THE EFFECT OF SIMULATED SEAL SCARER SOUNDS ON HARBOUR PORPOISES

Scientific Report from DCE – Danish Centre for Environment and Energy No. 247 2017

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

[Blank page]

THE EFFECT OF SIMULATED SEAL SCARER SOUNDS ON HARBOUR PORPOISES

Scientific Report from DCE – Danish Centre for Environment and Energy No. 247 2017

Line Hermannsen
Lonnie Mikkelsen
Jakob Tougaard

Aarhus University, Department of Bioscience

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

Series title and no.: Scientific Report from DCE – Danish Centre for Environment and Energy No. 247

Title: The effect of simulated seal scarer sounds on harbour porpoises

Authors: Line Hermannsen, Lonnie Mikkelsen, Jakob Tougaard
Institutions: Aarhus University, Department of Bioscience

Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL: http://dce.au.dk/en

Year of publication: December 2017
Editing completed: November 2017

Referee: Line A. Kyhn
Quality assurance, DCE: Jesper Fredshavn

Financial support: EnerginetDK

Please cite as: Hermannsen, L., Mikkelsen, L, and Tougaard, J. 2017. The effect of simulated seal scarer sounds on harbour porpoises. Aarhus University, DCE – Danish Centre for Environment and Energy, 40 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 247. http://dce2.au.dk/pub/SR247.pdf

Abstract: Powerful acoustic deterrents, so-called seal scarers, are commonly used in connection with pile driving of steel monopiles, to protect harbour porpoises against injury, in the form of temporary or permanent hearing loss. The objective of the seal scarer is to deter porpoises out to a safe distance from a pile driving site, before the pile driving itself starts. To determine the effective deterrence distance of seal scareres a controlled exposure study was conducted at Helgenæs, Denmark, where porpoises were exposed to low-level of replica seal scarer signals, while the animals were tracked visually from land. During control periods without sound the porpoises were predominantly observed in a band approximately 500-800 m from the coast, whereas very few animals were observed during sound exposure. Reaction distances to the reduced levels of the controlled exposure must be scaled up to be applied to a real seal scarer, which gives an estimated deterrence distance of 3,100 m.

Keywords: Porpoise, seal scarer, deterrence, pile driving, mitigation

Layout: Graphic Group, AU Silkeborg
Front page photo: Bioscience, AU

ISBN: 978-87-7156-295-8
ISSN (electronic): 2245-0203

Number of pages: 40

Internet version: The report is available in electronic format (pdf) at
http://dce2.au.dk/pub/SR247.pdf

Contents

[Blank page]

Preface

This project was commissioned by Energinet.dk to provide better data on the reaction thresholds of harbour porpoises (*Phocoena phocoena)* to sounds from a seal scarer in order to evaluate the effectiveness of seal scarers as a mitigation device during construction of offshore wind farms.

Many people contributed to the work. First and foremost thanks to the observers: Asger Emil Munch Schrøder, Mia Lybkær Kronborg Nielsen, Pernille Meyer Sørensen og Peter Schmedes, for endless hours of looking over the empty ocean. Thanks are also due to Mats Amundin, Kolmården Zoo, for lending us the theodolite; Peter T. Madsen, Zoophysiology, Aarhus University, for lending us the soundtraps and various other equipment; Kristian Beedholm for Labview programming and the volunteers at the Lighthouse at Sletterhage, who generously helped us overcome smaller and larger logistical problems and allowed us to use their lawn for equipment.

Bent Sømod and others at Energinet.dk are thanked for support and comments during the project and to a draft of this report.

Experiments were conducted under permission from the Danish nature Agency, who is also thanked for allowing us to use the clifftop for observations. The Danish maritime Authority gave permission to deploy loudspeakers and instruments on the sea bed.

Summary

Pile driving of steel monopile foundations for offshore wind turbines is a recent, but very significant addition to anthropogenic noise sources in the ocean. The primary concern with respect to impact of pile driving noise is marine mammals, most notably small cetaceans, including the harbour porpoise (*Phocoena phocoena*).

A significant potential effect of the pile driving noise is temporary habitat loss due to avoidance of the noise source. Another potential effect of pile driving is direct injury due to the sound pressure, which is sufficiently high to be able to induce temporary or permanent hearing loss.

Mitigation of injury from loud noise can be accomplished by three different methods: reduce the generated noise energy, reduce the radiated noise energy and reduce the received noise energy. Deterrence, by means of powerful seal scarers, belongs to the third type and has been used extensively for pile driving during construction of offshore wind farms in the North Sea and continues to be a key element in mitigation of noise induced injury. The objective of the seal scarer is to deter porpoises out to a safe distance from a pile driving site, before the pile driving itself starts.

In order to provide better estimates of the deterrence distance a so-called controlled exposure study was conducted at Helgenæs, Denmark. Harbour porpoises were tracked from land by means of a theodolite placed at a high observation point, before, during and after emission of replica seal scarer signals at reduced levels from an underwater loudspeaker.

Experiments were conducted over a period of three weeks in June-July 2015. In total, 121 groups of porpoises were observed during nine days with usable weather conditions. In total 14 trials with sound exposure were conducted.

During control periods without playback of sound the porpoises were predominantly observed in a band approximately 500-800 m from the coast, approximately along the 10 m depth contour. During trials with sound on the number of observations was too low to detect any clear patterns in distribution, except for some tracks clearly leading away from the loudspeaker.

Trials were scored as either “response” or “no response” without distinction between strong and weak responses. Two groups of porpoises that were within 300 m of the loudspeaker when the sound was turned on both responded, but beyond 300 m some groups responded and others did not. One group at 600 m responded very strongly, whereas several other groups that were closer at onset didn’t respond.

Reaction distances to the reduced levels of the controlled exposure must be scaled up to be applied to a real seal scarer. Doing so results in a scaled-up deterrence distance of 3,100 m, somewhat higher, but of the same order of magnitude as previous estimates.

Dansk resumé

Nedramning af stålfundamenter til havvindmøller er en ny, men betydelig kilde til undervandsstøj i havet. Den væsentligste bekymring i forhold til miljøpåvirkninger i denne sammenhæng vedrører havpattedyr, herunder marsvin (*Phocoena phocoena*).

En væsentlig potentiel påvirkning fra støjen er et midlertidigt tab af levested for marsvin, forårsaget ved bortskræmning af dyrene. En anden potentiel påvirkning er direkte skader forårsaget af de meget kraftige lydtryk der findes tæt på møllefundamentet mens det nedrammes. Disse lydtryk er høje nok til at kunne forårsage både midlertidige og permanente høreskader.

Påvirkningerne fra støjen kan reduceres på tre forskellige måder: reduktion af den genererede støj, reduktion af den udstrålede støj og reduktion af den modtagne støj. Bortskræmning, ved hjælp af kraftige sælskræmmere, er en afværgeforanstaltning af den tredje type, og bruges i udstrakt grad i forbindelse med pæleramning i havmølleparker i Nordsøen. Formålet med bortskræmning med en sælskræmmer er at skræmme marsvin ud i sikker afstand fra møllefundamentet forud for at selve ramningen begynder.

For at få et bedre estimat for bortskræmningsafstanden for marsvin blev et forsøg med kontrolleret eksponering gennemført på Helgenæs. Marsvin blev fulgt og deres position bestemt ved hjælp af en theodolit placeret på en høj klint. Dyrene blev fulgt før, under og efter at sælskræmmerlyde blev afspillet ved en reduceret lydstyrke fra en undervandshøjttaler.

Forsøgene blev udført igennem tre uger i juni-juli 2015. Totalt 121 grupper af marsvin blev observeret på de 9 dage, hvor vejret tillod observationer. Der blev gennemført 14 eksponeringer med sælskræmmerlyd.

I kontrolperioder uden afspilning af lyd blev marsvinene fortrinsvist observeret i afstand af omkring 500-800 fra kysten, omtrent langs med 10-meter dybdekurven. Under afspilning af lyd var antallet af observationer for lavt til at afdække et egentligt mønster i fordelingen, ud over et antal marsvinegrupper, det tydeligt svømmede væk fra lydkilden.

Observationsperioder med lyd blev klassificeret som enten “reaktion” eller “ikke-reaktion”, uden en graduering i responsens styrke. To grupper af marsvin indenfor 300 m af højttaleren da lyden blev tændt reagerede begge ved at svømme væk. Nogle af de grupper, der var længere væk end 300 m, reagerede, mens andre ikke gjorde det. En gruppe 600 m fra højttaleren reagerede kraftigt, mens andre grupper tættere på slet ikke reagerede.

Reaktionsafstandene til de reducerede lydtryk brugt i forsøget skal skaleres op for at kunne anvendes på de kraftigere, rigtige sælskræmmerlyde. Gøres dette, resulterer det i en opskaleret minimums reaktionsafstand på 3.100 m, noget højere end tidligere estimater, men dog i samme størrelsesorden.

1 Introduction

Pile driving of steel monopile foundations for offshore wind turbines is a recent, but very significant addition to the anthropogenic noise sources in the ocean. Sound levels from piling can be very loud, with source levels exceeding 230 dB re. 1 µPa (Tougaard et al. 2009, Zampolli et al. 2013), which has raised concern for possible detrimental effects on the marine environment. The primary concern has been marine mammals, most notably small cetaceans, including the harbour porpoise (*Phocoena phocoena*) (Madsen et al. 2006).

A significant potential effect of the pile driving noise is temporary habitat loss due to avoidance of the noise source. Several studies have shown that porpoises react by avoidance to pile driving out to distances of tens of km during pile driving and that this effects pertains to the following day (Tougaard et al. 2009, Brandt et al. 2011, Dähne et al. 2013). The energetic consequences of this type of disturbance are unknown and it is thus unclear to what degree extensive pile driving has potential to affect conservation status of local porpoise populations.

Another potential effect of pile driving is direct injury due to the high sound pressures. While sound pressures generated from pile driving is unlikely to have potential for inflicting tissue damage (blast trauma, as seen as a consequence of underwater explosions), they are sufficiently high to be able to induce temporary or permanent hearing loss (TTS and PTS; Southall et al. 2007, Lucke et al. 2009, Kastelein et al. 2015). As the inner ear is highly specialized for reception of sound and very sensitive, it is assumed that injury by noise will be detectable in the inner ear at lower levels of exposure than for any other tissue damage and a criterion for injury based on TTS or PTS is thus considered conservative and precautionary (Southall et al. 2007, Tougaard et al. 2015).

The long term consequences of a smaller or larger hearing loss on survival and reproduction are entirely unknown. Hearing loss inflicted by pile driving noise occurs at low frequencies (Kastelein et al. 2015), where porpoises have poor hearing (Kastelein et al. 2010) and it is unclear to which degree they depend on this low frequency hearing for orientation and prey capture. Nevertheless, direct injury to individual animals as a consequence of noise exposure should be avoided, whenever possible, and a precautionary approach to regulation is thus to minimize the risk that porpoises acquire PTS due to exposure to pile driving noise (Skjellerup et al. 2015).

Mitigation of injury from loud noise can be accomplished by three different methods: reduce the generated noise energy, reduce the radiated noise energy or reduce the received noise energy. The first two methods involve modifying the installation method to be less noisy or reducing the radiated noise by means of shielding by for example bubble curtains (see extensive review by Caltrans 2009). The last method, reduction of received energy by the animals, can be achieved by either conducting pile driving at times of the year where porpoise abundance is low (for areas with strong seasonal variation) or by deterring porpoises from the vicinity of the monopile before pile driving commences. This approach of deterrence has been used extensively for pile driving during construction of offshore wind farms in the North Sea and continues to be a key element in mitigation of noise induced injury.

1.1 Seal scarers as mitigation devices

Seal scarers or acoustic harassment devices (AHD) have been used for deterrence from the first offshore wind farms were constructed in the North Sea (Tougaard et al. 2009). AHDs were originally designed to deter seals from fishing gear and aquaculture installations. However, since these devices transmit sound at high levels and mainly in a frequency range of 10-40 kHz, the noise impacts also extend to other marine mammals. Even a high frequency specialist such as the harbour porpoise has good hearing in this frequency range (Kastelein et al. 2010) and the effects of such devices on this species have been addressed in several studies (see review by Hermannsen et al. 2015). The overall evaluation based on these previous studies is a minimum deterrence distance of harbour porpoises of about 200 m from an Airmar device and between 1300 and 1900 m from a Lofitech device if deterrence of most animals (but not all) is considered acceptable for mitigating effects of pile-driving events.

The objective of mitigation with a seal scarer is to deter most of the porpoises around a pile driving site out to a safe distance before the pile driving itself starts. As TTS and PTS is related to the total accumulated sound energy that the animal receives over a period of several hours (Southall et al. 2007, Kastelein et al. 2015), the calculation of this safe distance is not trivial. Such a calculation must take the movement of the animals into account, as PTS is not acquired instantly, but accumulates throughout the exposure to the pile driving sounds, which may last for several hours. For a particular pile driving scenario (source level of pile driving noise, sound transmission properties of the water and intervals between pile driving strikes) there is thus a critical distance, beyond which porpoises can escape from PTS by beginning to move away from the noise when the pile driving begins. In order for a seal scarer to be effective as mitigation against hearing damage, it must then be able to deter animals out beyond this critical distance before the pile driving commences.

A method to assess the sufficiency of a particular mitigation protocol was presented by Skjellerup et al. (2015). This method involves estimation of the critical distance for the particular scenario. If this critical distance is larger than the deterrence distance of the suggested AHD, the necessary reduction of radiated noise (by means of a bubble curtain or otherwise) can be computed. The predictions of the model from Skjellerup et al. (2015) rely on several assumptions, of which the effective deterrence distance of the AHD is of particular importance. As there is considerable uncertainty about this distance (Hermannsen et al. 2015), a field experiment was commissioned and conducted during the summer of 2015, in order to provide additional support for the deterrence distance used in the model of Skjellerup et al. (2015).

2 Methods

The type of experiment conducted is a so-called controlled exposure study, where porpoises are exposed to seal scarer sounds at predetermined times and their response to the sound followed and evaluated. Harbour porpoises were tracked from land by means of a theodolite placed at a high observation point. Animals were followed before, during and after emission of seal scarer signals from an underwater loudspeaker. Sound level of the signals were deliberately reduced to lower levels than from real seal scarers, in order to keep maximum reaction distances within visible range.

2.1 Experimental area

The experiments were conducted at Helgenæs, Denmark (Fig. 2.1), where the high point *Bursklint* (56º6.153N, 10º32.23E) enabled a good overview to the south-east with a height of 47 meters above sea level (Fig. 2.2). This location was chosen over Fyns Hoved, which has been used previously in this type of experiments (see e.g. Tougaard et al. 2012), for logistical reasons, as a German colleague had applied for and received permission to conduct playback studies there during the summer of 2015. Bursklint in any case offers clear advantages over Fyns Hoved. First and foremost, it is more than twice as high, allowing much higher precision in localisations and the orientation of the cliff offers reasonable shelter for westerly and especially north-westerly winds, in sharp contrast to the northwest-facing Fyns Hoved. An additional advantage is the closeness to Aarhus, only about 1 hour drive from the city centre.

