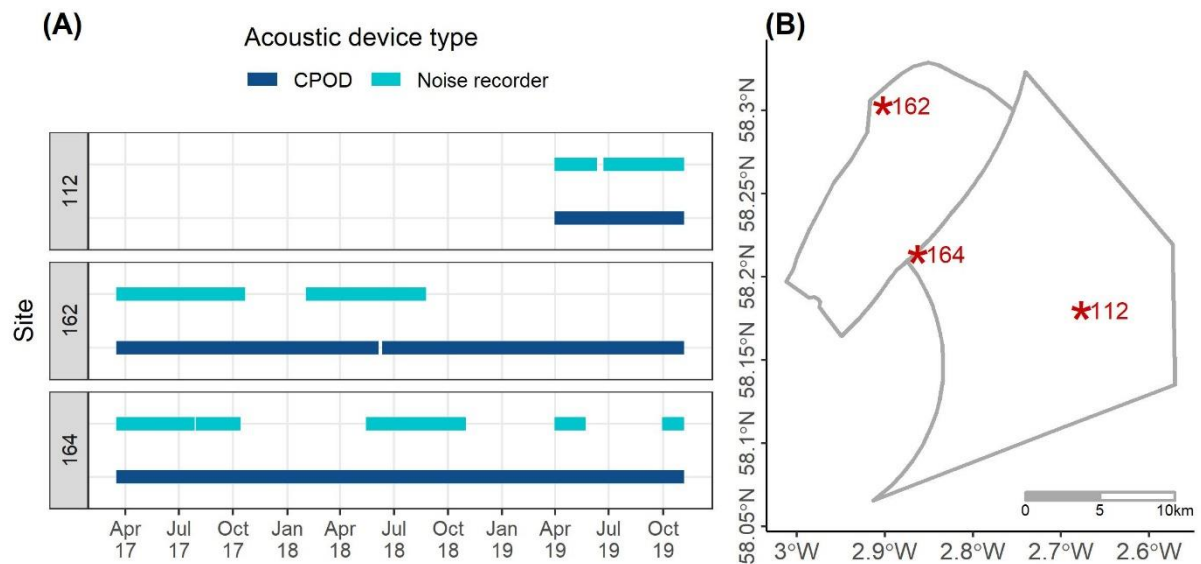


Supplementary Material

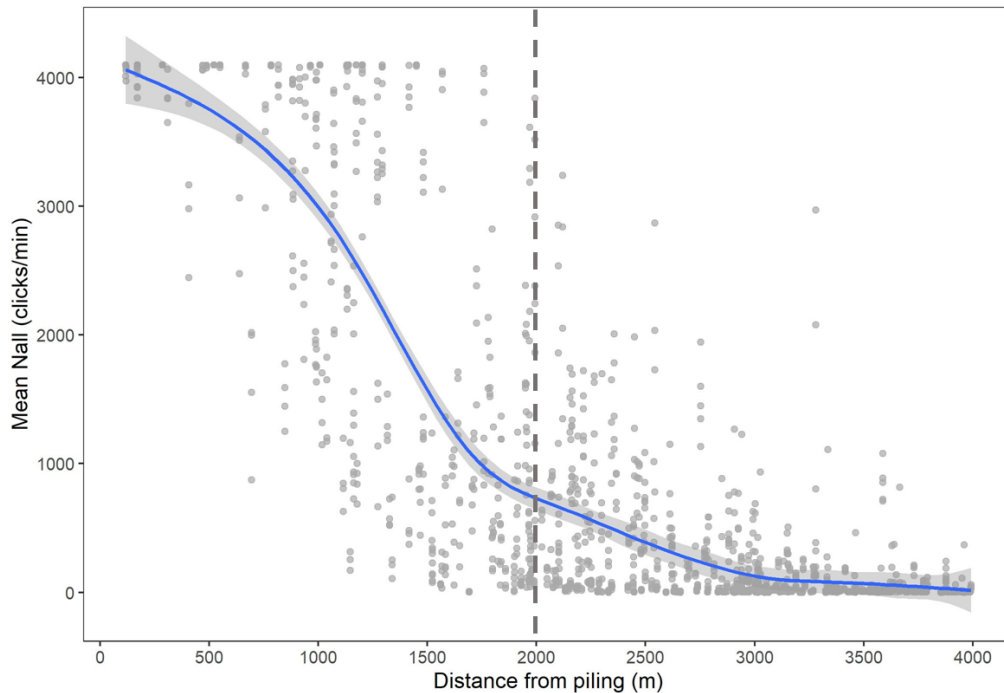
1 Supplementary Figures and Tables

1.1 Supplementary Figures

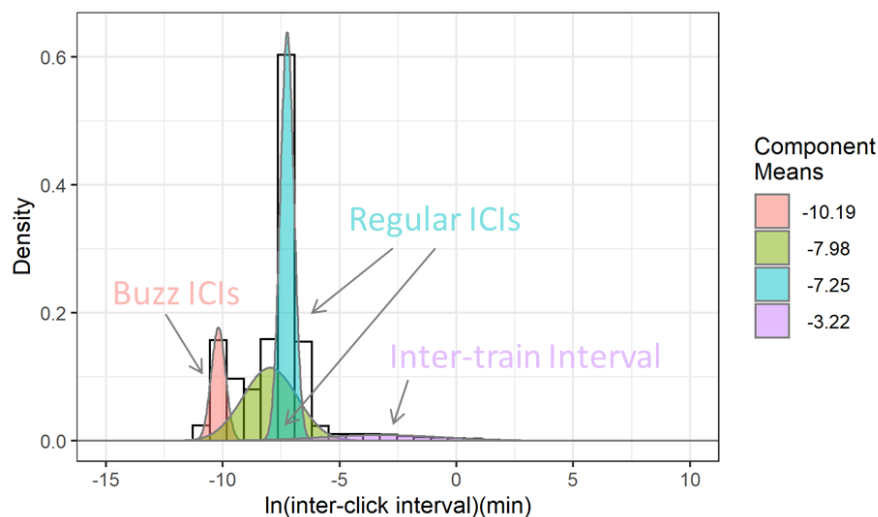


Supplementary Figure 1 (A) Passive Acoustic Monitoring timeline at three long-term monitoring sites to detect echolocation clicks with CPODs (in dark blue) and record underwater broadband noise levels with noise recorders (in light blue) **(B)** Noise recorders locations (in red) within the two offshore windfarms (grey line)

