whale + Radio Communication + Species + Behaviour + Calf Present	11.3
M20	Vessel Type + Time With Whale + Radio Communication + Species + Whale Behaviour + Calf Present + Vessel Type:Species	9.9
M21	Vessel Speed + Number of Vessels + Species + Whale Behaviour + Calf Present	13.2
M22	Vessel Speed + Time With Whale + Radio Communication + Species + Whale Behaviour + Calf Present	9.7
M23	Number of Vessels + Time with Whale + Radio Communication + Species + Behaviour + Calf Present	9.5
M24	Vessel Type + Number of Vessels + Species + Whale Behaviour + Calf Present + Vessel Type:Species + Ecotour Presence	12.8

Global Model		
M25	Vessel Type + Vessel Speed + Number of Vessels + Time with Whale + Radio Communication + Species + Whale Behaviour + Calf Present + Ecotour Presence + Vessel Type:Species	7.0

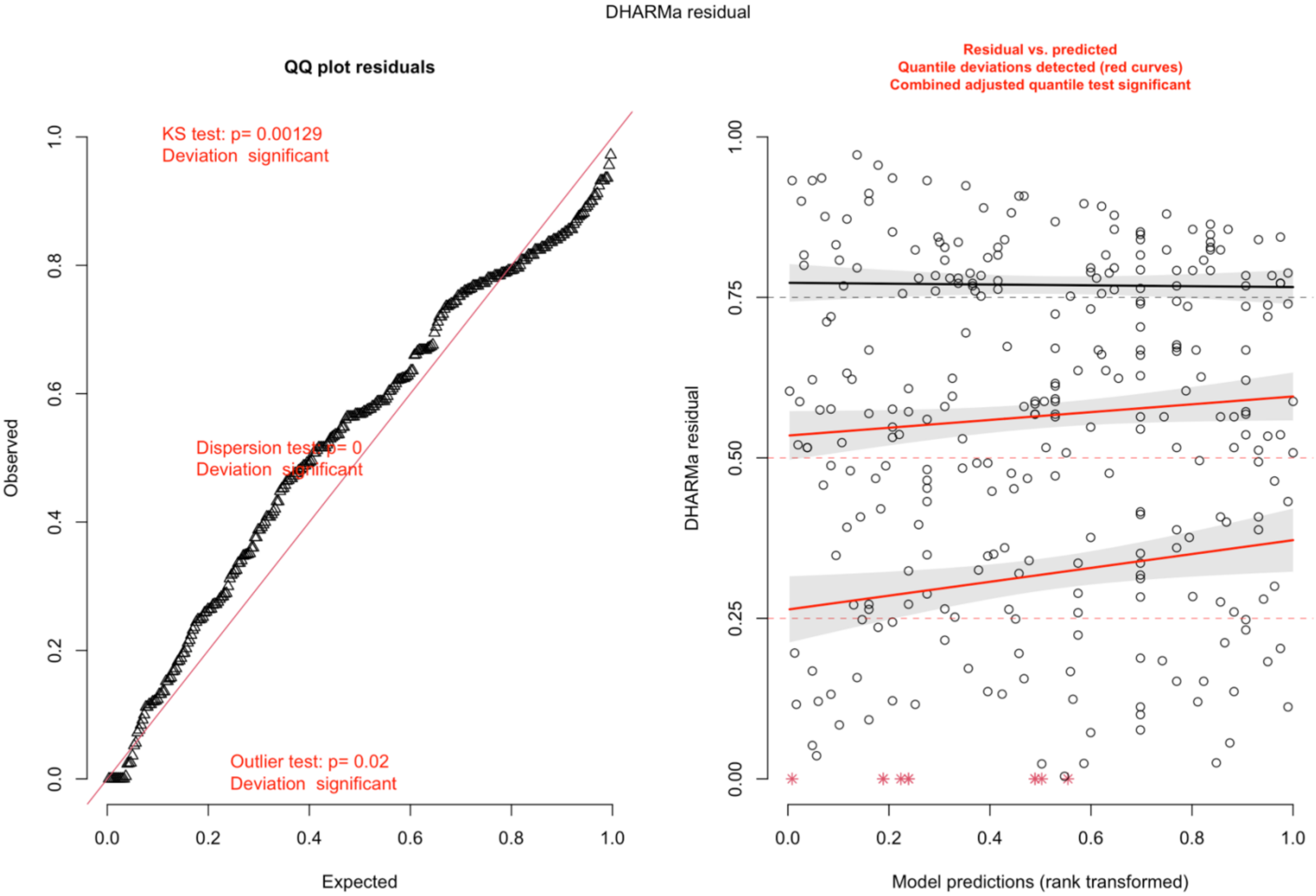

Figure S2. Model checking diagnostics for Distance to Whale model. The QQ plot displays a significant, but relatively small, deviation from expected values. Dispersion additionally checked with performance package, and showed no overdispersion, presenting conflicting results with DHARMa results. The residuals vs predicted plot shows deviations in two groups of residuals.

Table S4. Candidate set model for 2023 focal scans (n = 23) with Distance to Whale as the response variable, adjusted post-analysis with the inclusion of models that contain potentially important interactions. The new model (bold) was not competitive with the previously selected top model. All models include the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right.

Model	**Δ AIC**
Vessel Speed + Number of Vessels + Time with Whale	0.0
Vessel Type + Vessel Speed + Number of Vessels + Time with Whale + Radio Communication	2.7
Vessel Type + Number of Vessels + Time with Whale + Ecotour Presence	2.8
Number of Vessels + Time with Whale + Ecotour Presence	3.3
Number of Vessels + Time with Whale + Ecotour Presence + Number of Vessels*Ecotour Presence	**4.5**

Number of Vessels

Table S5. Candidate set model for 2023 focal scans (n = 22) with Number of Vessels as the response variable. All models have the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right. Vessel Type:Species denoted interaction term.

