

The following supplement accompanies the article

Table 1. Severity scoring panel results. For each exposure session, the table provides the severity scores and their corresponding justification for the 8 behavioral response categories (avoidance response, orientation response, change in locomotion, change in dive profile, cessation of feeding, cessation of resting, change in vocal behavior, change in group distribution). For the scoring procedure, each exposure trial was initially assigned a random exposure ID to blindfold the scorers to the experimental condition (whale ID and exposure session ID). Scores of severity depend on the behavioral response category (e.g. change in dive profile) and the duration of the response (“Duration” given in min in the Table below) related to the exposure duration (detailed scale in Table 1). A score ‘0’ was given when a certain behavioral response category was assessed as a no behavioral change (no scored response). The signs ‘X’ and ‘/’ indicate unscorable potential responses, either because the required data was missing (‘X’) or because the animal behavior during the 60 min pre-exposure period (defined as ‘PRE’) precluded to assess potential changes in other types of behavior (‘/’), i.e. an animal feeding can’t be assessed for a potential cessation of resting and vice versa. The scores preceded by the sign ‘≥’ correspond to potentially under-estimated scores (e.g. cases for which the duration of an identified response was impossible to assess because the tag came off prematurely during the exposure). When assimilating their respective scores to reach consensus, both teams disagreed only in two scored responses (in bold) for which the adjudicator was needed (indicated in the ‘Comments’ column). Moreover, occasionally an identified behavioral change was difficult to classify as either a response to the exposure or a coincidental change. In these cases, both teams agreed to mark the score as a low confidence score (score annotated with ‘LC’) and provided justification (‘Comments’ column). Once the final scores were obtained, the experimental conditions were revealed as well as the onset times of the scored responses (given as ‘Onset time’ in hh:min UTC) and corresponding maximum received sound pressure levels (‘SPL_{max}’ in dB re 1μPa) and cumulated sound exposure levels (‘SEL_{cum}’ in dB re 1 μPa²s). Data of the 2 non-focal whales (sw17_182a and sw17_186a) are shown in grey.

Whale ID	Exposure Session ID (By Order of Exposures)	Avoidance Response	Orientation Response	Change in Locomotion	Change in Dive Profile	Cessation of Feeding	Cessation of Resting	Change in Vocal Behavior	Change in Group Distribution	Comments
Sw16_126a	CAS	X	0	0	0	0	/	0	0	
	MPAS	0	0	0	0	6 LC Moderate cessation of feeding: the animal stopped buzzing during exposure for two dive cycles, until after the end of exposure. Onset time: 00:11 Duration: 59 SPL _{max} : 116 SEL _{cum} : 118	/	4 LC Moderate change in vocal behavior: the animal stopped buzzing for roughly two dive cycles. Onset time: 00:11 Duration: 59 SPL _{max} : 116 SEL _{cum} :	X	Low confidence because cessation of buzzing also happened during baseline. Onset time is based on timing of expected first buzz based from PRE exposure dive pattern.

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	HPAS	X	0	0	0	/	/	0	X	
Sw16_13 0a	NS	X	0	0	0	0	/	0	X	
	MPAS	0	0	3 LC Minor change in locomotio n: the animal made a turn (no avoidance). Onset time: 13:15 Duration: > 30 SPL _{max} : 86 SEL _{cum} : 82	0	0	/	0	0	Low confidence because of the low quality of the track.
	CAS	X	0	0	0	0	/	0	X	
Sw16_13 1a	NS	X	0	0	0	0	/	0	X	
Sw16_13 4a	NS	X	≥0	≥ 2 At least brief change in locomotio n: there was an increase of speed up to 3 m/s, which was never reached by the animal during baseline. Onset time: 19:00 Duration: unknown, tag came off prematur ally, right after	≥ 2 At least brief cessation of resting dives: a bit before the tag came off (indicated by the increase of speed), the animal had a particular ly short surfacing period and went down to 20 m depth. Onset time: 19:00 Duration:	/	≥ 4 At least brief cessation of resting: the animal interrupt ed a resting dive pattern a bit before the tag came off. Onset time: 19:00 Duration : unknow n, tag came off prematur ally, right after	≥0	X	