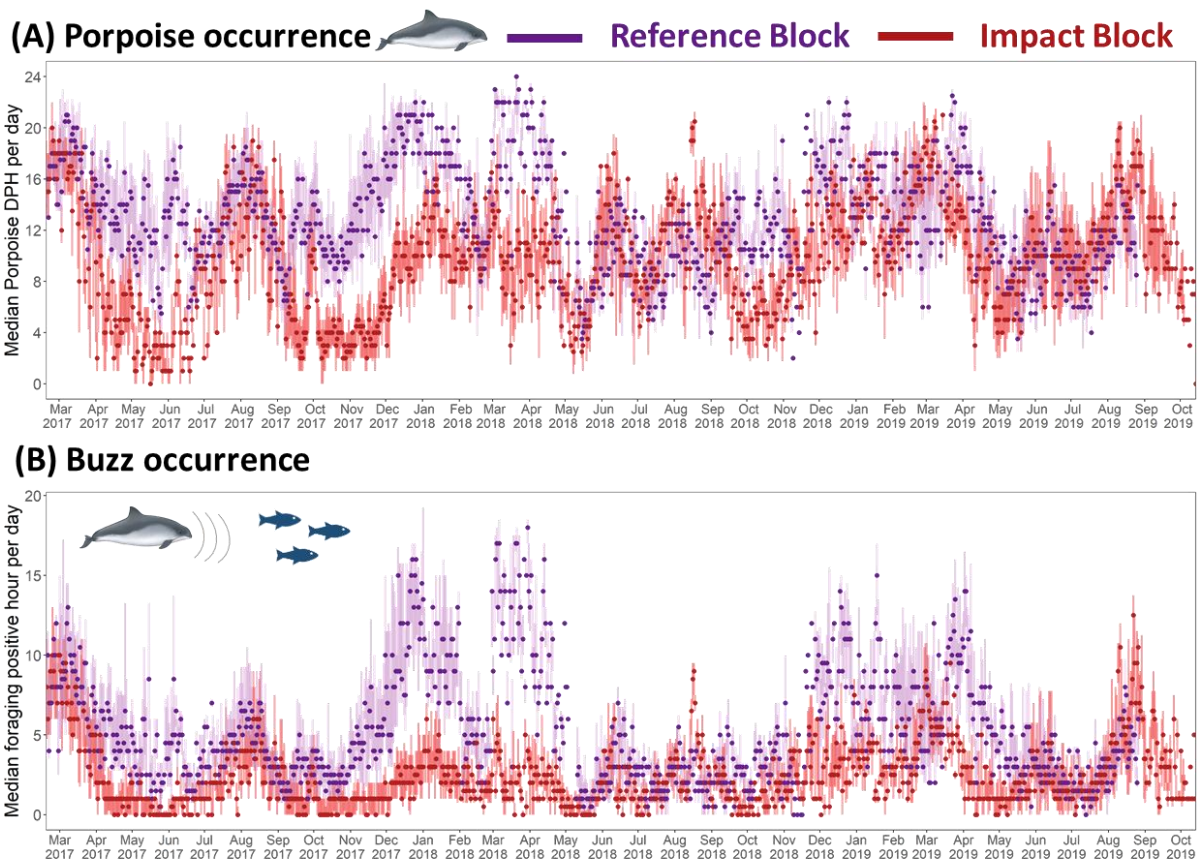
Mean Nall during all piling events in 2017 (02/04-02/12/2017)
from 36 deployments and 30 sites



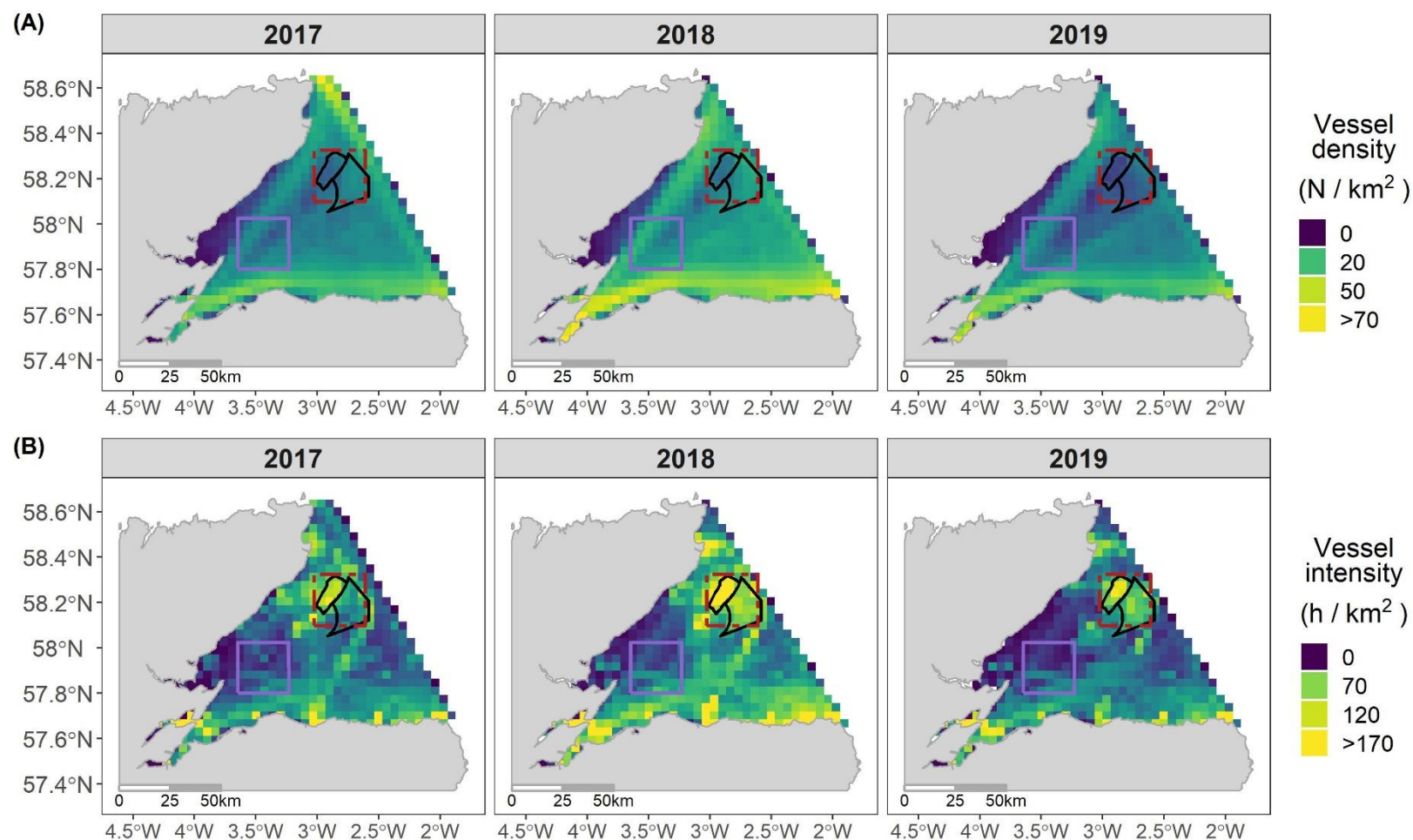
Supplementary Figure 2 Mean number of clicks per minute (Nall) (grey dots) at four sites in relation to distance from pile-driving locations for all pile-driving events at Beatrice offshore windfarm in 2017; the blue curve has been automatically fitted to the raw data using a loess smoother and shaded areas represent uncertainty; the grey dotted line represents the distance (2km) from pile-driving locations at which we estimate CPOD saturation to be unlikely



