The 3S² experiments – studying the behavioral effects of naval sonar on northern bottlenose whales, humpback whales and minke whales

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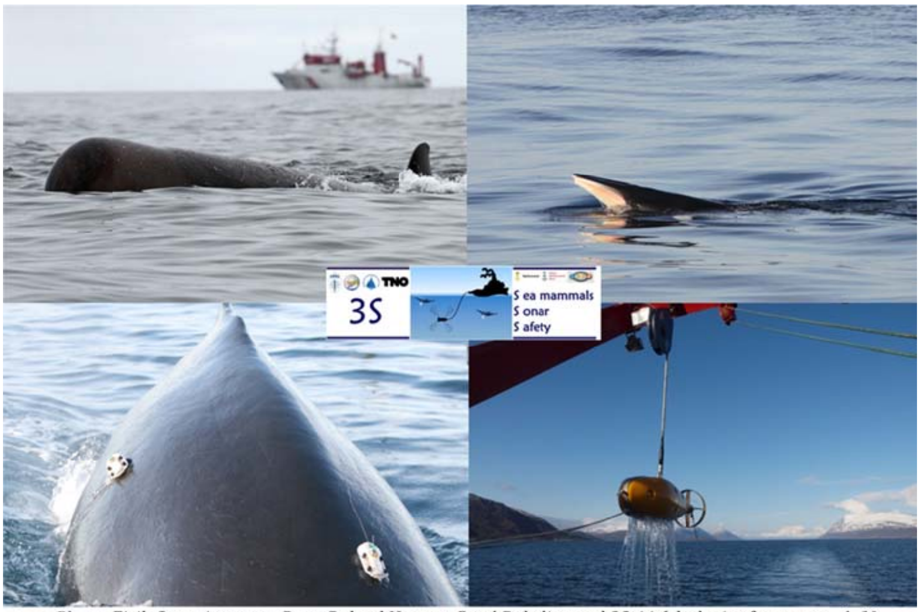

Photo: Eirik Grønningsæter, Rune Roland Hansen, René Dekeling and 3S-11 (clockwise from upper left)

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English summary

In order to properly consider how behavioral responses to anthropogenic noise affect marine mammals and establish safety limits for sonar operations, there is a need to establish behavioral impact criteria. In order to achieve this, knowledge about how marine mammals might respond, thresholds and durations of responses as well as the biological significance of behavioral changes are essential.

The 3S² project is a multidisciplinary and international collaborative effort to investigate behavioral reactions of cetaceans to naval sonar signals. The 3S² project (2011-2015) is a continuation of the initial 3S project (2006-2010) in which behavioral responses to naval sonar signals of three species of toothed whales (pilot whales, killer whales and sperm whales) and fish (herring) were studied in Norwegian waters. In 3S² two baleen whales (minke whales and humpback whales) and another toothed whale (northern bottlenose whale) were studied in the Arctic Barents and Greenland Seas. Three field trials were conducted, one each year in 2011, 2012 and 2013.

Controlled exposure experiments using 1-2 kHz sonar signals were conducted with eleven humpback whales, one minke whale and one bottlenose whale during the three field trials. Ship approaches without sonar transmissions and playbacks of killer whale vocalizations or broadband noise were conducted as controls. Behavioral parameters such as horizontal movement, diving, social interactions, and vocalizations were recorded by animal-attached tags and via visual and acoustic tracking.

In total, 30 tags were deployed on the three target species. 22 sonar exposure sessions and 31 control sessions (killer whale playback, noise playback and no-sonar control experiments) were conducted.

This report presents a description of the methodology used and a complete collection of data plots for every experiment conducted under the 3S² project. However, it does not contain any higher level analyses and interpretations. Such analyses have already been published, or will be published in peer-review literature in the coming months. The report concludes with a short discussion of the methodology, a summary of the status of knowledge and a description of future prospects.

Sammendrag (Norwegian summary)

En fullstendig vurdering av risiko knyttet til bruk av militære sonarer krever kunnskap om sjøpattedyrs atferdsmesige reaksjoner på denne type signaler. En slik risikovurdering må deretter anvendes under utforming av retningslinjer for bruk av sonarer. Kunnskap om hvordan dyrene reagerer, terskel for og varighet av responsene samt den biologiske betydningen til atferdsendringene er kritiske faktorer man må vurdere under utformingen av slike retningslinjer.

3S2-prosjektet er et tverrfaglig internasjonalt samarbeid for å undersøke hvordan hvaler reagerer på bruk av aktive militære sonarer. Prosjektet er en videreføring av 3S-prosjektet som startet i 2006. I perioden 2006-2010 studerte man spermhval, grindhval og spekkhogger, mens man i perioden 2011-2014 studerte vågehval, knølhval og nebbhval i norske farvann. Tre tokt med HU Sverdrup II er gjennomført i Barentshavet (Bjørnøya–Spitsbergen) og Grønlandshavet (Jan Mayen).

Kontrollerte eksperimenter er gjennomført hvor de tre målartene ble eksponert for relevante sonarsignaler. Kontrollforsøk hvor dyrene ble eksponert for bare fartøyet som nærmer seg, men uten sonartransmisjon, samt eksperimenter hvor de ble eksponert for avspilling av spekkhoggerlyder (predator) og hvit støy, er også gjennomført. Atferdsparametre som horisontal bevegelse, dykkatferd, sosial atferd og vokal atferd er registrert av sensorer som er festet på hvalen eller ved hjelp av visuell og akustisk sporing av dyrene fra båt. Totalt 30 sensorpakker ble festet på en av de tre målartene. 22 sonareksponeringer og 31 kontrollforsøk ble gjennomført.

Denne rapporten beskriver metodene som er brukt og inneholder en komplett samling av dataplott for hvert eksperiment som er gjennomført under 3S2-prosjektet. Den inneholder imidlertid ingen detaljerte analyser og tolkninger av dataene. Slike analyser er allerede publisert i fagfellevurderte vitenskapelige tidsskrift, eller vil bli publisert i nærmeste fremtid. Rapporten avsluttes med en kort diskusjon av metodikken som er brukt, samt en oppsummering av kunnskapsstatus.

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Preface

The 3S^2-project has been a multidisciplinary and international collaborative effort to investigate behavioral reactions of cetaceans to naval sonar signals. The main partners in the project have been:

- The Norwegian Defense Research Establishment (FFI)
- The Netherlands Organization for Applied Scientific Research (TNO)
- Sea Mammal Research Unit (SMRU), Scotland

In addition the following organizations have also made significant contributions to the project through their association with one or several of the main 3S-partners:

- Woods Hole Oceanographic Institution (WHOI), USA
- Institute of Marine Research (IMR), Norway
- Kelp Marine Research (KelpMR), The Netherlands
- CEREMA - DTer Est, Acoustics Group, Strasbourg, France.
- Centre for Research into Ecological & Environmental Modelling (CREEM), UK
- Defense Material Organization, The Netherlands
- LK-ARTS, Norway
- Balena Research Ltd, New Zealand
- Open Ocean Consulting, UK
- WildNature.no, Norway

The 3S^2 research project has been funded by;

- The Norwegian Ministry of Defence
- The Netherlands Ministry of Defence
- Office of Naval Research, USA
- DGA, French Ministry of Defense
- With some support for additional fieldwork in Jan Mayen in 2014-15 provided by SERDP, USA.

The achievements of each sea trial conducted as part of the project has been reported in separate cruise reports, including some examples of the data collected. This report presents the methodology used and a complete collection of the data collected during every experiment conducted under the $3S^2$-project. However, it does not contain any higher level analyses and interpretations. Such analyses have already or will be published in peer-review literature in the coming year. The report concludes with a short discussion of the status of knowledge and a list of already published and planned publications from the 3S-program, and some future prospects.

1 Introduction

1.1 Effects of sound on marine mammals

During the last decades there has been a significant overall increase of underwater anthropogenic noise, leading to increased background noise levels and more frequent exposure to high intensity impulse sounds (Hildebrand 2009). Potential negative effects of sonars on marine mammals have received particular attention after several atypical mass strandings of cetaceans in connection with naval sonar activity, mostly but not exclusively involving beaked whales (Frantzis 1998, Balcomb & Claridge 2001, D'Amico *et al.* 2009). These events triggered a significant research effort which initially was strongly focused on direct effects of noise, such as hearing impairment. Based on this research, accepted noise criteria for injury have been established (Southall *et al.* 2007), and most regulators currently base their management of effects of noise on marine mammals on criteria for acute (direct physiological) effects (Ellison *et al.* 2012). However, stranding events might be directly or indirectly caused by behavioural responses (Jepson *et al.* 2003, Cox *et al.* 2006). Furthermore, behavioural responses to anthropogenic disturbance can also lead to other negative effects on vital rates, such as habitat exclusion or cessation of important activities such as feeding, migration or reproduction. Since cetaceans generally have very sensitive hearing in the frequency range of naval sonars (0.2-10 kHz) (Popper & Ketten 2008), such responses might be triggered at much lower levels than acute effects, and thus the potential for population level effects cannot be ignored. Today researcher sand regulators are also concerned with potential larger scale effects caused by behavioural responses, in addition to the acute effects on individuals (Lam & Kvadsheim 2015). In the US, the Marine Mammal Protection Act requires that the Navy estimates the numbers of animals that are being harassed by their activities (Daly & Harrison 2012). Harassment in this context includes behavioural responses which can be of biological significance. In Europe, the implementation of indicator 11 (Tasker *et al.* 2010) in the Marine Strategy Framework Directive (European Commission 2008) acknowledges noise as a potential human stressor on the environment which needs to be regulated by all member states in order to achieve *"good environmental status"* (European Commission 2010).

1.2 Behavioral response studies

In order to properly consider how behavioral responses to anthropogenic noise might negatively affect marine mammals there is a need to also establish behavioral impact criteria. In order to achieve this, knowledge about how marine mammals might respond and the threshold and duration of behavioral changes are essential. Monitoring marine mammals during actual naval exercises using satellite tags, passive acoustic or visual monitoring (Tyack *et al.* 2011, McCarthy *et al.* 2011, Kuningas *et al.* 2013) can give useful information on larger scale movements. However, carefully designed experiments, where animals are exposed to an escalating acoustic dose give us the opportunity to define in greater detail the nature of responses and response thresholds (Miller *et al.* 2014, Antunes *et al.* 2014). Additional control experiments, such as playbacks of natural sounds, give support to interpret the biological relevance of the response and may help to understand the underlying mechanism triggering responses (Tyack *et al.* 2011, Curé *et al.* 2012, 2013, 2015). On smaller animals behavioral response studies (BRSs) can be conducted in a laboratory setting (e.g. Kvadsheim *et al.* 2010, Houser *et al.* 2013a,b, Kastelein *et al*. 2013), but on large cetaceans, for which experiments on captive animals are not an option, tagging technology allows sampling of both acoustic dose and details of the behavior of free ranging animals (Johnson & Tyack 2003). Such BRSs or controlled exposure experiments (CEE) have documented a range of behavioral effects of sonar, from subtle effects such as short changes in vocal behavior (Miller *et al.* 2000, Croll *et al.* 2001, Fristrup *et al.* 2003, Alves *et al.* 2014) and dive patterns (Sivle *et al.* 2012, Wensveen *et al.* 2015a) to more severe responses such as habitat avoidance (Tyack *et al.* 2011, DeRuiter *et al.* 2013, Miller *et al.* 2014) typically also associated with cessation of feeding (Miller *et al.* 2012, Goldbogen *et al.* 2013) and even separation of dependent offspring from their social group (Miller *et al.* 2012).

1.3 Ramp-Up

Ramp-up is a procedure where the transmitted level of sound is gradually increased at the start of an operation. The idea is that the gradual increase in source level offers animals near the source the opportunity to swim away and thus potentially decrease the risk of acute physiological effects once the source reaches full power. Ramp-up schemes are used for seismic surveys (Weir & Dolman 2007, Compton *et al.* 2008) and other offshore activities such as pile driving (David 2006). Several navies have adopted ramp-up procedures (Dolman *et al.* 2009).

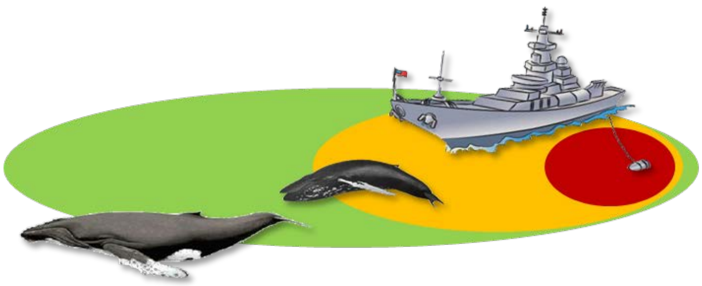


Figure 1.1 The theoretical assumption behind ramp-up is that it reduces the risk of physiological effects which occur at high received sound levels, because it triggers an avoidance response at intermediate received sound levels. The ***response threshold*** *is assumed to be somewhere between the* ***hearing threshold*** *and the* ***threshold of injury****. Ramp-up is already in use by several navies, but its effectiveness has never been tested experimentally.*

In order to actually mitigate the risk of acute physiological effects, the sonar has to trigger an avoidance response in the animal to allow enough time for it to move far enough to significantly reduce the risk of adverse effects of exposure to the more intense full power source. Based on knowledge on how some species respond to sonar and at what levels they respond, theoretical models indicate that ramp-up is effective in reducing risk to marine mammals (von Benda-Beckmann *et al.* 2014), but so far there is no empirical evidence to confirm this.

1.4 The Sea mammals and Sonar Safety (3S) research program

3S is an international research program with the aim to investigate behavioral reactions of cetaceans to naval sonar signals, in order to establish safety limits for sonar operations. During the first phase of the program (3S, 2006-2010) we worked along the coast of Northern Norway on three species of toothed whales, sperm whales (*Physeter macrocephalus*), killer whales (*Orcinus orca*) and pilot whales (*Globicephala melas*). These species were chosen partly because there were indications that they were responsive to sonar (killer whales), but partly also because they were relatively easily available and simple to work with in order to establish the experimental CEE-methodology. The specific science questions addressed were related to frequency and species specificity of responses. All the data from this project is provided in Miller *et al.* (2011) and the main results are reported in Miller *et al.* (2012).

In the second phase of the 3S-program (3S^2, 2011-2015) we switched target species to two species of baleen whales, minke whales (*Baleanoptera acutorostrata*) and humpback whales (*Megaptera noveangliae*), and one toothed whale, the northern bottlenose whale (*Hyperoodon ampullatus*). These species were chosen partly because there was a need for data also on baleen whale responsiveness, but also because both minke whale and bottlenose whales were considered likely to be very sensitive species. Other species of beaked whales have shown strong avoidance responses to naval sonar (Tyack *et al.* 2011, DeRuiter *et al.* 2013, Moretti *et al.* 2014), and both minke and beaked whales have been involved in strandings that were linked to naval sonar (Balcomb & Claridge 2001, D`Amico *et al.* 2009). Humpback whales were specifically chosen because they were expected to be easily available in the area and easy to tag, and therefore a good animal model for experimental studies on efficiency of ramp-up.

The basic design of the 3S-experiments is to deploy an acoustic and motion sensor tag on a target animal or animals and then after a baseline period conduct one or several dose escalation sonar exposures using a realistic naval sonar source towed behind an approaching ship. We have also conducted several control experiments, including ship approaches without sonar exposure and playbacks of killer whale sound or broadband noise. In addition to the data collected by the tag, we have also visually tracked the animals and collected data on group behavior. The advantage of this approach is that it allows systematic experiments and sound exposure that covers a wide received level range from barely audible to levels which are expected to be aversive. The use of a realistic moving source transmitting at high levels also make the results directly applicable to naval scenarios, except that our experimental exposures might have a shorter duration. The use of multiple consecutive exposures allows us to look at habituation or sensitization and the use of control experiments help us interpret the biological implications of responses and to separate the effect of the sonar from the effects of the approaching ship.

1.5 3S^2 project objectives

The basic questions addressed within the 3S^2-project are summarized in the box below. This technical report is no attempt to answer these questions, but instead the aim of this report is to present our methodology and the data collected during the three full scale sonar trials in 2011, 2012 and 2013. In addition we discuss the status of data collection and some future perspectives. Some of the specific analyses of the data to address these key questions are on-going, and the outcomes will be published in peer-review papers in the coming months. A list of already published reports and scientific papers is supplied in Appendix A.

The basic questions addressed within the 3S²-project

Do minke whales, humpback whales and bottlenose whales respond to sonar, at what levels do they respond, what is the biological significance of such responses and does ramp-up reduce risk of acute hearing impairment?

In addition we are addressing other important questions:

Are there major differences between species? How do responses to sonar compare to natural anti predator responses? Do the animals habituate or become sensitized? How does sociality influence responses in social animals? How does biological context modulate the response? Can improved acoustic DCL (Detection/Classification/Localization) technology add to the quality of the experiments by better detection and tracking of the target species.

2 Materials and Methods

Complementary details on observational methods, platforms and equipment can be found in the cruise plans and cruise reports (Kvadsheim *et al.* 2011, 2012, 2014).

2.1 Field site and study species

Data were collected on humpback whales (*Megaptera novaeangliae*), minke whales (*Balaenoptera acutorostrata*) and northern bottlenose whales (*Hyperoodon ampullatus*) during three research trials in the Arctic Northeastern Atlantic ocean near Bear Island and Svalbard and off Jan Mayen during 2011, 2012 and 2013 (Figure 2.1). Details of each annual cruise can be found in specific cruise reports (Kvadsheim *et al.* 2011, 2012, 2014).

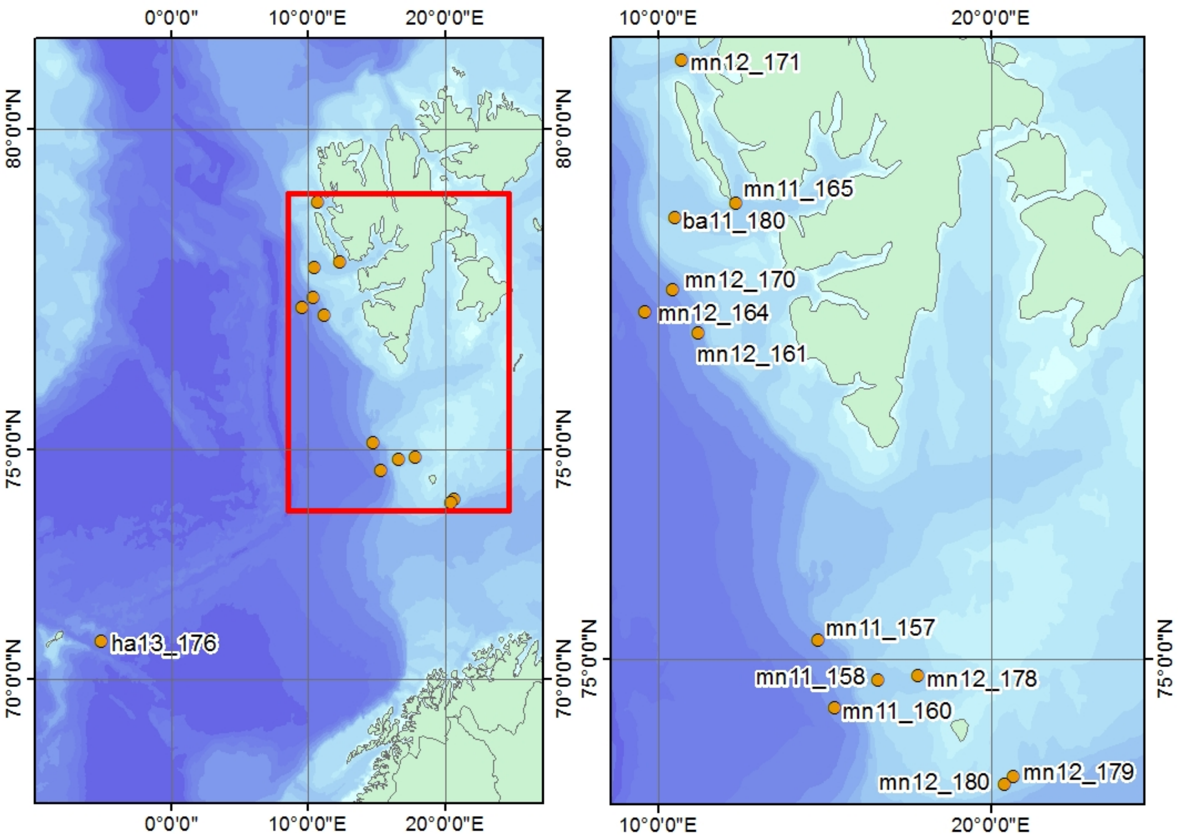


Figure 2.1 *Map of the study area with the location of sonar exposure experiments. The experimental code (e.g. mn11_158) includes a species code (humpback whales (mn), minke whale (ba) and bottlenose whale (ha)) followed by a calendar year code (2011 (11), 2012 (12) and 2013 (13)) and then the Julian day number.*

2.2 Animal welfare considerations

All animal research activities were permitted by the Norwegian Animal Research Authority (NARA Permit No. S-2011/38782), and were approved by the Animal Welfare Ethics Committee at the University of St Andrews and the Institutional Animal Care and Use Committee of the Woods Hole Oceanographic Institution. All of our experiments followed a safety plan designed to protect the welfare of the study animals as well as other animals in the area. Visual observers continuously scanned for whales throughout the exposures with a detailed plan in place to stop sonar transmissions if potentially hazardous responses occurred, or if any animal came too close to the sonar source. Our experimental design further involved limited duration of exposure periods, changing of subjects between experiments, and exposure of a limited number of animals, reducing risk of harm to experimental subjects.

2.3 Experimental materials

2.3.1 Ship and boats

The 55m FFI research vessel H.U. Sverdrup II (HUS) was used as the main platform for the experiments. From this platform two small boats were deployed for tagging of whales. One of these small boats (MOBHUS) was also used to track tagged whales during experiments.

2.3.2 Tags

Humpback whales and bottlenose whales were tagged with movement and sound-recording tags (DTAGv2, Johnson & Tyack, 2003). The DTAG was attached to the whale with suction cups using a 15 m cantilevered carbon fibre pole or a pneumatic remote deployment system ARTS (Kvadsheim *et al.* 2009). After 16-18 h the tags detached and floated to the surface for recovery. The DTAGs had one or two hydrophones and recorded sound with 16-bit resolution at a sampling rate of 96 or 192 kHz, as well as depth, 3-dimensional accelerometer and magnetometer sensors sampled at 50Hz. Additionally, the tag contained a VHF transmitter and in some deployments also a GPS data logger (SirTrack, F2G 134A, Fastloc 2) which recorded the horizontal location of the tagged whale when it surfaced. Minke whales were tagged with a smaller and simpler tag (CTAG) because previous experiences with minke whales confirmed that suction cup attachment was unreliable, possibly due to a slippery surface caused by loose epidermal skin (Kvadsheim *et al.* 2011). The CTAG was deployed using the ARTS system, and was attached to the whale by a 50 mm long barb which penetrates the skin and anchors within the blubber. It contained a VHF-transmitter and a Star Oddi DST Magnetic with time depth recorder and 3D magnetic and tilt sensors (Kvadsheim *et al.* 2011) sampled at 0.25Hz. The CTAG was released from the animal using a galvanic time release after 19 h. The digital processing radio direction finder (DF-Horten, ASJ Electronic Design, Horten, Norway) connected to 4 yagi antennas was installed on board both HUS and MOBHUS to able control of the tagged animal during tracking.

2.3.3 Acoustic arrays

To acoustically search for marine mammals and track bottlenose whales during experiments, the TNO developed passive acoustic array Delphinus was towed by HUS. The Delphinus is a single line array, 74 meters long, containing 18 low frequency hydrophones used for the detection and classification of marine mammal vocalization up to 20 kHz. Three UHF hydrophones with total baseline of 20m are used for the detection, classification and localization of marine mammal vocalizations up to 160 kHz. Additionally, the array includes a single triplet (consisting of 3 UHF hydrophones), which is used to solve the left-right ambiguity for the localization. The array is also equipped with depth and roll sensors. During the minke whale experiment in 2011, the light boat tracking the tagged whale also towed a smaller acoustic array containing calibrated hydrophones to benchmark the acoustic propagation model used to estimate received levels on the whale.

2.3.4 Sound sources

For the sonar exposure experiments the multi purpose towed acoustic source SOCRATES II was used, towed by the Sverdrup. This sophisticated and versatile source has been developed by TNO for underwater acoustic research. Socrates has two free flooded ring transducers, one for the frequency band between 0.95 kHz and 2.35 kHz (maximum source level 214 dB re 1 μPa m), and the other between 3.5 kHz and 8.5 kHz (maximum source level 199 dB re 1 μPa m). It also contains one hydrophone and depth, pitch, roll, and temperature sensors. In the experiments described here, two different signal types were used:

$LFAS_{deep}$ (1 - 2 kHz HFM upsweep) used for bottlenose whales.

$LFAS_{shallow}$ (1.3 - 2 kHz HFM upsweep) used for minke and humpback whales.

Sonar transmissions were initiated by a ramp-up procedure which implied a gradual increase of source level from 152 to 214 dB (re 1 μPa m). The ramp-up procedure was used as part of the risk mitigation plan, and also as part of the experimental design that aimed to gradually escalate the acoustic dose. The sonar pulse repetition interval for all experiments was always 20 s and the signal duration was 1 s, except during the ramp-up period of humpback whale experiments where the signal duration was 0.5 s.

For the killer whale sound and broadband noise playbacks a M-Audio Microtrack II recorder, amplified by a Cadence Z8000 amplifier connected to a Lubell LL9642T underwater loudspeaker (frequency range: 0.2-20 kHz) was used at a depth of 8 m. To measure the sound level of the source and to ensure that sounds were played back by the system without distortion, playback stimuli were recorded using a calibrated hydrophone placed 1 m from the source. The average sound pressure level of the killer whale stimuli ranged from 146 to 152 dB (re 1 μPa m) which corresponds to the average source level of killer whale vocalizations observed in natural conditions. The sound pressure level of control stimuli ranged from 145 to 150 dB (re 1 μPa m).

2.3.5 Sound speed profiles

During each sonar exposure run, a temperature profile was taken using a Sippican 77 XBT. In addition, after the end of every sonar exposure experiment, a temperature and salinity profile was taken along the transmission path using a SAIV SD200 CTD.

2.4 Experimental protocol

The protocol consisted of several phases; 1) searching, 2) tagging, 3) baseline pre-exposure, 4) experimental exposure sessions, and 5) post-exposure data collection. In the search phase, we searched for animals from HUS by visual observations and the towed acoustic array from HUS. Once whales were located, and weather conditions were acceptable, one or two tag boats were launched with tagging and photo-identification capability. During tagging attempts, the observer teams provided visual and acoustic tracking support to the tag boats, or they searched for new animals depending upon the situation. After a tag was attached to an animal, the tag boat took photo-identification photographs and tracked the tagged animal initially, until tracking was picked up by HUS. Tracking from HUS continued for a period of approximately 1 h and was then done mainly from MOBHUS until the tag was retrieved. Visual observers were present at all times at the observation platform of HUS, to support the observer team on MOBHUS.

In the experimental phase, we attempted to do 5 exposure sessions of the tagged animal, each about 1 h apart; 1) *no-sonar* ship approach, 2) first *sonar* exposure, 3) second *sonar* exposure, 4) *killer whale playback* and 5) *noise playback*. The first three exposure sessions were always kept in this order to avoid sensitization of the animal to the ship, while the order of the last two was randomized.

2.4.1 Sonar exposure and no-sonar controls

After a period of baseline pre-exposure data collection, the source vessel moved into position to start the first ship approach on the whale. The position of the tagged whale was estimated in real-time by the observers and relayed to the sonar operator on the source vessel (HUS). Sonar transmissions were always initiated by a ramp-up procedure which implied a gradual increase of source level from 152 to 214 dB (dB re 1μPa m). The primary goal of the movement of the source vessel was to achieve a gradual escalation of the received levels of sonar sounds, but the ship's movement was slightly different between the three species (see below). Humpback whales and the minke whale were also subject to the same approach by the source vessel but without sonar transmissions (*no-sonar control*), to enable comparison of potential responses to the sonar with responses to the approaching source vessel alone.

2.4.1.1 Minke whale - dose escalation

HUS approached the whale from a distance of 8.8 km at 4.4 m/s. First a *no-sonar control* run was conducted, which was followed by a sonar exposure run with a 10 min ramp-up. The animal was approached to intercept its course, determined prior to start of the exposure. Both sessions continued until 5 min after the closest point of approach (CPA), but the sonar exposure did not last longer than 70 min. This protocol was identical to that of Miller *et al.* (2011), which allows comparison of results between species.

2.4.1.2 Bottlenose whale – dose escalation

This species can conduct dives lasting more than one hour (Hooker & Baird, 1999), and good tracking of the animals therefore relies on successful acoustic tracking during deep dives, in combination with visual tracking when they are at the surface. To achieve this, the source vessel sailed 2*2 km boxes towing an acoustic array at 100-200m depth around the estimated position of the whale throughout the tracking period. During sonar exposure, the source ship started ˜5 km from the position of the whale and sailed ¾ of a 2*2 km box at 2.6 m/s while transmitting first a 20 min ramp-up, followed by 15 min of full power transmissions. The movement of the vessel during transmissions was pre-determined without respect to the position or movements of the whale. During the exposure the focal whale was not inside the box, but several km away from it, and thus the angle between the sonar and the whale changed very little. This protocol was close to those of Tyack *et al.*

(2011) and DeRuiter *et al.* (2013) to ensure comparability with existing data on other beaked whales.

2.4.1.3 Humpback whale – ramp-up

The sonar exposure and *no-sonar control* experiments conducted on humpback whales were specifically designed to test the effectiveness of the ramp-up procedure. Three different types of exposure sessions were conducted; *ramp-up*, *no-ramp-up* and *no-sonar control*, all with a duration of 10 min (Figure 2.2).

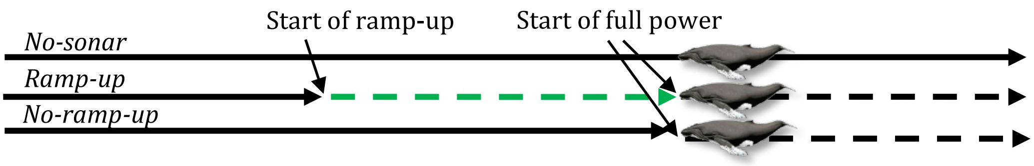


Figure 2.2 Schematic of the experimental design that was used to test the hypothesis that ramp-up will reduce the received sound level of humpback whales compared to sound levels received during no-ramp-up. Solid black lines represent periods when the source was not transmitting. The green dashed line and black dashed lines represent the 5-min ramp-up period and 5-min full power periods.

During the ramp-up session, sonar transmission was initiated approximately 1250 m from the tagged animal, and the source ship approached at 4.1 m/s on a straight and constant course with a gradual 5 min ramp-up of the source level (Figure 2.3), and then continued full power transmission for another 5 min while moving away from the animal after passage (Figure 2.2). The course was estimated by intercept calculators to intercept the animal at a closest point of approach (CPA) of 0 m based on the movement pattern of the animal prior to start of exposure. The *no-sonar* and *no-ramp-up* sessions followed the exact same procedure, except that there was no active transmission during *no-sonar* sessions, and that transmissions only started at full power at CPA during *no-ramp-up* sessions (Figure 2.2).

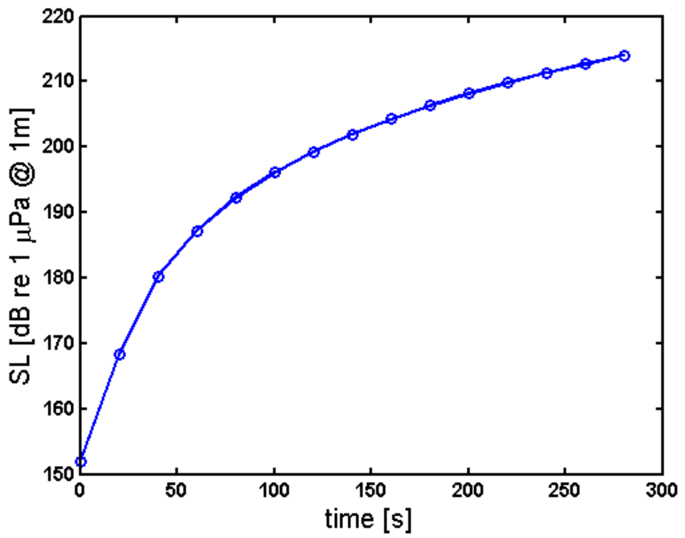


Figure 2.3 Optimal ramp-up scheme used in experiments with humpback whales.

The specific 5 min ramp-up scheme used in these experiments (Figure 2.3) was selected as the optimal ramp-up based upon a theoretical assessment of hearing loss risk (von Benda-Beckmann *et al.* 2011).

2.4.2 Killer whale and noise playback experiments

The killer whale sound playback was used as a positive control for assessing responses of animals to a natural threatening stimulus, i.e. predation risk, and the noise playback as a negative control of the killer whale sound playback to test the animal`s reaction to any unspecific noise. Such playback experiments were only conducted with humpback whales (Curé *et al.* 2015). The minke whale and the bottlenose whale responded so strongly to the preceding sonar exposure that any subsequent exposure was cancelled. Both acoustic stimuli were of 15 min duration. The killer whale playback stimulus was previously recorded in the North Pacific using DTAGS (Miller *et al.* 2010) and corresponds to natural sequences of vocalizations of a killer whale group attacking and feeding on marine mammal prey. The stimulus thus represents 'unfamiliar' mammal-eating killer whale sounds, expected to be perceived as an immediate risk of predation (Deecke *et al.* 2002, Curé *et al.* 2013, 2015). We used a source level that is typical for killer whales sounds but much lower than the source level of the sonar. Killer whale sounds fell within a frequency range of 0.5-120 kHz with most energy distributed between 1 and 2 kHz, corresponding to the fundamental frequency of the majority of the calls. This is also the fundamental frequency range of the sonar signals (1-2 kHz) used during the sonar exposures. The control stimulus was broadband ambient noise with most energy between 0.5 and 10 kHz, corresponding to non-vocal periods taken from the same recording as the killer whale sound recordings amplified to the same RMS power. Playbacks were conducted from a stationary small boat with the engine off. At the start of each sound playback, the playback vessel was positioned to the front and side of the tagged whale's travel path, at an approximate distance of 800 m from the tagged whale. Further details of the protocol are given in Curé *et al.* (2015).

2.5 Data collection and processing

2.5.1 Horizontal movement

Whale positions were determined from estimates of distance from the vessel to the whale, estimates of bearing to the whale relative to the ship's heading, and from records of the ship's magnetic or true heading. Distance was measured using laser-range finders and occasionally using big-eye reticles off the Sverdrup, or was estimated by eye when this was not possible. The relative bearing to the whale was measured using a protractor with a pointer. The heading of the observation boat at the time of each sighting was taken as the course over ground measured with a GPS.

Visual fixes of the whale`s position were recorded at surfacings more than two minutes apart. GPS fixes recorded by the Fastloc-GPS loggers when the whale was at the surface had a minimum time interval of 30 s. Speed and direction of movement of the tagged whale were calculated from the horizontal location obtained from sightings at the surface, from the GPS positions recorded by the Fastloc-GPS loggers or from the dead-reckoned track (section 2.5.3). Speed at each surfacing time *t* was calculated as the total great circle distance travelled between three surfacing locations (*t-1, t, and t+1*) divided by the total time between them. Direction of motion of the whale was calculated as the true bearing from the previous surfacing. Directness was calculated by dividing the total distance covered by the whale during three observation points on the track (i.e. the distance between the first surfacing and the third surfacing) by the cumulative distance between all three points, and is given as values between 0 (circular movement) and 1 (straight movement).

2.5.2 Social and surface behavior

In additional to recording of the position of the whale, visual observations also included recording of the group parameters and surface active behaviours as described in Visser *et al.* (2014). Surface behavior of the focal animal included breaching, lunging, rolling and fluking. Group observations included number of animals in the focal group, distance between individuals, synchrony of surfacing pattern, milling index, as well as distance to nearest other subgroup. Surface behavioural parameters were recorded at regular 2 min intervals when the tagged whale was present at the surface, or at the first surfacing of the tagged whale following a dive longer than 2 minutes. Tracking observations and surface behavioural parameters were recorded using Logger software made available by the International Fund for Animal Welfare.

2.5.3 Dead-reckoning track

Upon recovery of the DTAGs, data from the tag were converted to pressure, acceleration, magnetic field strength, and pitch, roll, and heading in the whale-frame axis using standard methods (Johnson & Tyack 2003). A dead-reckoned track (pseudotrack) was produced in the case of the bottlenose whale (ha13_176) because there was no visual track and no GPS sensor on the tag. Flow noise (<500 Hz) recorded on the audio channel was correlated with speed through the water (Miller *et al.* 2004) measured during steep (>60º pitch) transit periods to estimate speed through the water throughout the tag record (except for depths <10 m where 2 and 3 m/s were each modelled to bracket expected speeds near the surface). Estimated speed was combined with pitch and heading data to estimate a dead-reckoned track of the whale (Johnson & Tyack 2003, Miller *et al.* 2009). The position of the experiment whale at the start of the sonar transmissions was geo-referenced by finding the position with the smallest rms difference between observed sonar arrival times and predicted arrival times based upon the dead-reckoned track (Miller *et al.* 2015).

2.5.4 Vocalization of bottlenose whales

Acoustic recordings of tagged whale vocalization sounds were analysed only for the bottlenose whale. There was no acoustic sensor on the CTAG, thus no acoustic data was collected for the minke whale. For humpback whales, an initial scan of the acoustic recordings on the tags revealed that they made very few sounds, and we did not pursue this any further to reduce time costs. The audio recording of the bottlenose whale was audited to identify foraging sounds produced by the tagged whale and other nearby whales (Miller *et al.* 2015). Echolocation click and buzz sounds were used as acoustic cues indicating foraging activity. Audio files recorded by the DTAGs were displayed as spectrograms (Blackman-Harris window; FFT length: 512) with a 15 s duration window. The start and end of each detected sound was identified and marked, and it was ascribed to the tagged whale or another whale depending upon its relative amplitude and spectral characteristics.

Other biological sounds from the tagged or nearby whales were also annotated. Details can be found in Miller *et al.* (2015).

2.5.5 Lunge detection for humpback whales

For humpback whales, the acoustic record of the DTAG was used to detect lunge feeding events. Humpback lunge feeding involves engulfing a large volume of prey-rich water in the flexible buccal cavity and filtering out prey with the baleen. A lunge is characterized by an increase in speed followed by an abrupt drop in speed, as the whale first accelerates forward and then slows down quickly after the jaw opens. The low frequency flow noise measured on the acoustic record of the DTAG is a useful proxy for the whale's speed through the water, and was used here to identify lunge events replicating the method of Simon *et al.* (2012). We developed an automatic lunge detector that identified events with noise peaks that exceeded the 90th percentile (for depths >5m) of the flow noise (<500 Hz) in all dives deeper than 5 m and which were followed by at least a 12 dB drop in flow noise within 5 seconds. This 5-s period was truncated if the whale reached the surface (depth<0.5 m) to avoid false detections of drops in the noise level when the whale surfaced to breathe.

2.5.6 Analysis of measured exposure levels

Sonar signals recorded by the DTAG were extracted for detailed analysis of the sonar received levels, following the method established by Miller *et al.* (2011). For each sonar pulse we measured the broadband maximum RMS sound pressure level (SPL) over a 200 ms averaging window and the broadband cumulative sound exposure level (SEL_{cum}) throughout the exposure session. These broadband received levels were calculated from 1/3-octave bands between 1-40 kHz in which the signal exceeded the noise on the tag by 10 dB or more. The levels of some sonar pulses during the ramp-up at the start of each exposure session were below this threshold. The received level of those pulses was calculated by extrapolation using the measured level of the closest ping in time adjusted for the known difference in source level. The acoustic sensitivity of the DTAGs, determined from calibration measurements conducted before all three field trials was (mean ± SD) −185 ± 4 dB re 1 μPa^{-1} (N=6 tags).

2.5.7 Estimating exposure levels in minke whale

The CTAG used on the minke whale did not contain acoustic sensors and therefore received levels (RLs) had to be estimated by acoustic propagation modelling, which requires the distance between the source (HUS) and the whale to be known. As a benchmark of the received level estimate we compared the estimated RL to a RL measured using a small calibrated hydrophone array towed at 6 m depth behind the MOBHUS (close to the whale).

The position of the source was assumed to correspond to the GPS position of the tow vessel (HUS), and the depth of the source was recorded by a depth sensor inside the sonar tow body. The position of the array was assumed to correspond to the GPS position of MOBHUS, towing it. The position of the whale was based on the track collected from MOBHUS, and the depth of the whale was recorded by the CTAG. The position fixes of the minke whale were more sparse than the position updates of the MOBHUS and the HUS. To be able to do calculations of distance between the source and the whale for each ping, an interpolation of the minke whale’s positions between fixes were carried out by assuming that the whale’s speed and direction were constant between each observation.

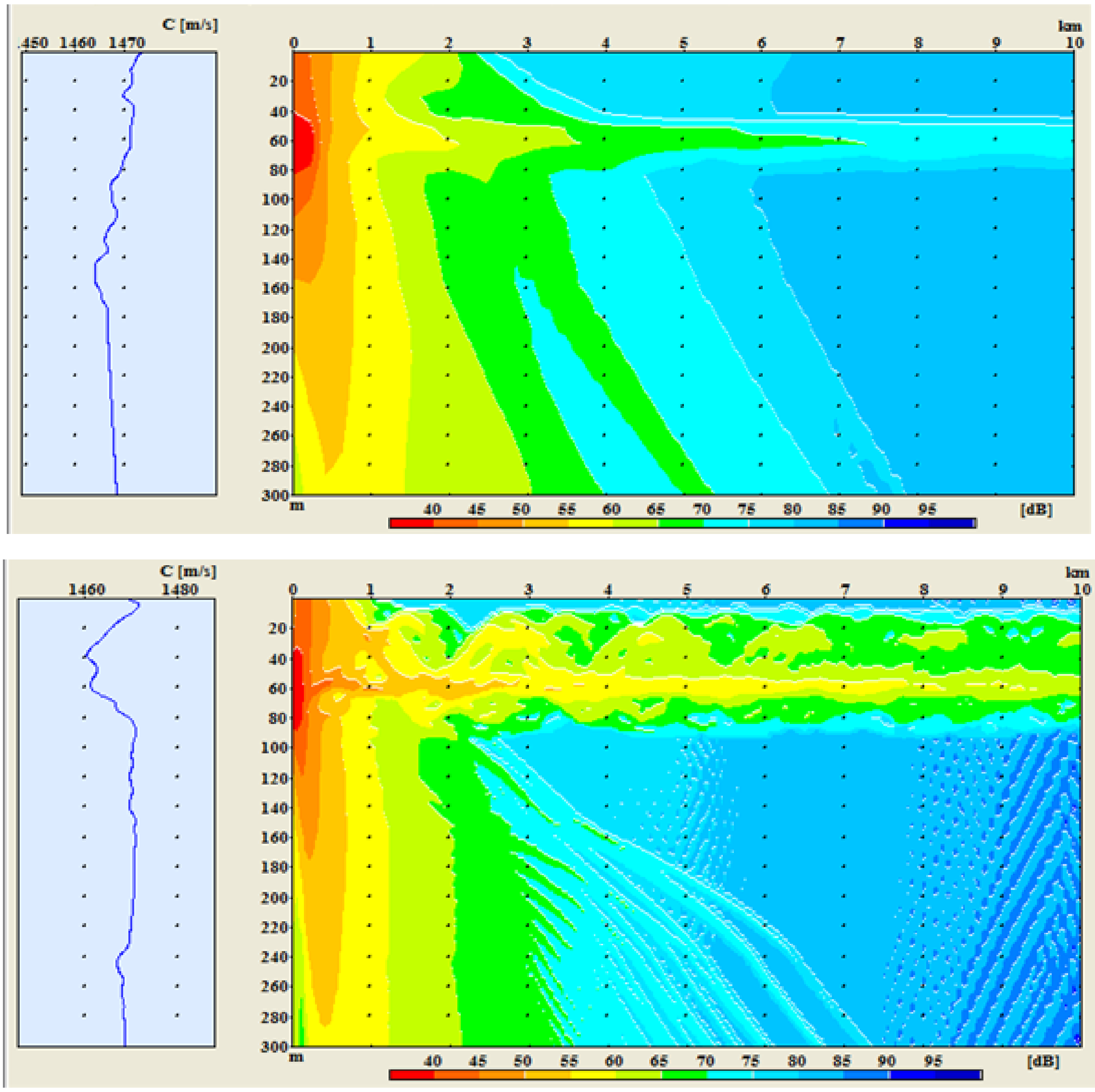


Figure 2.4 Measured sound speed profile (CTD) (left panels) and estimated transmission loss from LYBIN (right panels). Upper panel is CTD1 and lower panel is CTD2. Source depth is set to be 60m. The distance between the source and whale ranged from 3-9 km.

The acoustic ray trace model LYBIN (Dombestein & Gjersøe 2012) was used to calculate transmission loss (TL) from the source to a given distance and depth of the whale. Average incoherent TL in each cell of 50m horizontal by 3m vertical dimension was calculated at 1500 Hz. The directivity pattern of the real source at that frequency was included. Two sound speed profiles were measured along the propagation path immediately after the end of the experiment (Figure 2.4), and both were used to estimate TL (Figure 2.4). The depth of the source varied between 60 and 69 m during the exposure, and therefore TL was estimated at those two depths (Figure 2.5 and 2.6). The mean value of TL of the four combinations of source depth and sound speed profile was used as the best estimate of TL. Received sound pressure level (RMS over the 1 s pulse duration) was calculated as the transmitted source level minus TL for each ping. In addition cumulative sound exposure level across the entire exposure session was calculated.

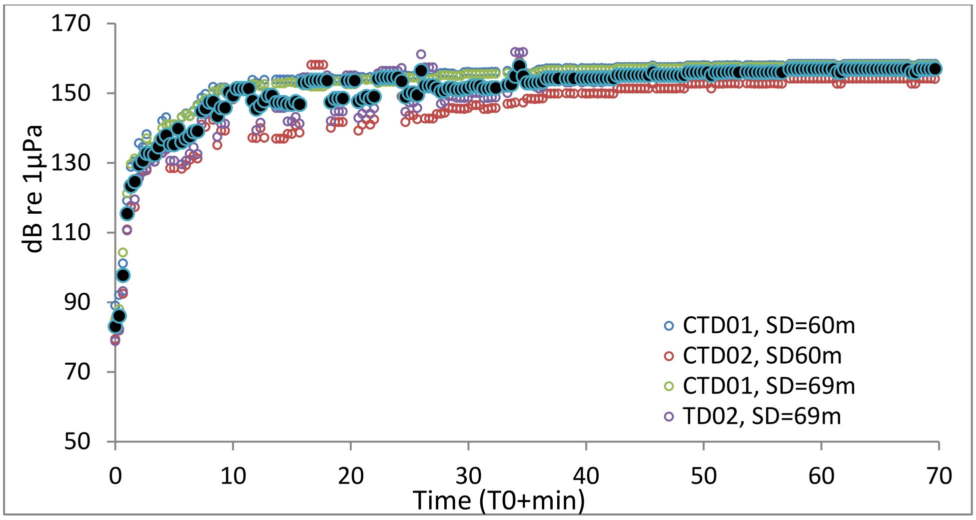


Figure 2.5 Estimated ping by ping received sound pressure level (RL) at the position and depth of the whale using two different sound speed profiles (CTD01 and CTD02) and two different source depths (SD=60m and SD=69m), as well as mean estimated RL. The average standard deviation was 3.6 dB.

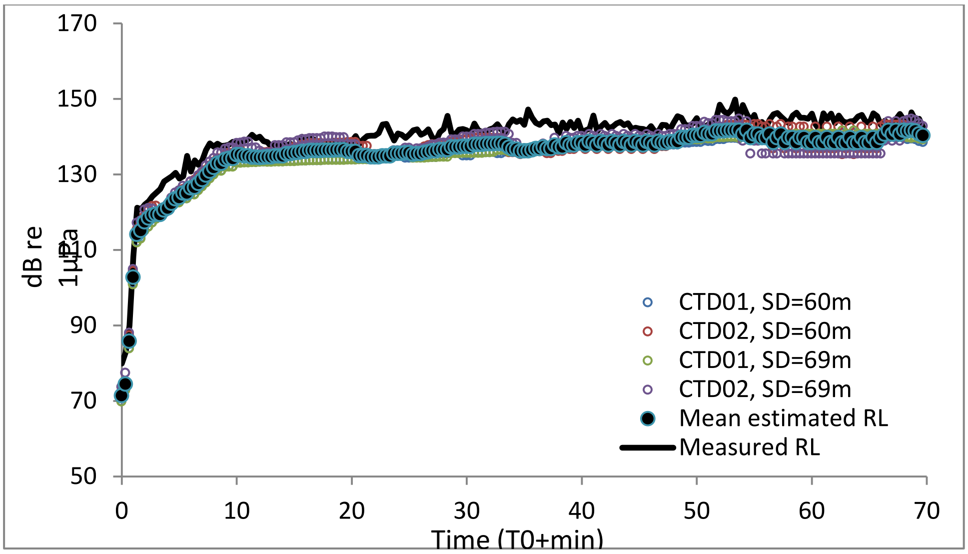


Figure 2.6 Estimated ping by ping received sound pressure level (RL) at the position and depth of the hydrophone antenna towed behind MOBHUS using two different sound speed profiles (CTD01 and CTD02) and two different source depths (SD=60m and SD=69m), as well as mean estimated RL (1-s averaging window), and the actual measured RL (200-ms averaging window). The mean difference between the measured and the best estimated level was 5dB.

3 Results

In total 30 tags were deployed to the three target species, 22 sonar exposure experiments and 31 control experiments (killer whale playback, noise playback and no-sonar control experiments) were conducted (Table 3.1).

Table 3.1 List of the experiments conducted with the three different species. Tag id is the deployment code for the tag deployment, the number indicates the number of exposures of each type; No-sonar control experiments, sonar experiments, killer whale playback experiments (KWPB) and broadband noise playback experiments (Noise PB).

Species	Year	tag id	*No-sonar control*	*Sonar*	*KWPB*	*Noise PB*	Comments
Humpback whale (*Megaptera novaeangliae*)	2011	mn11_157a	1	2	1	1	
	2011	mn11_158ab	1				Two tags on the same animal
	2011	mn11_160ab	1	2	1	1	Two tags on the same animal
	2011	mn11_165def	1	2	1	1	Three tags on two different animals
	2012	mn12_161ab	1	2	1	1	Two tags on the same animal
	2012	mn12_164ab	1	2	1	1	Tags on two different animals
	2012	mn12_170ab	1	2	1	1	Two tags on two different animals
	2012	mn12_171ab	1	2	1	1	Two tags on the same animal
	2012	mn12_178a	1	2			
	2012	mn12_179a	1	2			
	2012	mn12_180ab	1	2	1	1	Two tags on the same animal
Minke whale (*Balaenoptera acutorostrata*)	2011	ba11_180a	1	1			CTAG without acoustic sensors
Bottlenose whale (*Hyperoodon ampullatus*)	2013	ha13_176a		1			Lost visual contact with animal prior to exposure

For each of the experiments a standard set of data plots are presented in the subsequent section of the report.

1. A short textual description of the context of the experiments and relevant information form the experimental logs.
2. A geographical plot with the track of the tagged animal and the sound sources.
3. Time series plots of behavioral data recorded by the tags and by the marine mammal observers, and received exposure levels.
4. Both full data records (8-20 hrs) and close-ups around each experiment are shown.

3.1 Legend of data plots

Since the figures are the same for all data record, common figure legends are given here. Symbol legends are inserted in each figure.

FULL RECORD: Upper panel shows geographical plots with track of the source boat (Sverdrup) and the whale with experimental periods indicated. The position of the playback vessel and the position of tag deployment are also indicated. The track of the whale is generated from the visual track of observers from the Sverdrup or from the tag boat. In addition a Fastlock GPS was attached to the tag in some of the experiments, which gave a higher resolution track of the whale's position when it surfaced. The start and end of the experiments are also indicated.

The lower panel shows time series plots of different variables recorded. From the top; number of animals in the area, group size and individual spacing, surface display events (breach, surface lunges, birds in the area, roll and fluke outs), direction and directness of movement of the tracked whale, the horizontal speed of the whale calculated from movement track (for the bottlenose whale speed through the water is estimated from flow noise on the tag), and the time-depth profile of the tagged animal(s) with identified lunge events for humpback whales (red dots) and symbols indicating acoustic clicking, buzzing, and tail slap sounds for the bottlenose whales overlaying the dive profile. The start and end of exposure experiments are indicated with vertical lines.

BASELINE: Zoomed in view of the last 3 hrs of baseline before first exposure. Upper panel shows the geographical plot and lower panel the time series plot.

NO-SONAR CONTROL: Zoomed in view of the no-sonar control session (30min before start of exposure to 30 min after end of exposure). Upper panel shows the geographical plot and lower panel the time series plot. The color-coding on track of the animal and ship tracks indicates the time since the start of the exposure session, with blue and red marking the start and end, respectively.

SONAR 1: Zoomed in view of the first sonar exposure session. Upper panel shows the geographical plot and lower panel the time series plot. The additional third panel shows the transmitted source level and received exposure levels versus time both as ping by ping Sound Pressure Level (SPL) and accumulated Sound Exposure Level (SEL). These levels *were measured from the sounds recorded by the tag, except for minke whales where the exposure levels are estimated by sound propagation modelling.*

SONAR 2: Zoomed in view of the second sonar exposure session. Upper panel shows the geographical plot and lower panel the time series plot. The additional third panel shows the transmitted source level and received exposure levels versus time.

KILLER WHALE PLAYBACK: Zoomed in view of the killer whale playback session. Upper panel shows the geographical plot and lower panel the time series plot.

NOISE PLAYBACK: Zoomed in view of the noise playback session. Upper panel shows the geographical plot and lower panel the time series plot.

In some experiments, not all experimental sessions were covered, and thus some figures might be missing. For some experiments additional figures are also presented.

3.2 Data plots for minke whale

3.2.1 ba11_180a

June 19th 2011, subadult minke whale tagged with CTAG in the Icefjord channel 35 nmi off west coast of Spitsbergen at 13:33 UTC using the ARTS. Wind northwest 1-4 (Beaufort), changing cloud cover, sea state 2-3.

The tag started recording at 14:00 UTC, and record until 09:21 on June 20. The tag stayed on for 19:11 hrs.

VHF tracking was lost immediately after tag deployment, but was re-established from Sverdrup (HUS) at 15:30 UTC. MOBHUS was then deployed to take over tracking.

Minke whale ba11_180 with CTAG attached (photo: Patrick Miller)

No-sonar control approach: Closest point of approach (CPA) at 300m at 00:27:30 UTC

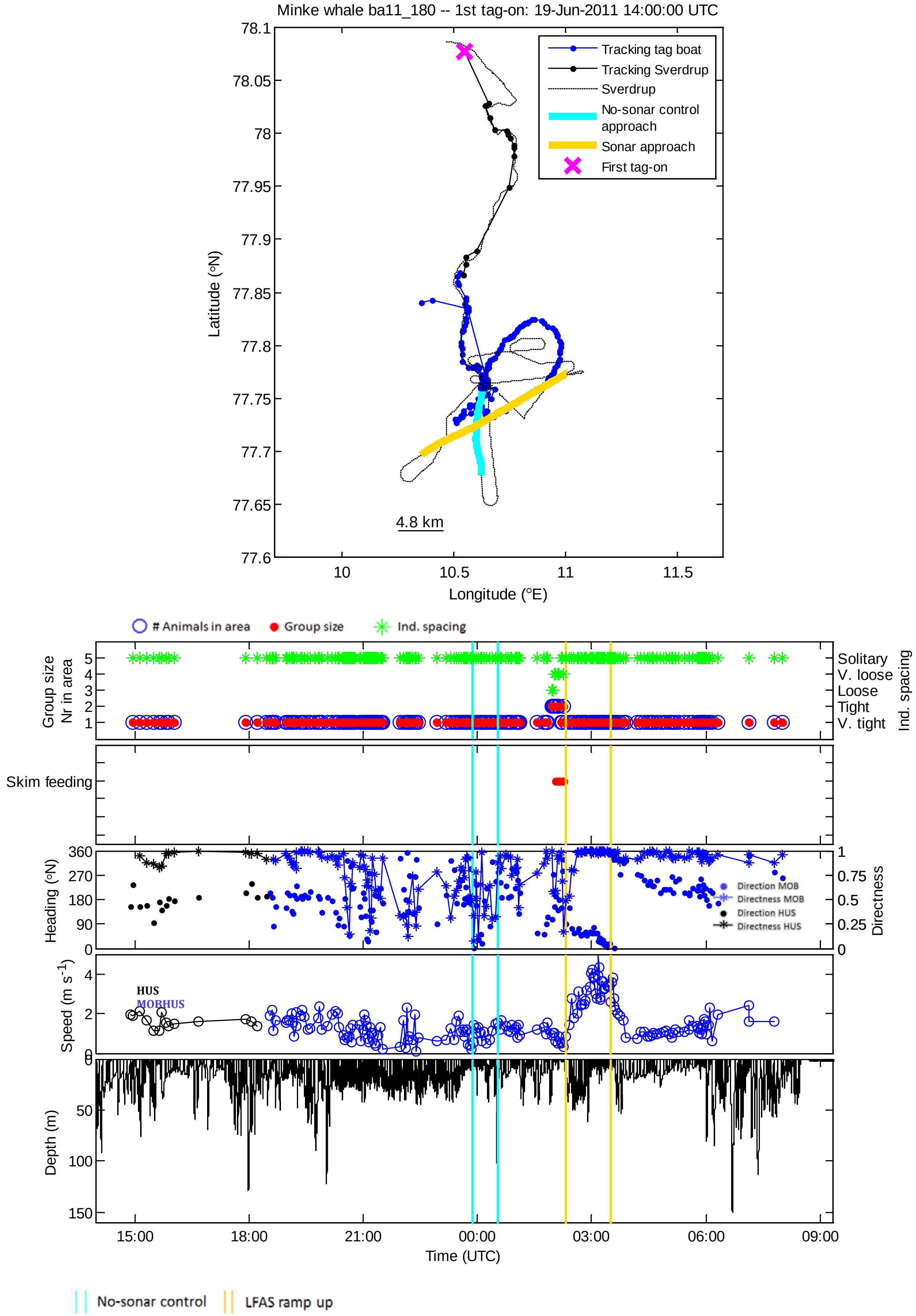
Sonar 1: Animal turned right before start of ramp-up (04:20:00 LT), thus we were approaching from behind from 8.8 km distance at 8 knots speed. 02:36:00 UTC we were increasing speed to 8.5 knots to try to catch up with the animal moving at speed away from us. 02:53:16 transmissions should have ended but we were still 4.5 km away from the animal. 03:05:59 the speed of the animal was now the same as ours, we were not gaining on it anymore. 03:06:25 course locked even though we are still 3.8 km away. 03:25:22 CPA @ 3.4 km. 03:30:00 transmission stopped.

04:00 UTC: Decision to extend post exposure time and cancel 2nd sonar approach.

Control sound playback: During deployment of the playback source boat, HUS ended up very close to focal animal. Experiment was discarded.

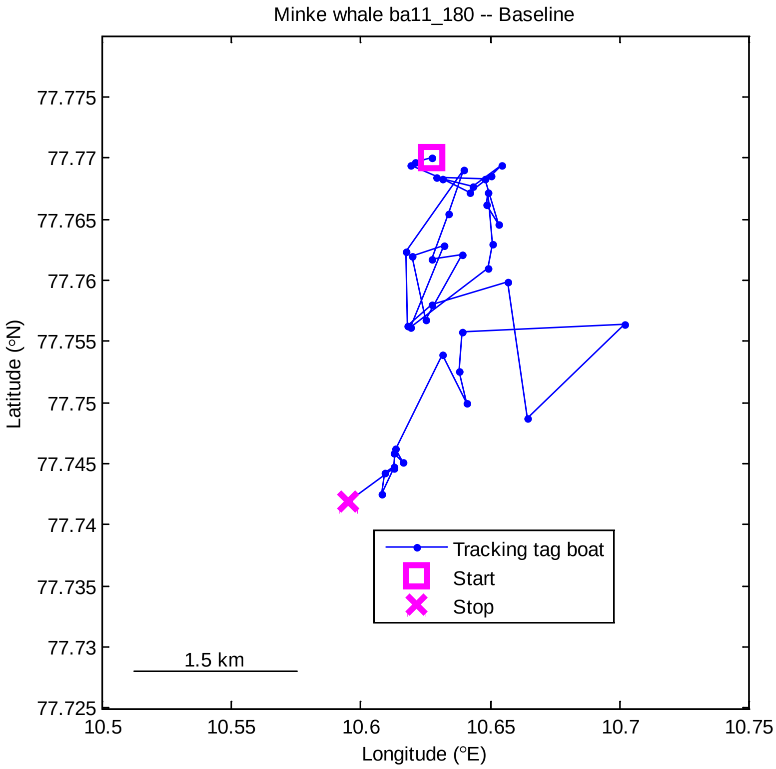
Biopsy: No biopsy collected

Tag off and recovered 08:44 UTC. The wind and sea gradually picked up in the last 6 hrs of the experiment.

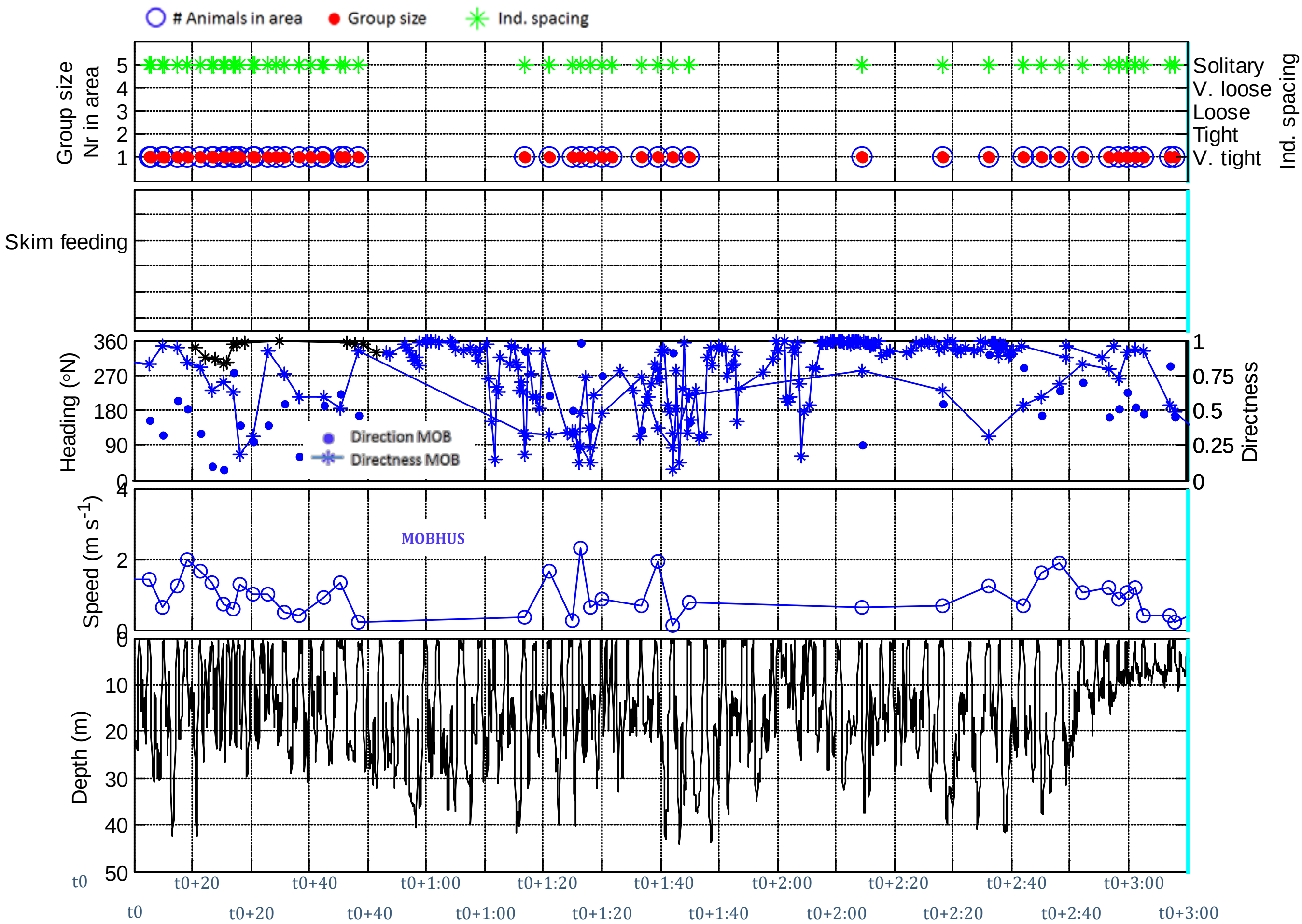


Minke whale ba11_180 -- 1st tag-on: 19-Jun-2011 14:00:00 UTC
Tracking tag boat
Tracking Sverdrup
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
4.8 km
Latitude (°N)
Longitude (°E)
78.1
78.05
78
77.95
77.9
77.85
77.8
77.75
77.7
77.65
77.6
10
10.5
11
11.5
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Skim feeding
Heading (°N)
Directness
Direction MOB
Directness MOB
Direction HUS
Directness HUS
Speed (m s-1)
HUS
MOBHUS
Depth (m)
15:00
18:00
21:00
00:00
03:00
06:00
09:00
Time (UTC)
No-sonar control
LFAS ramp up

BASELINE

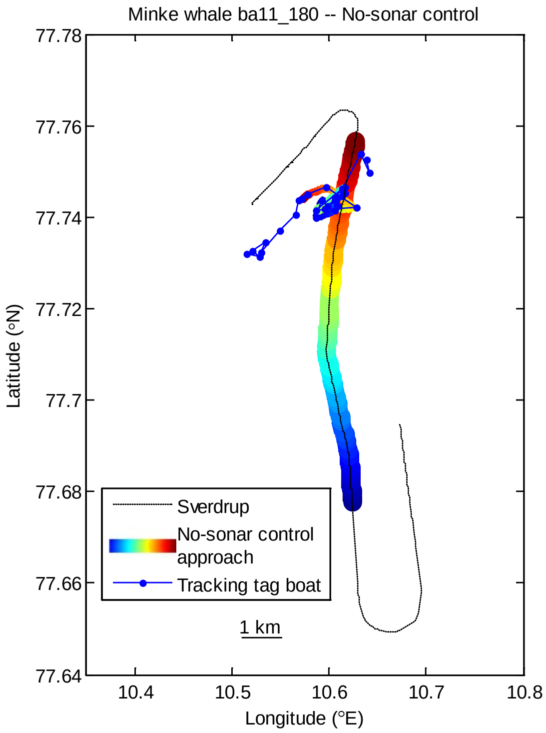


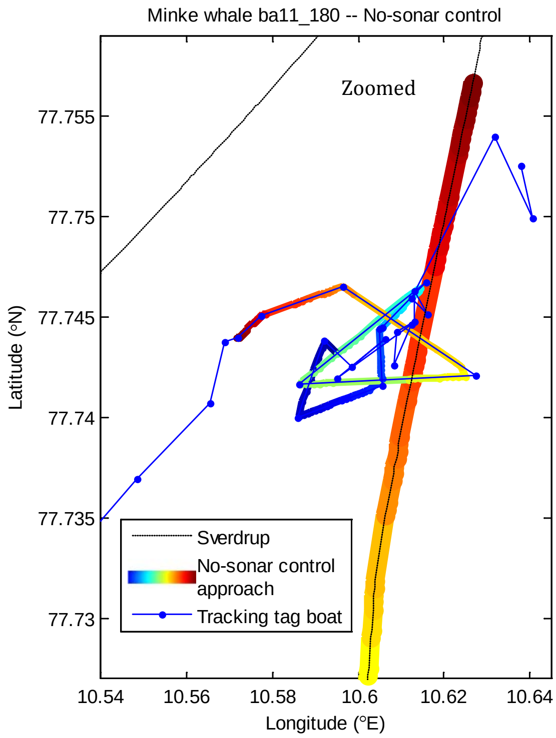
Minke whale ba11_180 -- Baseline
Latitude (°N)
Longitude (°E)
77.775
77.77
77.765
77.76
77.755
77.75
77.745
77.74
77.735
77.73
77.725
10.5
10.55
10.6
10.65
10.7
10.75
Tracking tag boat
Start
Stop
1.5 km

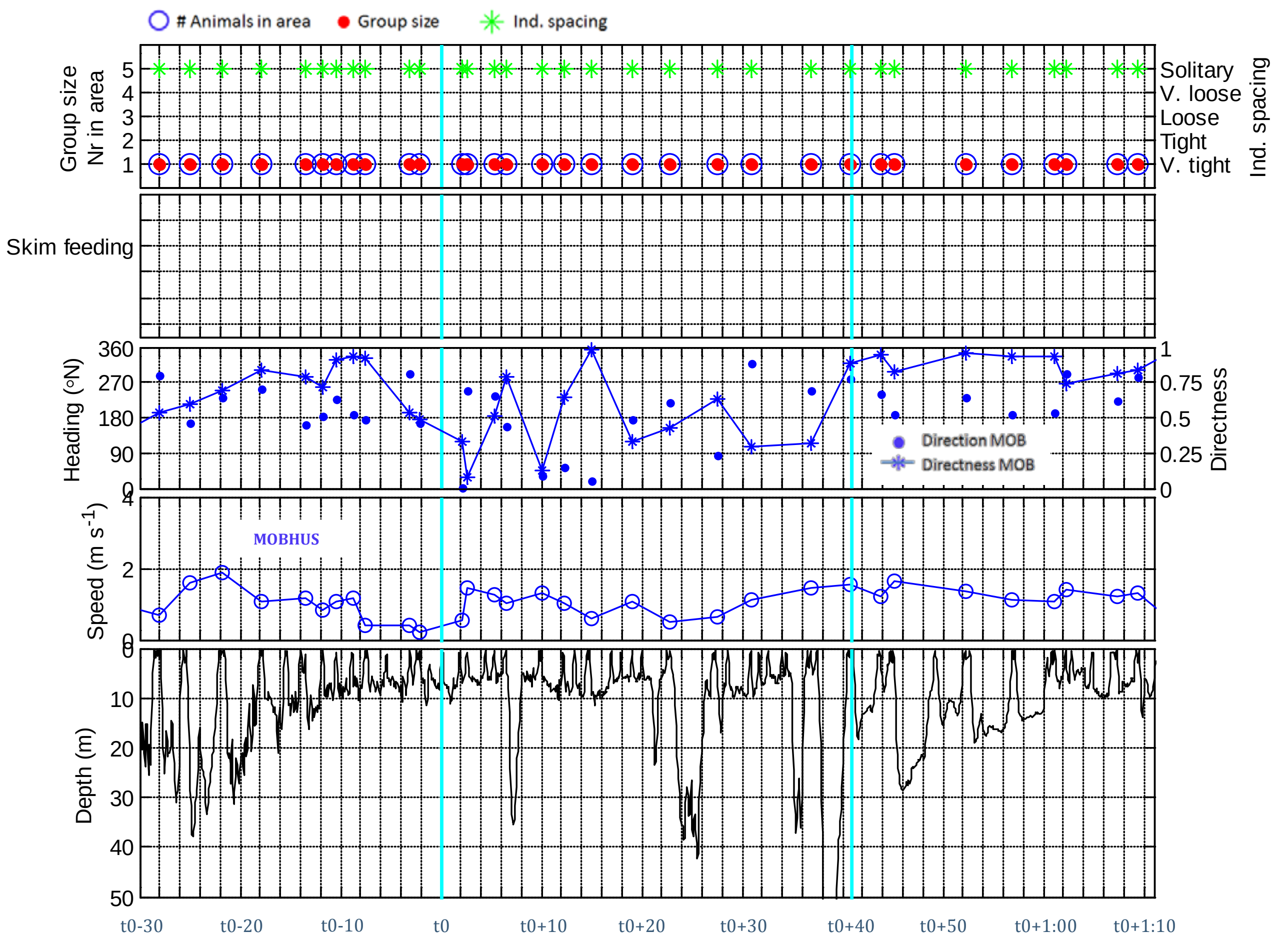


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Skim feeding
Heading (°N)
Direction MOB
Directness MOB
Directness
Speed (m s-1)
MOBHUS
Depth (m)
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

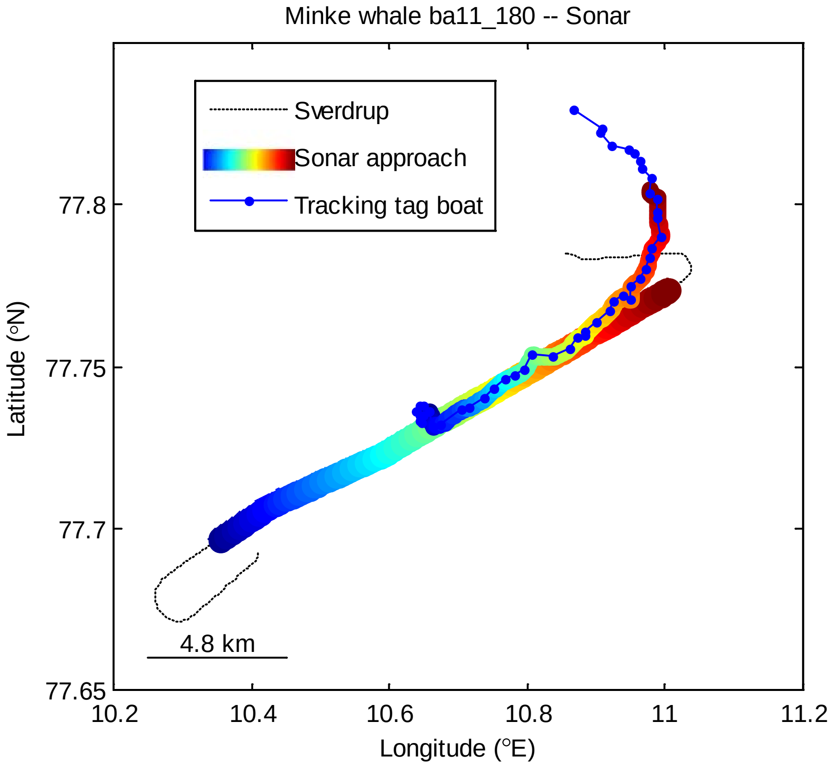
NO-SONAR CONTROL



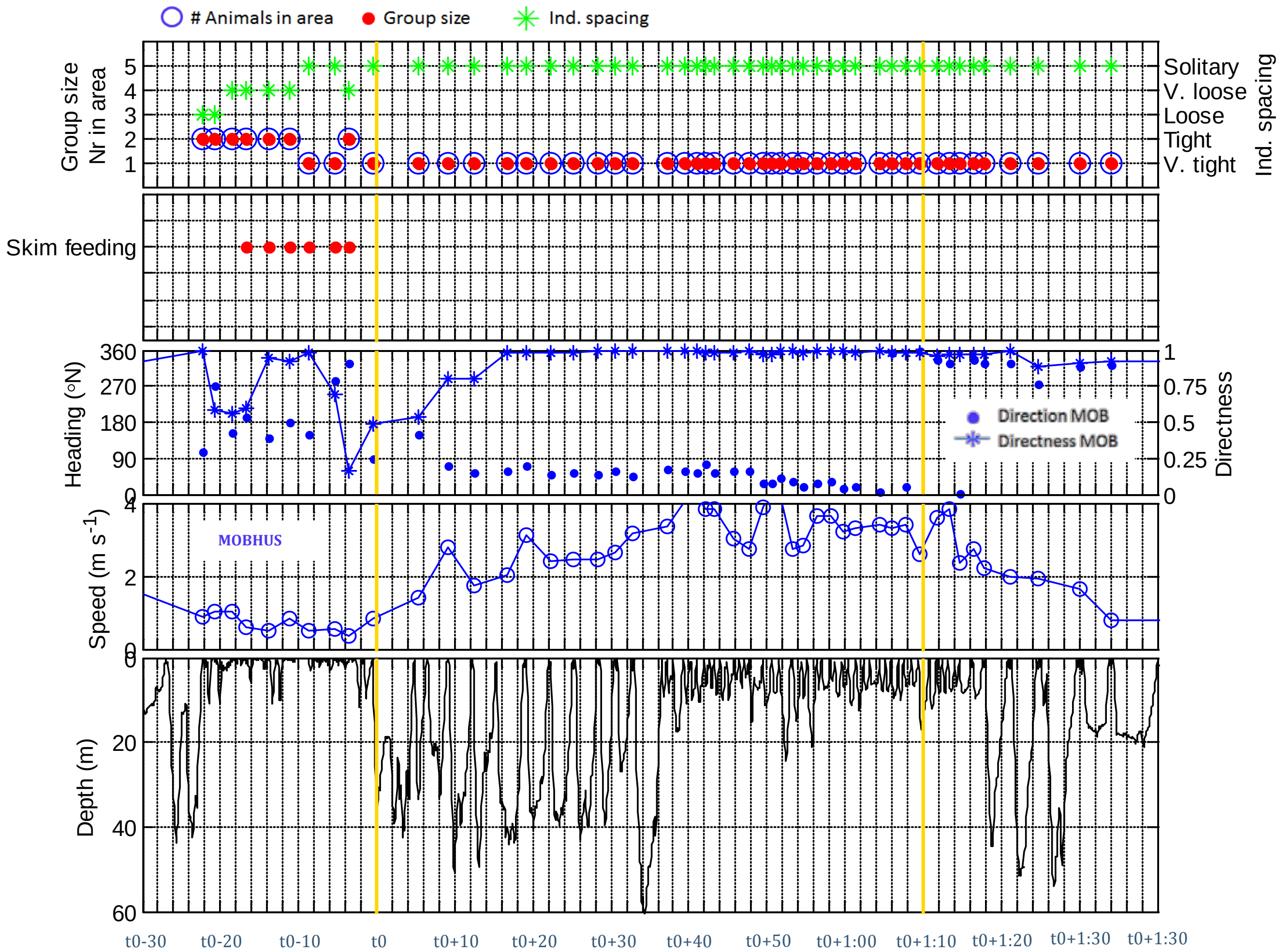




SONAR 1

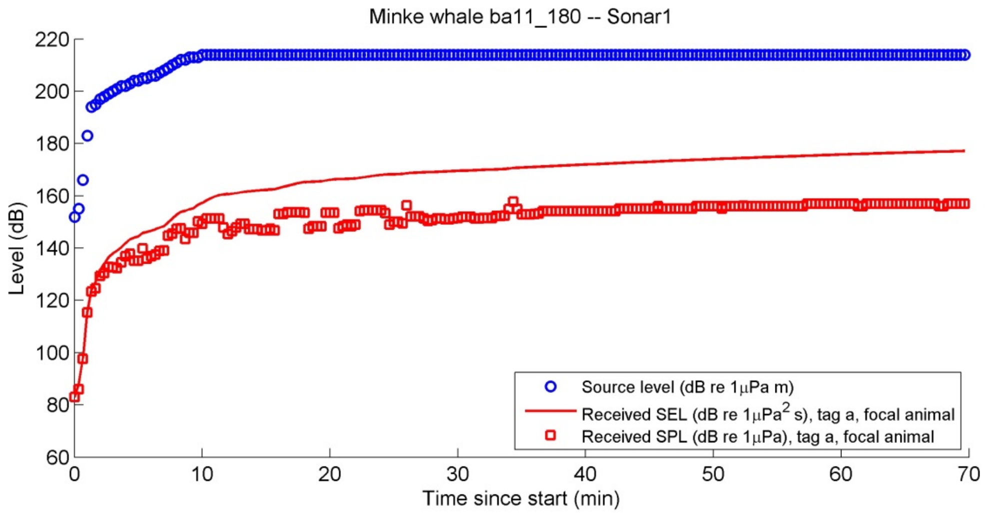


Minke whale ba11_180 -- Sonar
Sverdrup
Sonar approach
Tracking tag boat
Latitude (°N)
77.8
77.75
77.7
77.65
4.8 km
10.2
10.4
10.6
10.8
11
11.2
Longitude (°E)



Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Skim feeding
Heading (°N)
Direction MOB
Directness MOB
Directness
MOBHUS
Speed (m s-1)
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40
t0+50
t0+1:00
t0+1:10
t0+1:20
t0+1:30
t0+1:30

SONAR 1 – Received level



3.3 Data plots for northern bottlenose whale

3.3.1 ha13_176a

June 25th 2013, DTAG2 deployed on adult animal within a larger aggregation of bottlenose whales using the ARTS, 20nmi east-southeast of North Cape, Jan Mayen. South-west wind 3 (Beaufort), clouded sky, sea state 3. Tag stayed on for 18 hrs.