				onset time (at about 22 min after the start of exposure)	unknown, tag came off prematur aly, right after onset time (at about 22 min after the start of exposure)		onset time (at about 22 min after the start of exposure)			
Sw16_13 4b	NS	X	0	0	0	0	/	0	0	
	CAS	0	0	0	0	0	/	2 Brief change of vocal behavior: the whale produced slow clicks later than expected during the surfacing event of the exposure period, i.e. at the middle of the surfacing period. This was an unusual timing compared to the productio n of slow clicks that occurred at the beginning of several surfacing	0	

								events during baseline. Onset time: 05:53 Duration: ~1 SPL _{max} : 142 SEL _{cum} : 158		
	HPAS	0	0	0	0	0	/	0	0	
	MPAS	≥ 5 At least minor avoidance response: based on the track, there was a clear turn away from the source that might have begun at 22 min after the start of exposure or earlier, and that lasted roughly until 50 min. Onset time: 11:28 Duration: 28-30 SPL _{max} : 146	0	0	0	0	/	0	0	

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		SEL _{cum} : 152								
Sw16_13 5a	NS	0	0	3 Minor change in locomotio n: the whale made a horizontal turn towards the source (based on the three last sightings of the surfacing around the end of exposure) . Onset time: 03:16 Duration: ~8	0	0	/	0	0	
	HPAS	5 Minor horizont al avoidan ce respons e: there was an avoidan ce turn and an increase of speed up to 2.5–3 m/s for roughly 20min. Onset time: 05:44 Duratio	1 Brief orientatio n response: the animal displayed a wiggle in the dive profile. Onset time: 05:37 Duration: 2 SPL _{max} : 141 SEL _{cum} : 142	0	3 Minor change in dive profile: the whale conducted a short surfacing period and a short dive during sonar. Onset time: 05:44 Duration: 14 SPL _{max} : 167 SEL _{cum} : 168	5 Minor cessation of feeding: the whale interrupted feeding activity during exposure (when the production of regular clicks stopped) for one dive. Onset time: 05:49 Duration: 16 SPL _{max} : 175 SEL _{cum} : 181	/	3 Minor change in vocal behavior: the whale produced codas at the first surfacing period during exposure (at about 16min after the start of the exposure) and stopped clicking and	≥3 At least brief change in group distributi on: group size switched from 1 animal (before start of exposure) to 2 animals during exposure, and then switched back to 1 animal after the	

		n: 20 SPL _{max} : 167 SEL _{cum} : 168						buzzing at the following dive. Onset time: 05:41 Duration: 24 SPL _{max} : 154 SEL _{cum} : 155	end of exposure. Duration of response lasted at least the duration of the first surfacing during exposure. Onset time: 05:41 Duration: ≥4 SPL _{max} : 154 SEL _{cum} : 155	
	CAS	X	0	0	2 Brief change in dive profile: the start of the ascent of the dive occurred earlier than expected compared to PRE exposure dive pattern. Onset time: 08:12 Duration: 4 SPL _{max} : 117 SEL _{cum} : 133	/	/	4 Moderate change in vocal behavior: the animal started to produce codas during exposure near the end of the ascent of the first dive, and produced also codas during the ascent of the next dive. Onset time: 08:14 Duration: 41 SPL _{max} : 119	X	

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								SEL _{cum} : 137		
	MPAS	0	0	0	0	0	/	0	0	
Sw16_13 6a	NS	0	1 Brief orientatio n response: at 15 min after the start of the exposure, the animal exhibited a wiggle in the dive profile together with a change in pitch/orie ntation and slowed down to near 0 m/s. Onset time: 03:52 Duration: ~1	0	0	0	/	0	0	
	CAS	X	0	0	0	0	/	0	X	
	MPAS	0	0	0	0	0	/	0	0	
	HPAS	0	0	0	0	/	/	2 Brief change in vocal behavior: the animal interrupte d clicking for several minutes. Onset time:	0	