Figure 2.1. Study area (red dot) on the SE-coast of Helgenæs, facing the outer (eastern) part of Aarhus Bay, Denmark.

Figure 2.2. Bursklint seen from the sea side. Observation station was on the top to the right in the picture at arrow.

2.2 Acoustic signals

The signals of AHDs are so loud that they affect porpoises at distances of several kilometers, which is much further than the observation range of harbor porpoises from a high observation point, such as Bursklint. This creates difficulties for this type of visually conducted experiments (see Brandt et al. 2013 for an example) and it was thus decided to use simulated AHD sounds rather than an actual AHD. By using an underwater loudspeaker and computer generated sounds it was possible to reduce the source level of the signals to a level where expected reactions would occur within reasonable observation range from the cliff top.

The acoustic signal was a 12 kHz pure tone with a source level of 165 dB re 1µPa pp, i.e. roughly 25-30 dB lower in level than a real seal scarer. It was generated by a sound card in a standard laptop computer by means of custom software developed in Labview. Sampling rate was 44100 samples/s. Each signal was 0.5 s long, with randomized intervals between 0.6 s and 9 s, mimicking the normally emitted signals of a Lofitech AHD.

The signal from the sound card was amplified by a 12V car amplifier (Earthquake 1000W) and fed through a 300 m impedance matched cable to a Lubell LL9162 underwater loudspeaker (transmitting sensitivity at 12 kHz 168 dB re 1µPa/1V). This loudspeaker has a very low impedance and is designed to be driven from an amplifier with 8 Ω output impedance through a 7.5 Ω serial resistance. By careful selection of the thickness (gauge) of the copper cable, the serial resistance of the 300 m cable was exactly 7.5 Ω, assuring impedance matching of amplifier and loudspeaker.

The signal frequency was selected to be 12 kHz, within the frequency range used by most commercial AHD's (pure tones in the range 10-14 kHz) and because the directionality of the loudspeaker was most favourable at this frequency (figure 2.3).

The loudspeaker was deployed 2 m above the seabed, suspended between a 25 kg concrete anchor and two trawl balls (figure 2.4).

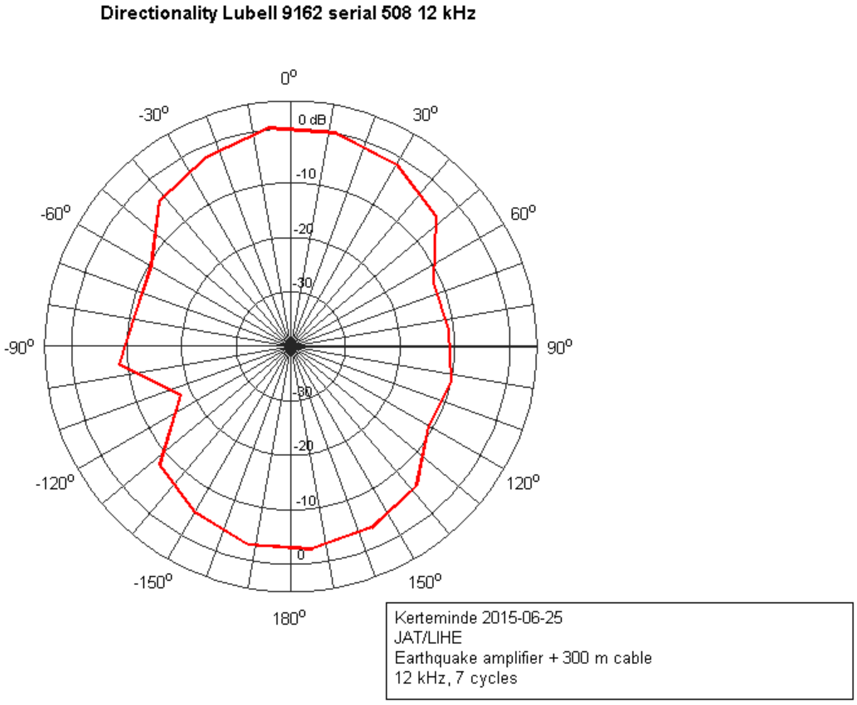


Figure 2.3. Directionality of the speaker as measured in a calibration tank (Kerteminde, Denmark). The directionality was measured with a calibrated Reson TC4014 hydrophone placed at different angles 0.75 m from the speaker.

Figure 2.4. Speaker setup. The Lubell LL6162 underwater loudspeaker (blue in black cage) suspended between anchor block (concrete tile) and flotation (orange trawl balls).

2.3 Theodolite tracking

A theodolite (Geodimeter total station system 500, Geotronics AB, Sweden) was used to track porpoises. The theodolite was linked to a computer via a serial cable (RS232) and could communicate with the software Cyclopes version 2004. Both computer and theodolite were powered by solar panels, connected to a 12 V lead-acid battery as back up. Cyclopes is specially developed to allow tracking of marine mammals by means of theodolite and provides real time display of the tracked animals. The theodolite was set up at the same location every day (marked by a pole in the ground) and the exact height of the station was determined daily before the experiment was initiated by measuring the relative height of the theodolite to a reference pole with a known height above sea level. The precise height of the pole, referenced to the Danish vertical standard, was measured by a professional surveyor by differential GPS). Variations in sea level due to tide were accounted for by measuring the water level on a fixed pole just off the beach. Tide height was measured approximately every hour when experiments were running and corrected for by the Cyclopes software.

Figure 2.5. Theodolite (Geodimeter system 500). Left: setup on tripod and 12V battery. Right: display and keyboard for setup and operation. Adjustment of the theodolite by means of the black dials on the sides. Main sighting scope in the centre of the instrument, auxiliary view finder seen on underside of the black battery box.

2.3.1 Determining position

Before use, the theodolite must be properly aligned, meaning that the base must be perfectly horizontal and the angle sensor in the horizontal plane must be referenced to a fix point with known compass bearing (true reading). As reference point we used the lighthouse on Hjelm.

Once calibrated and aligned correctly, the theodolite delivers two angle measurements to the computer upon pressing the REG button: the horizontal compass angle (true reading) and the vertical angle from zenith (the point directly above the theodolite. Subtracting 90 degrees from this latter angle gives the angle below the horizontal plane (ω in Fig. 2.6). Knowing this angle, together with the height of the theodolite above sea level and the curvature of the Earth allows for calculation of the great circle distance along the earth's surface from the theodolite station to the observed animal.

As observation distances are small compared to the radius of the Earth the curvature of the Earth can be ignored and the compass angle and radial distance can be treated as polar coordinates in the plane and easily converted to

Cartesian coordinates (easting and northing, relative to the theodolite station). By combining with the position of the theodolite station in Universal Transverse Mercator (UTM) projection (zone 32 north) one can convert theodolite readings to geographical coordinates.

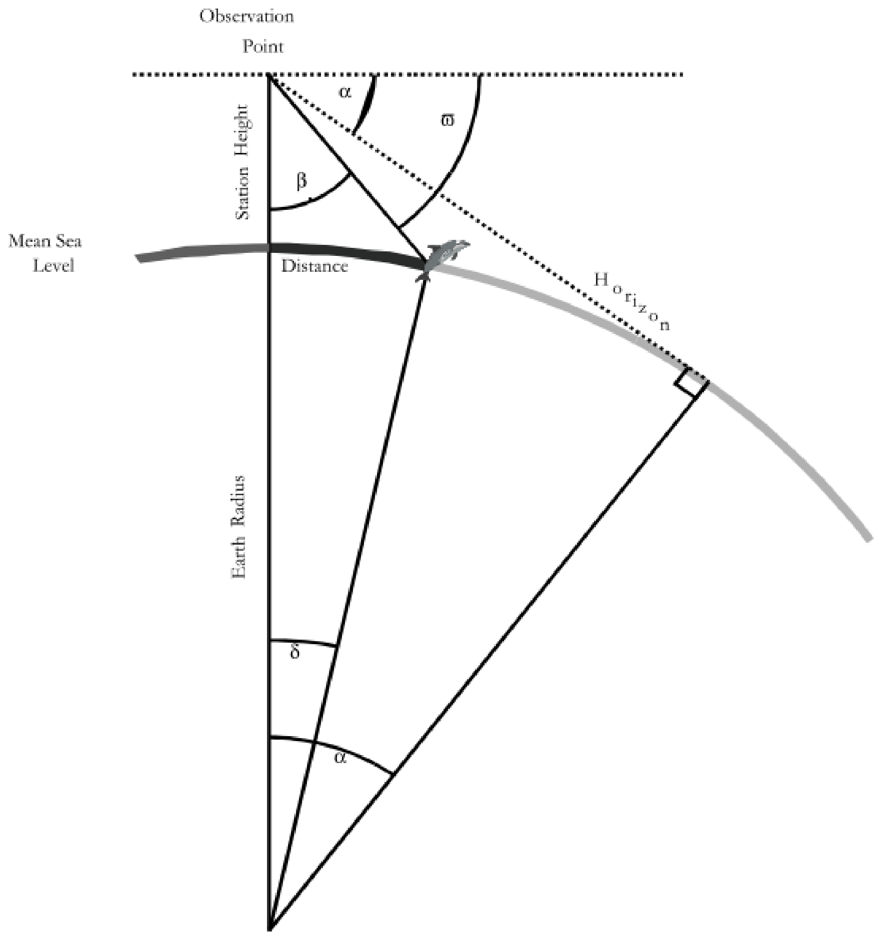


Figure 2.6. Angles in the vertical plane involved in determining the distance to a sighting. From Pythagoras manual.

2.3.2 Protocol for exposures and observations

Observations were conducted whenever weather permitted, i.e. low winds and especially a calm water surface. Between three and five observers took part in observations. During periods without sightings all observers scanned the experimental area with the naked eye or binoculars. Whenever one observer saw a porpoise or a group of porpoises one observer manned the theodolite, one the computer and the remaining observer(s) continued scanning with binoculars for new groups. The task of the observer manning the theodolite was to obtain as many positions of surfacings of the group as possible. Whenever the theodolite observer marked a position, whether a porpoise group or another target (keeping track of ships in the area), he / she communicated this information to the observer at the computer. The person at the computer kept track of recordings and took notes.

A trial with sound exposure was initiated, whenever the following criteria were fulfilled:

- At least one hour of baseline observations
- At least two hours since start of previous trial
- One or more porpoises observed for several minutes or more within approx. 500 m of the loudspeaker.

No more than five exposures were conducted on a single day.

2.4 Acoustic recordings

To estimate exposure levels of the seal scarer signals, stationary acoustic recorders, so-called SoundTraps (Ocean Instruments, Auckland, New Zealand), were deployed at four positions at ranges approx. 100-200 m around the Lubell speaker (figure 2.7). SoundTraps were deployed with an anchor and a buoy to keep them vertical in the water column with the hydrophone facing upwards at approx. 1.5 m above the sea bed. The recorders were set to a sampling rate of 288 kHz, which allowed for continuous recordings for approx. 6 days before the SoundTraps had to be serviced (download of recordings and recharging).

All equipment were deployed and recovered with a small inflatable boat. The layout of the experimental area is shown in figure 2.7. Most porpoises were observed at distances around marker B3 and beyond.

Figure 2.7. Overview of the experimental area. Star indicates position of Lubell loudspeaker, green markers location of soundtraps. Yellow scale bar is 200 m. Photo: Google Earth.

3 Results

Experiments were conducted over a period of 3 weeks in June-July 2015. Some days were devoted to setup, maintenance and recovery of equipment and on some days weather did not permit experiments. Table 3.1 shows the total effort distributed on individual days.

In total, 121 groups of porpoises were observed during nine days with usable weather conditions (sea state 0-2, wind speed < 6 m/s). The 121 groups of porpoises constituted a total of 1498 theodolite positions. One group covers between one and five porpoises, with a single observation of a group of 10 individuals so close together that they were recorded as one. In total 14 trials with sound exposure were conducted, of which the first was conducted without any observed porpoises and excluded from analysis (denoted exposure 0 in table 3.2).

Table 3.1. Field work overview with participants, effort and resulting data collected.

Date	Observers	Activities	No. porpoise groups observed	No. porpoise theodolite positionings	No. Trials (with sound)
29-06-2015	5 (LH, LM, JT, AS, MN)	Arrival, establishment of station and deployment of equipment	-		-
30-06-2015	5 (LH, LM, JT, AS, MN)	Deployment and test of equipment, measurements of theodolite station.	-		-
01-07-2015	5 (LH, LM, JT, AS, MN)	Observations	15	133	1
02-07-2015	4 (LH, LM, AS, MN)	No observations due to bad weather	-		-
03-07-2015	4 (LH, LM, MN, PS)	Observations and playback	25	270	1
04-07-2015	4 (LH, LM, MN, PS)	Observations and playback	22	155	2
05-07-2015	4 (LH, LM, MN, PS)	Observations and playback	17	224	2
06-07-2015	4 (LH, LM, MN, PS)	Observations stopped due to bad weather	0		0
07-07-2015	-	No observations due to bad weather Service of soundtraps	-		-
08-07-2015	-	No observations due to bad weather	-		-
09-07-2015	-	No observations due to bad weather	-		-
10-07-2015	-	No observations due to bad weather	-		-
11-07-2015	4 (LH, PS, JT, AS)	Soundtraps re-deployed. Observations and playback	9	110	1
12-07-2015	4 (LH, PS, JT, AS)	Observations and playback	16	335	5
13-07-2015	3 (LH, JT, AS)	Observations and playback	9	179	1
14-07-2015	4 (LH, JT, AS, PMS)	Observations and playback	2	60	1
15-07-2015	-	No observations due to weather	-		-
16-07-2015	4 (LH, JT, AS, PMS)	Observations stopped due to bad weather. Retrieval of equipment	6	32	0
17-07-2015	3 (LH, JT, AS)	Demobilisation, securing of data.	-		-
In total			121	1498	14

The maps in figure 3.1 shows all porpoise observations, separated into those made without and with sound on, respectively. The majority of observations were outside exposure periods, primarily due to the larger effort (at least one hour prior to and 45 minutes after exposure, vs. 15 minute observations during trials), but also the fact that porpoises reacted during most of the trials by swimming away reduced the number of observations. During no-sound periods the porpoises were predominantly observed in a band approximately 500-800 m from the coast, approximately along the 10 m depth contour. Fewer animals were observed at larger distances, likely due to the increasing difficulty of seeing animals. During trials with sound on the number of observations were too low to detect any clear patterns in distribution, except for some clear tracks leading away from the loudspeaker.