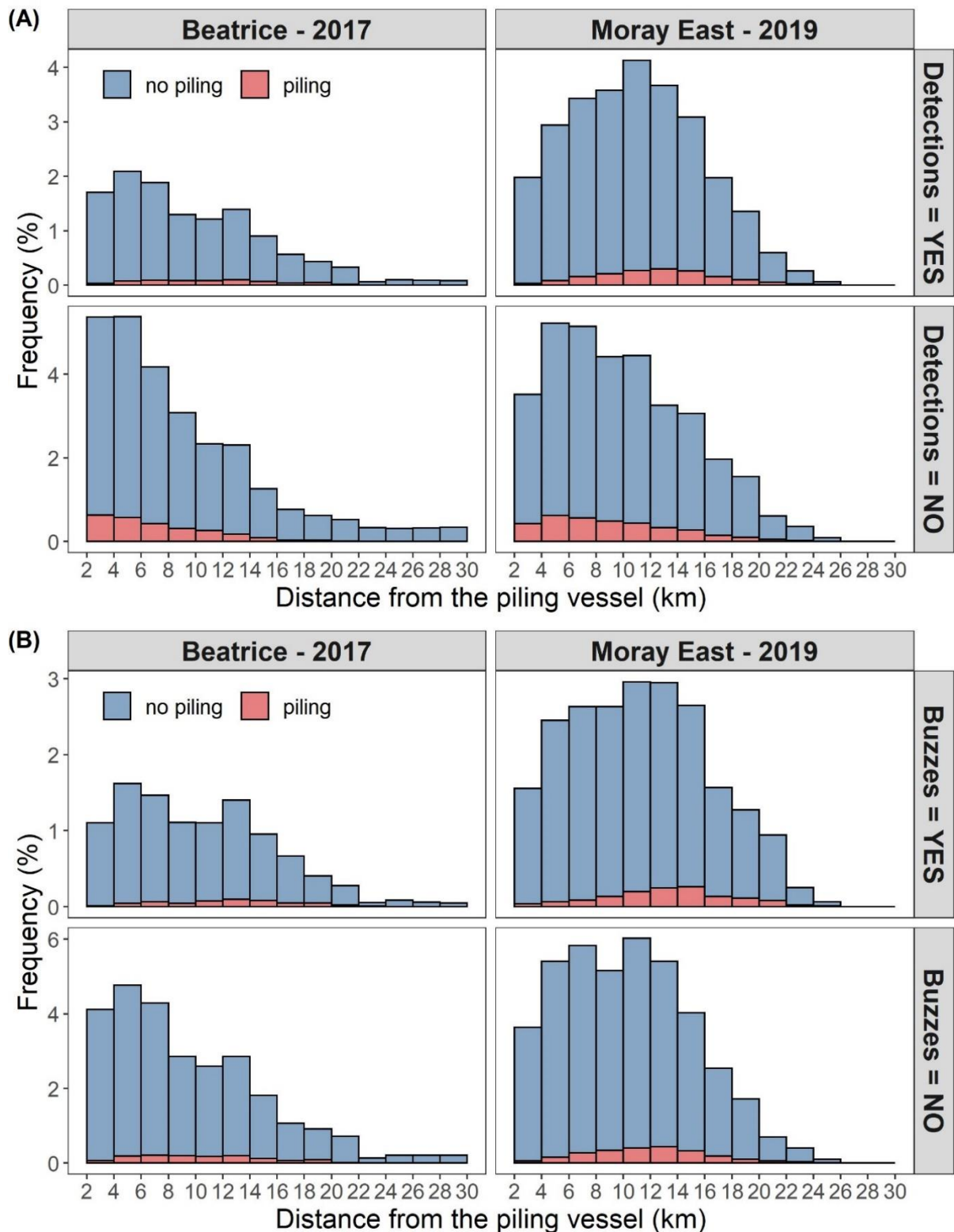
Supplementary Figure 3 Example of the results of a Gaussian mixture model using four components for one CPOD Inter-Click Interval (ICI) time series, following Pirotta et al. (2014). The buzz ICIs are represented in pink, the regular ICIs in blue and green, the inter-train intervals in purple. The x-axis represents the natural logarithm of the ICIs in minutes.



