Section S1. Methods

S1.1. Visual data collection

To confirm that observed killer whales were from the Northern Resident population, individuals were identified by on-water observers using photo-identification catalogues. Only scans with confirmed visual identification were used in the analyses.

Table S1. Vessel types and categories assigned to vessels observed from the platform in Johnstone Strait in the summers of 2019-2022.

Vessel Category	Vessel Type
Kayak	Ecotour Kayak
	Private Kayak
Recreation, Research or Monitoring	Ecotour Motor
	BC Parks
	Fisheries and Oceans Canada
	Marine Monitoring
	Charter passenger vessel
	Private Motor
	Sailboat
Commercial or Coast Guard	Canadian Coast Guard
	Commercial Fishing
	Tug with log tow
	Tug with tow
	Other Cargo (including tug without tow)
	Cruise ship
	Ferry

S1.2. Assessment of Beach Rubbing

The acoustic signal generated by beach rubbing is broadband (see Figure 2) with temporal and qualitative characteristics that make it distinguishable from other auditory signals. A characteristic beach rubbing acoustic signal begins with a higher amplitude band caused by the whale's initial impact with the pebble beach. The frequency range for this signal typically extends from 1 kHz to the upper limit of our recording settings, around 30 kHz. Thus, this range may extend to higher frequencies beyond what was recorded in our study. The higher amplitude band is followed by a fading gradient to lower amplitude for approximately the same frequency band. This component of the acoustic signal is caused by pebbles tumbling down the sloped surface, as well as pebbles being pushed along the trajectory of the whale. Qualitatively, the signal sounds as would be expected for an impact on a pebbly beach followed by rocks continuing to roll downward and is similar to the sound of shaking and inverting a rain stick.

S1.3. Modeling Vessel Impacts

Directed acyclic graph (DAG) development

The DAGitty package (Textor et al. 2016) in the statistical software R (Version 4.1.3; R Core Team, 2022) tested for any correlations among explanatory variables that were incompatible with the causal structure proposed in the DAG. Modifications to the DAG were made accordingly to ensure DAG-data consistency (Figure S1).