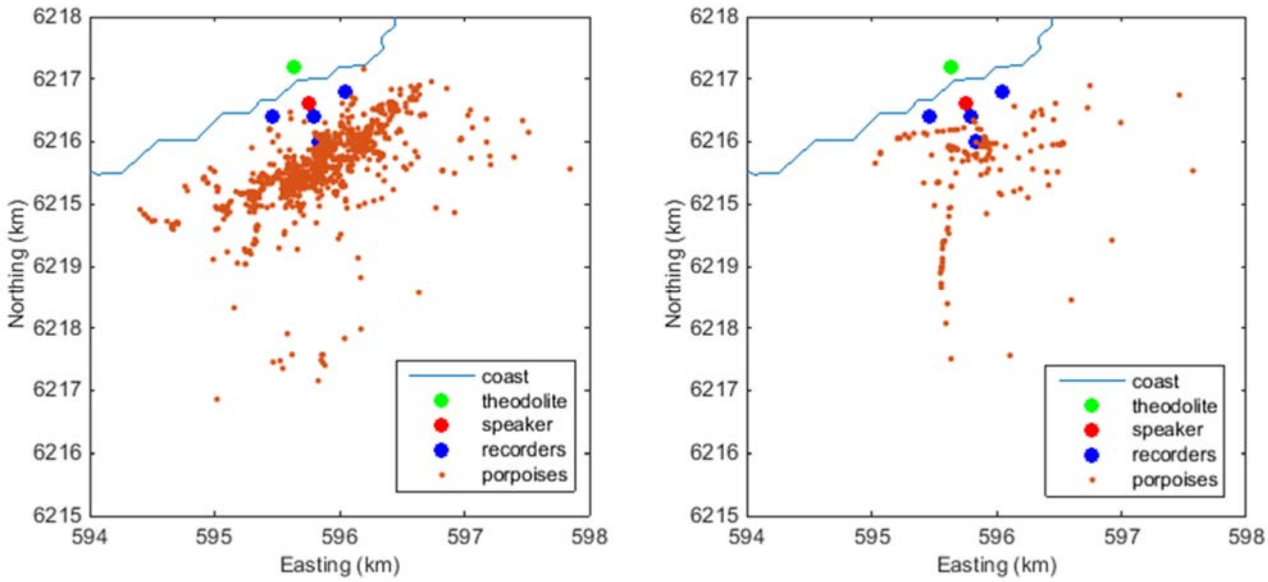


Figure 3.1. All observations of porpoise groups, separated into baseline and recovery observations without sound on (left) and exposure observations with sound on (right). Projection Universal Transverse Mercator (UTM), zone 32N.7

Table 3.2 lists information about all exposures, including a judgement of the response to the sounds. Individual tracks during trials are shown in figure 3.2 and 3.3. Included in table 3.2 is the distance between the loudspeaker and the porpoise(s) at the last observation before sound is turned on and the minimum distance between animal and loudspeaker during sound transmission. In many cases the porpoise(s) swam away immediately, in which case the two distances are identical, but in some cases the porpoise(s) approached the loudspeaker.

Table 3.2. Responses of observed porpoises during the exposures. Reaction was scored as positive if the animal (or group) approached the loudspeaker during playback and negative if the animal or group swam away from it. Pings indicate number of transmitted seal scarer pulses during the exposure. During trial 6 two groups of porpoises were followed simultaneously, the second one denoted 6a.

Trial	Date	Start time	Pings	Duration (min:sec)	Exposed groups	Obser-vations	Group size	Distance at start	Min. distance	Reaction	Total groups
0	01-07	16:18:58	20	14:26	0	-	-			-	1
1	03-07	16:19:02	23	13:48	2	42	2, 3	348	348	No response	7
2	04-07	15:34:12	19	13:50	2	8	1, 2	196	142	Negative	4
3	04-07	18:01:46	22	13:58	1	36	1	534	534	Negative	2
4	05-07	07:40:58	25	14:12	1	27	2	398	193	Strong negative	1
5	05-07	10:13:29	21	14:49	2	87	2,3	437	404	Strong negative	3
6	11-07	09:36:40	18	14:26	3	11	2,2,3	417	459	No response	4
6a								576	576	No response	
7	12-07	10:10:29	22	14:02	2	20	2,2	603	603	Strong negative	4
8	12-07	11:52:31	19	14:14	2	57	2,1	548	548	Positive	4
9	12-07	13:08:48	20	14:34	1	69	4	636	493	Positive	2
10	12-07	14:41:27	14	13:37	2	32	2,2	360	360	No response	3
11	12-07	16:00:07	21	14:48	1	65	2	294	294	Strong negative	3
12	13-07	09:23:32	24	13:51	2	141	2,1	351	348	No response	5
13	14-07	11:31:31	23	14:46	1	55	2	363	162	Positive	2

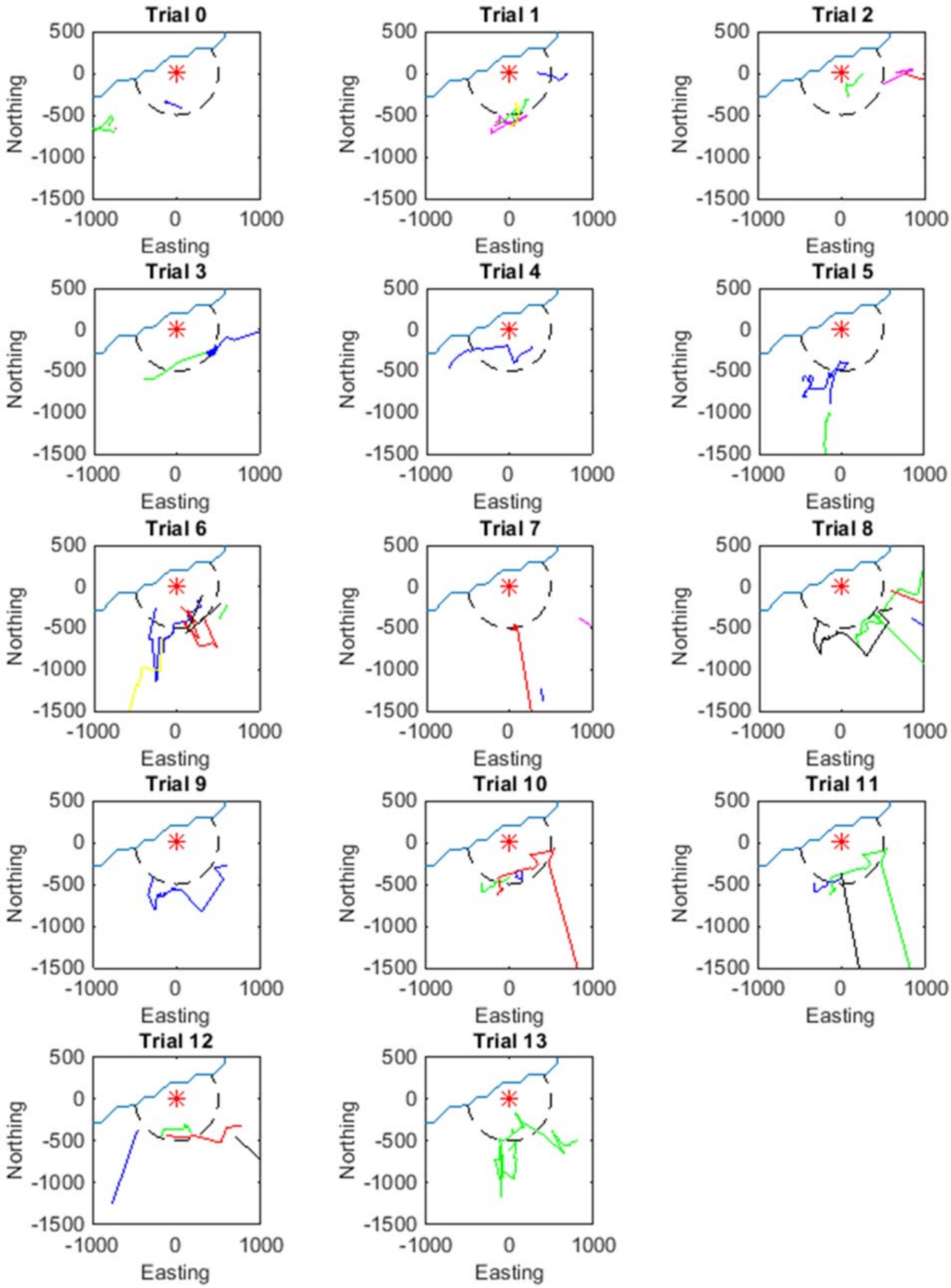


Figure 3.2. Tracks of groups of porpoises during all trials, from 1 hour before sound was turned on until 45 minutes after it was turned off. Individually coloured tracks indicate different groups of porpoises. The circles indicate 500 m iso-distance from the loudspeaker (red star). Map units in m (plane projection).

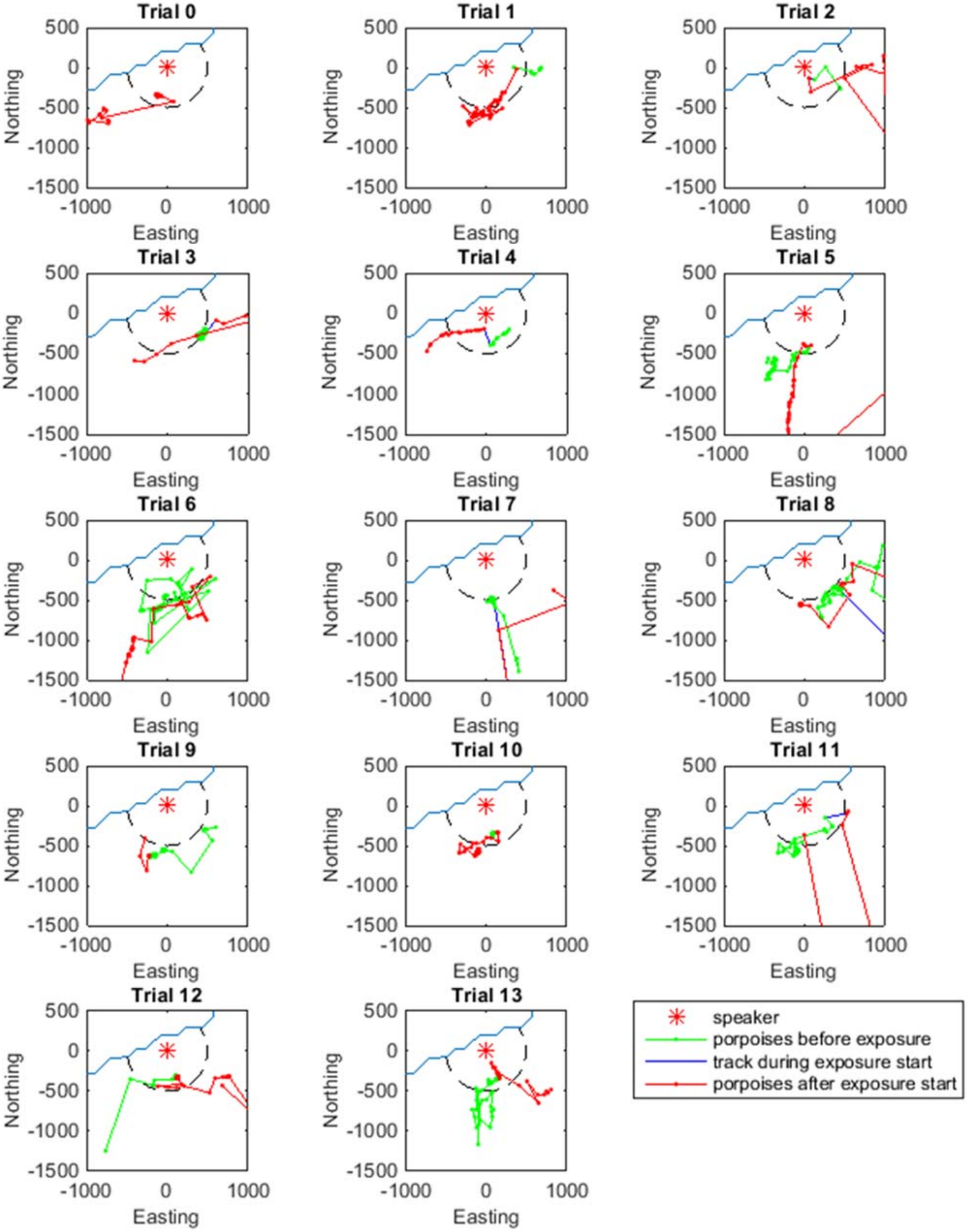


Figure 3.3. Same data as in figure 3.2, but colour coded according to whether observations were made before or after the sound was turned on. The small blue segment indicates the interval in which the first sound pulse was transmitted. Map units in m (plane projection).

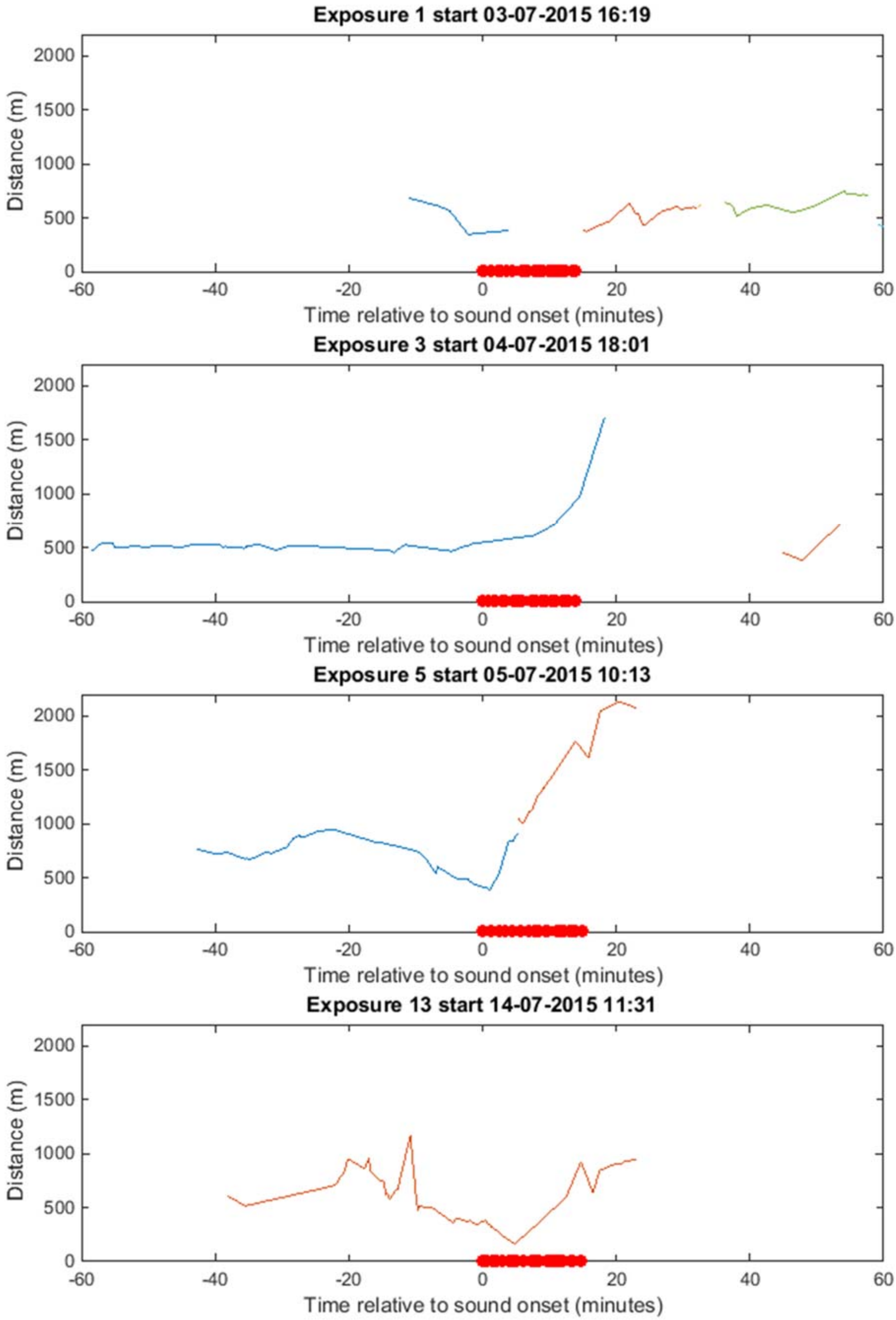


Figure 3.4. Examples of responses to sound, expressed as distance to loudspeaker. Exposure 1 and 13 were scored as "no response", whereas exposure 3 and 5 were scored as "response". Different colours of lines indicate that tracks were assigned to different groups of animals, although they in reality in some cases may have been the same. See text for further explanation.