Null Model		**deltaAIC**
M1	1	7.5
Social Influence Factors		
M2	Time with Whale + Radio Communication	10.1

M3	Distance to Whale + Time with Whale + Ecotour Presence	12.7
Context-Specific Factors		
M4	Vessel Type	9.5
M5	Species	8.3
M6	Species + Whale Behaviour	11.0
Social Influence and Context-Specific Factors		
M7	*Site + Radio Communication*	*0.0*
M8	Vessel Type + Site + Ecotour Presence	3.3
M9	Vessel Type + Site + Radio Communication	2.0
M10	Site + Radio Communication + Whale Behaviour	4.3
M11	Vessel Type + Site + Distance to Whale + Time with Whale	8.5
M12	Vessel Type + Site + Distance to Whale + Vessel Speed	8.7
M13	Vessel Type + Distance to Whale + Radio Communication + Time with Whale	13.6
M14	Time with Whale + Radio Communication + Species + Whale Behaviour	13.7
M15	Vessel Type + Species + Vessel Type:Species + Ecotour Presence	13.6
M16	Vessel Speed + Radio Communication + Site + Whale Behaviour	7.2
M17	Vessel Type + Species + Whale Behaviour + Site + Ecotour Presence	9.7
M18	Vessel Speed + Distance to Whale + Species + Behaviour + Site + Ecotour Presence	12.1
M19	Vessel Type + Vessel Speed + Species + Behaviour + Vessel Type:Species + Ecotour Presence	19.2

M20	Vessel Type + Time with Whale + Radio Communication + Species + Behaviour + Vessel Type:Species	17.4
M21	Vessel Speed + Time With Whale + Radio Communication + Species + Whale Behaviour + Site	10.9
Global Model		
M22	Vessel Type + Vessel Speed + Distance to Whale + Time with Whale + Site + Radio Communication + Ecotour Presence + Species + Behaviour + Vessel Type:Species	17.6

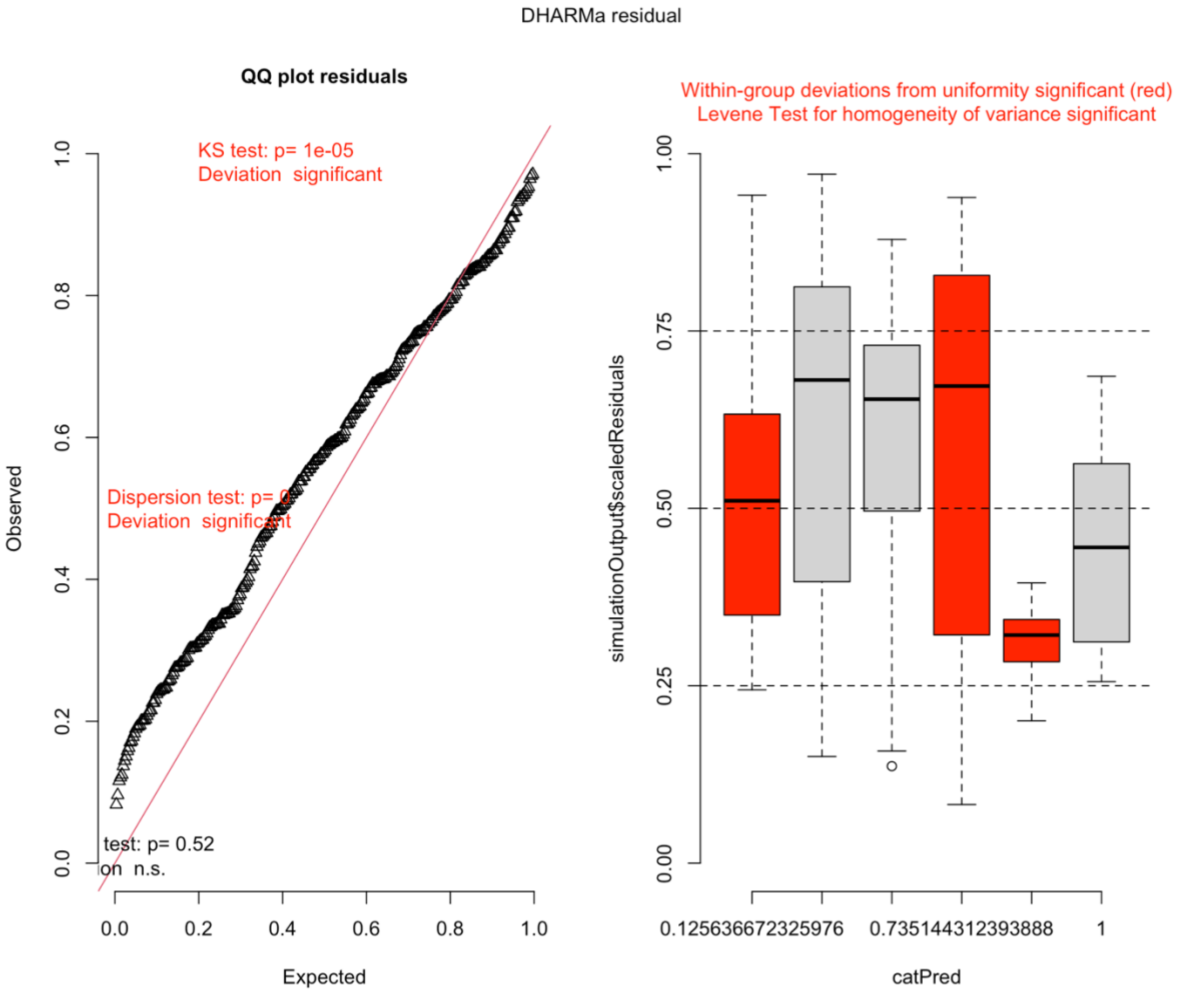

Figure S3. Number of Vessels model checking. The QQ plot displays a significant from expected values. Dispersion additionally checked with performance package, and showed no overdispersion, presenting conflicting results with DHARMa results. The residuals vs predicted plot shows deviations in three groups of residuals.

Table S6. Candidate set model for 2023 focal scans (n = 23) with Number of Vessels as the response variable, adjusted post-analysis with the inclusion of models that contain potentially important interactions. The new model included (bold) was not competitive with the previously selected top model. All models include the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right.

Model	**Δ AIC**
Study Site + Radio Communication	0.0
Study Site + Radio Communication + Vessel Type	2.0
Study Site + Vessel Type + Ecotour Presence	3.3
Study Site + Radio Communication + Vessel Type + Radio Communication*Whale Behaviour	**9.6**

Time with Whale

Table S7. Candidate set model for 2023 focal scans (n = 24) with Time with Whale as response variable. All models have the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right.