Bottlenose whale ha13_176 with DTAGv2. The tag stayed attached for 18 hrs but slid to a lower position so that we had difficulty tracking it. Photo Eirik Grønningsæter/ WildNature.no/3S Project/FFI.

<u>Pre exposure:</u> Duration 08:53 hrs. Tracking from HUS was not good, only occasional signals received and very few fixes. 06:15 UTC no more signals from the tag, MOBHUS deployed to try to relocate the focal animal.

07:15 UTC we were picking up regular beeps again from HUS and MOBHUS, but only single signals, preparing for the exposure.

08:46 UTC - tracking was not solid, but occasional clear signals suggested that we had located the tagged animal.

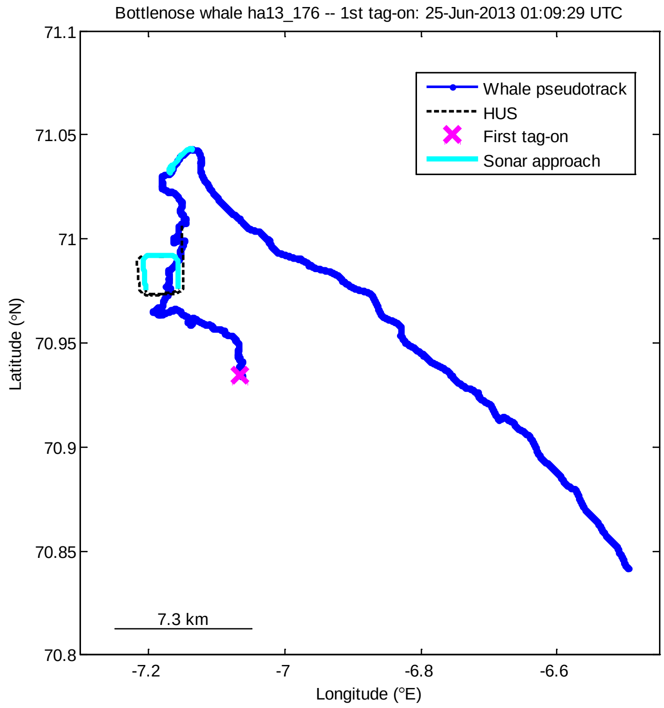
<u>Sonar 1:</u> 09:53:00 UTC start of ramp-up. 20 min 'linear' ramp-up and 15 min full power transmission in three legs of a 2·2 km predetermined box assuming the focal animal was within the box. Positioning of the animal was uncertain, and retrospective analysis showed that in fact the animal was ˜5 km from the position of the source ship at the start of exposure.

<u>Post exposure:</u> No signals from the tag. Very few visual observations and acoustic detections in this area in the 6 hr period after the exposure.

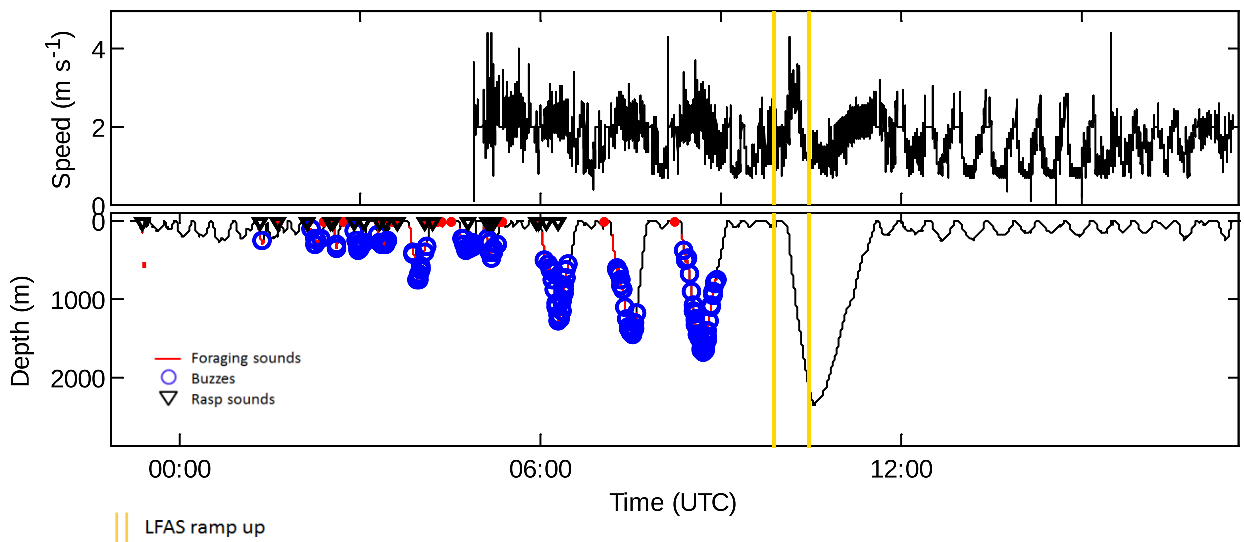
<u>Biopsy:</u> No biopsy collected

Tag recovered 07:44 UTC (June 26th) 24 nmi from last known fix. The GPS sensor had fallen off.

FULL RECORD

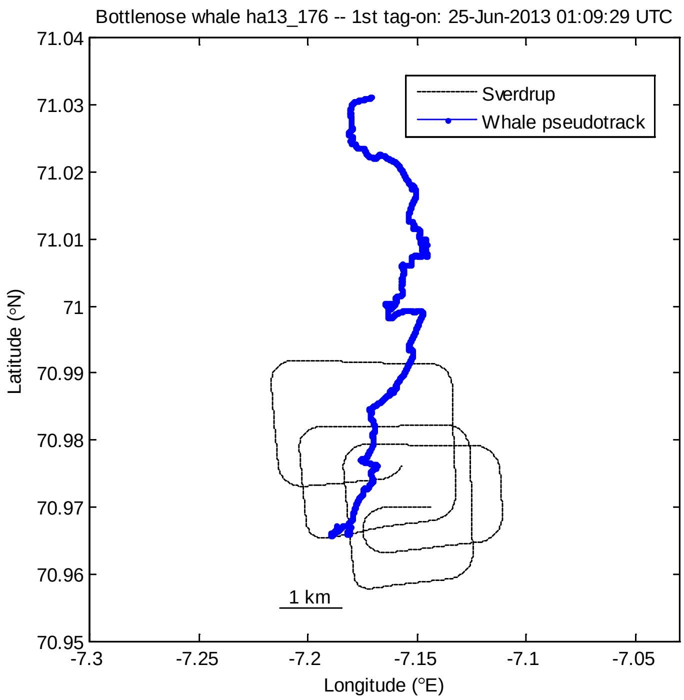


Bottlenose whale ha13_176 -- 1st tag-on: 25-Jun-2013 01:09:29 UTC
Whale pseudotrack
HUS
First tag-on
Sonar approach
Latitude (°N)
Longitude (°E)
7.3 km
71.1
71.05
71
70.95
70.9
70.85
70.8
-7.2
-7
-6.8
-6.6

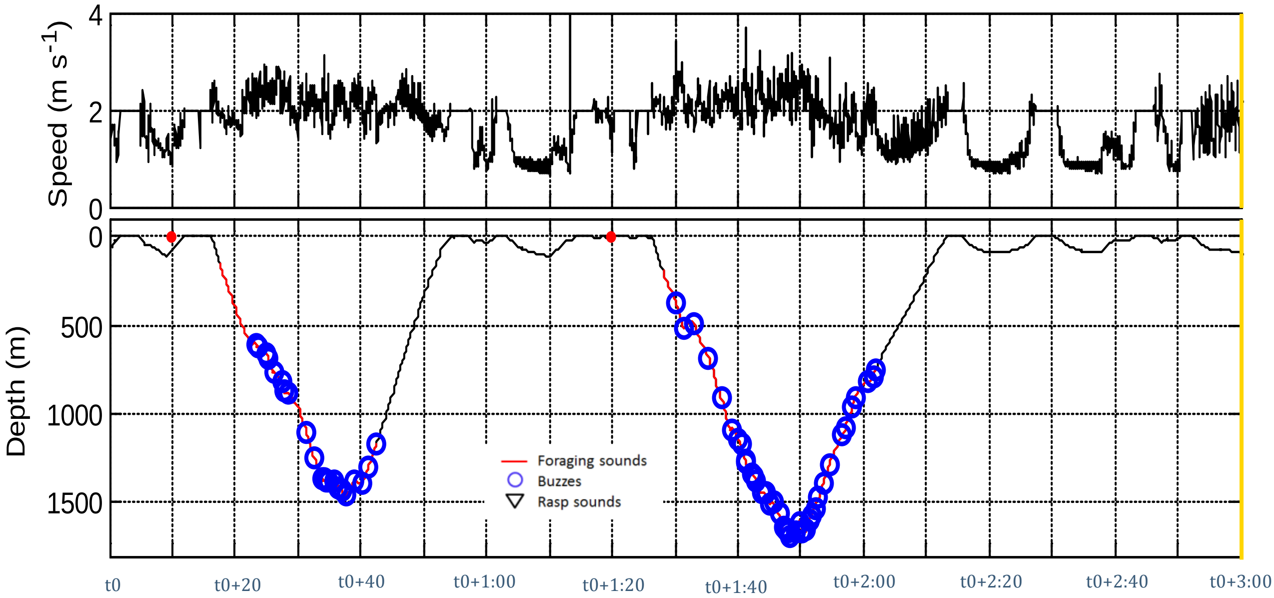


Speed (m s-1)
Depth (m)
Foraging sounds
Buzzes
Rasp sounds
00:00
06:00
12:00
Time (UTC)
LFAS ramp up

BASELINE

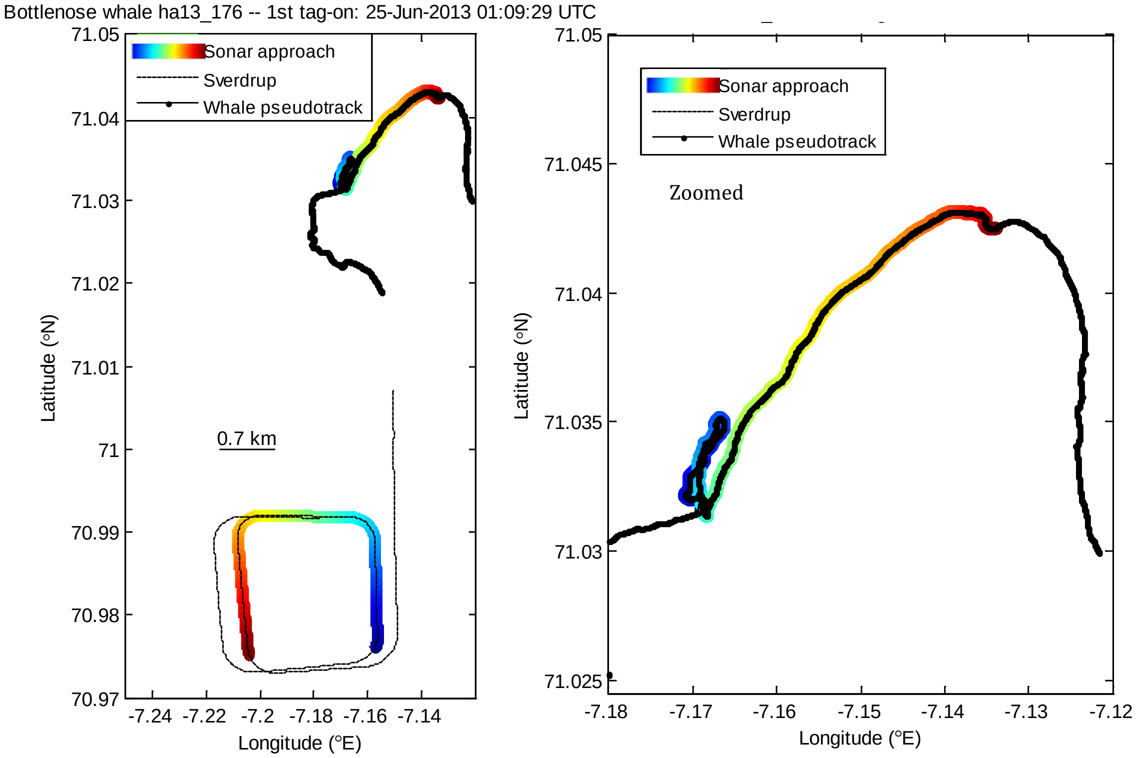


Bottlenose whale ha13_176 -- 1st tag-on: 25-Jun-2013 01:09:29 UTC
Sverdrup
Whale pseudotrack
1 km
Latitude (°N)
Longitude (°E)
71.04
71.03
71.02
71.01
71
70.99
70.98
70.97
70.96
70.95
-7.3
-7.25
-7.2
-7.15
-7.1
-7.05

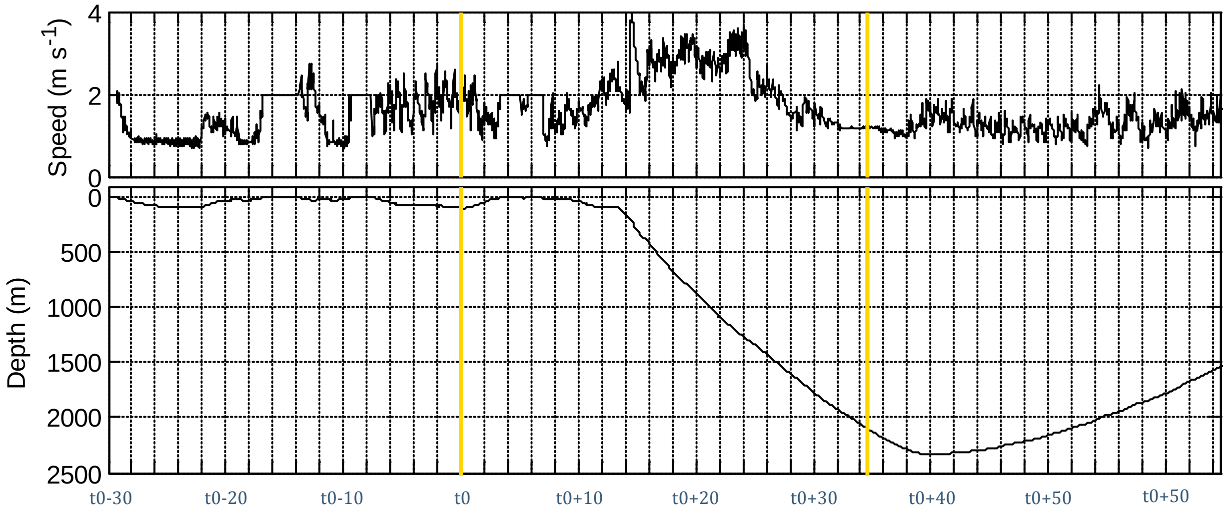


Speed (m s-1)
Depth (m)
4
2
0
0
500
1000
1500
Foraging sounds
Buzzes
Rasp sounds
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

SONAR 1

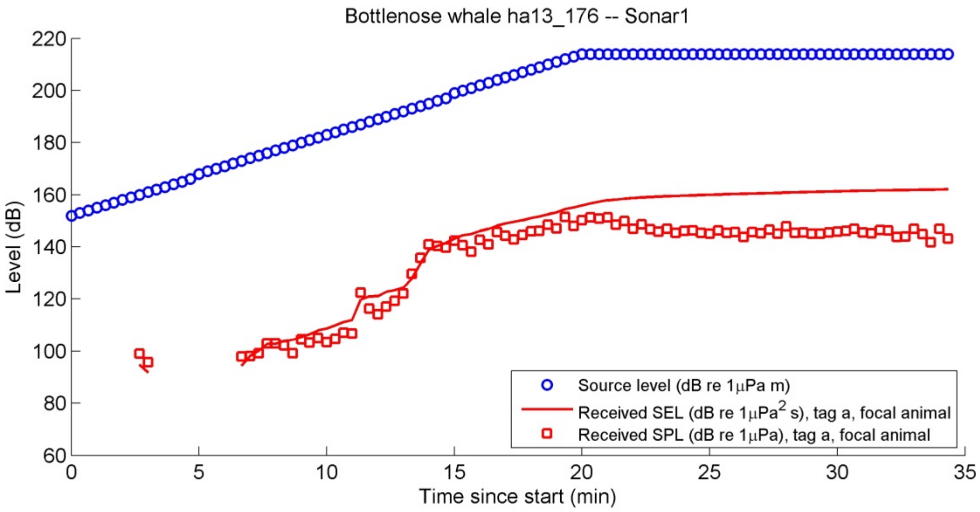


Bottlenose whale ha13_176 -- 1st tag-on: 25-Jun-2013 01:09:29 UTC
Sonar approach
Sverdrup
Whale pseudotrack
0.7 km
Latitude (°N)
Longitude (°E)
Zoomed

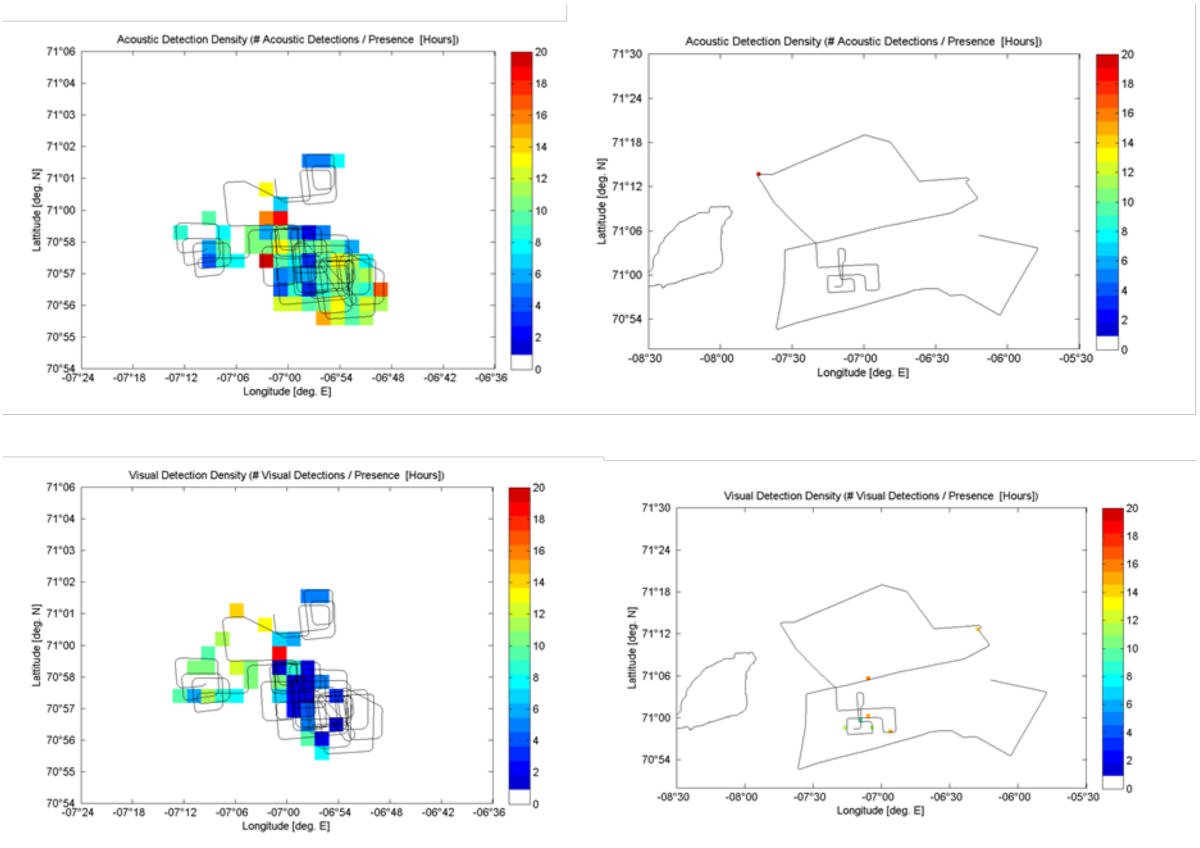


Speed (m s-1)
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40
t0+50
t0+50

SONAR 1 – Received level



SONAR 1 – Additional figures



Additional figure: Acoustic (upper panel) and visual (lower panel) detection rate (number of detections in each 1x1 km grid cell per surveyed hour) by the HUS in the 24 hours before (left) and after the sonar exposure.

3.4 Data plots for humpback whales

3.4.1 mn11_157a

June 5th 2011, DTAGv2 deployed with cantilever pole at 22:25 UTC northwest of Bear Island. Western wind 4 (Beaufort), changing cloud cover, sea state 3. Tag stayed on for 16:33 hrs until it released. Single animal, tagged, tracked and successful experiment conducted under difficult conditions. Several fin whales were present in the area.

<u>No-sonar control:</u> CPA 07:13:32 UTC at 250 m range.

<u>Sonar 1:</u> CPA 09:27:14 UTC at 1000m range. The animal broke 90° west during the first pings and we therefore missed the intercept course.

<u>Sonar 2:</u> The animal had a steady northern course. CPA 10:51:49 UTC, range was difficult to assess (200-500m).

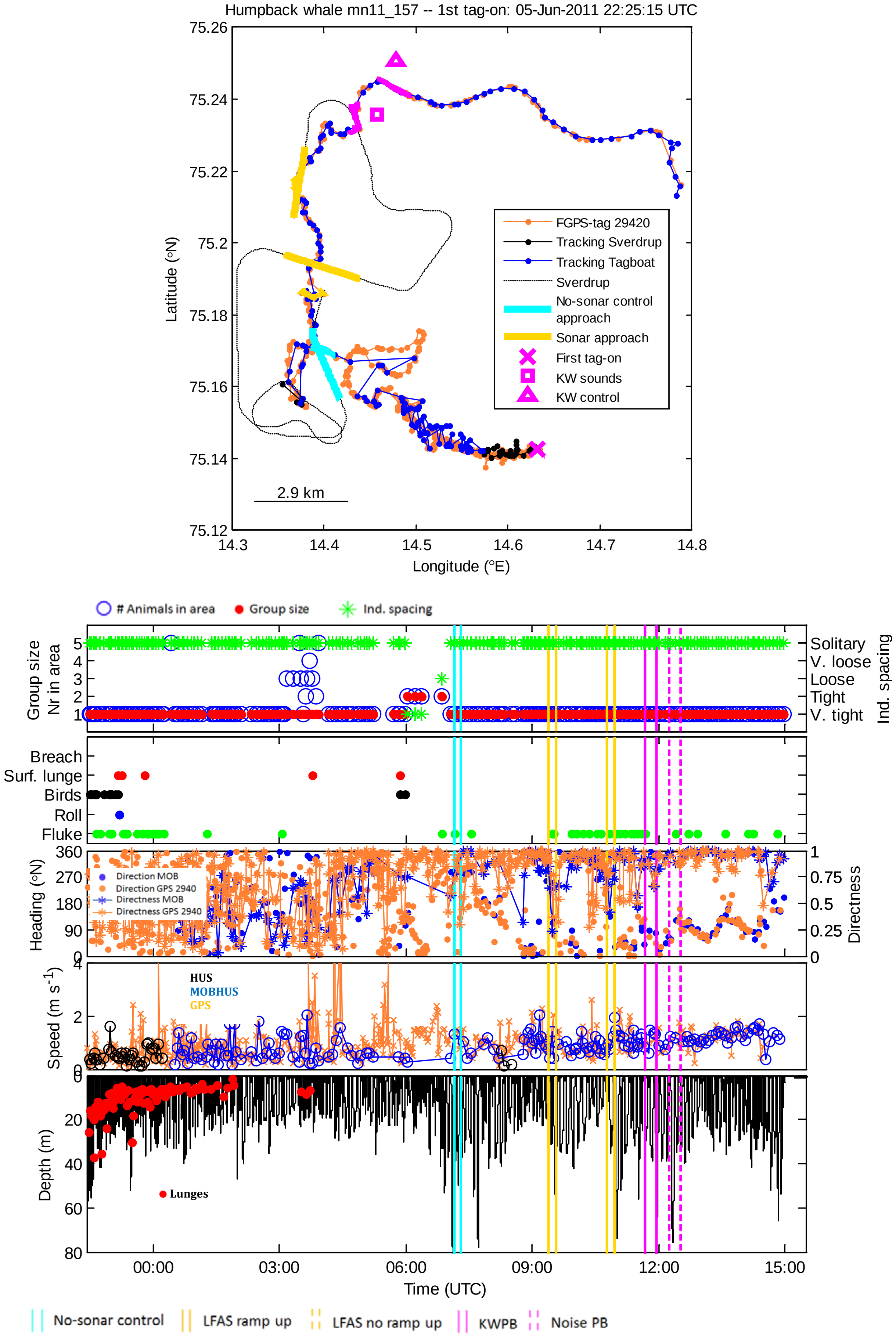
<u>Killer whale playback:</u> started 11:40 UTC

<u>Noise playback:</u> started 12:14 UTC.

<u>Biopsy:</u> Tag-boat collected biopsy ˜15:07 UTC, recovered DTAG and returned to Sverdrup.

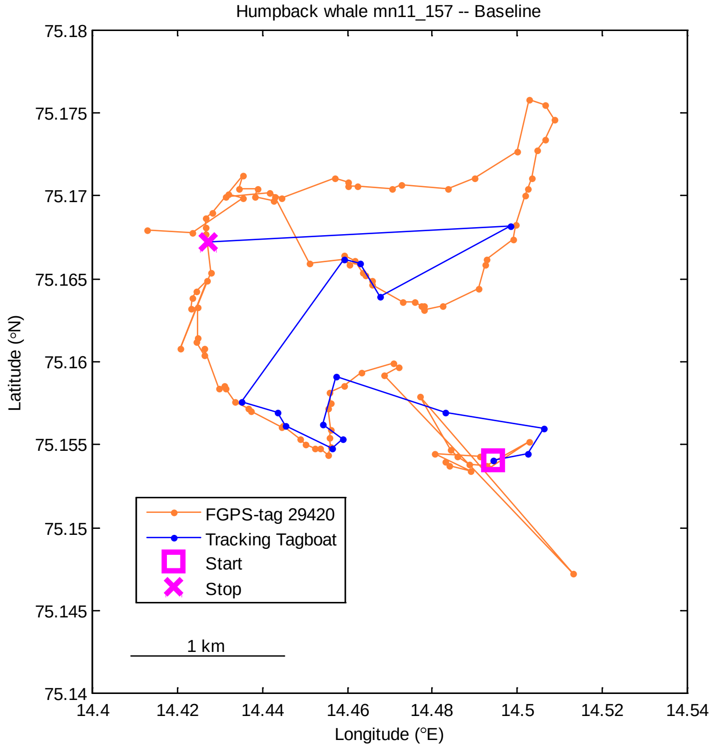
Humpback whale mn11_157 with DTAG deployed using the long cantilever pole (Photos by Rune Hansen, Rune Hansen and Leigh Hickmott (in clockwise order)).

FULL RECORD

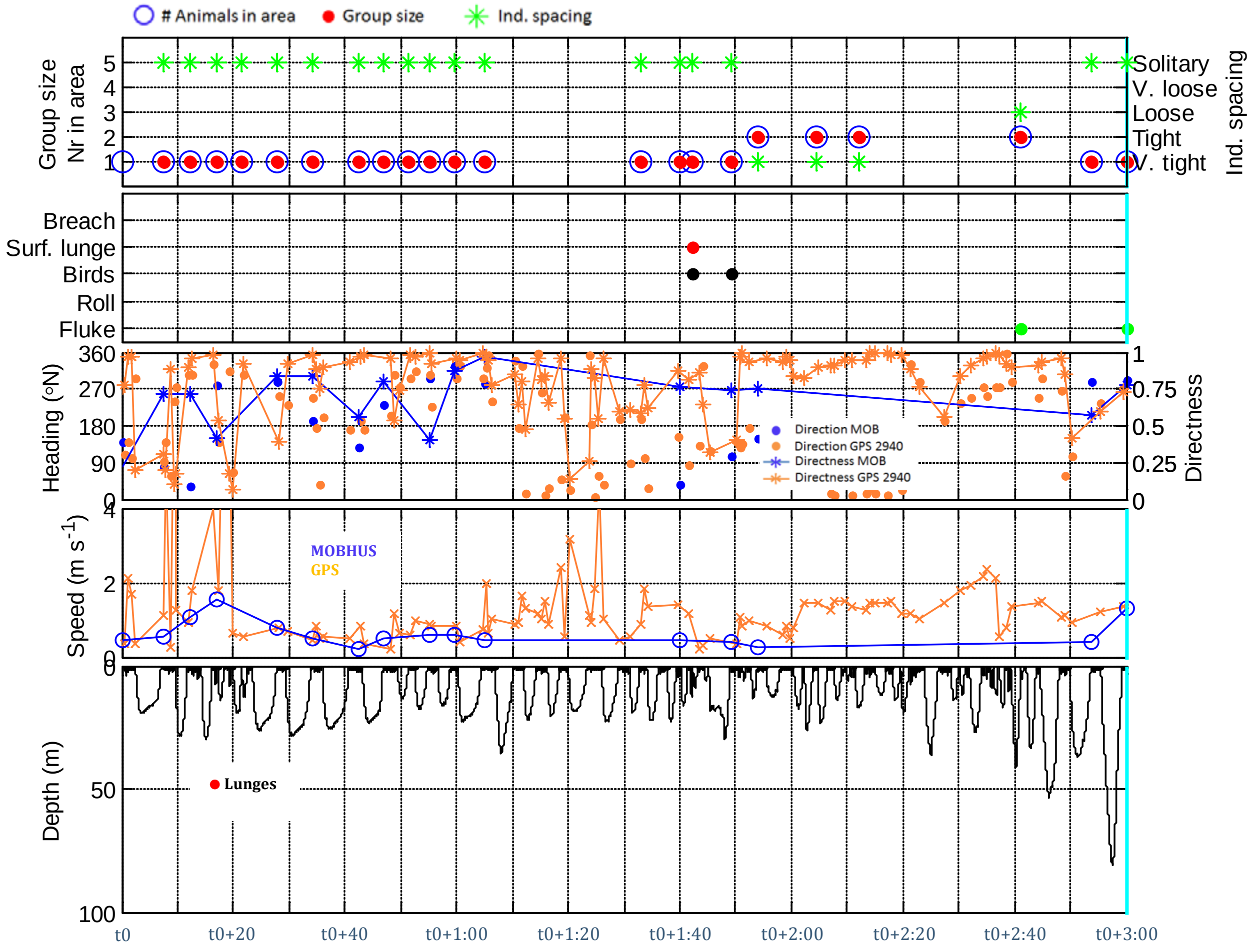


Humpback whale mn11_157 -- 1st tag-on: 05-Jun-2011 22:25:15 UTC
Latitude (°N)
Longitude (°E)
FGPS-tag 29420
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
KW sounds
KW control
2.9 km
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Directness
Speed (m s-1)
HUS
MOBHUS
GPS
Depth (m)
Lunges
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

BASELINE

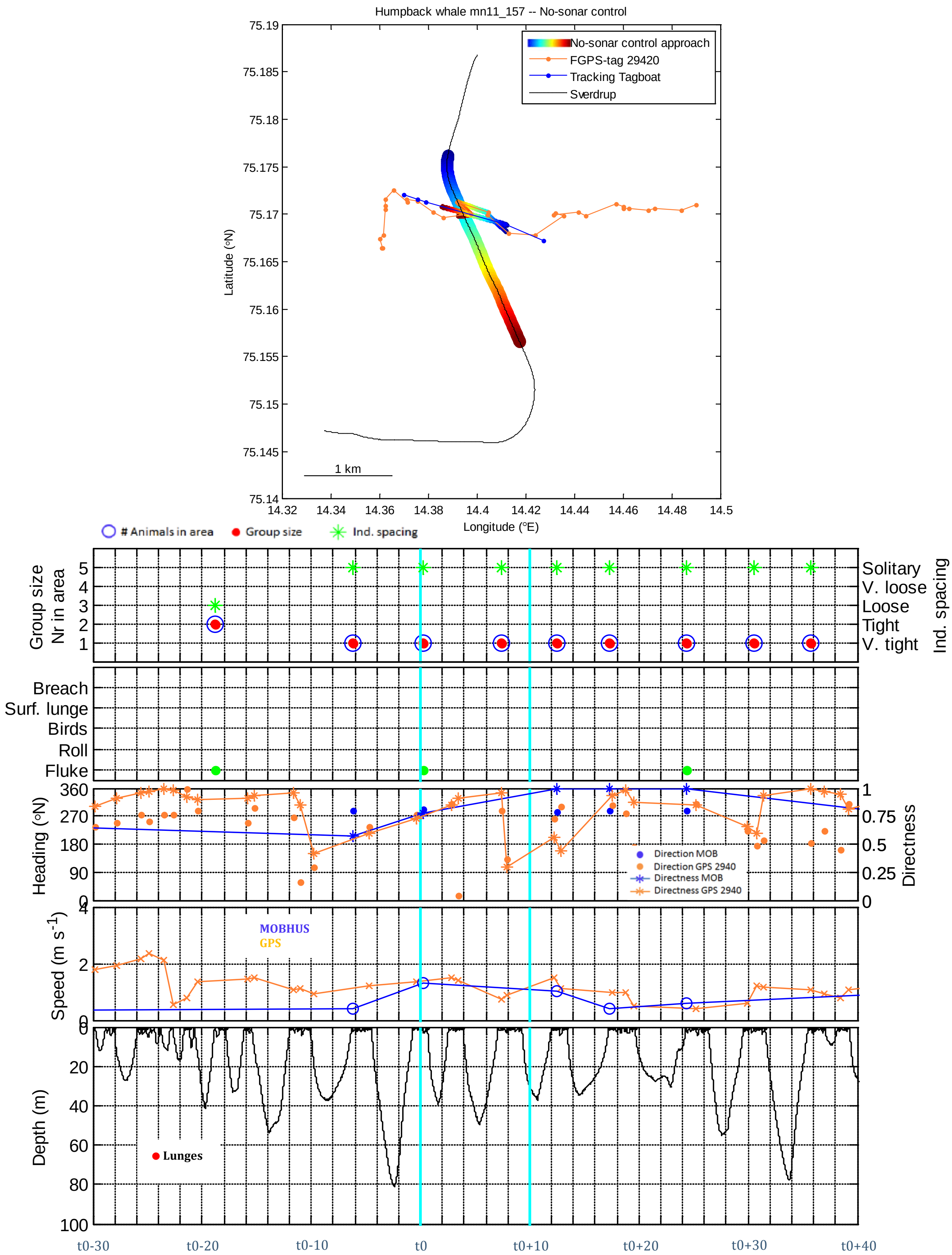


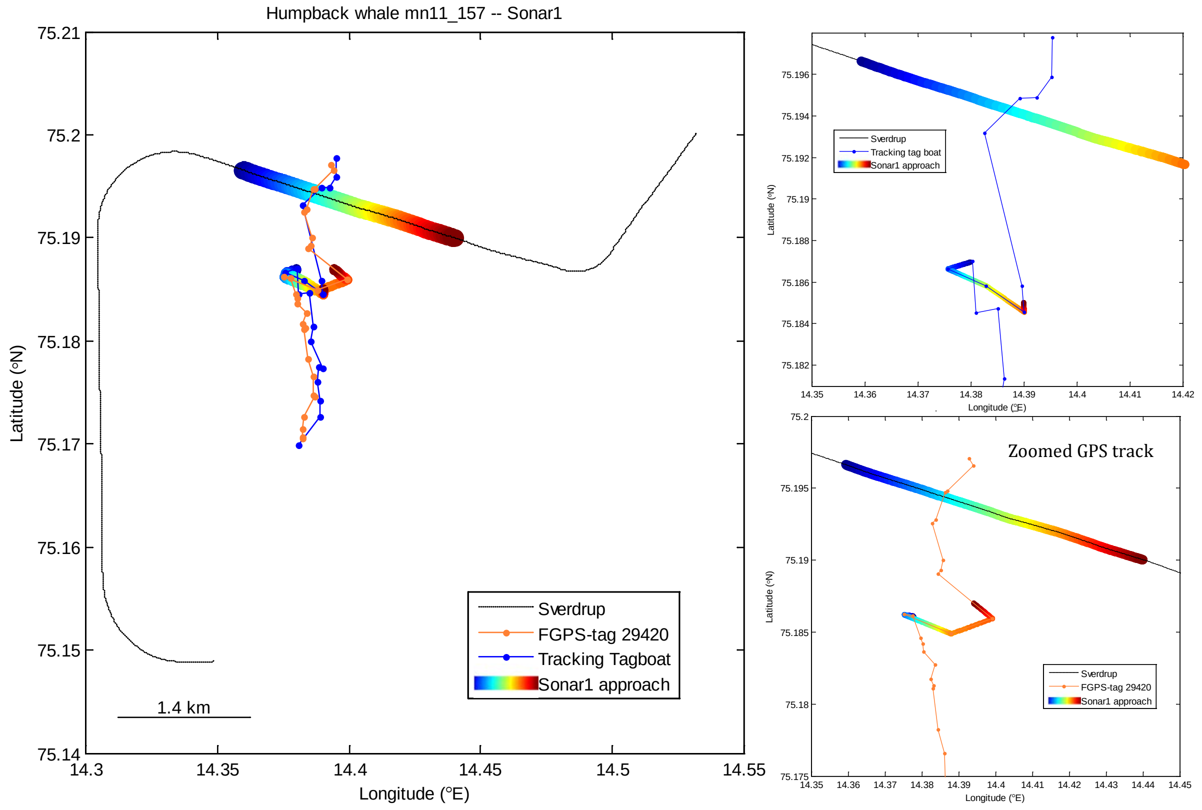
Humpback whale mn11_157 -- Baseline
Latitude (°N)
Longitude (°E)
FGPS-tag 29420
Tracking Tagboat
Start
Stop
1 km

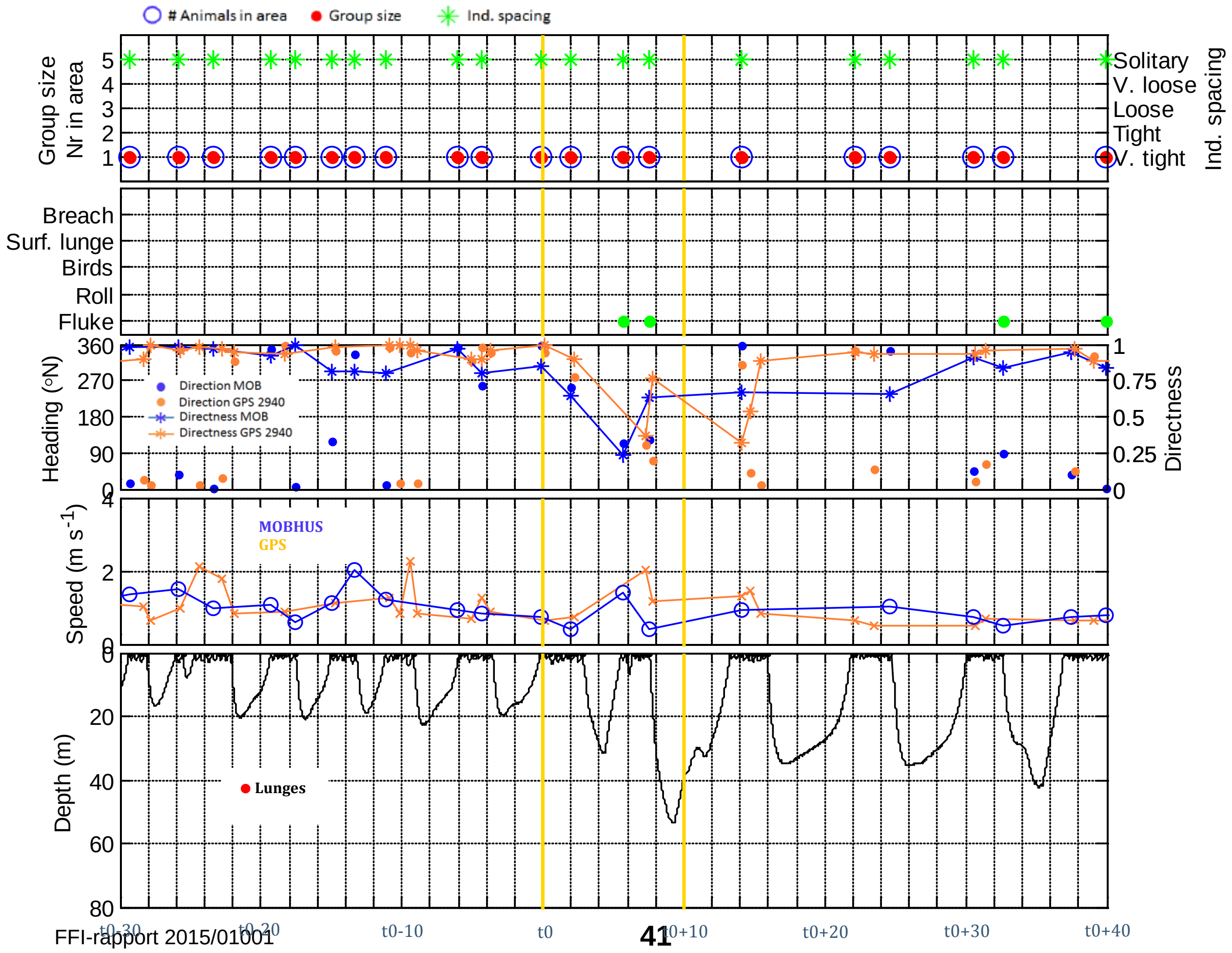


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Speed (m s-1)
MOBHUS
GPS
Depth (m)
Lunges
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

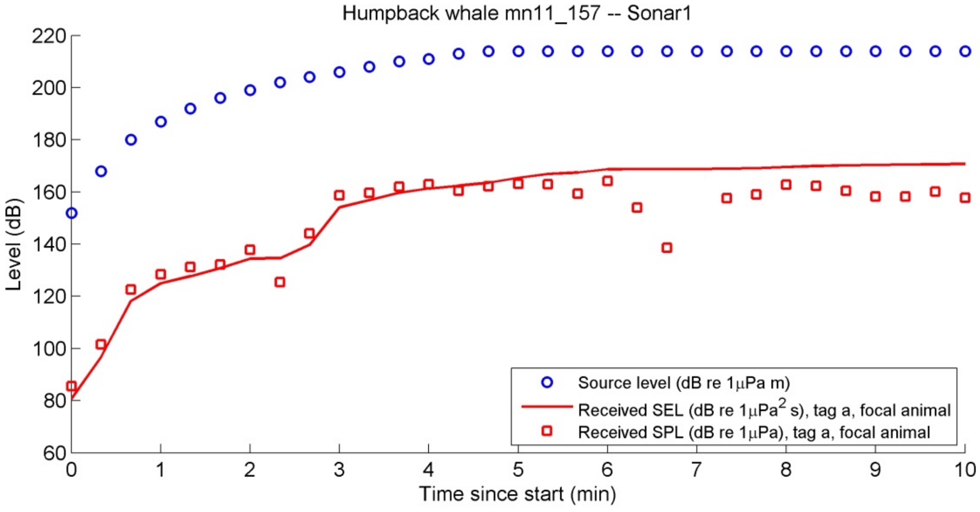
NO-SONAR CONTROL



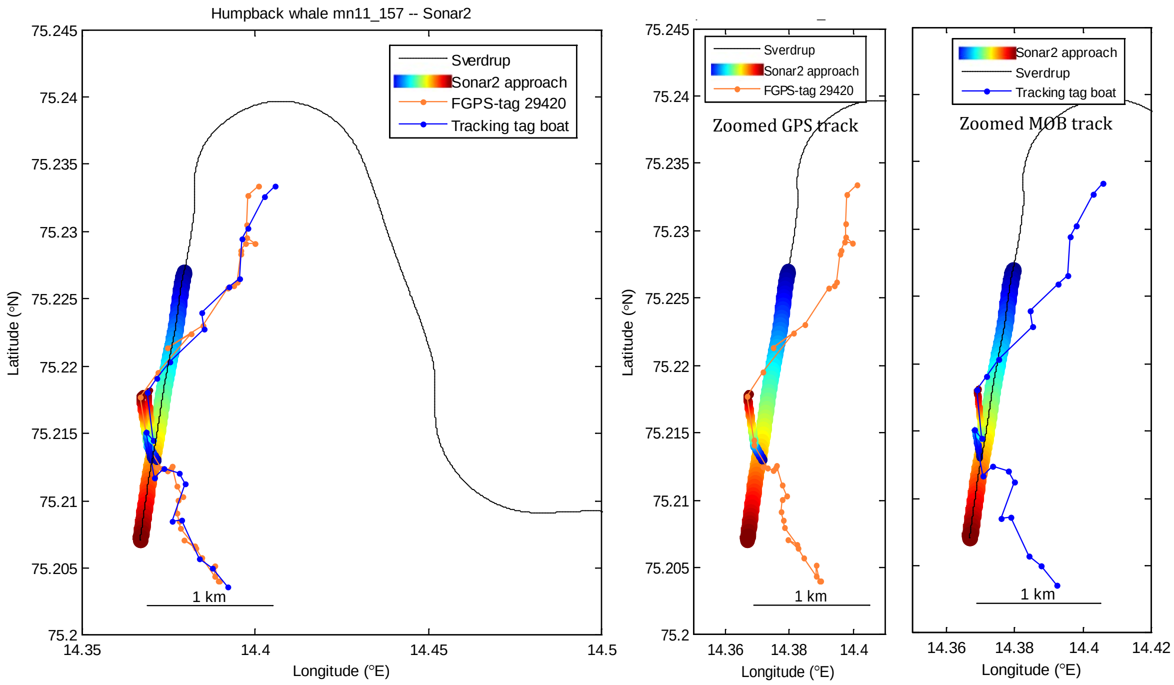

Humpback whale mn11_157 -- Sonar1
Latitude (°N)
Longitude (°E)
Sverdrup
FGPS-tag 29420
Tracking Tagboat
Sonar1 approach
1.4 km
Tracking tag boat
Zoomed GPS track


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Directness
Speed (m s-1)
MOBHUS
GPS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

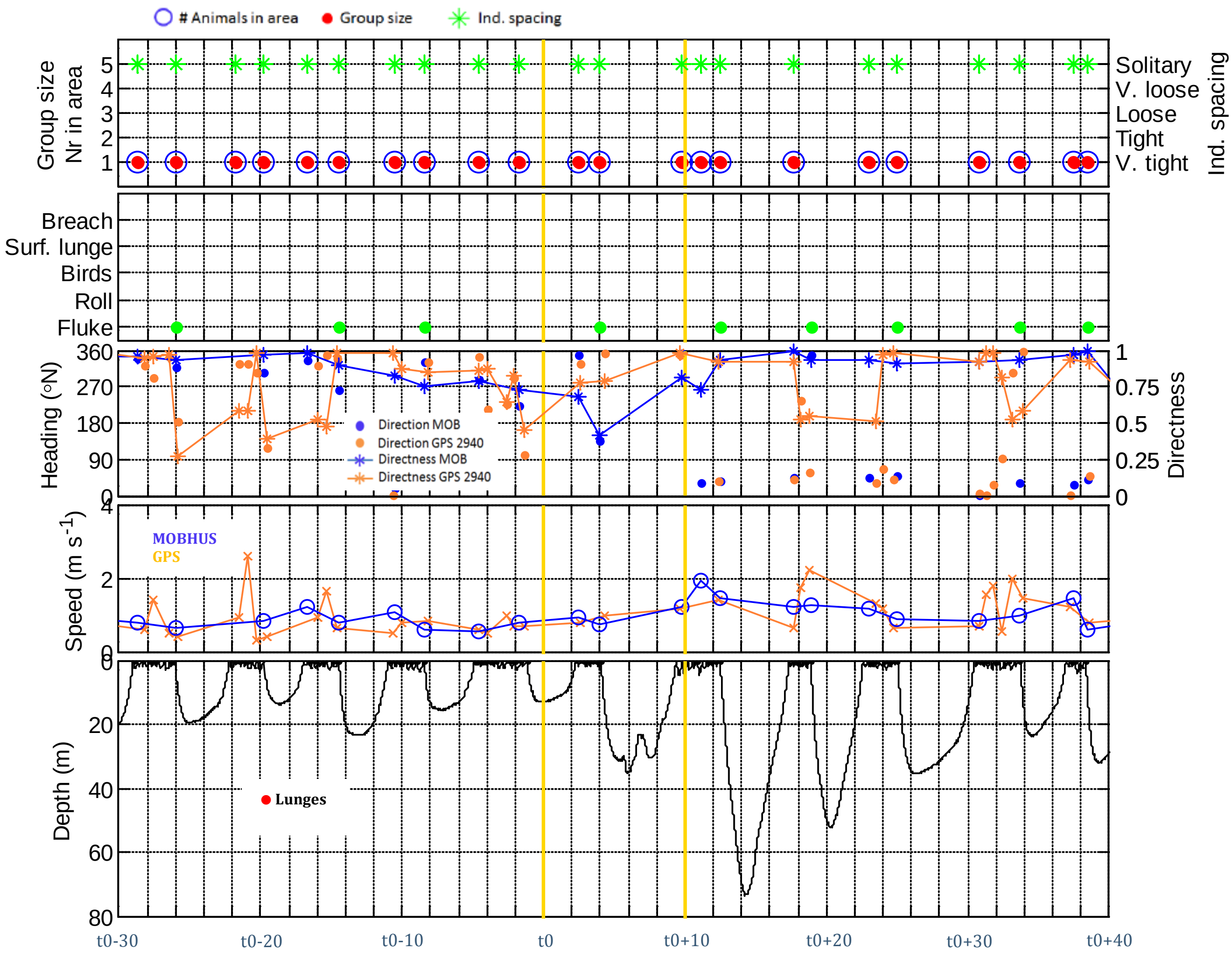
SONAR 1 – Received level



SONAR 2

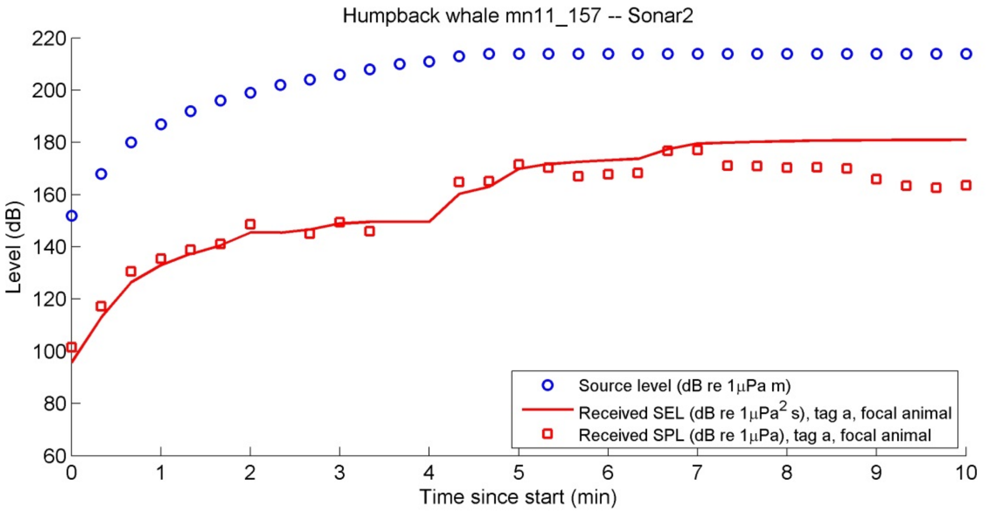


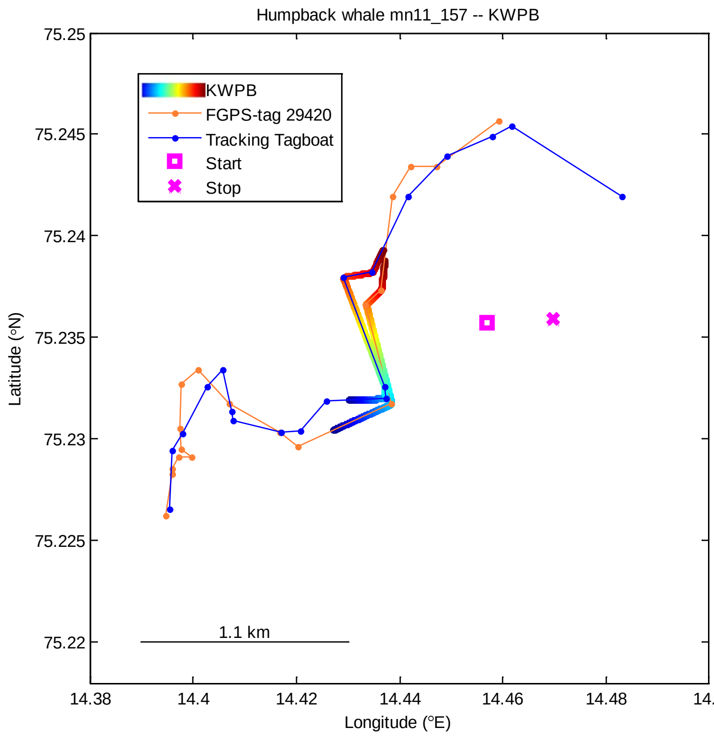
Humpback whale mn11_157 -- Sonar2
Sverdrup
Sonar2 approach
FGPS-tag 29420
Tracking tag boat
Latitude (°N)
Longitude (°E)
1 km
Zoomed GPS track
Zoomed MOB track

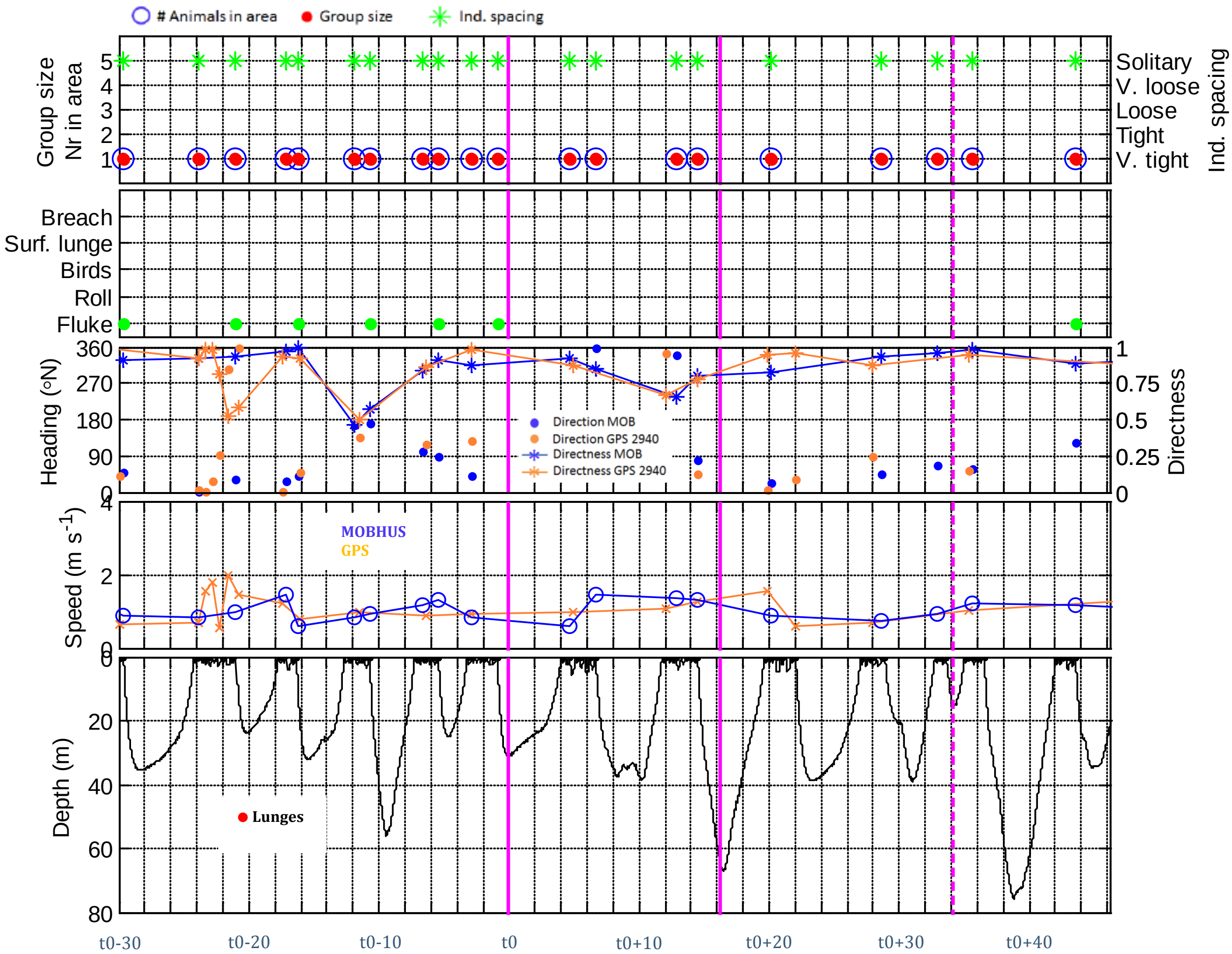


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Speed (m s-1)
MOBHUS
GPS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

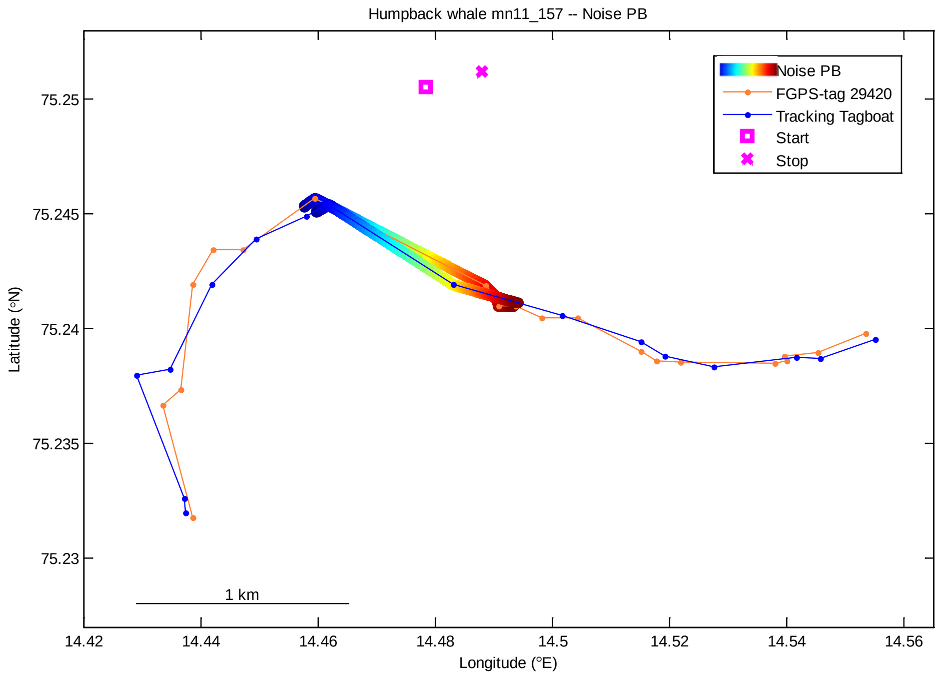
SONAR 2 – Received level

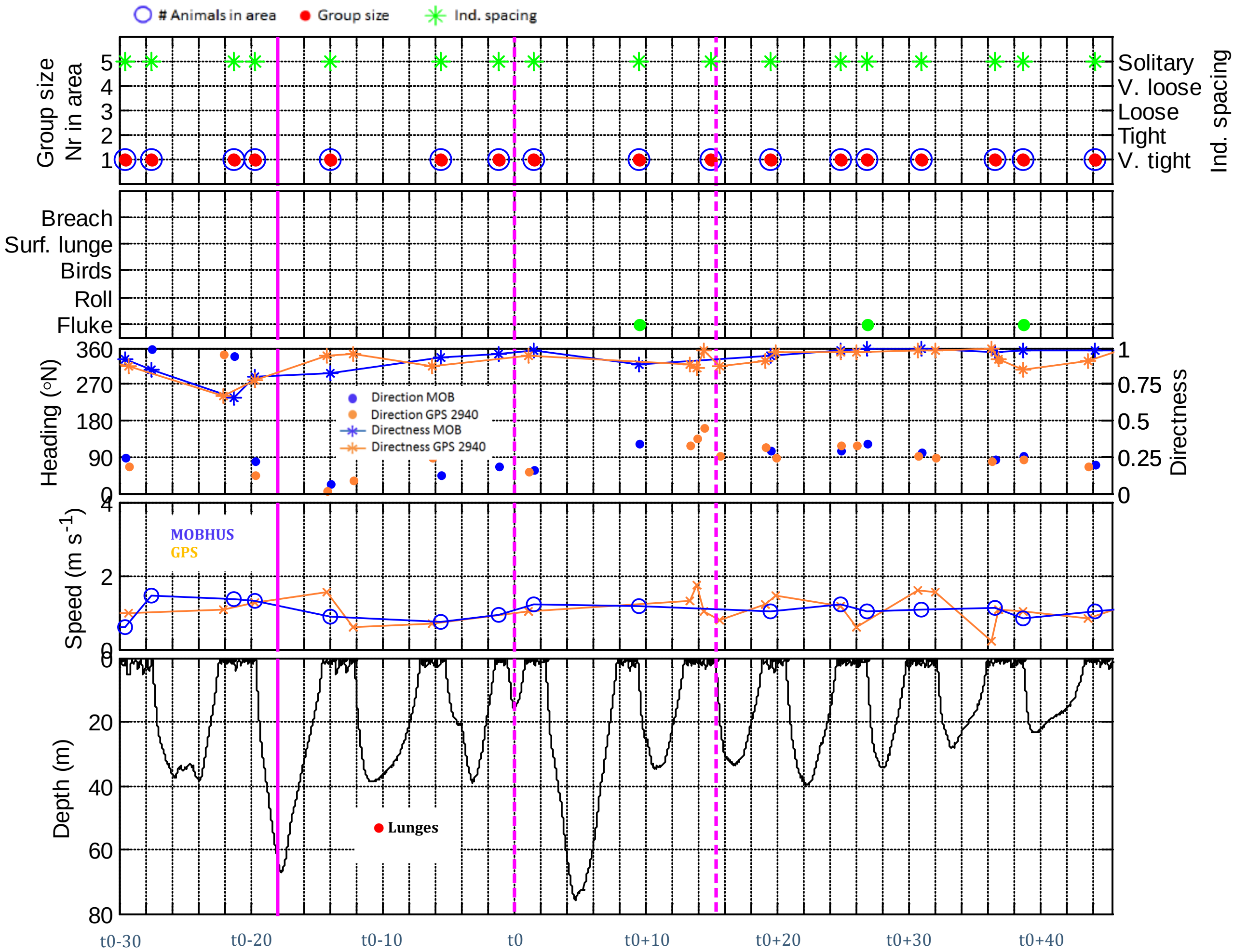



Humpback whale mn11_157 -- KWPB
KWPB
FGPS-tag 29420
Tracking Tagboat
Start
Stop
1.1 km
Latitude (°N)
Longitude (°E)


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Directness
MOBHUS
GPS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

NOISE PLAYBACK



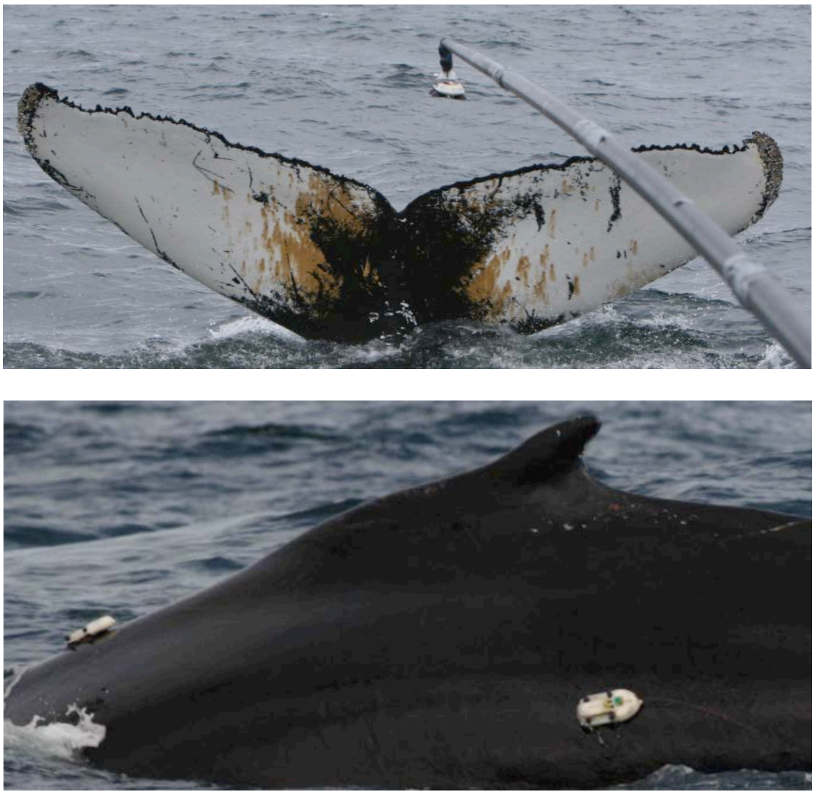


3.4.2 mn11_158ab

June 7th 2011, two DTAGs deployed with pole at 09:21(UTC) (tag a) and 09:33(UTC) (tag b) west of Bear Island. Northeast wind 2 (Beaufort), clouded, sea state 2. Both tags placed on the same animal. Tags stayed on for 10:12hrs (tag a), 07:21hrs (tag b), both tags came off prematurely due to high acceleration swimming after no-sonar control session. Several feeding animals in the area. The animals had a somewhat erratic behavior during pre-exposure phase, and it was therefore difficult to position HUS for approach. Tag b comes off at 18:09 (UTC) during pre-exposure.

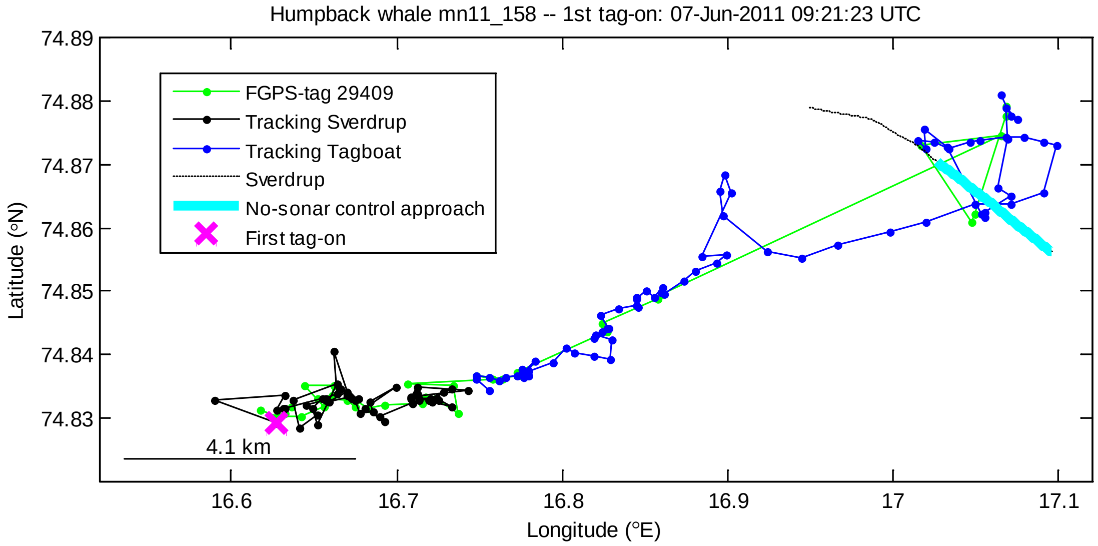
No-sonar control: CPA 18:41:53 UTC at 250m.