3.1 Responses to sound exposure

Figure 3.4 shows four examples of reactions to the seal scarer sounds, quantified as the distance between loudspeaker and observations. In exposure 1 there was no change in distance to the loudspeaker during sound on. However, there is only one observation during the period in which the sound is active, which could indicate a response to the sound. On the other hand, almost immediately after the sound is turned on another group of porpoises was observed. This could be interpreted as the same group or another group. In a precautionary way, this exposure was classified as “no response”, as this will, if anything, underestimate the reaction distance.

Exposure 3 shows a clear response, where the single porpoise, after having remained for more than one hour almost at the same spot, gradually disappears after the sound was turned on.

Exposure 5 shows a similarly clear response, but this time the response begins almost immediately after the sound was turned on.

The last example, exposure 13, shows a group of two porpoises that first moved closer to the sound source and then later moved away. This trial was scored as a “no reaction”. Results from all trials can be found in the appendix.

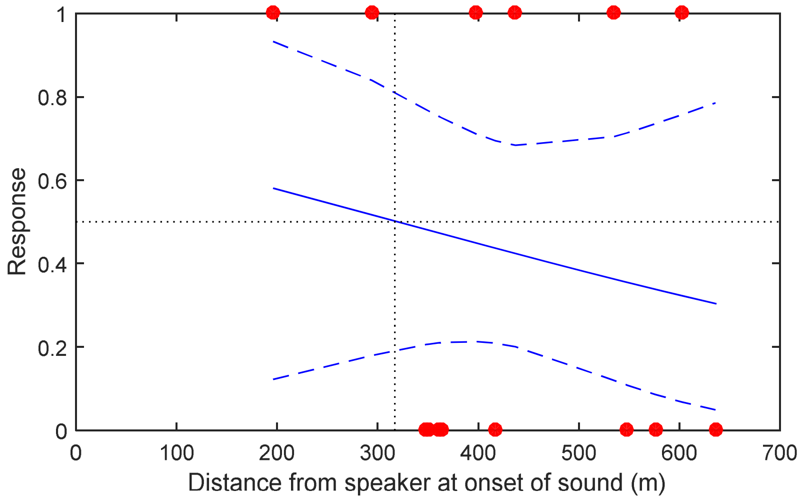


Figure 3.5. Dose-response curve for harbor porpoise exposure to AHD noise. Response to the AHD sound for each of the exposures plotted as distance to the speaker immediately before onset of AHD sound (red circles). Zero indicates no or positive response, 1 indicate negative response. Blue curve is best fitting cumulated Gaussian distribution found by logistic regression, with 95% confidence limits indicated as broken lines. Dotted lines indicate estimate of 50% deterrence distance for porpoises.

All trials, except trial 0, were scored as either “response” or “no response” (table 3.2) and a logistic regression was performed on the responses, with distance immediately before sound onset as the explanatory variable (figure 3.5). No distinction was made between strong and weak responses. A logistic regression was performed on the data, resulting in an estimate of the 50% deterrence distance of 317 m, with very wide confidence limits

3.2 Seal scarer signals

An example of the recorded seal scarer signals is shown in figure 3.6. Sounds were 500 ms in duration and in many cases had a strong onset pulse, likely caused by interference between the directly transmitted signal and the slightly delayed signal reflected from the underside of the sea surface (Lloyd’s mirror effect). Peak energy was as expected at 12 kHz, with additional harmonic overtones. The third harmonic at 36 kHz was the strongest, but still more than 40 dB below the fundamental and unlikely to have contributed to the audibility of the signal for porpoises.

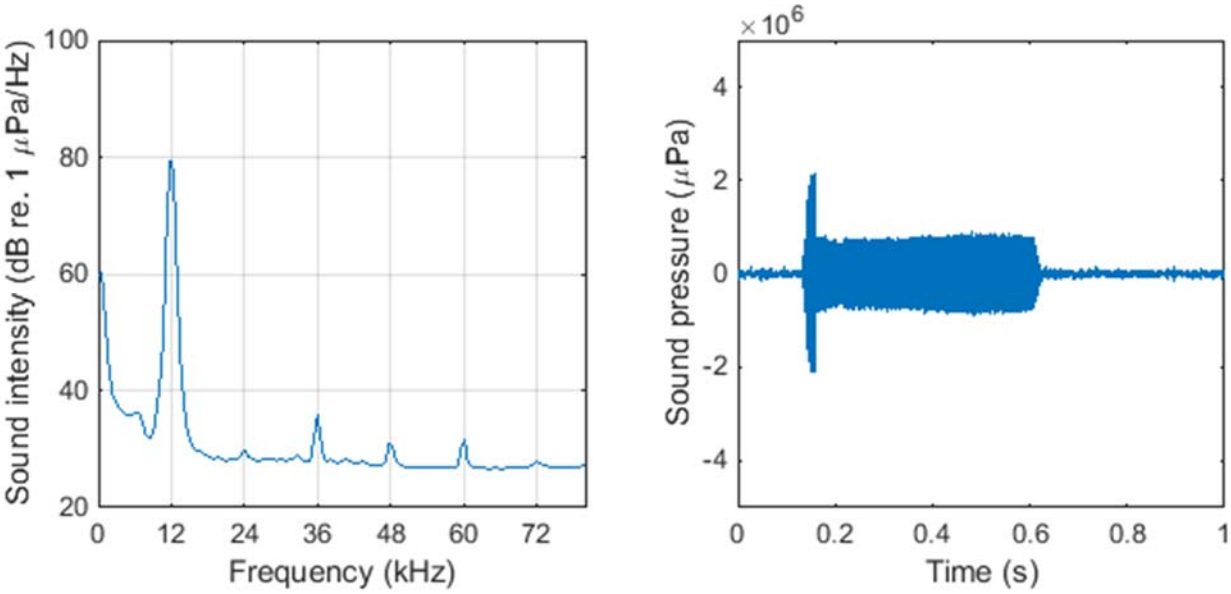


Figure 3.6. Example of sound from the seal scarer, as recorded by one of the soundtraps. Left: power spectrum density (Welch average: 512 point, Hann-weighted, 50% overlap), right: time signal. Signal down sampled to 32 ksamples/s.

4 Discussion

The porpoises at Helgenæs clearly responded to the simulated seal scarer sounds, in accordance with predictions based on previous studies. These studies have shown very large reaction distances to seal scarers, anywhere from some hundred meters (Johnston 2002) to several kilometres (Olesiuk et al. 2002, Brandt et al. 2012, Brandt et al. 2013). As outlined in Skjellerup et al. (2015) it is essential to know the deterrence range for assessing the effectiveness of seal scarers as mitigation devises to reduce the risk of inducing damage to porpoise hearing. The risk of inducing hearing loss (temporary or permanent) is determined by the cumulated noise exposure over subsequent pile driving pulses. This means that it is necessary to take account of how porpoises move away from the sound source (the pile driving). By swimming away the received noise level decreases from one pulse to the next, so the initial pulses received by the animal contribute much more to the cumulated exposure than the subsequent ones. The role of a seal scarer, when used as mitigation device, is thus to deter porpoises from the vicinity of the pile driving before it commences and in this way reduce the received level of the first pulses received by the animals, which again helps decrease the overall exposure level to the animal. In models for determining the impact from pile driving the distance at which porpoises can be considered with near-certainty to have been deterred is thus a central input parameter (Skjellerup et al. 2015).

Porpoise reactions differed with distance to the loudspeaker, but not in a straight forward way. The porpoises that were within 300 m of the loudspeaker when the sound was turned on (two groups) both responded, but beyond 300 m some responded and others did not. One group at 600 m responded very strongly, whereas several other groups that were closer at onset either didn’t respond or moved closer to the loudspeaker. It is not possible to know whether these latter animals were actively attracted to the noise or they just were unaffected by it. This large variation among groups probably is a reflection of a number of factors. Among those factors are individual differences in sensitivity to the AHD sounds, but likely also a high degree of context dependence. Porpoises engaged in important activities, such as foraging, are less likely to respond to the sound compared to porpoises that are merely travelling from A to B. In the context of predator avoidance in birds, this has been expressed as a trade-off between the risk of remaining and the cost of fleeing (Ydenberg and Dill 1986). Reformulated for porpoises one can describe this as a trade-off between the perceived danger or nuisance (depending on whether porpoises perceive the sound as a sign of danger or merely as annoying or disturbing) and the cost of leaving the area. If the porpoises are engaged in profitable foraging, the cost of leaving is larger than if they are just travelling through the area. In the first case, the cost is giving up a good feeding spot, whereas in the other case it is only the minute extra energy spend on a small detour. It is thus to be expected that the dose response function, as exemplified in figure 3.5 is relatively shallow and with a large range of distances over which the response translates from almost all animals responding negatively to hardly any.

This large variation in the dose response function means above all that a large number of exposures are required to accurately determine the parameters of the function (50% deterrence distance and standard variation) with sufficient accuracy. Despite this study only comprises 13 usable exposures and that considerable uncertainty is associated with determining the response function, the deterrence range of about 317 m matches well with previous studies with real seal scarers, as outlines below.

Reaction distances to the reduced levels of the controlled exposures must be scaled up to be applied to a real seal scarer. The source level in the current experiment was roughly 165 dB re. 1 µPapp, which is 24 dB lower than a real Lofitech AHD (Brandt et al. 2012). Scaling everything up in a simple fashion can be done by assuming spherical spreading + an absorption coefficient of 1 dB/km:

$$TL = 20\log_{10} r + \alpha r$$

If the deterrence range in the experiment is r and the additional transmission loss is ΔTL, then the upscaled deterrence range r’ can be found by solving the following equation for r’:

$$20\log_{10} r' + \ \alpha r' = 20\log_{10} r + \ \alpha r + \Delta TL$$

This cannot be done analytically, but the solution is easily found by numerical methods. If the maximum distance for complete deterrence is set to 300 m (from figure 3.5) with ΔTL of 24 dB, this yields a scaled-up deterrence distance r’ of = 3100 m. This deterrence range is slightly higher, but of the same order of magnitude as the previous estimates, ranging between 1300 m and 1900 m (Hermannsen et al. 2015).

There can be several reasons why the numbers do not match exactly, of which low precision in all estimates, including the present estimate, is probably a key reason, as well as differences in experimental conditions and methods of analysis. However, one cannot rule out that scaling up as done above overestimates the deterrence range. This overestimation could arise because the sound field does not scale in a linear way. The gradient in received sound levels is much larger around the reaction threshold in the down-scaled experiment, compared to a real seal scarer and the signal undergoes non-linear changes with distance due to multipath propagation. Both factors mean that there is information available for the porpoise in the signal itself about the distance to the source. It is imaginable that the response to a sound source is graded not just with received level, but also with distance to the source, especially if the sound is perceived as some kind of threat to the animal. If that is the case, then responses to a loud, but distant sound would be expected to be less severe than the response to a less loud, but closer source, even if the received sound pressure levels are the same.

However, summing up from the above it is concluded that seal scarers are very effective deterrents for harbour porpoises and real seal scarers are capable of deterring porpoises out to distances of several kilometers. They are therefore useful as mitigation devises, whenever exposure to loud sound is anticipated, but the disturbance cause by the seal scarer itself is so considerable, that it should also be factored into an assessment of noise exposure.

5 References

Brandt, M. J., A. Diederichs, K. Betke, and G. Nehls. 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series **421**:205-216.

Brandt, M. J., C. Höschle, A. Diederichs, K. Betke, R. Matuschek, and G. Nehls. 2013. Seal scarers as a tool to deter harbour porpoises from offshore construction sites. Marine Ecology Progress Series **475**:291-302.

Brandt, M. J., C. Höschle, A. Diederichs, K. Betke, R. Matuschek, S. Witte, and G. Nehls. 2012. Far-reaching effects of a seal scarer on harbour porpoises, *Phocoena phocoena*. Aquatic Conservation: Marine and Freshwater Ecosystems **23**:222-232.

Caltrans. 2009. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish. Sacramento, Calfornia.

Dähne, M., A. Gilles, K. Lucke, V. Peschko, S. Adler, K. Krügel, J. Sundermeyer, and U. Siebert. 2013. Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany. Environmental Research Letters **8**:025002.

Hermannsen, L., L. Mikkelsen, and J. Tougaard. 2015. Review: Effects of seal scarers on harbour porpoises. Research note from DCE - Danish Centre for Environment and Energy. Aarhus University, Roskilde, Denmark.

Johnston, D. W. 2002. The effect of acoustic harassment devices in harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy, Canada. Biol.Conserv. **108**:113-118.

Kastelein, R. A., R. Gransier, M. A. T. Marijt, and L. Hoek. 2015. Hearing frequency thresholds of harbor porpoises (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds. Journal of the Acoustical Society of America **137**:556-564.

Kastelein, R. A., L. Hoek, C. A. F. de Jong, and P. J. Wensveen. 2010. The effect of signal duration on the underwater detection thresholds of a harbor porpoise (*Phocoena phocoena*) for single frequency-modulated tonal signals between 0.25 and 160 kHz. Journal of the Acoustical Society of America **128**:3211-3222.

Lucke, K., U. Siebert, P. A. Lepper, and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America **125**:4060-4070.

Madsen, P. T., M. Wahlberg, J. Tougaard, K. Lucke, and P. L. Tyack. 2006. Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs. Marine Ecology Progress Series **309**:279-295.

Olesiuk, P. F., L. M. Nichol, M. J. Sowden, and J. K. B. Ford. 2002. Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (*Phocoena phocoena*) in Retreat Passage, British Columbia. Marine Mammal Science **18**:843-862.