Null Model		**DAIC**
M1	1	65.3

Social Influence Factors		
M2	Number of Vessels + Radio Communication	66.1
M3	Distance to Whale + Number of Vessels	38.6
M4	*Vessel Speed + Distance to Whale*	*0.0*
M5	Vessel Speed + Number of Vessels + Radio Communication	20.5
Context-Specific Factors		
M6	Vessel Type	64.7
M7	Species	66.3
M8	Species + Whale Behaviour	66.8
M9	Vessel Type + Species + Whale Behaviour	65.2
Social Influence and Context-Specific Factors		
M10	Vessel Type + Number of Vessels + Ecotour Presence	67.4
M11	Vessel Type + Distance to Whale + Number of Vessels	39.8
M12	Vessel Type + Vessel Speed + Distance to Whale	2.0
M13	Vessel Speed + Radio Communication + Whale Behaviour	22.0
M14	Radio Communication + Whale Behaviour	63.1
M15	Vessel Type + Distance to Whale + Number of Vessels + Radio Communication	40.0
M16	Number of Vessels + Radio Communication + Species + Behaviour	66.6
M17	Vessel Type + Species + Vessel Type:Species + Ecotour Presence	69.1
M18	Vessel Type + Vessel Speed + Species + Whale Behaviour + Vessel Type:Species + Ecotour Presence	26.8

M19	Vessel Type + Number of Vessels + Species + Whale Behaviour + Vessel Type:Species	68.5
M20	Vessel Speed + Distance to Whale + Species + Whale Behaviour	5.4
M21	Vessel Speed + Number of Vessels + Radio Communication + Species + Whale Behaviour	25.1
M22	Distance to Whale + Number of Vessels + Radio Communication + Species + Whale Behaviour	41.1
M23	Vessel Type + Vessel Speed + Distance to Whale + Species + Whale Behaviour + Vessel Type:Species	9.3
Global Model		
M24	Vessel Type + Vessel Speed + Distance to Whale + Number of Vessels + Radio Communication + Ecotour Presence + Species + Whale Behaviour + Vessel Type:Species	12.5

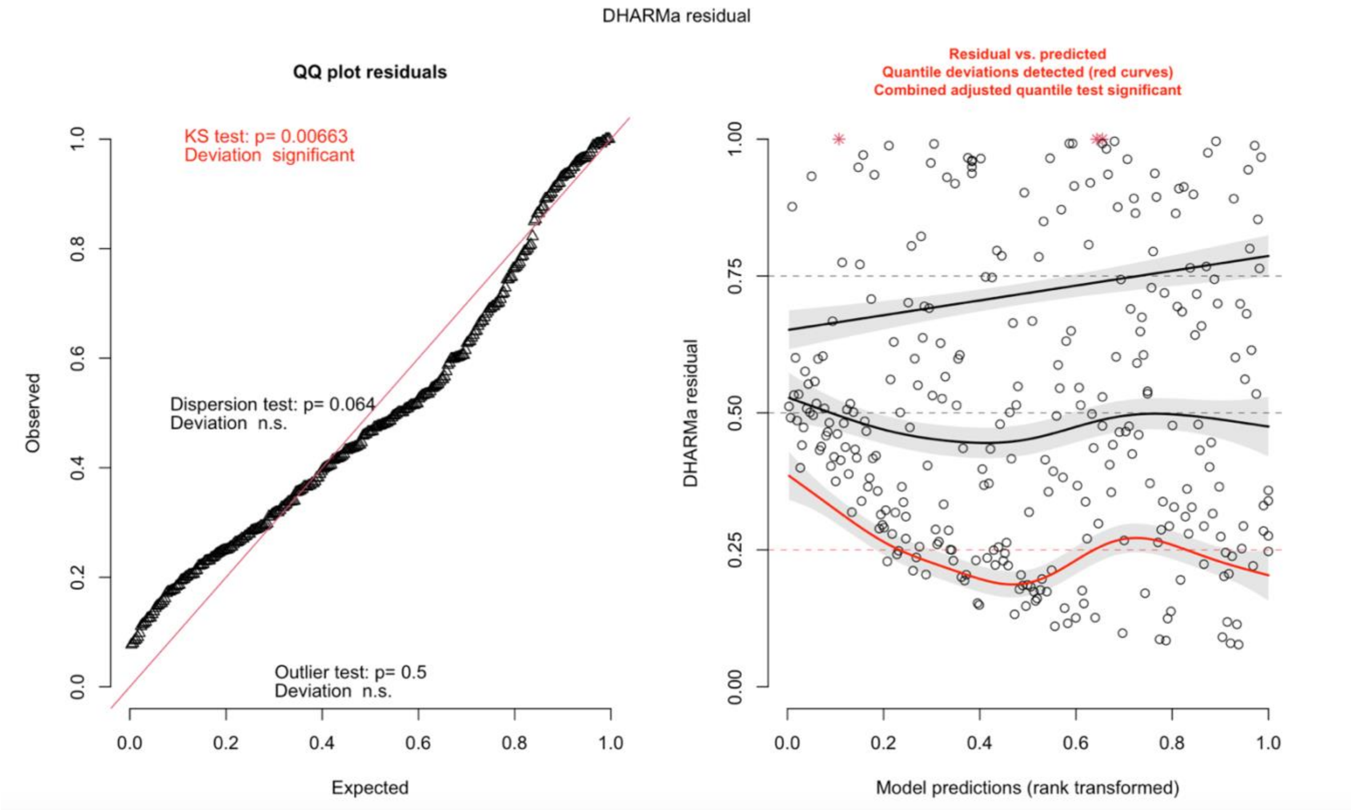

Figure S4. Time with Whale model checking. The QQ plot displays a significant, but small magnitude deviation from expected values. The residuals vs predicted plot shows deviations in one group of residuals.

Table S8. Candidate set model for 2023 focal scans (n = 26) with Time Spent with Whale as the response variable, adjusted post-analysis with the inclusion of models that contain potentially important interactions. New models with interactions included (bold) were not competitive with the previously selected top model. All models include the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right.

Model	**AIC Score**
Vessel Speed + Distance to Whale	0.0

Ecotour Presence + Vessel Speed + Distance to Whale + Ecotour Presence*Distance to Whale	**1.6**
Vessel Speed + Distance to Whale + Vessel Type	2.0
Vessel Speed + Distance to Whale + Vessel Type + Vessel Type*Distance to Whale	**4.0**