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								11:23 Duration: 2 SPL _{max} : 174 SEL _{cum} : 178		
Sw17_17 9a	MPAS	0	0	0	0	0	/	2 Brief change in vocal behavior: the animal produced one coda at the start of the exposure. Onset time: 13:23 Duration: 1 SPL _{max} : 94 SEL _{cum} : 89	X	
	HPAS	0	0	0	0	0	/	0	X	
	CAS	0	0	0	0	0	/	0	X	
Sw17_18 0a	NS	0	0	0	0	0	/	0	0	
	HPAS	0	0	0	0	0	/	0	X	
	MPAS	0	1 Brief orientatio n response: at the end of the exposure (a bit before the clang sound productio n), the pitch went down to -80. Onset	0	0	0	/	2 Brief change in vocal behavior: the animal produced clangs and slow clicks at the end of the exposure. Onset time: 02:03 Duration: 3	X	

			time: 02:03 Duration: 1 SPL _{max} : 157 SEL _{cum} : 166					SPL _{max} : 157 SEL _{cum} : 166		
	CAS	0	0	0	0	0	/	2 Brief change in vocal behavior: the animal produced slow clicks during the descent of the dive at about 7 min before the end of exposure. Onset time: 04:17 Duration: 1 SPL _{max} : 146 SEL _{cum} : 164	X	
Sw17_18 2a	NS	0	0	0	0	/	0	0	X	
	MPAS	0	0	0	4 Moderate change in dive profile: the whale stopped the resting dive cycle and performed two unusual	/	6 Moderate interruption of resting: the animal was resting before the start of exposure	0	X	

					dives (one during exposure and another one after the end of exposure) . Onset time: 01:21 Duration: 34–47 SPL _{max} : 114 SEL _{cum} : 129		and switched to an atypical dive shape (at roughly 28 min from the start of exposure) showing many wiggles and a positive pitch. Onset time: 01:21 Duration : 34–47 SPL _{max} : 114 SEL _{cum} : 129			
	CAS	0	0	0	0	0	/	0	X	
	HPAS	0	0	0	0	0	/	2 LC Brief modification in vocal behavior: the animal produced regular clicks a bit later than expected compare to baseline. Moreover , the whale emitted slow clicks	X	A low confidence was assigned to the score because this was unusual compared to baseline but not unusual in regards to this sperm whale population.

								during the descent of the dive which looked an unusual timing compared to baseline Onset time: 05:52 Duration: 1 SPL _{max} : 104 SEL _{cum} : 105		
Sw17_18 2b	NS	0	0	0	0	0	/	0	0	
	MPAS	0	0	0	0	0	/	0	0	
	CAS	5 Minor avoidance response: the animal turned away from the source for roughly 20 min. Onset time: 03:47 Duration: 20 SPL _{max} : 149 SEL _{cum} : 161	0	0	2 Brief change in dive profile: the whale conducted a particularly shallow and short dive between the two usual feeding dives. Onset time: 03:39 Duration: 3 SPL _{max} : 114 SEL _{cum} : 114	0	/	2 Brief change in vocal behavior: the whale produced codas during the first surfacing of the exposure period, for a bit less than 5 min. Onset time: 03:36 Duration: ~4 SPL _{max} : 114 SEL _{cum} : 114	0	
	HPAS	≥0	≥0	≥0	≥0	≥0	/	≥ 3 At least minor	≥0	

								<p>change in vocal behavior: the whale produced slow clicks at the middle of the ascent of the dive, which was earlier and deeper than expected compared to the baseline pattern. Moreover , the whale produced slow clicks during the descent which was unusual. Onset time: 05:42 Duration: at least 17 min. The duration of the response could not be assessed because the tag came off prematur</p>		
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								ely. SPL _{max} : 108 SEL _{cum} : 114		
Sw17_18 4a	NS	0	0	0	0	0	/	0	X	
	CAS	0	0	0	0	0	/	0	X	
	HPAS	0	0	0	0	0	/	0	X	
Sw17_18 6a	NS	0	0	0	0	0	/	0	X	Adjudicator needed for potential orientation response.
	HPAS	0	0	0	0	0	/	0	X	
	CAS	0	0	0	0	0	/	0	X	
Sw17_18 6b	NS	0	1 Brief orientatio n response: there was a change in pitch at the time of the clang emission. Onset time: 04:19 Duration: ~1	0	0	0	/	2 Brief change in vocal behavior: the whale produced clangs and slow clicks near the surface at 8–9 min after the start of exposure. Onset time: 04:19 Duration: ~1	X	
	HPAS	0	0	0	0	0	/	0	0	
	CAS	0	2 Minor orientatio n response: the whale conducted an unusual very shallow dive that started at about 25	3 Minor change in locomotio n: the animal turned towards the sound source. Onset time: 10:46 Duration:	3 Minor change in dive profile: the whale conducted an unusually shallow foraging dive that started at about	5 Minor cessation of feeding: there was a long interval between two foraging dives. Onset time: 10:58 Duration: 13 min SPL _{max} : 156	/	2 Brief change in vocal behavior: the whale produced trumpet sound about 1min before the end of exposure.	0	