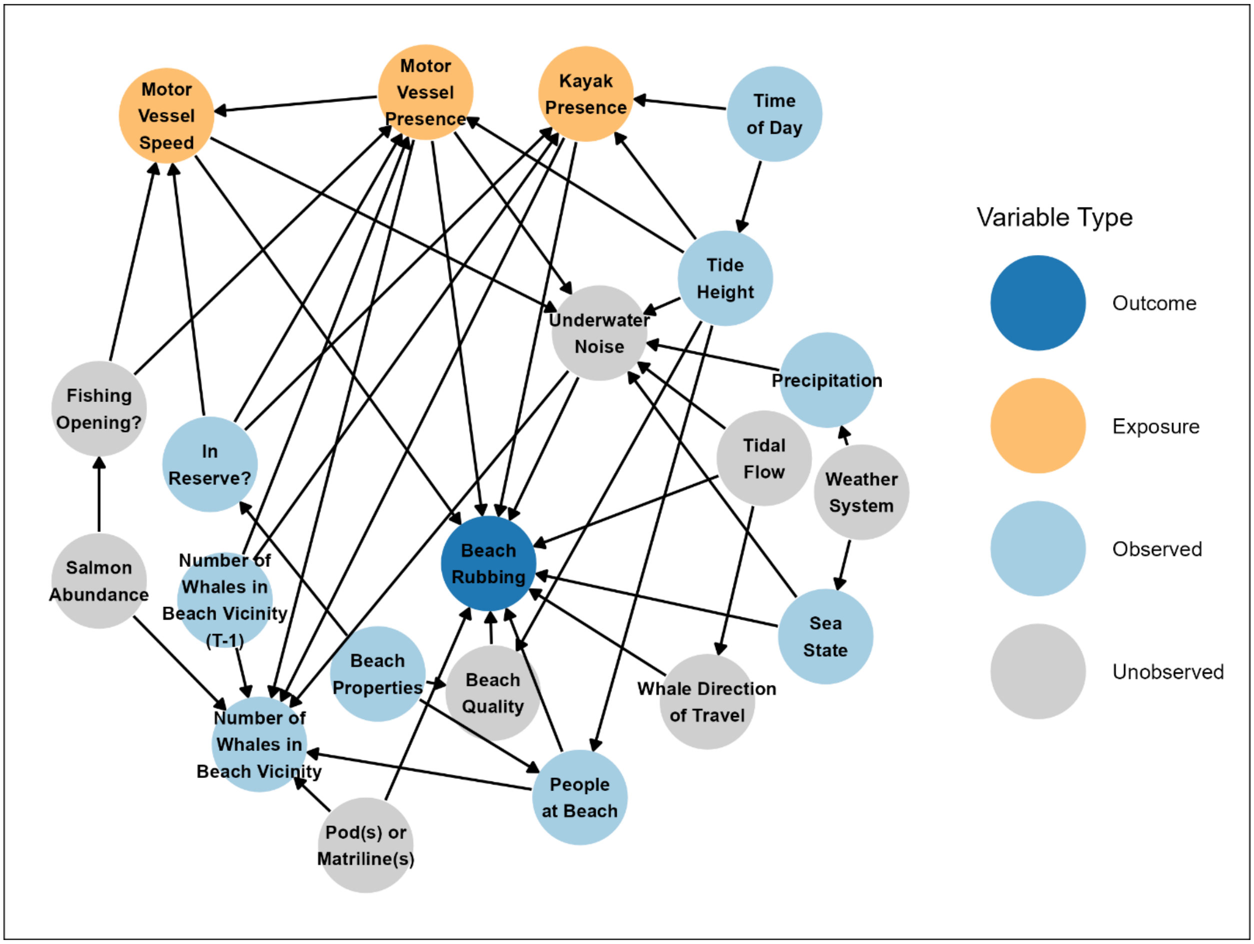

Figure S1. Causal directed acyclic graph for northern resident killer whale beach rubbing. Arrows connecting two nodes indicate a hypothesized causal effect of the originating node on the terminating node. “Exposure” variables were those whose effect we aimed to assess. “Observed” variables were used for testing DAG-data consistency, while “Unobserved” variables were not.

Section S2. Results

S2.1. Vessel presence

Table S2. Wilcoxon rank sum test results of difference the proportions of vessels of a given vessel category within 2 km of a given beach by year, using all scans for which NRKW were within the vicinity of the given beach (sample sizes indicated by N_a and N_b). P values were corrected for family-wise error rate using Holm's correction.

Beach	Vessel Category	$Year_a$	$Year_b$	N_a	N_b	W	Adjusted P Value
Kaizumi	Kayaks	2019	2020	17	15	91.5	1
		2019	2021	17	25	267.5	1
		2019	2022	17	39	324	1
		2020	2021	15	25	285	0.093
		2020	2022	15	39	362.5	1
		2021	2022	25	39	363	1
	Commercial or Coast Guard	2019	2020	19	16	137	1
		2019	2021	19	30	282	1
		2019	2022	19	46	415.5	1
		2020	2021	16	30	263	1
		2020	2022	16	46	390	1
		2021	2022	30	46	665.5	1
	Recreation, Research or Monitoring	2019	2020	30	43	536.5	1
		2019	2021	30	50	747	1
		2019	2022	30	57	786	1
		2020	2021	43	50	1218.5	1
		2020	2022	43	57	1325	1
		2021	2022	50	57	1330.5	1
Strider	Kayaks	2019	2020	17	1	8.5	NA
		2019	2021	17	16	127.5	1
		2019	2022	17	21	153	1
		2020	2021	1	16	7.5	1
		2020	2022	1	21	9	1
		2021	2022	16	21	155.5	1
	Commercial or Coast Guard	2019	2020	13	12	71.5	1
		2019	2021	13	22	130	1
		2019	2022	13	45	247	1
		2020	2021	12	22	132	1
		2020	2022	12	45	253.5	1
		2021	2022	22	45	468	1
	Recreation, Research or Monitoring	2019	2020	27	26	431.5	1
		2019	2021	27	53	764	1
		2019	2022	27	58	830.5	1
		2020	2021	26	53	614	1
		2020	2022	26	58	641.5	1
		2021	2022	53	58	1522	1

Table S3. Wilcoxon rank sum test results of difference in vessel counts by beach and year, using all scans for which NRKW were within the vicinity of the relevant beach (sample sizes indicated by N_a and N_b). P values were corrected for family-wise error rate using Holm's correction.

Beach(es)	$Year_a$	$Year_b$	N_a	N_b	W	Adjusted P Value
Kaizumi	2019	2020	31	49	1163.5	0.0007
	2019	2021	31	54	1212.5	0.0063
	2019	2022	31	63	1212.5	0.36
	2020	2021	49	54	1278	1.00
	2020	2022	49	63	1079.5	0.062
	2021	2022	54	63	1330	0.33
Strider	2019	2020	31	36	678	0.36
	2019	2021	31	62	1041.5	1.00
	2019	2022	31	66	979.5	1.00
	2020	2021	36	62	986	0.85
	2020	2022	36	66	905.5	0.14
	2021	2022	62	66	1805.5	0.85
Strider vs. Kaizumi	2019	2019	31	31	57	<0.0001
	2019	2020	31	49	265.5	<0.0001
	2019	2021	31	54	354	<0.0001
	2019	2022	31	63	277.5	<0.0001
	2020	2019	36	31	50	<0.0001
	2020	2020	36	49	239.5	<0.0001
	2020	2021	36	54	314.5	<0.0001
	2020	2022	36	63	254	<0.0001
	2021	2019	62	31	110.5	<0.0001
	2021	2020	62	49	514.5	<0.0001
	2021	2021	62	54	662	<0.0001
	2021	2022	62	63	520.5	<0.0001
	2022	2019	66	31	155	<0.0001
	2022	2020	66	49	663	<0.0001
	2022	2021	66	54	837.5	<0.0001
	2022	2022	66	63	664	<0.0001

