Evidence for ship noise impacts on humpback whale foraging behaviour

Hannah Blair[1,*], Nathan Merchant[2], Ari Friedlaender[3], David N. Wiley[4], & Susan E. Parks[1]

[1]Syracuse University
[2]Cefas
[3]Oregon State University Marine Mammal Institute
[4]Stellwagen Bank National Marine Sanctuary
*Correspondence (hannah.blair@stonybrook.edu)

Supplementary Materials

Expanded Methods

Due to near continuous shipping noise during daylight hours in the study habitat, analyses were limited to nighttime data including only tag records that contained data collected between one hour after sunset to one hour before sunrise to encompass periods with both high and low shipping noise. Selected records included a minimum of five feeding dives by the tagged whale and the passage of at least one large ship on the acoustic record. Feeding dives were defined as dives deeper than 10 m showing clear behaviors associated with bottom feeding [1].

Subsurface behaviors were visualized and quantified using the software application TrackPlot [2]. TrackPlot utilizes tag sensors (e.g. pressure, 3-axis accelerometers) to create a continuous dead reckoned pseudotrack of the whale's three-dimensional path [2]. This pseudotrack is represented by a ribbon marked by a chevron pattern on the dorsal surface to indicate travel direction and orientation (Figure 1). A side-roll exceeding a 40° deviation from a vertical orientation of the dorsal ridge is signified by the yellow coloration of the ribbon, and can be used to indicate the location of a bottom side-roll (Figure 1) [1–3]. Using TrackPlot seven dive behavior measurements were extracted from bottom side-roll dives: the duration of each dive (s), the rate of descent and ascent (m/s), the maximum depth (m), the number of bottom side roll events, the time between dives (s), and the surface time immediately following each dive (s) (Figure 1B). Depth profiles were examined in MATLAB R2013a.

The presence of ship noise was detected through the Dtag hydrophone recordings (sampling rate either 64 or 96 kHz, system sensitivity -171 dB re 1 μPa [4] (Figure 2A). The tags included a high pass filter at 400 Hz to minimize the contribution of flow noise to the recording. All recordings were decimated to 16 kHz to standardize sampling rates. Received level (RL) was measured using RavenPro 1.5 [5]. Sound pressure level (SPL) measurements to quantify the absolute RL of ship noise on each tag record were taken for a one-minute period in the 2-3 kHz frequency band during the bottom time periods of each dive analyzed, directly following the end of the whale's descent or as soon afterward as feasible to minimize the interference of acoustic energy from whale vocalizations and sand grating caused by the rolling behaviors. The RL measurements were made to allow us to distinguish between behaviors in response to an absolute RL vs. increased RL in the presence of ship noise, as humpback whales have shown differential response to increased RL from ambient wind generated noise vs. ship noise [6].

All statistical analyses were performed in R version 2.15.3. The dependent variable data were square root transformed to approximate a normal distribution. A series of linear mixed-effects models were applied to the data using the *lme* function in the *nlme* package. The seven metrics described above were the dependent variables tested. Two independent variables and their interaction were included in the models: RL and a binomial factor representing a dive in a ship noise exposure period or in a period of no ship noise (SN). Dives in the SN exposure group occurred during the same time period as each ship passage on the record. Dives in the non-exposure group occurred during a time period of the same duration as a ship passage directly before and directly after the ship passage, in order to more accurately target alterations in dives occurring because of noise presence and intensity as opposed to other stimuli. A random effect of the individual tag deployment was applied to all models. Best model fit was evaluated using the differences in Akaike's Information Criterion corrected for small sample sizes (AICc) [7]. Akaike weights (w_i) for each model were calculated based on model AICc values. Variable importance values were then calculated by summing the Akaike weights of all models in the series including a particular variable (Table S3) [7].

Supplementary Tables

Table S1. Tag records used in analysis.

Year	**Tag ID**	**Whale ID**	**Sex, Reproductive Status**	**Tag Duration (hh:mm)**	**Dates (mm/dd)**	**Number of Dives Analyzed**	**Number of Ship Passages**
2006	mn06_192a	Division	F, Subadult	22:06	07/11 - 07/12	28	2
2006	mn06_195a	Fulcrum	F, Pregnant	10:43	07/14 - 07/15	22	1
2006	mn06_196a	Dyad	F, Lactating	21:47	07/15 - 07/16	16	2
2006	mn06_200c	Bilbo	F, Lactating	06:07	07/19	8	1
2008	mn08_182a	Lavalier	F, Pregnant	18:31	06/30 - 07/01	28	3
2008	mn08_184b	Nile	F, Pregnant	12:32	07/02 - 07/03	33	3
2008	mn08_189a	Falcon	M, N/A	17:00	07/07 - 07/08	20	1
2009	mn09_108a	Division	F, Resting	17:31	04/18 - 04/19	16	2
2009	mn09_201a	Entropy	F, Pregnant	15:07	07/20 - 07/21	22	1
2009	mn09_206b	Samovar	F, Resting	18:44	07/25 - 07/26	25	2

Table S2. Mixed-effect models used to assess change in response variables. Bolded models indicate ΔAICc < 2. SN = Ship noise present or absent and RL = received level of ship noise. k indicates number of free parameters in each model.