			min after the start of exposure. Onset time: 10:58 Duration: 3 SPL _{max} : 160 SEL _{cum} : 177	~13 min SPL _{max} : 124 SEL _{cum} : 138	8min after the start of exposure. Onset time: 10:39 Duration: 30 SPL _{max} : 102 SEL _{cum} : 114	SEL _{cum} : 177		Onset time: 11:12 Duration: ~2 SPL _{max} : 174 SEL _{cum} : 189		
	MPAS	0	0	0	0	0	/	0	0	Adjudicator needed for potential avoidance response.
Sw17_18 8a	NS	0	0	0	0	0	/	0	0	
	MPAS	0	1 Brief orientation response: at the beginning of the foraging dive during exposure, the animal started an ascent and then went more vertically deeper. Onset time: 20:40 Duration: ~5 SPL _{max} : 105 SEL _{cum} : 111	0	0	0	/	0	X	
	HPAS	0	0	0	0	0	/	0	X	
	CAS	0	0	0	3	0	/	2	0	

					Minor change in dive profile: at 18 min after the start of exposure, the animal performed a particularly short surfacing period followed by one unusual dive. Onset time: 00:57 Duration: ~12 SPL _{max} : 152 SEL _{cum} : 163			Brief change in vocal behavior: the animal emitted two slow clicks at the middle of the first surfacing which was an unusual timing compared to baseline. Onset time: 00:54 Duration: 1 SPL _{max} : 137 SEL _{cum} : 152		
	CAS	0	0	0	4 Moderate change in dive profile: we would have expected the animal goes down for another wiggle with buzz production. Onset time: 03:20 Duration: 48	0	/	4 Moderate change in vocal behavior: there were less buzzes than expected. Onset time: 03:20 Duration: 48 SPL _{max} : 159 SEL _{cum} : 173	0	

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					SPL _{max} : 159 SEL _{cum} : 173					
Sw17_19 1a	NS	0	0	0	3 LC Minor change in dive profile: the whale conducted an unusually shallow feeding dive. Onset time: 21:33 Duration: 22	0	/	0	X	Low confidence because this shallow feeding dive occurred also during baseline, although this one occurring during baseline might have been due to pilot whale presence.
	HPAS	6 Moderate horizontal avoidance: the animal moved away at the surface based on pitch. Onset time: 01:19 Duration: ~31 SPL _{max} : 158 SEL _{cum} : 161	0	0	4 Moderate change in dive profile: at the end of its dive, the animal remained at surface for an unusual long period. Time: Onset time: 01:19 Duration: ~31 SPL _{max} : 158 SEL _{cum} : 161	6 Moderate cessation of feeding: the whale should have come back to a foraging dive earlier, and did not start feeding again until after the end of exposure. Onset time: 01:32 Duration: ~19 SPL _{max} : 163 SEL _{cum} : 171	/	2 Brief change of vocal behavior: the whale produced few clicks during the ascent of the dive at around 17 min after the start of exposure. Onset time: 01:18 Duration: 1 SPL _{max} : 158 SEL _{cum} : 161	0	
	MPAS	0	2 Minor change in orientation	0	4 Moderate change in dive	6 Moderate cessation of feeding: the	/	4 Moderate change in vocal	0	

			n behavior: the animal made a slow turn to the direction of the source and moved roughly towards it until the ship had passed. Onset time: 04:36 Duration: 7–8 SPL _{max} : 138 SEL _{cum} : 143		profile: the whale conducted a small shallow dive during exposure followed by another very shallow dive (resting) after the end of exposure. Onset time: 04:36 Duration: 45 SPL _{max} : 138 SEL _{cum} : 143	animal interrupted a cycle of deep foraging dives. Onset time: 04:40 Duration: 39 SPL _{max} : 147 SEL _{cum} : 152		behavior: the whale produced unusual slow clicks during the ascent and at bottom of the shallow dive, and ceased buzzing until 64min after the start of exposure. Onset time: 04:42 Duration: 37 SPL _{max} : 152 SEL _{cum} : 156		
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Table S2. Results of the ANOVA (sequential Wald test) showing the contribution of each factor to the final fitted GEE models applied to the ‘Proportion of scored responses’. Two GEE models were applied, one with the factor Signal having 2 levels (NS and Sonar), and one with Signal having 4 levels (NS, CAS, HPAS, MPAS). The full models included the three factors Signal (2 or 4 factor levels), Order (2 factor levels: ‘1st’ and ‘diff_1st’) and Blackfish (variable corresponding to the time needed at the start of the exposure to fully recover since last “blackfish” event, assuming full recovery lasts 15 hours). The NS and first sonar exposure sessions were assigned as first exposures (‘1st’) whereas the subsequent sonar exposures were assigned as different than first (‘diff_1st’). Only the factors Signal and Blackfish were retained in the best fitting model. The factor Order was not retained in the best GEE model, indicating that there was no effect of the first versus the subsequent exposures on the proportion of scored responses.