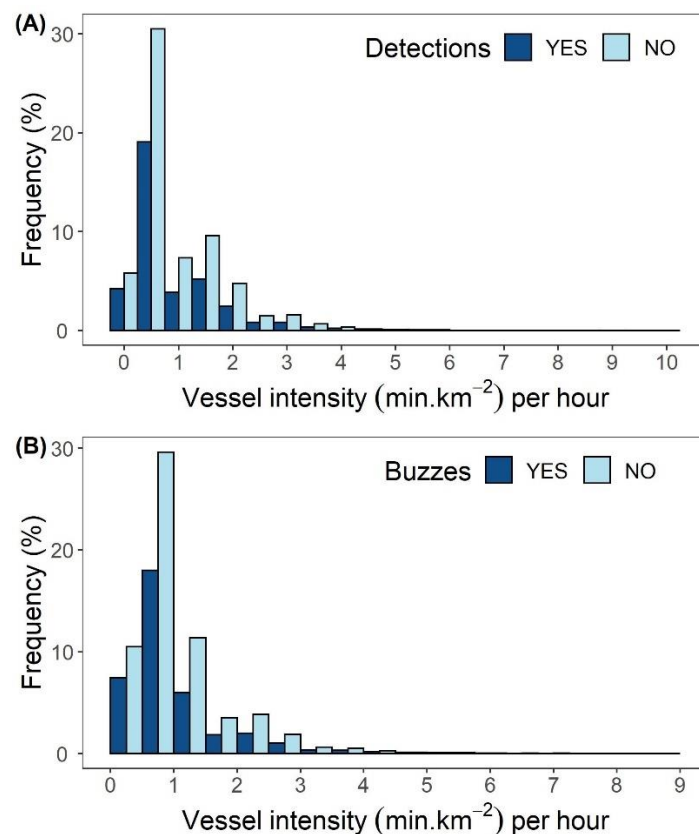
Supplementary Figure 4 Median harbour porpoise **(A)** detections per hour (DPH) and **(B)** foraging positive hours per day within the reference (in purple) and impact (in red) blocks between March 2017 and October 2019; the dots represent the median and the lines represent the first and third quantile



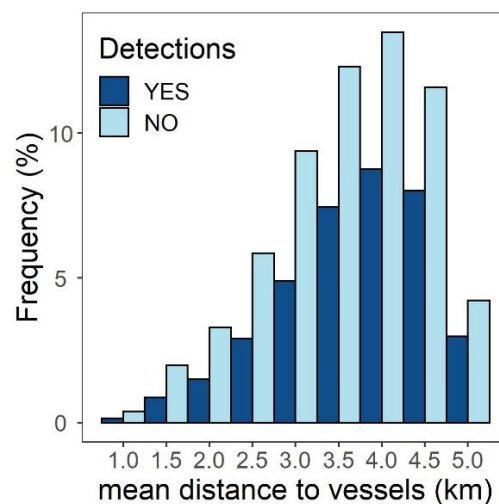
Supplementary Figure 5 Vessel density **(A)** and intensity **(B)** in the Moray Firth (4 x 4 km grid) between 2017 and 2019; the Beatrice and Moray East offshore windfarms are represented in black in the impact block (dashed red line) and the reference block is in purple.



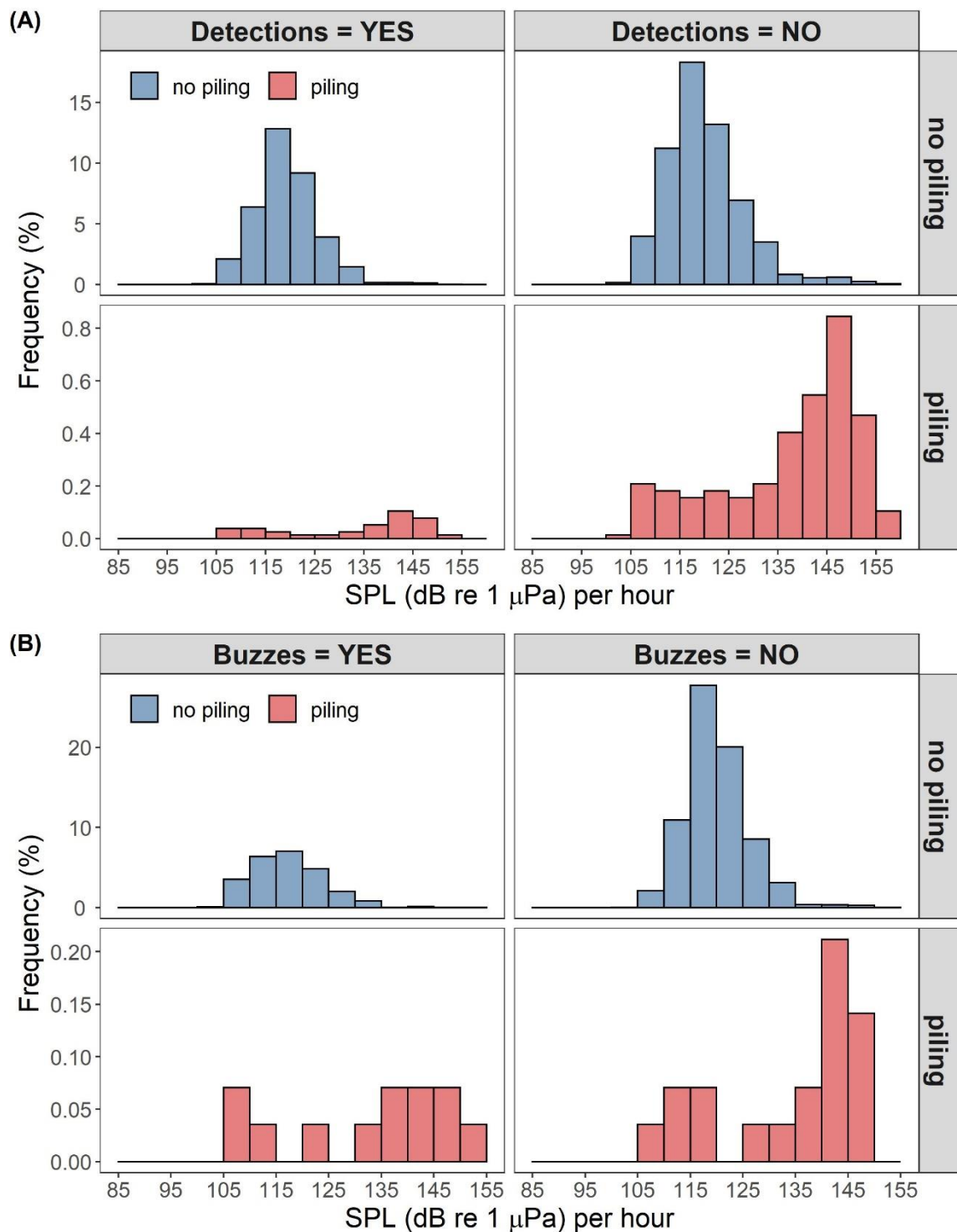
Supplementary Figure 6 Frequency distribution of the distance from the piling vessel (km) during (in red) and outside (in blue) piling hours, in presence-absence of harbour porpoise echolocation click detections **(A)** and buzzing activity **(B)**, between 2017 and 2019 at the Beatrice and Moray East offshore windfarms