Post exposure: Animal was feeding, 4 whales scattered in area. Tag b comes off at 19:33UTC

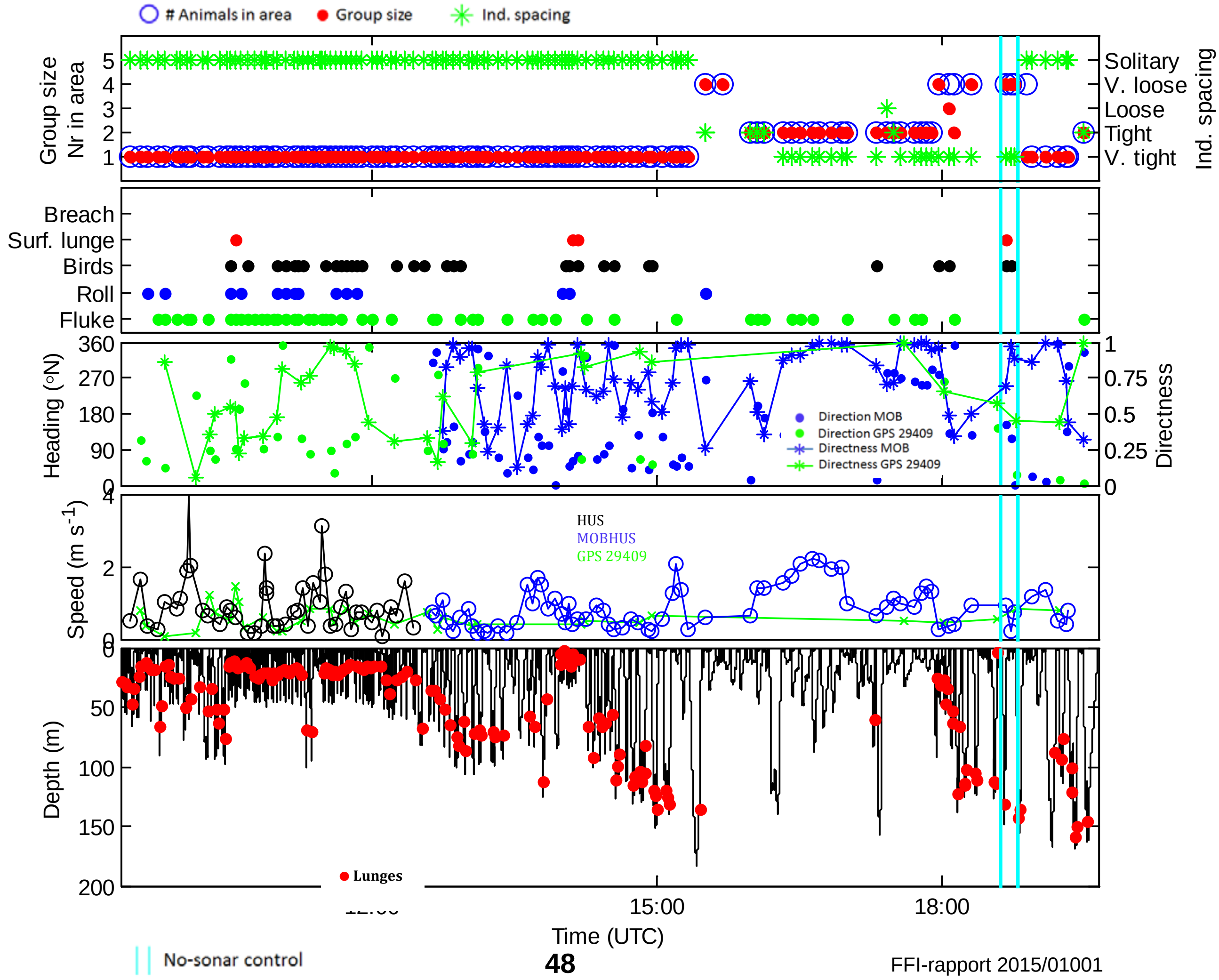


Humpback whale mn11_158 with two DTAGs (photos by Rune Hansen and Leigh Hickmott).

FULL RECORD

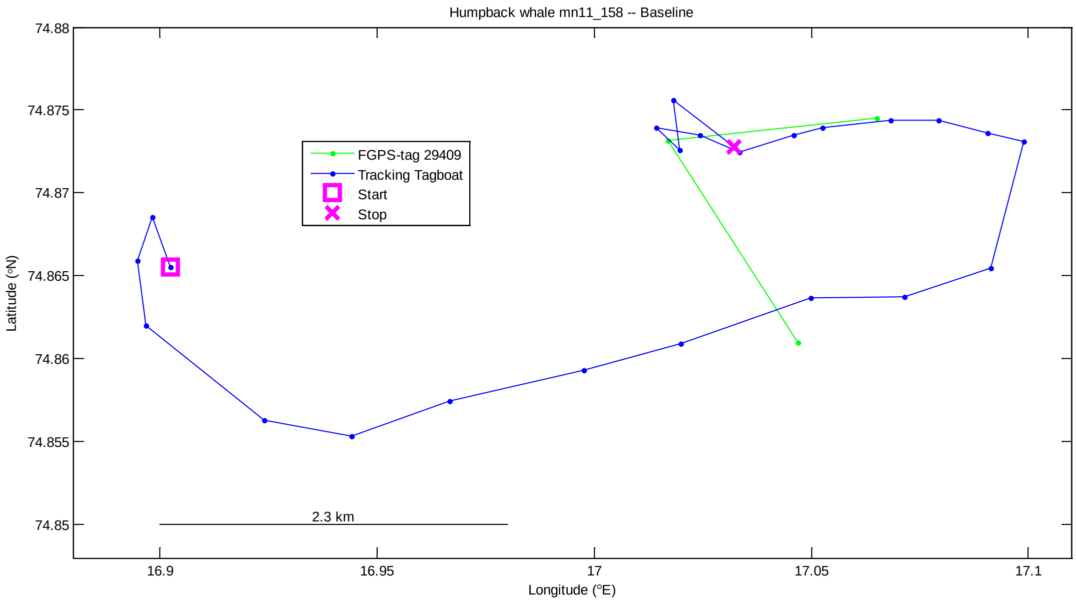


Humpback whale mn11_158 -- 1st tag-on: 07-Jun-2011 09:21:23 UTC
FGPS-tag 29409
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
First tag-on
4.1 km
Latitude (°N)
Longitude (°E)

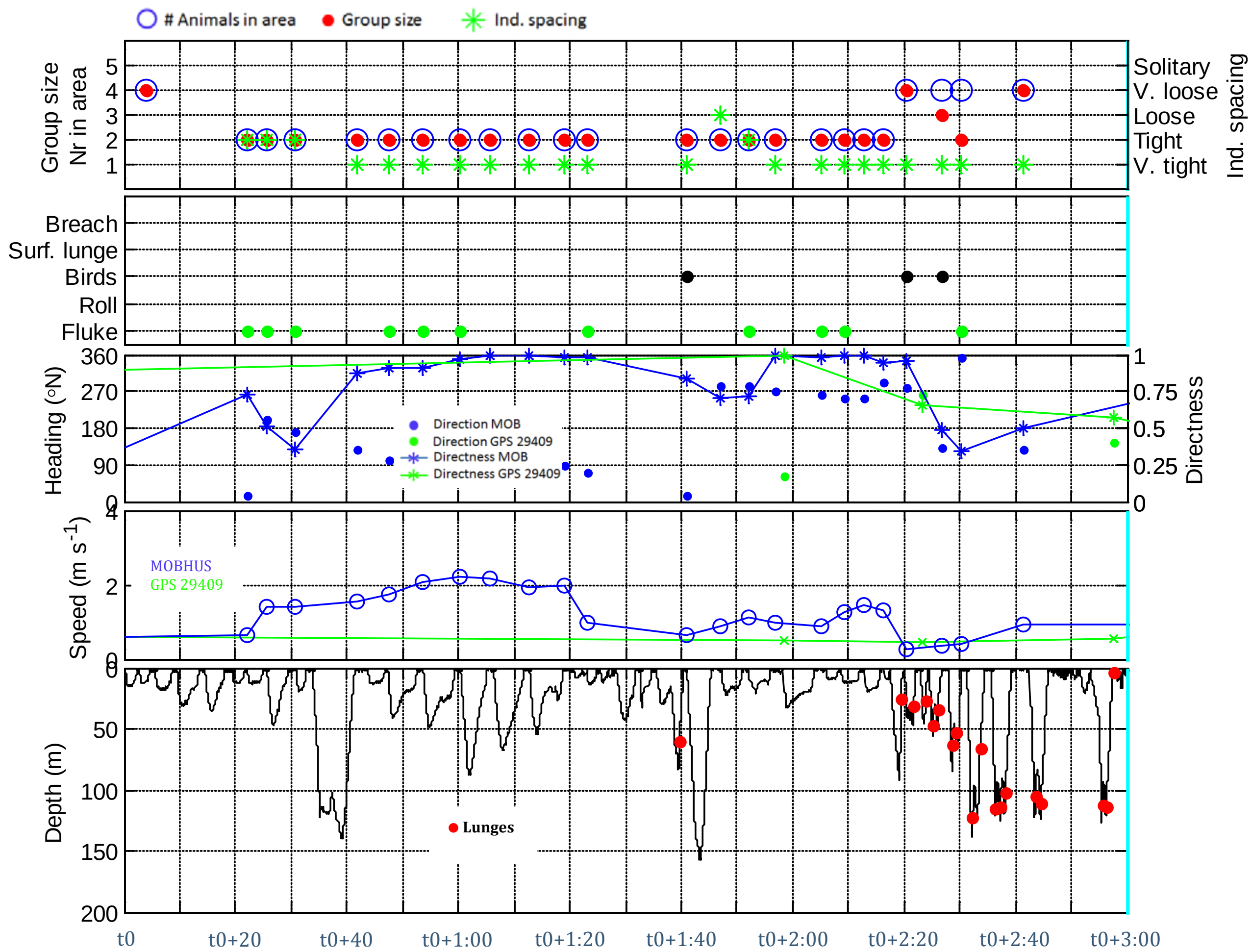


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
HUS
MOBHUS
GPS 29409
Depth (m)
Lunges
15:00
18:00
Time (UTC)
No-sonar control

BASELINE

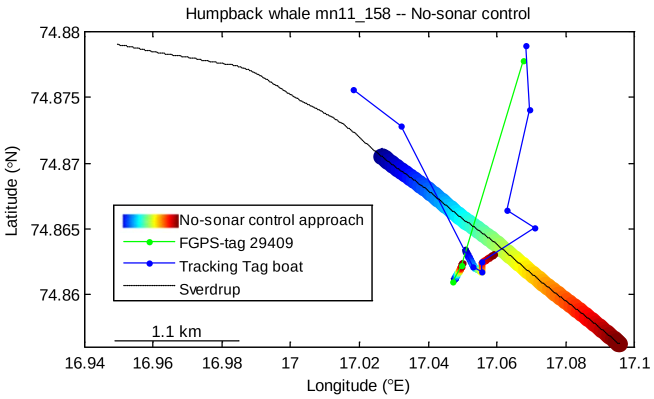


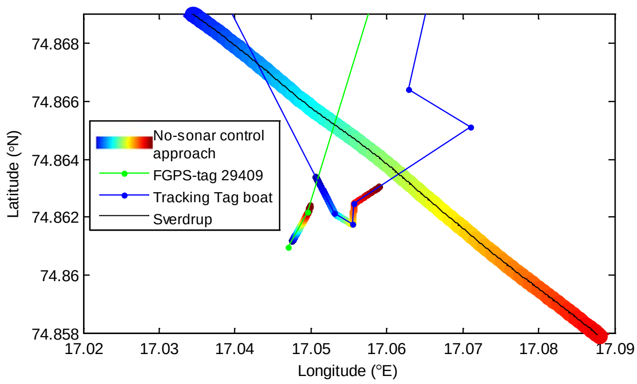
Humpback whale mn11_158 -- Baseline
FGPS-tag 29409
Tracking Tagboat
Start
Stop
2.3 km
Latitude (°N)
Longitude (°E)
74.88
74.875
74.87
74.865
74.86
74.855
74.85
16.9
16.95
17
17.05
17.1

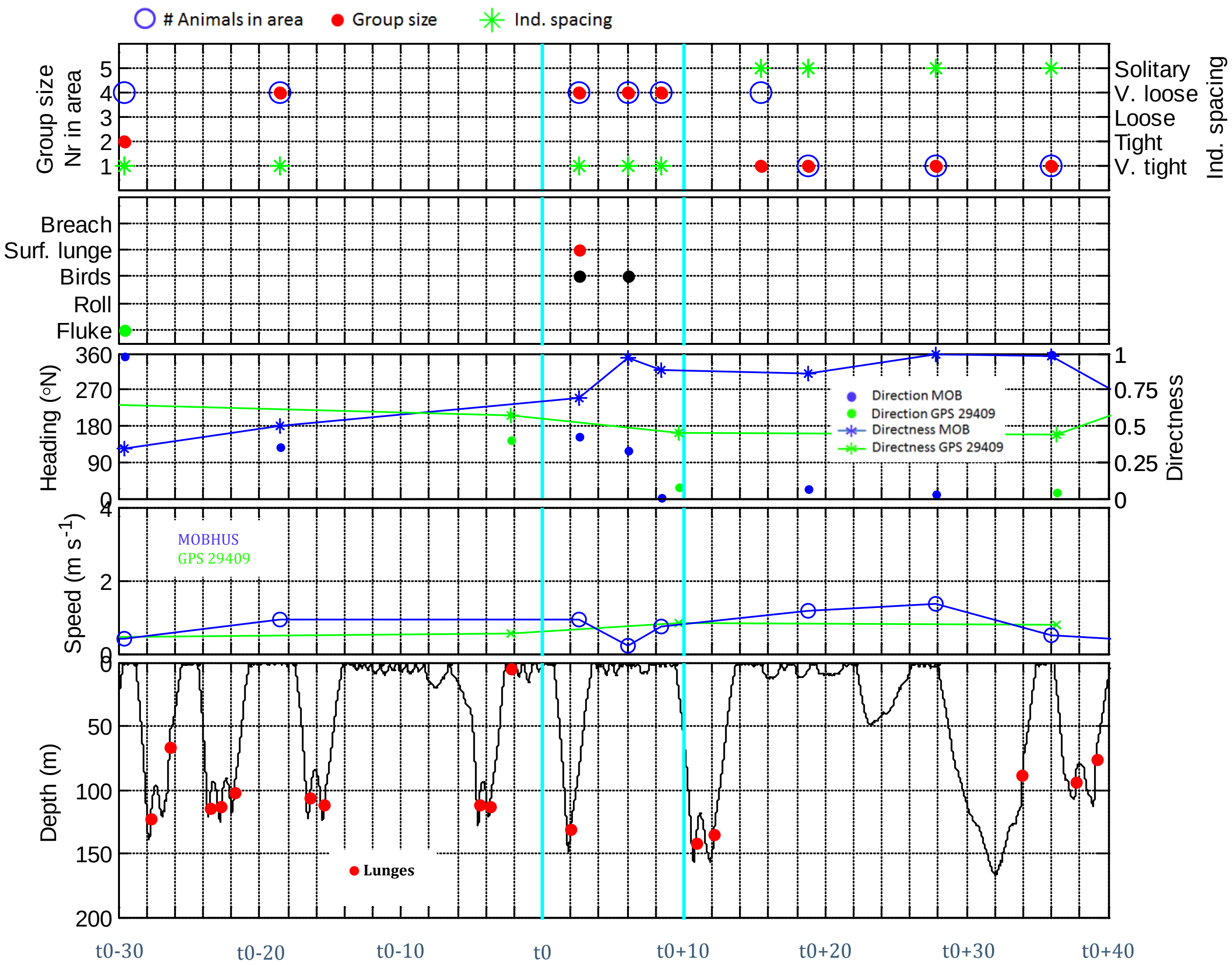


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
MOBHUS
GPS 29409
Depth (m)
Lunges
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

NO-SONAR CONTROL







3.4.3 mn11_160ab

June 8th 2011, DTAG deployed with cantilever pole at 22:34 (UTC) (tag a) and June 9th 00:14(UTC) (tag b) Northwest of Bear Island. Northern wind 1 (Beaufort), clouded, sea state 2. Two tags on the same animal, within a group of 4. Tags stayed on for 16:17hrs (tag a) until it was released and 01:49hrs (tag b) when high acceleration swimming caused premature release during pre-exposure.

No-sonar control: Approach speed was reduced to 7 knots because of current. The timing of the approach was therefore not perfect. CPA 07:23:23UTC at 300m range, but 1.5min late.

SONAR 1: CPA 09:19:42UTC at 250m range, 30s late. Fin whale was swimming alongside the source ship at 100m range in opposite direction. Several dolphins sighted within a few hundred meters of the source, some closed in on the ship from the side. Two incidents of animals very close shut down range, but no shut down was executed. Transmission was scheme executed as planned.

SONAR 2: CPA 10:41:22 (UTC) at 300m range, 10 s late. Several humpbacks, fins and dolphins were observed at 800-1000m range from source during approach. They appeared to have a normal behavior.

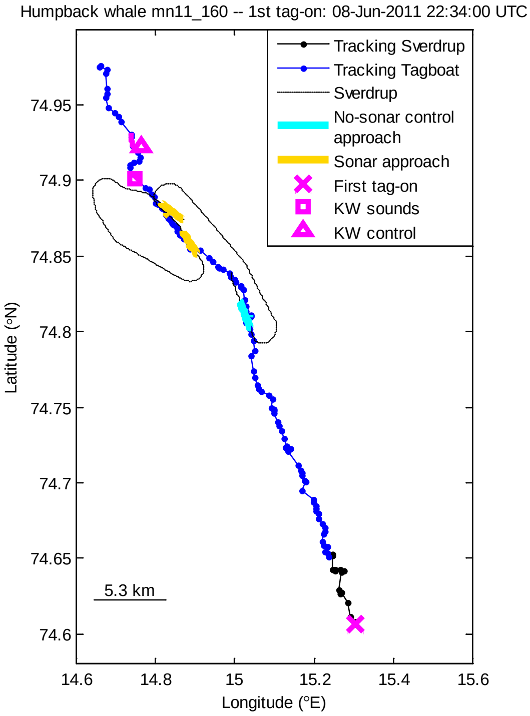
Killer whale playback: started 12:13 UTC

Noise playback: started 13:03 UTC

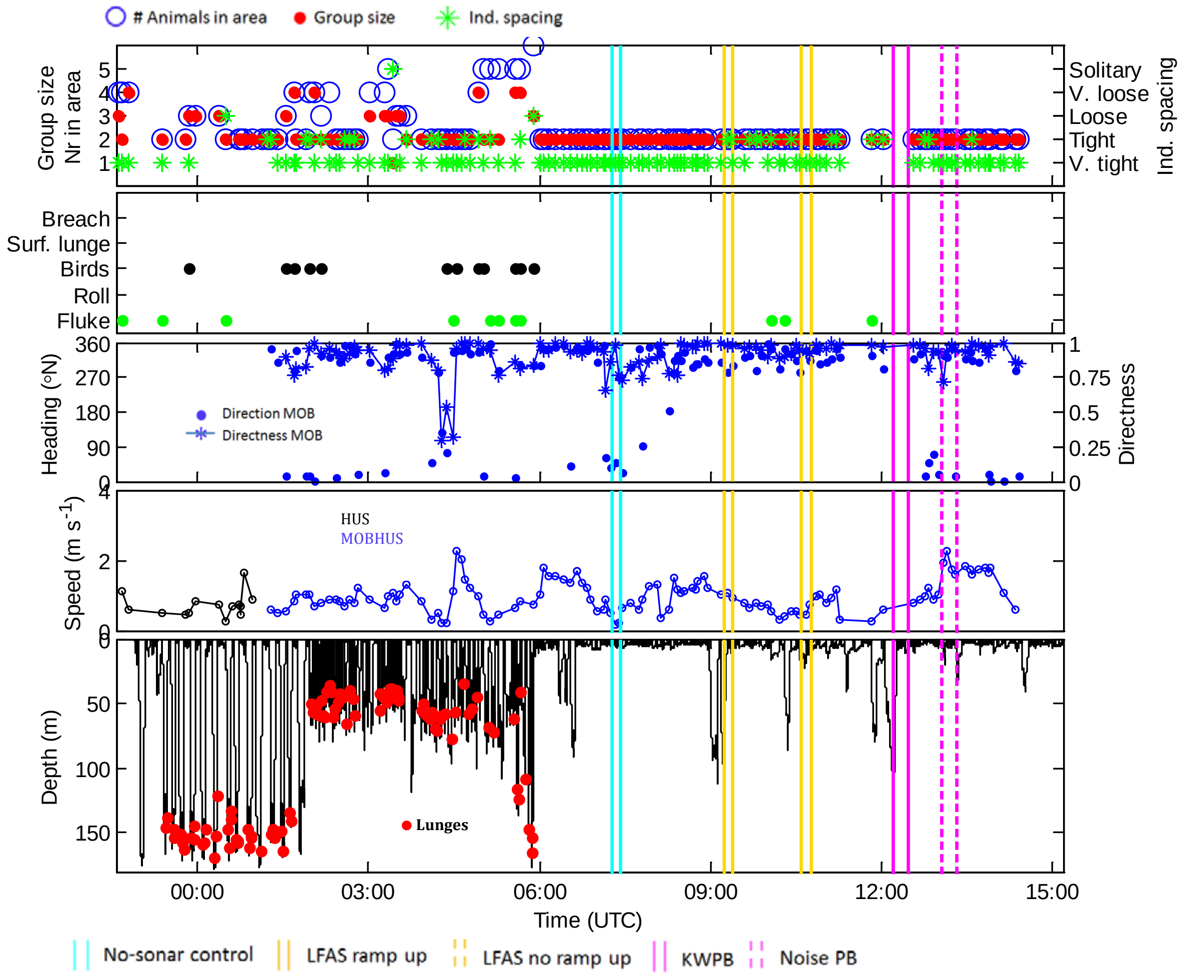
Biopsy: No successful biopsy because whale tracking was lost. Tag came off at 15:11 UTC, recovered within 5 min.

Humpback whale mn11_160 with two DTAGs. (Photos by Filipa Samarra and Leigh Hickmott).

FULL RECORD

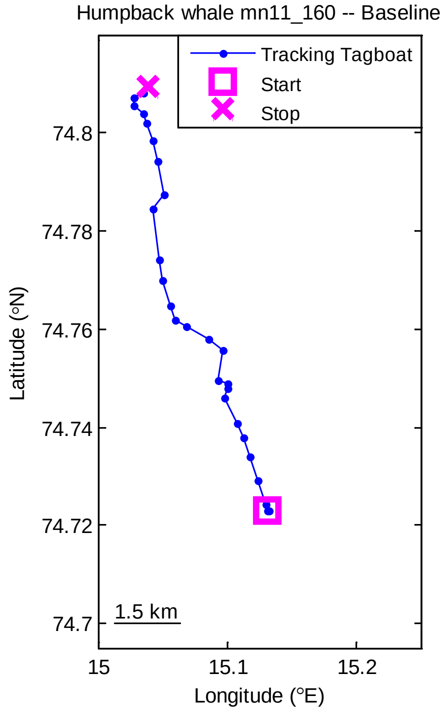


Humpback whale mn11_160 -- 1st tag-on: 08-Jun-2011 22:34:00 UTC
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
KW sounds
KW control
5.3 km
Latitude (°N)
Longitude (°E)

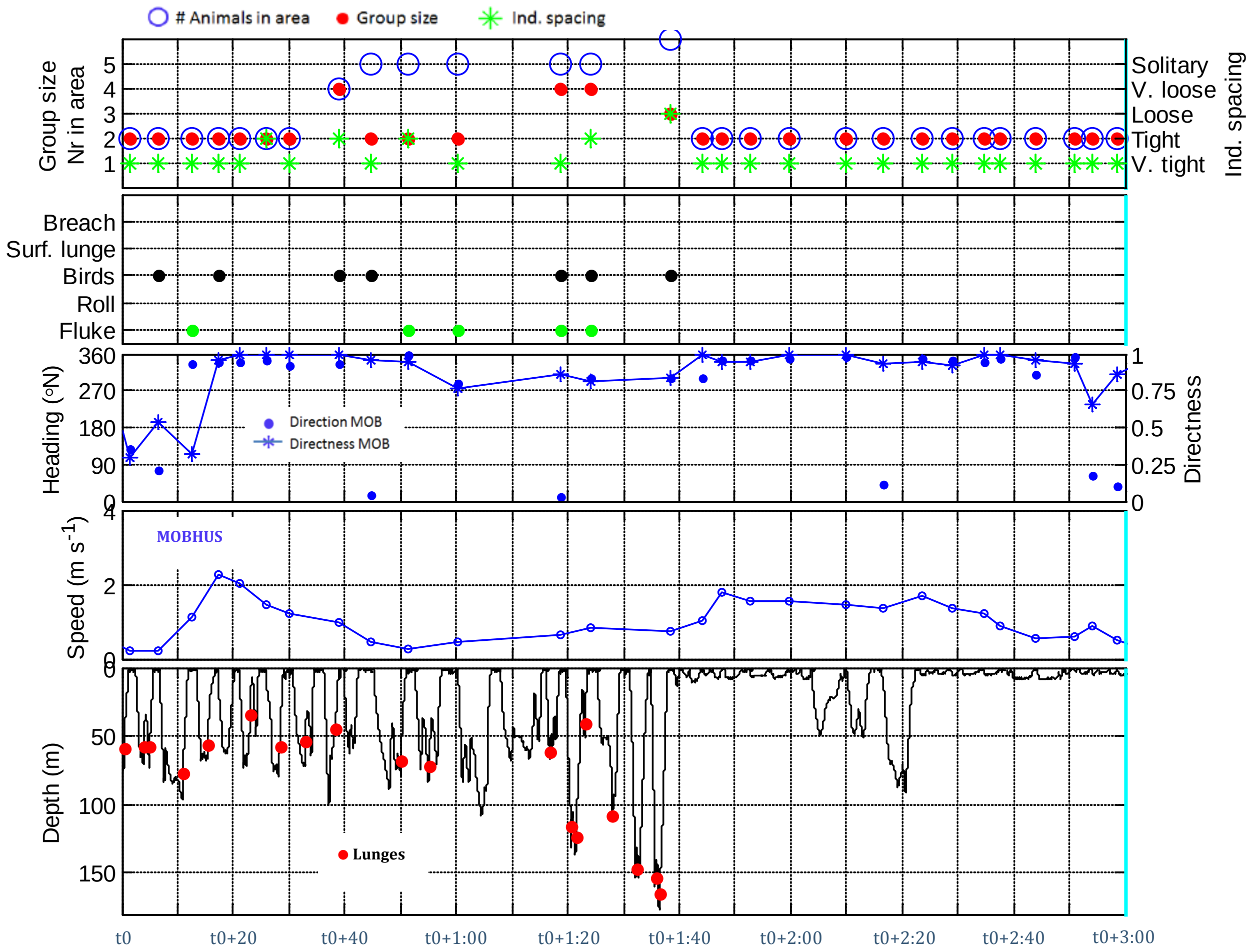


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
Speed (m s-1)
HUS
MOBHUS
Depth (m)
Lunges
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

BASELINE

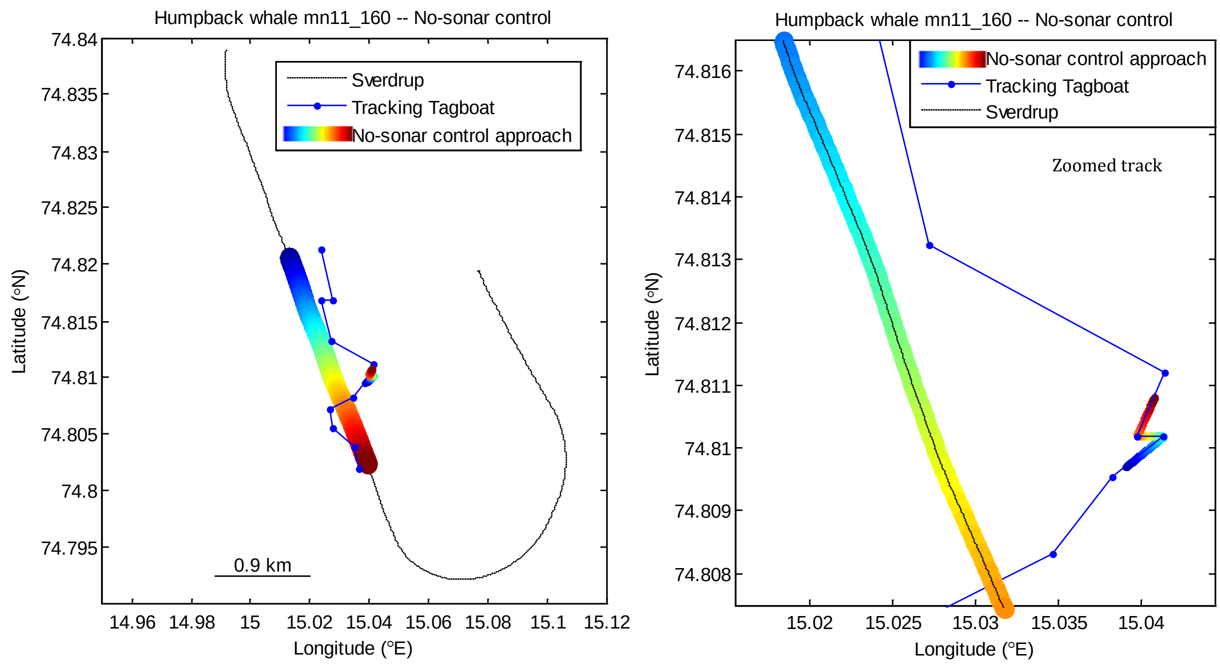


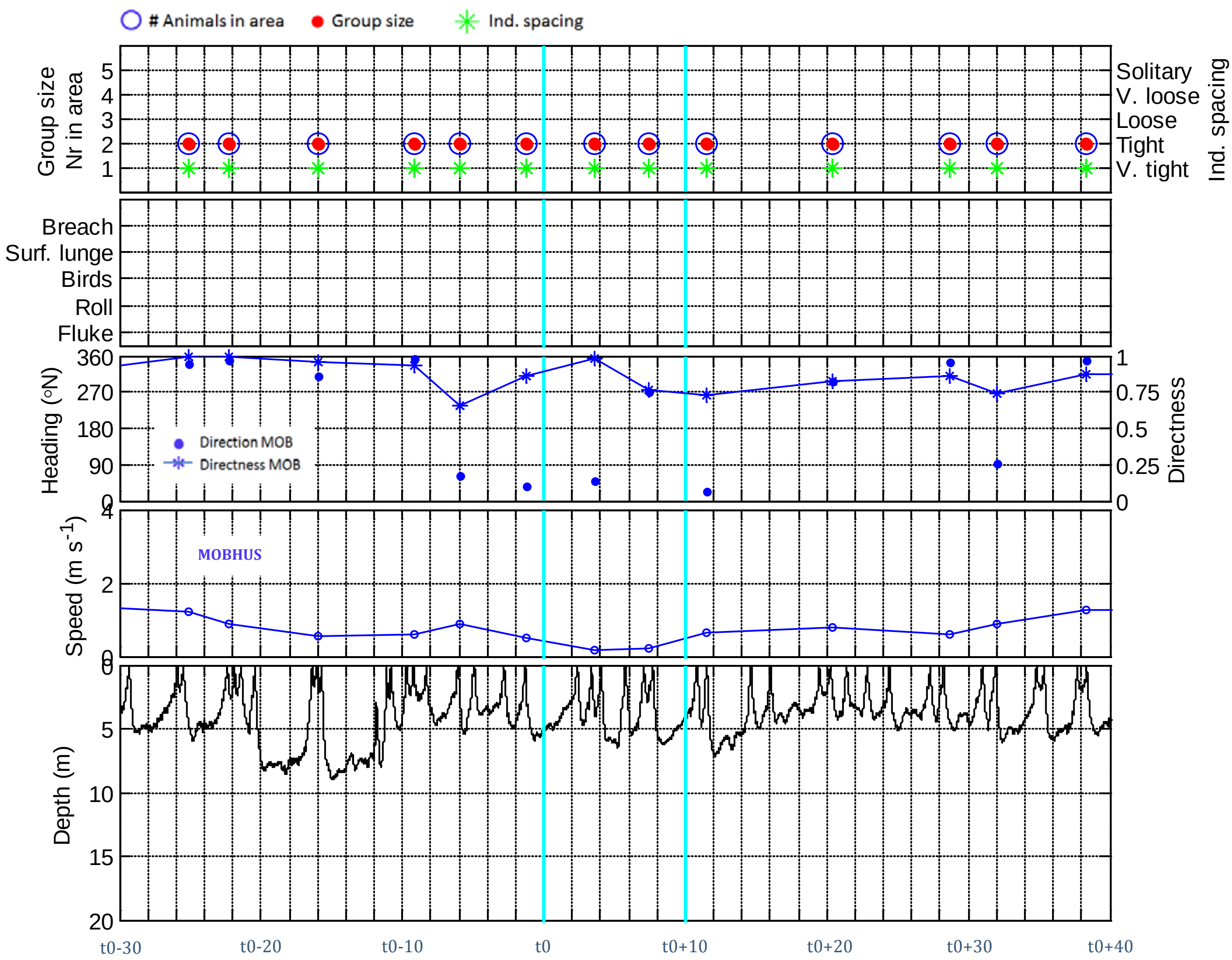
Humpback whale mn11_160 -- Baseline
Tracking Tagboat
Start
Stop
Latitude (°N)
74.8
74.78
74.76
74.74
74.72
74.7
1.5 km
15
15.1
15.2
Longitude (°E)

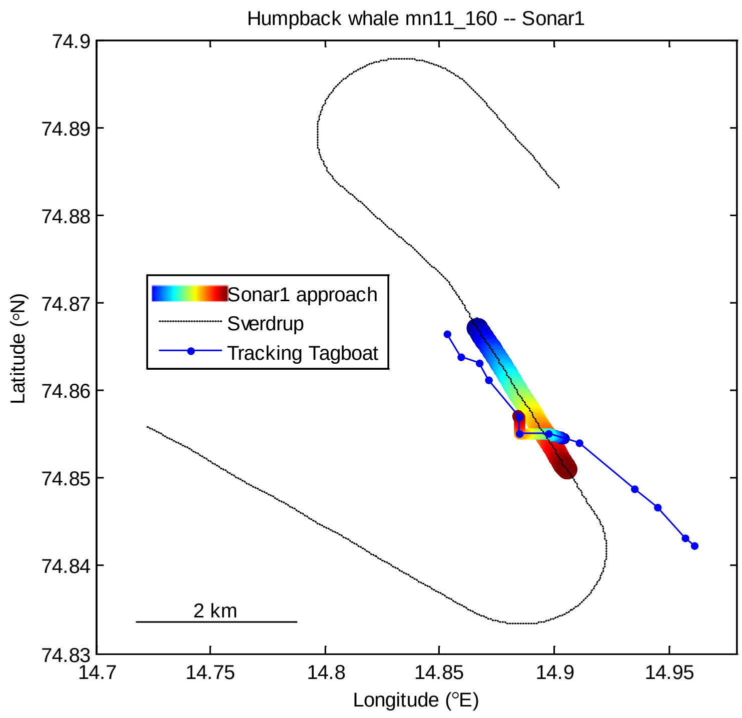


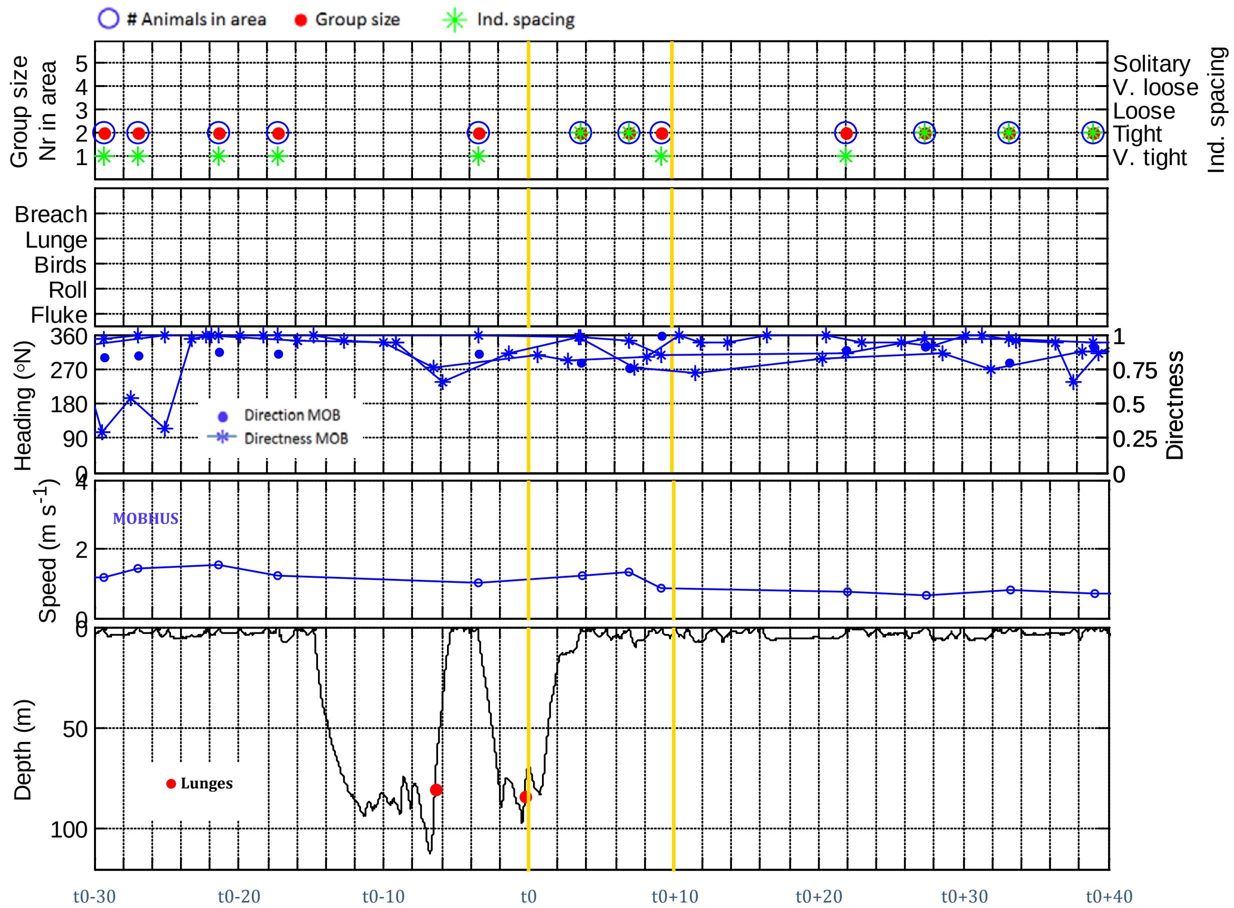
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
Speed (m s-1)
MOBHUS
Depth (m)
Lunges
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

NO-SONAR CONTROL

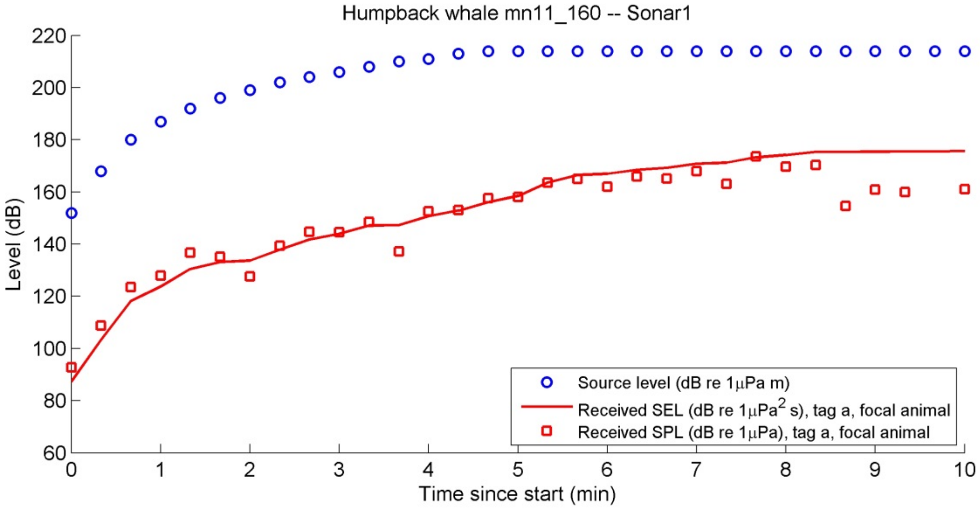




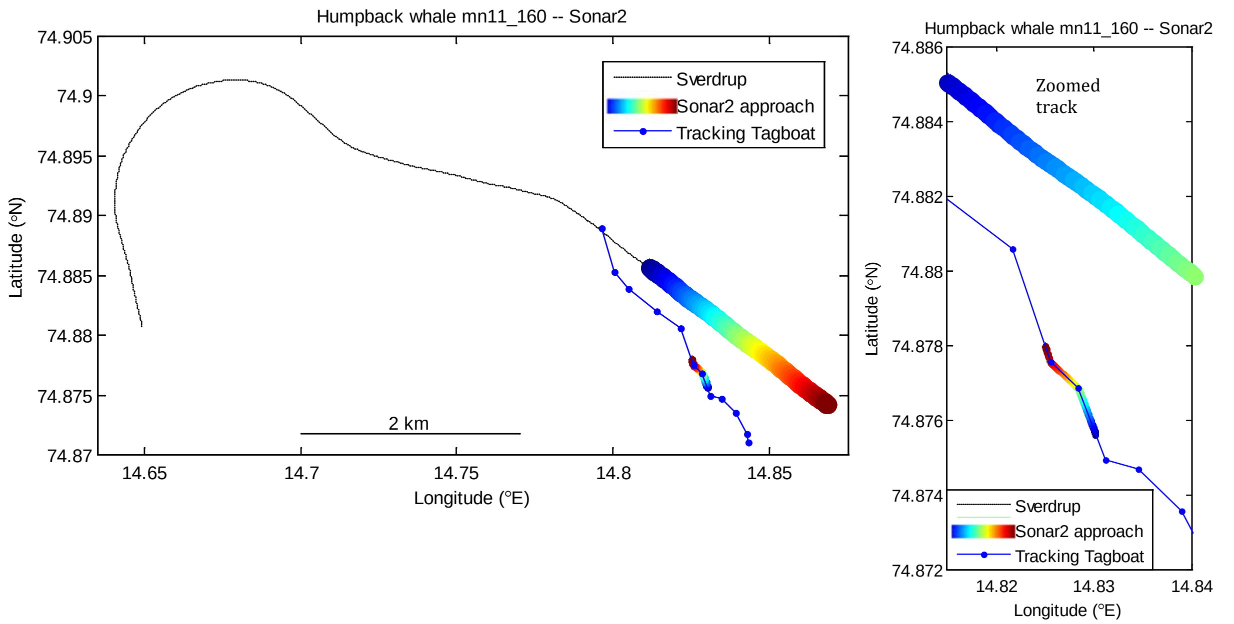

Humpback whale mn11_160 -- Sonar1
Sonar1 approach
Sverdrup
Tracking Tagboat
2 km
Latitude (°N)
Longitude (°E)
74.9
74.89
74.88
74.87
74.86
74.85
74.84
74.83
14.7
14.75
14.8
14.85
14.9
14.95


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
Speed (m s-1)
MOBHUS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

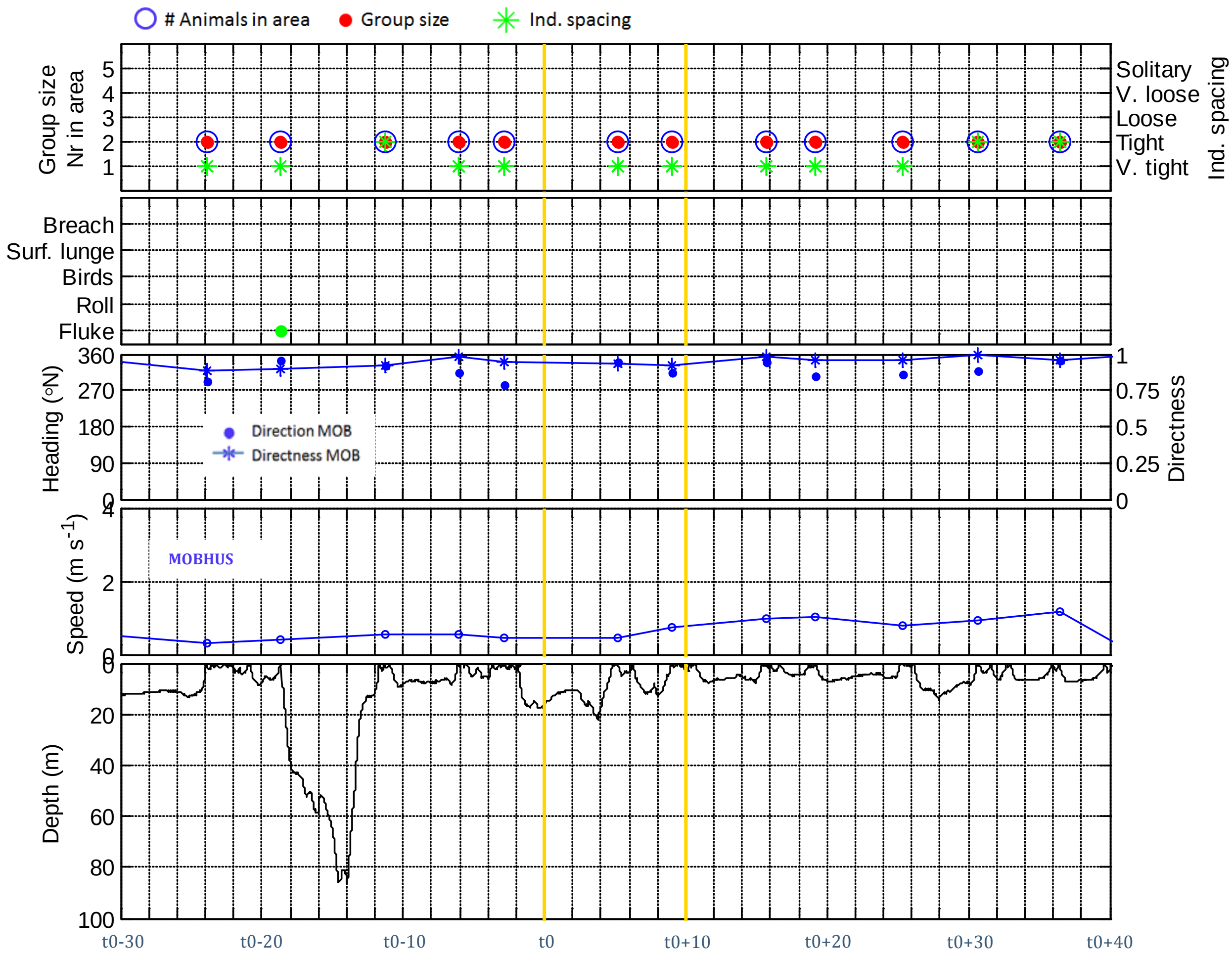
SONAR 1 – Received level



SONAR 2

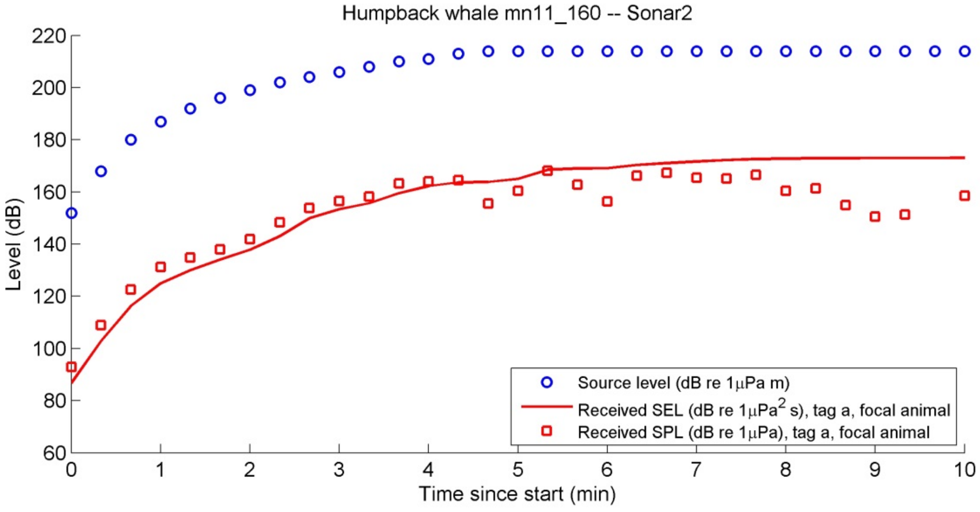


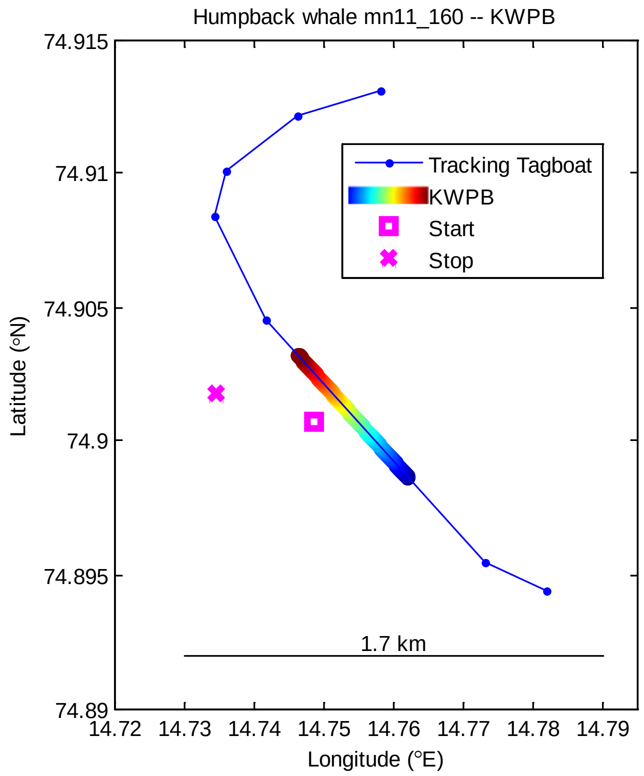
Humpback whale mn11_160 -- Sonar2
Sverdrup
Sonar2 approach
Tracking Tagboat
2 km
Latitude (°N)
Longitude (°E)
Zoomed track

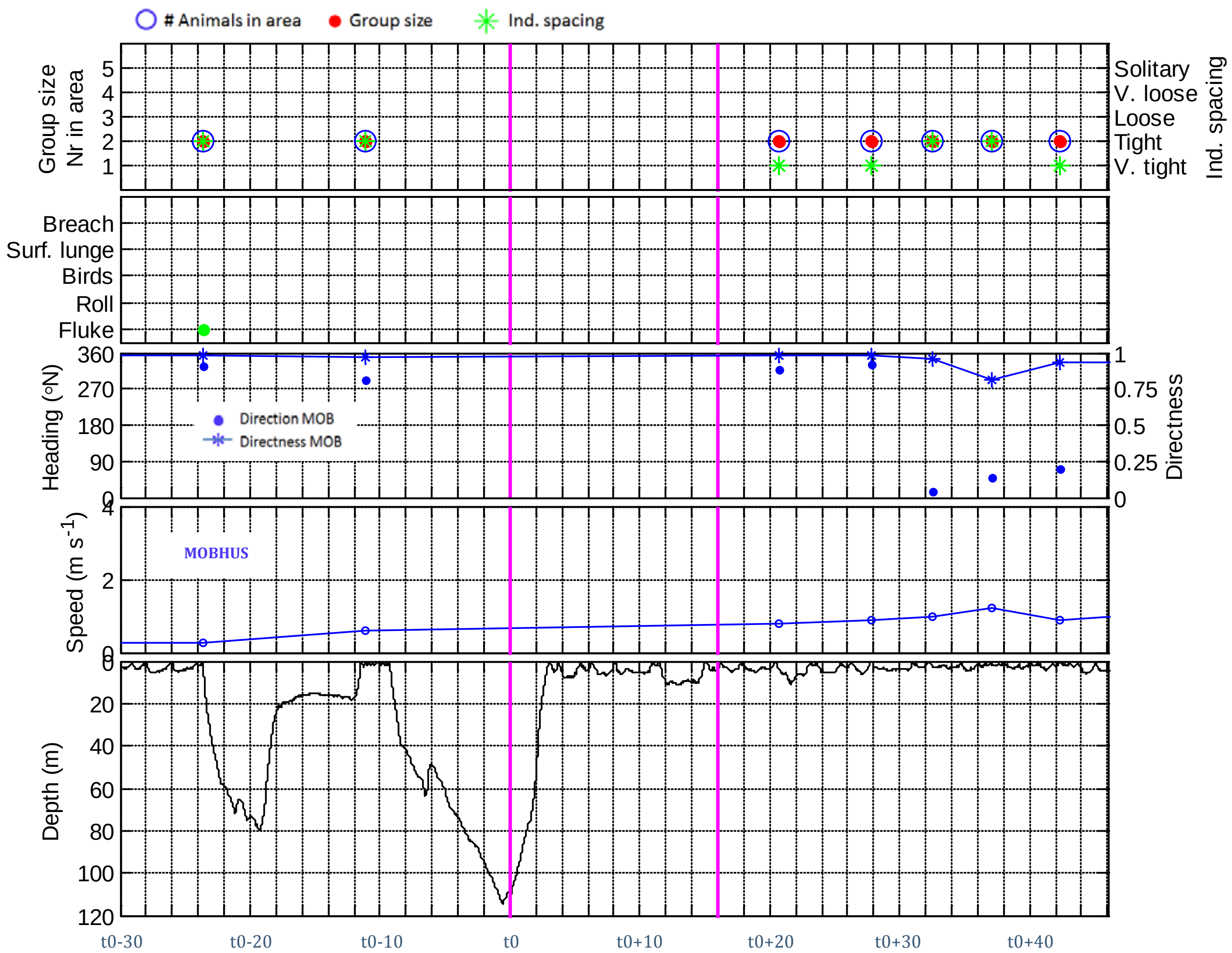


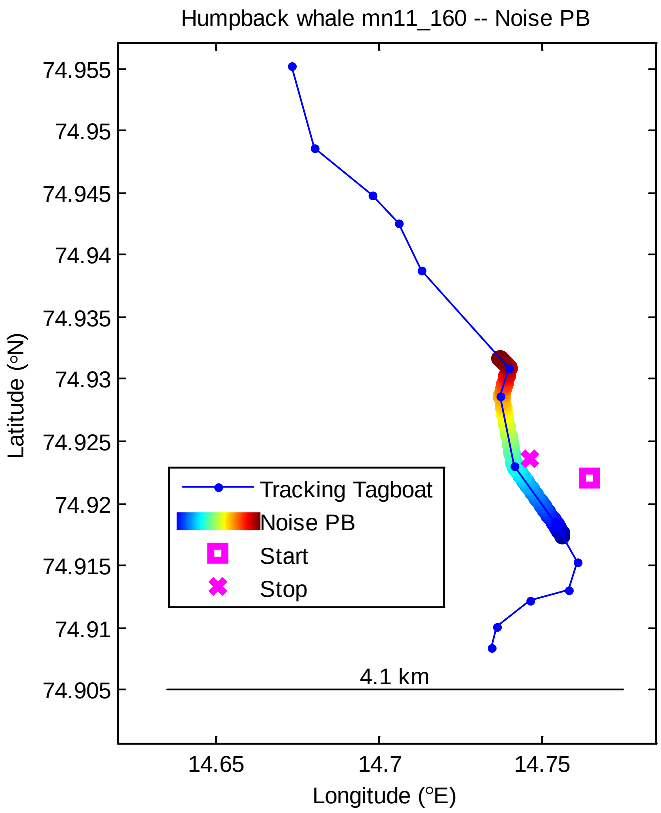
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
MOBHUS
Speed (m s-1)
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

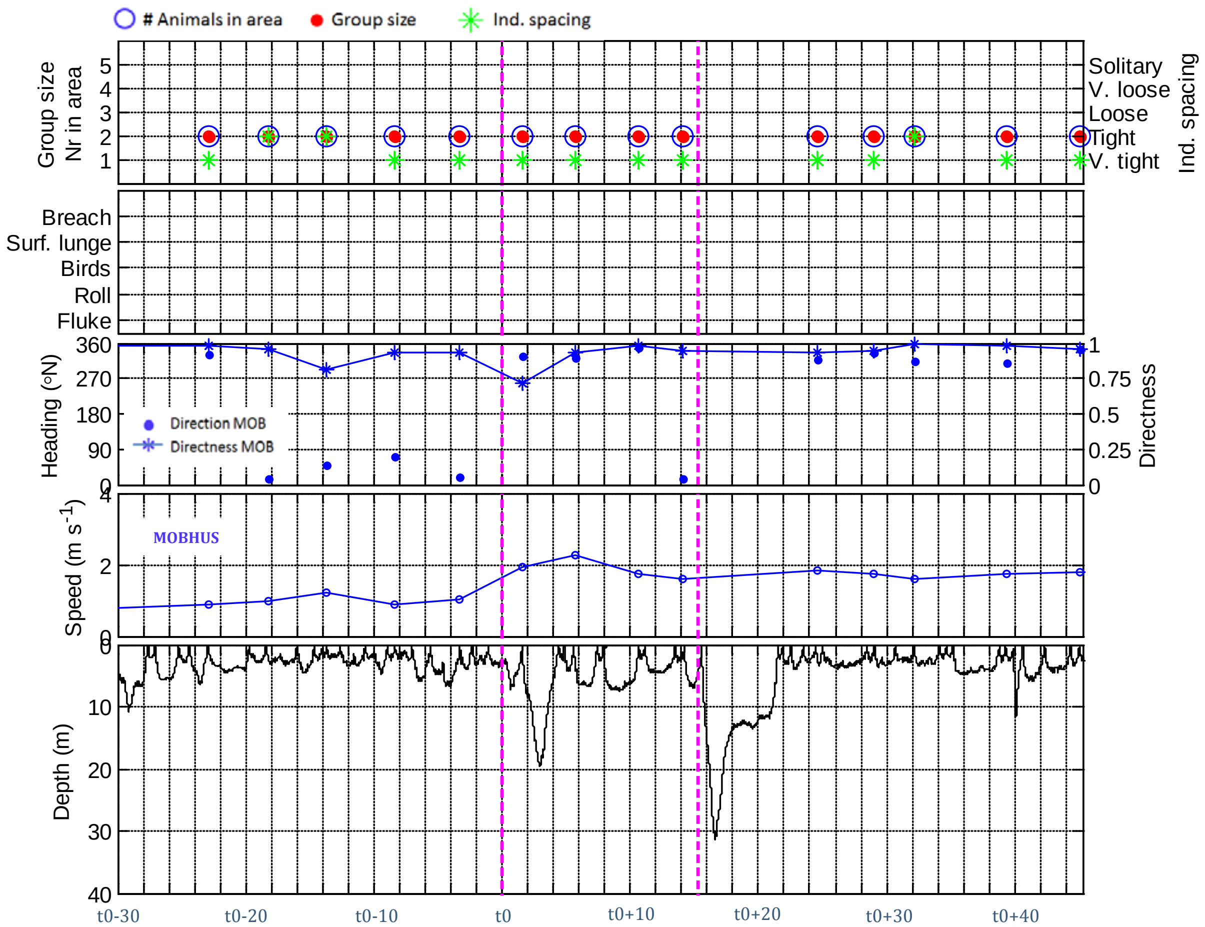
SONAR 2 – Received level




Humpback whale mn11_160 -- KWPB
Tracking Tagboat
KWPB
Start
Stop
1.7 km
Latitude (°N)
Longitude (°E)
74.915
74.91
74.905
74.9
74.895
74.89
14.72
14.73
14.74
14.75
14.76
14.77
14.78
14.79


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
MOBHUS
Speed (m s-1)
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40


Humpback whale mn11_160 -- Noise PB
Latitude (°N)
Longitude (°E)
74.955
74.95
74.945
74.94
74.935
74.93
74.925
74.92
74.915
74.91
74.905
14.65
14.7
14.75
Tracking Tagboat
Noise PB
Start
Stop
4.1 km


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
Speed (m s-1)
MOBHUS
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

3.4.4 mn11_165def

June 14th 2011, a total of 6 DTAGs deployed between 00:48 (UTC) (tag a) and 14:00 (UTC) (tag f). All tags deployed with cantilever pole in Icefjord Channel, Spitsbergen. Weather; Northwest wind 1 (Beaufort), clear sky, sea state 1. Tag a and b were deployed on the same animal and both tags came off prematurely after 04:48 and 04:56 hrs because of high acceleration swimming. New tagging attempts resulted in four tags deployed on three different animals. Tag c deployed on 2nd animal released after 00:43 hrs due to release failure, and there was also no data on this tag. Tag d and f was deployed on the same animal as tag a and b and stayed on for 17:49 hrs and 13:32 hrs, respectively, until they released. Tag e was deployed on a third animal and came off after 13:01 hrs due to breaching. Thus, we ended up with three tags on two different animals, for most of this record. All tags were recovered, except tag f which was lost because of VHF failure. This tag was found by miracle two days later (still without VHF). The two animals (d(f) and e) were travelling together.

No-sonar control: CPA at 17:45:47 UTC at 100m range, 7s late. Perfect approach!

Sonar 1: CPA at 20:00:59 UTC at 250m range and with perfect timing.

Sonar 2: CPA at 21:08:55 UTC, about 25s late. However, 1 min later (21:09:52 UTC) the animal was still sighted 150 m from the source. CPA must have been very close but difficult to judge since the animal went on a long dive.

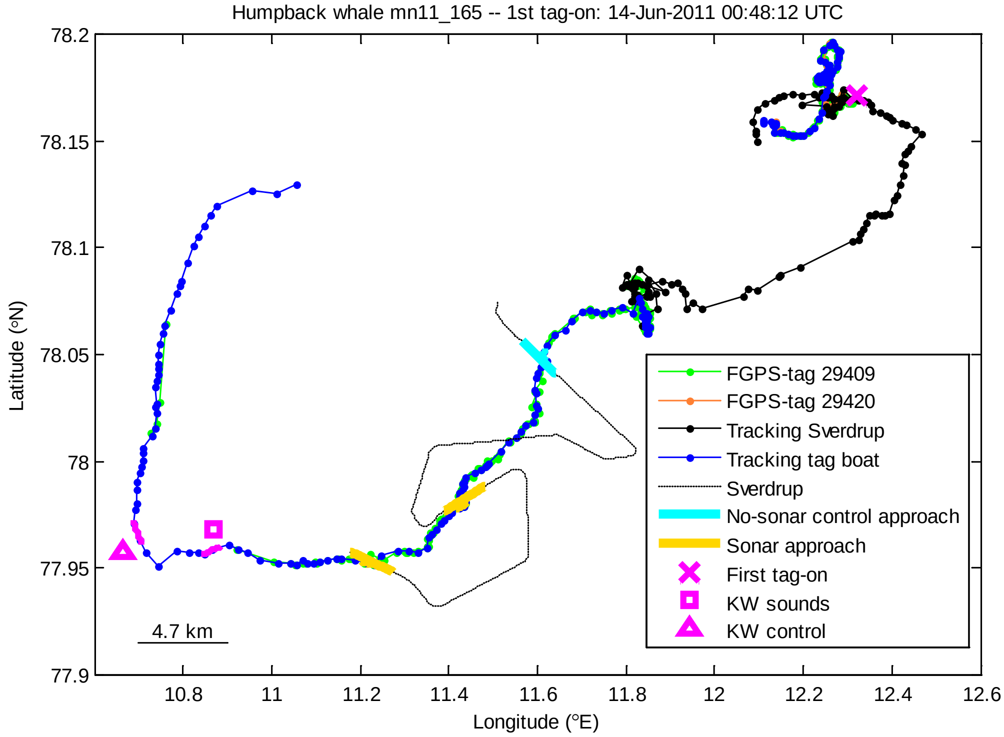
Killer whale playback: started 22:33 UTC

Noise playback: started 23:22 UTC

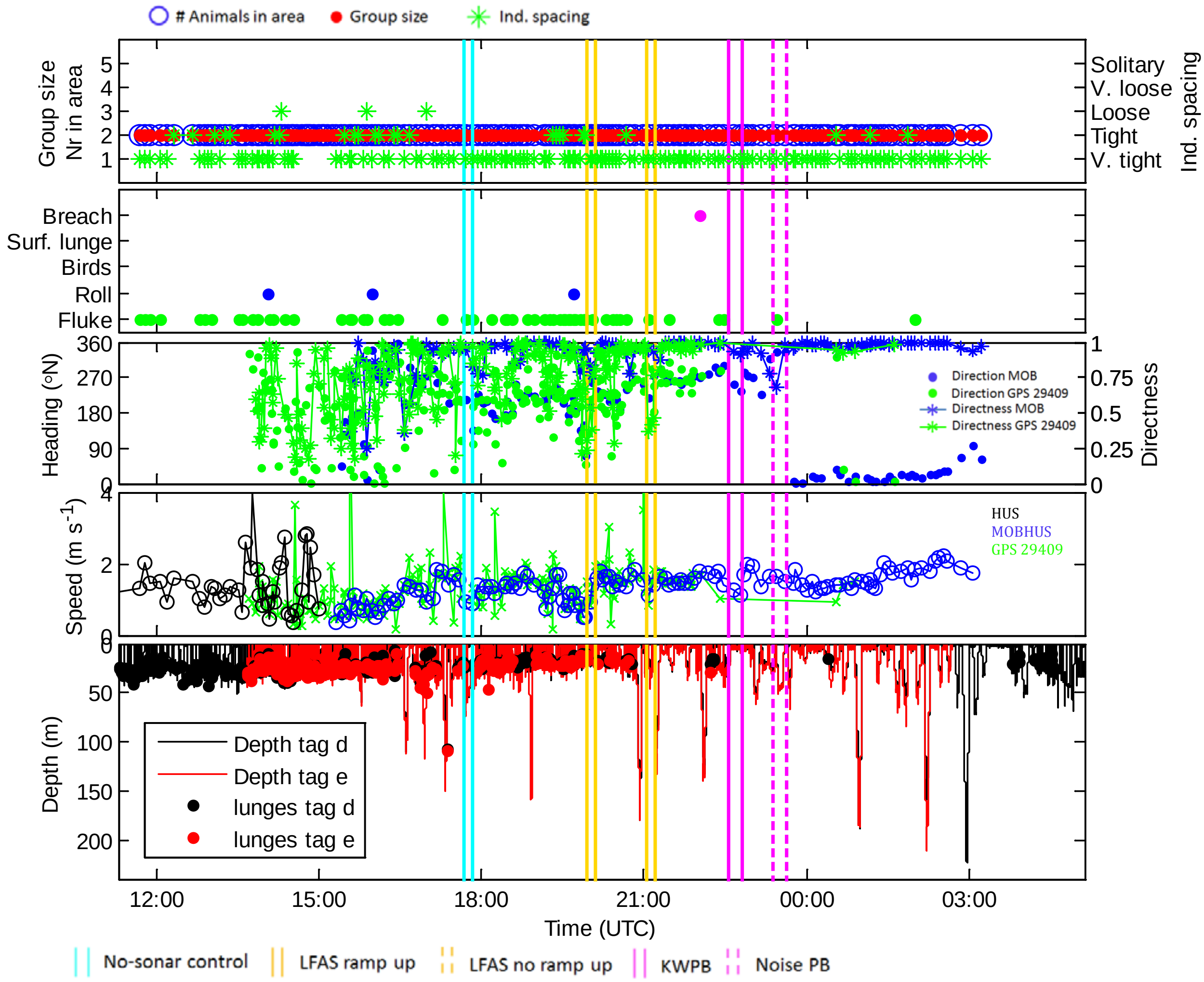
Biopsy: collected from both animals between 02:01-02:43 UTC. Tag e off 02:41 UTC, tag d off 05:07 UTC and finally tag f off 06:32 UTC.

Humpback whale mn11_165e (upper panel, photos by Lars Kleivane) and mn11_165d(f) (lower panel, photos by Lars Kleivane).