Factors of the best fitting GEE models	χ^2	p-value
Signal (2 levels: NS and Sonar)	4.58	0.032*
Blackfish	9.69	0.0019**
Signal (4 levels: NS, CAS, HPAS, MPAS)	9.8	0.036*
Blackfish	10.8	0.0014**

CAS: Continuous Active Sonar; MPAS: Medium-level Pulsed Active Sonar; HPAS: High-level Pulsed Active Sonar; NS: No-Sonar control.
*p < 0.05 ; **p < 0.01.

Table S3. Results of the GEE models fitted to the ‘Proportion of scored responses’ variable. Each GEE model corresponds to the best fitted model selected from results of the ANOVA (see Table S2). P-values and coefficient estimates are provided. For the factor Signal, these values represent the paired difference between factor levels (each factor level vs. the considered reference factor level). For the Blackfish covariate, the coefficient estimate corresponds to the expected change in the proportion of scored responses when increasing by an hour the time needed by the animal to fully recover (assuming full recovery since a blackfish event lasts 15 h).

Factors of the Best Fitting GEE Models	Coefficient Estimate \pm SD; p-value		
Signal (2 levels: NS, Sonar)	Sonar vs. NS 0.9236 \pm 0.4317; p = 0.0324*		
Blackfish	0.0875 \pm 0.0281; p = 0.0019**		
Signal (4 levels: NS, CAS, HPAS, MPAS)	CAS vs. NS 1.2360 \pm 0.4562; p = 0.0067**		
	MPAS vs. NS 0.8386 \pm 0.6723; p = 0.2123	MPAS vs. CAS -0.3974 \pm 0.6246; p = 0.5246	
	HPAS vs. NS 0.6572 \pm 0.5944; p = 0.2688	HPAS vs. CAS -0.5788 \pm 0.6535; p = 0.3758	HPAS vs. MPAS -0.1814 \pm 0.7127; p = 0.799
Blackfish	0.0934 \pm 0.0285; p = 0.0010**		

See Table S2 for definition of abbreviations CAS, MPAS, HPAS, NS.