Skjellerup, P., C. M. Maxon, E. Tarpgaard, F. Thomsen, H. B. Schack, J. Tougaard, J. Teilmann, K. N. Madsen, M. A. Mikaelsen, and N. F. Heilskov. 2015. Marine mammals and underwater noise in relation to pile driving - report of working group. Energinet.dk.

Southall, B. L., A. E. Bowles, W. T. Ellison, J. Finneran, R. Gentry, C. R. Green, C. R. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas, and P. L. Tyack. 2007. Marine mammal noise exposure criteria. Aquatic Mammals **33**:411-521.

Tougaard, J., J. Carstensen, J. Teilmann, H. Skov, and P. Rasmussen. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbour porpoises (*Phocoena phocoena,* (L.)). Journal of the Acoustical Society of America **126**:11-14.

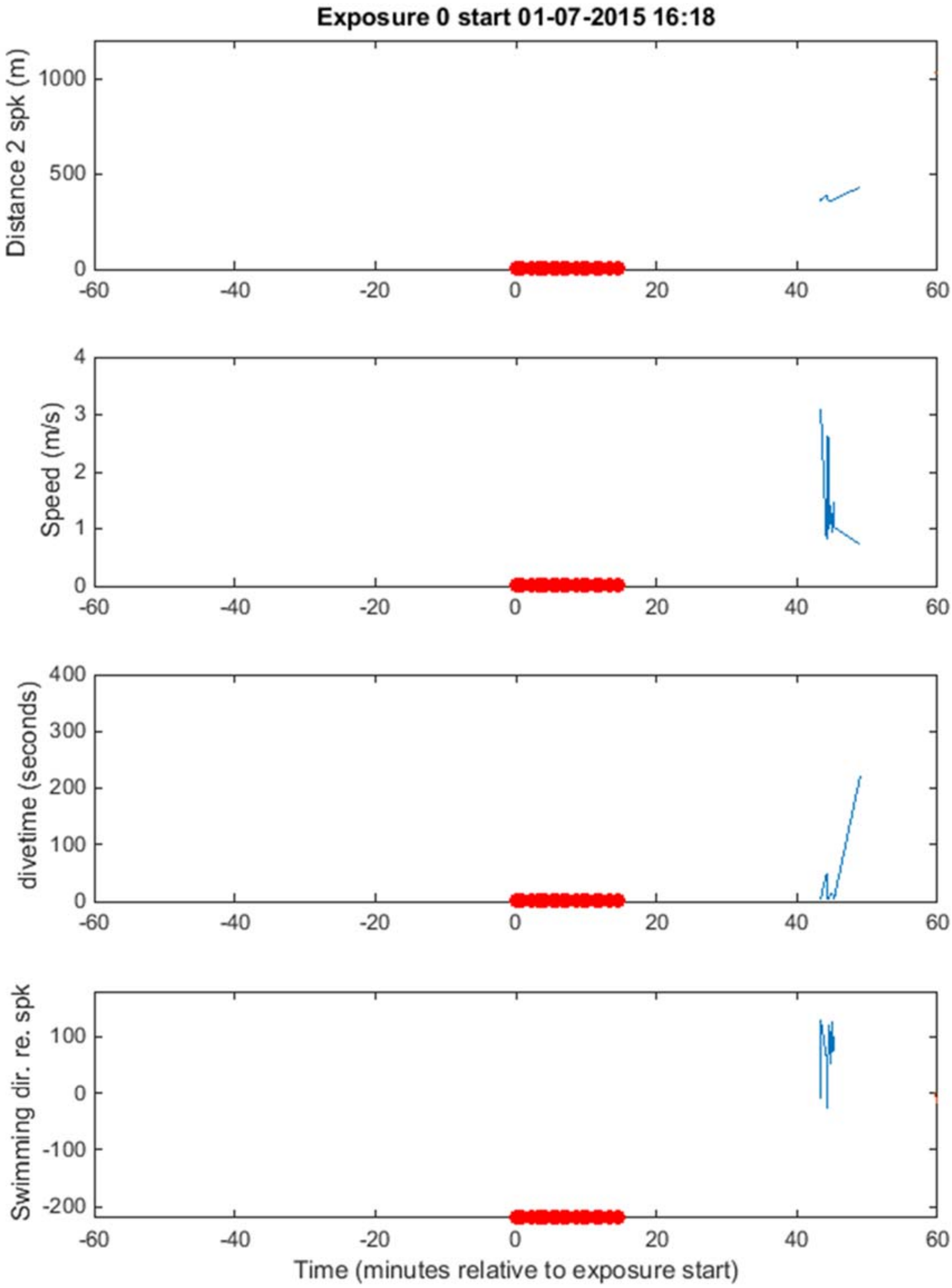
Tougaard, J., L. A. Kyhn, M. Amundin, D. Wennerberg, and C. Bordin. 2012. Behavioral reactions of harbor porpoise to pile-driving noise. Pages 277-280 *in* A. N. Popper and A. D. Hawkins, editors. Effects of Noise on Aquatic Life. Springer, New York.

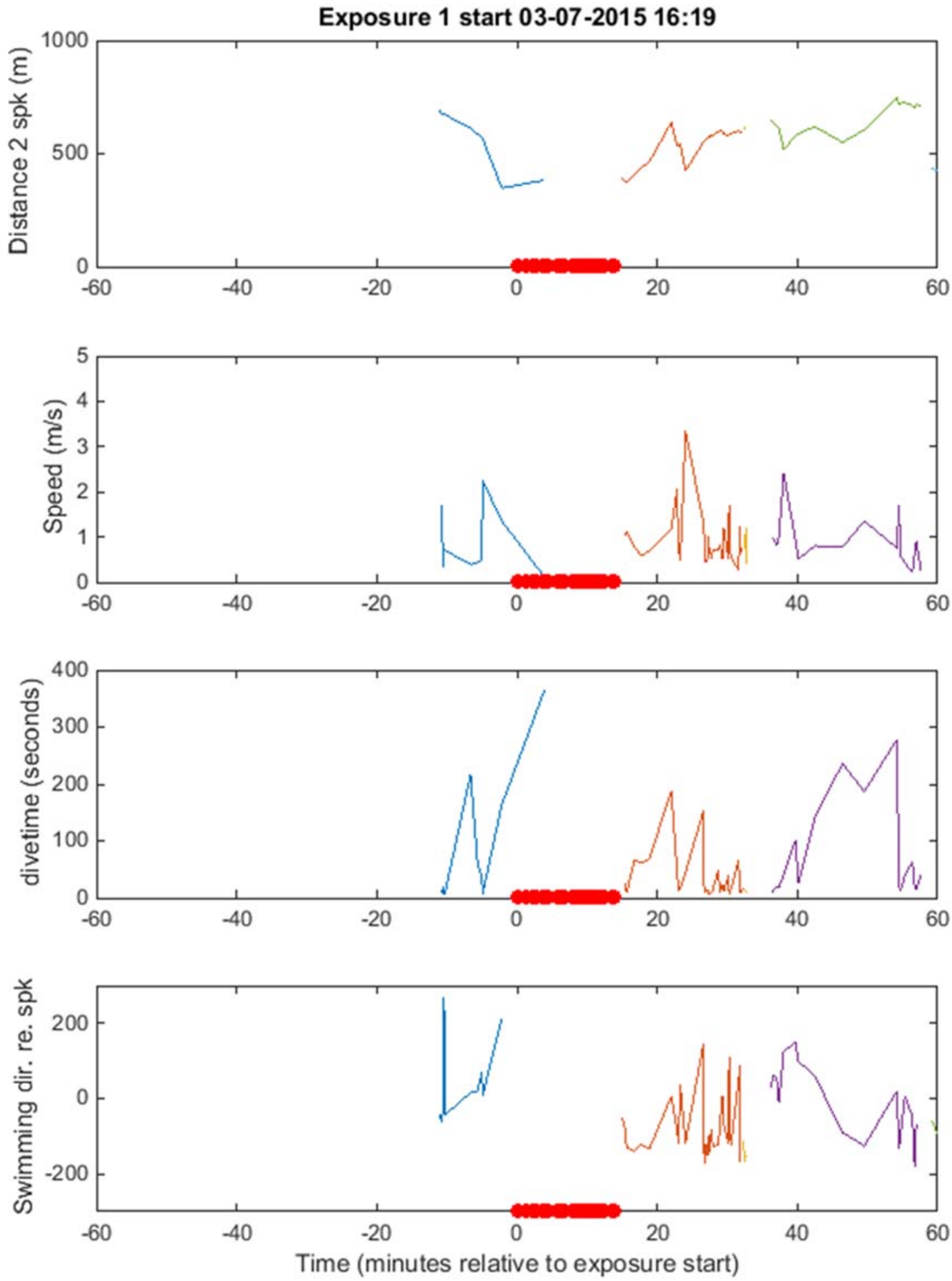
Tougaard, J., A. J. Wright, and P. T. Madsen. 2015. Cetacean noise criteria revisited in the light of proposed exposure limits for harbour porpoises. Marine Pollution Bulletin **90**:196-208.

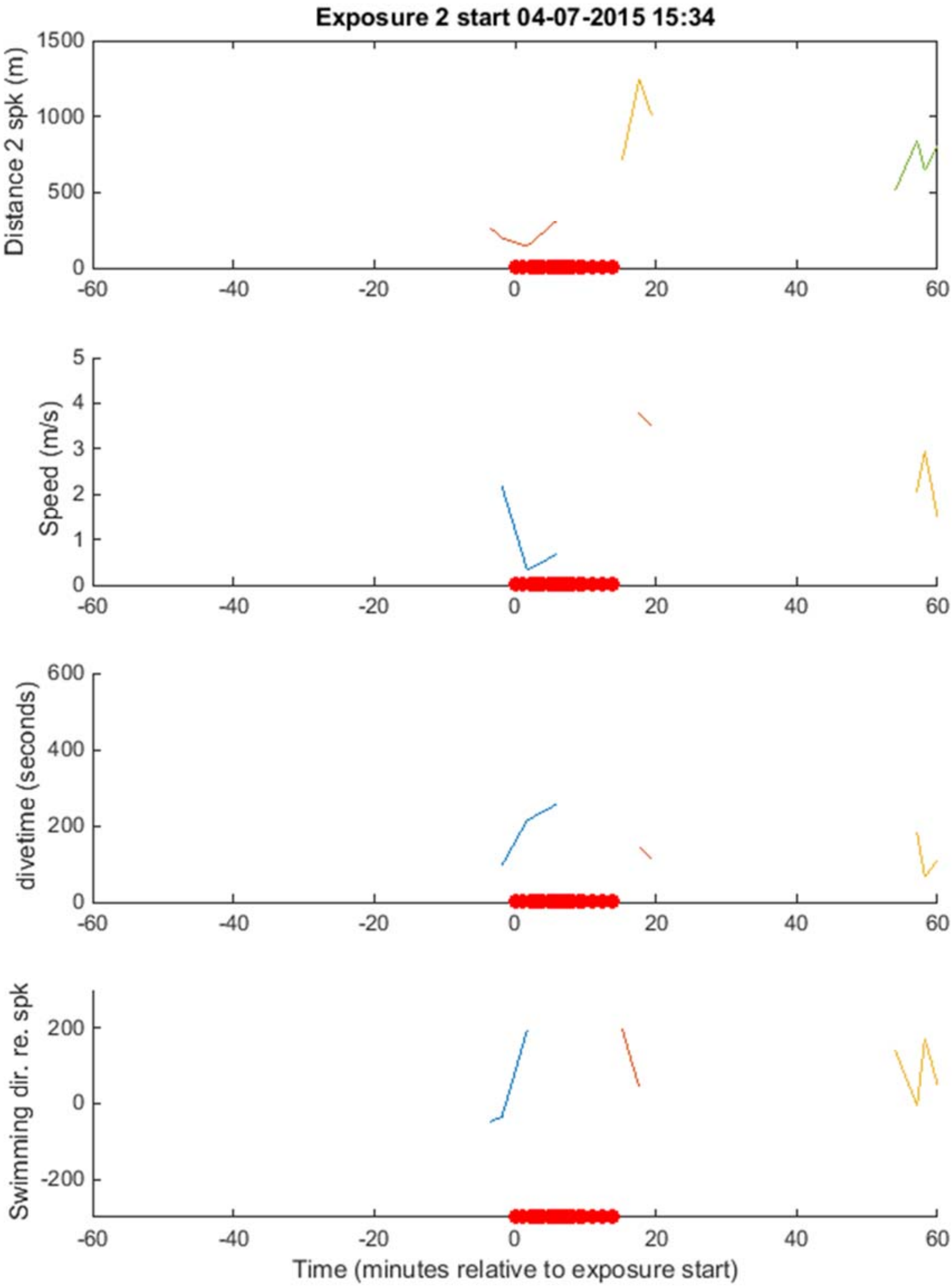
Ydenberg, R. C., and L. M. Dill. 1986. The echonomics of fleeing from predators. Advanced Studies of Behaviour **16**:229-249.