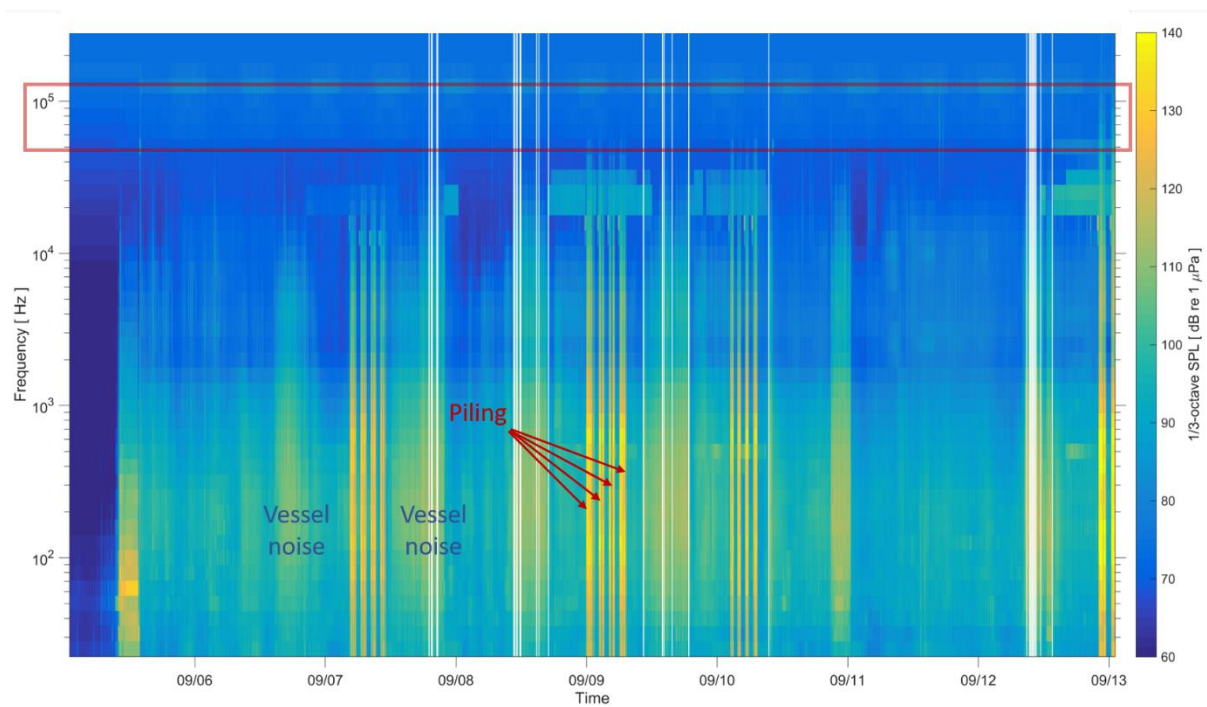
Supplementary Figure 7 Frequency distribution of the vessel intensity (min/km²) per hour, in presence (dark blue) or absence (light blue) of harbour porpoise echolocation click detections **(A)** and in presence (dark blue) or absence (light blue) of buzzes **(B)**, between 2017 and 2019 at the Beatrice and Moray East offshore windfarms



Supplementary Figure 8 Frequency distribution of the mean distance between any vessels and each CPOD per hour, in presence (dark blue) or absence (light blue) of harbour porpoise echolocation click detections between 2017 and 2019 at the Beatrice and Moray East offshore windfarms



Supplementary Figure 9 Frequency distribution of the broadband sound pressure level (SPL) per hour during (in red) and outside (in blue) piling hours, in presence-absence of harbour porpoise echolocation click detections **(A)** and buzzing activity **(B)**, between 2017 and 2019 at the Beatrice and Moray East offshore windfarms



Supplementary Figure 10 1/3 octave band spectrogram to highlight variability in noise levels between 5 and 13 September 2017 at Beatrice offshore windfarm, 60-s resolution; at high frequencies (red box) both piling and vessel noise are below ambient noise levels.

1.2 Supplementary Tables

Supplementary Table 1 Date of the key construction activities at Beatrice and Moray East offshore windfarms between April 2017 and February 2020

Construction Activity	Windfarm	Time-period (dd/mm/yyyy)
Piling Jacket Foundation Installation Turbine Installation Piling	Beatrice	02/04/2017 - 02/12/2017
	Beatrice	13/08/2017 - 11/07/2018
	Beatrice	14/07/2018 - 14/05/2019
	Moray East	20/05/2019 - 27/02/2020

Supplementary Table 2 Metadata of the noise recorder deployments used in the analyses