*p < 0.05; **p < 0.01

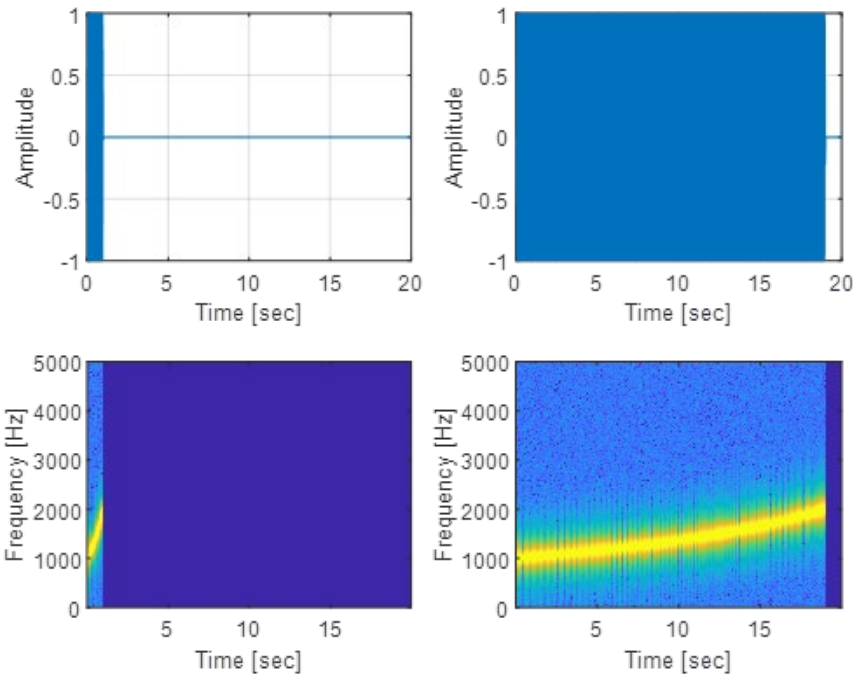


Figure S1. Amplitude (arbitrary unit) and frequency (Hz) over time (s), at top and bottom respectively, for both PAS (left) and CAS (right) signals. PAS is composed of a 1 s-pulse signal followed by 19 s silence. CAS is composed of a longer 19 s-signal followed by 1 s silence. PAS: Pulsed Active Sonar; CAS: Continuous Active Sonar.