Response	Model	k	AICc	ΔAICc	w_i
Descent Rate	**RL**	**4**	**-389.91**	**0**	**0.59**
	RL, SN	**5**	**-388.56**	**1.35**	**0.30**
	RLxSN	6	-386.49	3.42	0.11
	SN	4	-375.76	14.15	0.00
	Null (random effects only)	3	-375.33	14.58	0.00
Ascent Rate	**RL, SN**	**5**	**-288.14**	**0**	**0.45**
	RLxSN	6	-286.10	2.03	0.16
	RL	4	-285.98	2.16	0.15
	Null (random effects only)	3	-285.94	2.20	0.15
	SN	4	-284.59	3.54	0.08
Number of Rolls	**RL**	**4**	**394.84**	**0**	**0.41**
	RL, SN	**5**	**395.49**	**0.65**	**0.30**
	Null (random effects only)	3	397.11	2.27	0.13
	RLxSN	6	397.37	2.53	0.12
	SN	4	399.16	4.31	0.05

Table S3. Variable importance for descent rate, ascent rate and number of rolls

Response	Variable	Variable Importance
Descent Rate	RL	0.89
	SN	0.30
	RLxSN	0.11
Ascent Rate	RL	0.61
	SN	0.53
	RLxSN	0.16
Number of Rolls	RL	0.71
	SN	0.34
	RLxSN	0.12

Supplementary Figures

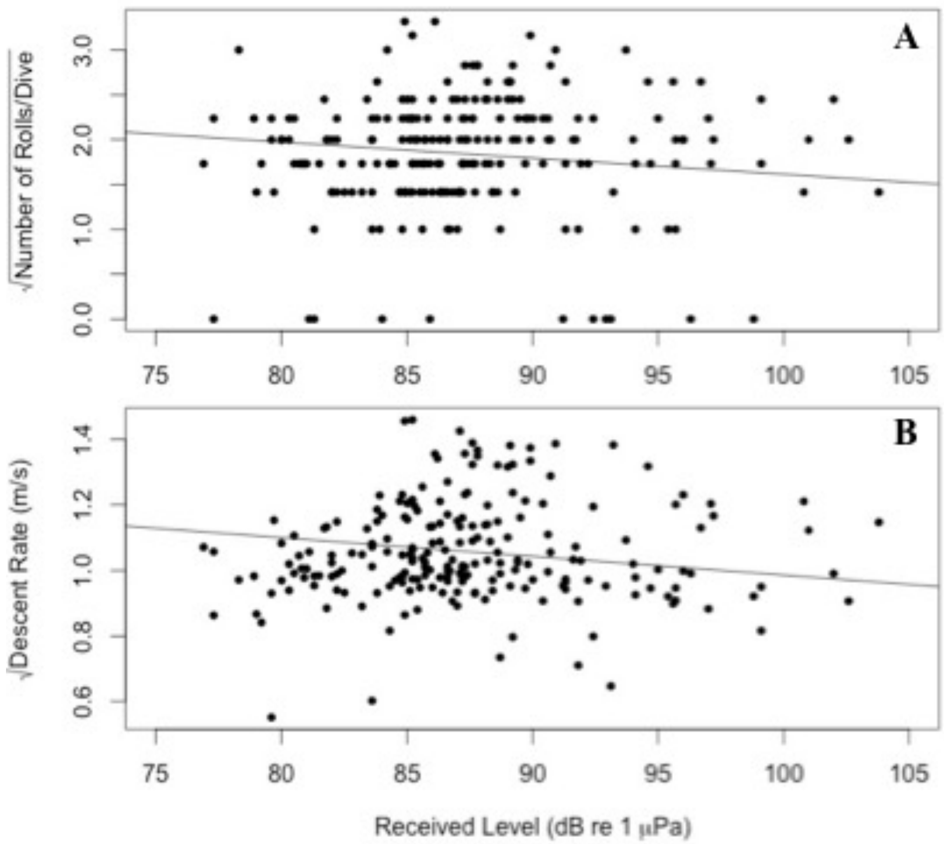

Figure S1. According to the respective best-fit models, as RL increased, A) number of rolls per dive decreased by 29% and B) descent rate decreased by 14.5%.

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