Deployment	Location	Device Type	Recording (ON/TOTAL) period (mins)	Pre-amp gain	Sample rate (kHz)	Lat	Long	Date data started	Date data ended	Depth (m)
760	162	SoundTrap	10/30	HIGH	96	58.3033	-2.9019	17/03/2017	21/05/2017	62
761	164	SoundTrap	10/30	HIGH	96	58.2139	-2.8615	17/03/2017	21/05/2017	40.9
790	164	SoundTrap	10/30	HIGH	96	58.2137	-2.8620	21/05/2017	28/07/2017	41
791	162	SoundTrap	10/30	HIGH	96	58.3030	-2.9019	21/05/2017	31/07/2017	63
887	162	SoundTrap	10/30	HIGH	96	58.3029	-2.9021	31/07/2017	22/10/2017	63
888	164	SoundTrap	10/30	HIGH	96	58.2138	-2.8612	30/07/2017	13/10/2017	41.1
917	162	SM2M	10/60		96	58.3030	-2.9013	02/02/2018	23/06/2018	62
958	162	SoundTrap	10/30	HIGH	96	58.3032	-2.9010	11/06/2018	25/08/2018	62
959	164	SM2M	10/60		96	58.2136	-2.8616	15/05/2018	31/10/2018	40
987	112	SoundTrap	No duty cycle	HIGH	48	58.1798	-2.6754	31/03/2019	11/06/2019	51
1032	164	SoundTrap	No duty cycle	HIGH	48	58.2136	-2.8613	31/03/2019	23/05/2019	41
1041	112	SM2M	10/60		96	58.1798	-2.6756	22/06/2019	06/11/2019	51

Supplementary Table 3 Construction-related vessel information based on AIS data, Marine Traffic and Metcalfe et al. (2018)

Name	MMSI	IMO	Call sign	Vessel type name	Vessel category based on Metcalfe et al. (2018)	Vessel type detailed	Function during windfarm construction	Length overall x breadth extreme	Gross tonnage	Web-link
APOLLO	253586000	9769764	LXBP	Other Type	Unassigned	Offshore Supply Ship	Offshore Heavy Lift DP2 jack up Vessel	89.28 x 42.02 m	10510	link
ARAMIS	257167000	0	LDEH	Diving ops	Offshore service vessels	Dive vessel	Dive Support Vessel	16 x 5 m	-	link
ARTEMIS	235006582	8644802	2SNV	-	Unassigned	Trawler	Guard Vessel	23.13 x 6 m	131	link
ATLANTIC TONJER	374032000	7008025	MLPD5	Fishing	Fishing vessels	Multipurpose Offshore Vessel	Multipurpose Offshore Vessel; Boulder clearance	80.77 x 18 m	3349	link
ATLANTIS	205231000	9139139	ORKN	-	Unassigned	Motor Hopper	Motor Hopper Vessel - rock placement operations	80.06 x 22.06 m	1998	link
ATLAS WY 101	235001670	8792415	MPUD 3	Fishing	Fishing vessels	Fishing Vessel	Guard Vessel	20 x 6 m	-	link
BKM 103	212492000	0	5BFL2	Other Type	Unassigned	Tug	Multicat Tug	26.5 x 11 m	185	link
BLUE CASTOR	220294000	6403424	OUKR2	Other Type	Unassigned	Pollution Control Vessel	Pollution Control Vessel - Pre-Lay Grapnel Run	46.02 x 7.95 m	720	link
BOA SUB C	257342000	7814656	MJLF4	Fishing	Fishing vessels	Multipurpose Offshore Vessel	Multipurpose Offshore Vessel; Soil plug removal /Grouting	138.5 x 30.64 m	16562	link
BOUNTIFUL	232004846	9656644	LAFR8	Other Type	Unassigned	Fishing Vessel	Guard Vessel	22 x 7 m	-	link
BREMEN FIGHTER	304742000	9321287	V20Y1	Tug	Port service craft	Tug	Heavy Lift Vessel	48.81 x 14.06 m	1262	link
BUGSIER 10	218321000	9429560	DFWB2	Tug	Port service craft	Tug	Barge Tow Vessel	32 x 12.6 m	485	link

Name	MMSI	IMO	Call sign	Vessel type name	Vessel category based on Metcalfe et al. (2018)	Vessel type detailed	Function during windfarm construction	Length overall x breadth extreme	Gross tonnage	Web-link
CENTAURUS	305820000	9433755	V2ED3	Tug	Port service craft	Anchor Handling Vessel	Barge Tow Vessel	48.81 x 14.06 m	1262	link
C-FENNA	232008023	9675963	MBAH3	Tug	Port service craft	Utility vessel	Buoy maintenance - cabling activities	26.48 x 11 m	255	link
C-ODYSSEY	235088132	9636307	2ETW7	Other Type	Unassigned	Utility vessel	trenching/boulder moving - Utility Vessel	25.55 x 11 m	150	link
CORAL WIND	235086491	0	2EMX8	-	Unassigned	Reserved	Workboat	14 x 5 m	-	link
EDT KENNEDY	210779000	8205620	HOBO	Other Type	Unassigned	Offshore Supply Ship	DP 2 ROV Support Vessel	75 x 17.25 m	2948	link
EGESUND	219012959	9059248	OWEQ2	Tug	Port service craft	Tug	Towing Vessel	22.5 x 7.7 m	136	link
ERACLEA	247278500	9499656	IITX2	Tug	Port service craft	Tug	Barge Tow Vessel	50 x 15 m	1397	link
FLINTSTONE	245861000	9275153	LAGE8	Other Type	Unassigned	Pipe Burying Vessel	Pipelay/ Boulder Clearance and Scour Protection installation	154.6 x 32.23 m	21710	link
FORTH CONSTRUCTOR	235004217	0	GXAD	Tug	Port service craft	Work Vessel	Tunnelling and seabed preparation	28.5 x 9.5 m	265	link
FORTH WARRIOR	235116011	9803742	2JHR8	Tug	Port service craft	Tug	boulder moving - Utility Vessel	27 x 12 m	-	link
GV MORNING DAWN	232253000	8701416	MHEU3	Wing in ground	Unassigned	Standby Safety Vessel	Guard Vessel - Standby Safety Vessel	45 x 9 m	499	link
GENESIS	235008110	0	MGGT9	Other Type	Unassigned	Fishing Vessel	Guard Vessel	30.23 x 6 m	298	link
GV SEAGULL	233714000	9112545	MVBO2	Other Type	Unassigned	Fishing Vessel	Guard Vessel	30 x 8 m	349	link
GV HEATHERBELLE	235004610	0	MAEK9	-	Unassigned	Trawler	Guard Vessel	20.87 x 6 m	127	link