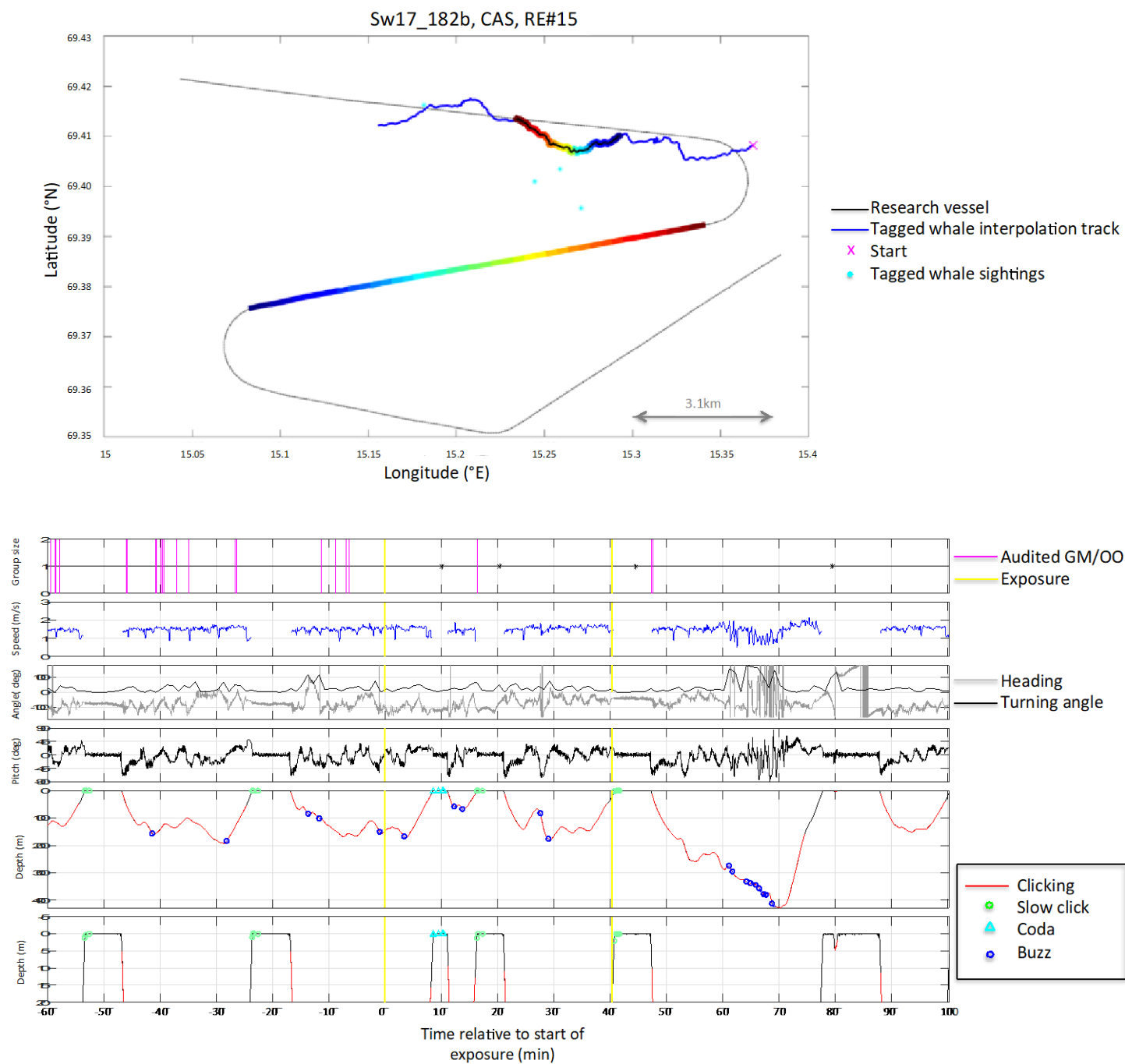


Figure S2. Example of standardized data plots of the tagged sperm whale sw17_182b during the time period from 60 min prior to a CAS exposure (random exposure RE #15) to 60 min after the exposure. The upper panel shows the geographic tracks of the research vessel and the tagged whale. The temporal progression of the whale and vessel tracks during the exposure period were coded using a similar color gradient, with blue and red indicating the position at the start and end of the exposure, respectively. The lower panel shows the time series plots for the following behavioral variables: group size, swim speed, heading and turning angle, pitch and depth. Moreover, whale sounds are indicated on the dive profile: regular echolocation clicks indicated as “clicking”, slow clicks, codas and buzzes. The start and end of the exposure period are indicated with yellow vertical lines. Magenta vertical lines indicate sounds of blackfish species heard on the tag, i.e. audited long-finned pilot whales (GM for *Globicephala melas*) and/or killer whales (OO for *Orcinus orca*). To follow a blinding procedure of the severity scoring, the experimental conditions (whale ID, type of exposure) were revealed only after the two teams had reached a consensus on the scored putative responses. Un-blinded data plots of all tagged whales are published in Kvadsheim et al. 2021 [18].