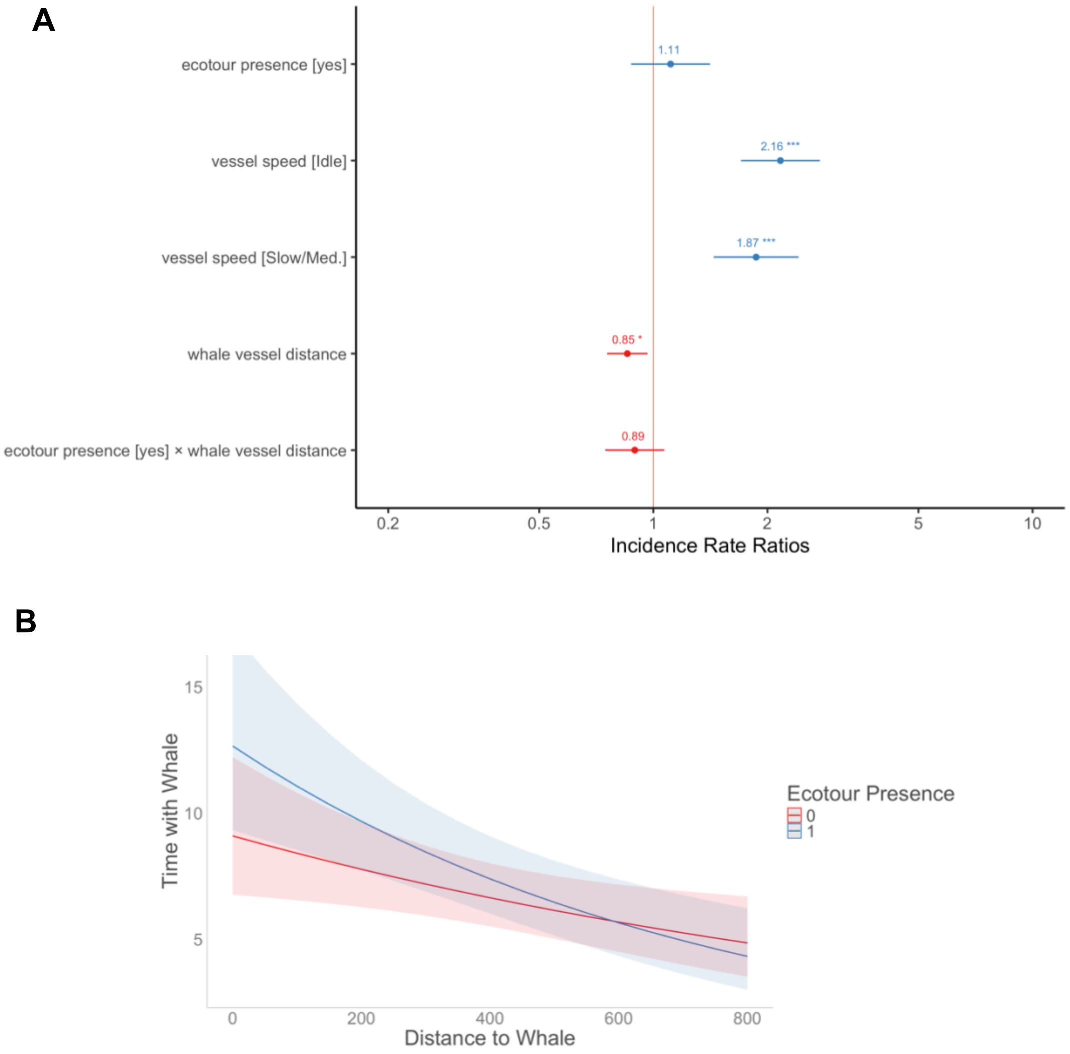

Figure S5. Focal scan model predicting Time Spent with Whale as response: ***A)*** *parameter coefficients, and CIs for fixed effects. Dots represent the magnitude of effect on vessel distance, and the lines span 95% CI.* ***B)*** *predicted time spent with a whale as a function of the interaction between vessel distance to whale and the presence of an ecotour vessel. Red (0) indicates no ecotour vessel presence in the focal scan, and blue (1) indicates at least one ecotour vessel was present in the scan. Shaded areas represent 95% CIs, and the lines represent model predictions.*

Appendix C

2022/2023 Focal Scan Modelling Approach

Vessel Distance to Whale

The top model from the 2022/2023 focal scans (n = 367) explained ~70% of the variation in the data and revealed that the average number of vessels present in a scan, the time with whale influenced the vessel distance to a whale (Table S4, Figure S4). Vessel distance increased by ~6.2% as the average number of vessels within 1km of the focal whale increased by one (Figure S4A). There was a negative association between vessel time spent with a whale and vessel distance. Vessel distance decreased by 18.3% with every additional 10 minutes a vessel spent around a whale (Figure S4).

Both predictor variables had a similar influence on the vessel distance to a whale (RVI = 0.10, 0.11 for Number of Vessels and Time with Whale, respectively; Figure S4A).