Name	MMSI	IMO	Call sign	Vessel type name	Vessel category based on Metcalfe et al. (2018)	Vessel type detailed	Function during windfarm construction	Length overall x breadth extreme	Gross tonnage	Web-link
GV MOREMMA	235007170	0	MKHC6	Fishing	Fishing vessels	Other	Guard Vessel	15 x 5 m	-	link
GV REPLENISH	235055180		5BAJ4	Other Type	Unassigned	Fishing Vessel	Guard Vessel	24.45 x 48 m	158	link
GV RESPLENDENT	235018597	8825341	MJUJ2	Other Type	Unassigned	Fishing Vessel	Guard Vessel	25.41 x 6.43 m	155	link
GV SHEMARAH II	232007650	9120889	MVRR7	Anti-pollution equipment	Port service craft	Trawler	Guard Vessel	27 x 8 m	301	link
GV FISHER BOYS	234750000	0	MXHY7	Fishing	Fishing vessels	Fishing Vessel	Guard Vessel	20 x 6 m	-	link
GV PLEIADES BF155	235069008	0	2BSR7	Diving ops	Offshore service vessels	Fishing Vessel	Guard Vessel	18 x 6 m	-	link
HAVEN SEAJACK 3	235089873	0	2UQQ	Dredging	Offshore service vessels	Dredger	-	34 x 11 m	-	link
HAVEN SEARISER	235075576	0	2HFO4	Dredging	Offshore service vessels	Dredger	Jack Up Barge - Dredger	18 x 18 m	-	link
HAVILA VENUS	259305000		LAZC	Other Type	Unassigned	Offshore Supply Ship	Offshore supply ship	92 x 22 m	6455	link
ISLE OF JURA	232021966	0	PBZD	Dredging	Offshore service vessels	Utility vessel	Tug - Multicat Anchoring and Dive Vessel	33 x 15 m	499	link
IVERO	232013165	8108377	MCJO3	Other Type	Unassigned	Research/Survey Vessel	Research/Survey Vessel; Multi-purpose Vessel / IACs Post-boulder clearance Survey	34.4 x 9.78 m	307	link

Name	MMSI	IMO	Call sign	Vessel type name	Vessel category based on Metcalfe et al. (2018)	Vessel type detailed	Function during windfarm construction	Length overall x breadth extreme	Gross tonnage	Web-link
KAMARINA	247278400	9499644	IITW2	Tug	Port service craft	Tug	Barge Tow Vessel	50 x 15 m	1397	link
KMS ABILITY N294	235014666	0	MDFW3	Fishing	Fishing vessels	Trawler	Guard Vessel	23.06 x 6.4 m	111	link
KMS RESOLUTE	235069036	9698939	3FSA3	Cargo	Bulk carrier and cargo vessels	Fishing Vessel	Guard Vessel	24 x 8 m	-	link
MAERSK CONNECTOR	219275000	9743813	OWEB2	Other Type	Unassigned	Cable Layer	Survey / ROV Vessel	139 X 28 m	10678	link
MAERSK TRADER	220584000	9388596	OXRO2	Tug	Port service craft	Offshore Supply Ship	Anchor Handler / ROV	73.2 x 20 m	4678	link
MANU PEKKA	212701000	0	5BJH2	Dredging	Offshore service vessels	Dredger	Dredger	48 x 15 m	-	link
MERLIN DIVER	576451000	8968856	YJQG4	Other Type	Unassigned	Utility vessel	Guard Vessel	24.99 x 6.18 m	110	link
NATALIE C	232004523	0	GHNE	Fishing	Fishing vessels	Other	Guard Vessel	23 x 6 m	-	link
NEXANS SKAGERRAK	257253000	7619458	LCEK	Other Type	Unassigned	Cable Layer	Cable Laying Vessel - cable laying and trenching	99.75 x 35.41 m	10147	link
NKT VICTORIA	257016000	9791016	LAWV7	Other Type	Unassigned	Cable Layer	Cable Laying Vessel	140 x 30 m	16171	link
NORMAND SERVICE	257062690	9484845	LAZT7	Cargo	Bulk carrier and cargo vessels	Offshore Supply Ship	Offshore Supply Ship - DP 2 Platform Supply Vessel	88.41 x 18.98 m	4007	link
NORSEMAID	235007967	9099107	VQEB2	Other Type	Unassigned	Research/Survey Vessel	Survey and Crew Transfer	23.3 x 5.1 m	200	link
OCEAN ENTERPRISE	232018791	0	MFFY6	Tug	Tug	Port Tender	Workboat	14 x 7 m	-	link
OLEG STRASHNOV	212905000	9452701	5BNL2	Other Type	Unassigned	Crane Ship	Heavy Lift Vessel	183 x 47 m	47426	link

Name	MMSI	IMO	Call sign	Vessel type name	Vessel category based on Metcalfe et al. (2018)	Vessel type detailed	Function during windfarm construction	Length overall x breadth extreme	Gross tonnage	Web-link
OPPORTUNE	233608000	7816056	2WKN	Local vessel	Unassigned	Trawler	Guard Vessel	25.9 x 7.2 m	201	link
PD 174 CONSORTIUM	235000620	0	MNYQ5	Fishing	Fishing vessels	Other	Guard Vessel	21 x 7 m	-	link
PEGASUS	305389000	9433743	V2ED2	Tug	Port service craft	Anchor Handling Vessel	Barge Tow Vessel	48.81 x 14.06 m	1262	link
POLE STAR	235000500	9211987	ZQQC5	Other Type	Unassigned	Buoy-Laying Vessel	Buoy Laying Vessel	51.52 x 12.1 m	1174	link
PRESIDENT HUBERT	205067000	8117471	ORLD	Tug	Port service craft	Tug	Anchor Handling Tug	60 x 15 m	1738	link
RESILIENT GUARD VESS	232711000	7305382	GSEE	Tug	Port service craft	Fishing Vessel	Guard Vessel	26.21 x 6.58 m	154	link
RIX LYNX	235115745	9802358	2JGQ6	Cargo	Bulk carrier and cargo vessels	Offshore Supply Ship	CTV	27.4 x 8 m	106	link
ROCKPIPER	209449000	9583861	5BML3	Other Type	Unassigned	Pipe Burying Vessel	Pipe Burying Vessel - Rock Layer	158.6 x 36 m	30601	link
RONA	235084204	0	MACN3	Passenger	Passenger vessels	Dive vessel	Tail end Vessel; Crew Transfers; Medical Emergency	10 x 4 m	-	link
SARDONYX 2	234311000	8957182	MQUY6	Fishing	Fishing vessels	Trawler	Guard Vessel	18.38 x 6.5 m	119	link
SEACAT INTREPID	235107284	0	2HWU6	High speed craft	Passenger vessels	High speed craft	CTV	27 x 10 m	-	link
SEAHORSE	244137000	8213744	PCAP	Dredging	Offshore service vessels	Pipe Burying Vessel	Pipe Burying Vessel	162.01 x 38.05 m	19516	link
SEAJACKS SCYLLA	356068000	9429974	MSBB3	Tug	Tug	Offshore Construction Vessel	Offshore Construction Vessel	139 x 50 m	23641	link
SFF GV ARTEMIS	233975000	0	MVIX5	Tug	Port service craft	Trawler	Guard Vessel	27.69 x 8.7 m	399	link