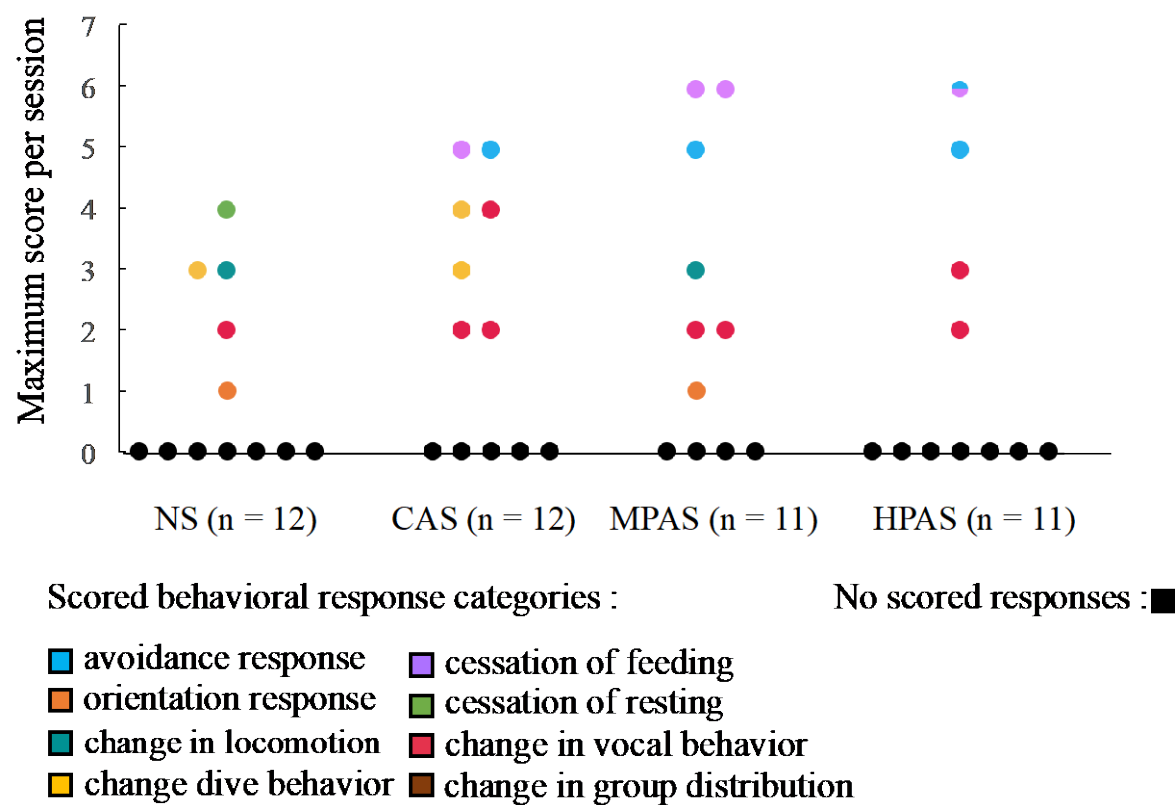


Figure S3. Maximum score of severity per session across the 4 exposure types (NS, CAS, HPAS and MPAS) for the total number of exposure sessions (N = 46). Each dot represents the max score for a given exposure session, labeled with a color code representing the corresponding scored behavioral response category (e.g. in blue for avoidance response) or indicating sessions with no scored responses (in black). For instance, the purple dot assigned with a max score 5 for one of the CAS exposure sessions, corresponds to cessation of feeding. Bicolored dots correspond to exposures with a max score represented twice, i.e. for 2 different behavioral response categories. For instance, the half blue/half purple dot represented with a max score of 6 for one of the HPAS exposure sessions correspond to an exposure for which two max scores of 6 were attributed, one corresponding to an avoidance response and the other one to a cessation of feeding. In this graph, the focal dataset of all 8 assessed behavioral response categories (including the ‘cessation of resting’) is represented. n: number of exposure sessions. See Table S2 for definition of abbreviations CAS, MPAS, HPAS, NS.

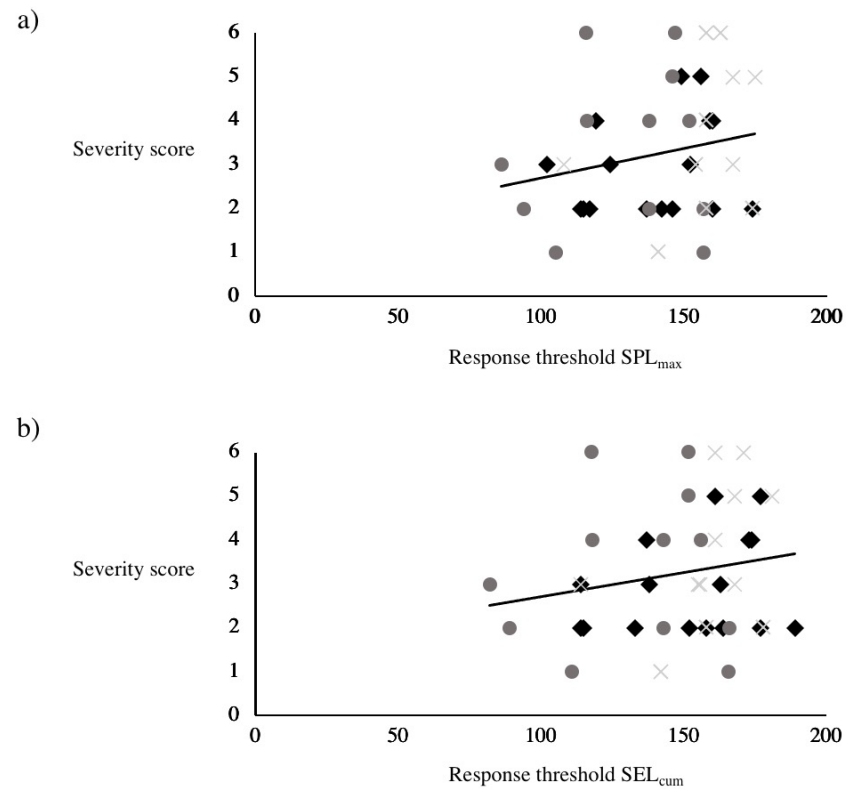


Figure S4. Severity of the 40 scored behavioral responses of the focal whale dataset versus received level thresholds of the corresponding response onsets across the three types of sonar exposures CAS (diamond), MPAS (circle) and HPAS (cross). Received levels thresholds are given as **(a)** maximum sound pressure levels (SPL_{max} , in dB re 1 μPa), and **(b)** cumulated sound exposure levels (SEL_{cum} , in dB re 1 $\mu Pa^2 s$). Linear trend lines are represented for each cluster a and b, i.e. severity scores versus SPL_{max} ($y = 0,0136x + 1.334$) and versus SEL_{cum} ($y = 0,0109x + 1.6243$).