FULL RECORD

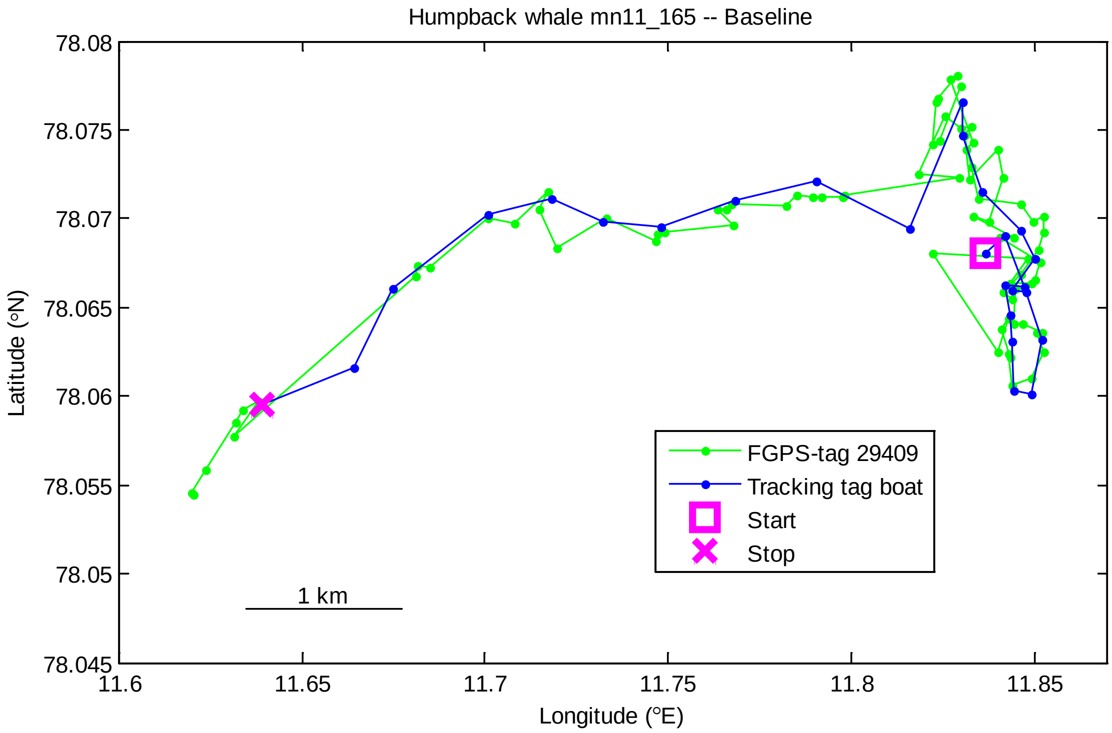


Humpback whale mn11_165 -- 1st tag-on: 14-Jun-2011 00:48:12 UTC
Latitude (°N)
Longitude (°E)
4.7 km
FGPS-tag 29409
FGPS-tag 29420
Tracking Sverdrup
Tracking tag boat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
KW sounds
KW control

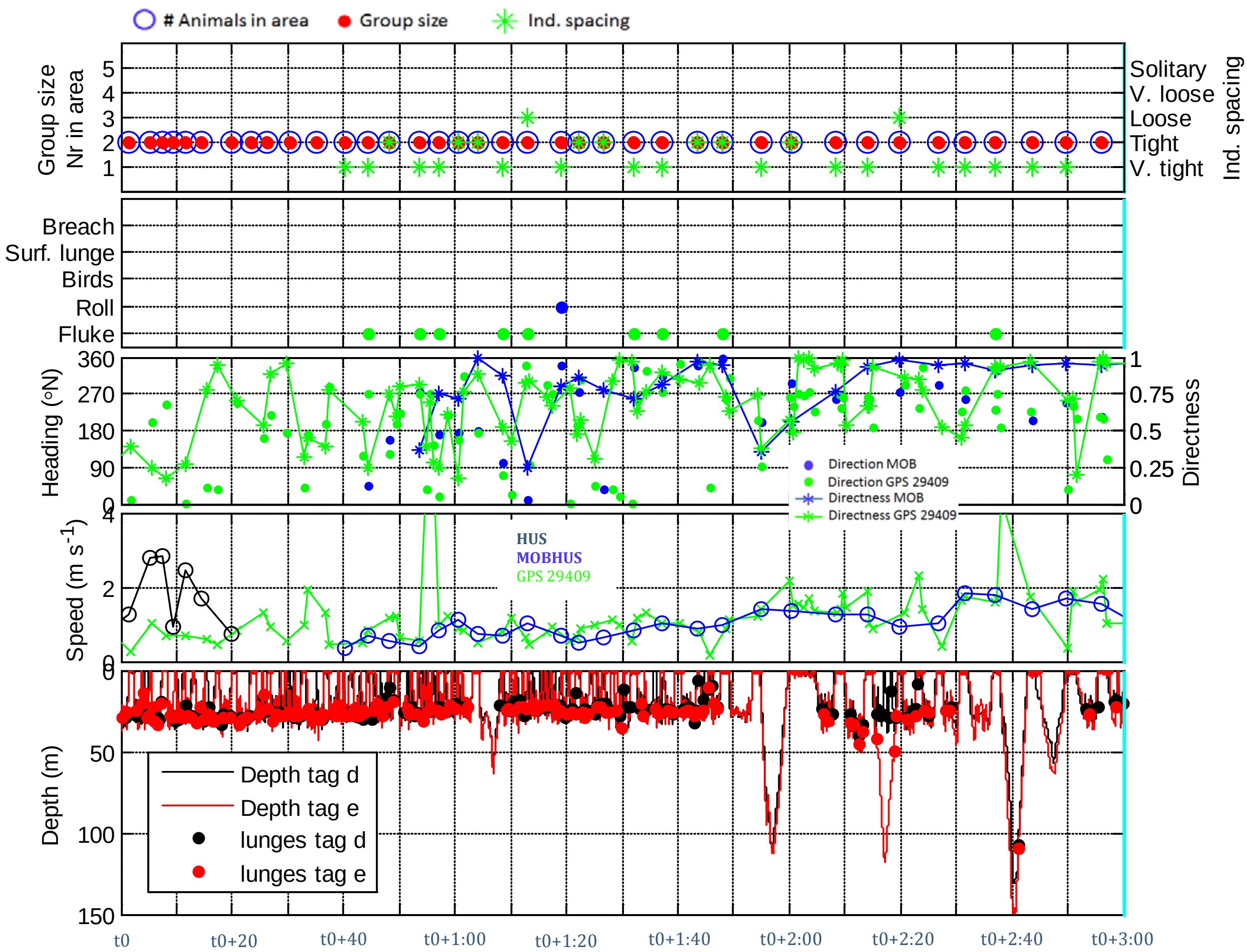


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
HUS
MOBHUS
GPS 29409
Depth (m)
Depth tag d
Depth tag e
lunges tag d
lunges tag e
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

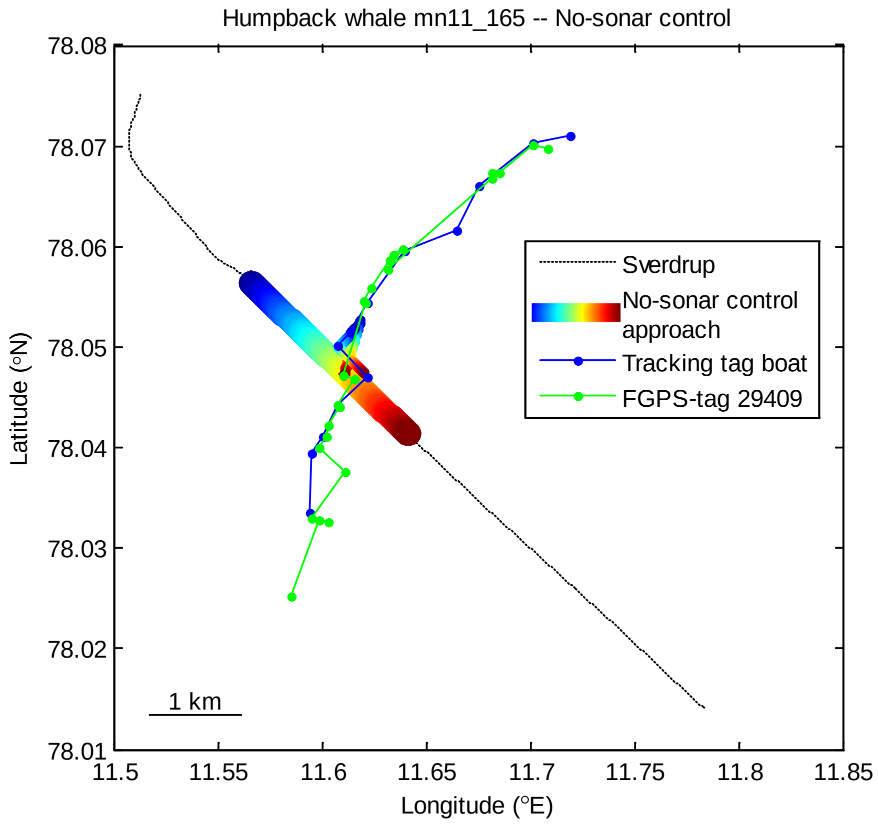
BASELINE

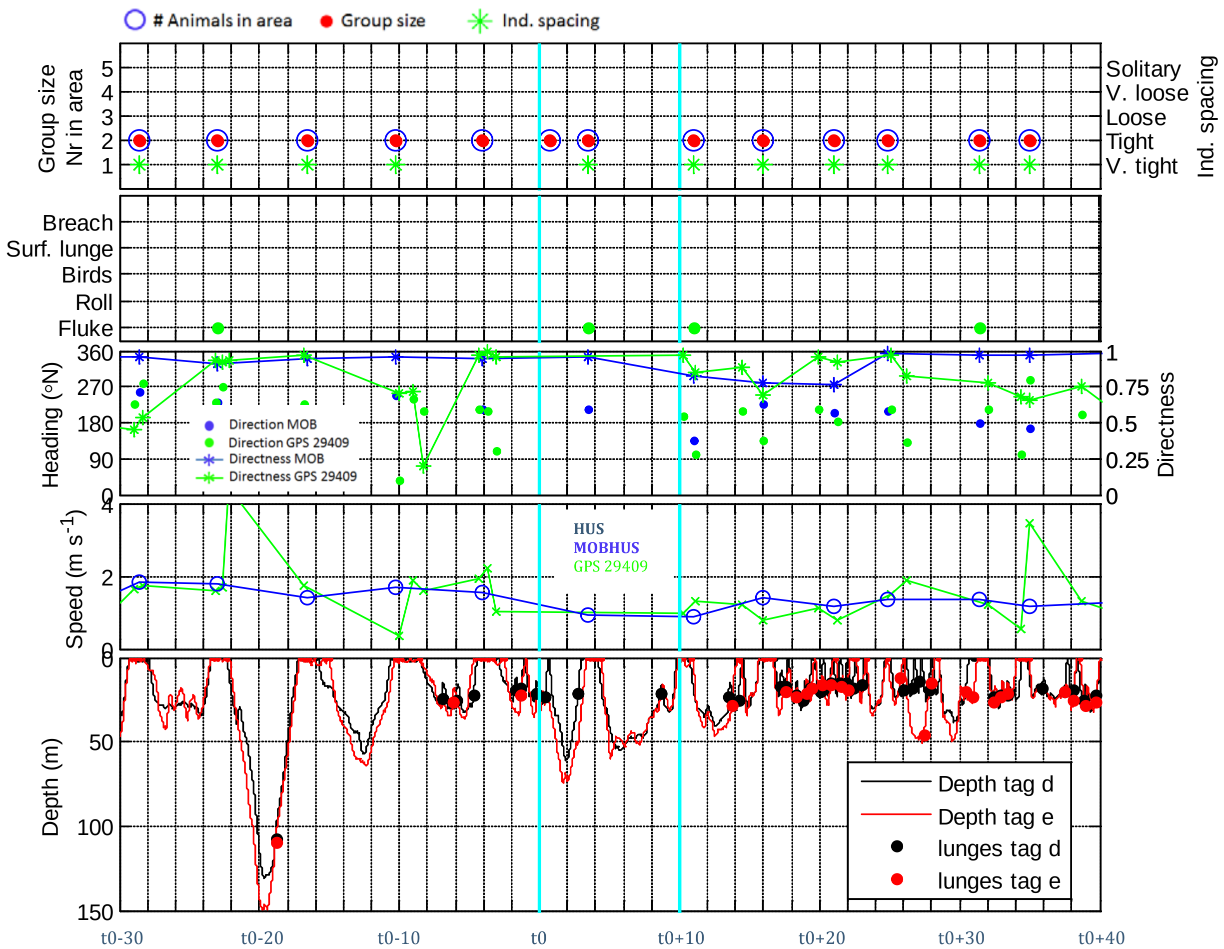


Humpback whale mn11_165 -- Baseline
Latitude (°N)
Longitude (°E)
78.08
78.075
78.07
78.065
78.06
78.055
78.05
78.045
11.6
11.65
11.7
11.75
11.8
11.85
1 km
FGPS-tag 29409
Tracking tag boat
Start
Stop

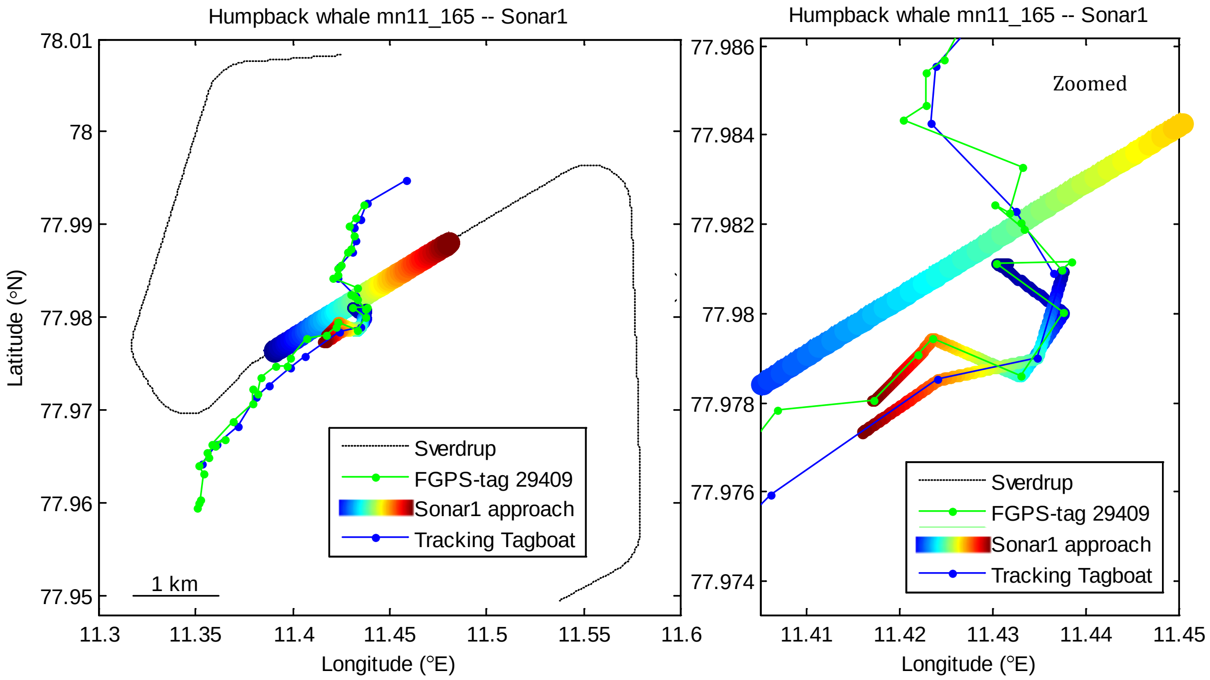


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
HUS
MOBHUS
GPS 29409
Depth (m)
Depth tag d
Depth tag e
lunges tag d
lunges tag e
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

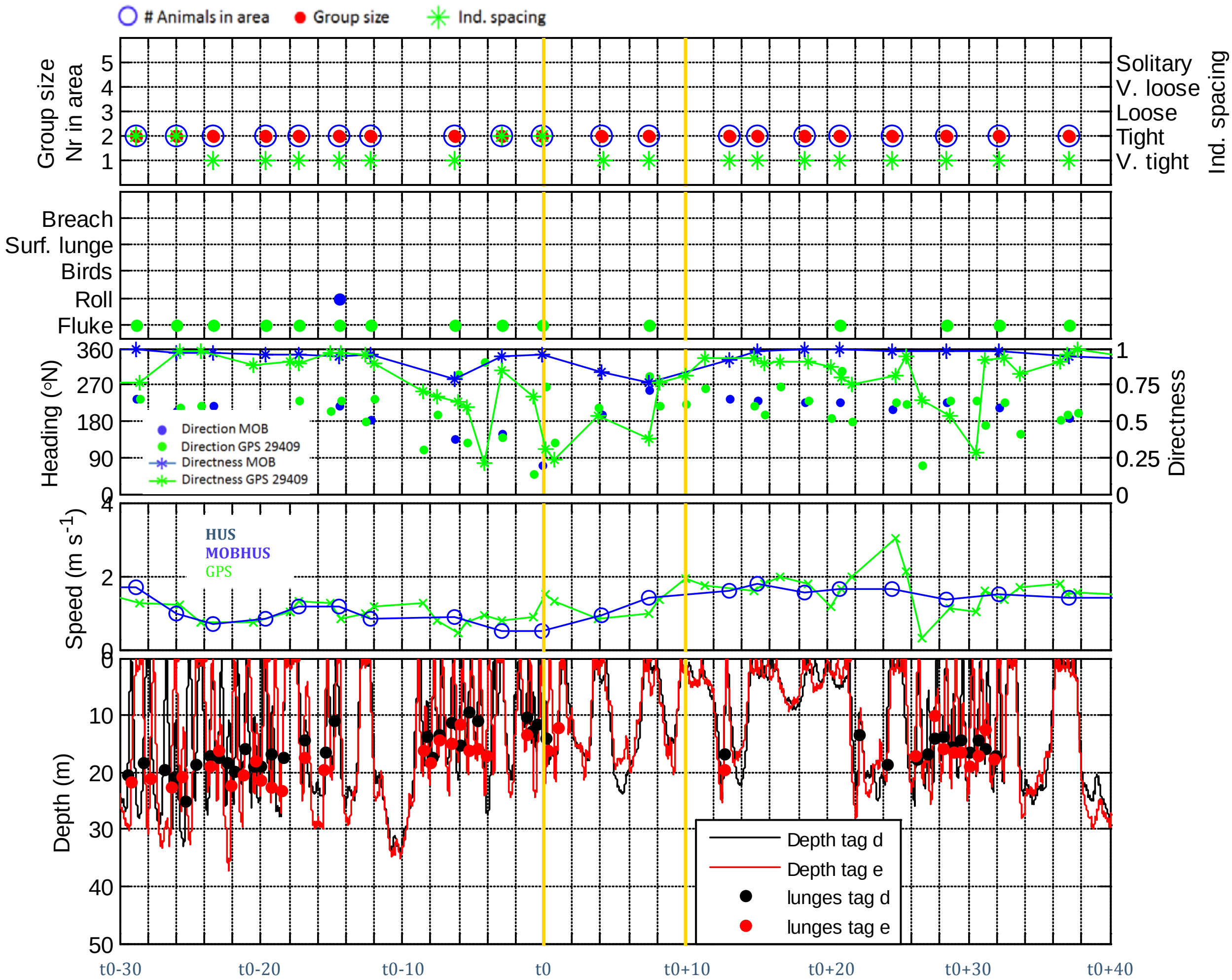

Humpback whale mn11_165 -- No-sonar control
78.08
78.07
78.06
78.05
78.04
78.03
78.02
78.01
Latitude (°N)
11.5
11.55
11.6
11.65
11.7
11.75
11.8
11.85
Longitude (°E)
1 km
Sverdrup
No-sonar control approach
Tracking tag boat
FGPS-tag 29409


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Directness
Speed (m s-1)
HUS
MOBHUS
GPS 29409
Depth (m)
Depth tag d
Depth tag e
lunges tag d
lunges tag e
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 1

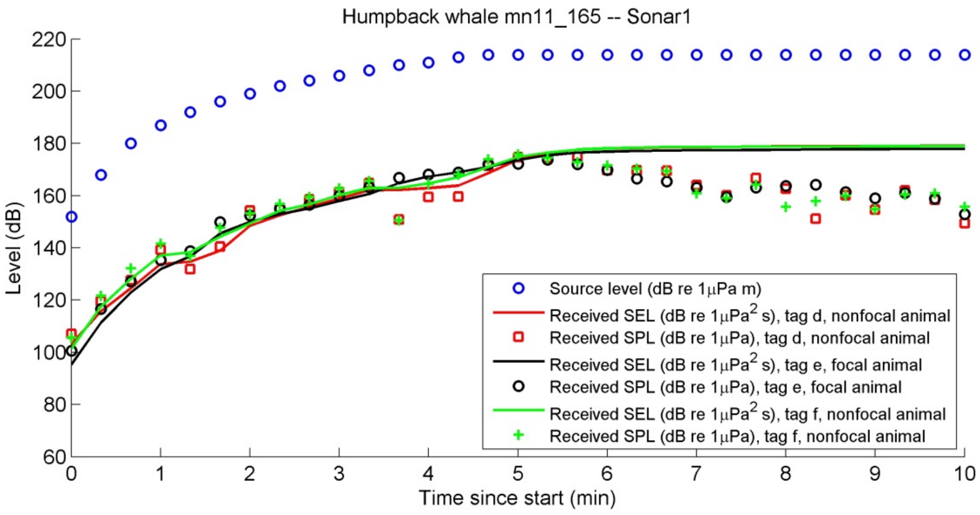


Humpback whale mn11_165 -- Sonar1
Latitude (°N)
Longitude (°E)
1 km
Sverdrup
FGPS-tag 29409
Sonar1 approach
Tracking Tagboat
Zoomed

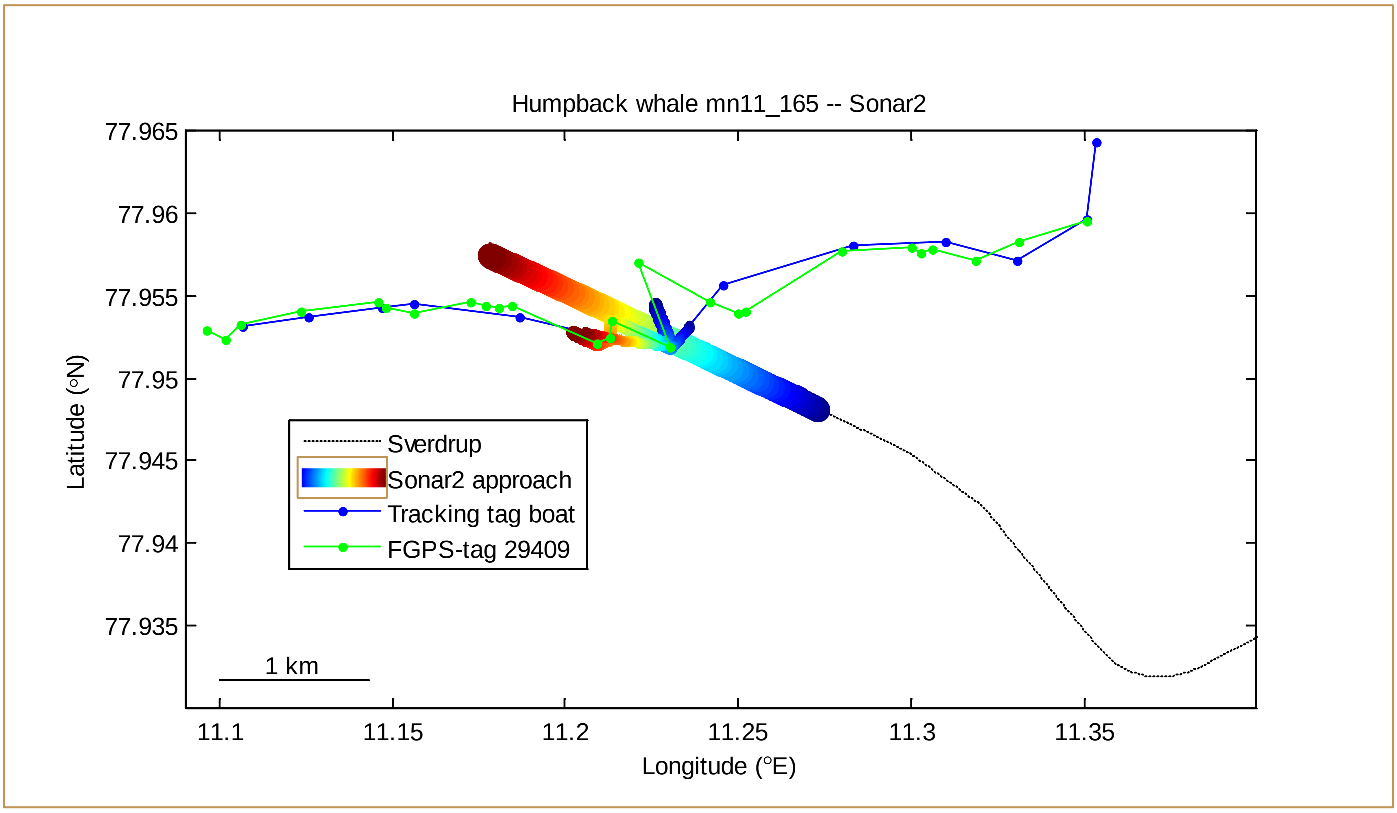


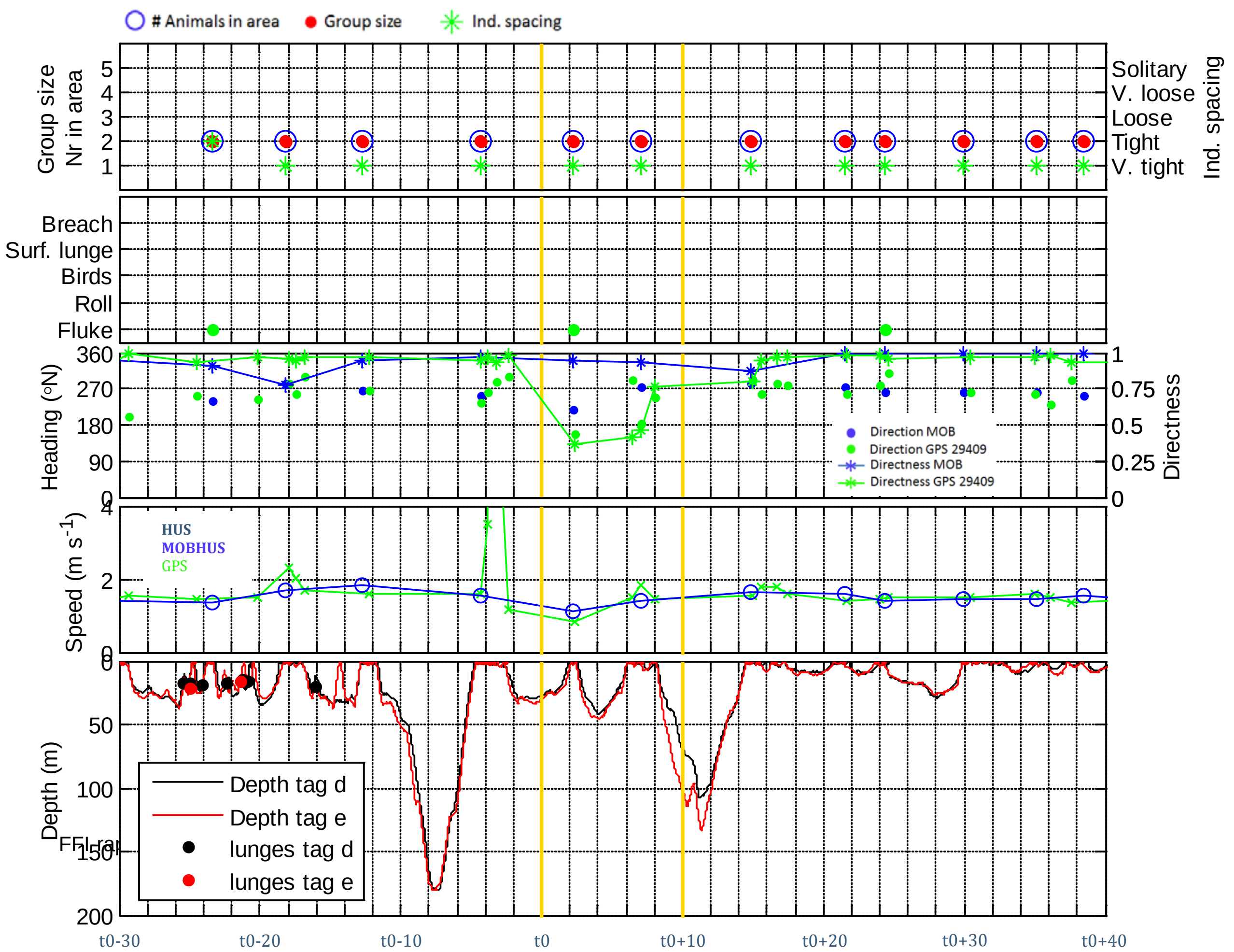
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
HUS
MOBHUS
GPS
Depth (m)
Depth tag d
Depth tag e
lunges tag d
lunges tag e
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 1 – Received level

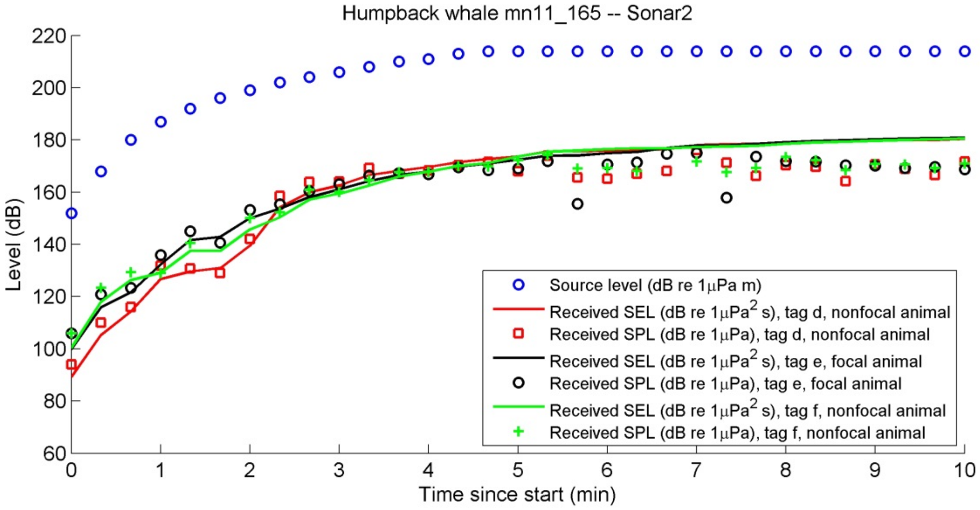


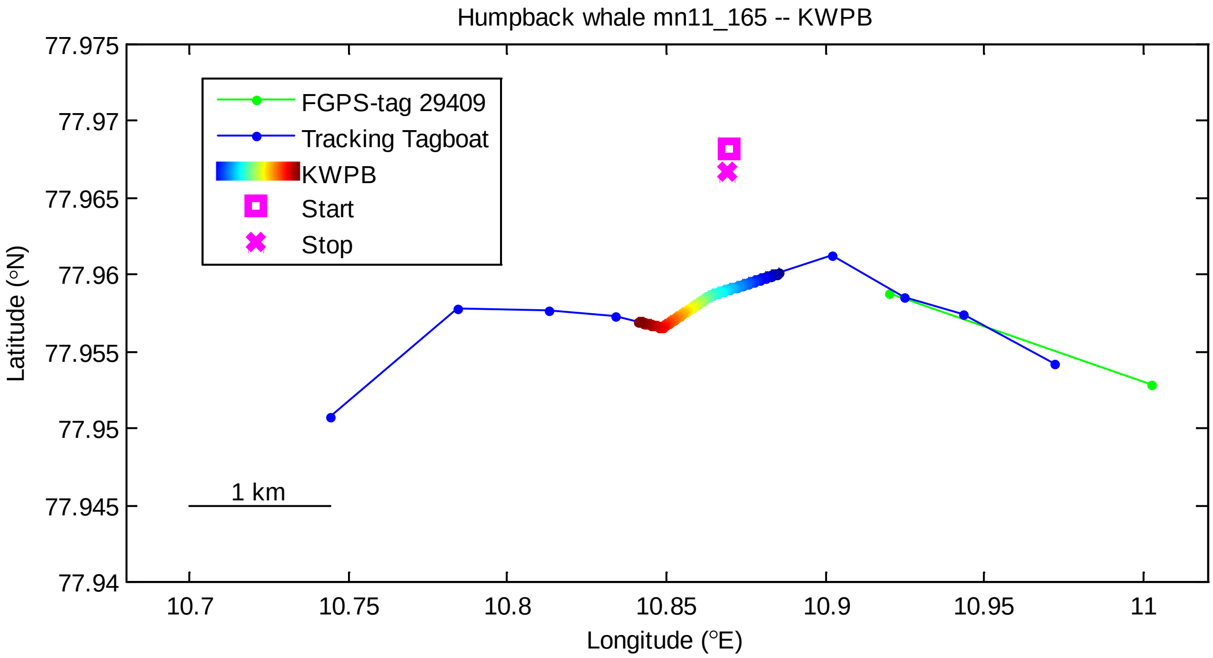
SONAR 2

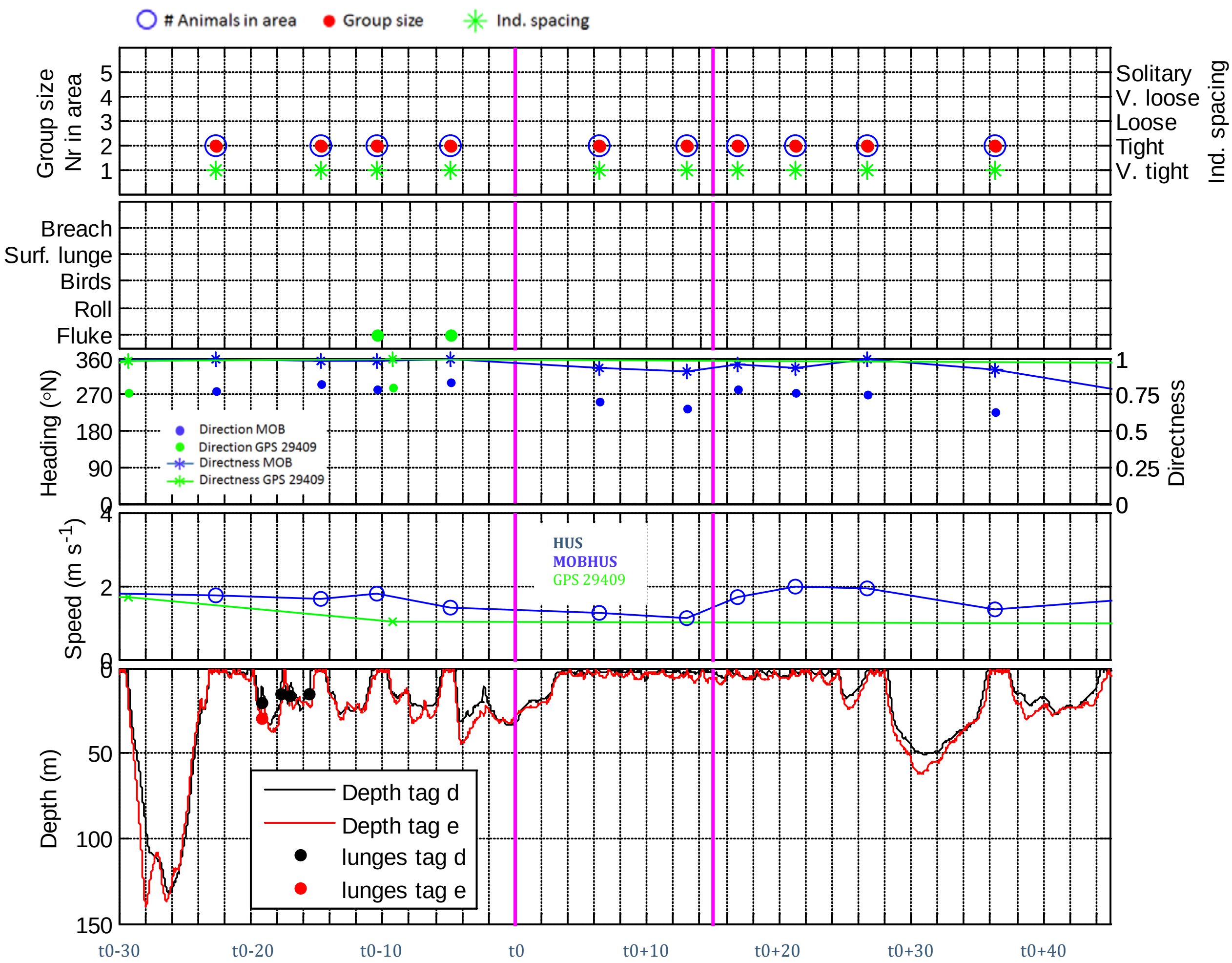

Humpback whale mn11_165 -- Sonar2
Latitude (°N)
Longitude (°E)
Sverdrup
Sonar2 approach
Tracking tag boat
FGPS-tag 29409
1 km

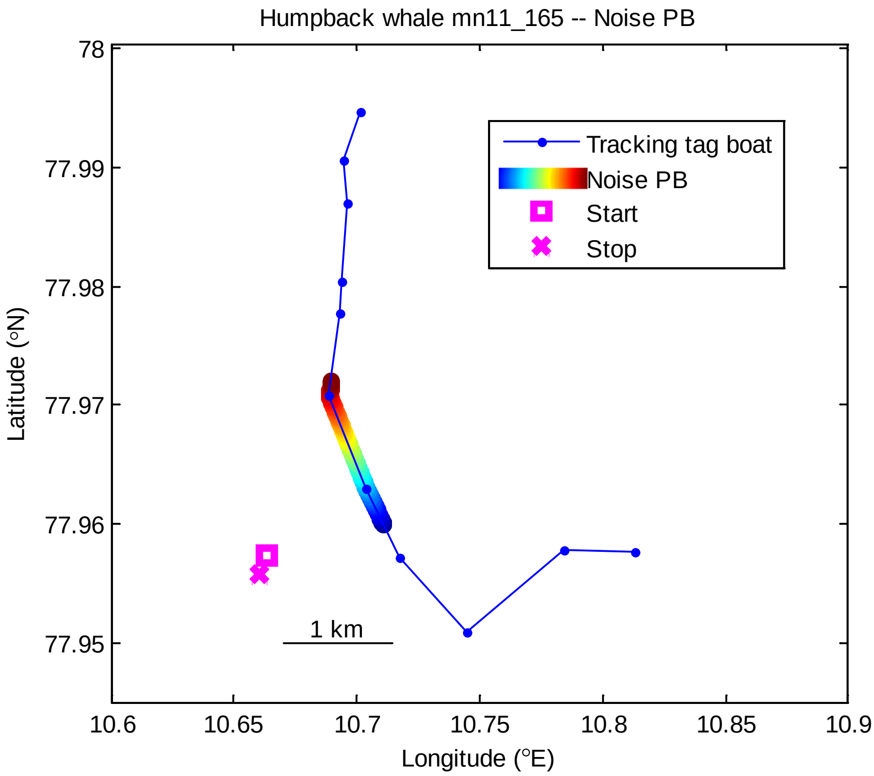

Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
HUS
MOBHUS
GPS
Depth (m)
Depth tag d
Depth tag e
lunges tag d
lunges tag e
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

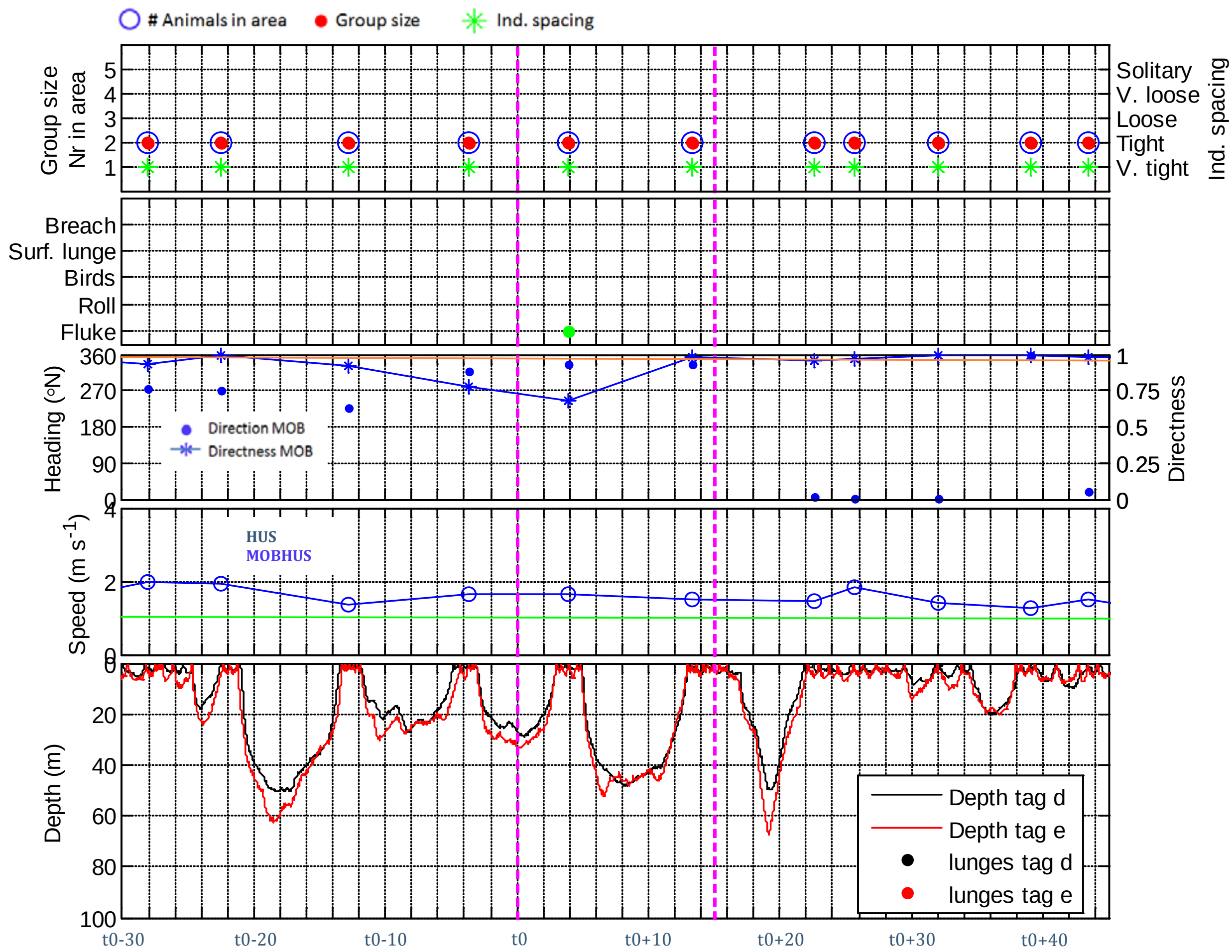
SONAR 1 – Received level




Humpback whale mn11_165 -- KWPB
FGPS-tag 29409
Tracking Tagboat
KWPB
Start
Stop
1 km
Latitude (°N)
Longitude (°E)
77.975
77.97
77.965
77.96
77.955
77.95
77.945
77.94
10.7
10.75
10.8
10.85
10.9
10.95
11


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Directness
Speed (m s-1)
HUS
MOBHUS
GPS 29409
Depth (m)
Depth tag d
Depth tag e
lunges tag d
lunges tag e
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40


Humpback whale mn11_165 -- Noise PB
Tracking tag boat
Noise PB
Start
Stop
1 km
Latitude (°N)
Longitude (°E)
78
77.99
77.98
77.97
77.96
77.95
10.6
10.65
10.7
10.75
10.8
10.85
10.9


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
Speed (m s-1)
HUS
MOBHUS
Depth (m)
Depth tag d
Depth tag e
lunges tag d
lunges tag e
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

3.4.5 mn12_161ab

June 9th 2012, two DTAGs deployed with the ARTS on the same animal on the Bellsund Bank west of Spitsbergen (1st tag on 13:47 UTC). Southeast wind 2 (Beaufort), clear sky, sea state 1. Second tag came off after just 15 min. First tag stayed on until it released after 14 hrs (tag was triggered 3 h before actually deployed). GPS-logger gave only a few fixes due to errors in settings, and most fixes recorded were before the tag was deployed on the whale. Several other humpbacks and fin whales sighted in the area.

No-sonar control: started at 22:44:00. 38 kHz echosounder on UHS was accidentally left on during session. CPA at 50m range, but 77s early.

No-sonar control 2: CPA at 50m range. This session was supposed to be a sonar session, but transmissions were cancelled because of error in the CPA calculator.

Sonar 1: Transmission started 00:59:00U TC. CPA at 300m range. The tagged animal was sighted from HUS traveling in parallel at 400 m distance.

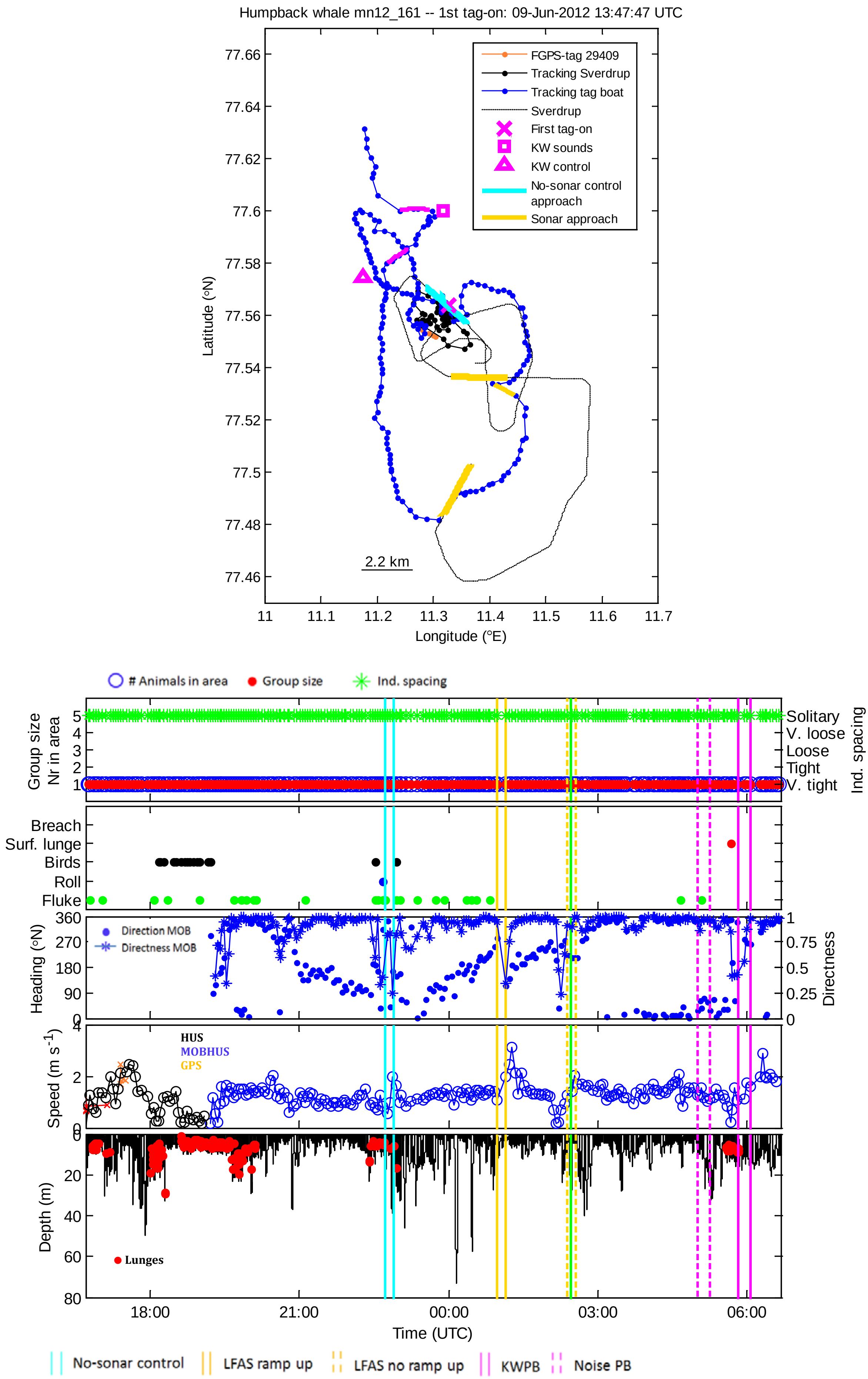
Sonar 2: No-ramp up session started at 02:23:00 UTC. 02:26:10 UTC CPA at 0m range, but 2 min early. Full power transmission started 02:28:00 UTC. CPA was very close (0m), but early. The source passed the animal by 200-300m before transmission started.

Playback: Killer whale playback and noise playback conducted

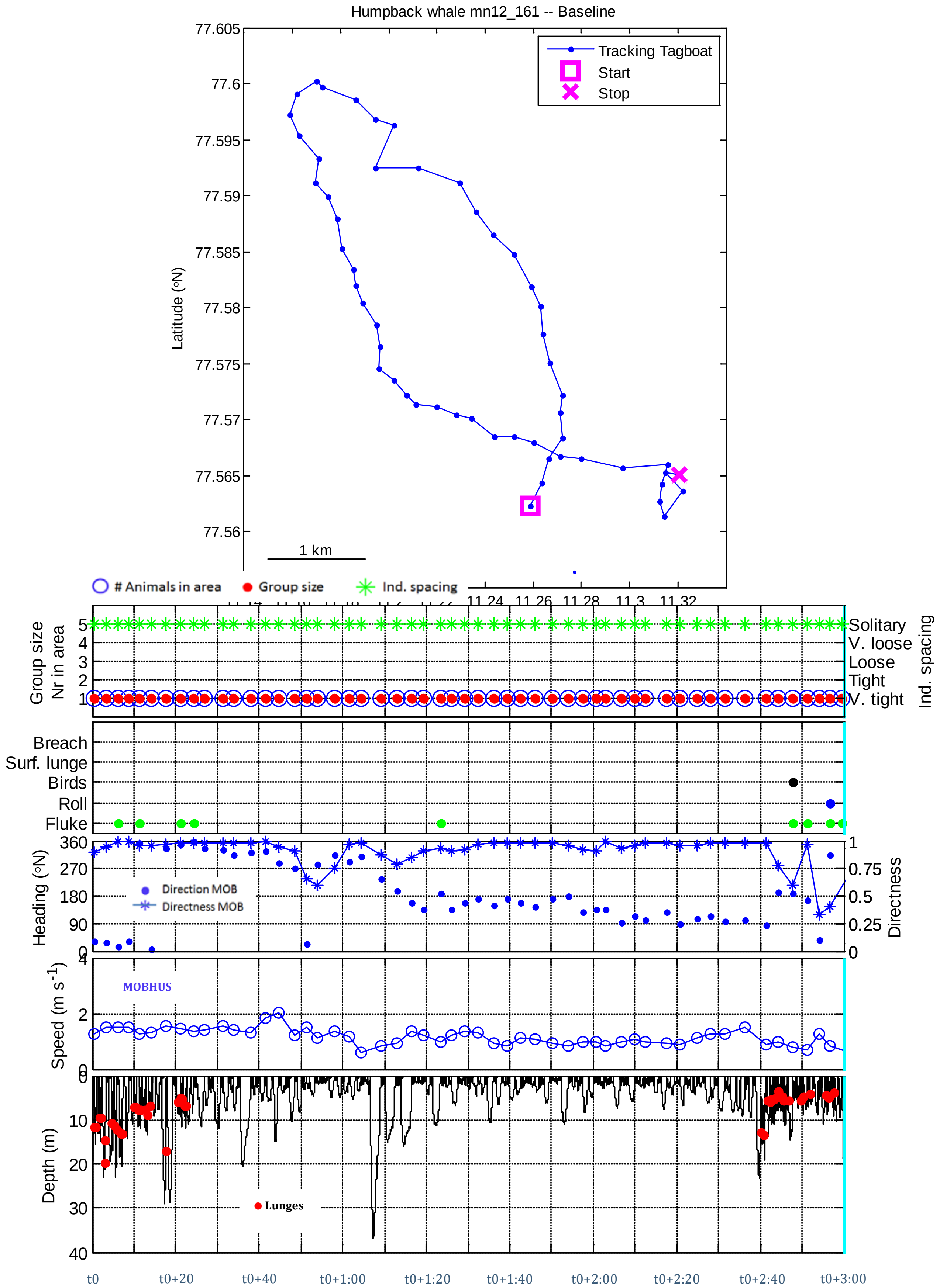
Biopsy collected 40min after tag off.

Humpback whale mn12_161 (photos by Paul Ensor).

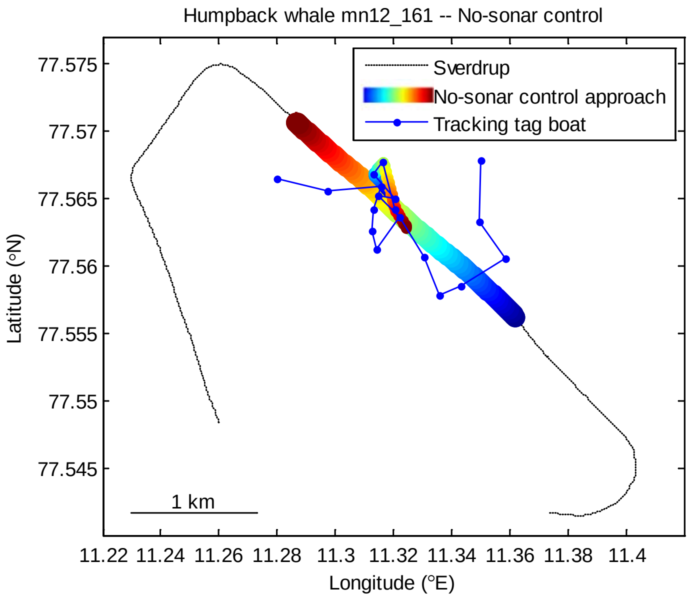
FULL RECORD

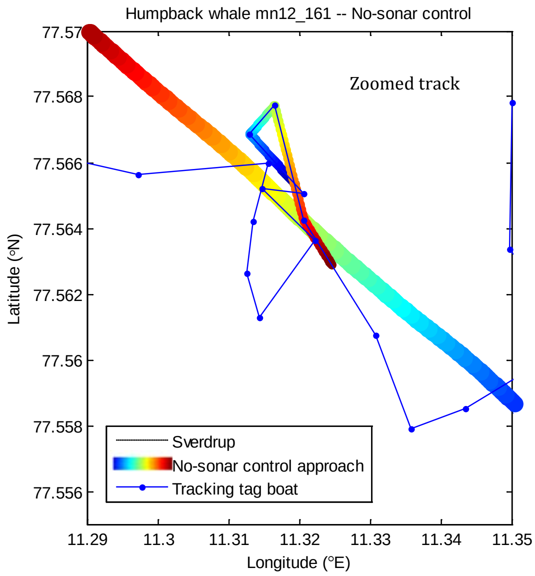


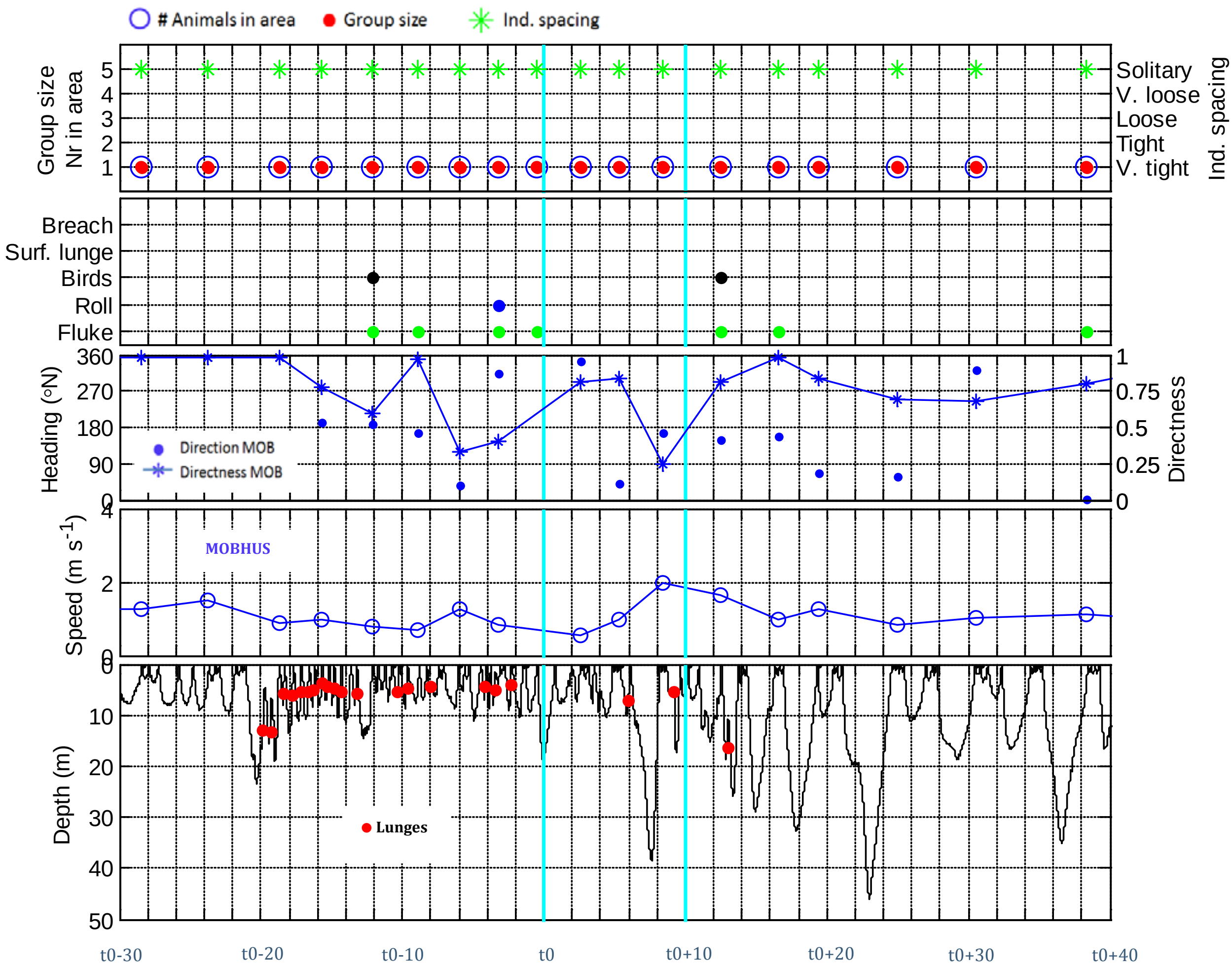
Humpback whale mn12_161 -- 1st tag-on: 09-Jun-2012 13:47:47 UTC
FGPS-tag 29409
Tracking Sverdrup
Tracking tag boat
Sverdrup
First tag-on
KW sounds
KW control
No-sonar control approach
Sonar approach
2.2 km
Latitude (°N)
Longitude (°E)
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Direction MOB
Directness MOB
Heading (°N)
Directness
HUS
MOBHUS
GPS
Speed (m s-1)
Depth (m)
Lunges
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB


Humpback whale mn12_161 -- Baseline
Tracking Tagboat
Start
Stop
Latitude (°N)
77.605
77.6
77.595
77.59
77.585
77.58
77.575
77.57
77.565
77.56
1 km
11.24
11.26
11.28
11.3
11.32
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
MOBHUS
Speed (m s-1)
Depth (m)
Lunges
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

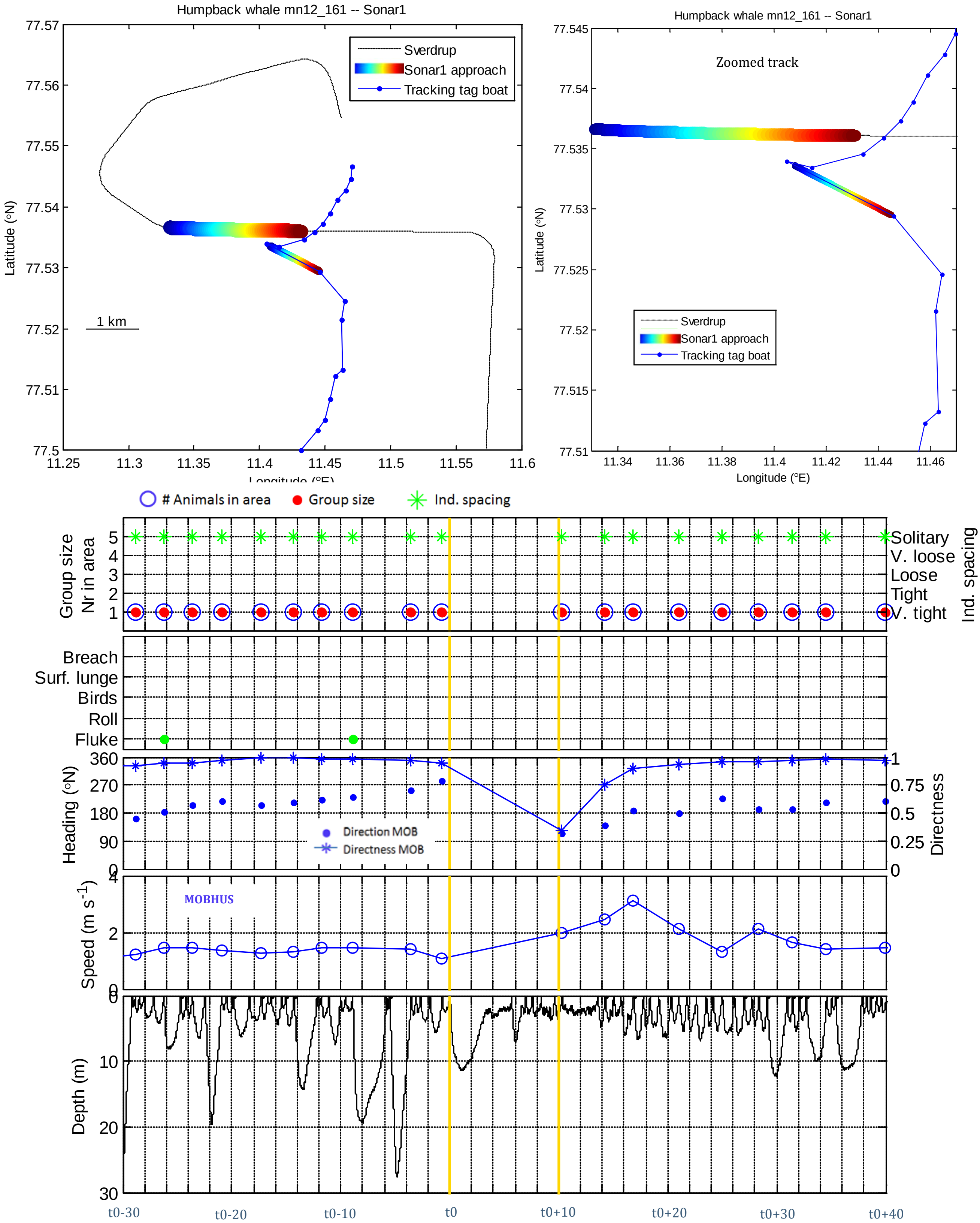
NO-SONAR CONTROL





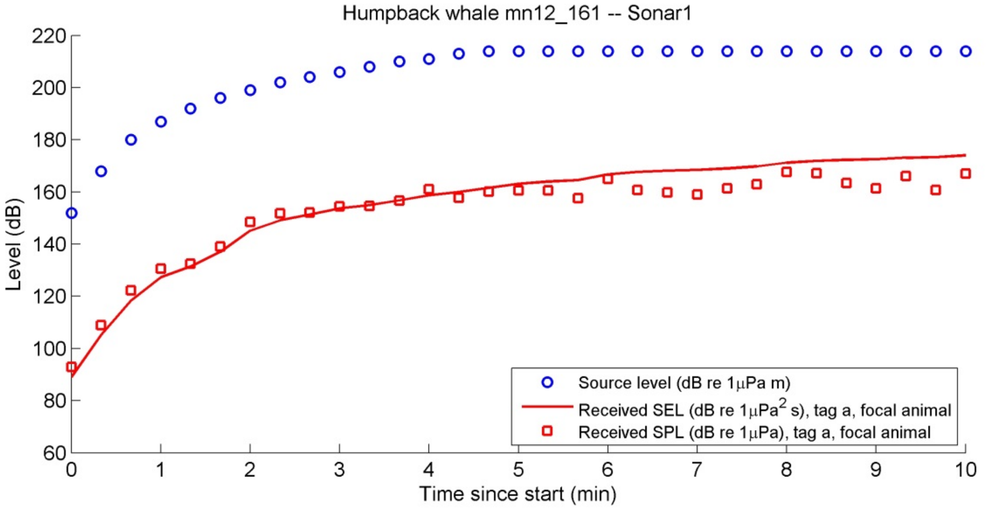


SONAR 1

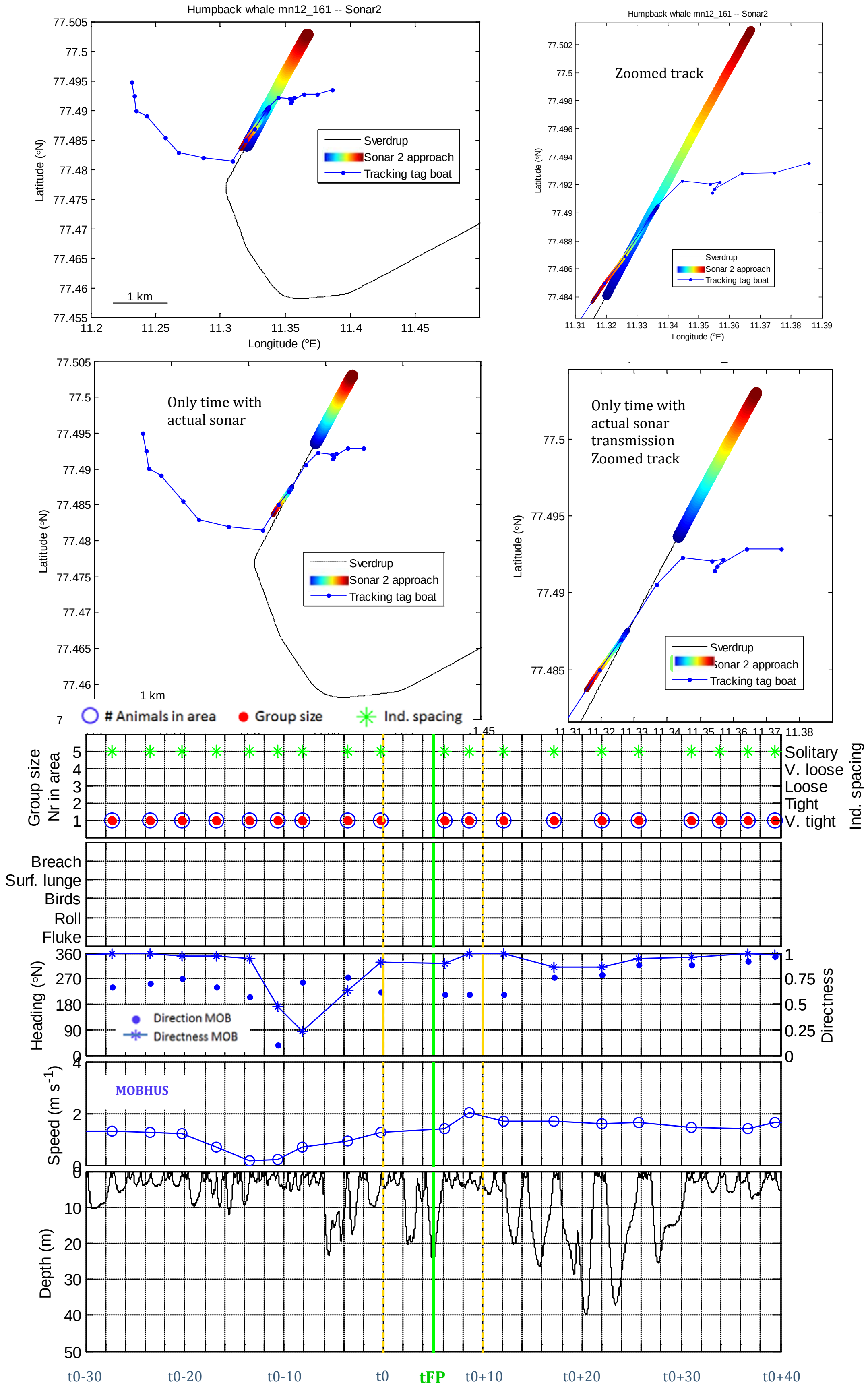


Humpback whale mn12_161 -- Sonar1
Sverdrup
Sonar1 approach
Tracking tag boat
1 km
Latitude (°N)
Longitude (°E)
Humpback whale mn12_161 -- Sonar1
Zoomed track
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Directness MOB
MOBHUS
Speed (m s-1)
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 1 – Received level

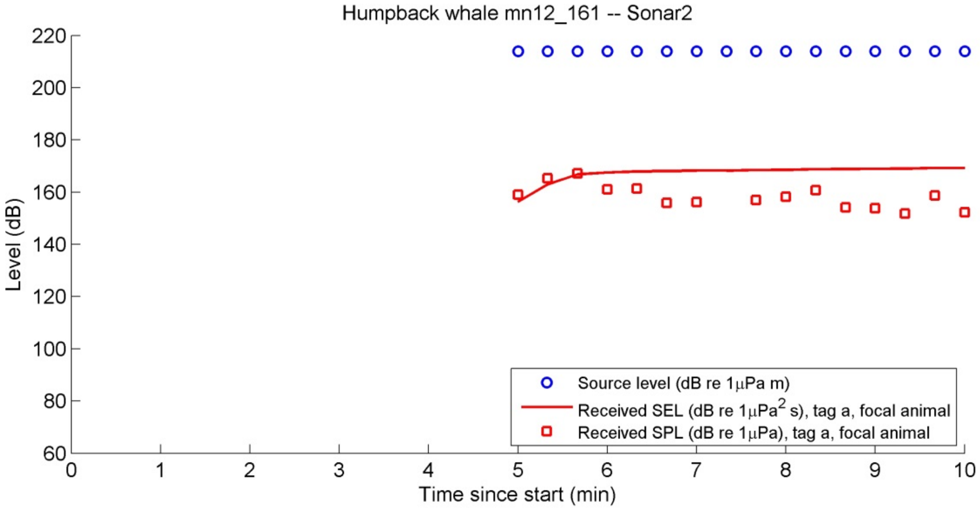


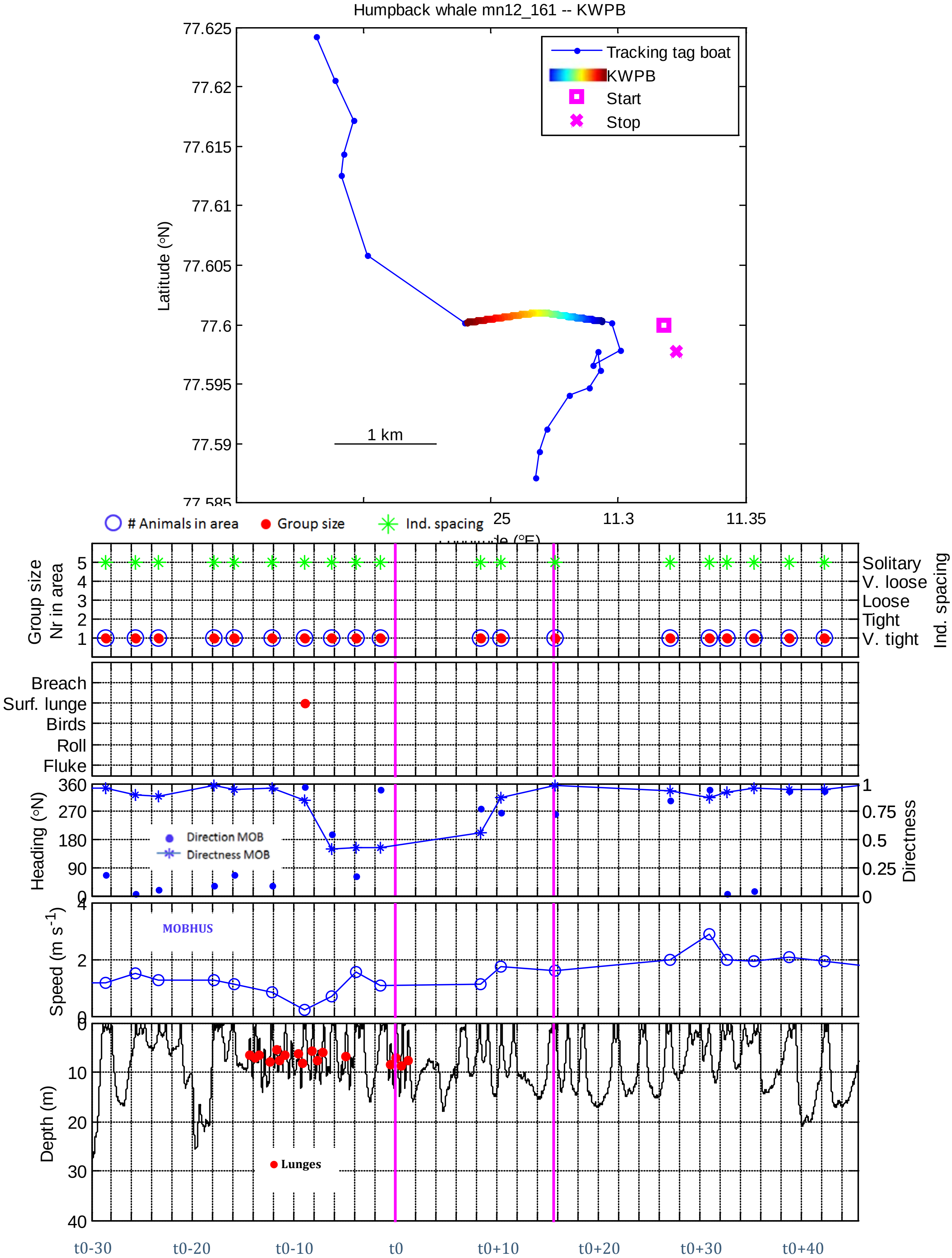
SONAR 2



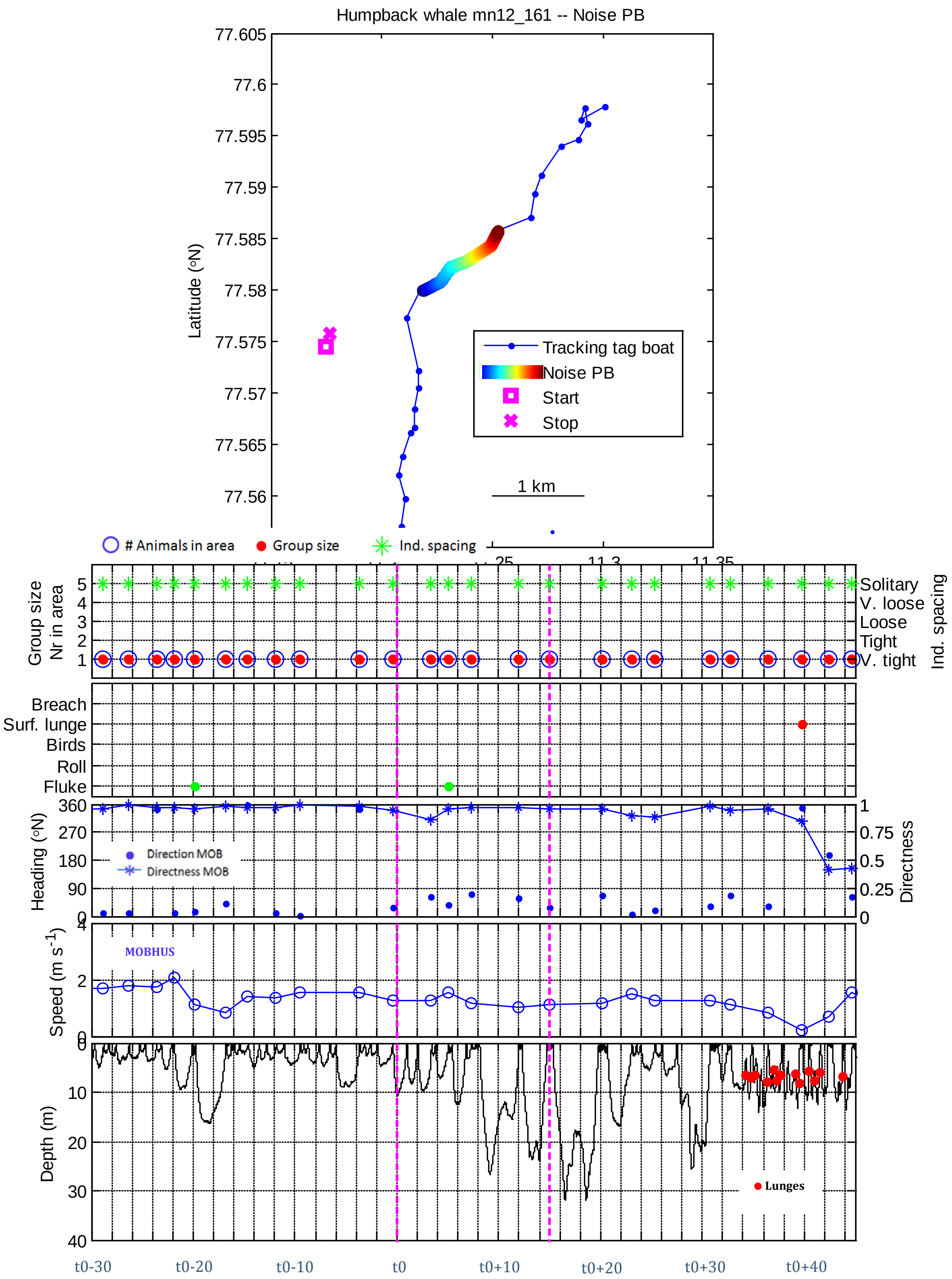
Humpback whale mn12_161 -- Sonar2
Latitude (°N)
Longitude (°E)
1 km
Sverdrup
Sonar 2 approach
Tracking tag boat
Zoomed track
Only time with actual sonar
Only time with actual sonar transmission Zoomed track
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
MOBHUS
Speed (m s-1)
Depth (m)
t0-30
t0-20
t0-10
t0
tFP
t0+10
t0+20
t0+30
t0+40

SONAR 2 – Received level





Humpback whale mn12_161 -- KWPB
Tracking tag boat
KWPB
Start
Stop
1 km
Latitude (°N)
77.625
77.62
77.615
77.61
77.605
77.6
77.595
77.59
11.3
11.35
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
Speed (m s-1)
MOBHUS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40



Humpback whale mn12_161 -- Noise PB
Latitude (°N)
Tracking tag boat
Noise PB
Start
Stop
1 km
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Directness MOB
Directness
MOBHUS
Speed (m s-1)
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

3.4.6 mn12_164ab

June 12th on Icefjord Banks west of Spitsbergen. Eastern wind 2 (Beaufort), changing cloud cover, sea state 2. Good placement of tag at 17:17 UTC. Tag falls off after 9 hrs 17 min, the same tag redeployed on associated animal after 2hrs. Tag off again after 8 hrs 37 min.

No-sonar control: started 22:28:00 UTC. Good approach estimated CPA at 75m.

Sonar 1: Good approach, estimated CPA at 50m. Three humpbacks in focal group. Two very close together, the third further away. Animals seen under water close to the source ship during approach. Seemed to orient themselves towards HUS and passed calmly 150 m behind the ship. No other animals close during the approach

Decided to delay next approach by 15 min because of potential prolonged behavioral response.