Table S4. Wilcoxon rank sum test results of difference in vessel counts for the whole study area by year, using all scans for which NRKW were within the vicinity of either beach (sample sizes indicated by N_a and N_b). P values were corrected for family-wise error rate using Holm's correction.

$Year_a$	$Year_b$	N_a	N_b	W	Adjusted P Value
2019	2020	17	21	295	0.0039
2019	2021	17	23	281.5	0.077
2019	2022	17	37	357	0.43
2020	2021	21	23	161.5	0.13
2020	2022	21	37	181.5	0.0042
2021	2022	23	37	293	0.13

Table S5. Wilcoxon rank sum test results of difference in vessel counts by beach for when NRKW are in the relevant beach vicinity (2019-2022; sample size shown as N_b) compared to when NRKW are not in the study area (2022; sample size shown as N_a). P values were corrected for family-wise error rate using Holm's correction.

Beach	Vessel Category	N_a	N_b	W	Adjusted P Value
Kaizumi	Kayaks	63	96	2139.5	0.0026
	Recreation, Research or Monitoring	205	180	6168.5	<0.0001
	Commercial or Coast Guard	158	111	8760	1.00
Strider	Kayaks	63	55	1688	1.00
	Recreation, Research or Monitoring	205	164	12473.5	<0.0001
	Commercial or Coast Guard	158	92	6998	0.93

S2.2. NRKW beach visits

Table S6. Wilcoxon rank sum test results of difference in duration of NRKW visit to the vicinities of Kaizumi and Strider Beaches (number of consecutive 15 minute scans) by beach and year (sample sizes indicated by N_a and N_b). Values from 2020 and 2021 did not significantly differ, so were combined to represent years with lower traffic due to the COVID-19 pandemic. Adjusted P values were corrected for family-wise error rate using Holm's correction.

Beach(es)	Year_a	Year(s)_b	N_a	N_b	Alternative Hypothesis	W	Unadjusted P Value	Adjusted P Value
Kaizumi	2019	2020 & 2021	20	43	less	269	0.0062	0.050
	2020	2021	22	21	two-sided	209.5	0.59	0.89
	2022	2020 & 2021	41	43	less	571	0.0016	0.014
Strider	2019	2020 & 2021	10	32	less	155	0.45	0.89
	2020	2021	15	17	two-sided	88.5	0.14	0.68
	2022	2020 & 2021	28	32	less	341.5	0.05	0.30
Kaizumi vs. Strider	2019		20	10	less	61.5	0.035	0.25
	2020 & 2021		43	32	less	628.5	0.26	0.77
	2022		41	28	less	500.5	0.16	0.68

S2.3. Predicting with Beach Rubbing Vessel Variables

Table S7. Two-sided Spearman's rank correlation test results of correlations between rubbing bout duration at Kaizumi Beach and mean vessel count (N = 17).

Vessel Category	Vessel distance	R	P value
Kayaks	within 1 km	-0.059	0.82
	within 2 km	0.047	0.86
Motor Vessels	within 1 km	0.24	0.36
	within 2 km	0.18	0.50
All Vessels	within 1 km	-0.045	0.86
	within 2 km	0.093	0.72