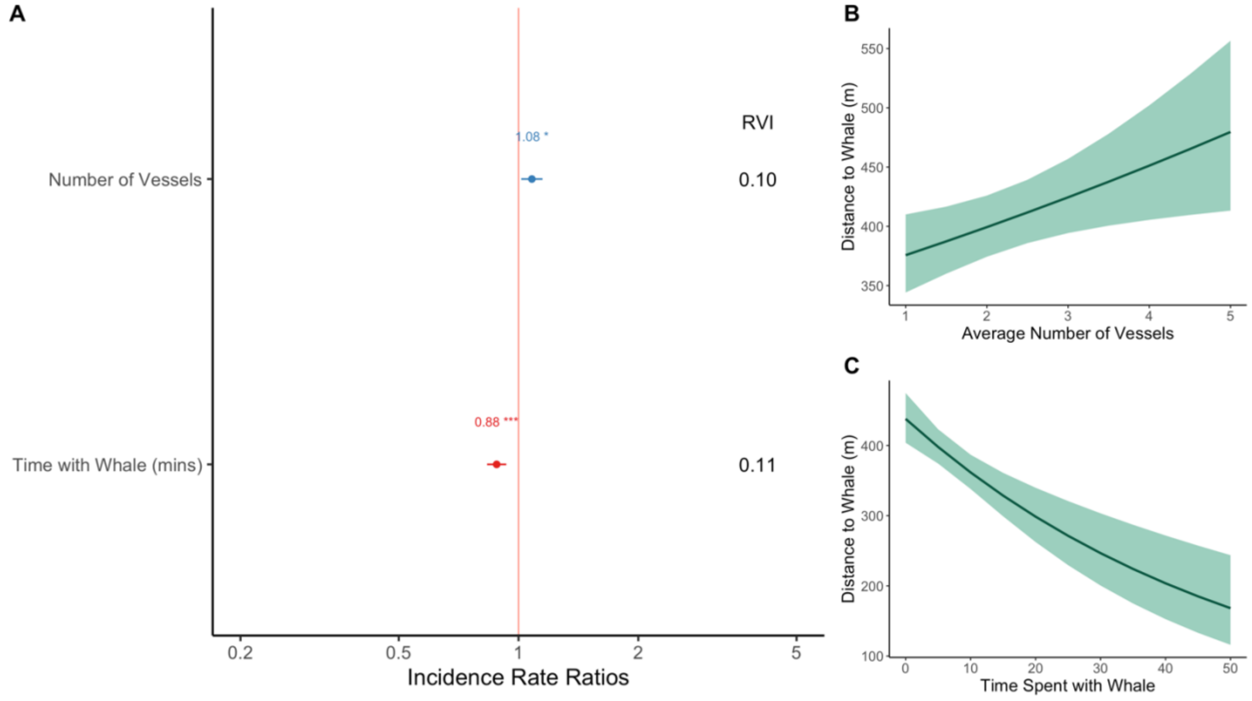

Figure S6. Focal scan top model predicting Vessel Distance to Whale as response: ***A)*** *parameter coefficients, and CIs for fixed effects. Dots represent the magnitude of effect on vessel distance, and the lines span 95% CI. Relative Variable Importance (RVI) shown on the right for each fixed effect;* ***B)*** *predicted vessel distance to whale as a function of the median number of vessels within 1km of a whale during a focal scan;* ***C)*** *predicted vessel Distance to Whale as a function of the time with a whale observed during the focal scan;* ***B)*** *to* ***C)*** *represent 95% CIs, and the lines represent model predictions.*

Table S9. Candidate set model predicting vessel distance to whale for 2022/2023 focal scans. All models have the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right.

Null Model		**AIC**
M1	1	18.7
Vessel Metrics Only		
M2	Vessel Type	18.3
M3	Vessel Type + Ecotour Presence	17.8
M4	Time with Whale	4.1
M5	*Number of Vessels + Time with Whale*	*0.0*
M6	Number of Vessels + Time with Whale + Ecotour Presence	2.0
M7	Number of Vessels	15.4
M8	Number of Vessels + Time with Whale + Vessel Type + Ecotour Presence	1.4
M9	Number of Vessels + Vessel Type	15.5

M10	Vessel Type + Number of Vessels + Time with Whale	0.6
Species Metrics Only		
M11	Species	17.3
M12	Species + Behaviour	22.1
M13	Species + Behaviour + Calf Present	24.0
Vessel and Species Metrics		
M14	Vessel Type + Species + Vessel Type:Species + Ecotour Presence	16.2
M15	Vessel Type + Species + Whale Behaviour + Calf Present + Vessel Type:Species	24.0
M16	Time with Whale + Species + Behaviour + Calf Present	10.3
M17	Vessel Type + Time With Whale + Species + Whale Behaviour + Calf Present + Vessel Type:Species	9.4
M18	Number of Vessels + Species + Whale Behaviour + Calf Present	20.4
M19	Number of Vessels + Time with Whale + Species + Behaviour + Calf Present	5.6
M20	Vessel Type + Number of Vessels + Species + Whale Behaviour + Calf Present + Vessel Type:Species + Ecotour Presence	21.6
Global Model		
M21	Vessel Type + Number of Vessels + Time with Whale + Species + Whale Behaviour + Calf Present + Ecotour Presence + Vessel Type:Species	6.0

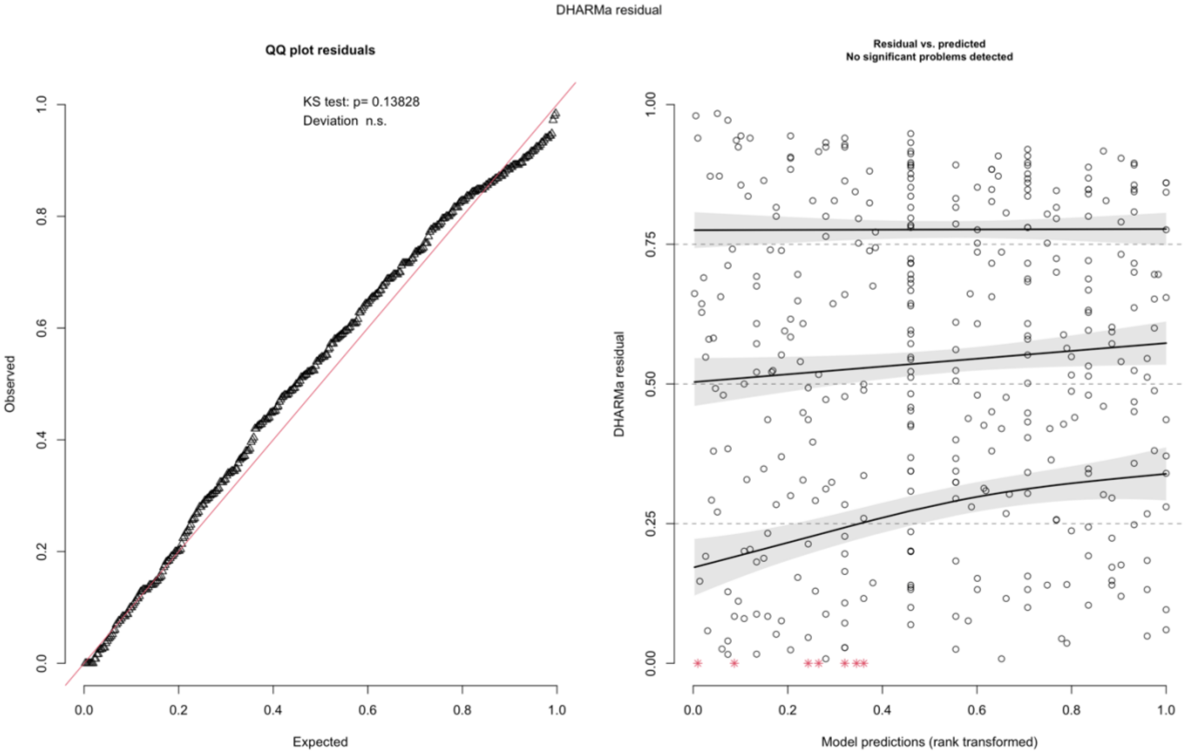

Figure S7. Distance to Whale model checking with DHARMa package. The QQ plot displays no significant deviation from expected values. The residuals vs predicted plot shows no significant problems detected in model fit.

Number of Vessels

Overall, the top model explained ~29% of the variation in the data (n = 367), with the fixed effects alone accounting for 4% of the variation in the number of vessels. The top model revealed that the presence of an ecotour vessel, and study site influenced the number of vessels (Table S5, Figure S6). There was an average of ~0.8x ($\hat{y}$: 2.4; CI: 1.9 – 3.0) more vessels when an ecotour vessel was present in the focal scan (Figure S6B). We observed more vessels at some study sites than others. Donegal Head had on average 1.4x ($\hat{y}$: 1.9; CI: 1.6– 2.3) more vessels than Blackney Pass ($\hat{y}$:1.4 ; CI: 1.1– 1.8; Figure 3D). Blackfish Sound had on average ~1.3x ($\hat{y}$: 1.9; CI: 1.5 – 2.4) more vessels than Blackney Pass (Figure S6C).