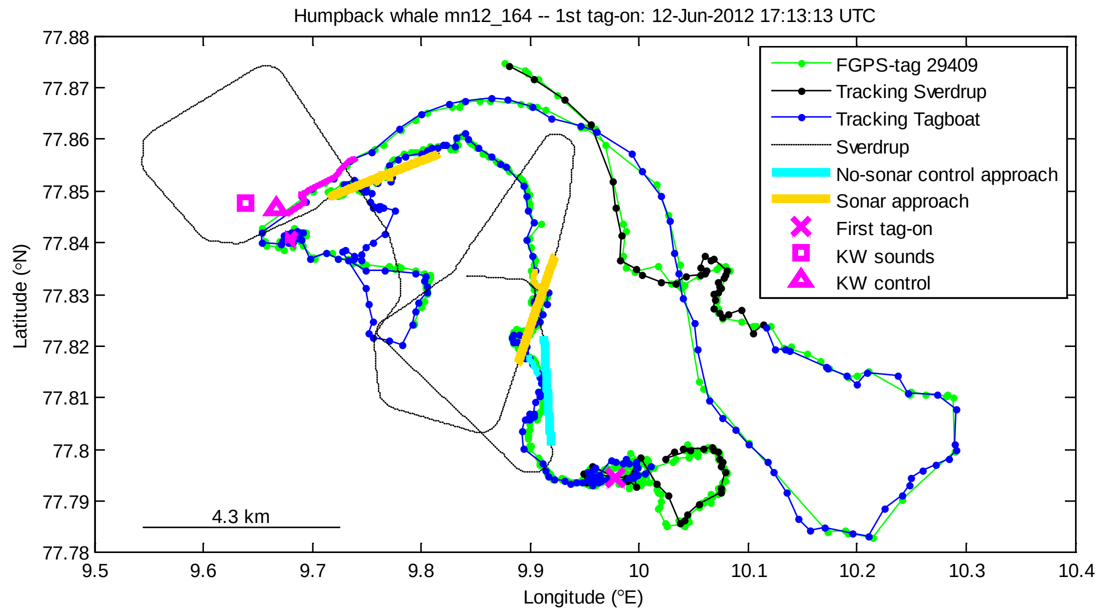
Sonar 2: No Ramp Up control session. Two animals still travelling close together. Sighted off the bow of the source ship diving under the ship during approach. Full power transmission started at 01:43:00 UTC. Animal surfaced behind the ship at CPA estimated to 0m (01:44:04 UTC). Since vertical separation (65m) kept them out of the mitigation zone we continued transmission. A minke whale was also sighted 500m from the ship 10 min before transmission. Not seen again.

02:32 UTC tag off! Redeployed within 1 hr, but off again after 15min. 04:31UTC tag deployed again on associated animal.

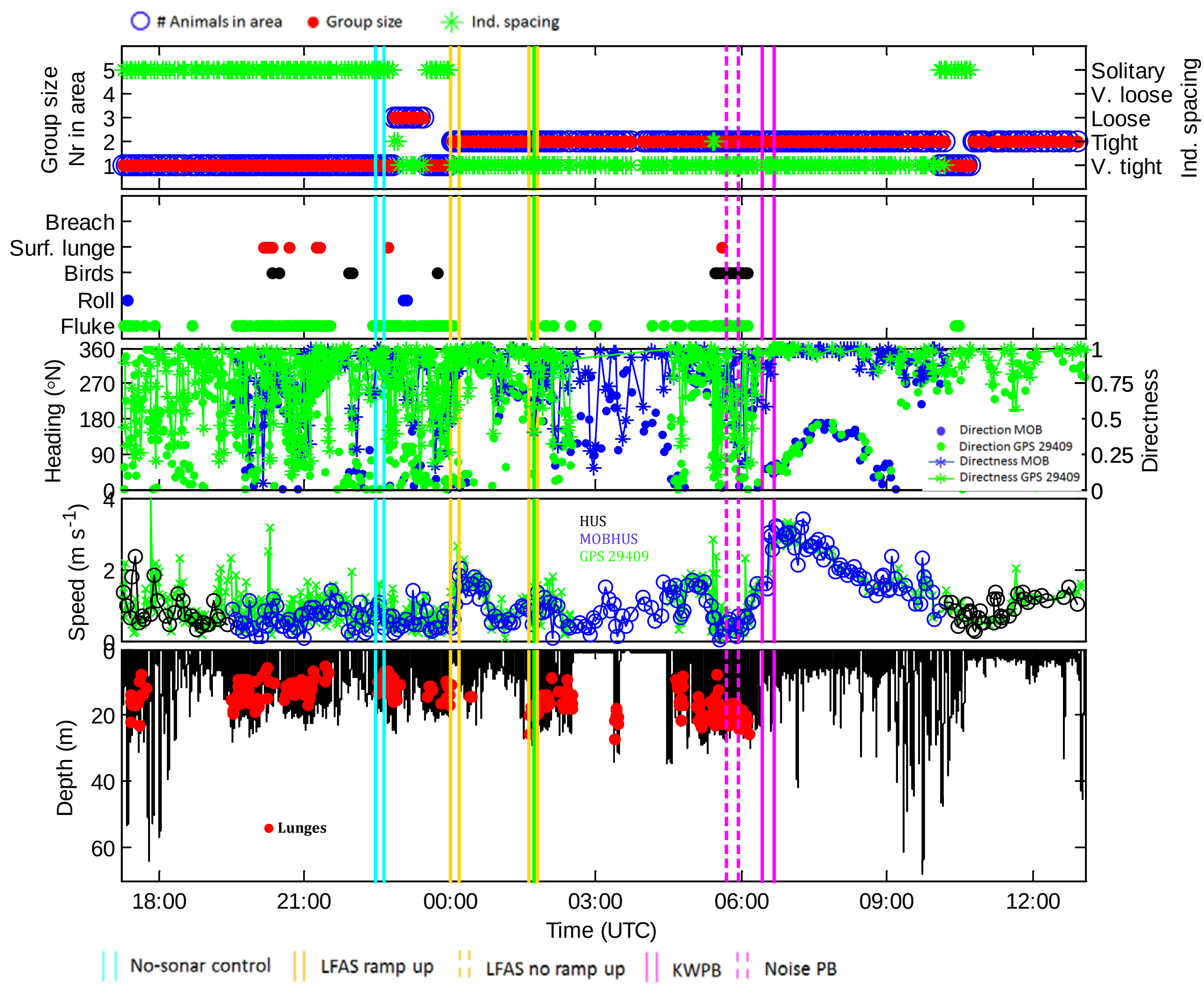
Killer whale playback and control playback completed by 06:40 UTC.

Biopsy collected from both animals with the tag stilled attached (09:12 and 10:59 UTC). MOBHUS recovered and tracking taken over by HUS. Tag recovered by 13:30 UTC.

The two associated humpback whales mn12_164a and b (photos by Paul Ensor).

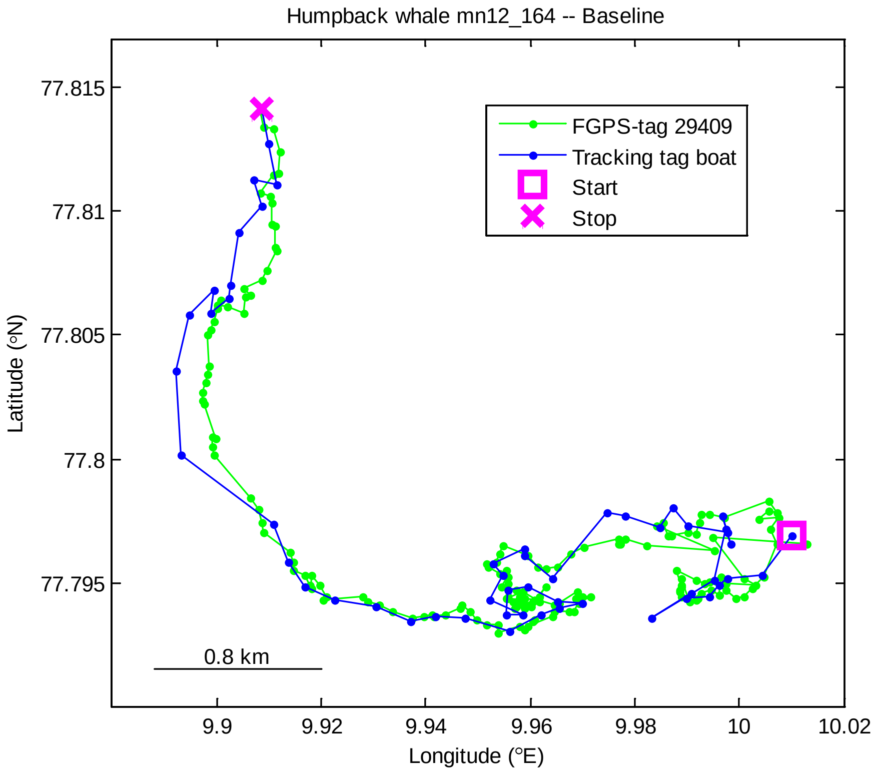


Humpback whale mn12_164 -- 1st tag-on: 12-Jun-2012 17:13:13 UTC
Latitude (°N)
Longitude (°E)
4.3 km
FGPS-tag 29409
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
KW sounds
KW control

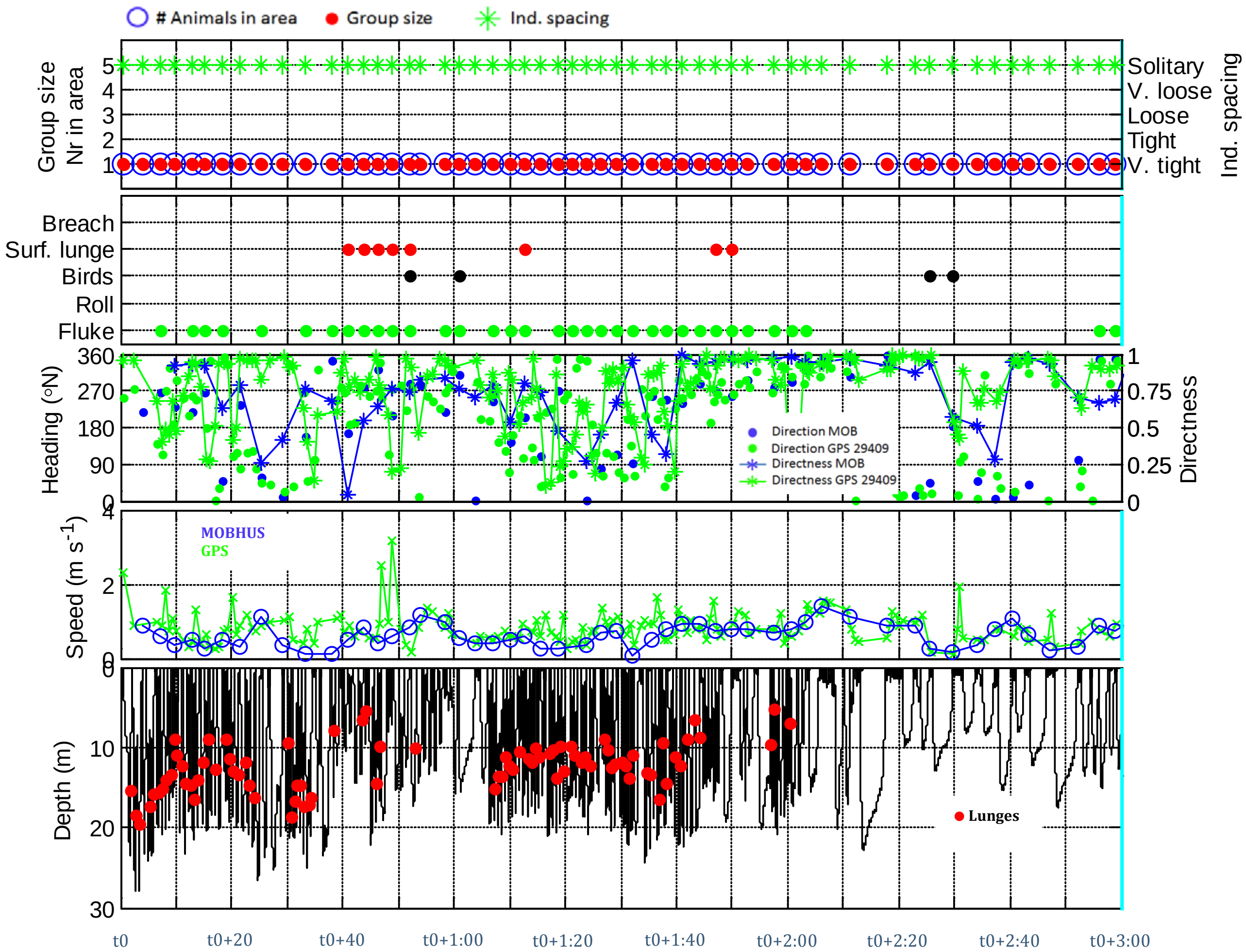


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
HUS
MOBHUS
GPS 29409
Depth (m)
Lunges
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

BASELINE

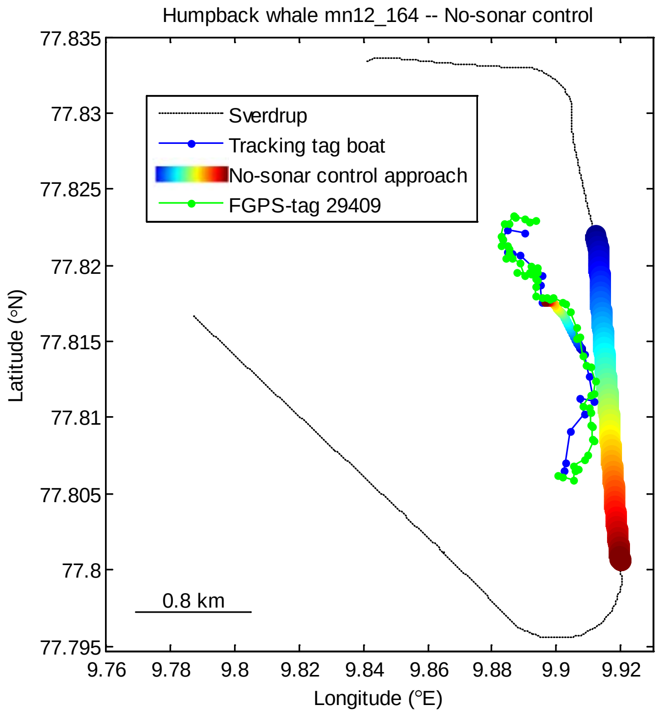


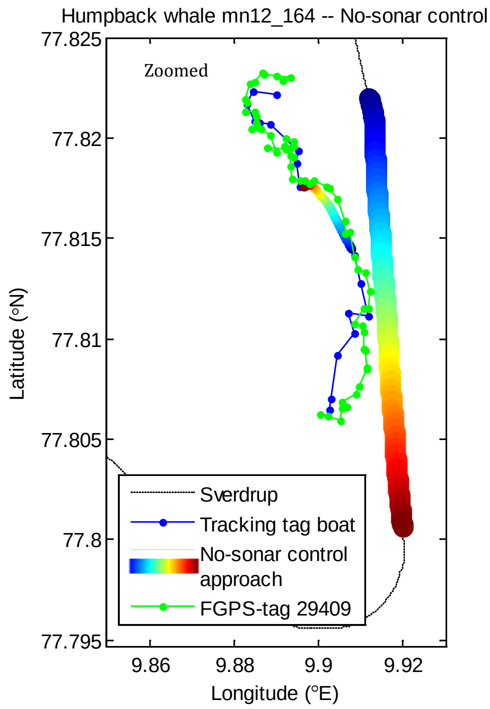
Humpback whale mn12_164 -- Baseline
FGPS-tag 29409
Tracking tag boat
Start
Stop
Latitude (°N)
77.815
77.81
77.805
77.8
77.795
0.8 km
9.9
9.92
9.94
9.96
9.98
10
10.02
Longitude (°E)

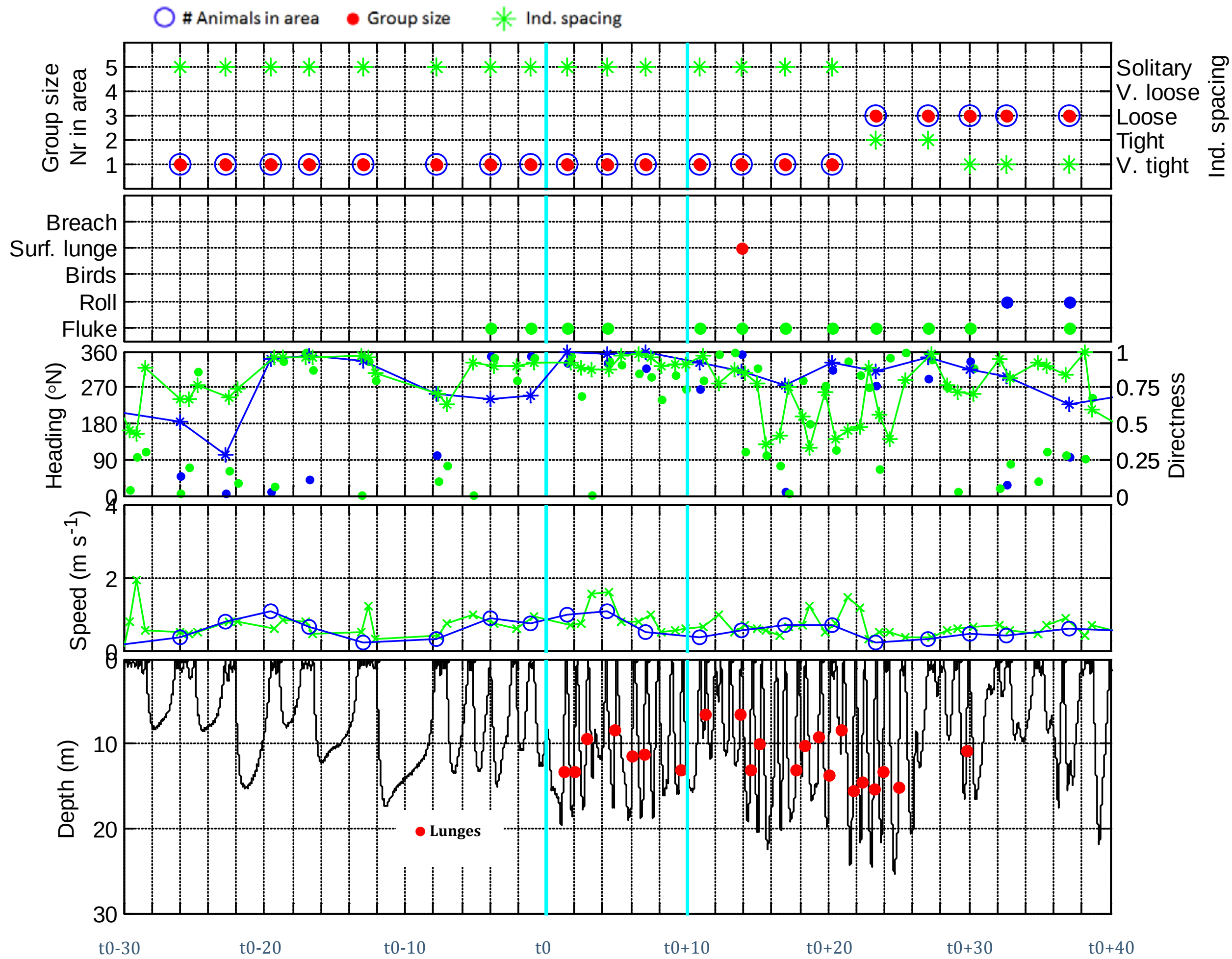


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
360
270
180
90
0
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
1
0.75
0.5
0.25
0
Directness
Speed (m s-1)
4
2
0
MOBHUS
GPS
Depth (m)
0
10
20
30
Lunges
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

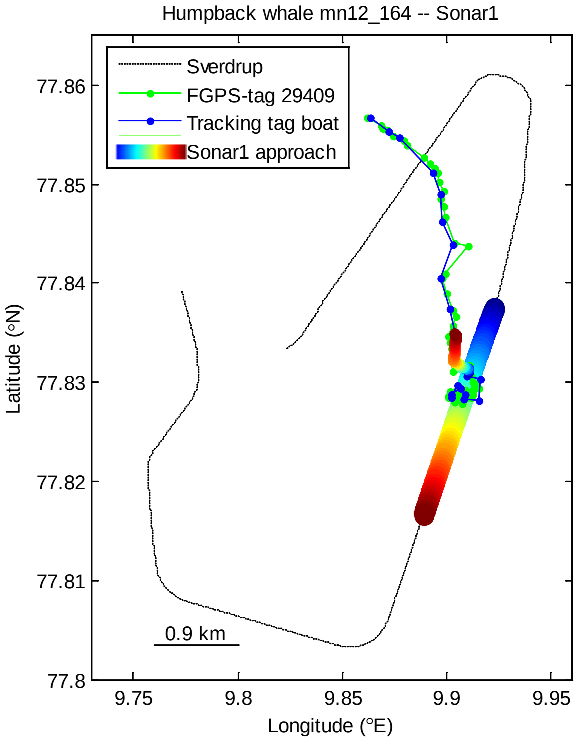
NO-SONAR CONTROL



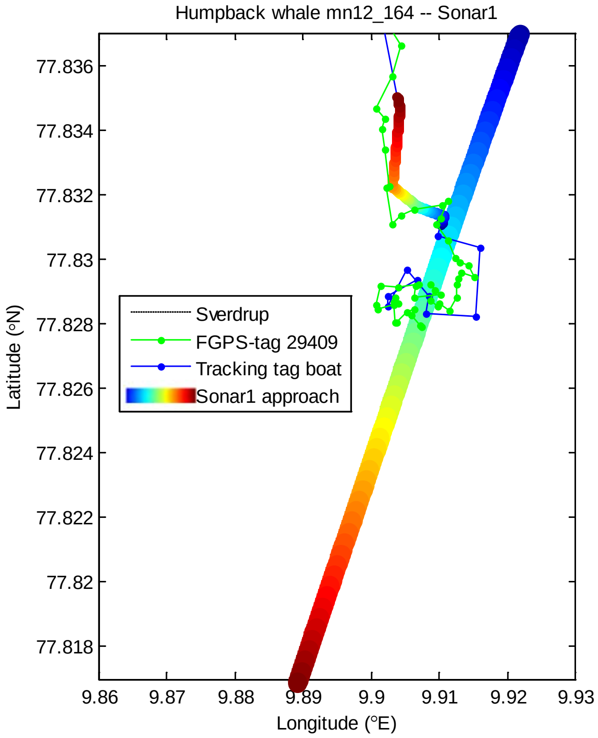




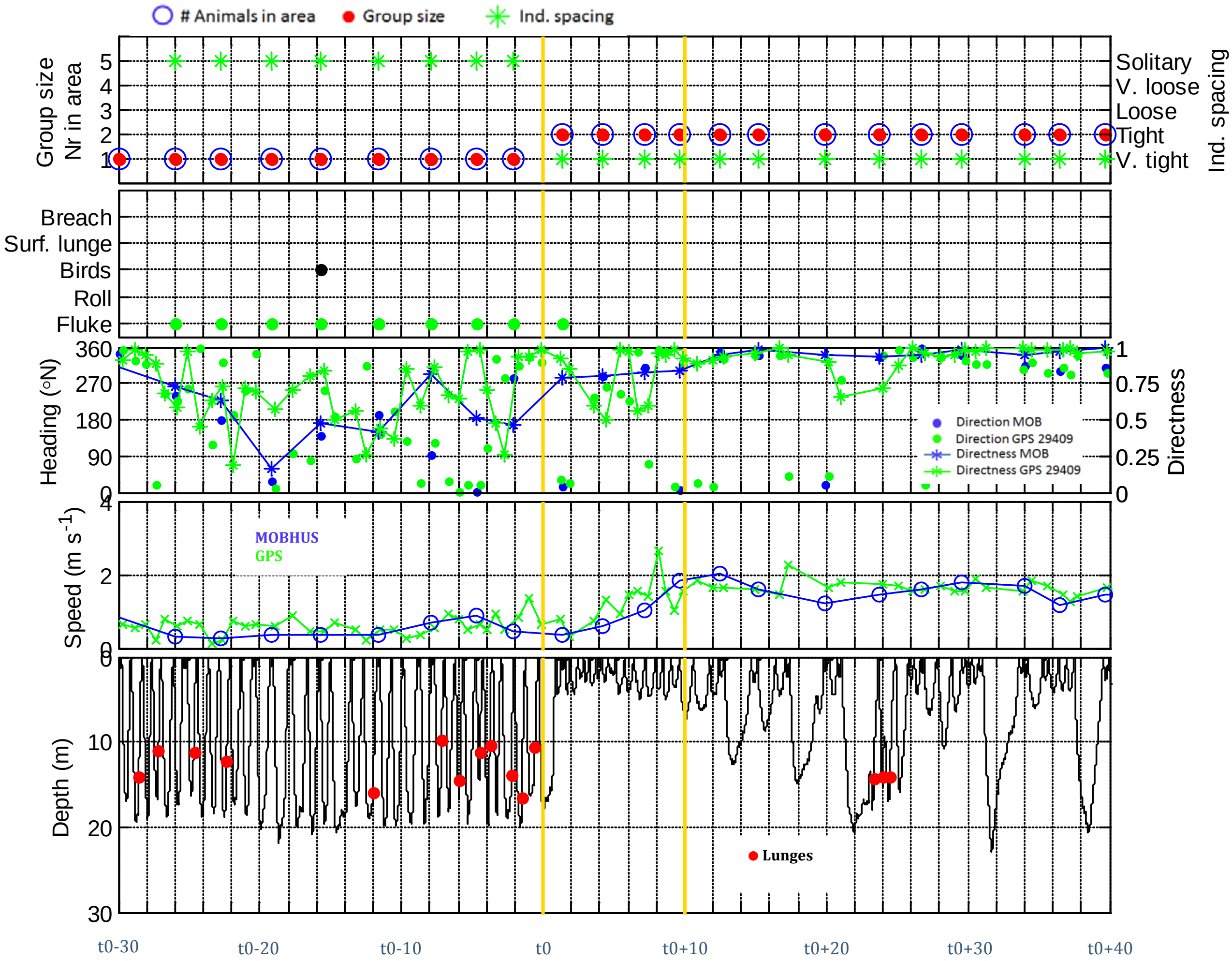
SONAR 1



Humpback whale mn12_164 -- Sonar1
Sverdrup
FGPS-tag 29409
Tracking tag boat
Sonar1 approach
0.9 km
Latitude (°N)
Longitude (°E)

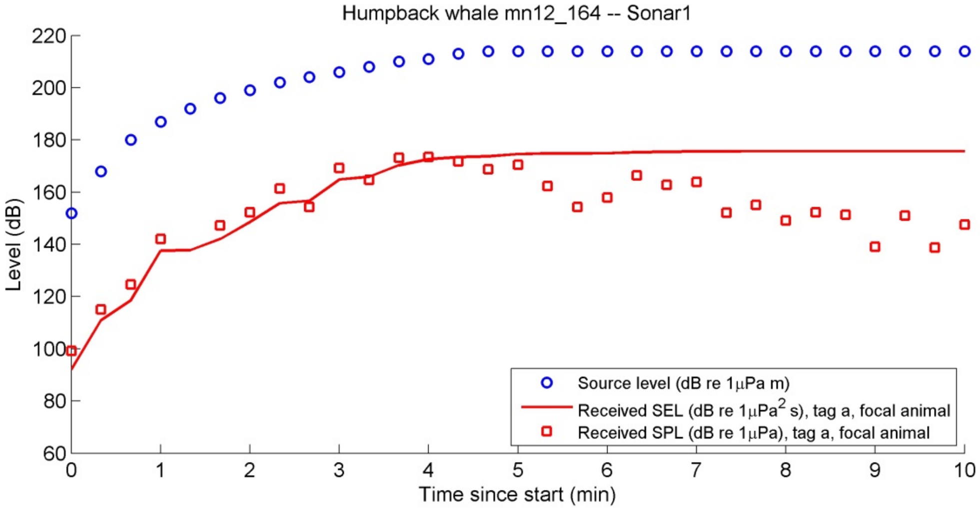


Humpback whale mn12_164 -- Sonar1
Sverdrup
FGPS-tag 29409
Tracking tag boat
Sonar1 approach
Latitude (°N)
Longitude (°E)

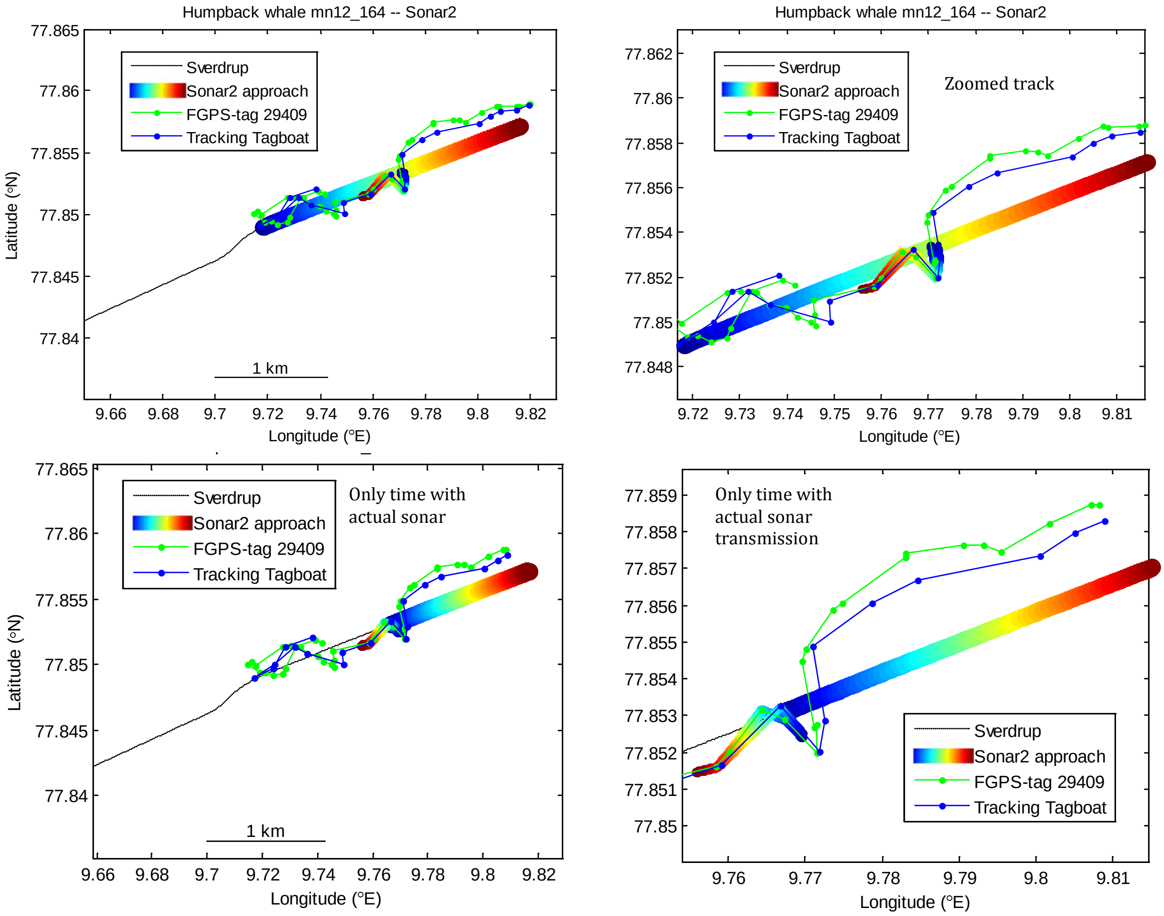


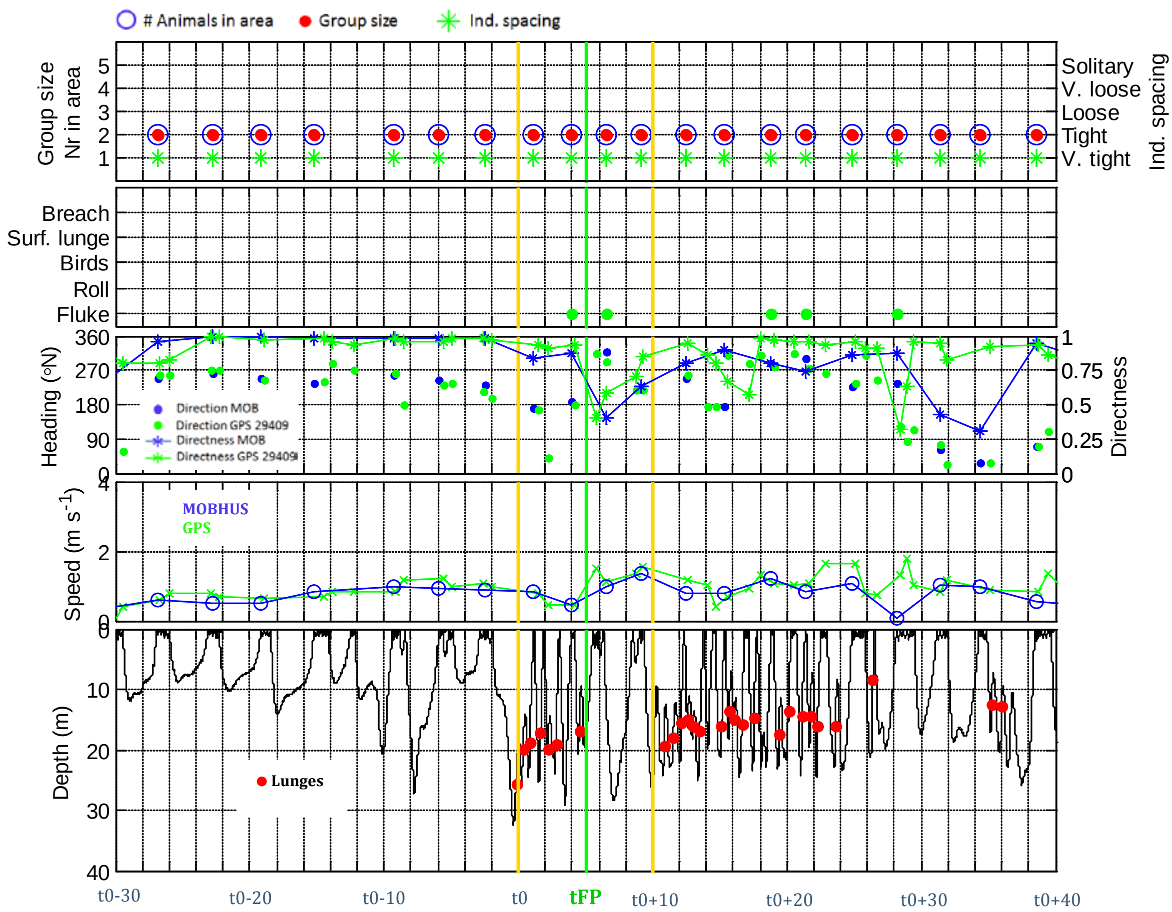
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Speed (m s-1)
MOBHUS
GPS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 1 – Received level

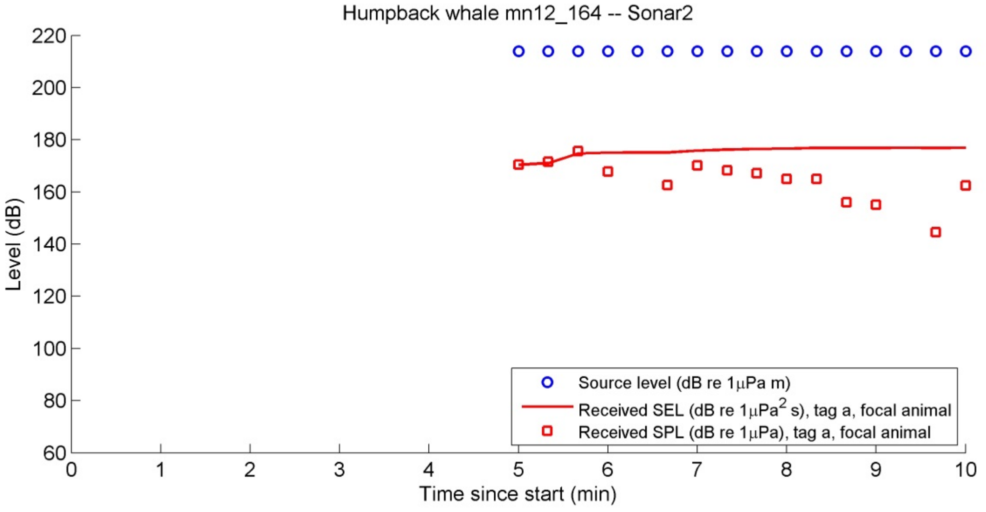


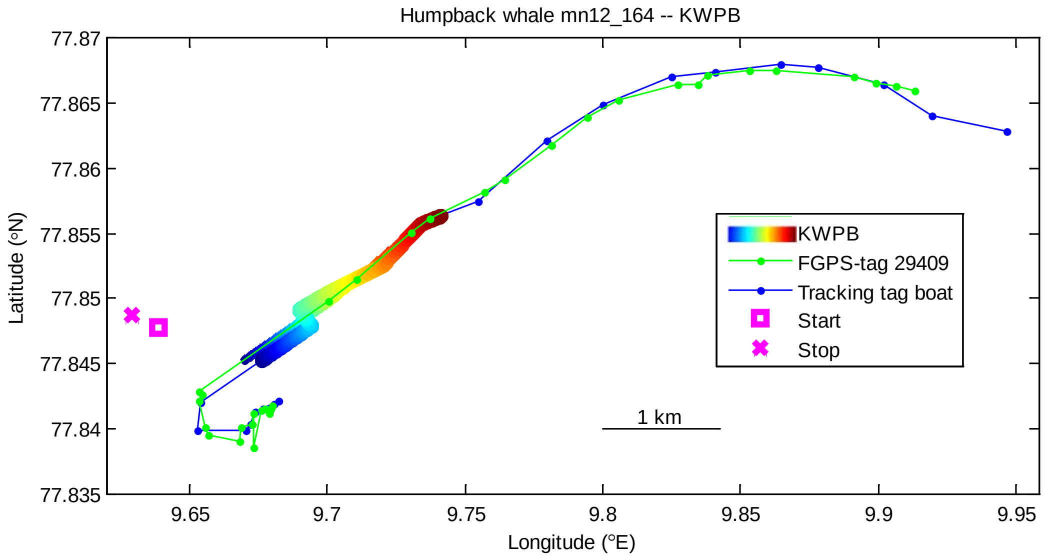
SONAR 2

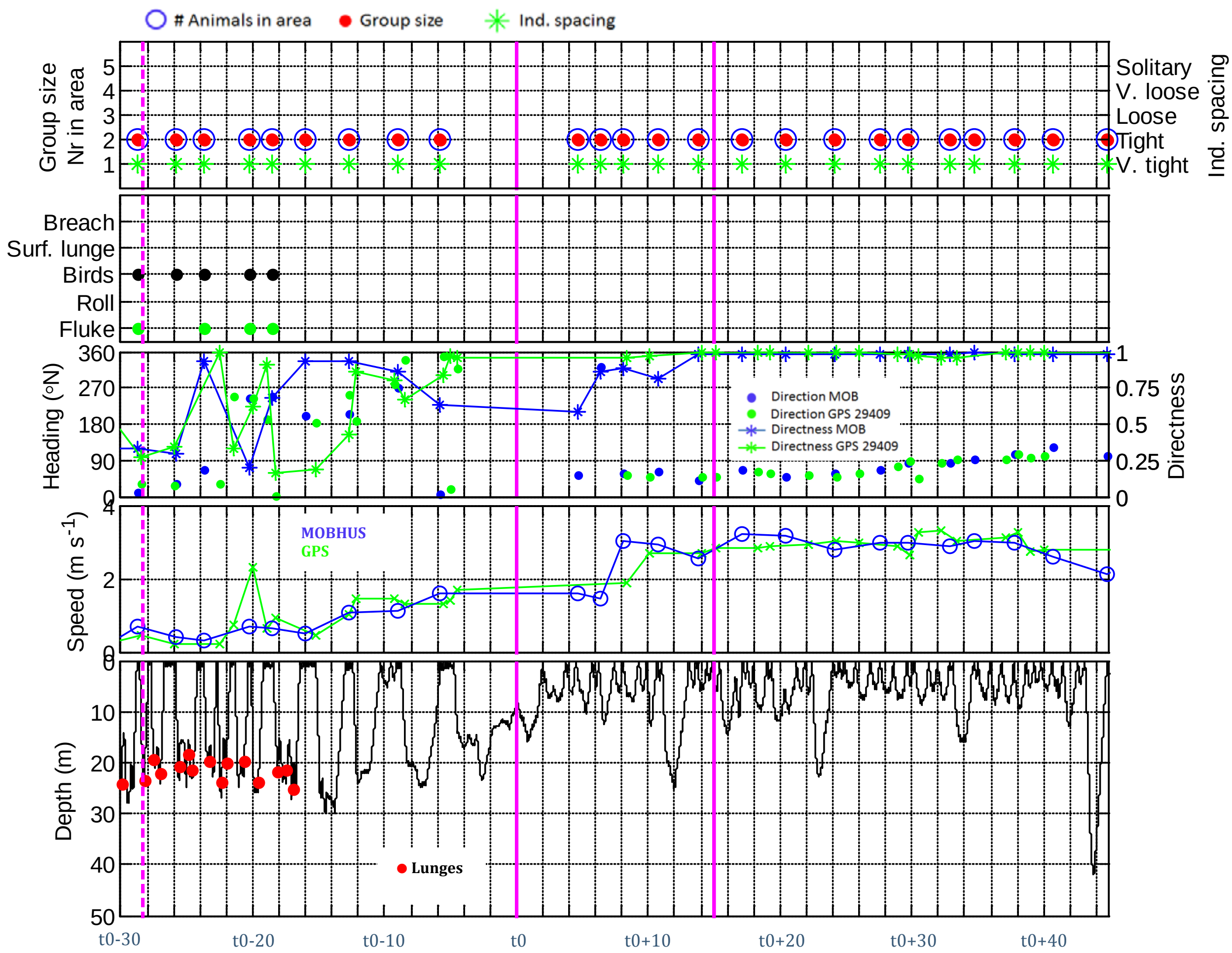

Humpback whale mn12_164 -- Sonar2
Sverdrup
Sonar2 approach
FGPS-tag 29409
Tracking Tagboat
1 km
Zoomed track
Only time with actual sonar
Only time with actual sonar transmission
Latitude (°N)
Longitude (°E)


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Directness
Speed (m s-1)
MOBHUS
GPS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
tFP
t0+10
t0+20
t0+30
t0+40

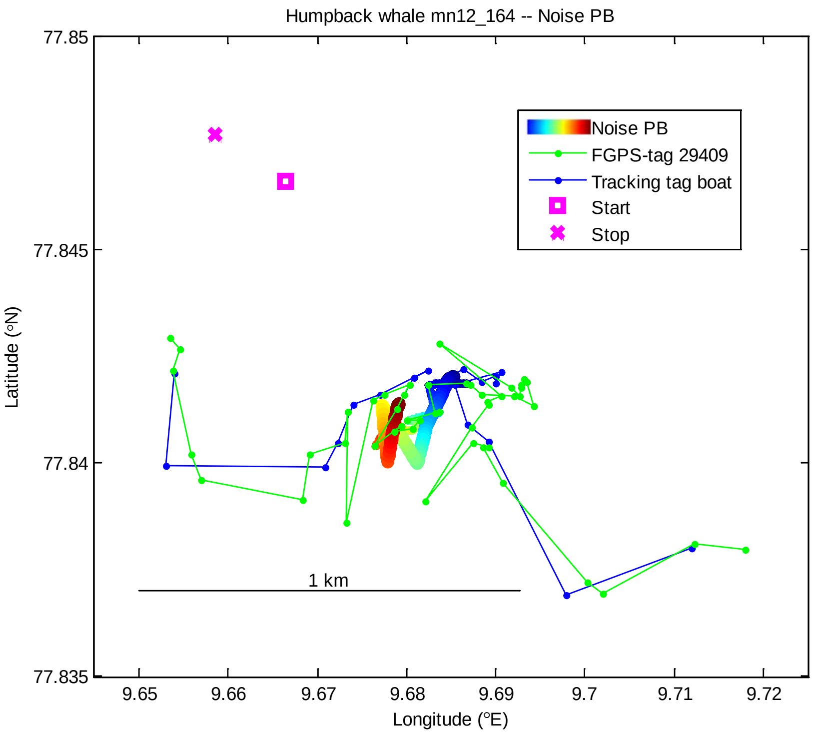
SONAR 2 – Received level

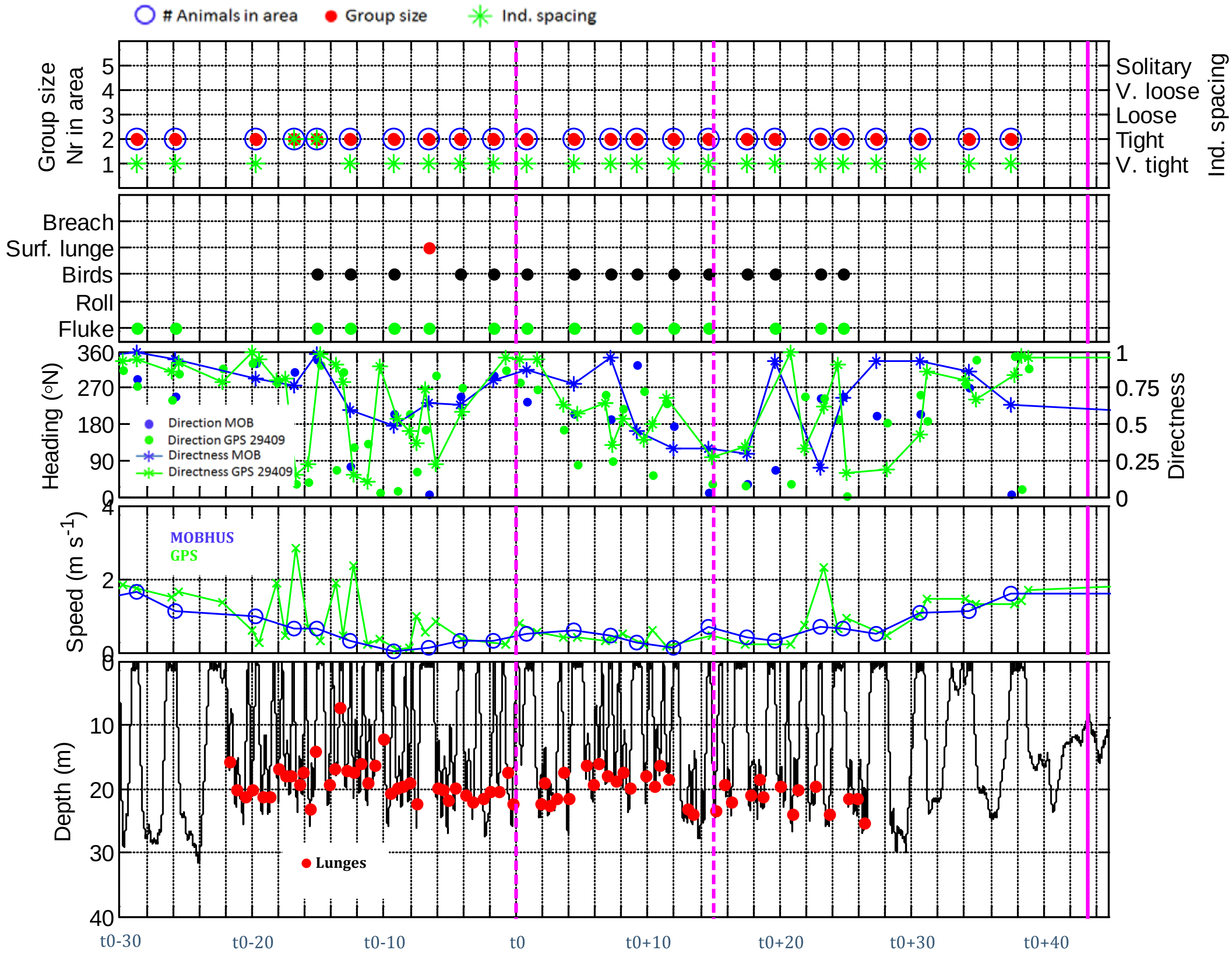



Humpback whale mn12_164 -- KWPB
Latitude (°N)
Longitude (°E)
77.87
77.865
77.86
77.855
77.85
77.845
77.84
77.835
9.65
9.7
9.75
9.8
9.85
9.9
9.95
KWPB
FGPS-tag 29409
Tracking tag boat
Start
Stop
1 km


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Directness MOB
Directness GPS 29409
Directness
MOBHUS
GPS
Speed (m s-1)
Lunges
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

NOISE PLAYBACK





3.4.7 mn12_170ab

June 18th 2012 on the Bellsund-Icefjord banks 30 nmi off west coast of Spitsbergen. Northeast wind 2 (Beaufort), clouded, seastate 2. Two strongly associated animals, possibly mother and calf, both tagged with DTAGs between 03:32 and 03:50 (UTC) using the ARTS system. The two tags stays on the whales for 16:50 and 15:52 hrs.

<u>No-sonar control:</u> Good approach.

Several trawlers in the area within 2 nmi of the tagged whales between 09:30 and 10:30 (UTC) (between no-sonar control and Sonar 1)

<u>Sonar 1:</u> Good approach

<u>Sonar 2:</u> Bad timing of CPA

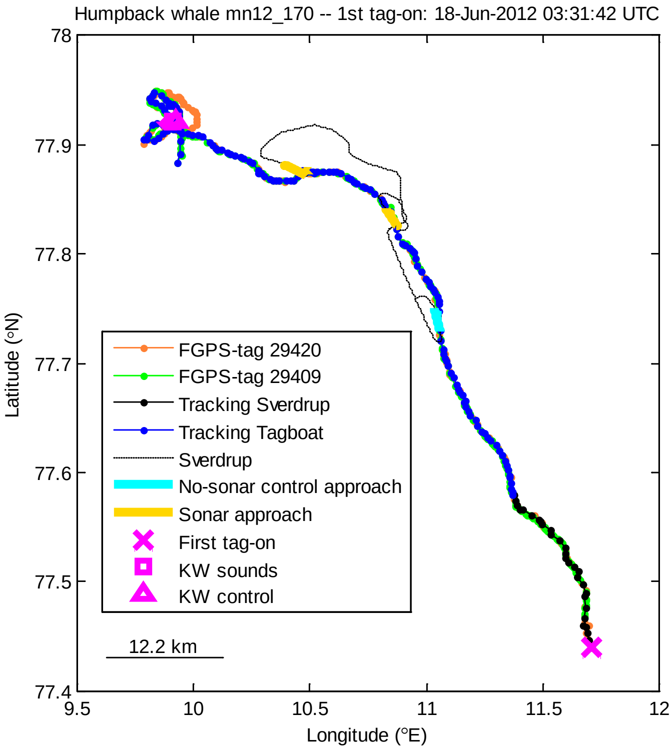
<u>Killer whale and control sound playback:</u> no comments listed

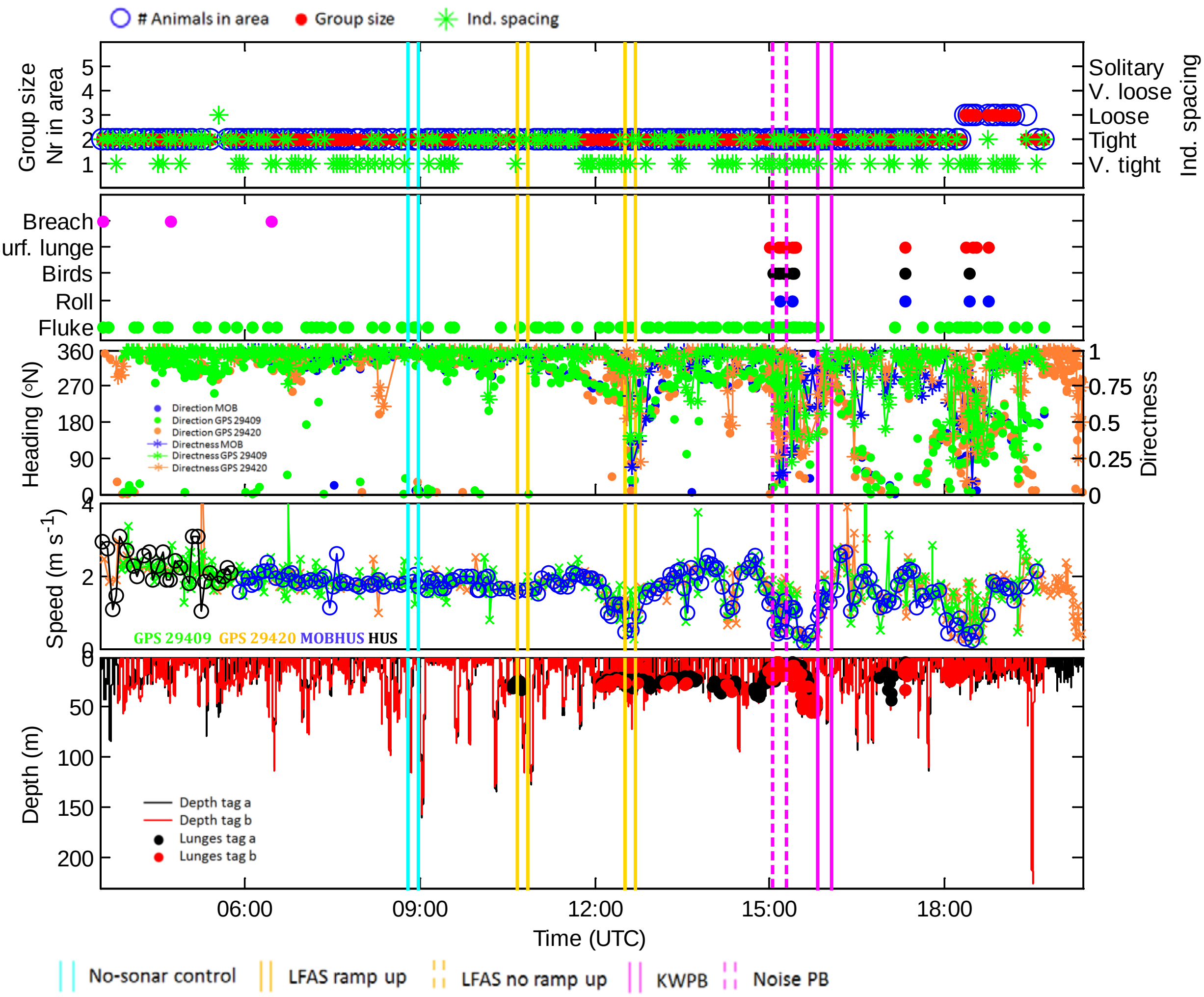
<u>Biopsy:</u> During biopsy collection (18:30-21:00 (UTC) the two tagged whales split up, HUS tracked the smallest one, MOBHUS the bigger one which joined another humpback. Biopsy collected from both focal animals.

Humpback whale mn12_170a (left column) and b (right column) tagged with the ARTS

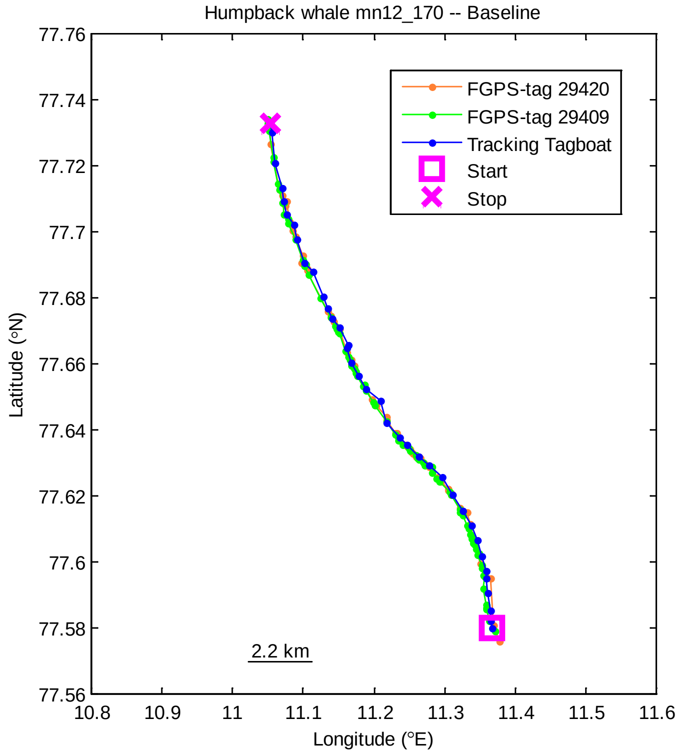
(photos by Paul Ensor).

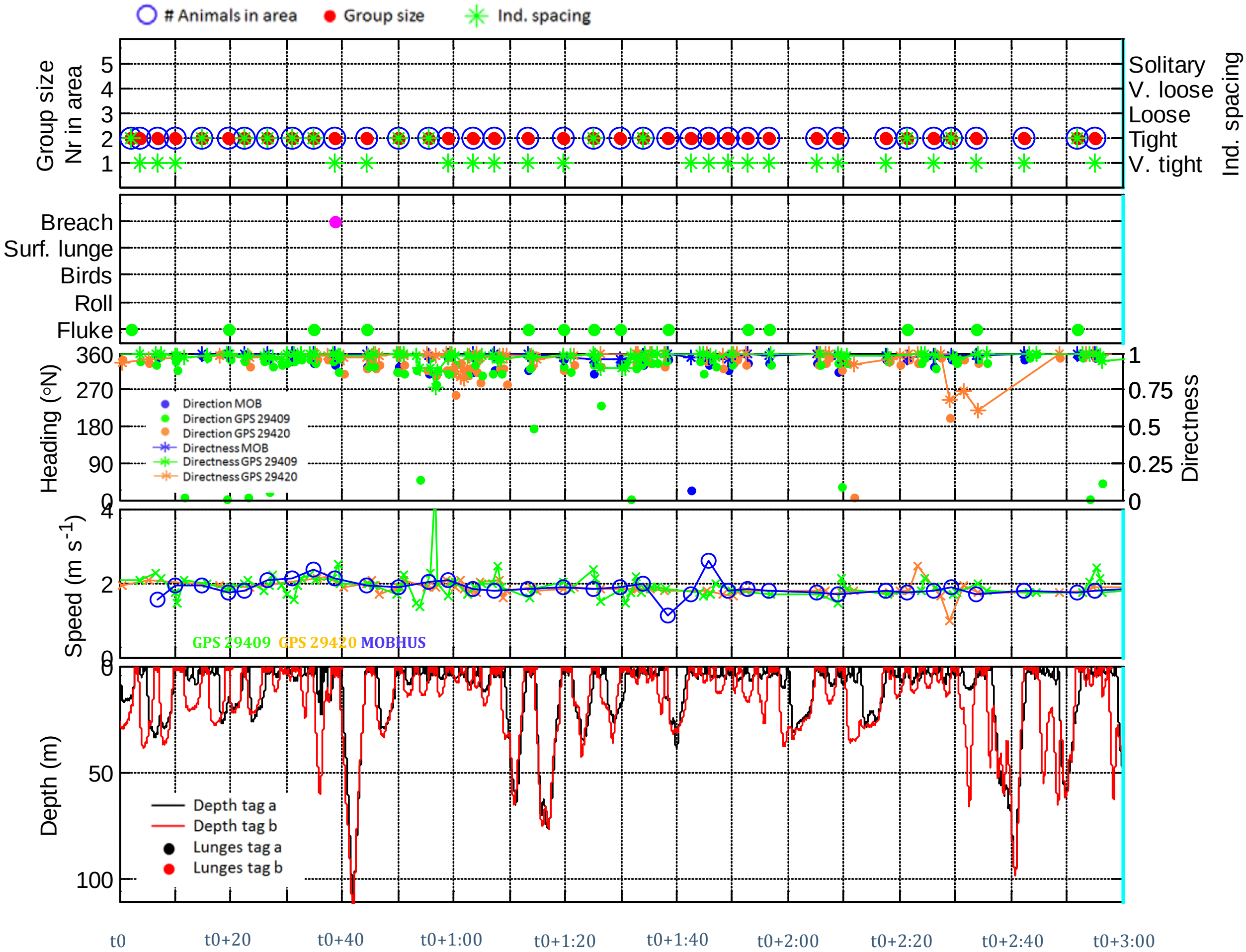
FULL RECORD

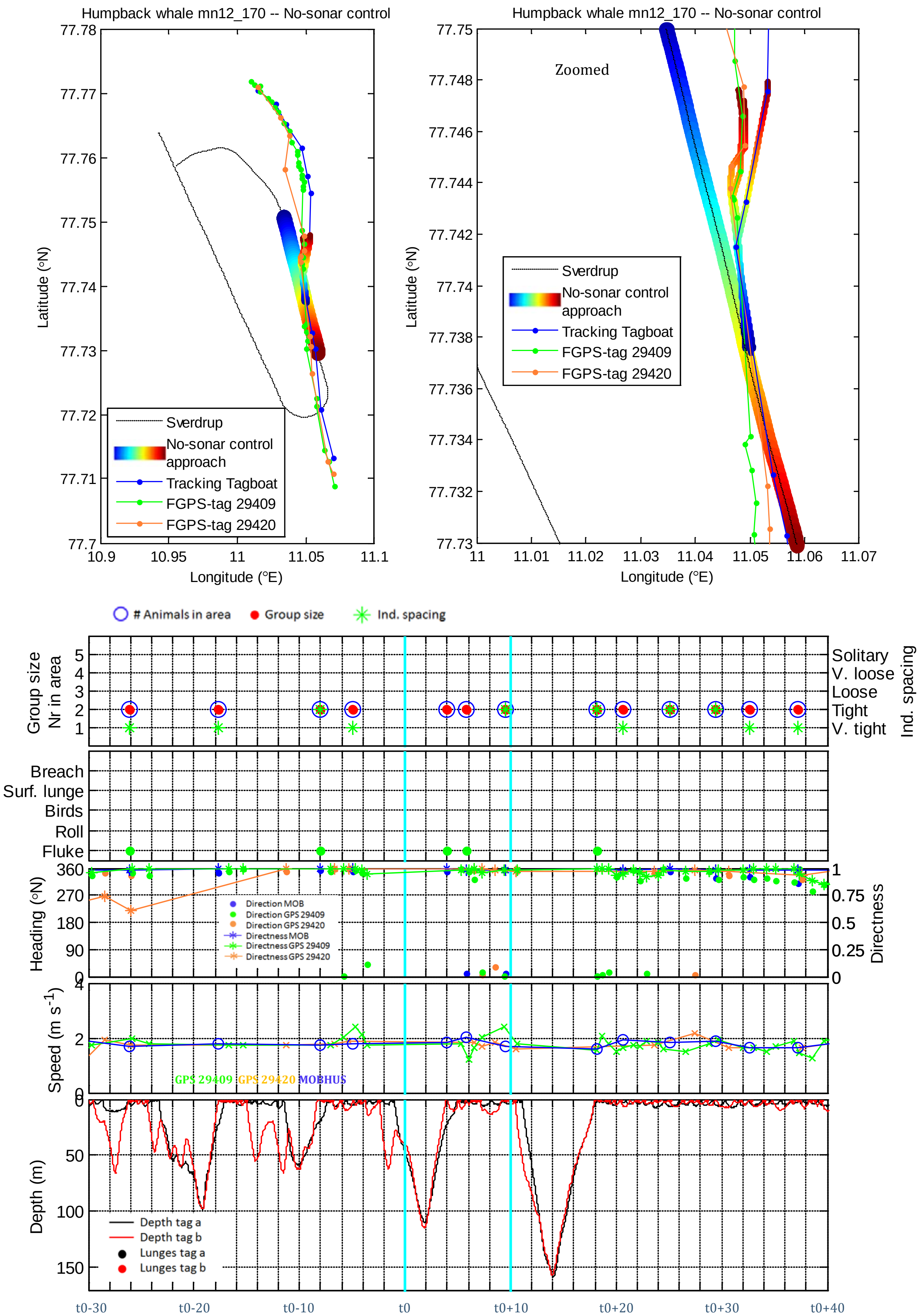

Humpback whale mn12_170 -- 1st tag-on: 18-Jun-2012 03:31:42 UTC
Latitude (°N)
Longitude (°E)
78
77.9
77.8
77.7
77.6
77.5
77.4
9.5
10
10.5
11
11.5
12
FGPS-tag 29420
FGPS-tag 29409
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
KW sounds
KW control
12.2 km


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Directness
Speed (m s-1)
GPS 29409 GPS 29420 MOBHUS HUS
Depth (m)
Depth tag a
Depth tag b
Lunges tag a
Lunges tag b
06:00
09:00
12:00
15:00
18:00
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

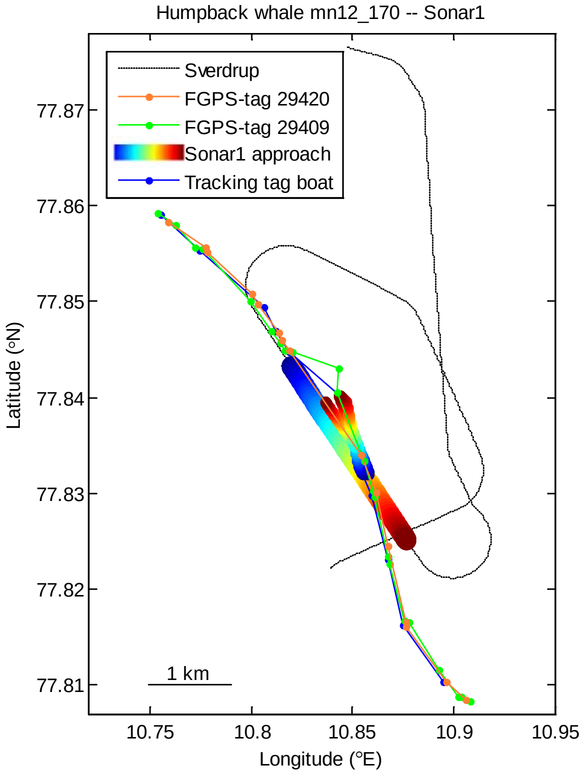
BASELINE


Humpback whale mn12_170 -- Baseline
FGPS-tag 29420
FGPS-tag 29409
Tracking Tagboat
Start
Stop
2.2 km
Latitude (°N)
Longitude (°E)
77.76
77.74
77.72
77.7
77.68
77.66
77.64
77.62
77.6
77.58
77.56
10.8
10.9
11
11.1
11.2
11.3
11.4
11.5
11.6

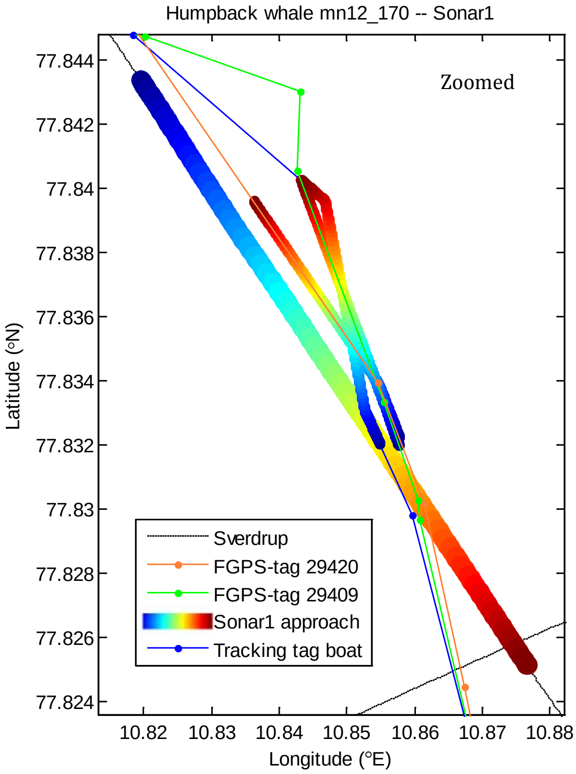

Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Directness
Speed (m s-1)
GPS 29409
GPS 29420
MOBHUS
Depth (m)
Depth tag a
Depth tag b
Lunges tag a
Lunges tag b
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00


Humpback whale mn12_170 -- No-sonar control
Latitude (°N)
Longitude (°E)
Sverdrup
No-sonar control approach
Tracking Tagboat
FGPS-tag 29409
FGPS-tag 29420
Humpback whale mn12_170 -- No-sonar control
Zoomed
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Speed (m s-1)
GPS 29409 GPS 29420 MOBHUS
Depth (m)
Depth tag a
Depth tag b
Lunges tag a
Lunges tag b
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

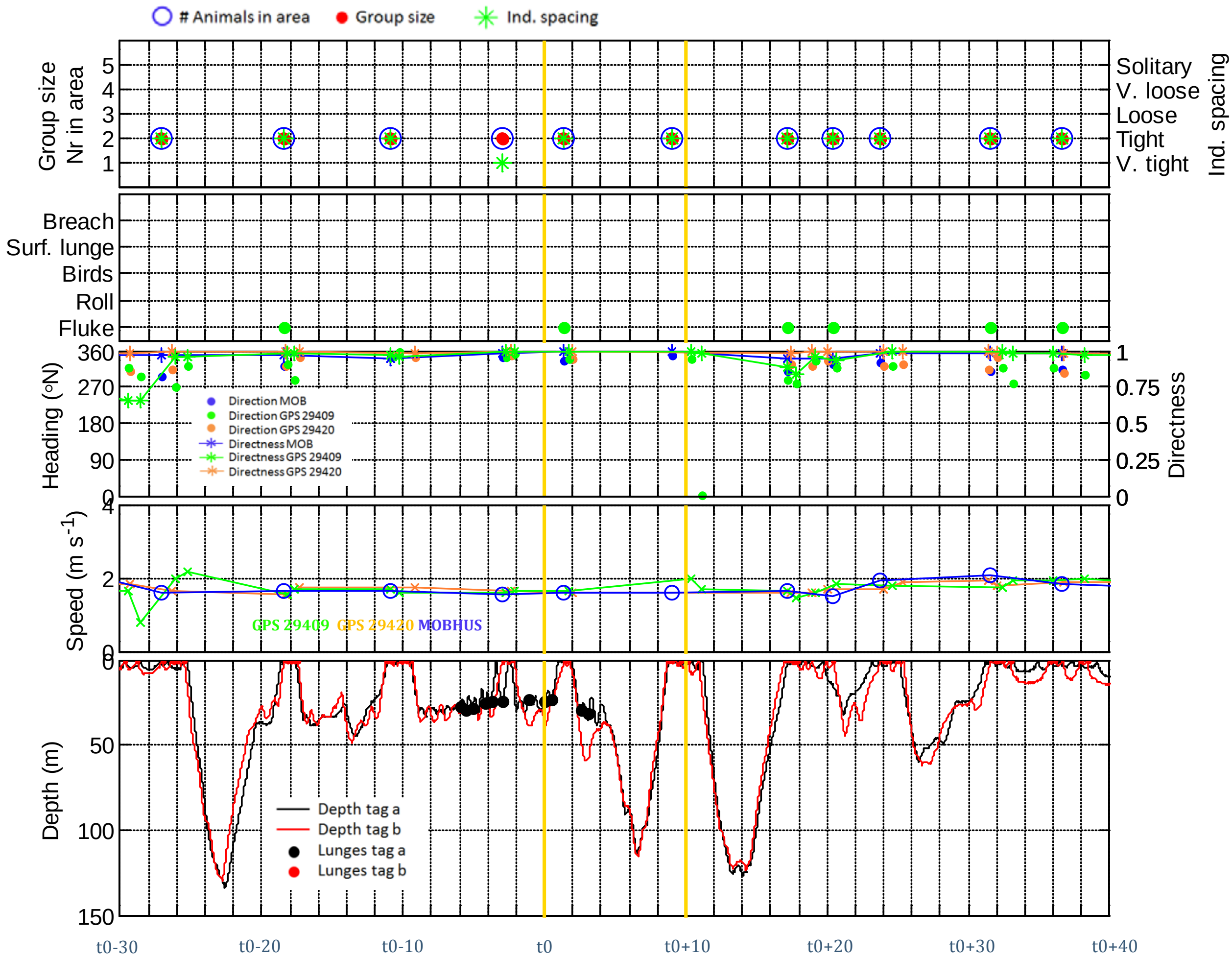
SONAR 1



Humpback whale mn12_170 -- Sonar1
Sverdrup
FGPS-tag 29420
FGPS-tag 29409
Sonar1 approach
Tracking tag boat
1 km
77.87
77.86
77.85
77.84
77.83
77.82
77.81
10.75
10.8
10.85
10.9
10.95
Latitude (°N)
Longitude (°E)

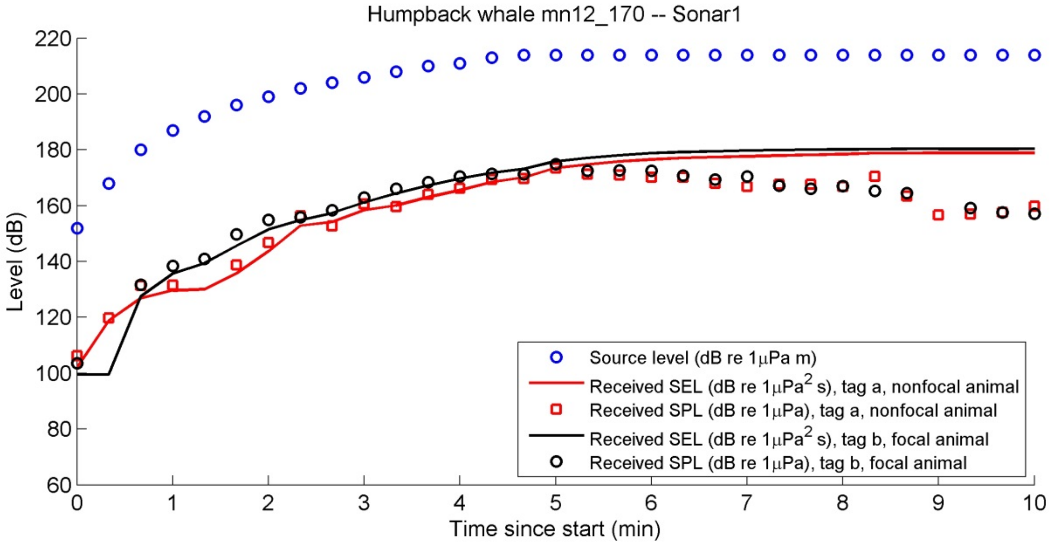


Humpback whale mn12_170 -- Sonar1
Zoomed
Sverdrup
FGPS-tag 29420
FGPS-tag 29409
Sonar1 approach
Tracking tag boat
77.844
77.842
77.84
77.838
77.836
77.834
77.832
77.83
77.828
77.826
77.824
10.82
10.83
10.84
10.85
10.86
10.87
10.88
Latitude (°N)
Longitude (°E)