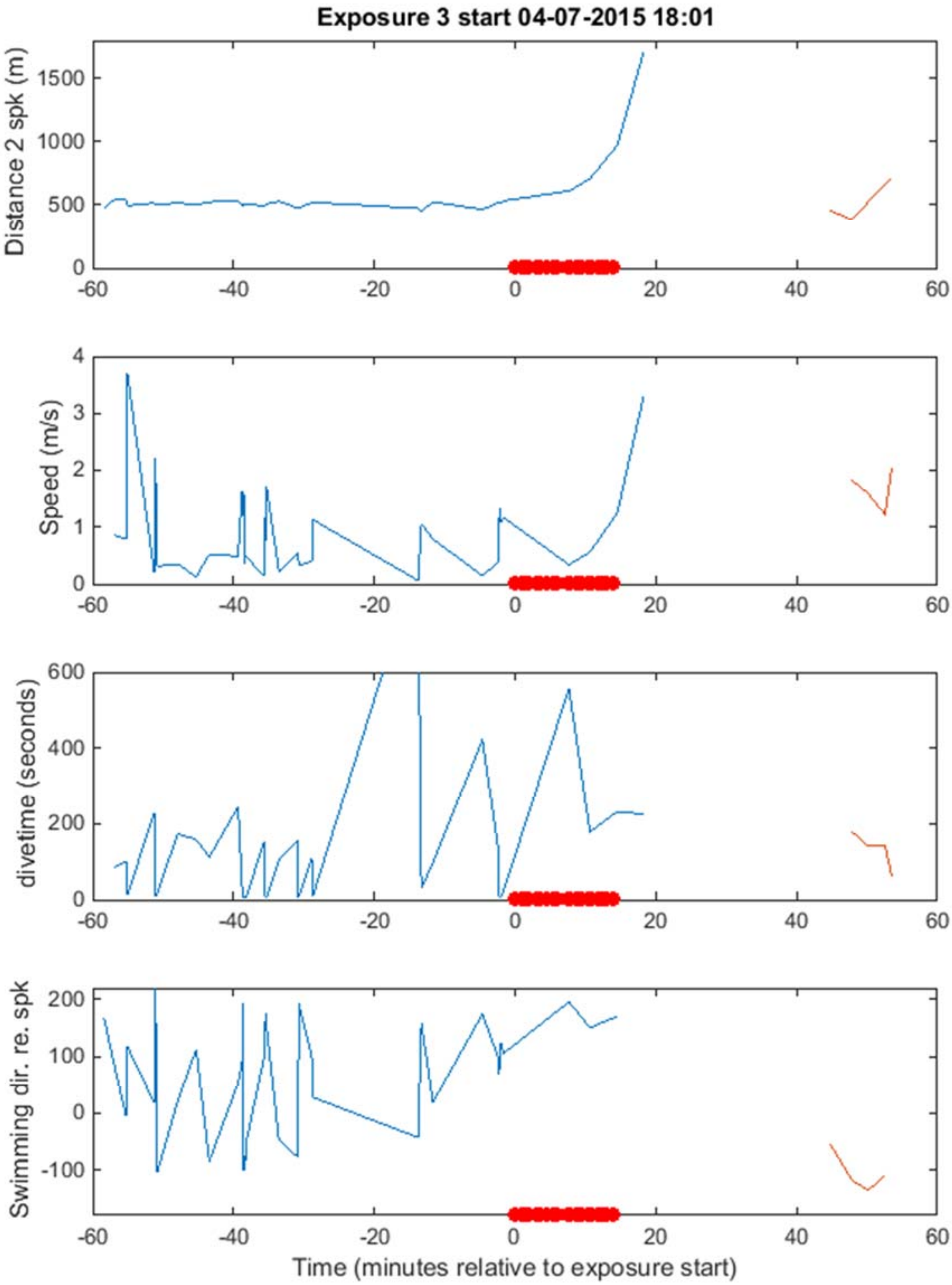
Zampolli, M., M. J. J. Nijhof, C. A. F. de Jong, M. A. Ainslie, E. H. W. Jansen, and B. A. J. Quesson. 2013. Validation of finite element computations for the quantitative prediction of underwater noise from impact pile driving. Journal of the Acoustical Society of America **133**:72-81.

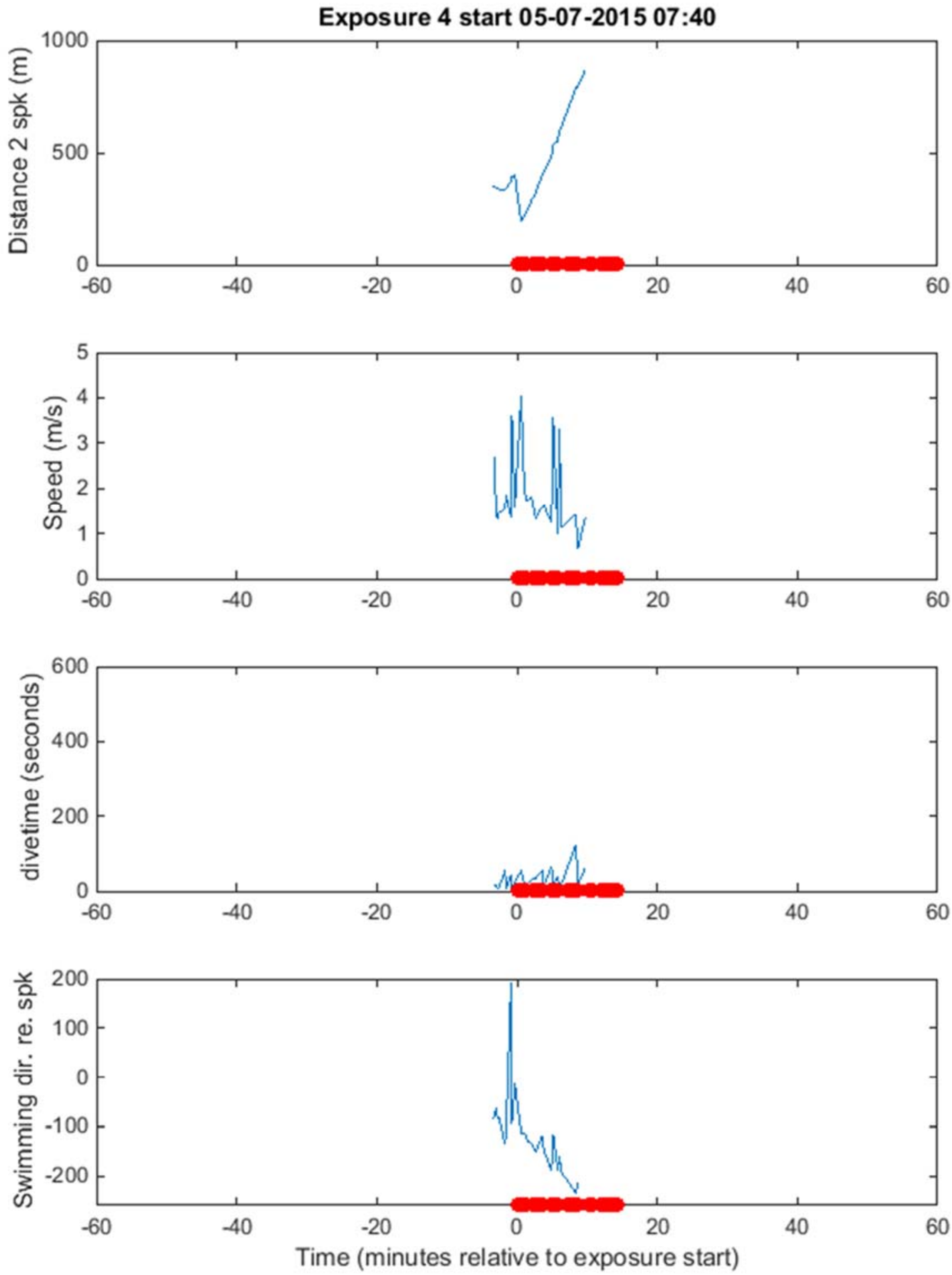
Appendix: Individual exposures



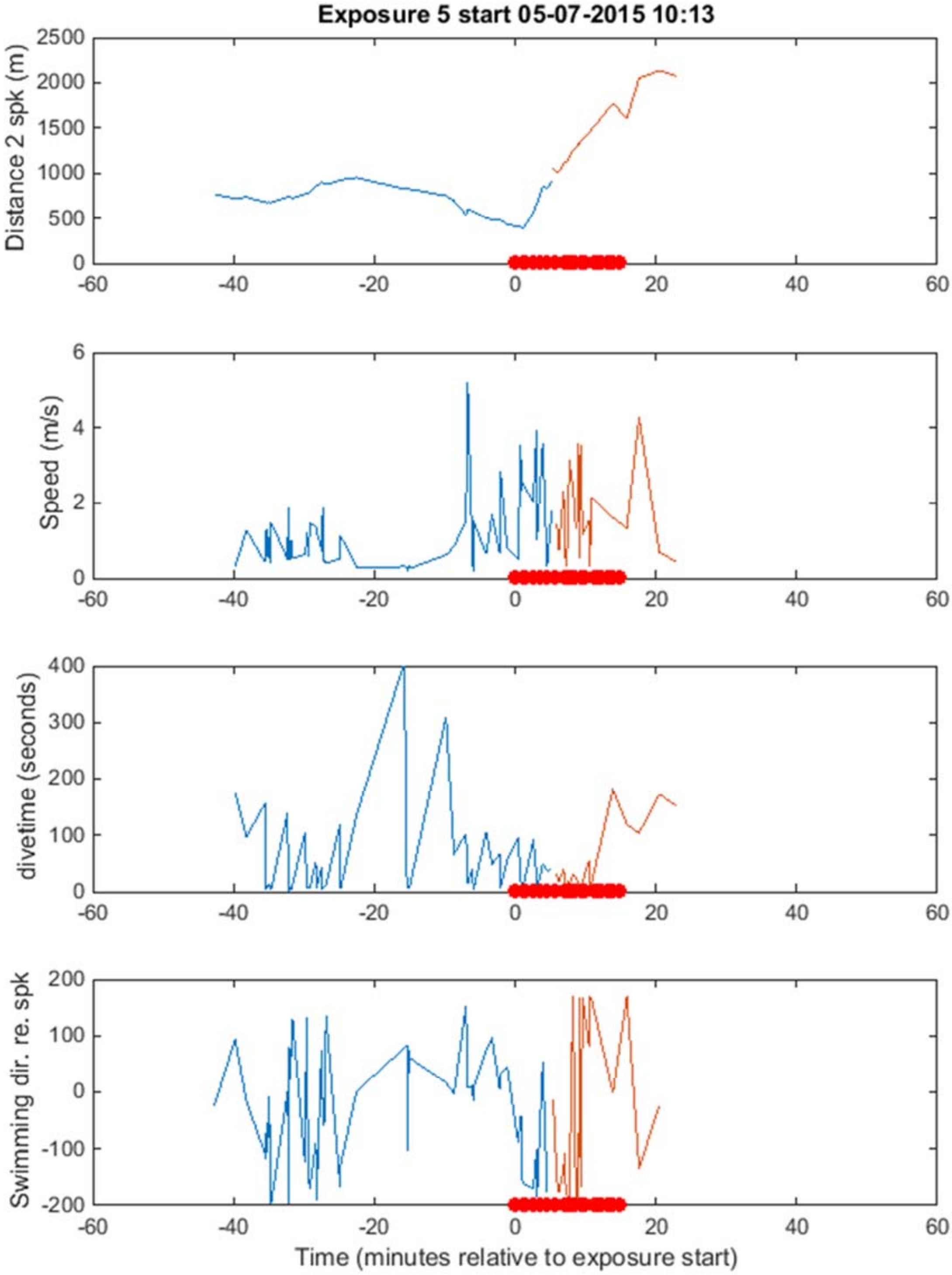

Exposure 1 start 03-07-2015 16:19
Distance 2 spk (m)
1000
500
0
Speed (m/s)
5
4
3
2
1
0
divetime (seconds)
400
300
200
100
0
Swimming dir. re. spk
200
0
-200
-60
-40
-20
0
20
40
60
Time (minutes relative to exposure start)


Exposure 2 start 04-07-2015 15:34
Distance 2 spk (m)
1500
1000
500
0
-60
-40
-20
0
20
40
60
Speed (m/s)
5
4
3
2
1
0
divetime (seconds)
600
400
200
0
Swimming dir. re. spk
200
0
-200
Time (minutes relative to exposure start)

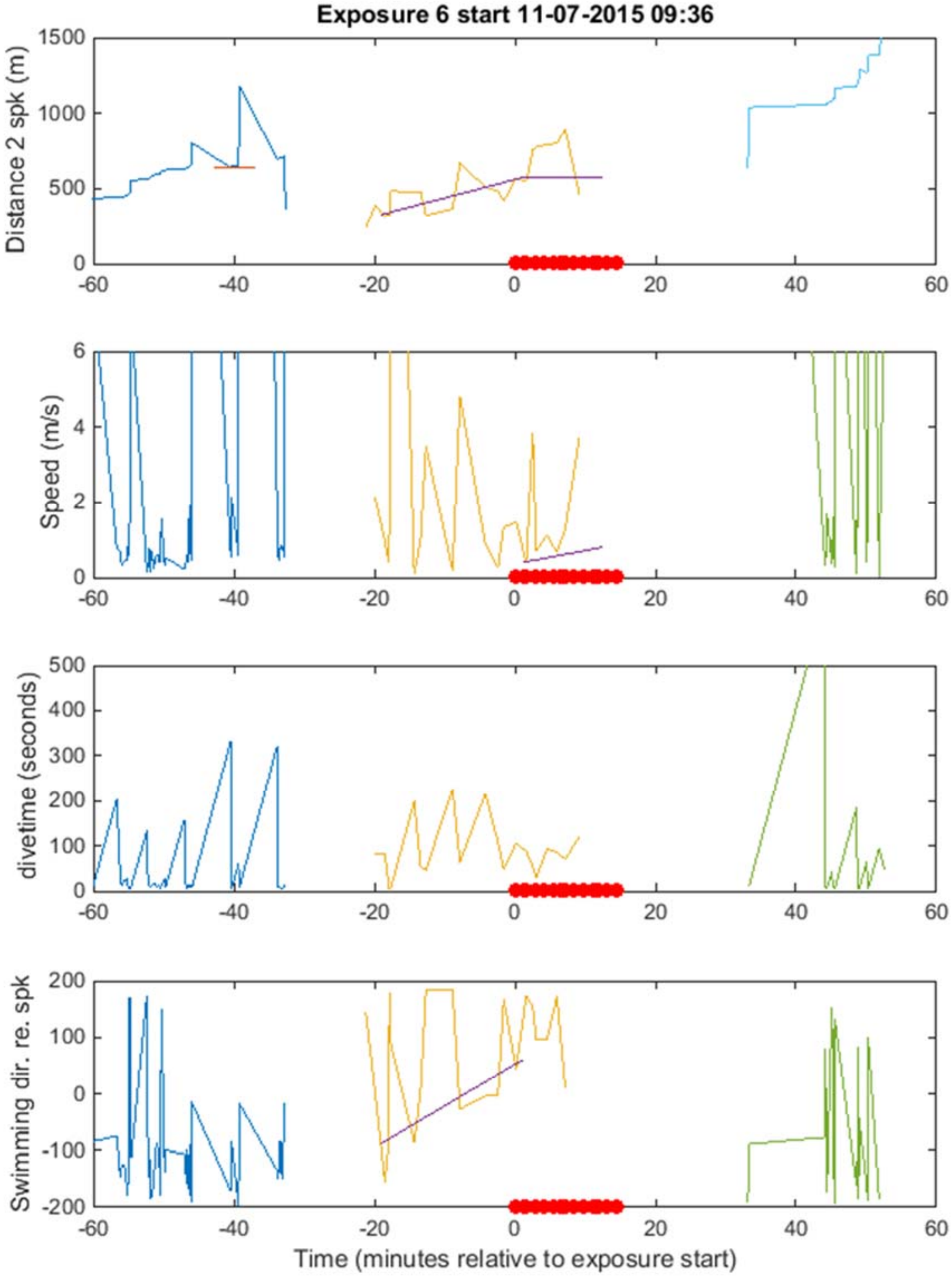

Exposure 3 start 04-07-2015 18:01
Distance 2 spk (m)
1500
1000
500
0
-60
-40
-20
0
20
40
60
Speed (m/s)
4
3
2
1
0
divetime (seconds)
600
400
200
0
Swimming dir. re. spk
200
100
0
-100
Time (minutes relative to exposure start)