Ecotour presence and study site had a similar importance on the number of vessels (RVI = 0.06, 0.05, respectively; Figure S6A).

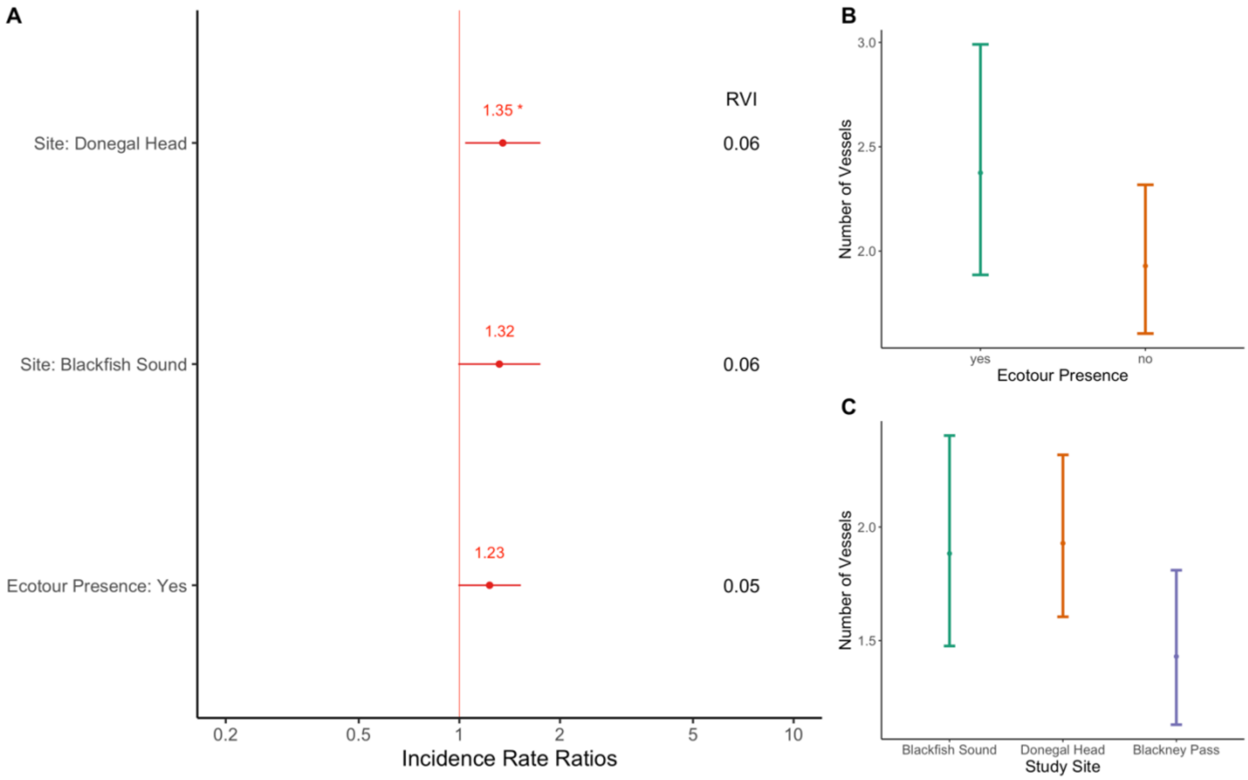

Figure S8. Focal scan top model predicting the number of vessels around a whale as response: ***A)*** *parameter coefficients, and CIs for fixed effects. Dots represent the magnitude of effect on the number of vessels, and the lines span 95% CI. Relative Variable Importance (RVI) shown on the right for each fixed effect;* ***B)*** *predicted number of vessels as a function of ecotour presence during a scan;* ***C)*** *predicted number of vessels as a function of the study site where the scan was conducted. Coloured error bars in* ***B)*** *and* ***C)*** *represent 95% CIs, and the dots represent model predictions.*

Table S10. Candidate set model predicting number of vessels for 2022/2023 focal scans (ΔAIC <4). All models have the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right.

Null Model		**AIC**
M1	1	1.5
Vessel Metrics Only		
M2	Vessel Type	3.5
M3	*Site + Ecotour Presence*	*0.0*
M4	Time with Whale	3.4
M5	Distance to Whale + Ecotour Presence	2.9
M6	Site + Vessel Type	3.5
M7	Distance to Whale + Time with Whale + Site + Vessel Type	6.3
M8	Vessel Type + Site + Distance to Whale	4.3
M9	Vessel Type + Distance to Whale + Time with Whale	6.4
Species Metrics Only		
M10	Species	2.8
M11	Species + Whale Behaviour	7.1
Vessel and Species Metrics		
M12	Vessel Type + Species + Whale Behaviour + Site + Ecotour Presence	8.3
M13	Vessel Type + Species + Vessel Type:Species + Ecotour Presence	5.7
M14A	Site + Behaviour	7.0
M14B	Site	1.5

M15	Vessel Type + Species + Whale Behaviour + Vessel Type:Species + Ecotour Presence	9.5
M16	Time with Whale + Species + Whale Behaviour + Ecotour Presence	9.2
M17	Vessel Type + Time with Whale + Species + Whale Behaviour + Vessel Type:Species	12.5
M18	Distance to Whale + Species +_Whale Behaviour + Site + Ecotour Presence	8.2
M19	Time With Whale + Species + Whale Behaviour + Site	10.5
Global Model		
M20	Vessel Type + Distance to Whale + Time with Whale + Site + Ecotour Presence + Species + Behaviour + Vessel Type:Species	12.7