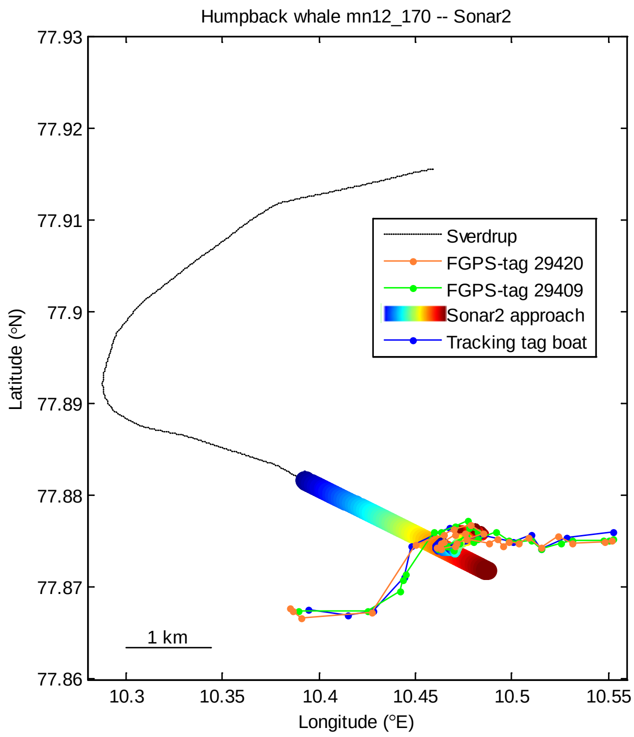


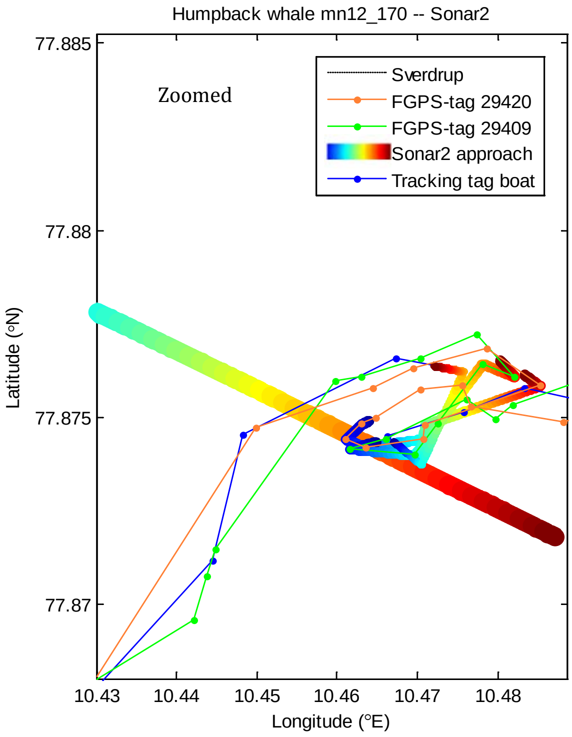
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Directness
Speed (m s-1)
GPS 29409
GPS 29420
MOBHUS
Depth (m)
Depth tag a
Depth tag b
Lunges tag a
Lunges tag b
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

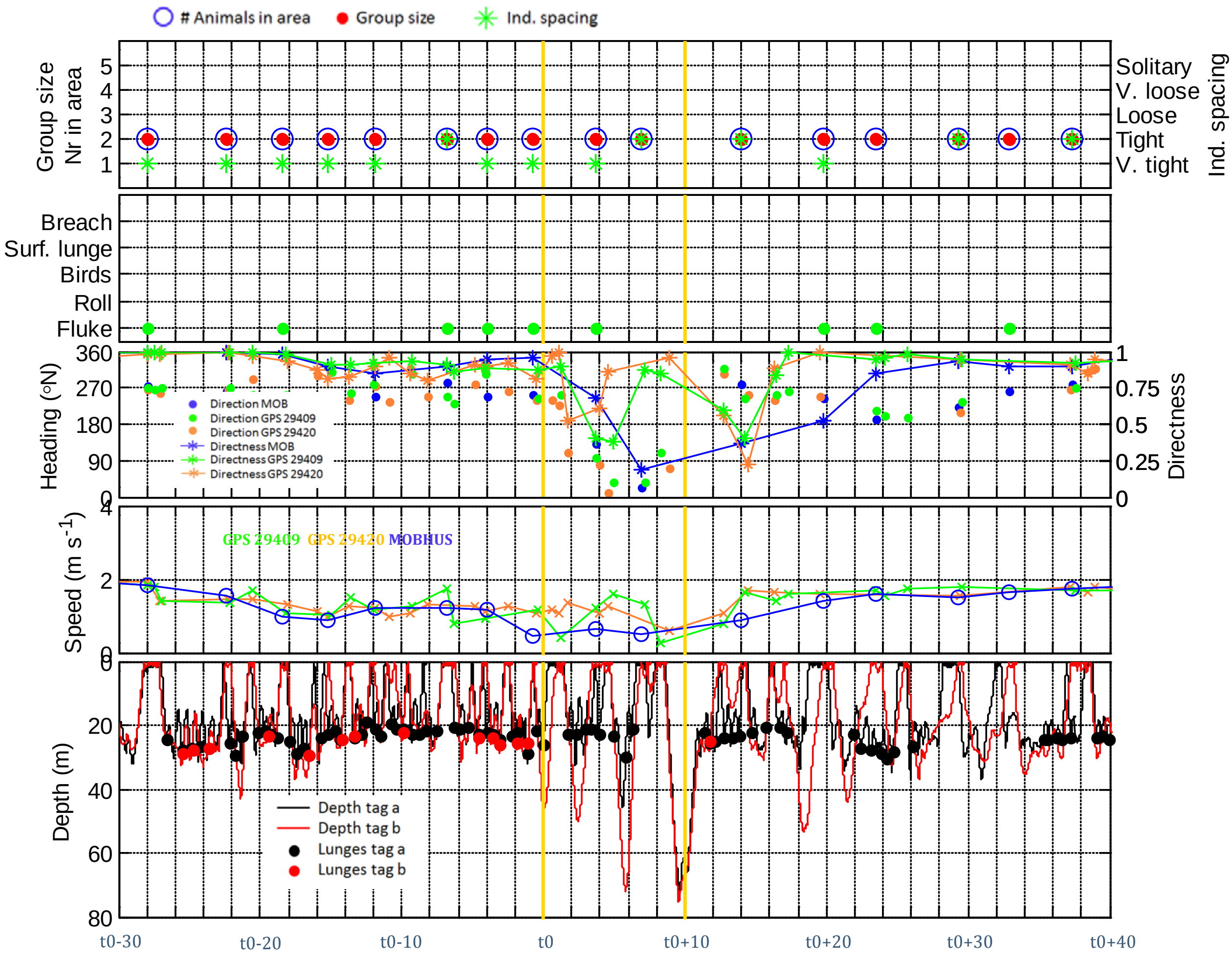
SONAR 1 – Received level



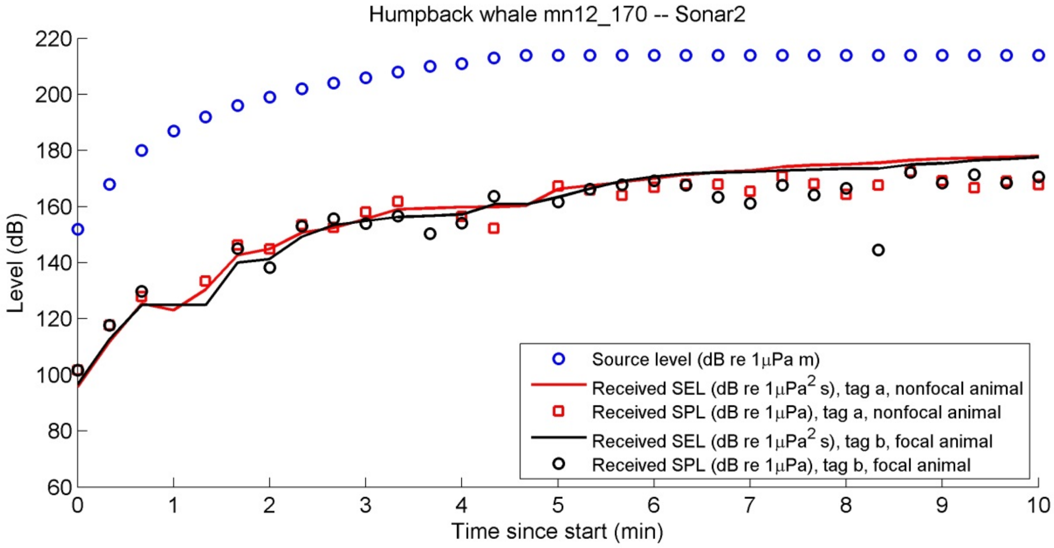
SONAR 2

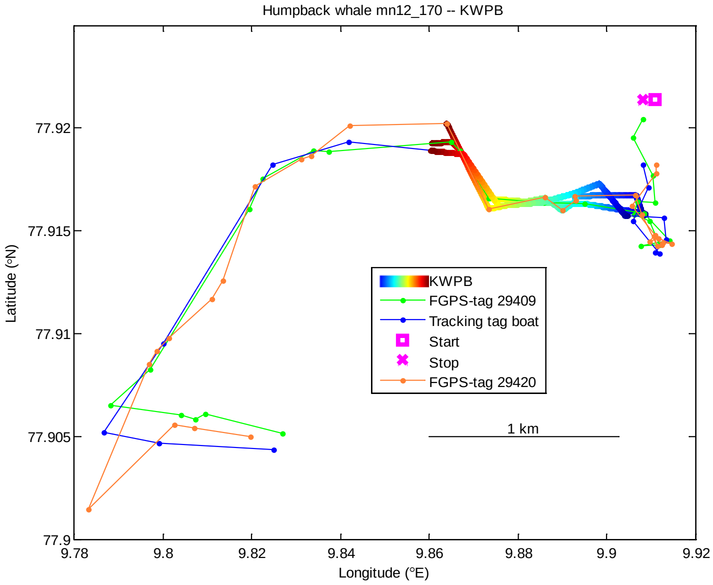

Humpback whale mn12_170 -- Sonar2
77.93
77.92
77.91
77.9
77.89
77.88
77.87
77.86
Latitude (°N)
10.3
10.35
10.4
10.45
10.5
10.55
Longitude (°E)
1 km
Sverdrup
FGPS-tag 29420
FGPS-tag 29409
Sonar2 approach
Tracking tag boat

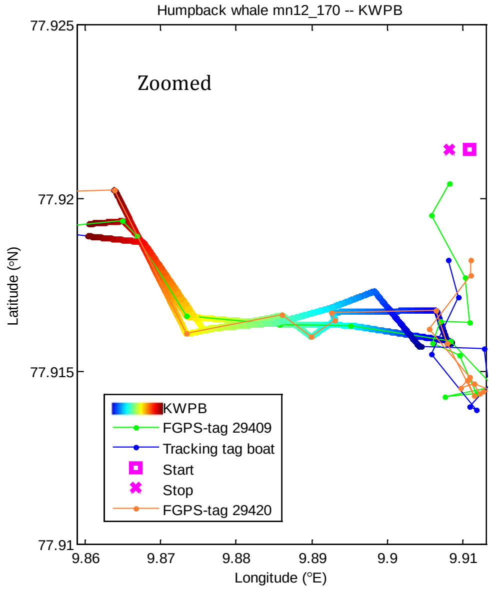

Humpback whale mn12_170 -- Sonar2
Zoomed
77.885
77.88
77.875
77.87
Latitude (°N)
10.43
10.44
10.45
10.46
10.47
10.48
Longitude (°E)
Sverdrup
FGPS-tag 29420
FGPS-tag 29409
Sonar2 approach
Tracking tag boat

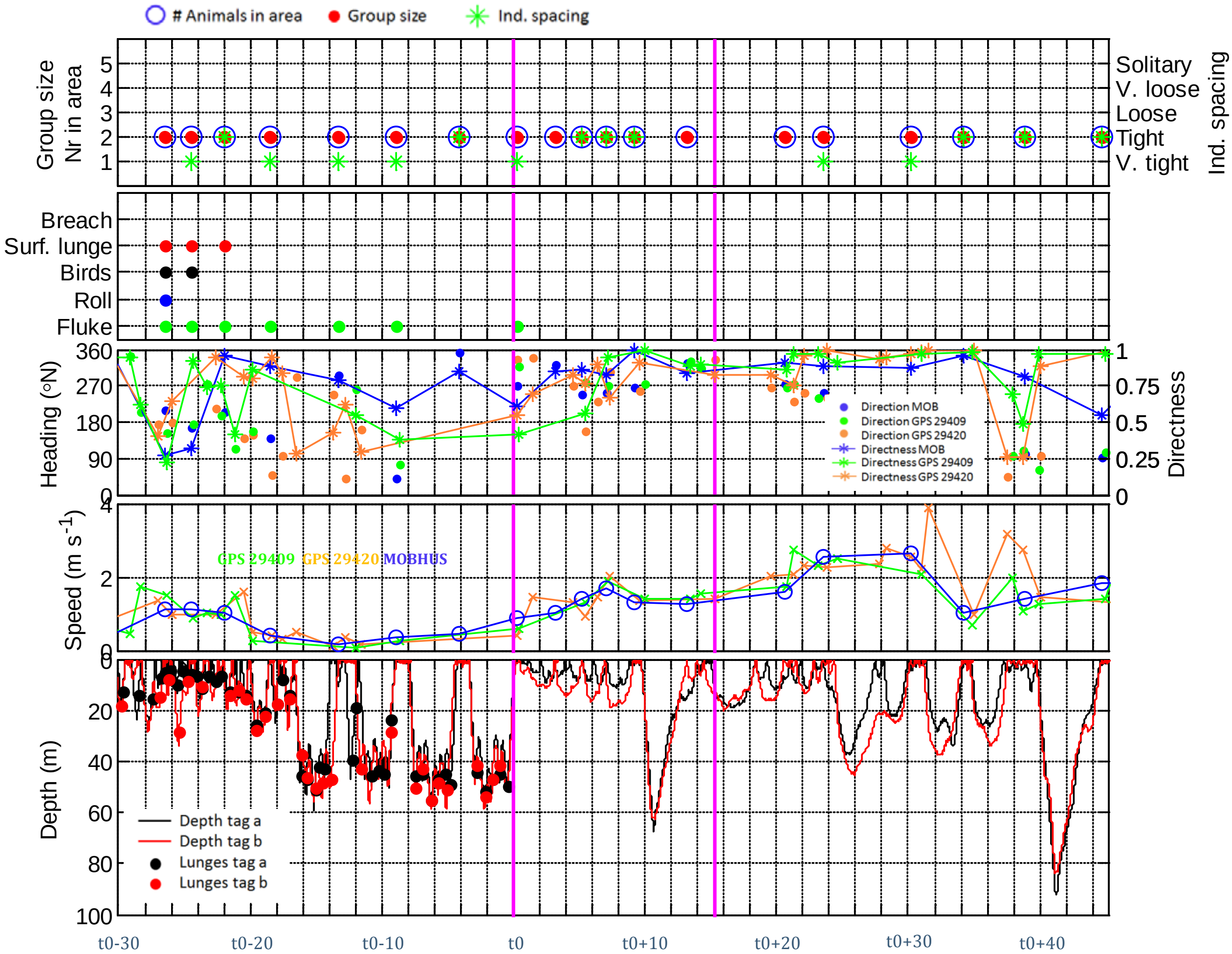

Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Directness
GPS 29409
GPS 29420
MOBHUS
Speed (m s-1)
Depth (m)
Depth tag a
Depth tag b
Lunges tag a
Lunges tag b
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 2 – Received level

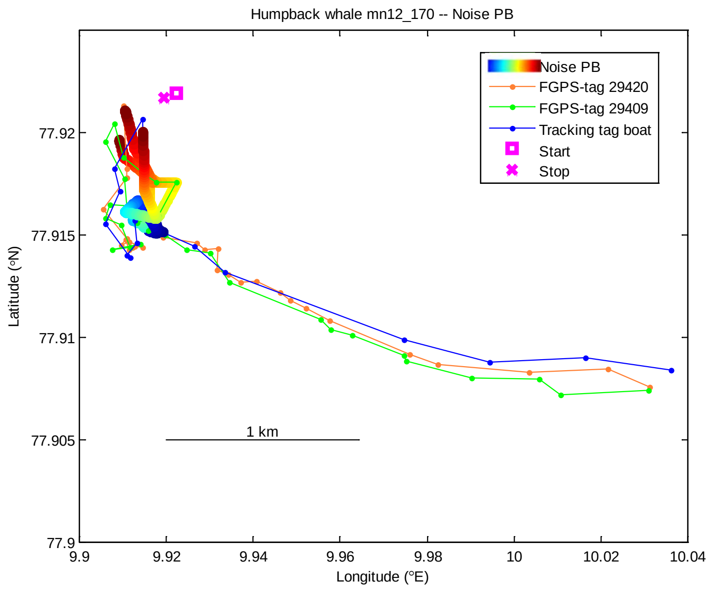


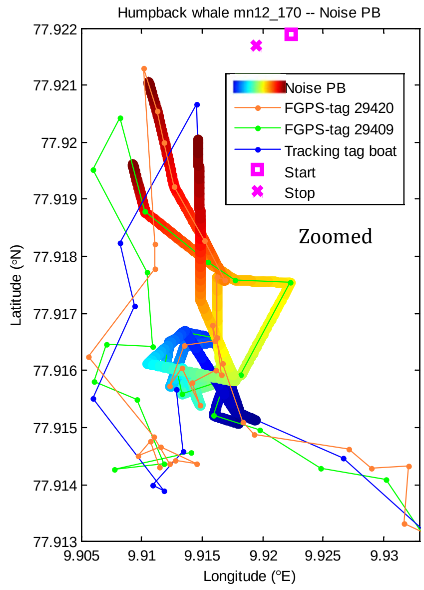

Humpback whale mn12_170 -- KWPB
KWPB
FGPS-tag 29409
Tracking tag boat
Start
Stop
FGPS-tag 29420
1 km
Latitude (°N)
Longitude (°E)

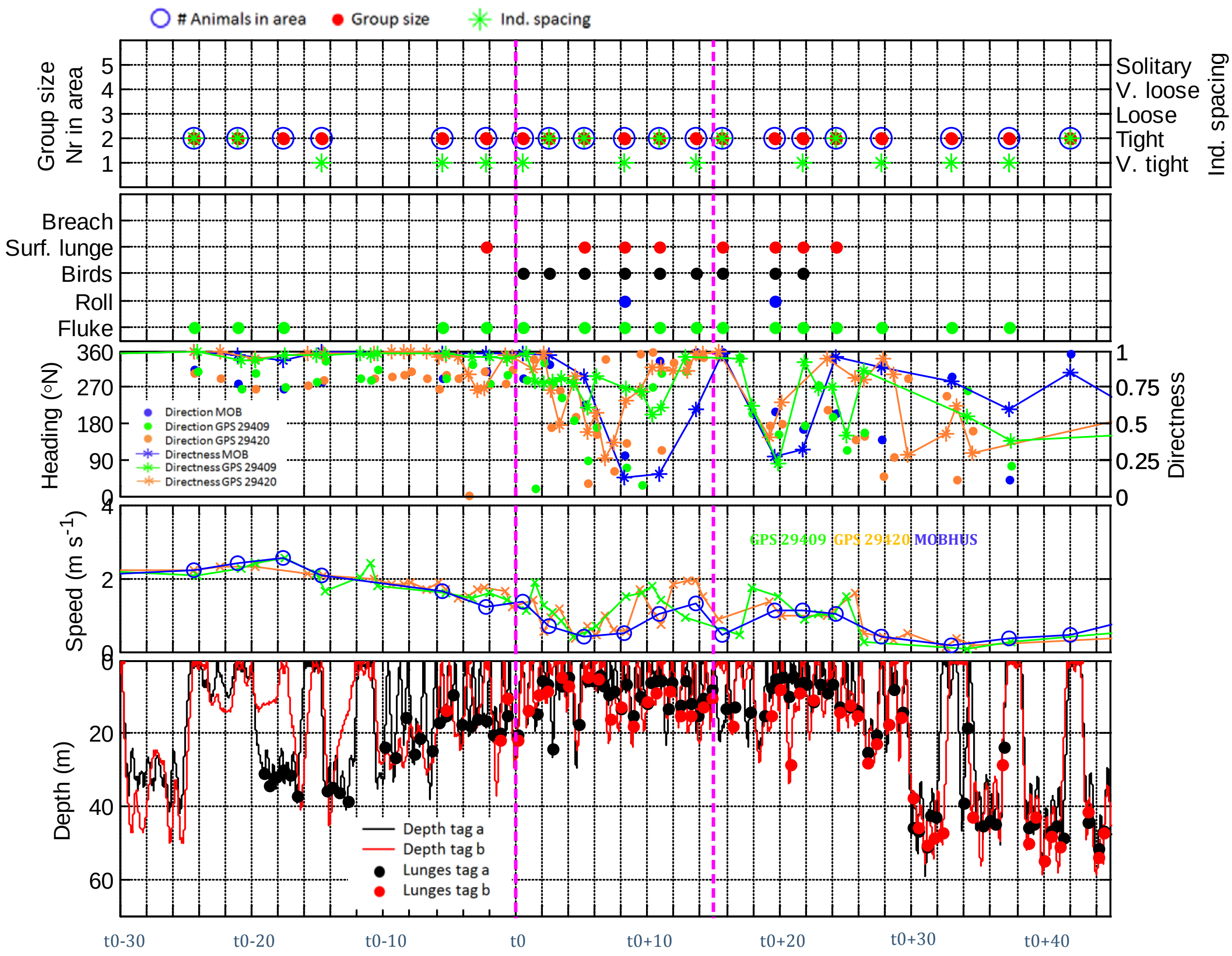

Humpback whale mn12_170 -- KWPB
Zoomed
KWPB
FGPS-tag 29409
Tracking tag boat
Start
Stop
FGPS-tag 29420
Latitude (°N)
Longitude (°E)


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Directness
Speed (m s-1)
GPS 29409
GPS 29420
MOBHUS
Depth (m)
Depth tag a
Depth tag b
Lunges tag a
Lunges tag b
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

NOISE PLAYBACK







3.4.8 mn12_171ab

June 19th 2012 in Kongsfjord channel Northwest on Spitsbergen. Northeast wind 3 (Beaufort), rain, seasate 1. Two tags placed on same animal at 11:23 and 12:22 UTC using the cantilever pole system. Tags stayed on for 17:18 and 17:15 hrs until planned release. There is a whaling vessel operating in the area, chasing minke whales. At 15:43 UTC a minke whale was shot close to (ca 250m) focal humpback whale.

No-sonar control: CPA at 50 m range, but a bit late.

Sonar 1: CPA at 200m range, but again a bit late. The whaling ship is now 2.5 nmi from focal whale. No whales other than focal whales observed in the area.

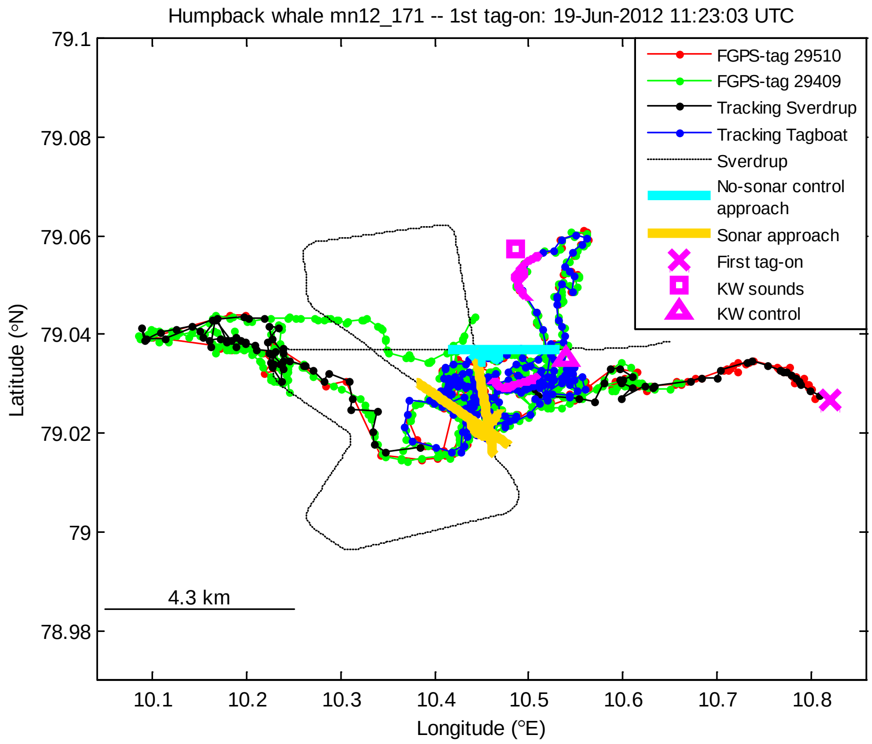
Sonar 2: CPA at 50m range, good approach.

Killer whale and noise playback: no comments noted.

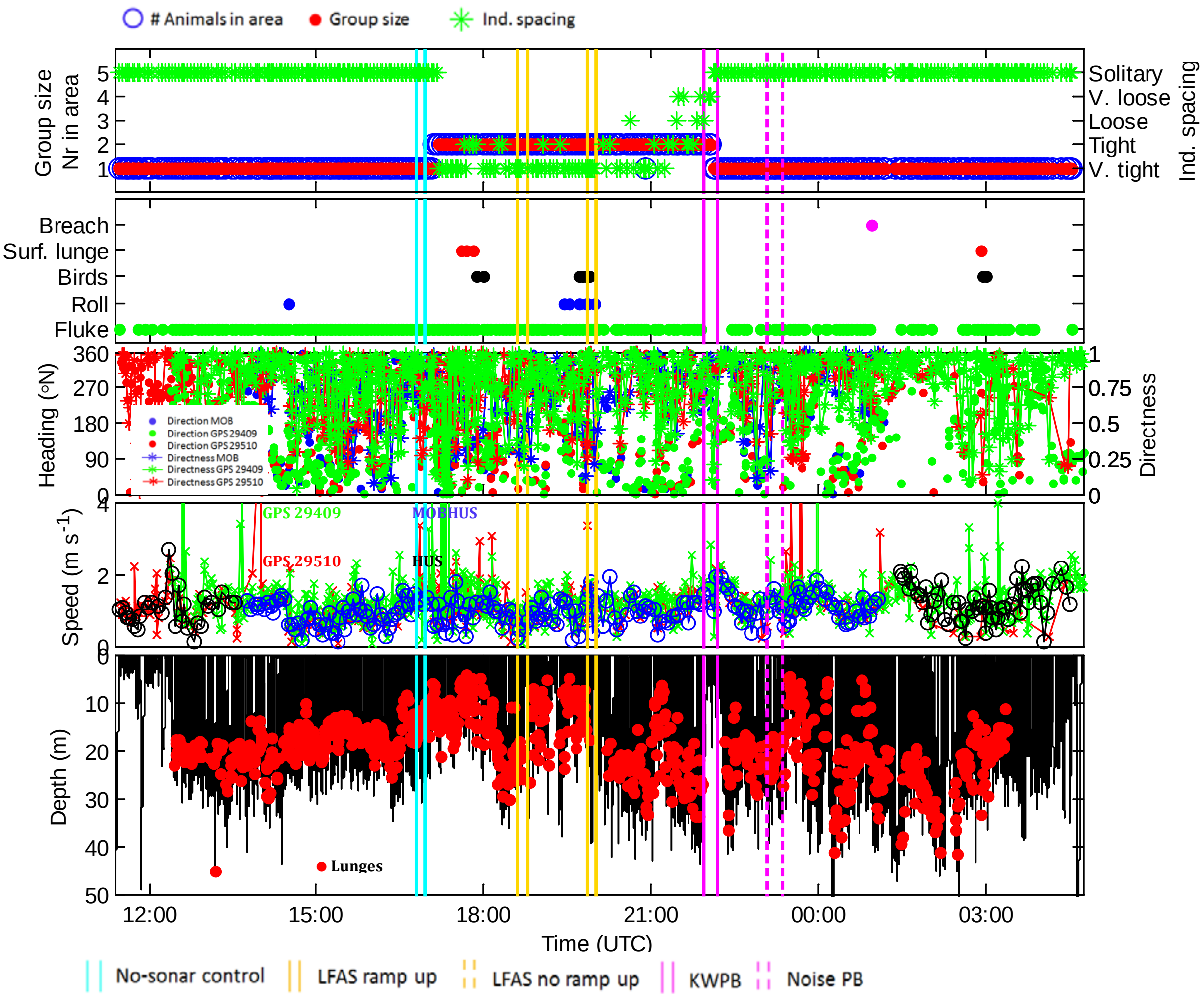
Biopsy: After playbacks weather conditions aggravated. Biopsy collected 04:44 UTC in difficult conditions. Tag release delayed. From 01:20 UTC tracking was was done from HUS. Tag recovery 05:01 and 06:44 UTC.

Humpback whale mn12_171ab with two DTAGs (photos by Paul Ensor).

FULL RECORD

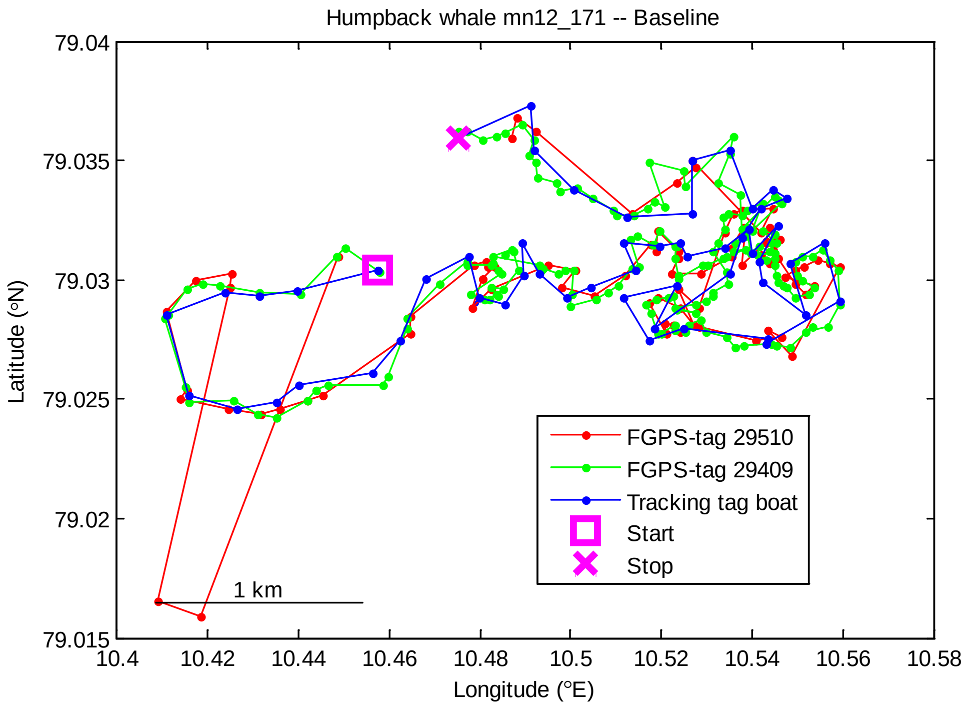


Humpback whale mn12_171 -- 1st tag-on: 19-Jun-2012 11:23:03 UTC
FGPS-tag 29510
FGPS-tag 29409
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
KW sounds
KW control
4.3 km
Latitude (°N)
Longitude (°E)

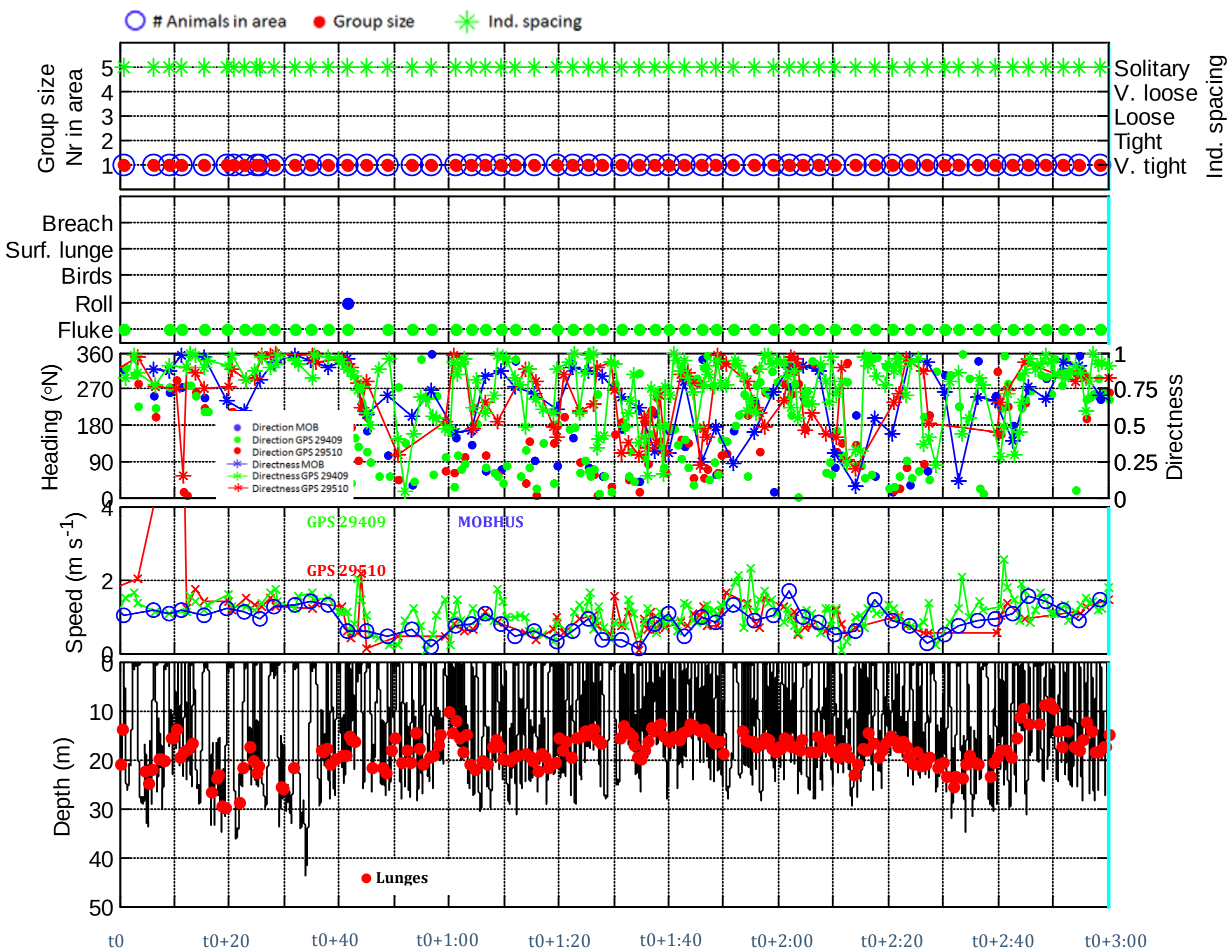


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29510
Directness MOB
Directness GPS 29409
Directness GPS 29510
Speed (m s-1)
GPS 29409
GPS 29510
MOBHUS
HUS
Depth (m)
Lunges
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

BASELINE

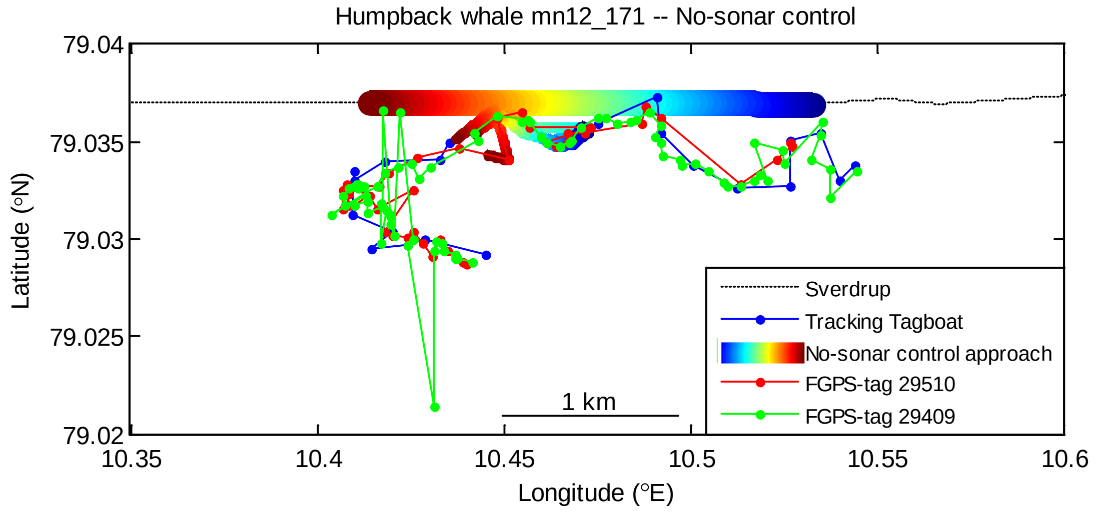


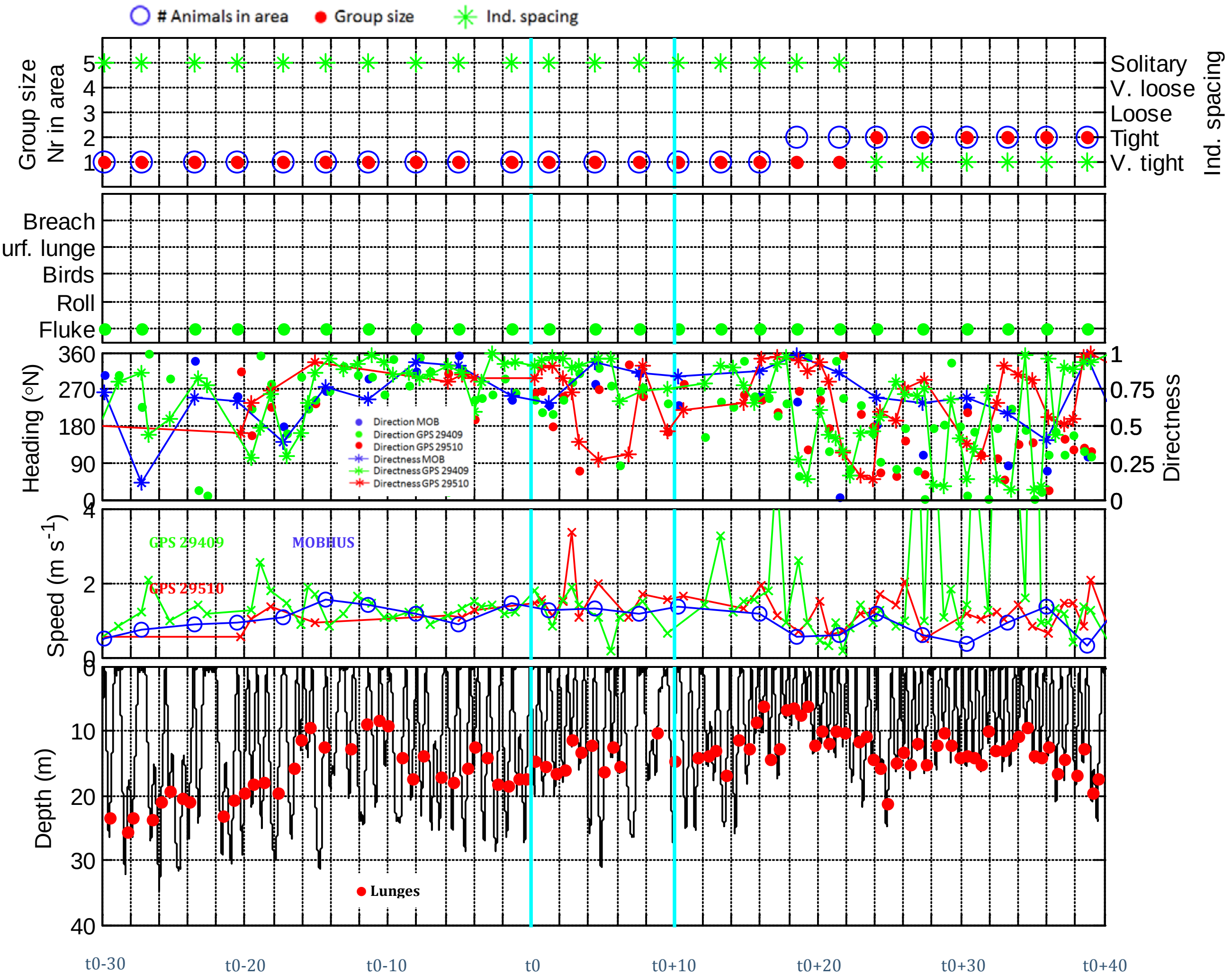
Humpback whale mn12_171 -- Baseline
Latitude (°N)
Longitude (°E)
79.04
79.035
79.03
79.025
79.02
79.015
10.4
10.42
10.44
10.46
10.48
10.5
10.52
10.54
10.56
10.58
1 km
FGPS-tag 29510
FGPS-tag 29409
Tracking tag boat
Start
Stop



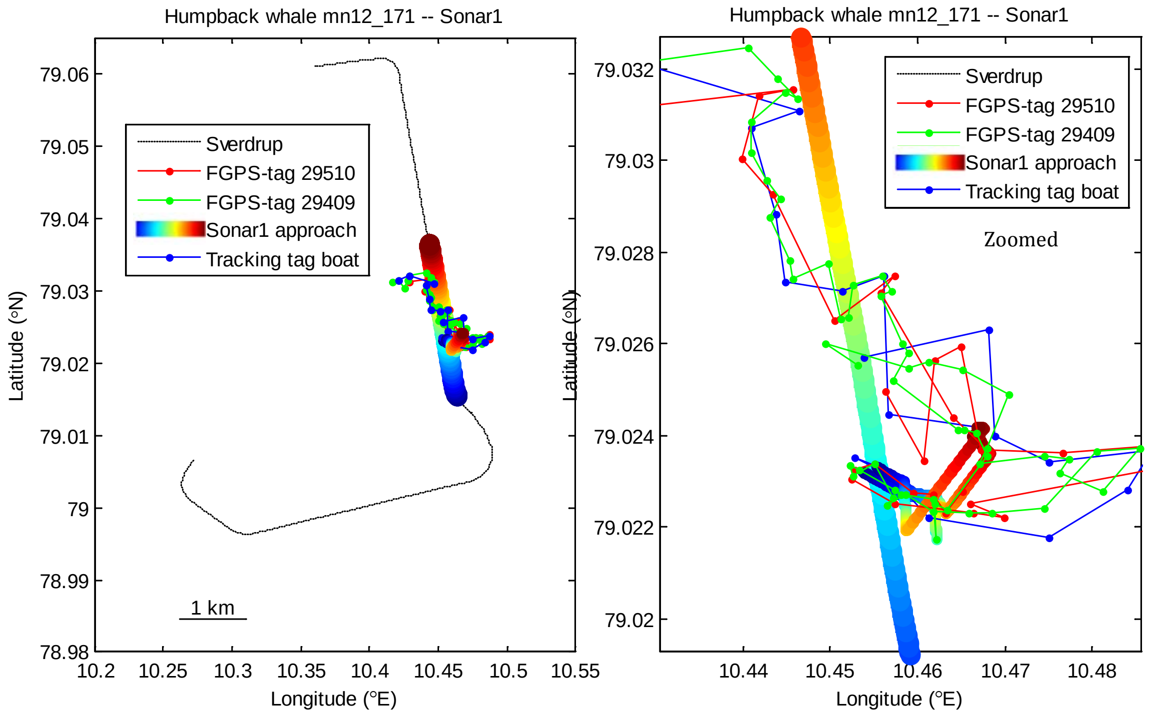
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29510
Directness MOB
Directness GPS 29409
Directness GPS 29510
Speed (m s-1)
GPS 29409
MOBHUS
GPS 29510
Depth (m)
Lunges
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

NO-SONAR CONTROL

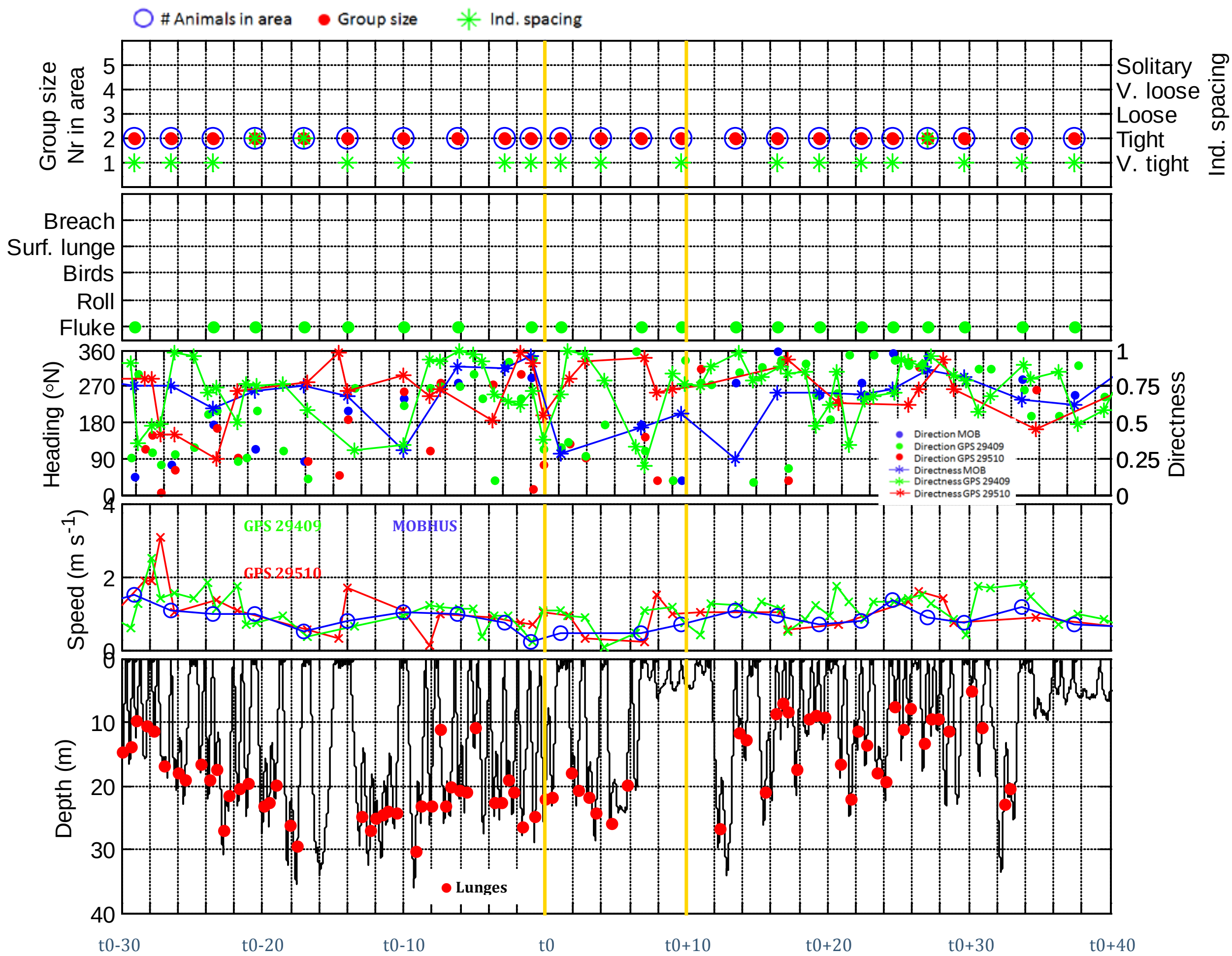




SONAR 1

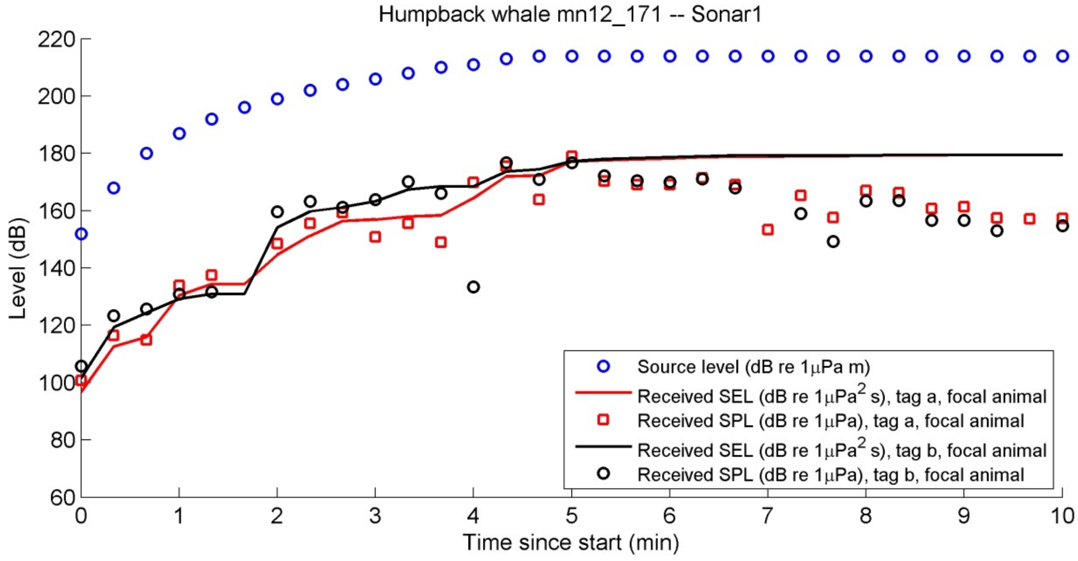


Humpback whale mn12_171 -- Sonar1
Humpback whale mn12_171 -- Sonar1
Sverdrup
FGPS-tag 29510
FGPS-tag 29409
Sonar1 approach
Tracking tag boat
Zoomed
1 km
Latitude (°N)
Longitude (°E)

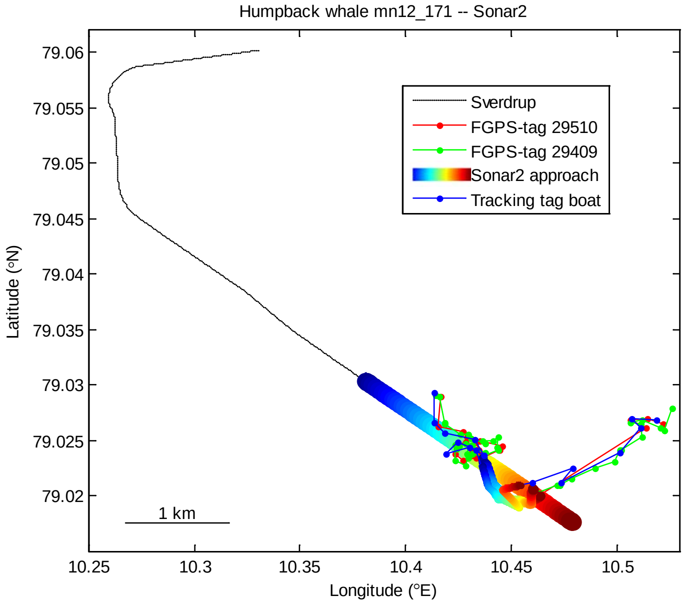


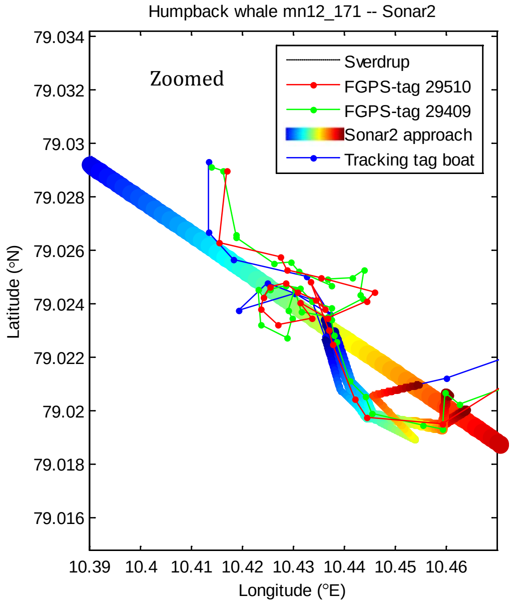
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29510
Directness MOB
Directness GPS 29409
Directness GPS 29510
Speed (m s-1)
GPS 29409
MOBHUS
GPS 29510
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

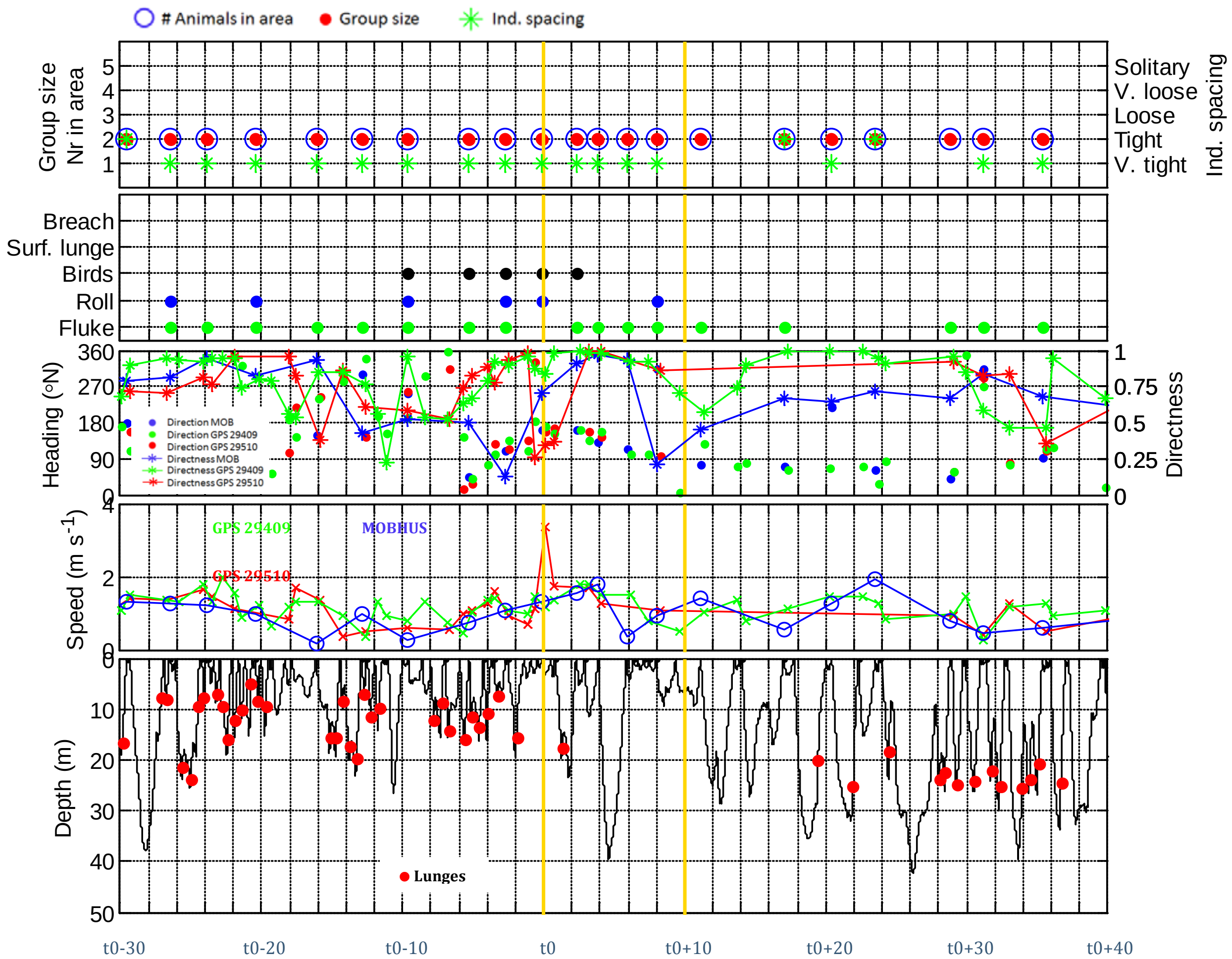
SONAR 1 – Received level



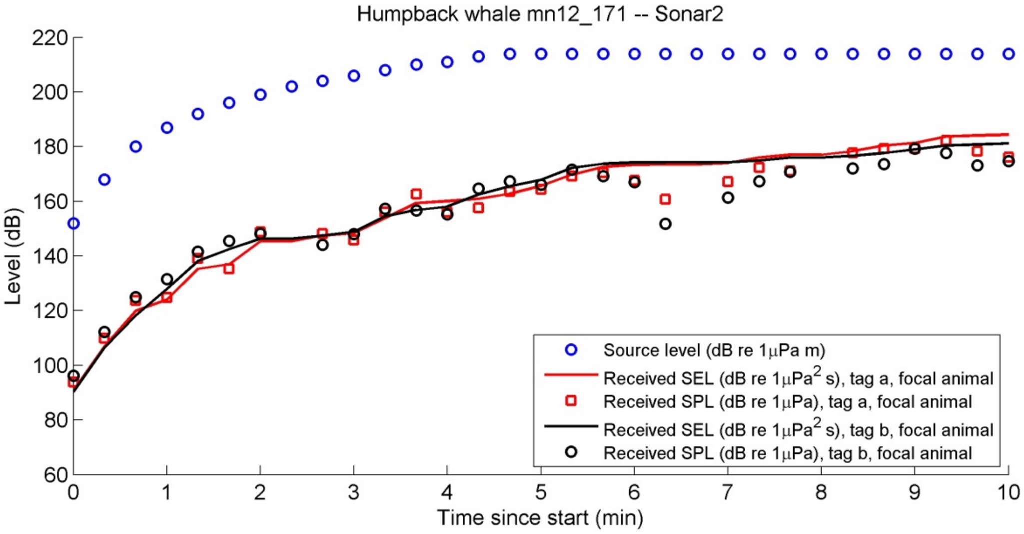
SONAR 2

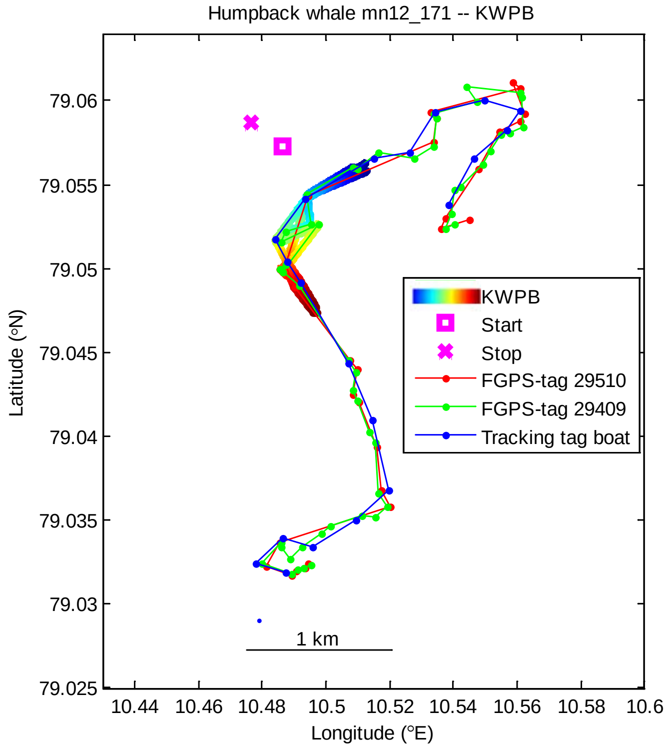

Humpback whale mn12_171 -- Sonar2
Latitude (°N)
Longitude (°E)
Sverdrup
FGPS-tag 29510
FGPS-tag 29409
Sonar2 approach
Tracking tag boat
1 km
79.06
79.055
79.05
79.045
79.04
79.035
79.03
79.025
79.02
10.25
10.3
10.35
10.4
10.45
10.5

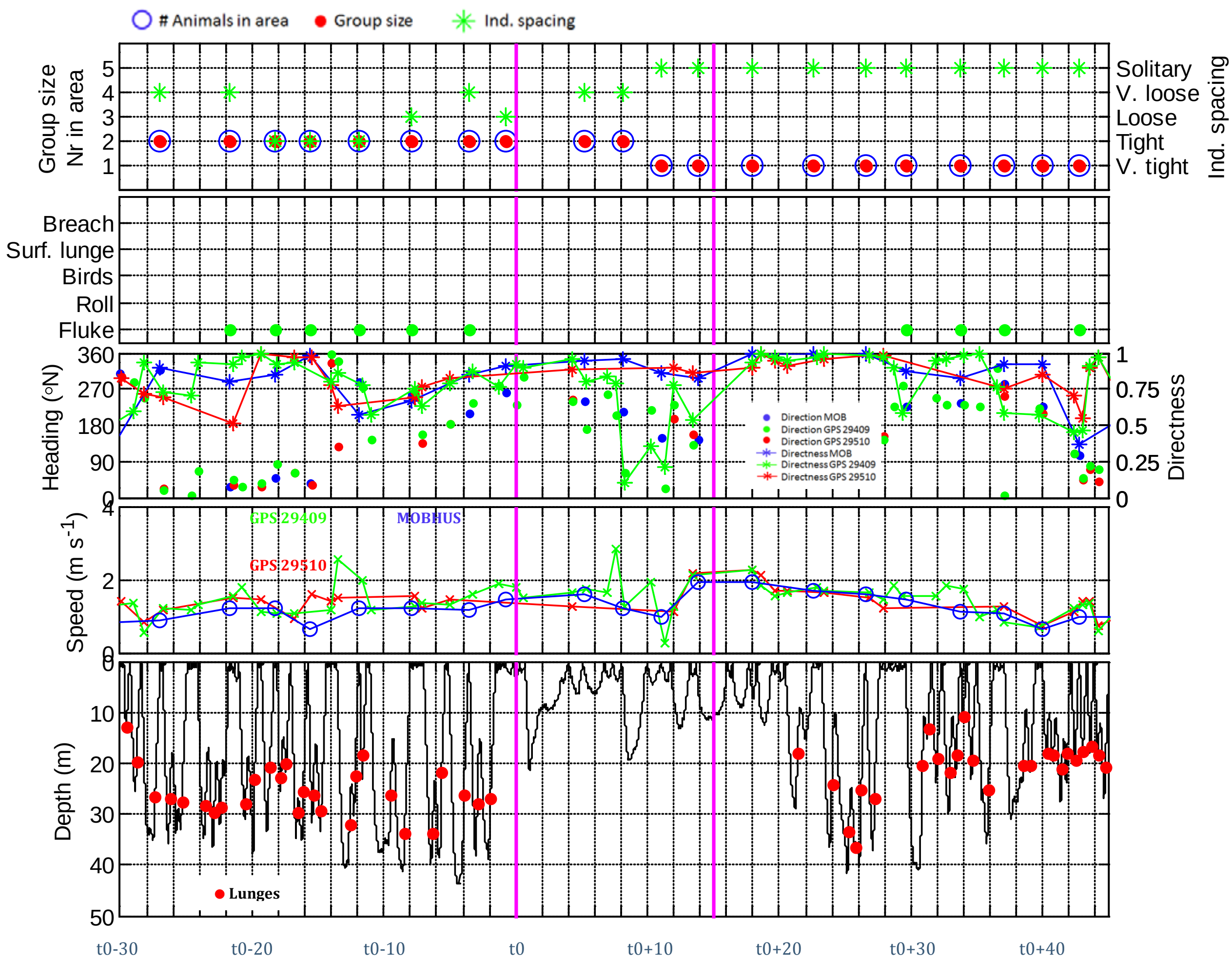

Humpback whale mn12_171 -- Sonar2
Zoomed
Latitude (°N)
Longitude (°E)
Sverdrup
FGPS-tag 29510
FGPS-tag 29409
Sonar2 approach
Tracking tag boat
79.034
79.032
79.03
79.028
79.026
79.024
79.022
79.02
79.018
79.016
10.39
10.4
10.41
10.42
10.43
10.44
10.45
10.46


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29510
Directness MOB
Directness GPS 29409
Directness GPS 29510
Speed (m s-1)
GPS 29409
MOBHUS
GPS 29510
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

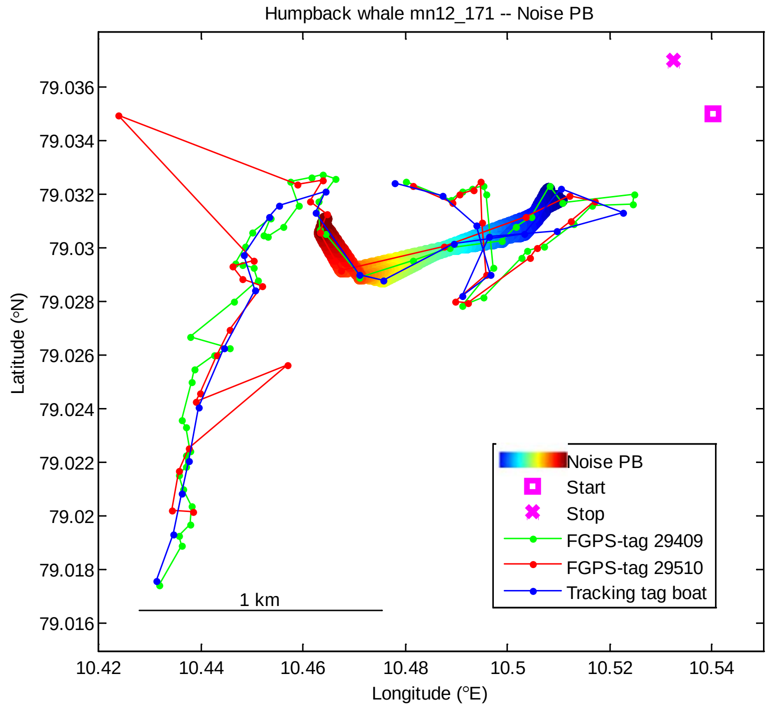
SONAR 2 – Received level

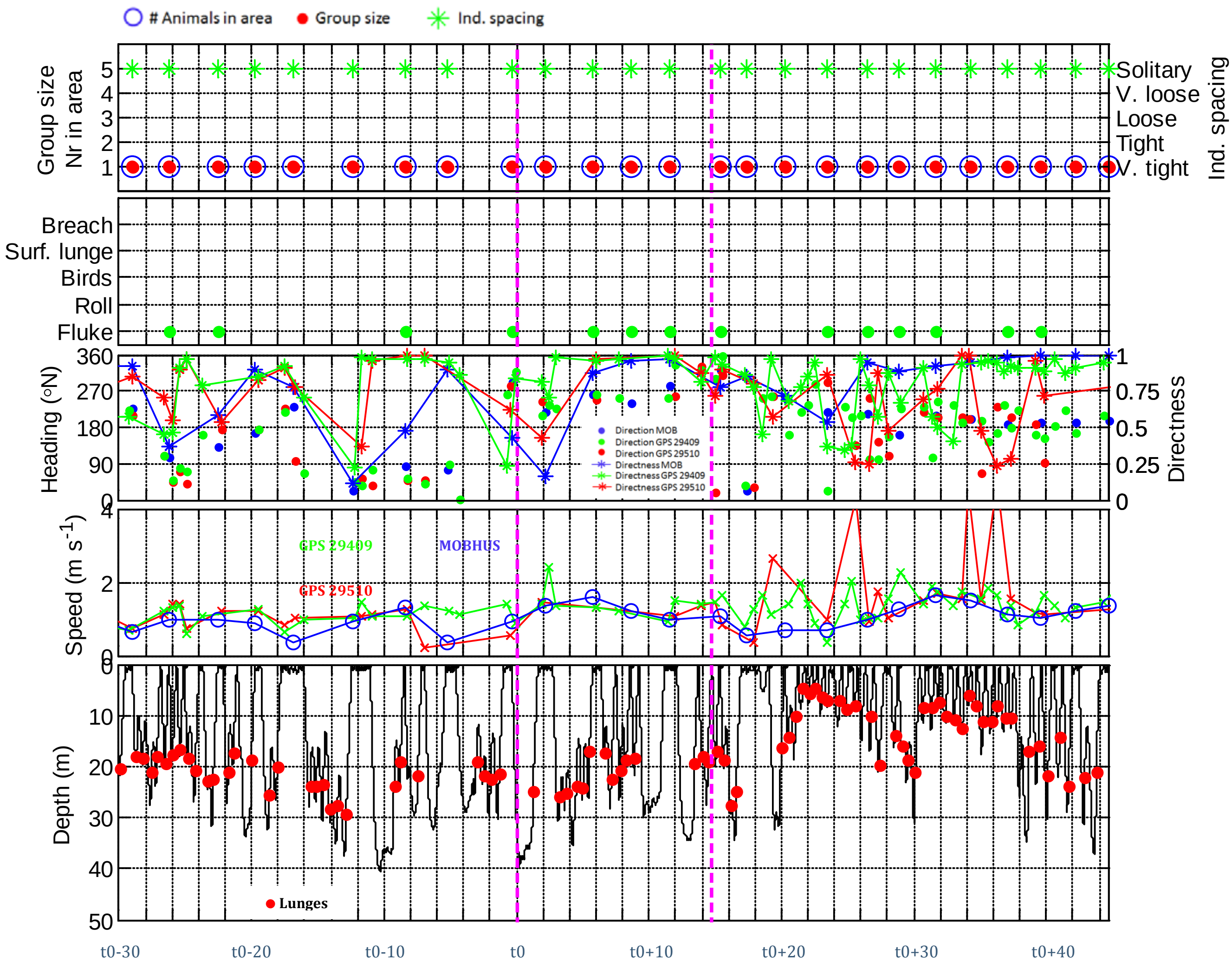



Humpback whale mn12_171 -- KWPB
Latitude (°N)
79.06
79.055
79.05
79.045
79.04
79.035
79.03
79.025
10.44 10.46 10.48 10.5 10.52 10.54 10.56 10.58 10.6
Longitude (°E)
1 km
KWPB
Start
Stop
FGPS-tag 29510
FGPS-tag 29409
Tracking tag boat


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29510
Directness MOB
Directness GPS 29409
Directness GPS 29510
GPS 29409
MOBHUS
GPS 29510
Speed (m s-1)
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

NOISE PLAYBACK





3.4.9 mn12_178a

June 26th 2012 Northwest of Bear Island. Western wind 1 (Beaufort), clouded, sea state 1. Sightings of 20-30 humpbacks in the eye of Kveithola. Tag deployed on adult animal with cantilever pole. Tag came off after the animal breached following the second sonar session, and therefore no playback experiments were conducted. Total tag on time was 8.5 hrs.

No-sonar control: started 05:15:03 UTC. CPA seemed to be perfect for intercept and timing but the animal did one very long dive during entire approach. Before start of session three other subgroups of humpback whales were sighted within 1nmi of focal animal.

Sonar 1: started 07:25:30 UTC . Difficult approach because of long dives and consequently few position updates. The intercept looked good, but timing is difficult to predict. All animals were submerged during the last 8-9 min of the approach. CPA estimated to be 750m range and 30s early.

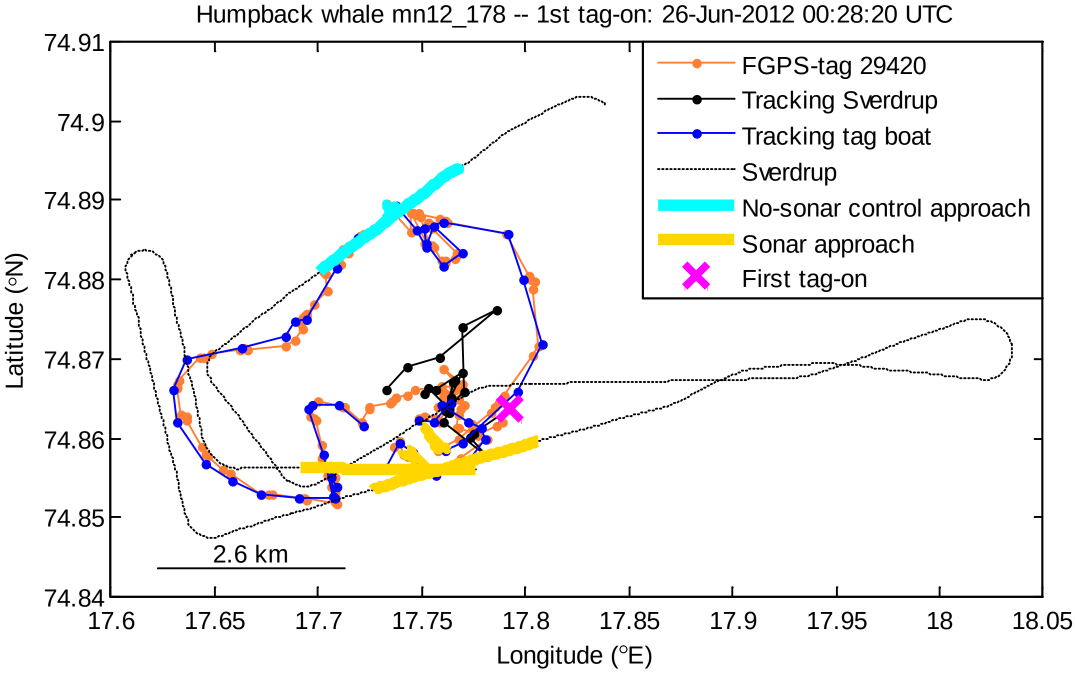
Sonar 2: started 08:46:00 UTC. CPA at 100m range but 1min too early.

09:09 UTC tag off after breaching. No playback experiments were conducted.