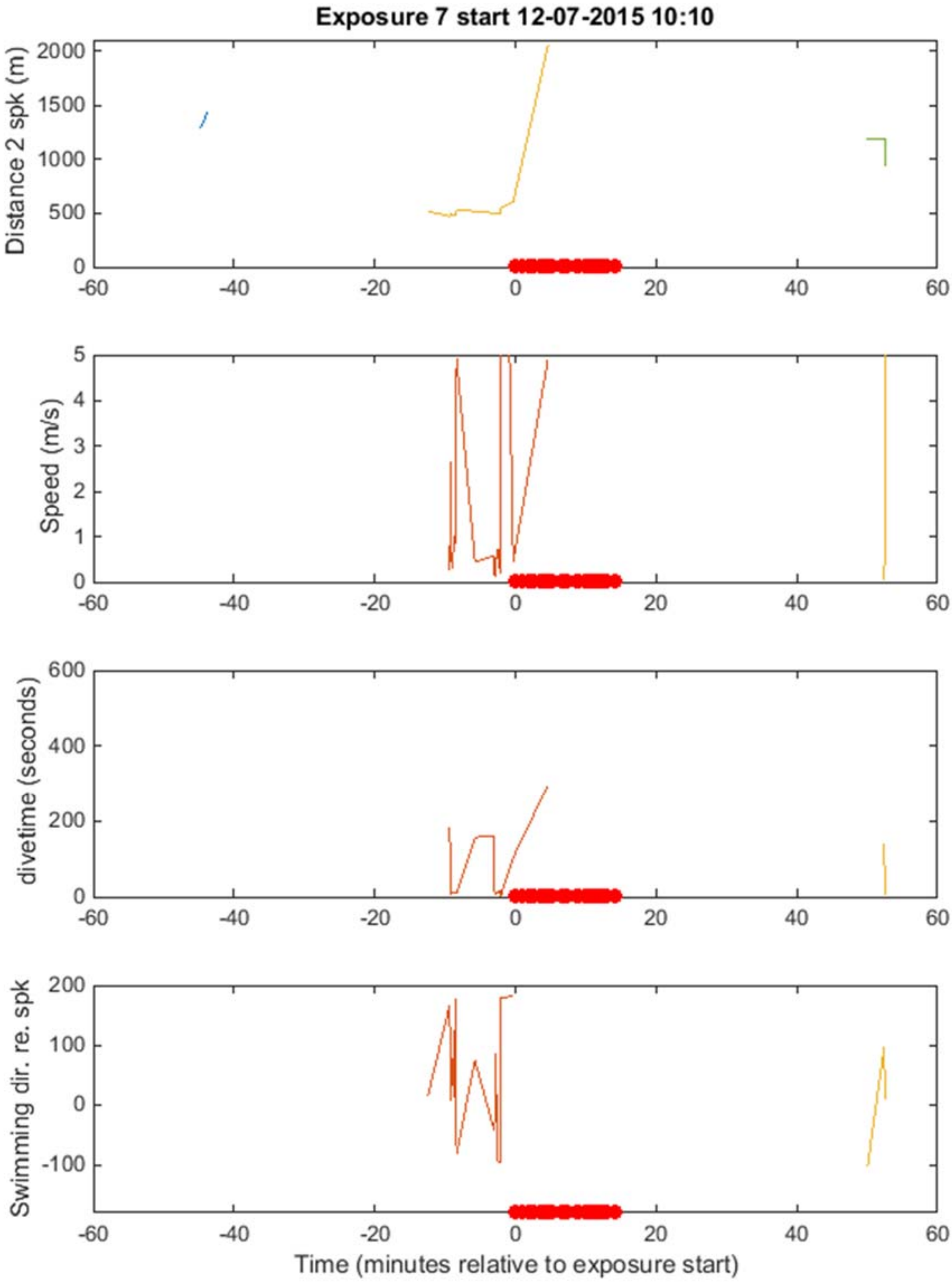


Exposure 4 start 05-07-2015 07:40
Distance 2 spk (m)
1000
500
0
-60
-40
-20
0
20
40
60
Speed (m/s)
5
4
3
2
1
divetime (seconds)
600
400
200
Swimming dir. re. spk
100
-100
-200
Time (minutes relative to exposure start)

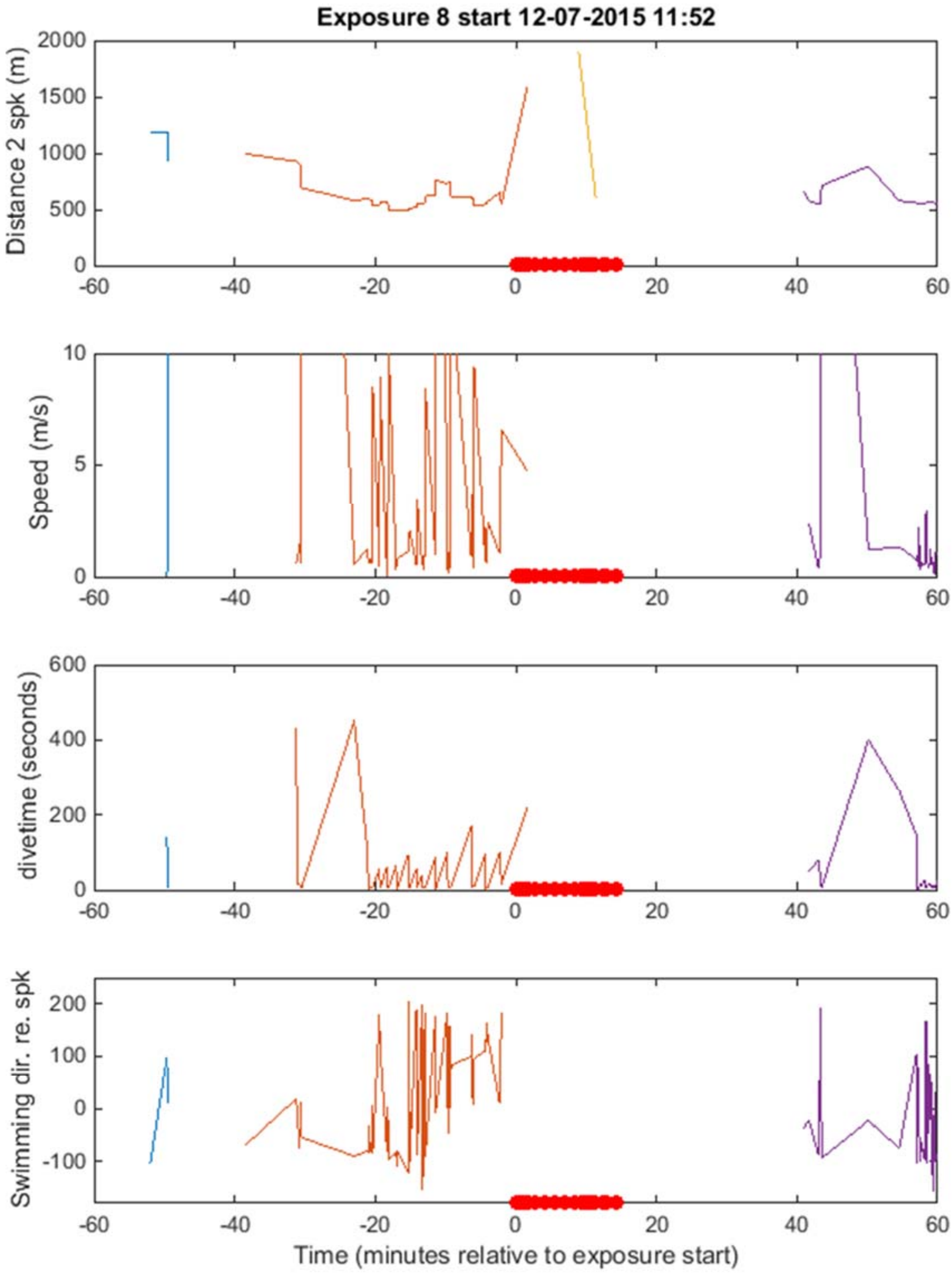


Exposure 5 start 05-07-2015 10:13
Distance 2 spk (m)
2500
2000
1500
1000
500
0
-60
-40
-20
0
20
40
60
Speed (m/s)
6
4
2
0
divetime (seconds)
400
300
200
100
0
Swimming dir. re. spk
200
100
0
-100
-200
Time (minutes relative to exposure start)

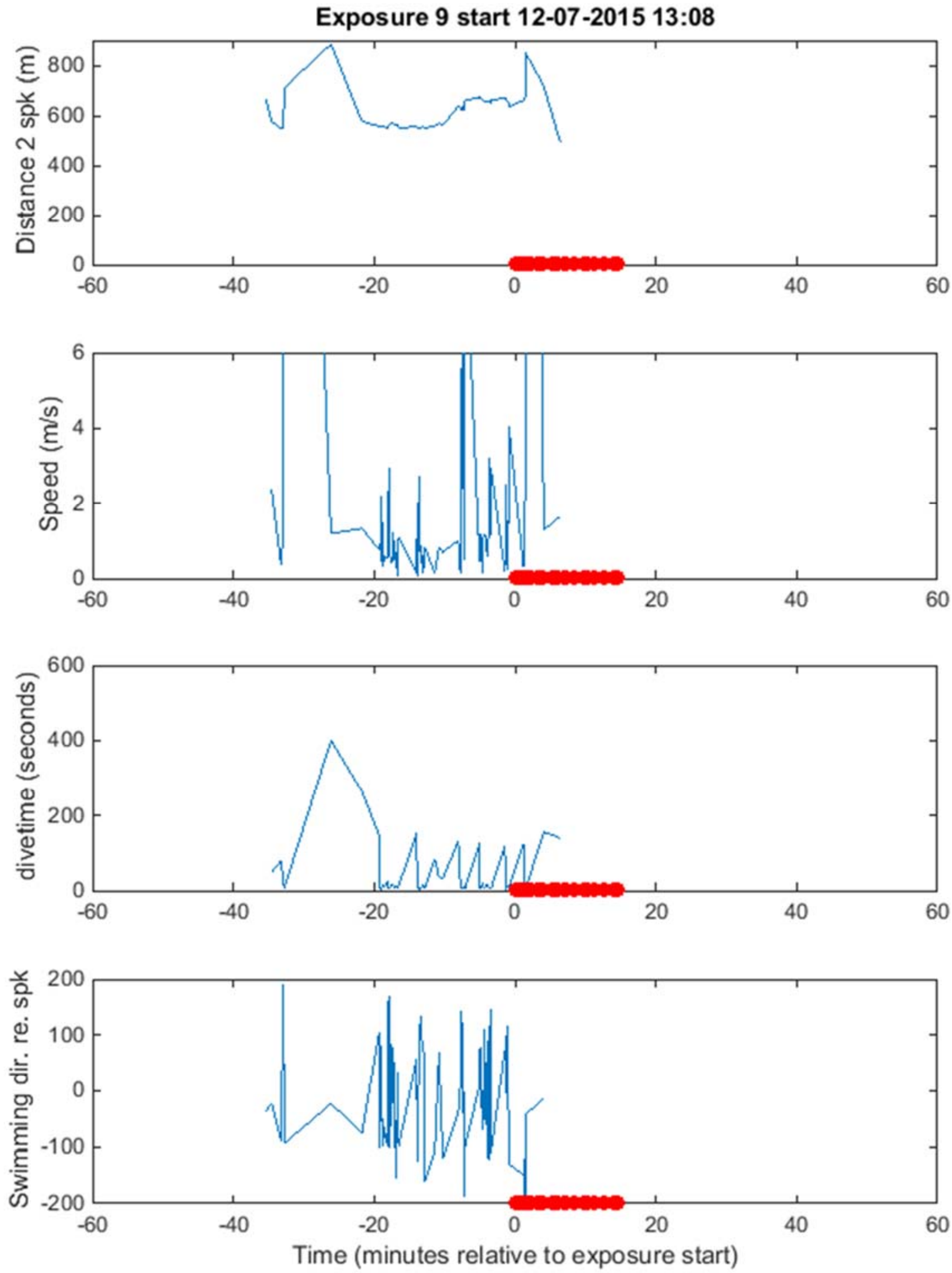

Exposure 6 start 11-07-2015 09:36
Distance 2 spk (m)
Speed (m/s)
divetime (seconds)
Swimming dir. re. spk
Time (minutes relative to exposure start)