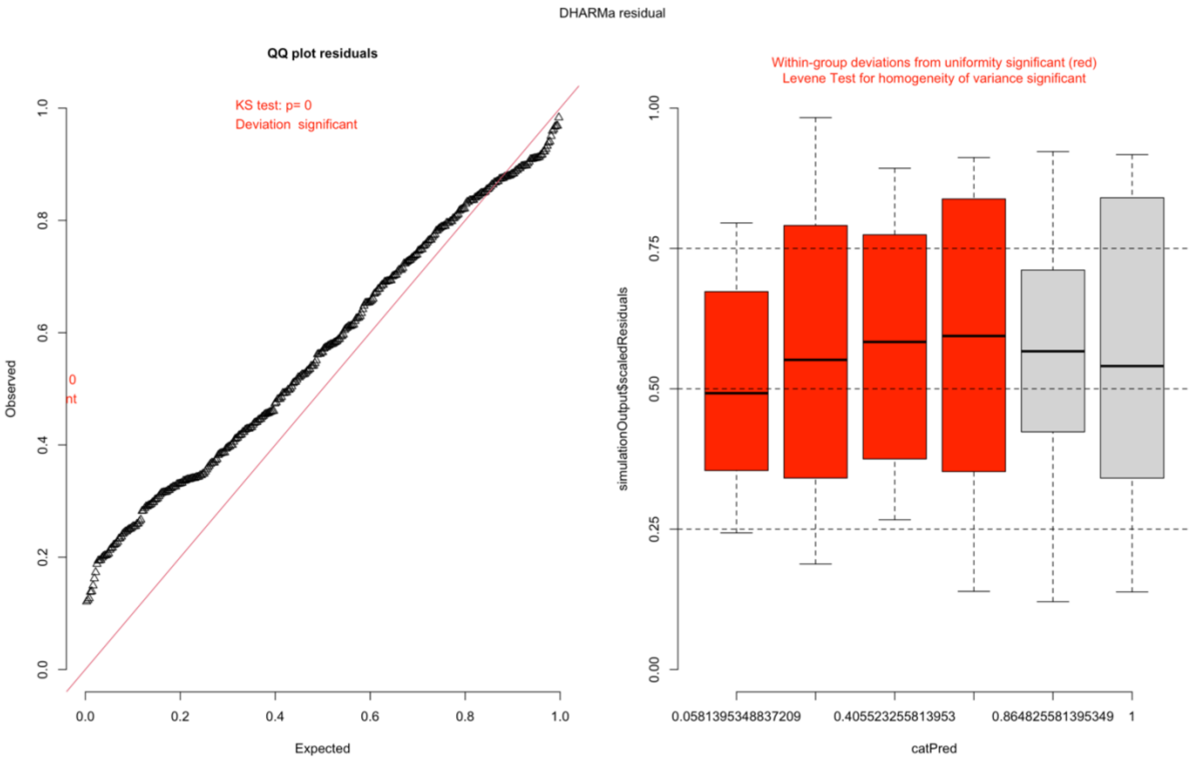

Figure S9. Number of Vessels model checking using the R package DHARMa. The QQ plot displays a significant deviation from expected values, particularly at values closer to 0. The residuals vs predicted plot shows within-group deviations from uniformity.

Time with Whale

Overall, the top model explained ~32% of the variation in the data (n = 367), with the fixed effects alone accounting for 13% of the variation in the time a vessel spent with a whale. The top model revealed that the vessel distance to the whale influenced the vessel time with the whale (Table S6, Figure S8). We observed a negative association between the vessel distance to a whale and their time with the whale. Every 50m increase in the vessel distance to a whale revealed a ~7% decrease in the time that they spent with the whale (Figure S8B).

A vessel’s distance to a whale was ~2.2x more important (RVI = 0.11, Figure S8A) than vessel type (RVI = 0.05), to influence the time a vessel spent with a whale during a focal scan.

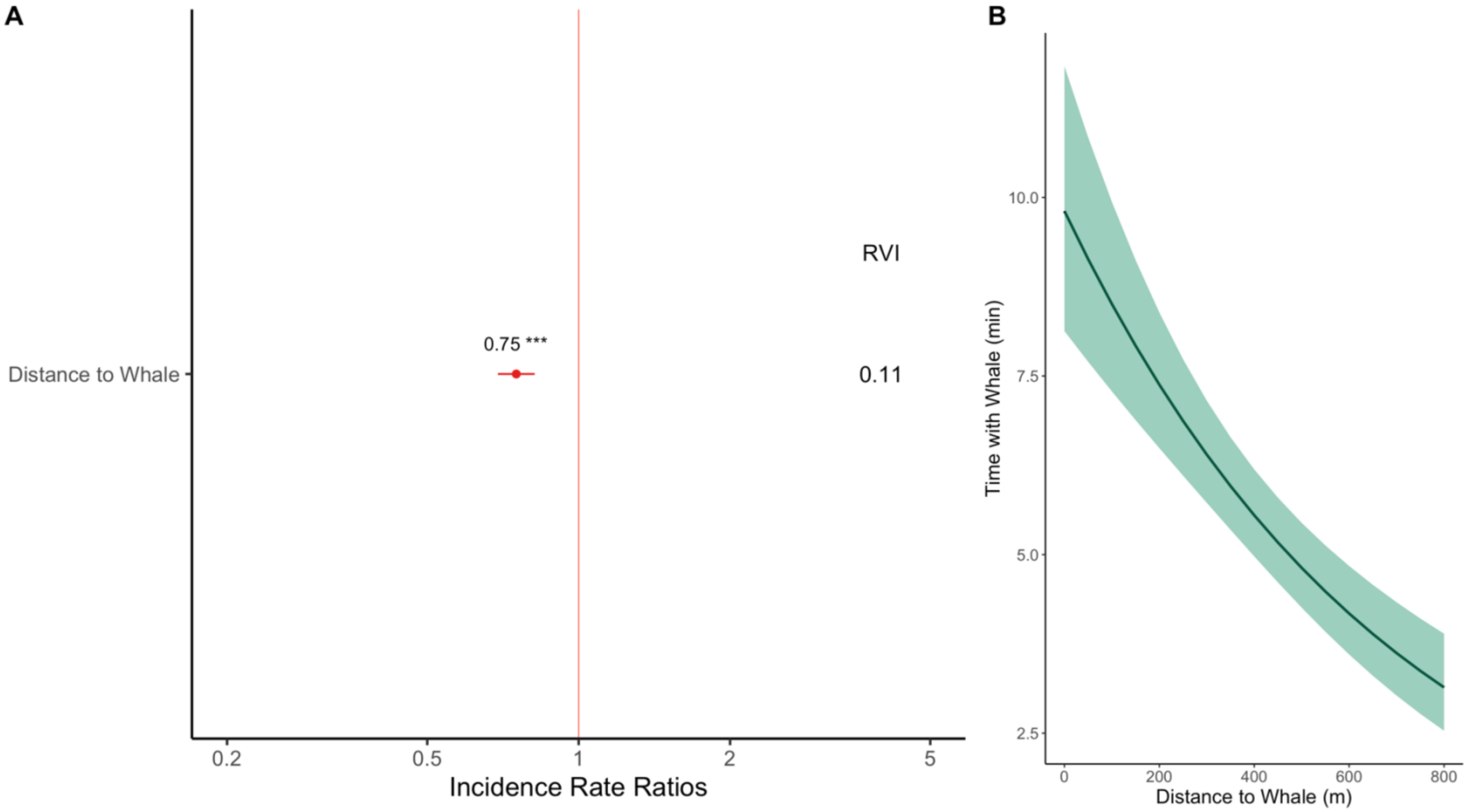

Figure S10. Focal scan top model predicting the time a vessel spends within 1km of a whale as the response: ***A)*** *parameter coefficients, and CIs for fixed effects. Dots represent the magnitude of effect on the number of vessels, and the lines span 95% CI. Relative Variable Importance (RVI) shown on the right for each fixed effect;* ***B)*** *predicted time with whale as a function of the vessel distance to whale during a scan; shaded regions or coloured error bars represent 95% CIs, and the lines represent model predictions.*

Table S11. Candidate set model for 2023 focal scans (n= 24) with time with whale as response variable. All models have the focal scan number as a random effect. The top model is indicated in italics, with corresponding delta AIC scores on the right.