Biopsy: collected 10:37 UTC

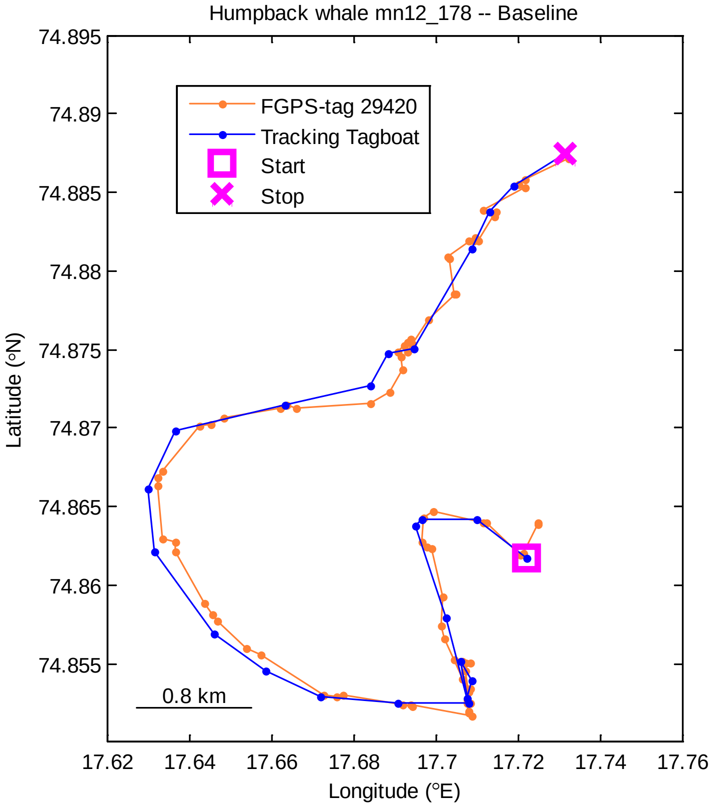
Humpback whale mn12_178 (photos by Paul Ensor).

FULL RECORD

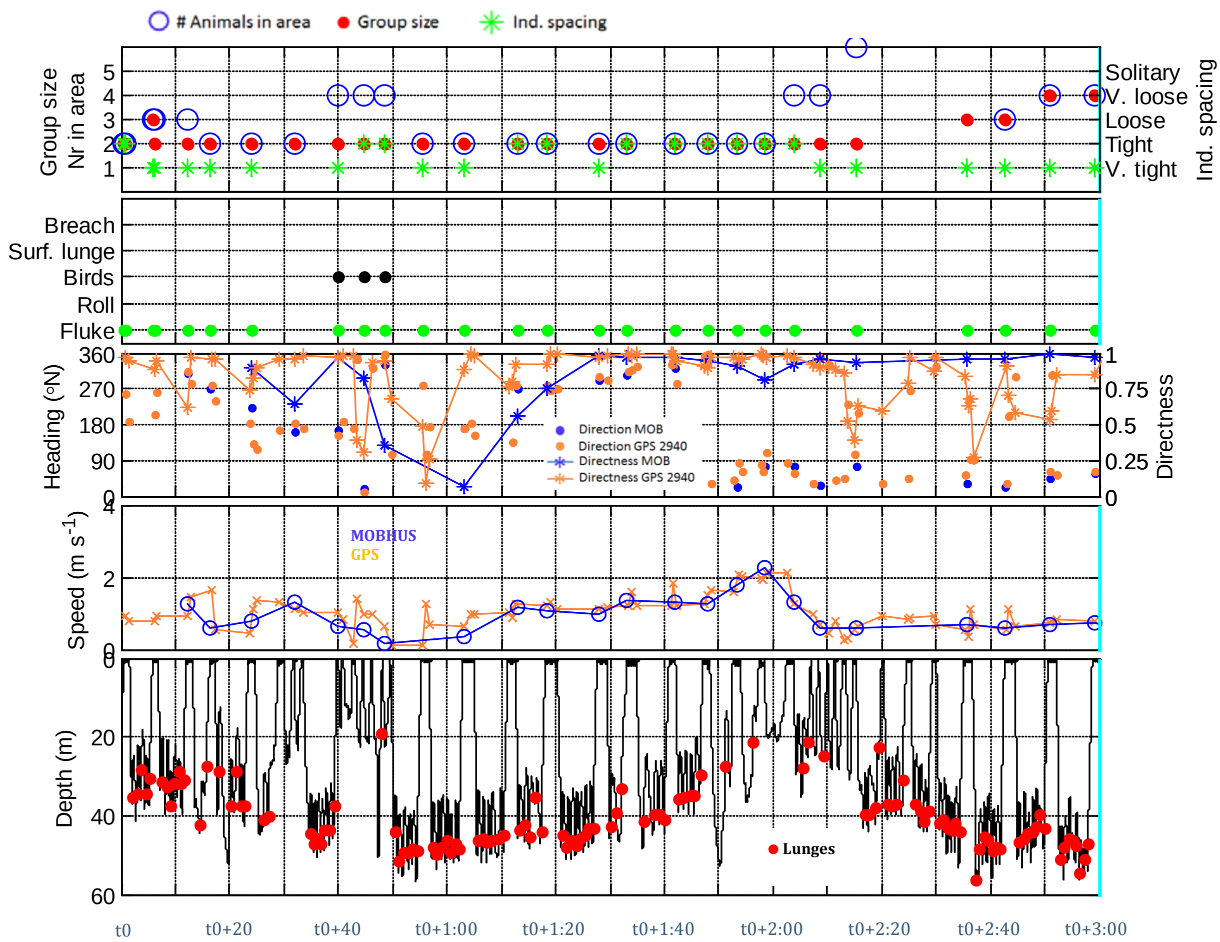

Humpback whale mn12_178 -- 1st tag-on: 26-Jun-2012 00:28:20 UTC
FGPS-tag 29420
Tracking Sverdrup
Tracking tag boat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
2.6 km
Latitude (°N)
Longitude (°E)
74.91
74.9
74.89
74.88
74.87
74.86
74.85
74.84
17.6
17.65
17.7
17.75
17.8
17.85
17.9
17.95
18
18.05

● **Lunges**

BASELINE

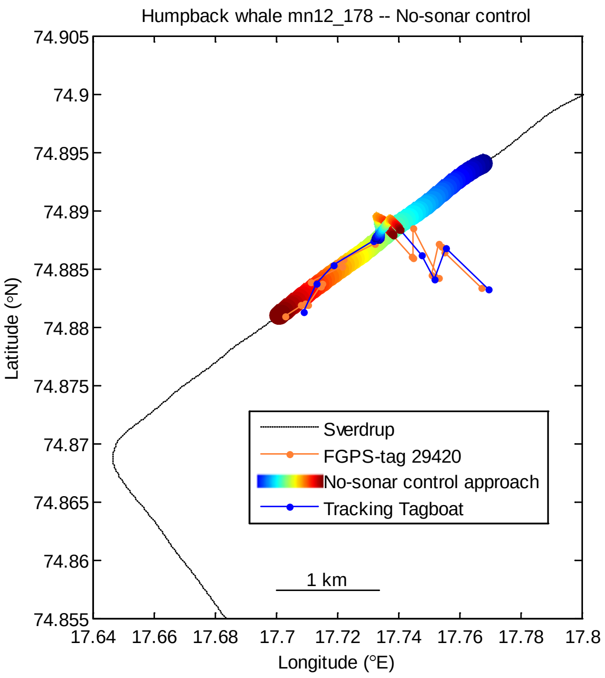


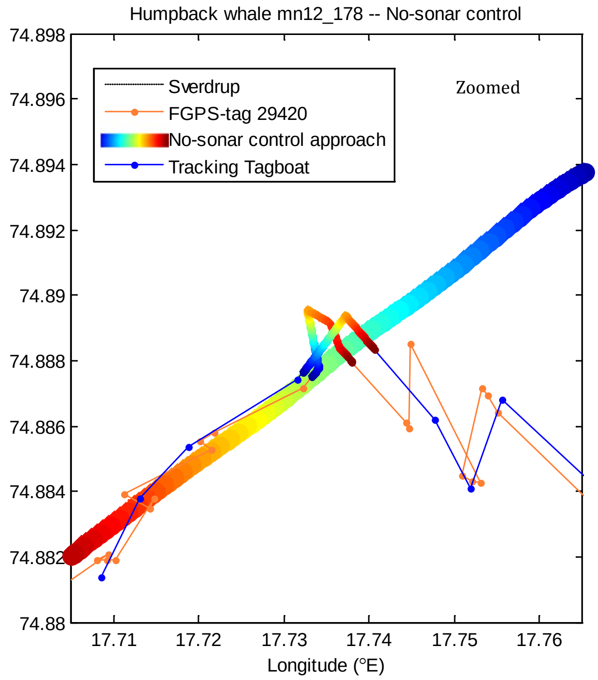
Humpback whale mn12_178 -- Baseline
FGPS-tag 29420
Tracking Tagboat
Start
Stop
0.8 km
Latitude (°N)
Longitude (°E)

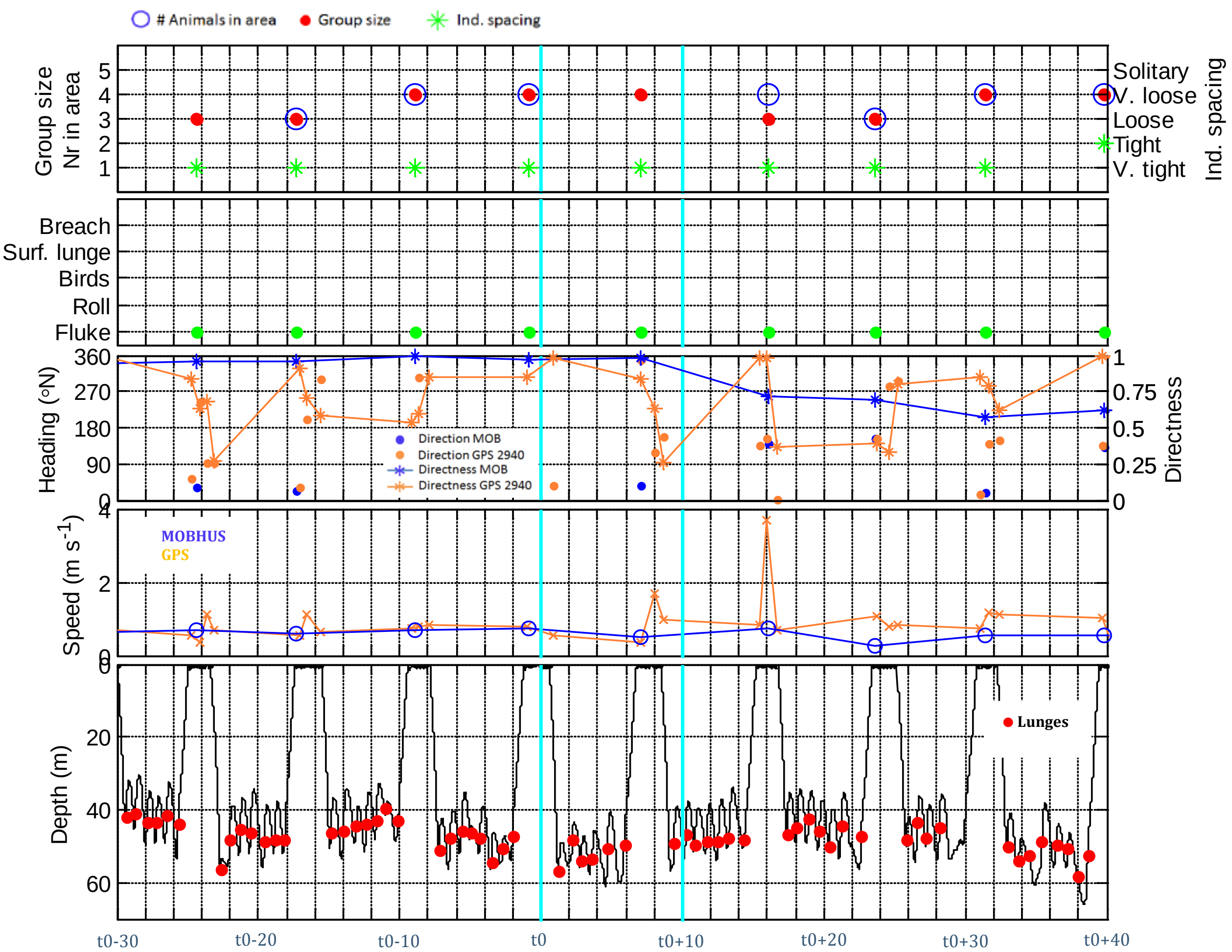


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Speed (m s-1)
MOBHUS
GPS
Depth (m)
Lunges
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

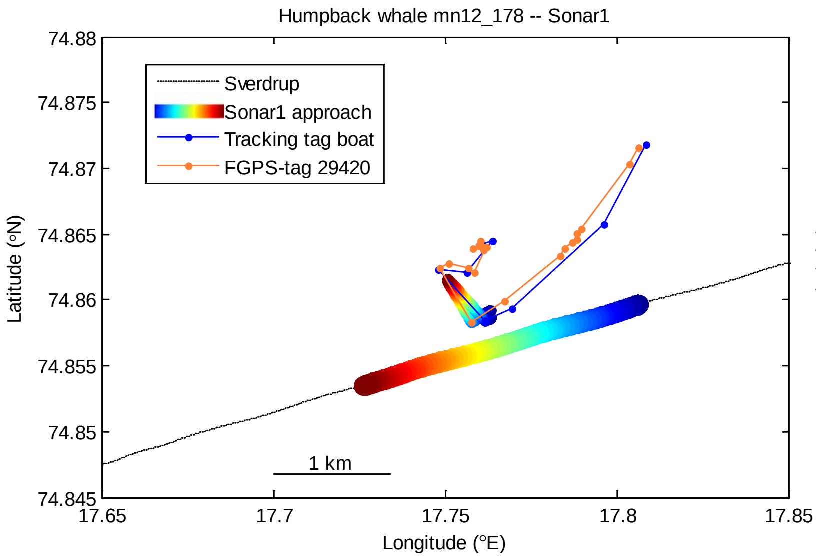
NO-SONAR CONTROL



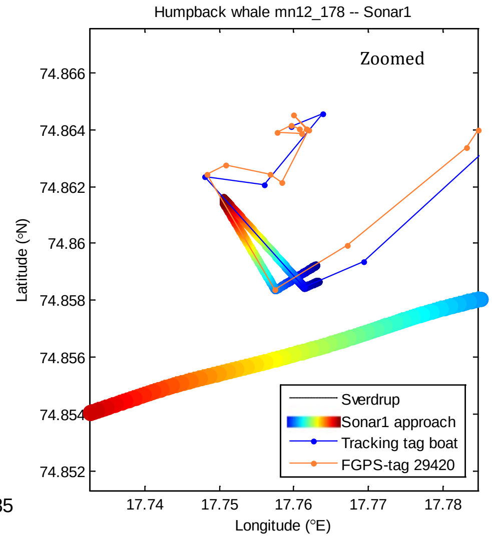




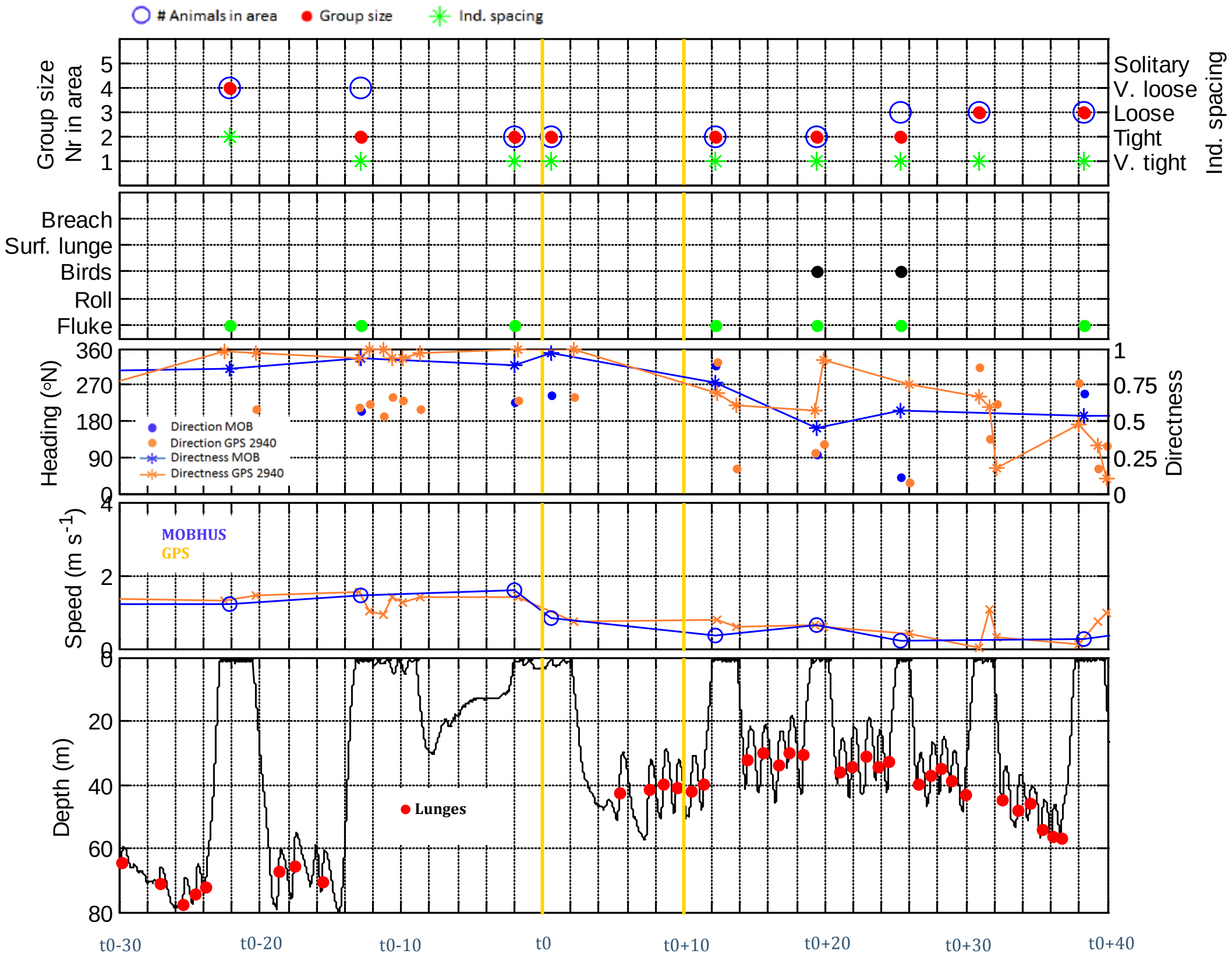
SONAR 1



Humpback whale mn12_178 -- Sonar1
Sverdrup
Sonar1 approach
Tracking tag boat
FGPS-tag 29420
1 km
Latitude (°N)
Longitude (°E)
74.88
74.875
74.87
74.865
74.86
74.855
74.85
74.845
17.65
17.7
17.75
17.8
17.85

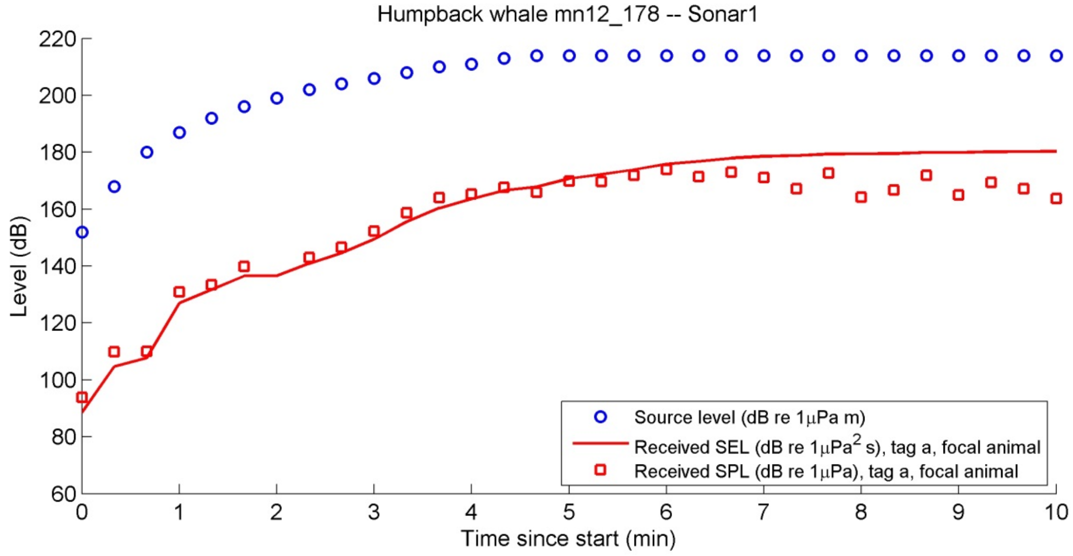


Humpback whale mn12_178 -- Sonar1
Zoomed
Sverdrup
Sonar1 approach
Tracking tag boat
FGPS-tag 29420
Latitude (°N)
Longitude (°E)
74.866
74.864
74.862
74.86
74.858
74.856
74.854
74.852
17.74
17.75
17.76
17.77
17.78

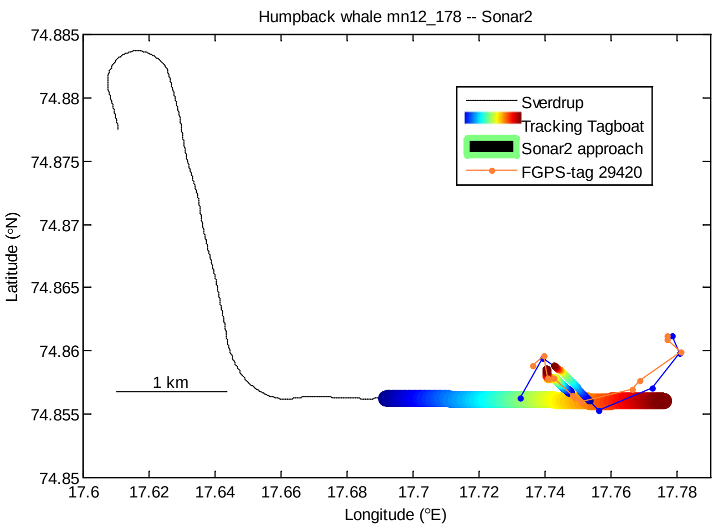


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Directness
Speed (m s-1)
MOBHUS
GPS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

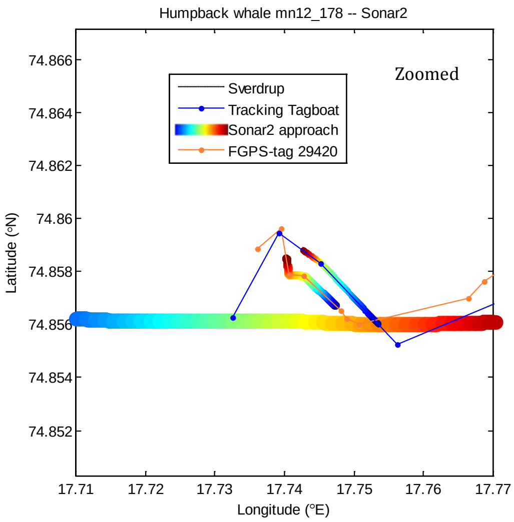
SONAR 1 – Received level



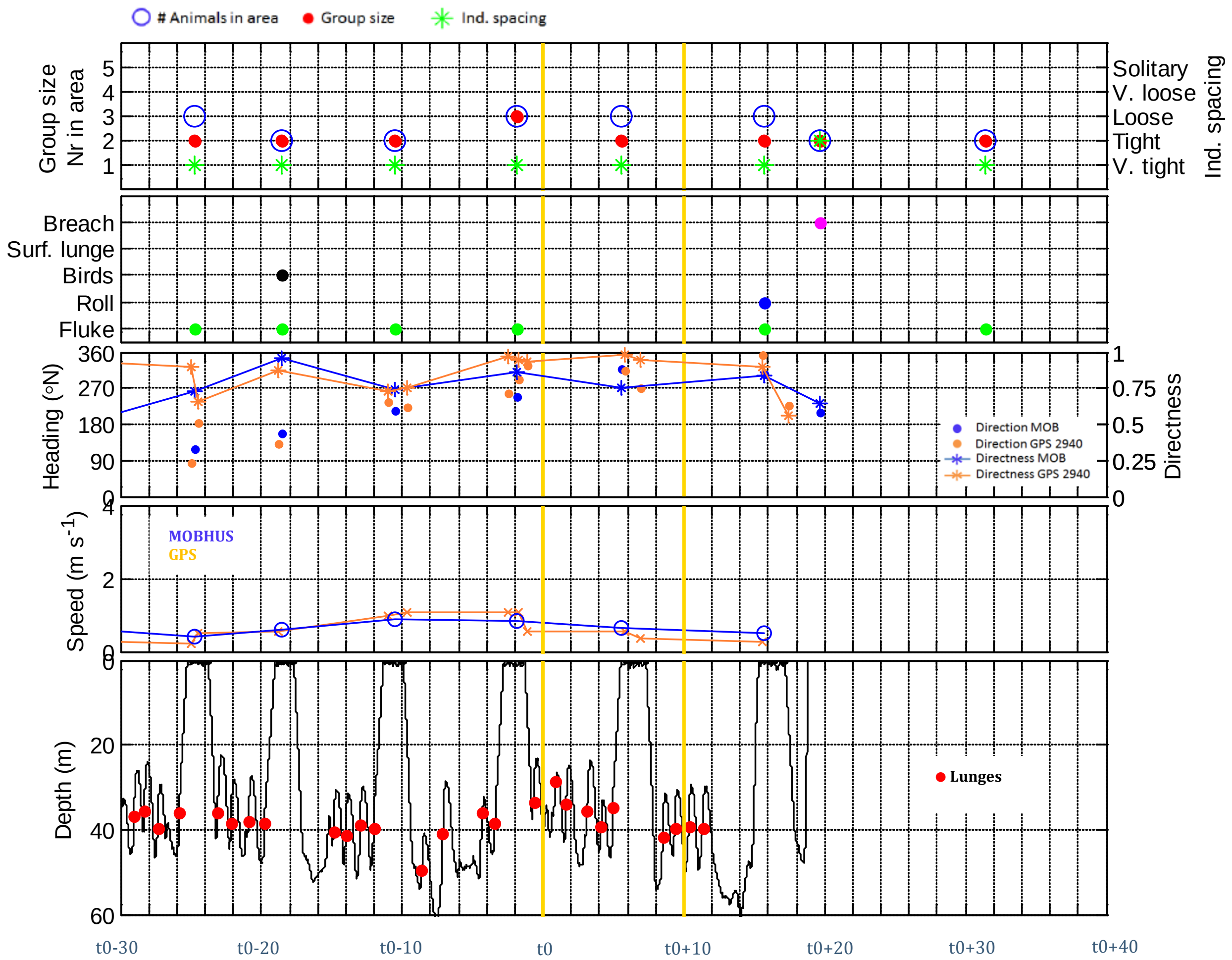
SONAR 2



Humpback whale mn12_178 -- Sonar2
Sverdrup
Tracking Tagboat
Sonar2 approach
FGPS-tag 29420
1 km
Latitude (°N)
Longitude (°E)

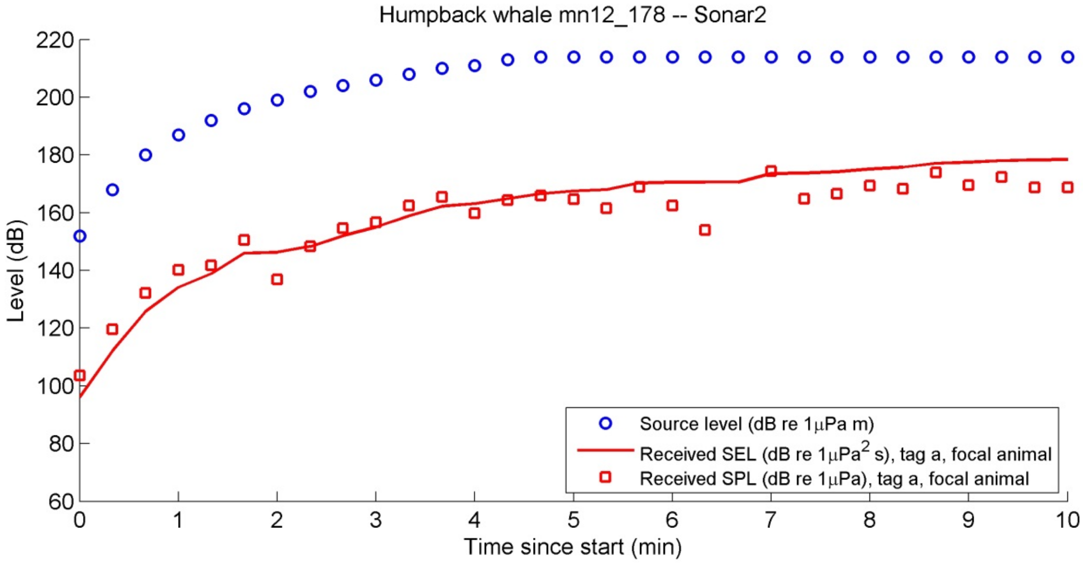


Humpback whale mn12_178 -- Sonar2
Zoomed
Sverdrup
Tracking Tagboat
Sonar2 approach
FGPS-tag 29420
Latitude (°N)
Longitude (°E)



Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
MOBHUS
GPS
Speed (m s-1)
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 2 – Received level



3.4.10 mn12_179a

June 27th South of Bear Island, northeastern wind 3 (Beaufort), changing cloud cover, sea state 2. Sightings of many humpback whales in the area. Tag deployed on large male travelling with three other animals at 07:53 UTC. Tag released after 10 hrs. Playbacks were not conducted, because of time constraint.

<u>No-sonar control:</u> started 12:19 UTC. There was a big trawlers approaching the animal at high speed at 12:24, it was asked to turn away. CPA at 400m range but timing became very wrong. The animal turned 180 deg from coming towards, to moving away around T0. In combination with long dives (few updates) the silent approach became a failure. The reason for the sudden change in direction could be the shallow water in the direction of travel. The decision was made to redo the silent approach.

<u>No-sonar control 2:</u> started 13:51 UTC. CPA at 150m range, 55s late.

<u>Sonar 1:</u> started at 15:07 UTC. CPA 1min late at 200-300m range.

<u>Sonar 2:</u> started at 16:19:00 UTC. The animal did a long dive, thus no sightings and position updates, throughout the exposure session. CPA is difficult to estimate, but looked good for intercept and timing.

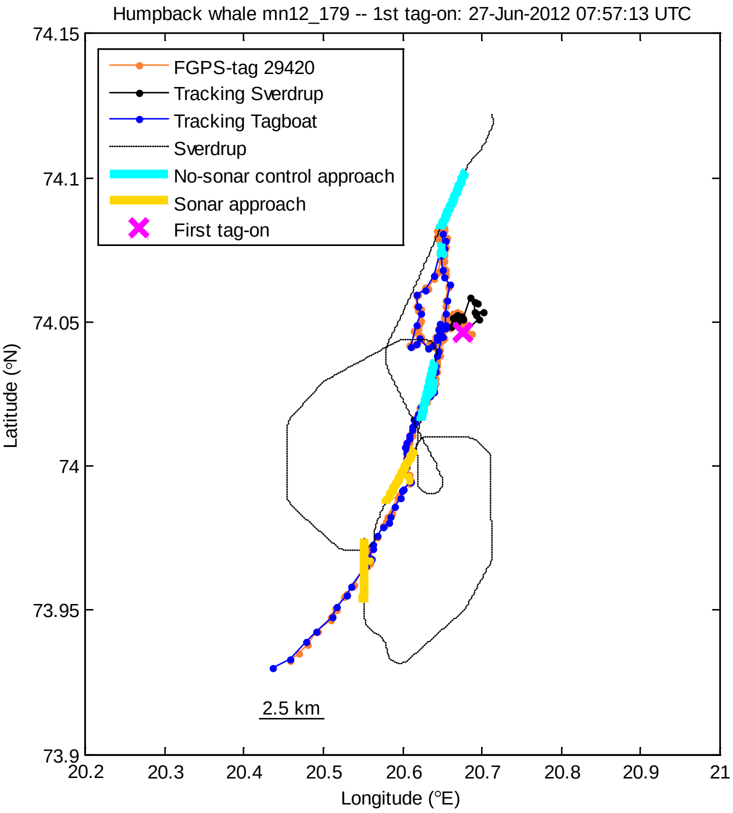
<u>No playback experiments was conducted</u>

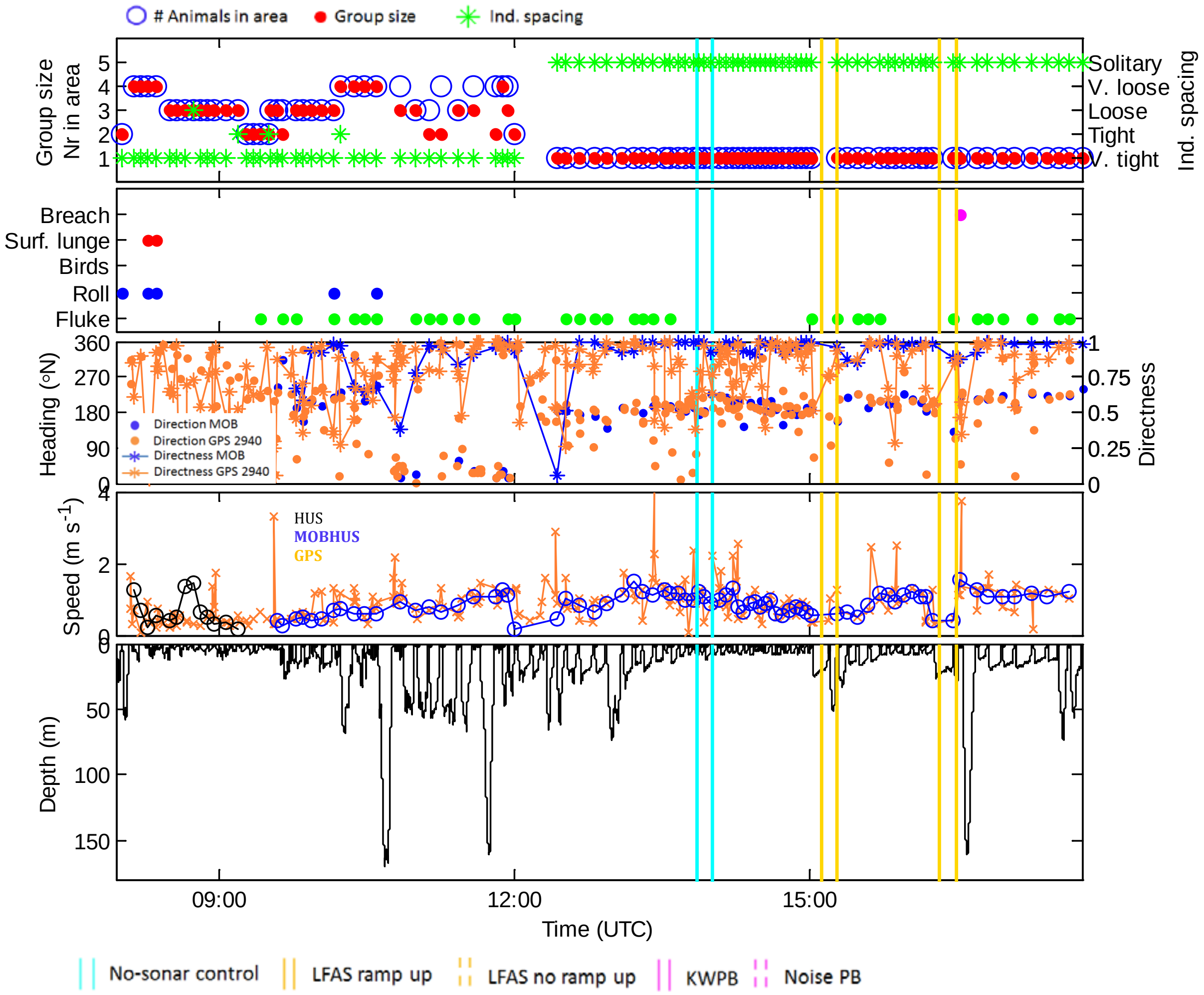
<u>Biopsy</u> collection was attempted but failed.

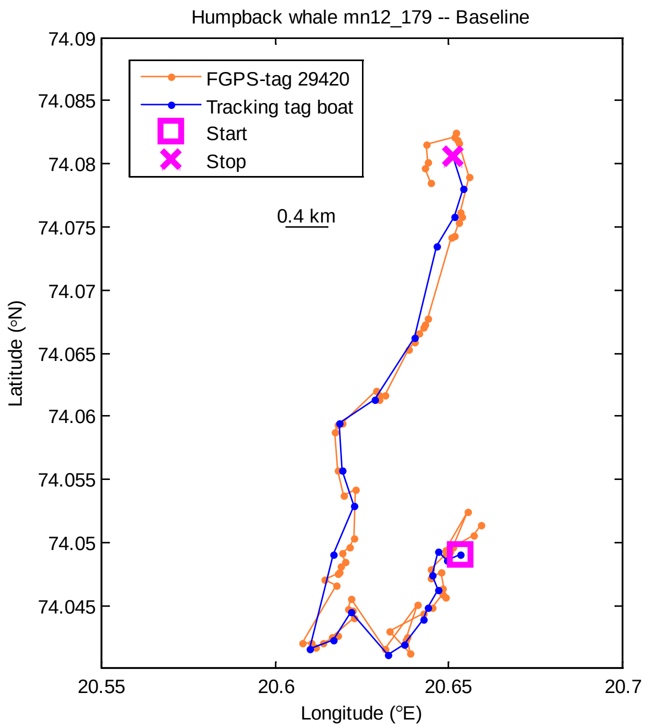
Humpback whale mn12_179 (photos by Lars Kleivane).

FULL RECORD

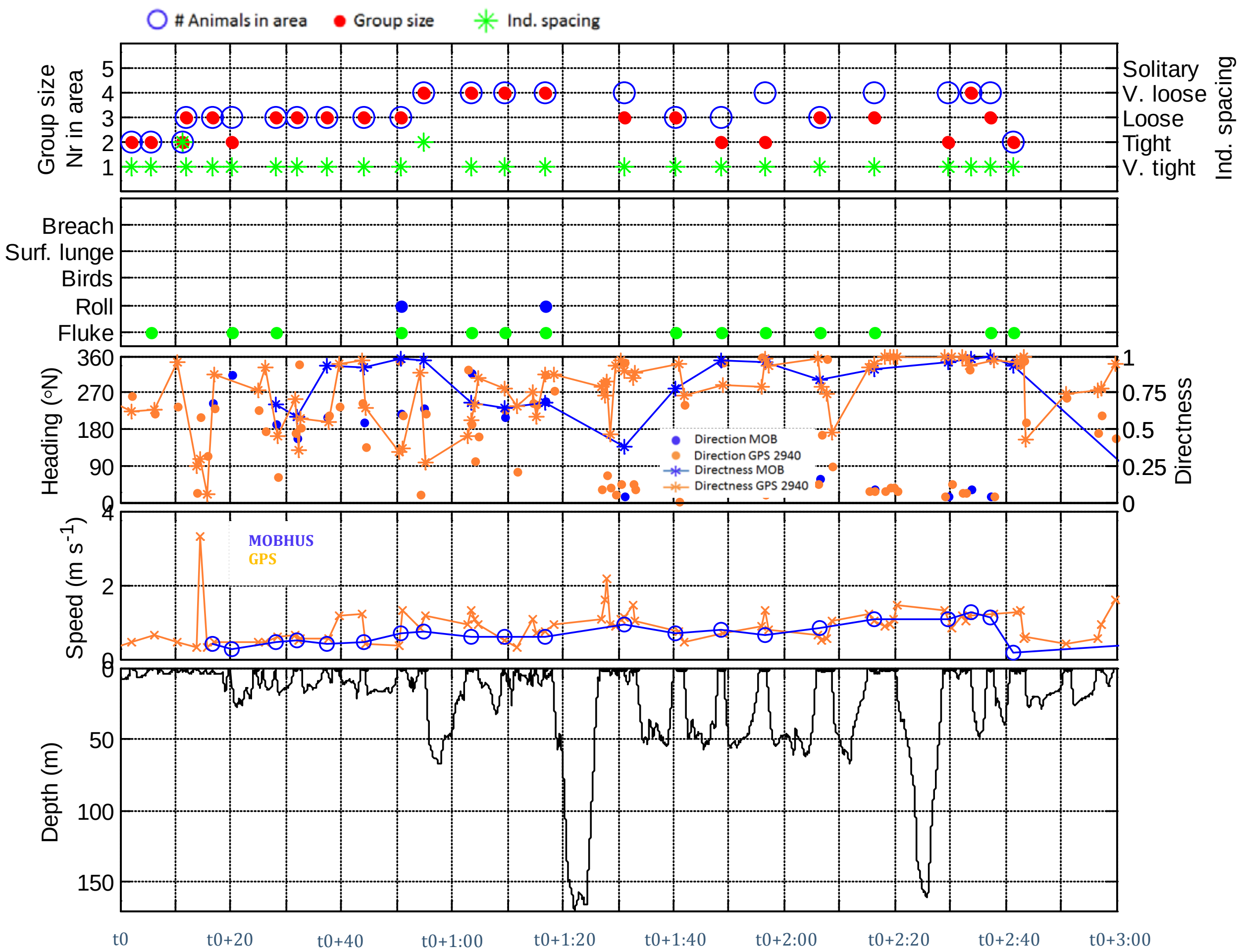

Humpback whale mn12_179 -- 1st tag-on: 27-Jun-2012 07:57:13 UTC
FGPS-tag 29420
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
2.5 km
Latitude (°N)
Longitude (°E)
74.15
74.1
74.05
74
73.95
73.9
20.2
20.3
20.4
20.5
20.6
20.7
20.8
20.9
21


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Directness
Speed (m s-1)
HUS
MOBHUS
GPS
Depth (m)
09:00
12:00
15:00
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

BASELINE

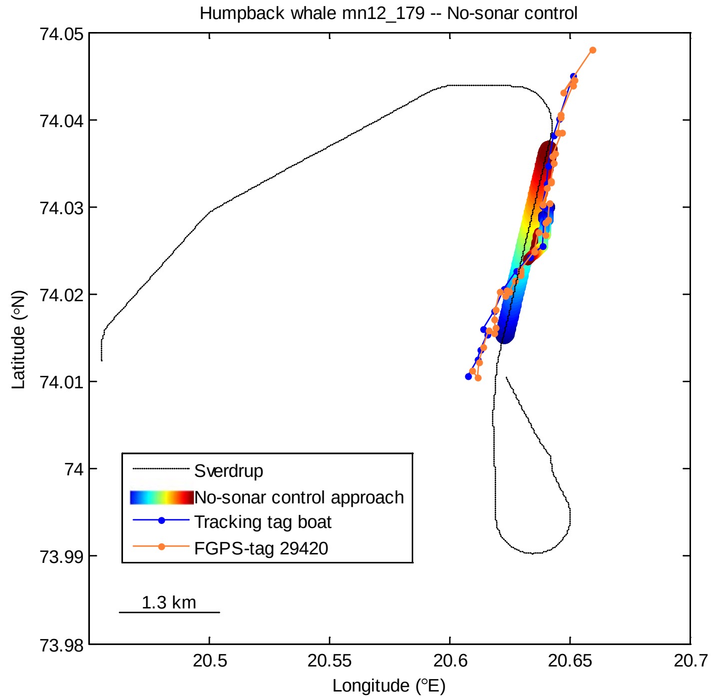


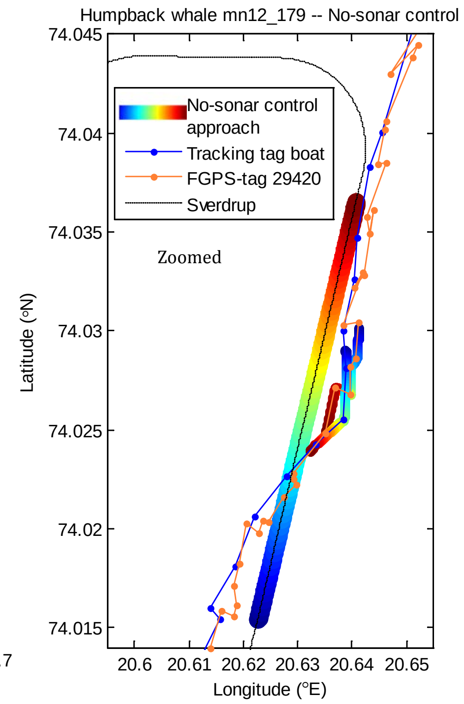
Humpback whale mn12_179 -- Baseline
FGPS-tag 29420
Tracking tag boat
Start
Stop
0.4 km
Latitude (°N)
Longitude (°E)

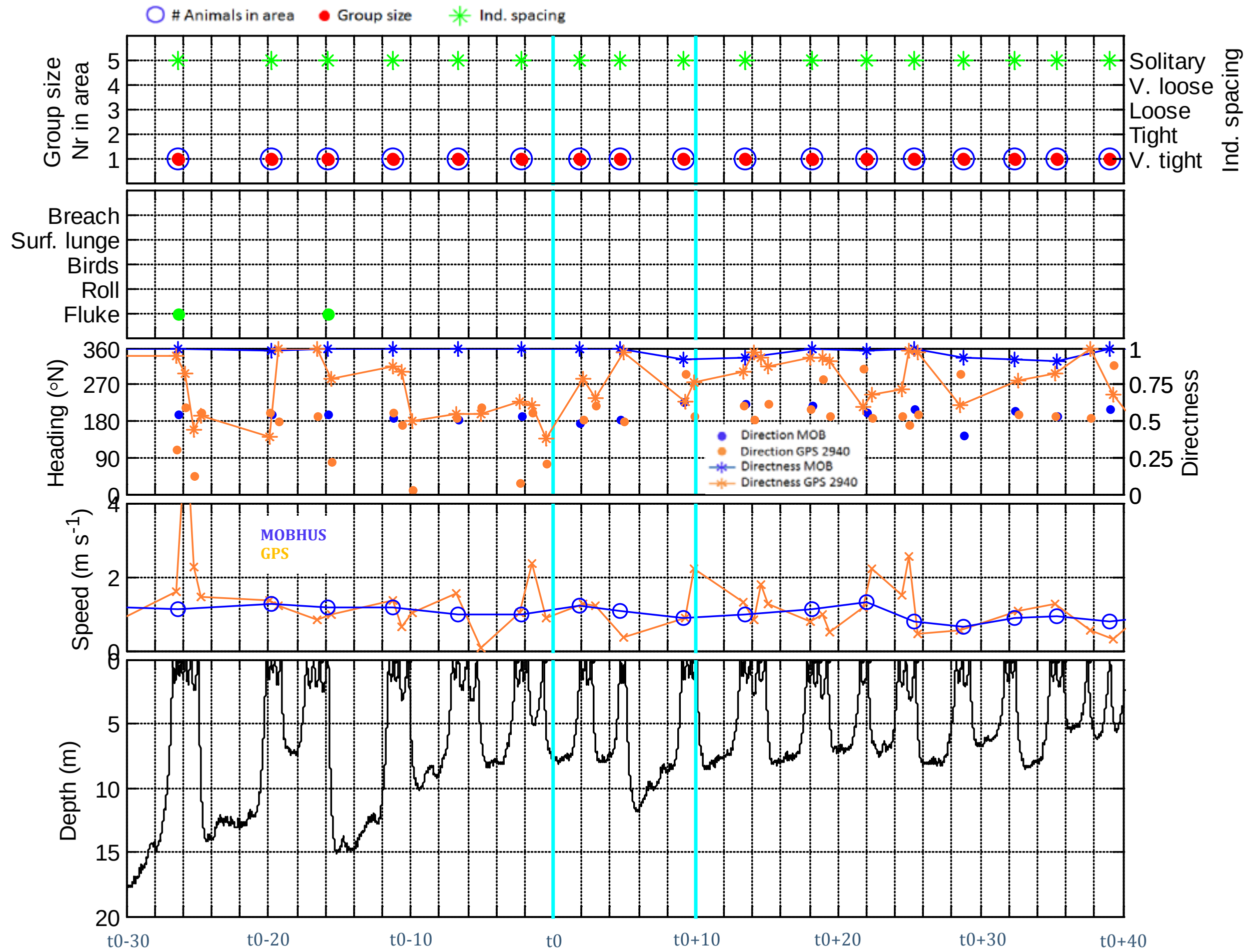


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Directness
Speed (m s-1)
MOBHUS
GPS
Depth (m)
t0
t0+20
t0+40
t0+1:00
t0+1:20
t0+1:40
t0+2:00
t0+2:20
t0+2:40
t0+3:00

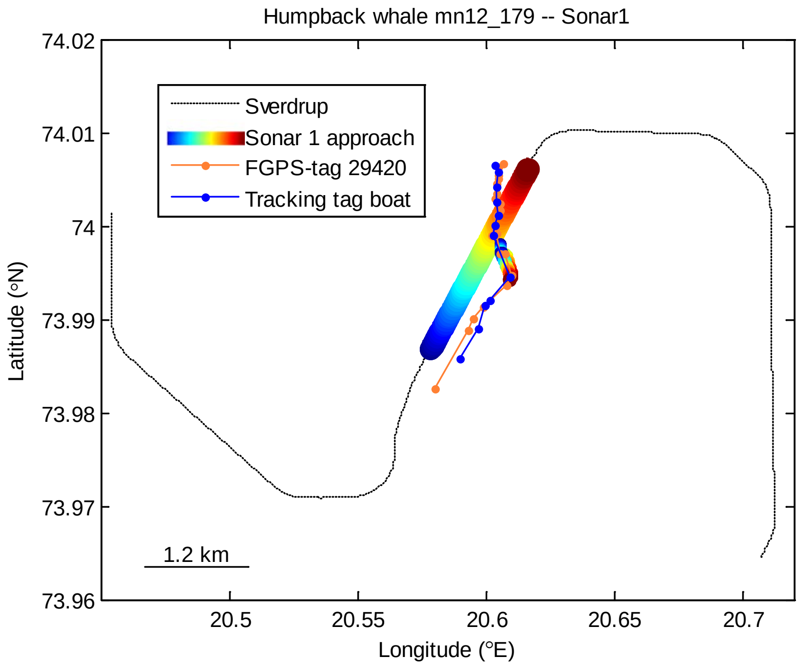
NO-SONAR CONTROL

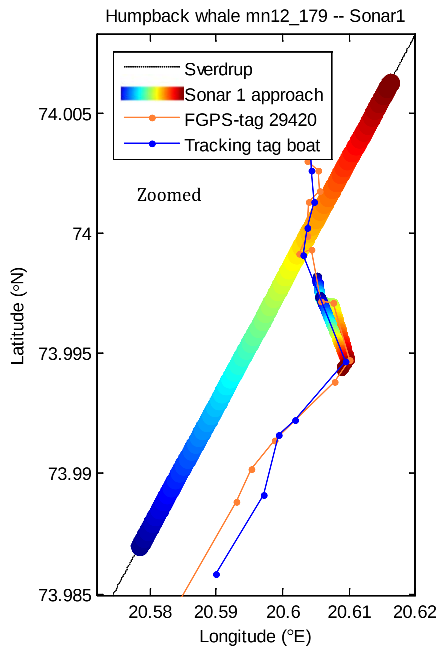


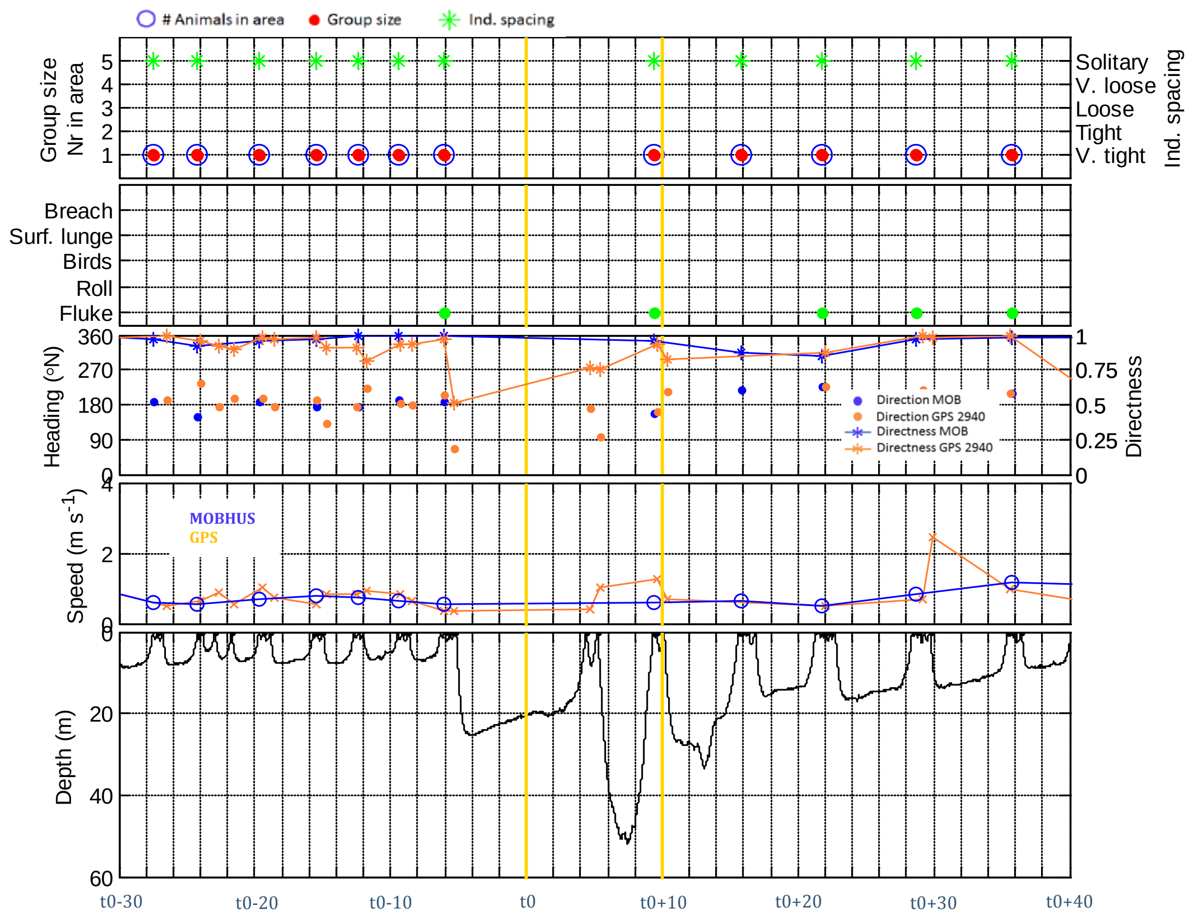




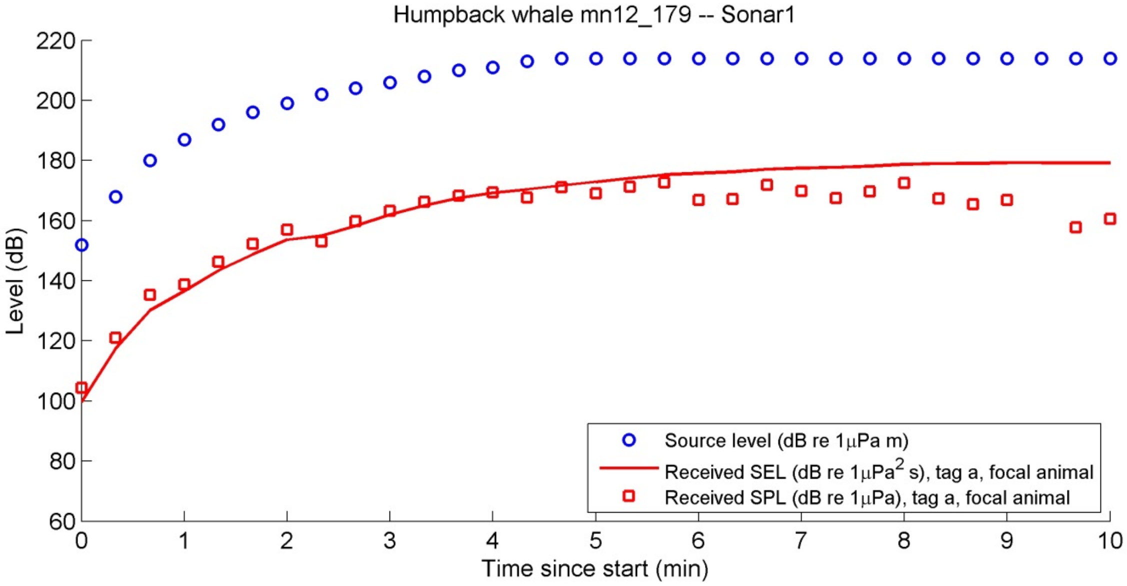
SONAR 1


Humpback whale mn12_179 -- Sonar1
Sverdrup
Sonar 1 approach
FGPS-tag 29420
Tracking tag boat
1.2 km
Latitude (°N)
Longitude (°E)
74.02
74.01
74
73.99
73.98
73.97
73.96
20.5
20.55
20.6
20.65
20.7

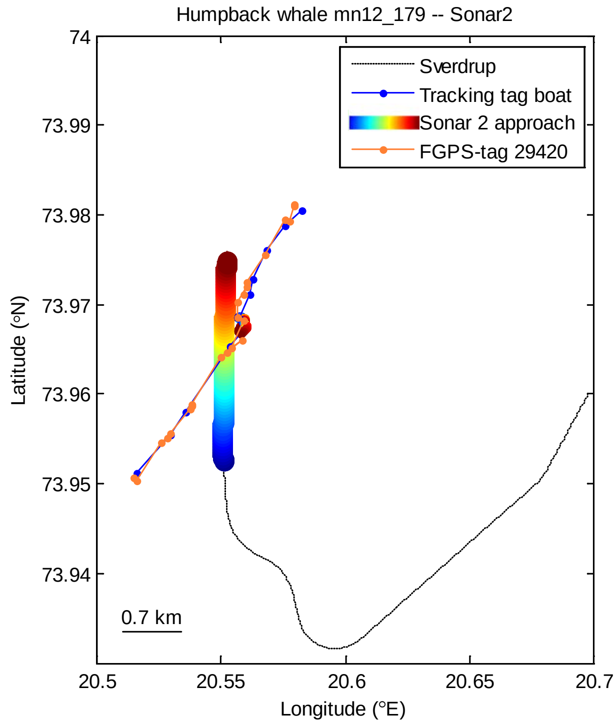

Humpback whale mn12_179 -- Sonar1
Sverdrup
Sonar 1 approach
FGPS-tag 29420
Tracking tag boat
Zoomed
Latitude (°N)
Longitude (°E)
74.005
74
73.995
73.99
73.985
20.58
20.59
20.6
20.61
20.62

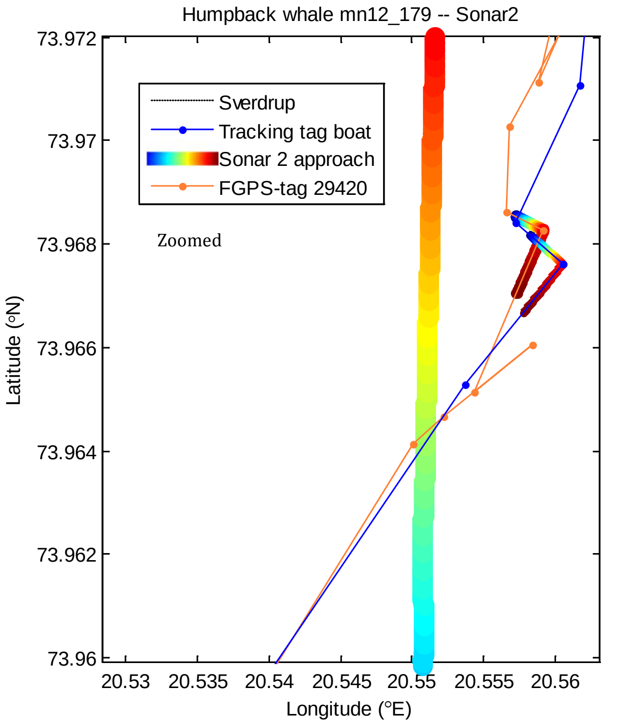

Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Speed (m s-1)
MOBHUS
GPS
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

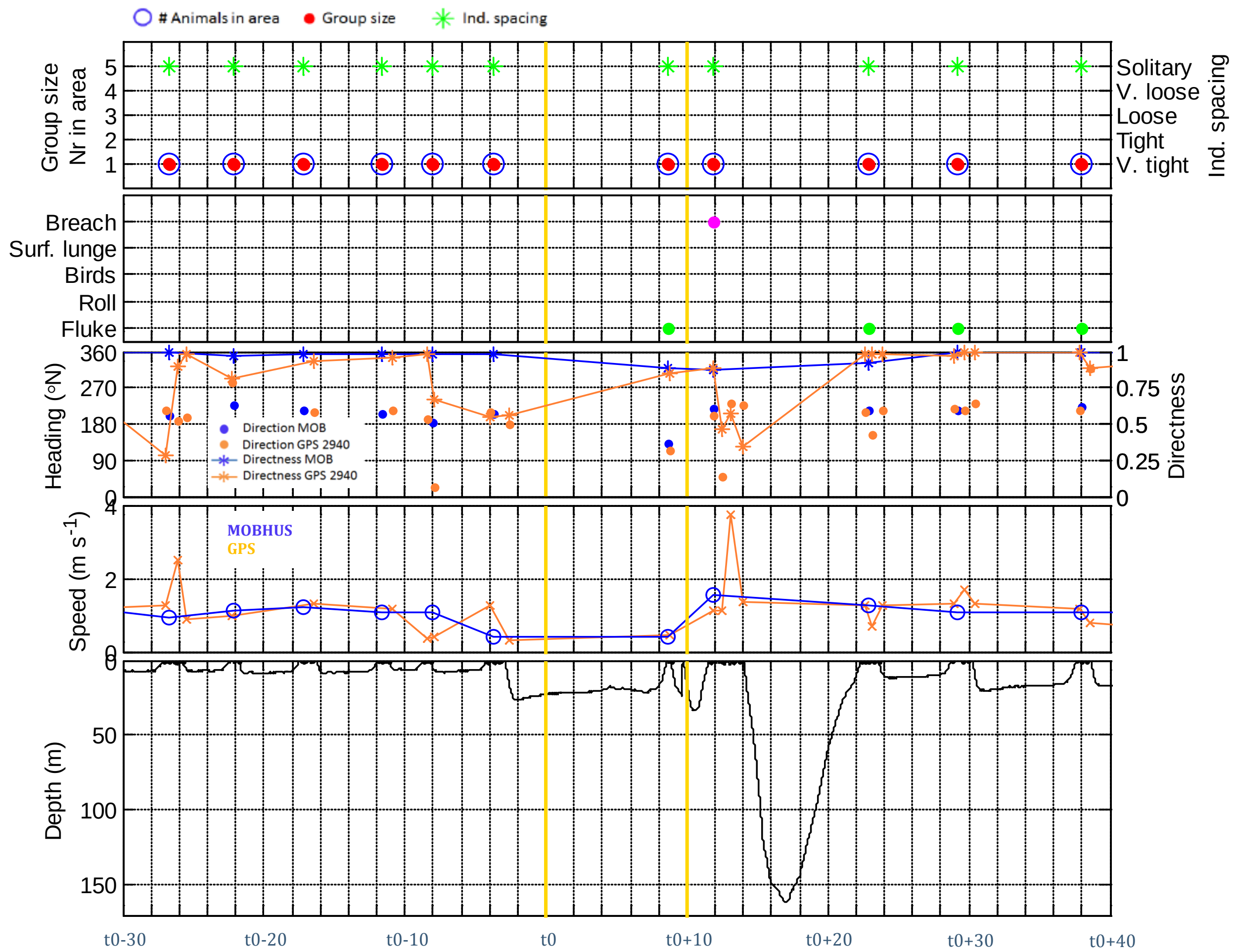
SONAR 1 – Received level



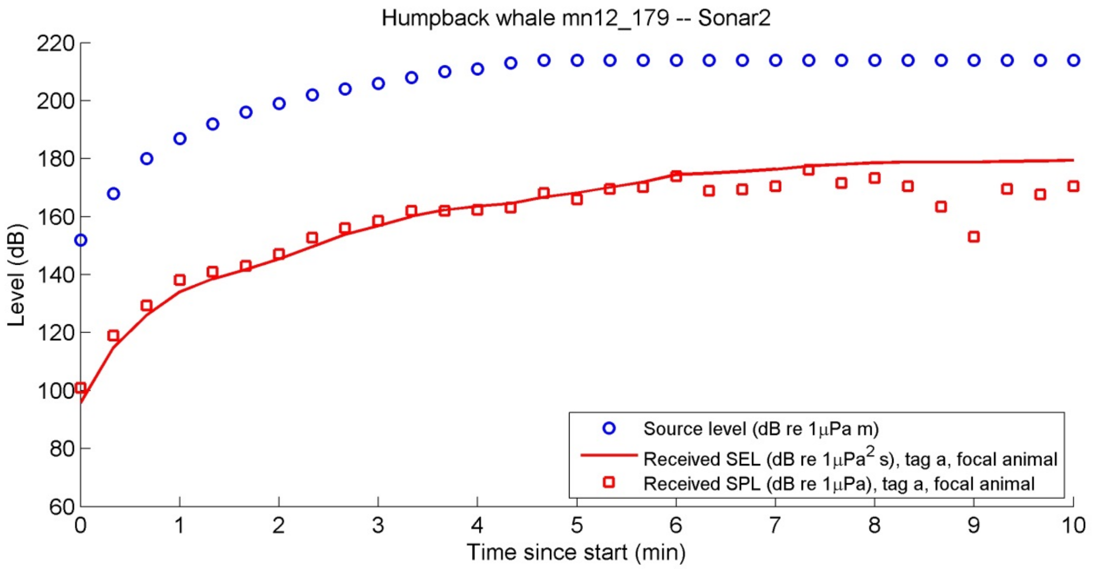
SONAR 2


Humpback whale mn12_179 -- Sonar2
Sverdrup
Tracking tag boat
Sonar 2 approach
FGPS-tag 29420
0.7 km
Latitude (°N)
Longitude (°E)
74
73.99
73.98
73.97
73.96
73.95
73.94
20.5
20.55
20.6
20.65
20.7


Humpback whale mn12_179 -- Sonar2
Sverdrup
Tracking tag boat
Sonar 2 approach
FGPS-tag 29420
Zoomed
Latitude (°N)
Longitude (°E)
73.972
73.97
73.968
73.966
73.964
73.962
73.96
20.53
20.535
20.54
20.545
20.55
20.555
20.56


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Direction MOB
Direction GPS 2940
Directness MOB
Directness GPS 2940
Directness
Speed (m s-1)
MOBHUS
GPS
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 2 – Received level



3.4.11 mn12_180ab

June 28th in Leirdjupet Northeast of Bear Island. Western wind 2 (Beaufort), changing cloud cover, sea state 2. Two tags placed on the same animal at 16:03 and 17:08 UTC. Distant seismic signals were recorded on the towed array during most of this experiment.

No-sonar control: started 21:01:00. Animals moved away from our sailing path, CPA at 250m range.

Sonar 1: We missed the first ping of ramp up. Approach was good, timing at little early, but this could be caused by the behavior of the animal. CPA estimated to 250m range. At least 5 other animals (humpbacks) were sighted within 1000 m range during the approach, they were all feeding close to the surface with many birds around.

The next sonar session was delayed because the animal stopped feeding during Sonar 1, and returned to normal feeding just prior to the planned second session.

Sonar 2: Good approach, estimated CPA at 150m range. Four other animals (humpbacks) within 1000m range during approach. Two groups of two animals, one mother calf pair. Focal group surfaced frequently during this session (2-3min dives). Animals moved slowly all the time.

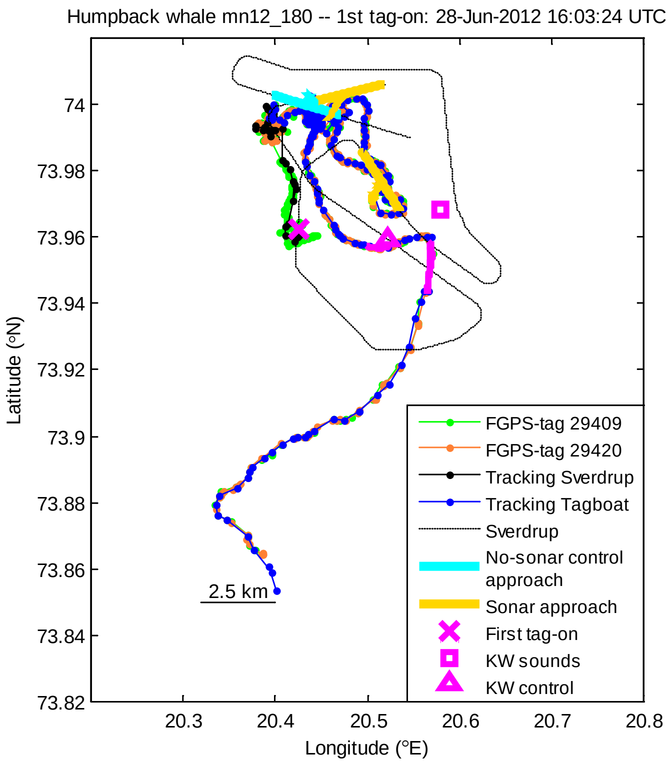
Killer whale and noise playback: successfully conducted, but no comments noted.

First tag off came off at 07:00 and second tag off at 07:40 UTC . The focal animal was repeatedly associated with large groups of dolphins in the post-exposure phase.

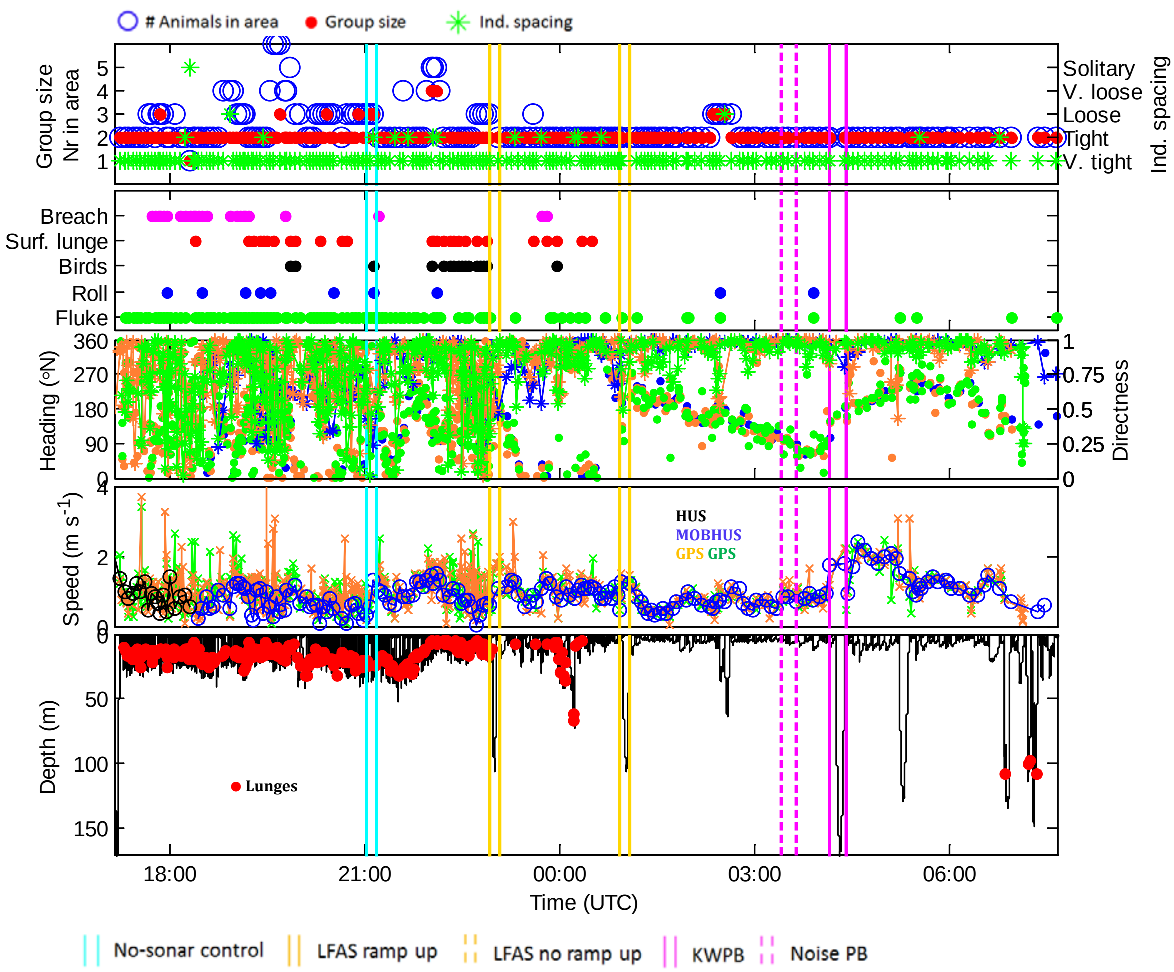
Biopsy collected of focal and associated animals between 07:30-08:30 UTC .

Humpback whale mn12_180 travelling with a small calf (photos by Lars Kleivane).