Name	MMSI	IMO	Call sign	Vessel type name	Vessel category based on Metcalfe et al. (2018)	Vessel type detailed	Function during windfarm construction	Length overall x breadth extreme	Gross tonnage	Web-link
SHAULORA BF794	234014000	0	2KDQ	Fishing	Fishing vessels	Fishing Vessel	Guard Vessel	17 x 5 m	-	link
SHUNA	235007528	0	VQBP3	Tug	Port service craft	Tug	Towing Vessel	17 x 6 m	-	link
SIEM AIMERY	258182000	9694737	LATX7	Other Type	Unassigned	Cable Layer	Cable Laying Vessel	95 x 21 m	8530	link
SIEM N-SEA	311031800	9424508	C6YG5	Diving ops	Offshore service vessels	Offshore Supply Ship	Offshore Supply Ship - Boulder Removal Vessel	93.6 x 19.74 m	4869	link
SIEM RUBY	257733000	9413444	LEQY	Dredging	Offshore service vessels	Offshore Supply Ship	Offshore Supply Ship - trenching	91 x 22.04 m	7558	link
SIEM STINGRAY	311000620	9676292	C6DA3	Other Type	Unassigned	Offshore Supply Ship	Cable Laying Vessel - Offshore Supply Ship	120.8 x 27 m	8878	link
SKUA	232006107	0	MANX9	Other Type	Unassigned	Other	-	16 x 4 m	-	link
SMIT SENTOSA	205696000	9662356	ORRX	Tug	Port service craft	Tug	Anchor Handling Tug	52 x 15 m	1463	link
SMIT SERAYA	566804000	9662368	9V9845	Tug	Port service craft	Anchor Handling Vessel	Barge Tow Vessel	51.8 x 15 m	1463	link
STANISLAV YUDIN	210334000	8219463	5BYM2	Other Type	Unassigned	Crane Ship	Heavy Lift Vessel	183.3 x 40 m	25527	link
STRIL EXPLORER	259006000	0	MASY7	Other Type	Unassigned	Offshore Supply Ship	DP2 Construction support and ROV vessel	76.4 x 16.2 m	3631	link
SWIFT SHORE	232005290	0	2JAH	Fishing	Fishing vessels	Other	Guard Vessel	21 x 7 m	-	link
TEAL OF WICK	235000773	0	ZQXM9	Diving ops	Offshore service vessels	Dive vessel	Tail end Vessel; Multipurpose vessel	20 x 8 m	-	link
UNION BOXER	205575000	9537537	ORPS	Tug	Port service craft	Anchor Handling Vessel	Anchor Handling Tug	41 x 12 m	810	link

Name	MMSI	IMO	Call sign	Vessel type name	Vessel category based on Metcalfe et al. (2018)	Vessel type detailed	Function during windfarm construction	Length overall x breadth extreme	Gross tonnage	Web-link
UNION FIGHTER	205566000	9537525	ORPP	Tug	Port service craft	Anchor Handling Vessel	Barge Tow Vessel	41 x 13 m	810	link
UNION PRINCESS	205642000	9242766	ORQU	Tug	Port service craft	Anchor Handling Vessel	Barge Tow Vessel	67.4 x 16 m	2258	link
UNION SOVEREIGN	205644000	9262742	ORQW	Tug	Port service craft	Offshore Supply Ship	Barge Tow Vessel	67.4 x 15.5 m	2263	link
VOE JARL	235055168	0	MECU3	Tug	Tug	Tug	HDD Utility Vessel	26 x 11.5 m	161	link
VOS PRELUDE	245969000	9444340	PBZK	Cargo	Bulk carrier and cargo vessels	Offshore Supply Ship	Supply Vessel	73.6 x 16 m	2177	link
WALVIS	576448000	7208649	YJQG3	Other Type	Unassigned	Utility vessel	Guard Vessel	23.85 x 6 m	108	link
WATERFALL	235071392	0	2CBT4	High speed craft	Passenger vessels	High speed craft	Workboat	15 x 6 m	-	link
WB 1	232011832	0		Dredging	Offshore service vessels	Dredger	Dredger - stuck removal	24 x 24 m	-	link
WHALSA LASS	235089425	9633812	2EZQ4	Tug	Port service craft	Tug	Anchor Handling Vessel - Utility Vessel - HDD duct removal	26 x 11.5 m	167	link
WOODSTOCK	235069559	0	2BUY7	Tug	Port service craft	Crane Ship	Support Vessel	34.14 x 10 m	256	link

2 References

- Metcalf, K., Godley, B.J., Bréheret, N., Chauvet, E., Collins, T., Witt, M.J., Curran, B.K., Parnell, R.J., Turner, R.A., 2018. Using satellite AIS to improve our understanding of shipping and fill gaps in ocean observation data to support marine spatial planning. 1834-1845.
- Pirotta, E., Thompson, P.M., Miller, P.I., Brookes, K.L., Cheney, B., Barton, T.R., Graham, I.M., Lusseau, D., 2014. Scale-dependent foraging ecology of a marine top predator modelled using passive acoustic data. *Functional Ecology* 28, 206-217.