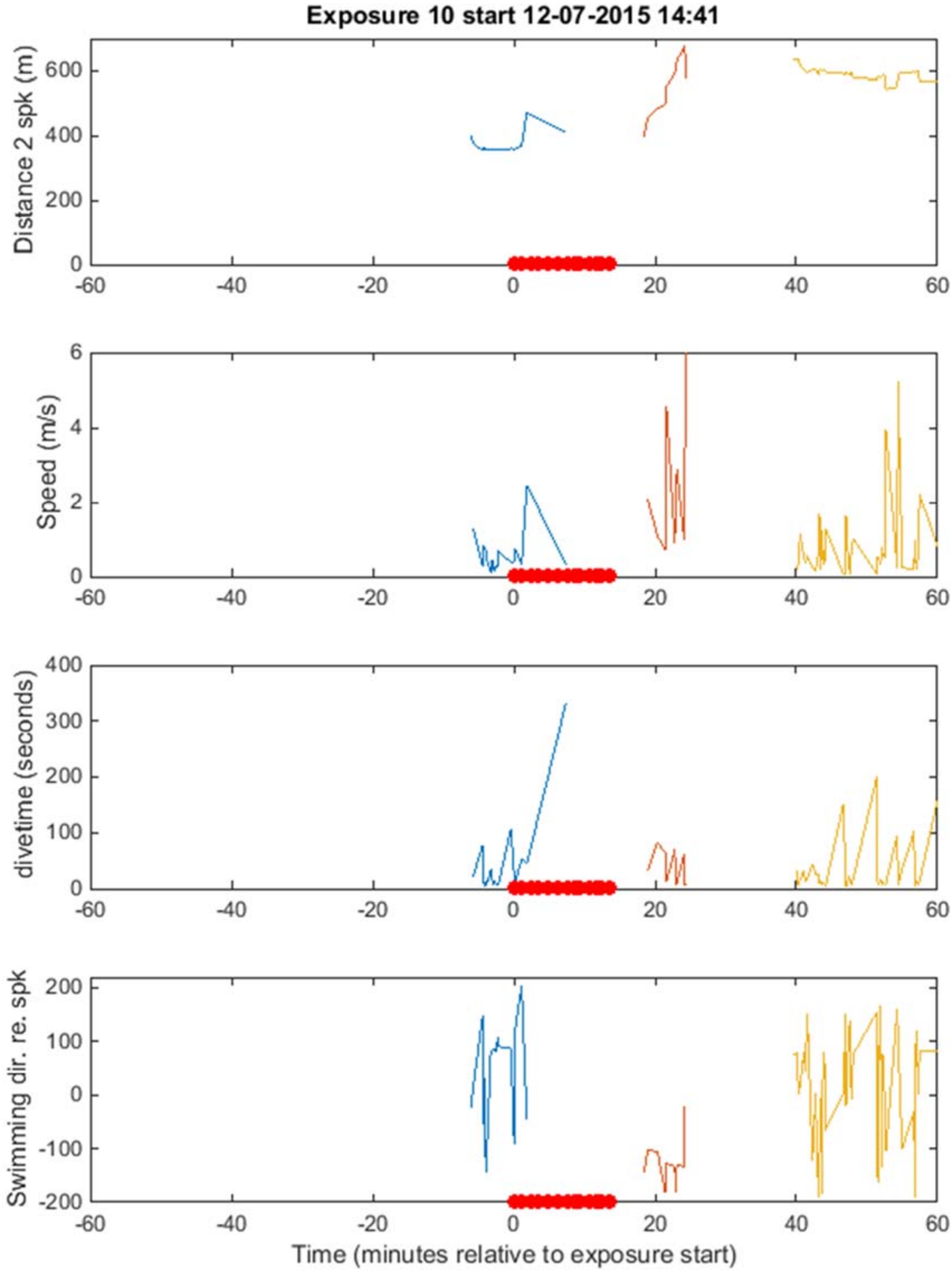


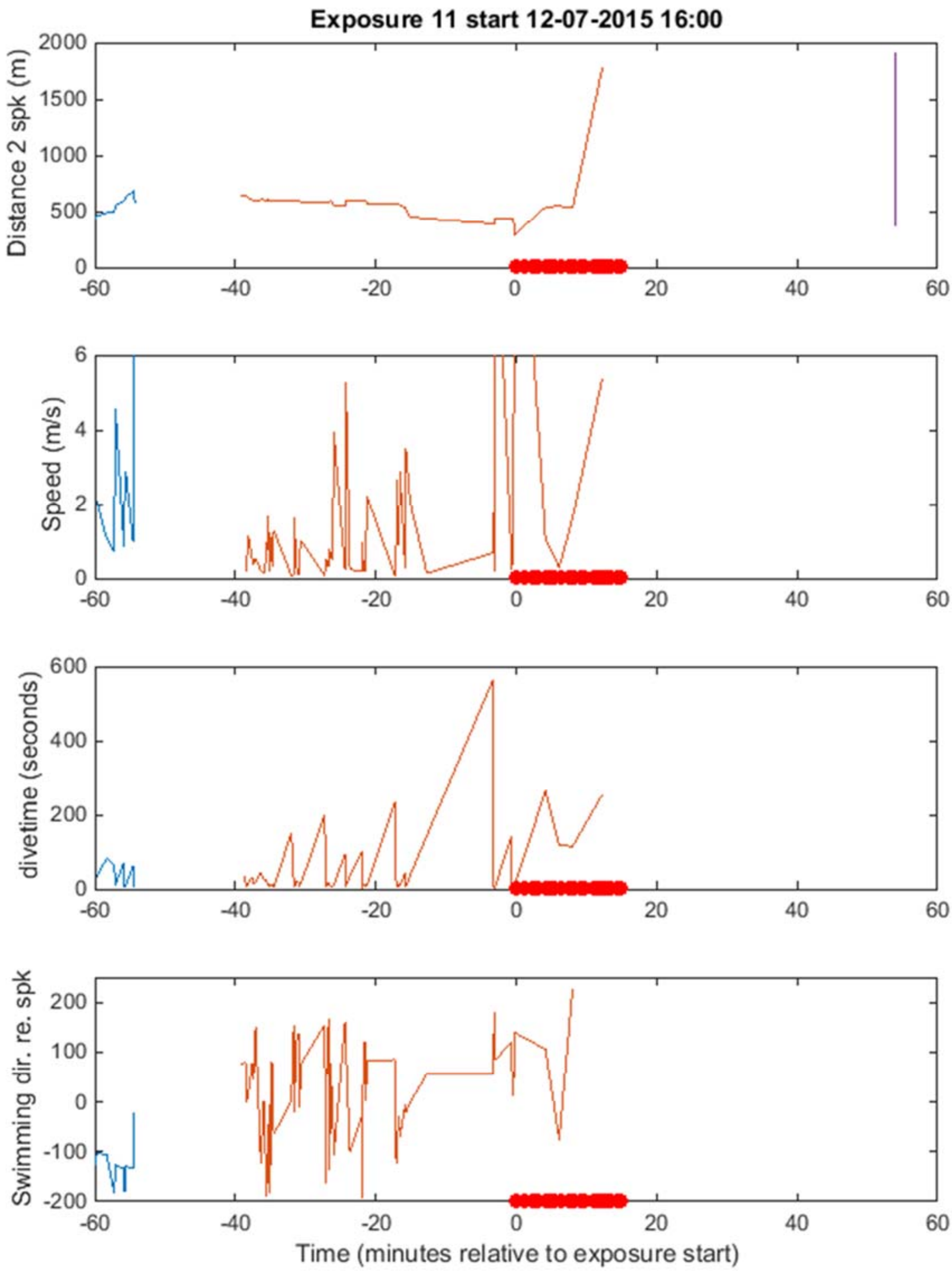
Exposure 7 start 12-07-2015 10:10
Distance 2 spk (m)
Speed (m/s)
divetime (seconds)
Swimming dir. re. spk
Time (minutes relative to exposure start)



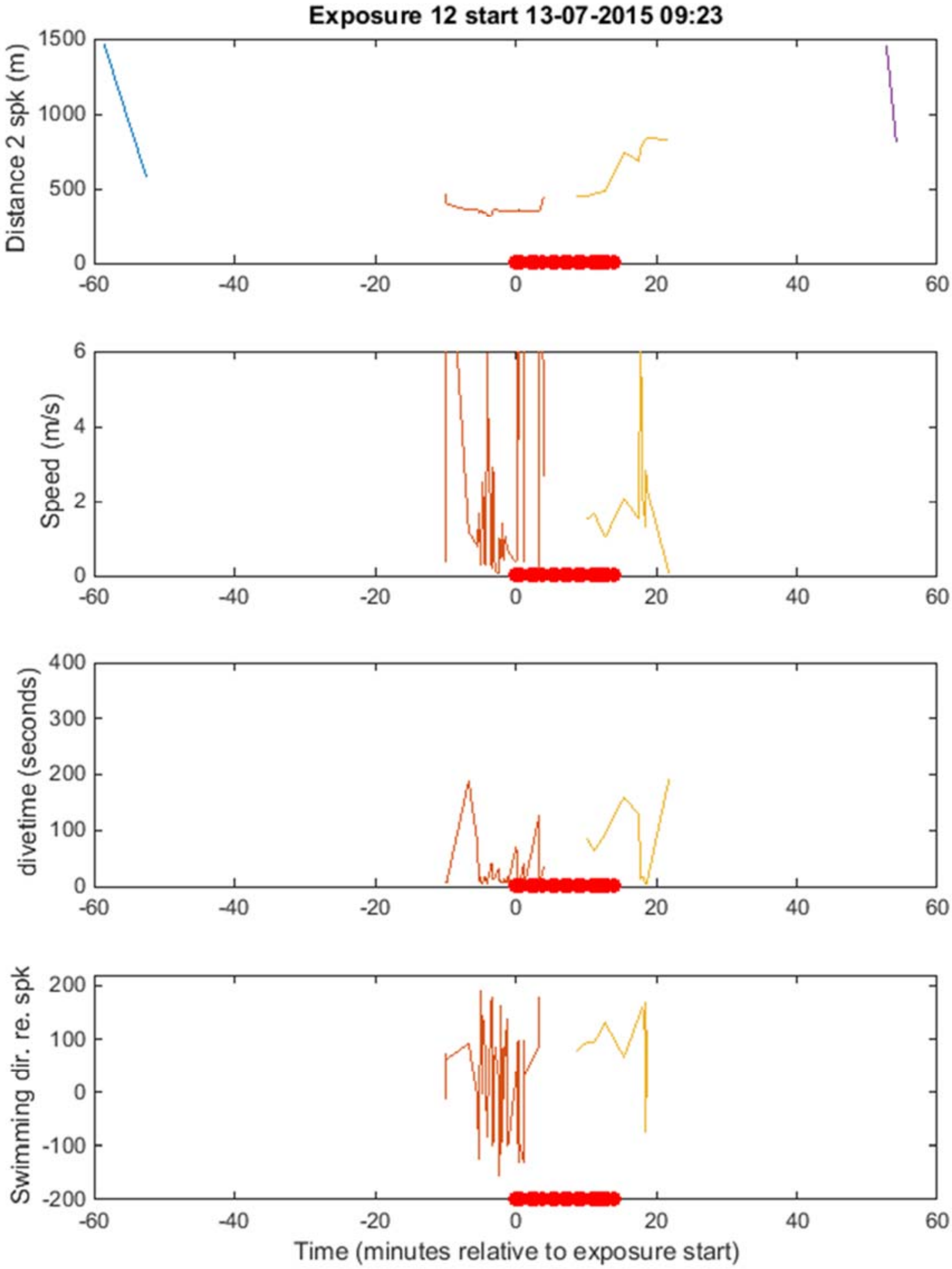
Exposure 8 start 12-07-2015 11:52
Distance 2 spk (m)
2000
1500
1000
500
0
-60
-40
-20
0
20
40
60
Speed (m/s)
10
5
0
divetime (seconds)
600
400
200
0
Swimming dir. re. spk
200
100
0
-100
Time (minutes relative to exposure start)


Exposure 9 start 12-07-2015 13:08
Distance 2 spk (m)
800
600
400
200
0
-60
-40
-20
0
20
40
60
Speed (m/s)
6
4
2
0
divetime (seconds)
600
400
200
0
Swimming dir. re. spk
200
100
0
-100
-200
Time (minutes relative to exposure start)

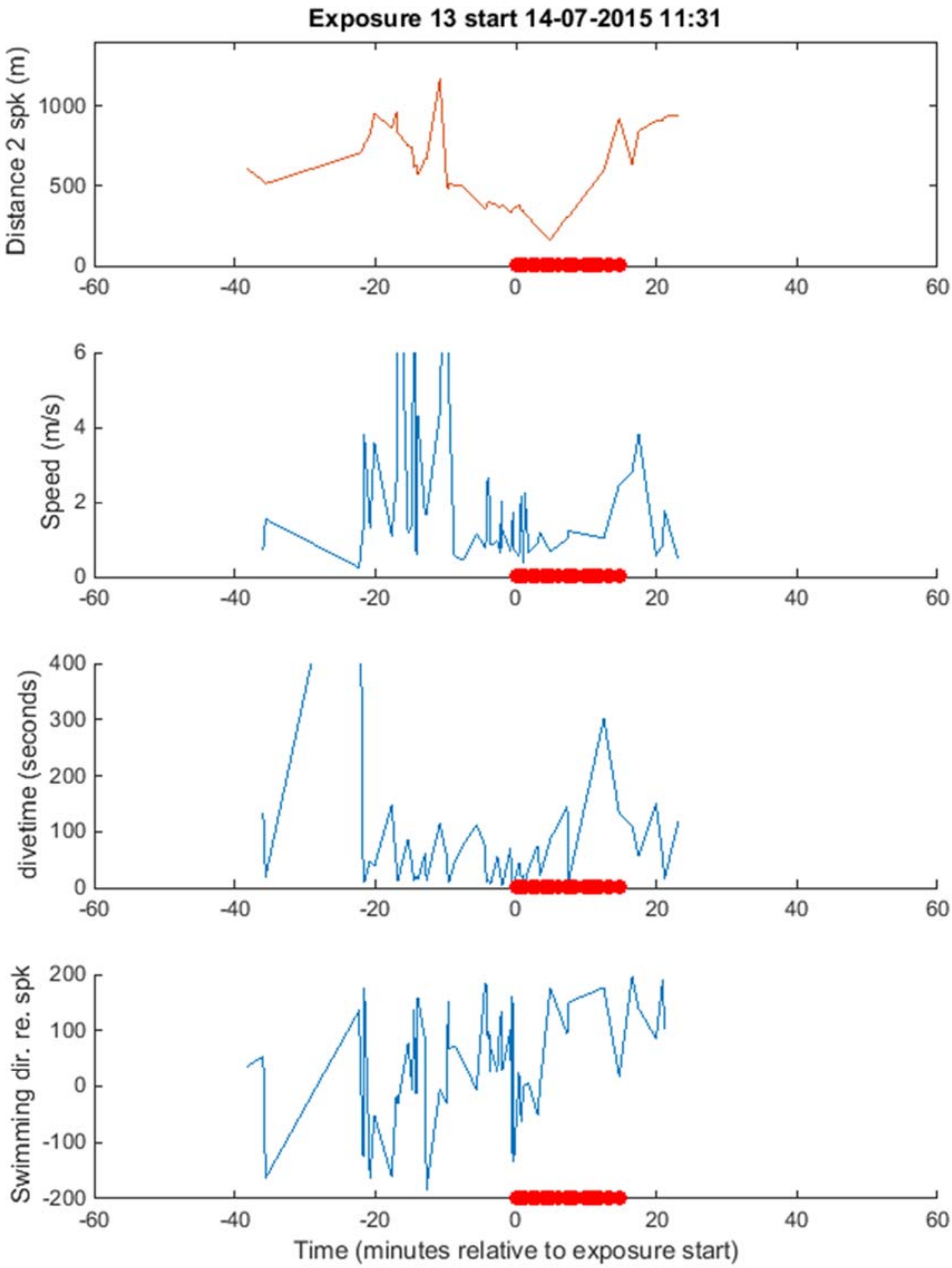

Exposure 10 start 12-07-2015 14:41
Distance 2 spk (m)
Speed (m/s)
divetime (seconds)
Swimming dir. re. spk
Time (minutes relative to exposure start)



Exposure 11 start 12-07-2015 16:00
Distance 2 spk (m)
Speed (m/s)
divetime (seconds)
Swimming dir. re. spk
Time (minutes relative to exposure start)



Exposure 12 start 13-07-2015 09:23
Distance 2 spk (m)
1500
1000
500
0
-60
-40
-20
0
20
40
60
Speed (m/s)
6
4
2
0
divetime (seconds)
400
300
200
100
0
Swimming dir. re. spk
200
100
0
-100
-200
Time (minutes relative to exposure start)


Exposure 13 start 14-07-2015 11:31
Distance 2 spk (m)
Speed (m/s)
divetime (seconds)
Swimming dir. re. spk
Time (minutes relative to exposure start)

THE EFFECT OF SIMULATED SEAL SCARER SOUNDS ON HARBOUR PORPOISES

Powerful acoustic deterrents, so-called seal scarers, are commonly used in connection with pile driving of steel monopiles, to protect harbour porpoises against injury, in the form of temporary or permanent hearing loss. The objective of the seal scarer is to deter porpoises out to a safe distance from a pile driving site, before the pile driving itself starts. To determine the effective deterrence distance of seal scareres a controlled exposure study was conducted at Helgenæs, Denmark, where porpoises were exposed to low-level of replica seal scarer signals, while the animals were tracked visually from land. During control periods without sound the porpoises were predominantly observed in a band approximately 500-800 m from the coast, whereas very few animals were observed during sound exposure. Reaction distances to the reduced levels of the controlled exposure must be scaled up to be applied to a real seal scarer, which gives an estimated deterrence distance of 3,100 m.

ISBN: 978-87-7156-295-8
ISSN: 2245-0203