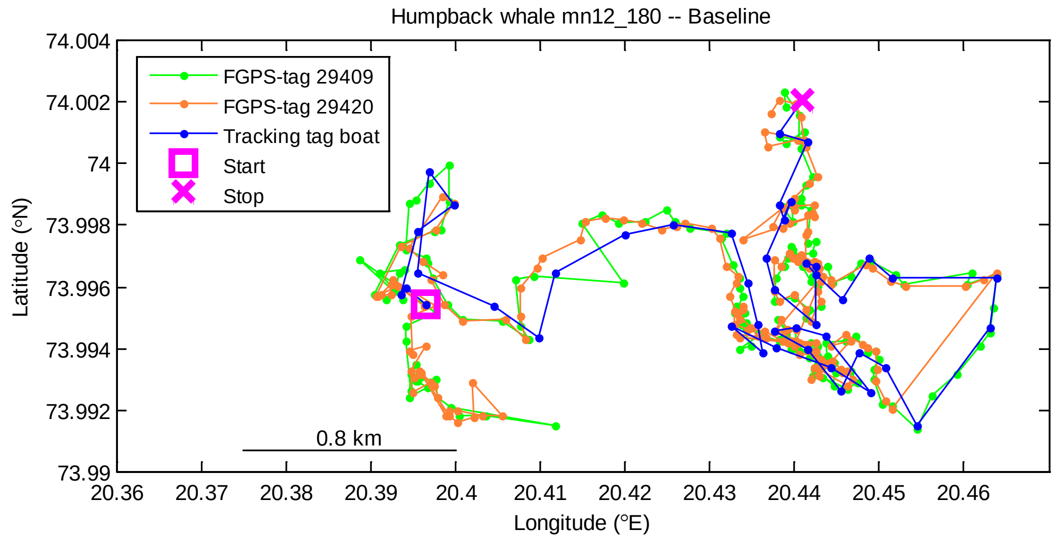
FULL RECORD

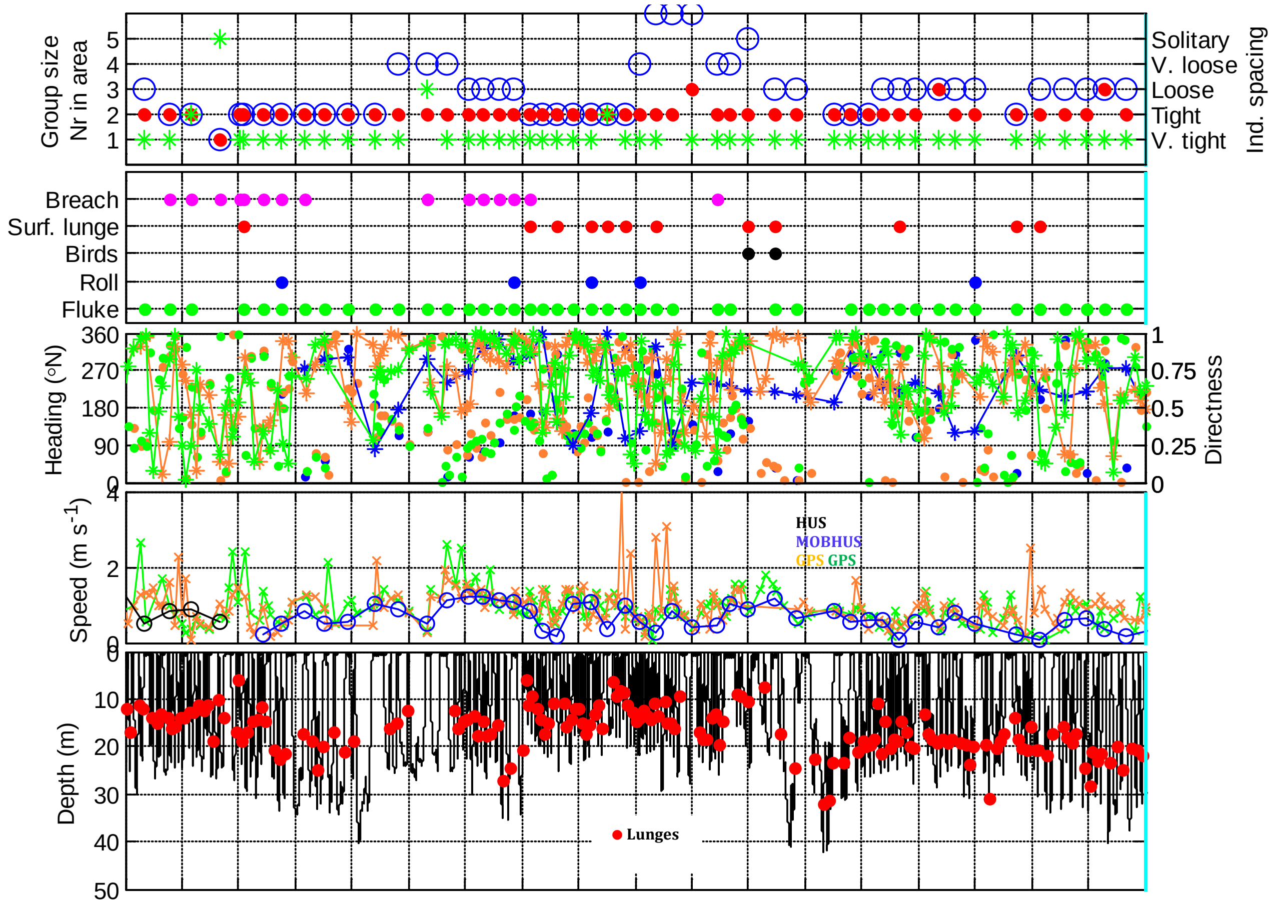


Humpback whale mn12_180 -- 1st tag-on: 28-Jun-2012 16:03:24 UTC
Latitude (°N)
Longitude (°E)
2.5 km
FGPS-tag 29409
FGPS-tag 29420
Tracking Sverdrup
Tracking Tagboat
Sverdrup
No-sonar control approach
Sonar approach
First tag-on
KW sounds
KW control

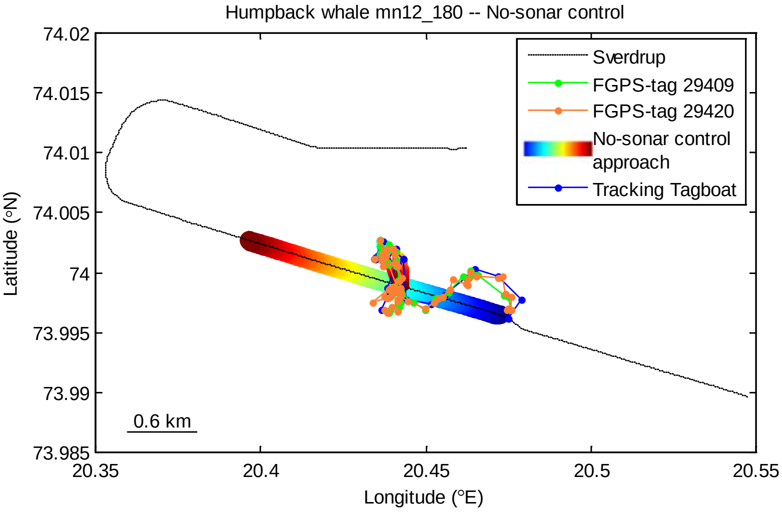


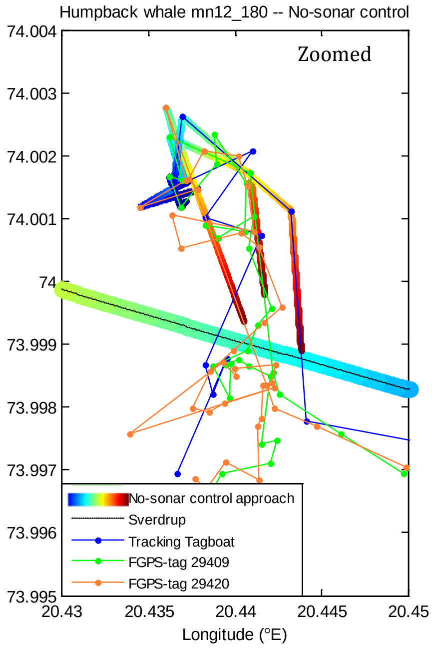
Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Speed (m s-1)
HUS
MOBHUS
GPS GPS
Depth (m)
Lunges
Time (UTC)
No-sonar control
LFAS ramp up
LFAS no ramp up
KWPB
Noise PB

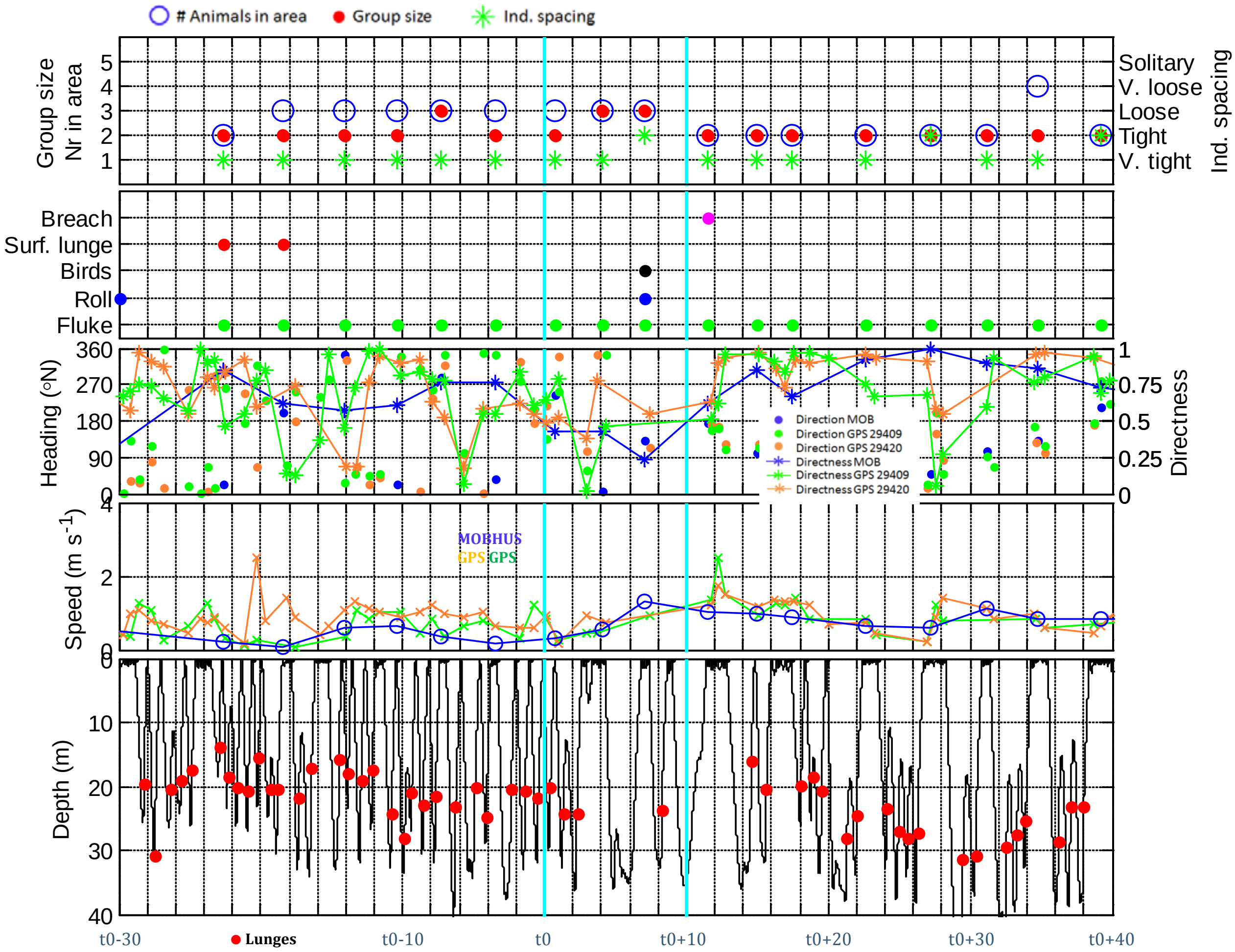

Humpback whale mn12_180 -- Baseline
FGPS-tag 29409
FGPS-tag 29420
Tracking tag boat
Start
Stop
0.8 km
Latitude (°N)
Longitude (°E)
74.004
74.002
74
73.998
73.996
73.994
73.992
73.99
20.36
20.37
20.38
20.39
20.4
20.41
20.42
20.43
20.44
20.45
20.46


Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Speed (m s-1)
HUS
MOBHUS
GPS GPS
Depth (m)
Lunges

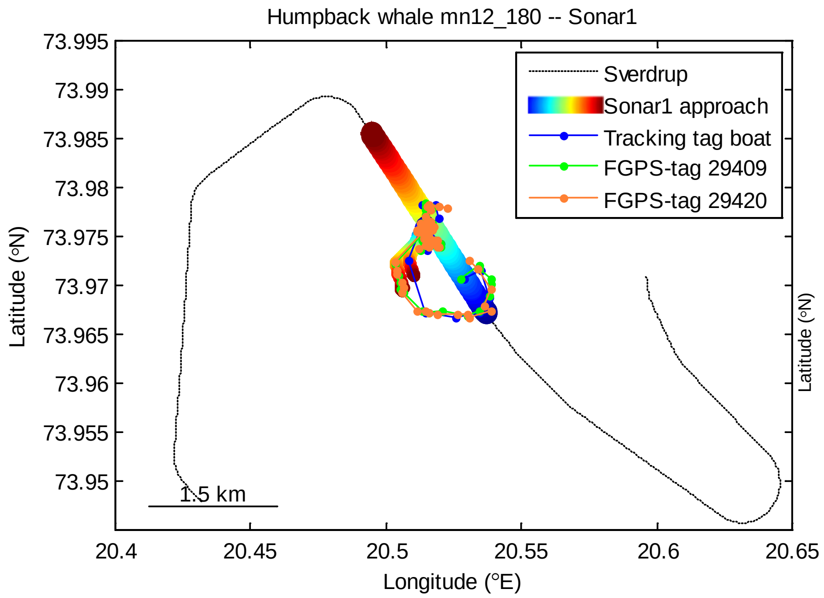
NO-SONAR CONTROL

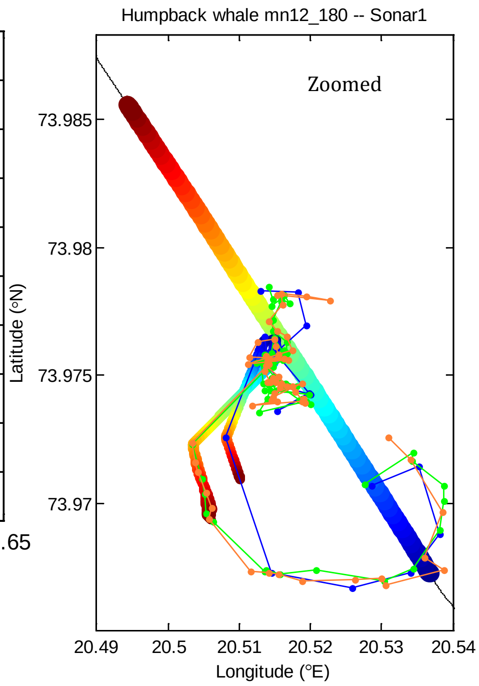


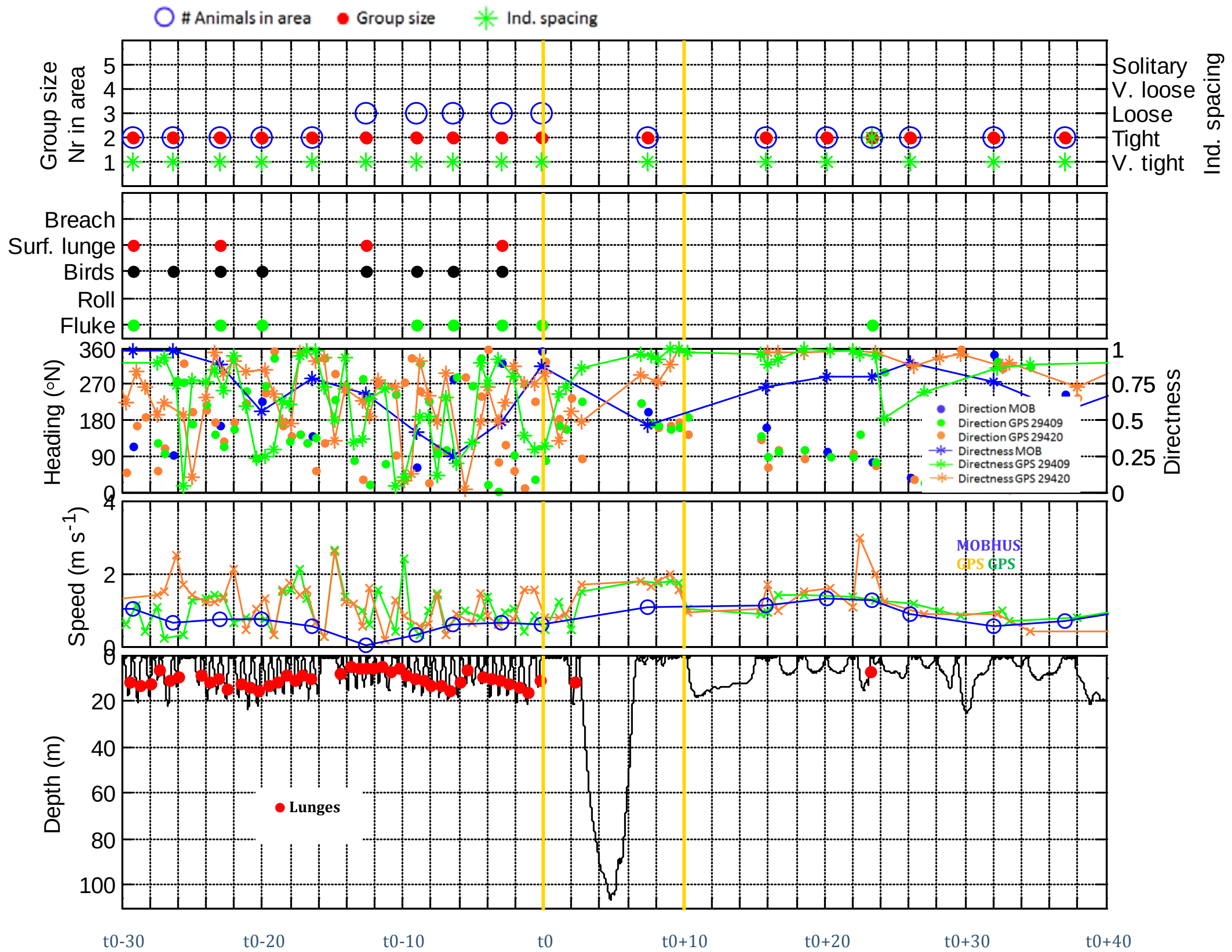




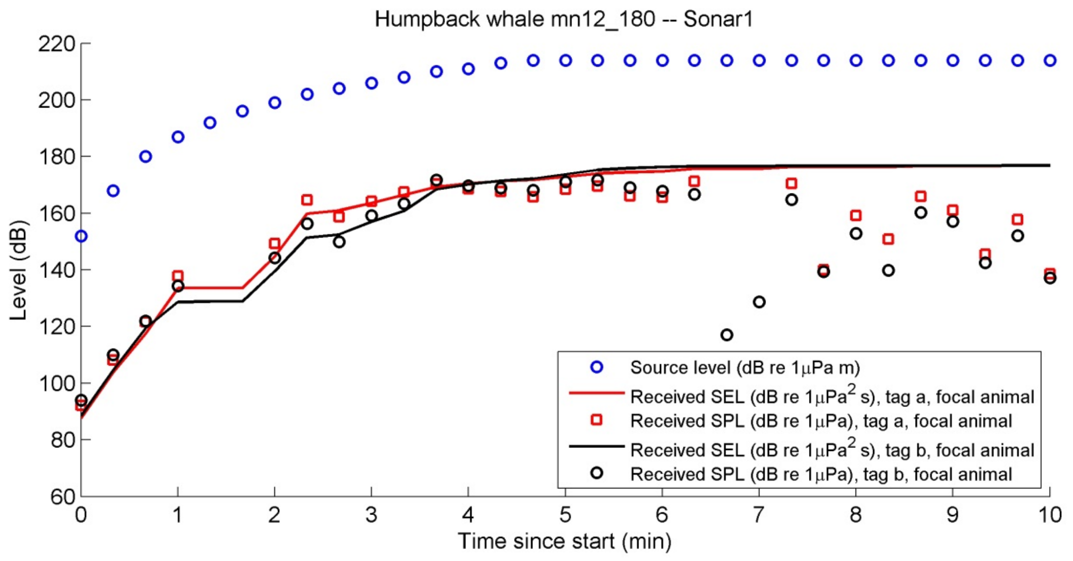
SONAR 1


Humpback whale mn12_180 -- Sonar1
Sverdrup
Sonar1 approach
Tracking tag boat
FGPS-tag 29409
FGPS-tag 29420
1.5 km
Latitude (°N)
Longitude (°E)
73.995
73.99
73.985
73.98
73.975
73.97
73.965
73.96
73.955
73.95
20.4
20.45
20.5
20.55
20.6
20.65

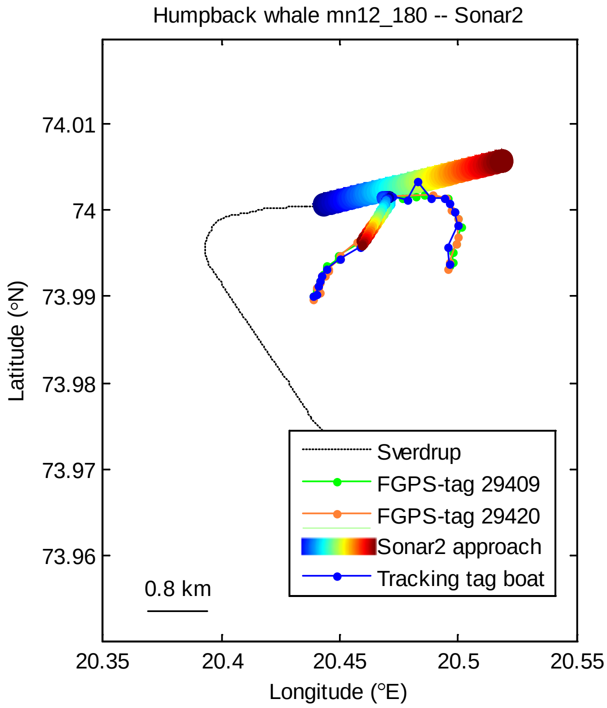

Humpback whale mn12_180 -- Sonar1
Zoomed
Latitude (°N)
Longitude (°E)
73.985
73.98
73.975
73.97
20.49
20.5
20.51
20.52
20.53
20.54

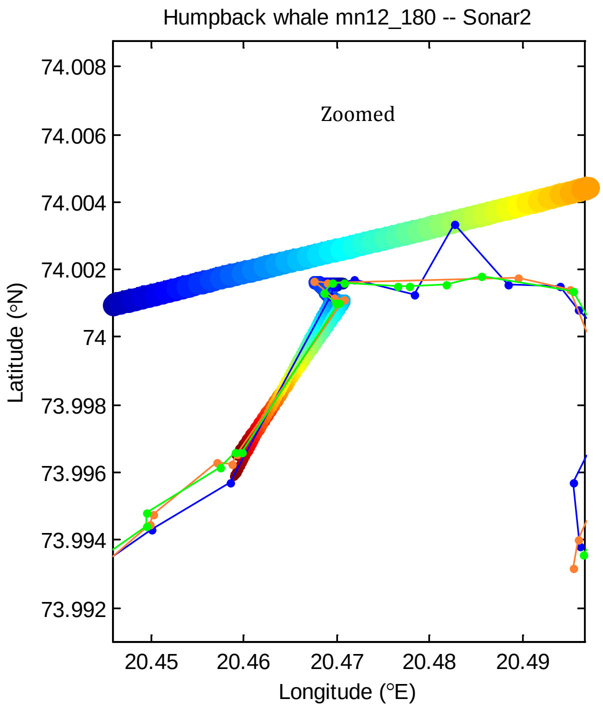

Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Speed (m s-1)
MOBHUS
GPS GPS
Depth (m)
Lunges
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

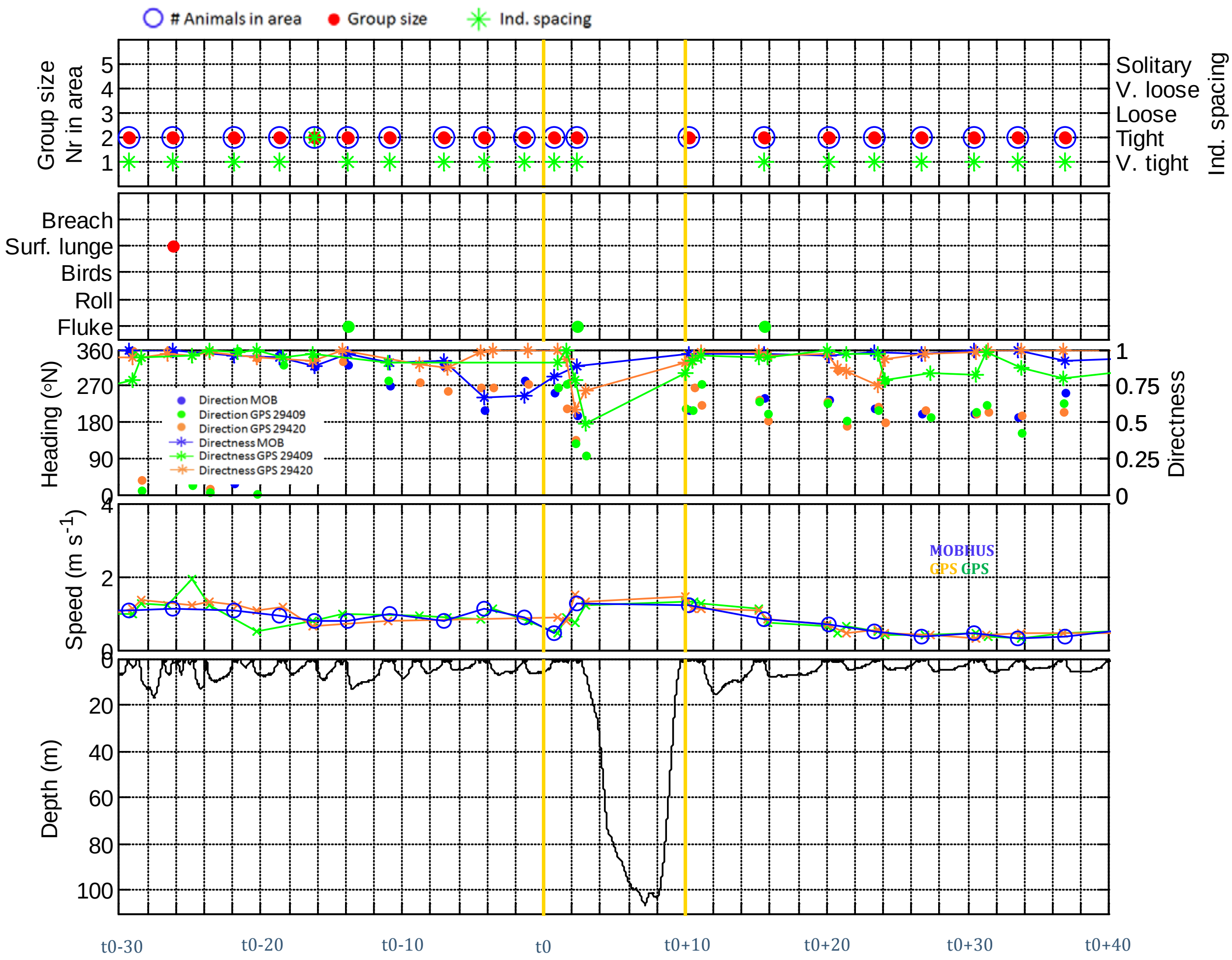
SONAR 1 – Received level



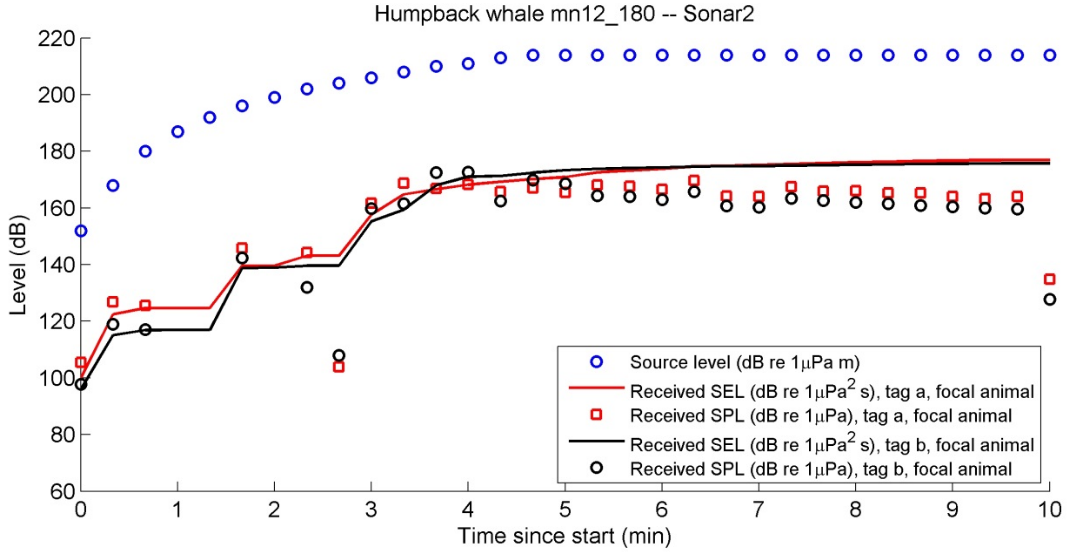
SONAR 2

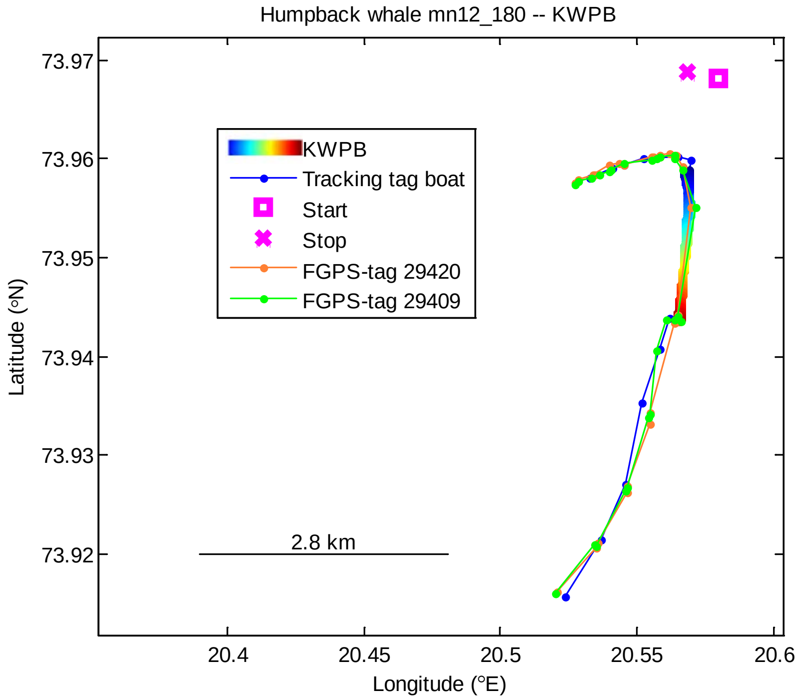

Humpback whale mn12_180 -- Sonar2
74.01
74
73.99
73.98
73.97
73.96
Latitude (°N)
0.8 km
Sverdrup
FGPS-tag 29409
FGPS-tag 29420
Sonar2 approach
Tracking tag boat
20.35
20.4
20.45
20.5
20.55
Longitude (°E)


Humpback whale mn12_180 -- Sonar2
Zoomed
74.008
74.006
74.004
74.002
74
73.998
73.996
73.994
73.992
Latitude (°N)
20.45
20.46
20.47
20.48
20.49
Longitude (°E)

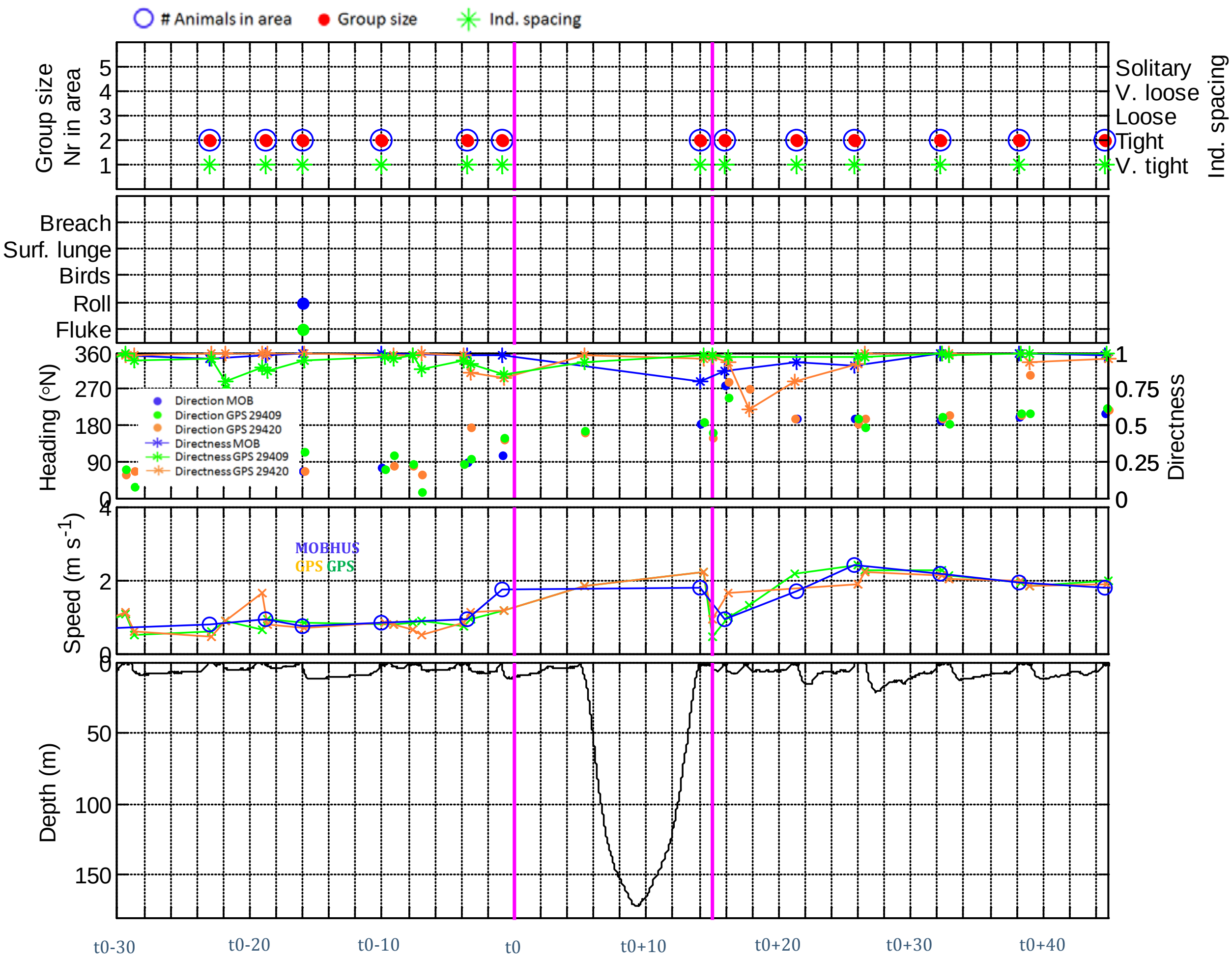

Animals in area
Group size
Ind. spacing
Group size
Nr in area
5
4
3
2
1
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
360
270
180
90
0
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
1
0.75
0.5
0.25
0
Directness
Speed (m s-1)
4
2
0
Depth (m)
20
40
60
80
100
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

SONAR 2 – Received level

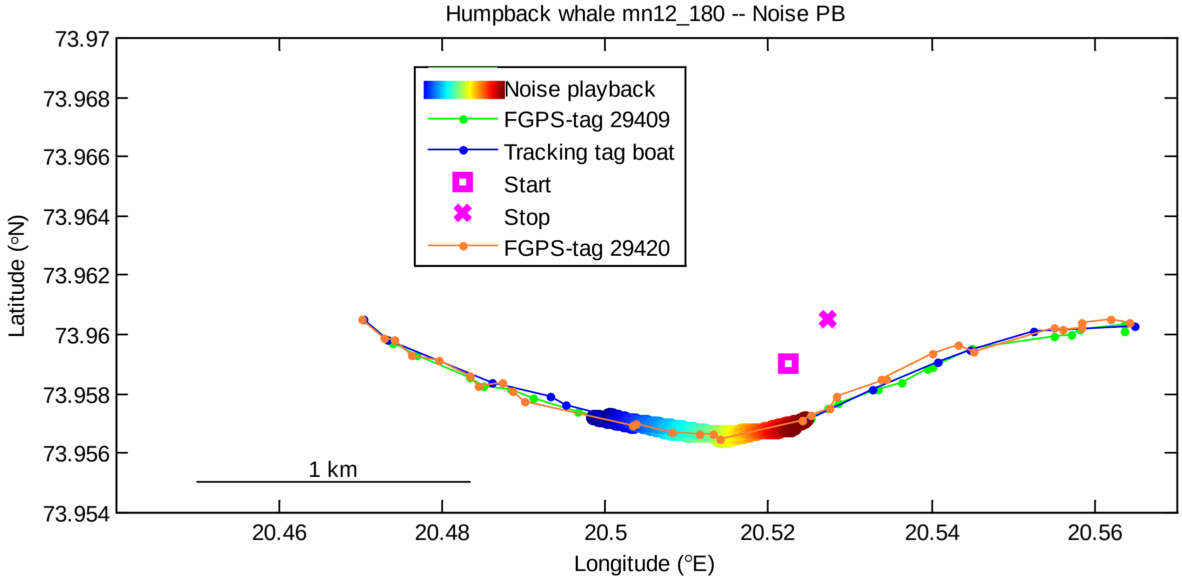


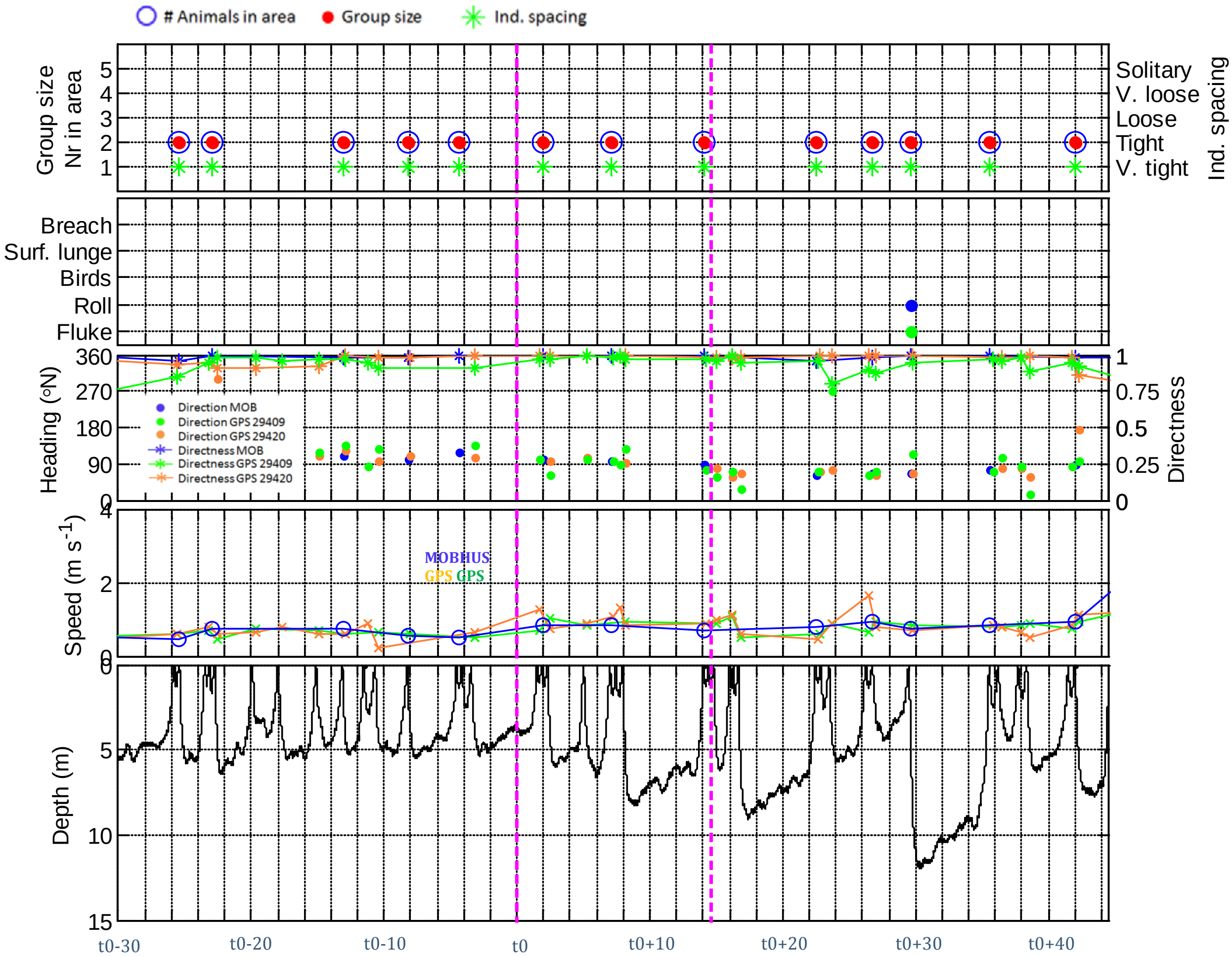


Humpback whale mn12_180 -- KWPB
KWPB
Tracking tag boat
Start
Stop
FGPS-tag 29420
FGPS-tag 29409
2.8 km
Latitude (ºN)
Longitude (°E)
73.97
73.96
73.95
73.94
73.93
73.92
20.4
20.45
20.5
20.55
20.6



Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (ºN)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
Speed (m s-1)
MOBHUS
GPS GPS
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40


Humpback whale mn12_180 -- Noise PB
Noise playback
FGPS-tag 29409
Tracking tag boat
Start
Stop
FGPS-tag 29420
1 km
Latitude (°N)
Longitude (°E)
73.97
73.968
73.966
73.964
73.962
73.96
73.958
73.956
73.954
20.46
20.48
20.5
20.52
20.54
20.56


Animals in area
Group size
Ind. spacing
Group size
Nr in area
Solitary
V. loose
Loose
Tight
V. tight
Ind. spacing
Breach
Surf. lunge
Birds
Roll
Fluke
Heading (°N)
Directness
Direction MOB
Direction GPS 29409
Direction GPS 29420
Directness MOB
Directness GPS 29409
Directness GPS 29420
MOBHUS
GPS GPS
Speed (m s⁻¹)
Depth (m)
t0-30
t0-20
t0-10
t0
t0+10
t0+20
t0+30
t0+40

4 Discussion

4.1 Collected data

During the three 3S[2] sea trials with full sonar capability in 2011, 2012 and 2013 we deployed 29 tags to the three target species, collected baseline data on behaviour, and conducted 22 sonar exposure experiments and 31 control experiments. Additional baseline data on minke whales were also collected during smaller sea trials in 2010, and on bottlenose whales in 2014-2015 supported by the funding agency SERDP (award RC-2337, Miller, PI).

Table 4.1. Summary table of all 3S data collected between 2005 and 2015. Control experiments include playback of killer whales sounds or control sounds and the no-sonar approaches of the sonar source vessel. Killer whales, pilot whales, sperm whales and herring were studied as part of the 3S-project (2005-2010, light blue), whereas minke whales, bottlenose whales and humpback whales, were studied in the current 3S-2 project (2010-2015, dark blue).

Species	# TAGs deployed	# Sonar exp.	# Control exp.	Trials/year
Killer whales	22	8	3	3S-05, 3S-06, 3S-08, 3S-09, ICE-09
Pilot whales	34	14	28	3S-08, 3S-09, 3S-10, 3S-13
Sperm whales	10	10	9	3S-08, 3S-09, 3S-10
Herring	0	38	25	3S-06, 3S-08
Minke whales	2	1	2	3S-10, 3S-11
Bottlenose whales	16	1	3	3S-13, JM-14, JM-15
Humpback whales	27	20	29	3S-11, 3S-12
SUM	**111**	**92**	**99**	

The 3S[2] project was a success in terms of the total amount of data collected. However, the dataset is very imbalanced across the species. The total dataset on humpback whales is expected to give conclusive results on how sensitive this species is to sonar and the effectiveness of ramp-up. However, we conducted only a single sonar exposure experiment on minke whales (during 3S-11; Kvadsheim *et al.* 2011, Sivle *et al.* 2015) and a single experiment on bottlenose whales (during 3S-13; Kvadsheim *et al.* 2014, Miller *et al.* 2015). Thus, more data on minke whales and bottlenose whales are clearly needed to draw firm conclusion about their sensitivity to sonar. However, the single experiments on minke whales and bottlenose whales do indicate that these species may be very sensitive to sonar, or at least more sensitive than any of the individual humpback whales that were subject to similar sonar exposures (Sivle *et al.* 2015). Retrospectively therefore, maybe we should have focused more on the most sensitive species. However, the experience from the 3S[2]-project as well as from the first 3S-project, is that the species which are most sensitive to anthropogenic disturbance, and thus probably the most important species to study, are also the most difficult species to both tag, track and experiment with. This should be taken into consideration when evaluating the success of behavioral response studies.

4.2 3S CEE Methodology

Conducting controlled exposure experiments (CEE) on cetaceans requires a multidisciplinary team and very specialized skills and equipment. During the first phase of the 3S-project in 2005-2010 (Miller *et al.* 2011) we established the basic methodology. In this second phase (3S^2) we switched to other species and even though some important changes were made, the primary aspects of the experimental design, data collection methodology, equipment and research team remained the same, but with some important improvements.

The sonar exposure experiments were designed to give a realistic escalation of the exposure levels to identify thresholds of different type of responses. We have used a high power naval sonar source towed by a research vessel to make the exposures realistic, while at the same time maintaining experimental control of the exposure. No-sonar control experiments, where the source vessel moved in exact same way, even towing the source but without transmitting, were conducted to enable us to separate effects of the sonar from effects of the approaching ship. Positive control experiments with playbacks of predator sounds enable us to better interpret the biological significance of responses, and to better understand the underlying behavioral mechanism triggering responses to sonar. Some of the changes in the methodology between phase 1 and phase 2 of 3S are particularly worth mentioning:

1.) No-sonar control sessions were consistently conducted as the first exposure session of each experiment. The no-sonar control sessions were intended to assess the effect of the vessel-alone. By conducting these as the first exposure session we avoid possible sensitization to the source vessel following a sonar session, which could lead to an overestimation of the effect of the source vessel only.

2.) We added Sirtrack GPS loggers to version 2 Dtags. These loggers provided a wealth of information related to the movement of humpback whales, and has enabled derivation of a much-finer movement track than would have been possible using visual observation alone (Wensveen *et al.* 2015b).

3.) We created a specific ship movement trajectory for northern bottlenose whale sonar exposures moving slowly in a small box. The movement of the vessel during sonar transmissions was pre-determined with only the starting position determined at the start of the exposure session. This protocol was intended to be more similar to previous experiments with beaked whales (Tyack *et al.* 2011, DeRuiter *et al.* 2013) which used stationary sources.

4.) We started using a smaller boat (8m) deployed off the mother ship to serve as the platform for tracking and observing the whales after tagging, instead of a larger, independent ship. This was done because of the cost involved in renting another ship big enough to operate in the Arctic oceans. Working in small boats at high seas makes the operation highly weather limited, and some flexibility is lost when operating with only one larger independent ship compared to two, particularly in the search phase of the operation. However, since the tagging of the whales is limited by sea state as it has to occur from the small boats anyway, we probably lost very few real opportunities to conduct more experiments, and thus, the cost-benefit trade-off may have been wise. The data collection from the smaller boats worked surprisingly well and high quality data were collected. However, working long hours on small open boats in the Arctic oceans can be challenging to the field crew, and requires spirit, endurance and good equipment.

5.) The Delphinus passive acoustic system was significantly improved with new processing and new sensors (von Benda-Beckmann *et al.* 2010). Particularly during the 3S-13 trial off Jan Mayen this system proved to be very efficient in tracking the vocalizing northern bottlenose whales underwater, also having the capability to resolve the left-right ambiguity (Kvadsheim *et al.* 2014). The benefit of this technical development was further enhanced by the implementation of systems which combine acoustic and visual information and tag boat position information. This information was made available to the visual observers with a wireless data link to a tablet pc. This proved to be very useful for tracking groups over time and for bringing the tag boats closer to the animals (Kvadsheim *et al.* 2014). The Delphinus array was also used to monitor presence/absence during and after sonar exposure in combination with visual sightings to support analyses of larger scale responses?

4.2.1 Improving tagging capability

Controlled exposure experiments require that a tag is deployed to the whale, primarily to collect relevant behavioral data from on-board sensors, but also to enable tracking of the focal individual. Tagging the whale is often an important limiting factor determining the number of experiments we are able to conduct within a field season. We therefore worked systematically to improve tagging techniques.

The ARTS-DTAG-system (Kvadsheim *et al.* 2009), which launches the DTAG at longer ranges than the traditional carbon fiber poles (<8m), was further improved during the project, and this turned out to be very important in getting tags on the whales more efficiently, particularly for bottlenose whales and minke whales that were very challenging to approach close enough to tag (Kvadsheim *et al.* 2011, 2014).

There was little development of the tag sensors and housing during the project, except that attaching the off-the-shelf Fastlock-GPS loggers to the tags gave a very valuable and detailed track of the whale, which is a significant improvement over the visual tracks (Wensveen *et al.* 2015b). Also, the development of the digital direction finder (DF-Horten) was an important improvement. This system significantly improved our ability to track the VHF-signal of the tag because of its higher sensitivity and ability to temporarily store the angle of arrival.

However, tagging continues to be a very critical component of this type of research. During 3S-11 and earlier trials we struggled to tag minke whales with acoustic and motion sensor DTAGs, used very successfully with other species, and therefore a lot of effort was invested in improving tagging techniques with this species. We came very close many times, but we did not manage to tag more than one minke whale for a duration longer than a few minutes, and on that occasion we used the smaller and simpler CTAG (Kvadsheim *et al.* 2011). Given the total effort invested in trying to tag minke whales, and lack of success (Kvadsheim *et al.* 2011, 2012, 2014), we conclude that with this species smaller tags which can be launched at longer distances should be used to improve the tagging success rate, even if this means using simpler sensor equipment on the tag which reduce the quality of the data.

Also for bottlenose whales tagging proved to be very difficult. However, this species has since been successfully tagged with DTAGs from sail boats during more recent baseline trials around Jan Mayen in 2014 and 2015. However, further improvement of the ARTS system to extend the tagging range still seem important to increase tagging efficiency further.

The multi sensor DTAG developed at Woods Hole Oceanographic Institution (USA) has been a robust and remarkable tool, which has increased data quality significantly compared to earlier generation tags. However, during the 3S-2 trials the number of tags available has sometimes been critical. Version 2 DTAGs are now old and technical failures happen more frequently. For future projects a transfer to the newer version 3 DTAGs is mandatory. Increased availability of such newer tags, inclusion of GPS sensors and adaptation of the tag to be launched with the ARTS system will improve data collection rate and data quality in the future.

4.3 Analysis and publication plan

The data collected and presented in this report are currently being analyzed and a detailed analysis-and-publication plan has been developed. This plan implies that results from the $3S^2$ experiments will appear in scientific literature shortly after this report is published. Table 4.2 summarizes the most important analyses planned and their status.

Behavioral response studies like the $3S^2$ experiments generate complex datasets, but the time and cost required to conduct such experiments are high, and thus sample sizes are generally low, in some cases critically low. We typically also see a lot of variability in the results, as is common for behavioral responses of animals, which we can be only partly explained (e.g. Miller *et al.* 2012, 2014, Sivle *et al.* 2015). Low sample sizes of high-resolution data series combined with high between-animal variability is a big analytical challenge, and therefore systematic qualitative techniques, or expert scoring, of behavioral responses have been developed (Miller *et al.* 2012, Sivle *et al.* 2015). However, in the recent years several new quantitative analysis techniques have also been applied, like Mahalanobis distance (e.g. Miller *et al.* 2014, Antunes *et al.* 2014, Miller *et al.* 2015), Bayesian methods (e.g. Miller *et al.* 2014, Antunes *et al.* 2014), hidden state models (e.g. Isojunno & Miller 2015, Isojunno *et. al.* 2015), Recurrent event survival analysis (Harris *et al.* 2015, Sivle *et al.* 2015) and Generalized estimating equations (GEE) (e.g. Visser *et al.* 2014, Curé *et al.* 2015, Sivle *et al.* 2015). These analysis techniques have been developed in close collaboration with the MOCHA project (http://www.creem.st-and.ac.uk/mocha/). Because of these recent developments we are in a strong position to get results and conclusions published in peer-reviewed literature soon.

Three scientific papers which report the outcomes of the $3S^2$-project are already published or in press (Miller *et al.* 2015, Sivle *et al.* 2015 and Curé *et al.* 2015).

Sivle *et al.* (2015) gives a first comprehensive overview of the results. In this study, expert scoring of putative behavioural responses was performed on all sonar and control experiments in the 3S²-dataset. A scale ranging from no effect (0) to high potential to affect vital rates (9) if animals were exposed repeatedly was used. This scale was established by Southall *et al.* (2007) but later modified by Miller *et al.* (2012) and Sivle *et al.* (2015). The most common response during sonar exposures in all three species was avoidance of the sound source, but other responses such as changes in dive behaviour and cessation of feeding were also commonly observed. The minke whale and bottlenose whale started avoiding the source at a received sound pressure level (SPL) of 146 and 130 dB re 1μPa, respectively. Humpback whales generally had less severe responses that were triggered at higher received levels. Thus, the single experiments with bottlenose and minke whales suggest they have greater susceptibility to sonar disturbance than humpback whales, but additional studies are needed to confirm this result (Sivle *et al.* 2015).

Table 4.2. Working titles, lead author and status of the primary publications from the 3S² dataset. Some additional analysis are underway, but more related to the baseline behavior of the animals.

Working title	**Lead author**	**Status**
Efficacy of ramp-up as a method to mitigate detrimental effects of active sonar in humpback whales	Wensveen	Submitted to *Royal Soc Proc B.* in August 2015
Dose-response for behavioural effects of naval active sonar in humpback whales	Wensveen	Analysis ongoing. Draft manuscript expected by November 2015.
Behavioural responses of minke whales to naval sonar – pooling data from SOCAL and 3S	Kvadsheim	Analysis completed. Expected submission in November 2015
Effects of naval sonar on lunge feeding in humpback whales	Sivle	Draft manuscript. Expected submission in October 2015
Effects of sonar on Bottlenose whales	Miller	Published in *Royal Soc Open Science* in June 2015.
The severity of behavioural changes observed during experimental sonar exposures of humpback whales, northern bottlenose whales and minkes whales	Sivle	Accepted for publication in *Aquatic Mammals.* Expected to appear in December 2015 issue (41.4)
Contrasting the response of 3 cetacean species to sonar versus playback of killer whale sounds	Curé/Miller/Isojunno	Analysis on-going. Draft manuscripts expected in December 2015.
Behavioural responses of humpback whales to killer whale sound playbacks	Curé	Published in Marine Ecological Progress Series in April 2015

Using quantitative analysis, Miller *et al.* 2015 confirmed that at a received SPL of 130 dB re 1 μPa, the bottlenose whale initiated strong avoidances response and started moving away from the sonar source and performed the longest and deepest dive (94min, 2339 m) ever recorded for this species. A reported sharp decline in both acoustic and visual detections of conspecifics after exposure, suggests that other whales in the area might have responded similarly (Miller *et al.* 2015).

Also using quantitative analysis Curé *et al.* (2015) found that predator sound playbacks to humpback whales induced cessation of feeding, change in the diving pattern and a clear directional and rapid horizontal avoidance away from the sound source. Sivle *et al.* (2015) found that these killer whale playbacks induced more severe responses than sonar signals.

4.4 Future perspective - 3S^3?

Following completion of the data collection part of the 3S^2-project, we have identified four important data gaps which will also greatly increase the value of the existing data:

4.4.1 Increased sample sizes

The sample size for minke whales and bottlenose whales are subcritical (n=1). Analyses indicate that these species are particularly sensitive, but this needs to be tested by replication of the experiments.

4.4.2 Effects of exposure duration.

Our sonar exposure experiments are shorter (<1 hr) than typical naval sonar exercises (>6 hrs). If the exposures were longer, the animals might habituate or become sensitized. Longer duration exposure experiments are necessary to understand how we can extrapolate from our experimental data, to real world scenarios.

4.4.3 Received level versus proximity

It's still not fully understood which quality of the stimuli triggers responses when marine mammals are exposed to sonar. In our experiments, responses occurred at ranges of 0.5-9 km from the source (Miller *et al.* 2012, Antunes *et al.* 2014, Miller *et al.* 2014, Isojunno *et al.* 2015, Sivle *et al.* 2015). Operational naval sonar sources are more powerful than the source used in our experiments, and if we extrapolate from our observed SPL response thresholds, such levels could be experienced at more than 10 times this range with some sonar systems (Miller *et al.* 2014). However, the increased distance to the source might lead to lower response thresholds than expected by reduction in received level alone (e.g. DeRuiter et al 2013). It's important to better understand the interaction between received acoustic levels and proximity to the source for better estimates of the actual effects zone of naval sonar systems.

4.4.4 Continuous Active Sonar (CAS)

Current operational sonar systems typically transmit at 1-10% duty cycle, and in our experiments we have used 5%. Recent technological development with increased computational power and sonar systems which has enough dynamic range to listen and transmit at the same time, allows for use of much higher duty cycles. A final consideration is therefore that new types of sonars, such as Continuous Active Sonar (CAS), are being developed by nations sponsoring 3S, and we have no information of whether cetacean responses to CAS might differ from what we have measured for intermittent sonar pulses. CAS may elicit responses at lower or higher received level due to different sound pressure and exposure level profile over time. In particular, increasing the duration or the duty cycle of sonar signals increases concerns over the masking potential of the sound exposure. Masking may affect critical behaviours, such as foraging of echolocation species, and finding mates and social cohesion by reducing communication ranges (Clark et al 2009).

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Miller, P.J.O., R.N. Antunes, P.J. Wensveen, F.I.P. Samarra, A. Catarina Alves, P.H. Kvadsheim, L. Kleivana, F.-P.A. Lam, M.A. Ainsle, P.L. Tyack and L. Thomas. (2014). Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. *Journal of the Acoustical Society of America*. 135, 975. http://dx.doi.org/10.1121/1.4861346

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von Benda-Beckmann et al. (2011). 3S2 Ramp-up experiment - experimental protocol and theoretical Ramp-up design. In: Kvadsheim et al. (2011). Behavioural response studies of cetaceans to naval sonar signals in Norwegian waters - 3S-2011 Cruise Report. *FFI-rapport 2011/01289* von Benda-Beckmann, A.M., P.J. Wensveen, P.H. Kvadsheim, F.P.A. Lam, P.J.O. Miller, P.L. Tyack, M.A. Ainslie (2014). Modelling effectiveness of gradual increases in source level to mitigate effects of sonar on marine mammals. *Cons. Biol.* DOI: 10.1111/cobi.12162

Weir, C. R., and S. J. Dolman. 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. *Journal of International Wildlife Law and Policy* 10: 1–27.

Wensveen P.J., A.M. von Benda-Beckmann, M.A. Ainslie, F-P.A. Lam, P.H. Kvadsheim, P.L. Tyack and P.J.O. Miller (2015a). How effectively do horizontal and vertical response strategies of long-finned pilot whales reduce sound exposure from naval sonar? *Marine Environmental Research*106: 68-81

Wensveen P.J., L. Thomas, P.J.O. Miller (2015b). A path reconstruction method integrating dead reckoning and position fixes applied to humpback whales. *Movement ecology* (in press).

Appendix A List of 3S publications

Publications are listed chronologically.

** core deliverables (publications directly addressing the main objectives of the project - effects of sonar on marine life.*

A.1 Peer review papers

Lam, FP & Kvadsheim, PH (2015). Effects of Sound in the Ocean on Marine Mammals - ESOMM-2014 Conference. *Aquatic Mammals* (in press).

Wensveen PJ, Thomas, L Miller, PJO (2015). A path reconstruction method integrating dead reckoning and position fixes applied to humpback whales. *Movement ecology* (in press)

*Sivle, L, PH Kvadsheim, C Curé, S Isojunno, PJ Wensveen, FPA Lam, F Visser, L Kleivane, PL Tyack, C Harris, PJO Miller (2015). Severity of expert-identified behavioural responses of humpback whale, minke whale and northern bottlenose whale to naval sonar. *Aquatic Mammals* (in press)

*Harris, C.M., D. Sadykova, S.L. DeRuiter, P.L. Tyack, P.J.O. Miller, P.H. Kvadsheim, F.P.A. Lam, and L. Thomas. (2015). Dose response severity functions for acoustic disturbance in cetaceans using recurrent event survival analysis. *Ecosphere* (in press)

*Isojunno, S, C. Curé, PH Kvadsheim, FPA. Lam, PL Tyack, PJ Wensveen, PJO. Miller (2015). Sperm whales reduce foraging effort during exposure to 1-2 kHz sonar and killer whale sounds. *Ecological Applications* (in press).

Samarra, F and Miller PJO (2015). Prey-induced behavioural plasticity of herring-eating killer whales. *Marine Biology* 162, 809-821. doi:10.1007/s00227-015-2626-8

*Miller PJO, PH Kvadsheim, FPA Lam, PL Tyack, C. Cure, SL DeRuiter, L Kleivane, L Sivle, SP van IJsselmuide, F Visser, PJ Wensveen, AM von Benda-Beckmann, L Martin López, T Narazaki, SK Hooker (2015). First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise. *R. Soc. open sci.* 2: 140484. http://dx.doi.org/10.1098/rsos.140484

Curé C, Sivle LD, Visser F, Wensveen P, Isojunno S, Harris C, Kvadsheim PH, Lam FPA, Miller PJO. (2015). Predator sound playbacks reveal strong avoidance responses in a fight strategist baleen whale. *Mar Ecol Prog Ser* 526: 267–282. doi: 10.3354/meps11231

*Wensveen PJ, von Benda-Beckmann AM, Ainslie MA, Lam F-PA, Kvadsheim PH, Tyack PL and Miller PJO (2015). How effectively do horizontal and vertical response strategies of long-finned pilot whales reduce sound exposure from naval sonar? *Mar. Env. Res.*106: 68-81

Fais, A., Aguilar Soto, N., Johnson, M. Pérez-González, C., Miller, P. J. O., Madsen, P. T. 2015. Sperm whale echolocation behaviour reveals a directed prior—based strategy informed by prey distribution. Behavioural Ecology and Sociobiology 69: 663-674.

Isojunno, S and Miller PJO (2015). Sperm whale response to tag boat presence: biologically informed hidden state models quantify lost feeding opportunities. *Ecosphere* 6: 1-46

*Sivle, L.D., Kvadsheim, P.H. and Ainslie, M.A. (2014). Potential for population-level disturbance by active sonar in herring. *ICES J. Mar. Sci.* doi: 10.1093/icesjms/fsu154

Visser F., Miller P.J.O., Antunes R.N., Oudejans M.G., Mackenzie M.L., Aoki K., Lam F.P.A., Kvadsheim P.H., Huisman J. and Tyack P.L. (2014). The social context of individual foraging behaviour in long-finned pilot whales (Globicephala melas). *Behaviour* 151: 1453-1477. DOI: 10.1163/1568539X-00003195.

*Antunes R., Kvadsheim P.H., Lam F.P.A., Tyack, P.L., Thomas, L., Wensveen P.J., Miller P. J. O. (2014). High response thresholds for avoidance of sonar by free-ranging long-finned pilot whales (Globicephala melas). *Mar. Poll. Bull.*83: 165-180. DOI: 10.1016/j.marpolbul.2014.03.056

*Alves, A., Antunes, R., Bird, A., Tyack, P., Miller, P.J.O., Lam, F.P.A. and Kvadsheim, P.H. (2014). Vocal matching of naval sonar signals by long-finned pilot whales (Globicephala melas). *Marine Mammal Sci* 30: 1248-1257. DOI: 10.1111/mms.12099.

*Miller, P.J.O., Antunes, R., Wensveen, P., Samarra, F.I.P., Alves, A.C., Tyack, P., Kvadsheim, P. H., Kleivane, L., Lam, F. P., Ainslie, M. and Thomas, L (2014). Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. *J. Acoust. Soc Am.*135, 975-993

*Fahlman A, Tyack PL, Miller PJ and Kvadsheim PH (2014). How man-made interference might cause gas bubble emboli in deep diving whales? *Frontiers in Physiology* 5: 1-6.

*von Benda-Beckmann, A.M., P.J. Wensveen, P.H. Kvadsheim, F.P.A. Lam, P.J.O. Miller, P.L. Tyack, M.A. Ainslie (2014). Modelling effectiveness of gradual increases in source level to mitigate effects of sonar on marine mammals. *Cons. Biol* 28: 119-128. (DOI: 10.1111/cobi.12162)

*Kuningas S, Kvadsheim PH, Lam FPA, Miller PJO (2013). Killer whale presence in relation to naval sonar activity and prey abundance in northern Norway. *ICES J. Mar. Sci.* (Sept 4. doi:10.1093/icesjms/fst127)

Aoki K, Sakai M, Miller PJO, Visser F, Sato K (2013) Body contact and synchronous dives in pilot whales. *Behavioural Processes* 99, 12-20.

Oliviera, C., Wahlberg, M., Johnson, M., Miller, P. J. O., Madsen, P. T. (2013). The function of male sperm whale slow clicks in a high latitude habitat: Communication, echolocation or prey debilitation? *J. Acoust. Soc. Am 133,* 3135-3144.

Curé, C., Antunes, R., Alves, AC., Visser, F., K**v**adsheim, PH., & Miller, PLO (2013). Responses of male sperm whales (Physeter macrocephalus) to killer whale sounds: implications for anti-predator strategies. *Scientific Reports* **3** : 1579 (DOI: 10.1038/srep01579)

Curé, C., Antunes, R., Samarra, F., Alves, A-C., Visser, F., Kvadsheim, PH., Miller, PJO. (2012). Pilot whales attracted to killer whale sounds: Acoustically-mediated interspecific interactions in cetaceans. *PlosOne* **7**:1-5

*Miller, P.J.O., Kvadsheim, P.H., Lam, F.P.A.., Wensveen, P.J., Antunes, R., Alves, A.C., Visser, F., Kleivane, L., Tyack, P.L., Sivle, L.D. (2012). The severity of behavioral changes observed during experimental exposures of killer (Orcinus orca), long-finned pilot (Globicephala melas), and sperm whales (Physeter macrocephalus) to naval sonar. *Aquatic Mammals* 38: 362-401.

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Sayigh, L., Quick, N. Hastie, G. and Tyack, P. (2012) Repeated call types in short-finned pilot whales, Globicephala macrorhynchus. *Mar. Mamm. Sci.* 29: 312-324. (DOI: 10.1111/j.1748-7692.2012.00577.x)

*Kvadsheim, P.H., Miller, P.J.O., Tyack, P., Sivle, L.D., Lam, F.P.A., and Fahlman, A. (2012). Estimated tissue and blood N_2 levels and risk of in vivo bubble formation in deep-, intermediate and shallow diving toothed whales during exposure to naval sonar. *Frontiers in Aquat. Phyisol.* 3: article 125.

*Sivle, L.D., Kvadsheim, P.H., Ainslie, M.A., Solow, A., Handegard, N.O., Nordlund, N., Lam, F.P.A. (2012). Impact of naval sonar signals on herring (Clupea harengus) during summer feeding. *ICES J. Mar. Sci.* (May 14. 2012; doi:10.1093/icesjms/fss080).

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*Doksæter L, OR Godø, NO Handegard, P Kvadsheim, FPA Lam, C Donovan and P Miller (2009). Behavioral responses of herring (Clupea harengus) to 1-2 kHz sonar signals and killer whale feeding sounds. *J. Acoust. Soc. Am.* 125: 554-564.

A.2 Reports and proceeding papers

*Kvadsheim, PH, F-P Lam, P Miller, LD Sivle, P Wensveen, M Roos, P Tyack, L Kleivane, F Visser, C Curé, S Ijsselmuide, S Isojunno, S von Benda-Beckmann, N Nordlund, R Dekeling (2015). The 3S2 experiments - Studying the behavioural effects of naval sonar on northern bottlenose whales, humpback whales and minke whales. *FFI-rapport* 2015/01001 (http://rapporter.ffi.no/rapporter/2015/01001.pdf)

*Kvadsheim, P., Lam, FP., Miller, P., Wensveen, P., Visser, F., Sivle, LD., Oudejans, M., Kleivane, L., Curé, C., Ensor, P., van Ijsselmuide, S., and Dekeling, R. (2014). Behavioural responses of cetaceans to naval sonar signals – the 3S-2013 cruise report. *FFI-rapport* 2014/00752**.** (http://rapporter.ffi.no/rapporter/2014/00752.pdf).

Shamir L, Yerby C, Simpson R, von Benda-Beckmann A, Tyack P, Samarra F, Miller P, Wallin J (2014) Classification of large acoustic datasets using machine learning and crowdsourcing: Application to whale calls *J. Acoust. Soc Am*. 135: 953-962 (http://dx.doi.org/10.1121/1.4861348)

Ainslie MA, and von Benda-Beckmann AM (2013) Optimal soft start and shutdown procedures or stationary or moving sound sources. *POMA - ECUA 2012 - 11th European Conference on Underwater Acoustics, Proc. Of Meetings on Acoustics* DOI:10.1121/1.4789477.

*Kvadsheim, P., Lam, FP., Miller, P., Wensveen, P., Visser, F., Sivle, LD., Kleivane, L., Curé, C., Ensor, P., van Ijsselmuide, S., and Dekeling, R. (2012). Behavioural responses of cetaceans to naval sonar signals in Norwegian waters – the 3S-2012 cruise report. *FFI-rapport* 2012/02058. (http://rapporter.ffi.no/rapporter/2012/02058.pdf).

*Kvadsheim, P.H., Lam, F.P. Miller P. Doksæter, L., Visser, F., Kleivane, L., van Ijsselmuide, S., Samarra, F., Wensveen, P., Curé, C., Hickmott, L., and Dekeling, R. (2011). Behavioural response studies of cetaceans to naval sonar signals in Norwegian waters - 3S-2011 cruise report. *FFI report* 2011/01289 (http://rapporter.ffi.no/rapporter/2011/01289.pdf)

*Miller, P.J.O., Antunes, R., Alves, A.C., Wensveen, P., Kvadsheim, P.H., Kleivane L., Nordlund, N., Lam, F.P., vanIjsselmuide, S., Visser, F., and Tyack, P. (2011). The 3S experiments: studying the behavioral effects of sonar on killer whales (Orcinus orca), sperm whales (Physeter macrocephalus), and long-finned pilot whales (Globicephala melas) in Norwegian waters. *Scottich Ocean Inst. Tech. Rept. SOI-2011-001* (http://soi.st-andrews.ac.uk/documents/424.pdf)

*Kvadsheim, P, FPA Lam, P Miller, AC Alves, R Antunes, A Brocconcelli, S van Ijsselmuide, L Kleivane, M Olivierse and F Visser (2009). Cetaceans and naval sonar – the 3S-2009 cruise report. *FFI report* 2009/01140 (http://rapporter.ffi.no/rapporter/2009/01140.pdf)

Knudsen, FR, Gammelsæter OB, Kvadsheim, PH, Nøttestad L (2008). Detecting killer whales with fisheries sonar. *Marine Scientist* 22: 26-29.

Sheldon-Robert, MK, SP Beerens, FPA Lam (2008) The Delphinus array for passive marine mammal detection. *Proceedings MAST conference, Cadiz*.

Doksæter, L., Kvadsheim, P.H., Godø, O.R., Benders, F.P.A., Miller, P.J.O., Lam, F-P., Handegard, N.O. & Hjellvik, V. (2007). Observations of the behaviour of herring exposed to low- (1-2 kHz) and mid- (6-7 kHz) frequency sonar signals. In: *Proceedings from The Effect of Noise on Aquatic Life International Conference, Nyborg, Denmark, August 13-17 2007.*

Knudsen, F.R., Gammelsæter, O.B., Kvadsheim, P.H. & Nøttestad, L. (**2007**) Evaluation of fisheries sonars for whale detection in relation to seismic survey operations. In: *Proceedings from The Effect of Noise on Aquatic Life International Conference, Nyborg, Denmark, August 13-17 2007.*

*Kvadsheim, P, F Benders, P Miller, L Doksæter, F Knudsen, P Tyack, N Nordlund, FPA Lam, F Samarra, L Kleivane and OR Godø (2007). Herring (sild), killer whales (spekkhogger) and sonar – the 3S-2006 cruise report with preliminary results. *FFI report* 2007/01189 (http://rapporter.ffi.no/rapporter/2007/01189.pdf)

A.3 Theses with 3S-contributions

Dreteler, K (2015). What is the effect of behavioral response on accumulated sound exposure? *MSc thesis, Leiden University*

Roos M (2015). Respiration timing and underwater activity in killer whales (Orcinus orca). *MPhil thesis, University of St Andrews.*

Isojunno, S (2014). Influence of natural factors and anthropogenic stressors on sperm whale foraging effort and success at high latitudes. *PhD-thesis, University of St.Andrews.*

Visser, F. (2014). Moving in concert - social and migratory behavior of dolphins and whales in the North Atlantic Ocean. *PhD-thesis, University of Amsterdam*

Kuningas, S (2013). Population dynamics and distribution of northern Norwegian killer whales in relation to wintering herring. *PhD-thesis, University of St.Andrews.*

Filbri, CN (2013). The effect of boat noise on killer whale (Orcinus Orca) vocalization, *Bachelor Thesis, Leiden University*.

Kok, ACM (2013). Put your money where your mouth is. Correlations between surface social, diving and acoustic behaviour in long-finned pilot whales (Globicephala melas). *MSc thesis, Leiden University*

Lamoni, L. (2012). Boy-talk: acoustic characterisation of sperm whale slow clicks in a male-only high latitude feeding ground. *MSc thesis, Univ. St.Andrews*

Wensveen, P. J. (2012). The effects of sound propagation and avoidance behavior on naval sonar levels received by cetaceans. *MPhil thesis, University of St. Andrews.*

Ammerlaan, I. (2011) A new algorithm for determination of interclick intervals. *BSc-thesis, Fontys University of Applied Sciences, Eindhoven.*

Doksæter, L (2011). Behavioral effects of naval sonar on fish and cetaceans. *PhD thesis, University of Bergen.*

Hadley, M.L. (2011). Tracking sperm whales using passive acoustics and particle filters. *PhD thesis, University of Southampton*

Samarra, F.I.P (2011). Functional design and use of acoustic signals produced by killer whales *(Orcinus orca).* PhD-thesis, *University of St.Andrews*

Shepherd, C. E. (2010). The three dimensional beam pattern of sperm whale usual clicks. *MSc thesis, University of Southampton.*

Marijke Olivierse, M. (2009). Behavioural responses of marine mammals in their horizontal movement as a result of exposure to sonar. *BSc-thesis, University of St.Andrews/SMRU.*

Podt, A. (2009). Effects of anthropogenic noise on killer whale vocalization. *Bachelor thesis, Leiden University* (In Dutch, with English summary)

Shapiro, A. D. (2008). Orchestration: the movement and vocal behavior of free ranging Norwegian killer whales (Orcinus orca). *Ph.D. thesis, Massachusetts Institute of Technology, Woods Hole Oceanographic Institution.*