	Null Model	**AIC**
M1	1	40.4
Vessel Metrics Only		
M2	Vessel Type	39.0
M3	Vessel Type + Number of Vessels + Ecotour Presence	40.9
M4	Number of Vessels	40.9
M5	Distance to Whale + Number of Vessels	1.9
M6	*Distance to Whale*	*0.0*
M7	Distance to Whale + Number of Vessels + Vessel Type	2.4
M8	Vessel Type + Distance to Whale	0.5
M9	Vessel Type + Distance to Whale + Number of Vessels	2.4
Species Metrics Only		
M10	Species	41.9
M11	Species + Whale Behaviour	39.4
Vessel and Species Metrics		
M12	Vessel Type + Species + Whale Behaviour	37.2
M13	Vessel Type + Species + Vessel Type:Species + Ecotour Presence	42.4
M14	Whale Behaviour	38.8
M15	Vessel Type + Species + Whale Behaviour + Vessel Type:Species + Ecotour Presence	39.7

M16	Number of Vessels + Species + Behaviour	39.9
M17	Vessel Type + Number of Vessels + Species + Whale Behaviour + Vessel Type:Species	38.7
M18	Distance to Whale + Species + Whale Behaviour	0.8
M19	Number of Vessels + Species + Whale Behaviour	39.9
M20	Distance to Whale + Number of Vessels + Species + Whale Behaviour	2.7
M21	Vessel Type + Distance to Whale + Species + Whale Behaviour + Vessel Type:Species	0.5
Global Model		
M22	Vessel Type + Distance to Whale + Number of Vessels + Species + Whale Behaviour + Vessel Type:Species + Ecotour Presence	2.3

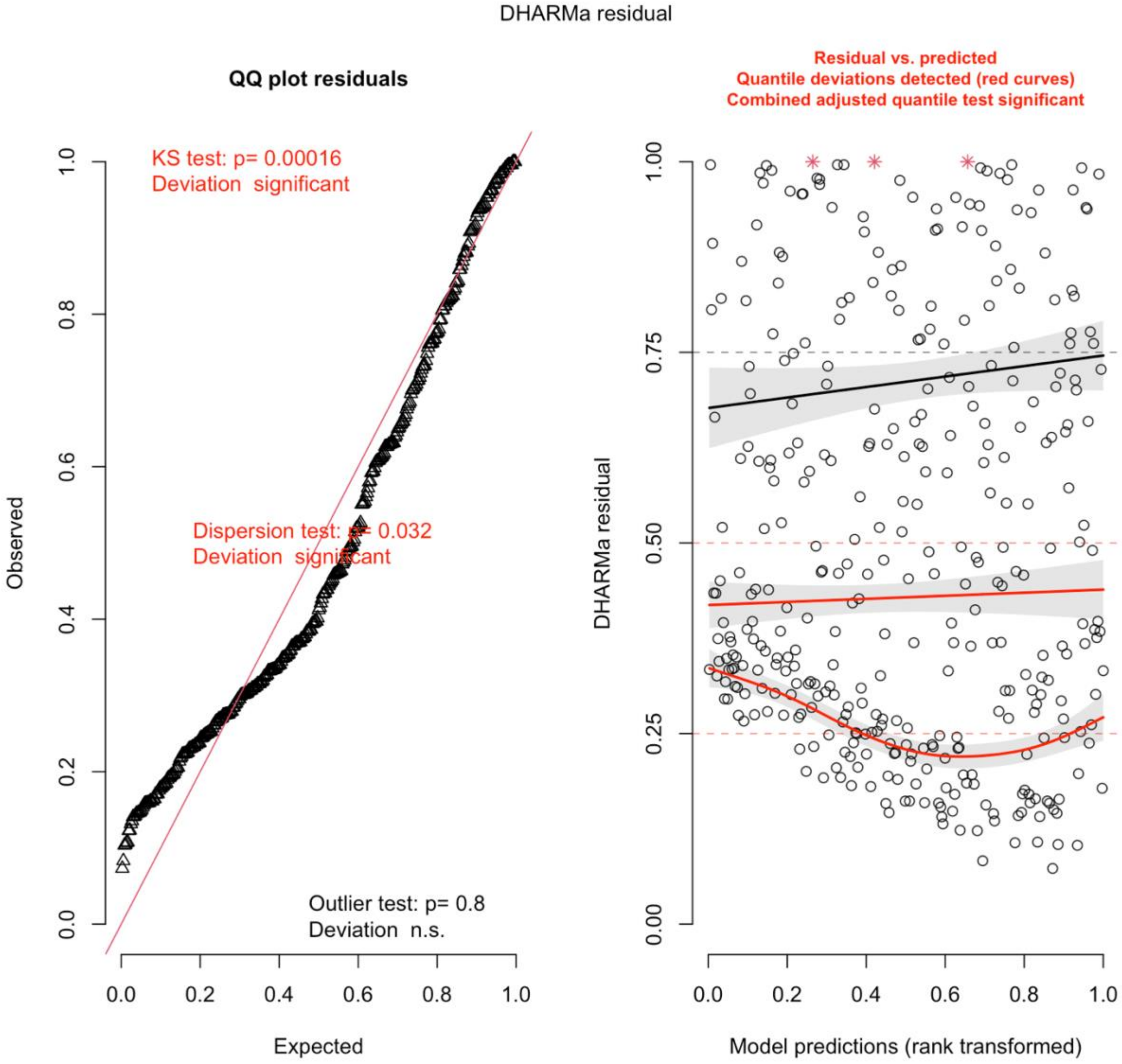

Figure S11. Time with Whale model checking using the R package DHARMa. The QQ plot displays a significant deviation from expected values. The residuals vs predicted plot shows deviations from observed outcomes in 2 groups of residuals.