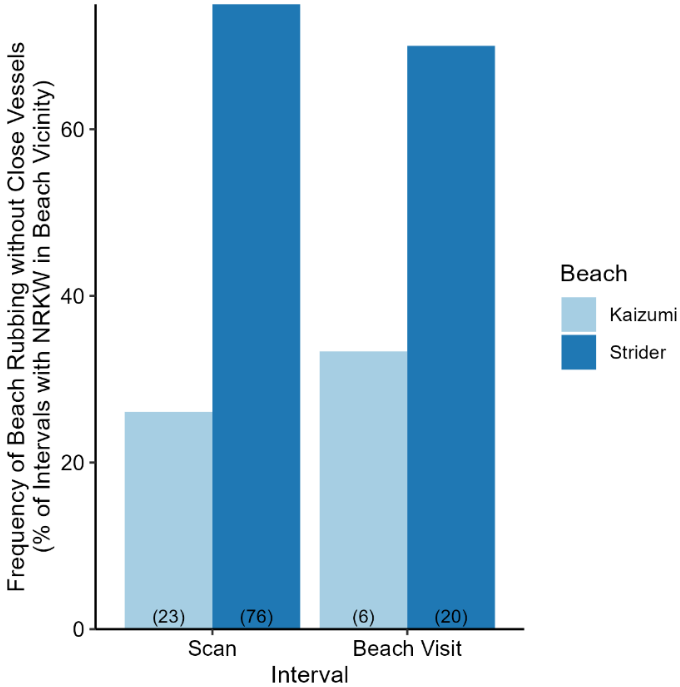

Figure S2. Observed rates of rubbing at Kaizumi and Strider Beaches in the absence of close vessels (within 2km of the beach), using the percentage of scans with beach rubbing out of those with NRKW in the pertinent beach vicinity (left) or the percentage of visits to the beach vicinity that included any beach rubbing (right). Sample size (number of scans or number of beach visits, as appropriate) is indicated in parentheses.

Table S8. Comparison of candidate models of beach rubbing at Kaizumi Beach, ordered according to AICc values. Only the top model was among the top model set (based on cut-off of Δ AICc > 4). The top-ranked model would be considered the single best model if its weight was greater than 0.9. Motor vessel and kayak presence was assessed as a count within a distance threshold (1 km, 2 km, or all visible), or as binary presence/absence of vessels within 2 km. Variables included in a given model are indicated by an 'X'.

Model Components									
Motor Vessels	Kayaks	Motor Vessel Speed	Tide Height	Day	Prior Rub	Degrees of Freedom	AICc	Δ AICc	Model Weight
-	-		X	X	X	2	83.72	0.00	0.55
All	All	X	X	X	X	5	88.52	4.81	0.05
1 km	All	X	X	X	X	5	88.52	4.81	0.05
All	2 km	X	X	X	X	5	88.52	4.81	0.05
2 km	All	X	X	X	X	5	88.52	4.81	0.05
All	1 km	X	X	X	X	5	88.53	4.81	0.05
1 km	1 km	X	X	X	X	5	88.53	4.81	0.05
2 km	2 km	X	X	X	X	5	88.53	4.81	0.05
1 km	2 km	X	X	X	X	5	88.53	4.81	0.05
2 km	1 km	X	X	X	X	5	88.53	4.81	0.05
-	-					1	99.37	15.65	0.00
Presence / Absence	Presence / Absence	X	X	X	X	24.59	122.7	38.99	0.00

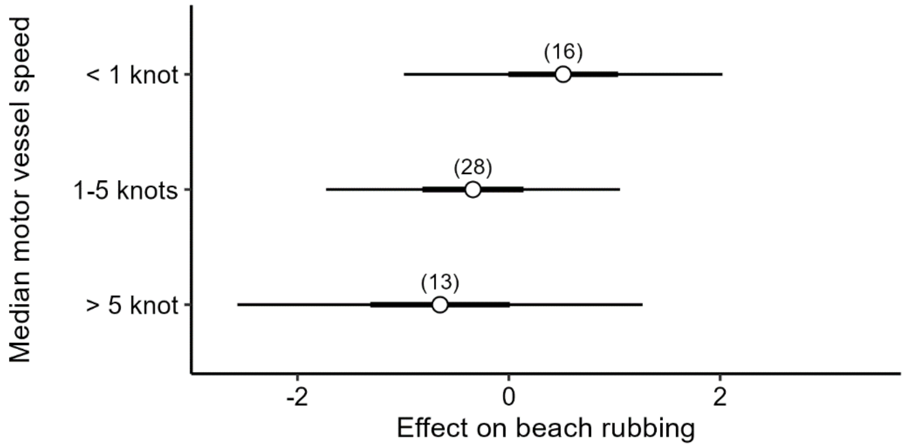

Figure S3. Effect of motor vessel speed on the probability beach rubbing, at Kaizumi Beach, for summers 2020-2021, based on median speed of motor vessels within 2 km of the beach, according to the top GAMM. Points represent effect size estimates and thick and thin bars represent the 50% and 95% confidence intervals, respectively. The number of scans in the dataset for each median speed bin are shown in parentheses above the points. The model intercept (estimate: -1.64, SE: 0.54) and the effect of prior rubbing (estimate: 2.26, SE: 0.58) were significant model parameters.

References

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Textor, J., van der Zander, B., Gilthorpe, M.S., Liskiewicz, M., Ellison, G.T., (2016). Robust causal inference using directed acyclic graphs: the R package 'dagitty'. Int J Epidemiol 45, 1887-1894.