REPORT

2017 Narwhal Tagging Study - Technical Data Report

Mary River Project, Baffin Island, Nunavut

Submitted to:

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Executive Summary - English

Commercial shipping operations associated with the Mary River Project (the Project), an iron ore mining project owned by Baffinland Iron Mines Corporation (Baffinland) and located in the Qikiqtani region of Nunavut (Figure 1-1), overlap with established summering grounds for narwhal during the open-water season. Project Certificate No. 005, amended by the Nunavut Impact Review Board (NIRB) on 27 May 2014, authorizes Baffinland to mine up to 22.2 million tonnes per annum (Mtpa) of iron ore from Deposit No. 1. Of this 22.2 Mtpa, the Company is currently authorized to transport 6.0 Mtpa of ore to Milne Port for open water shipping through the Northern Shipping Route using chartered ore carrier vessels. The Northern Shipping Route encompasses Milne Inlet, Eclipse Sound, Pond Inlet, and adjacent water bodies. Primary concerns identified along the Northern Shipping Route include potential disturbance effects on narwhal (*Monodon monoceros*) from shipping that may lead to changes in distribution, abundance, migration patterns, behaviour and subsequent availability of narwhal for harvesting by local communities.

To address Project Certificate terms and conditions applicable to narwhal, Golder Associates (Golder) partnered with Fisheries and Oceans Canada (DFO) to undertake the 2017 Narwhal Tagging Study in Tremblay Sound, Nunavut. The collaborative research program involved Golder expanding on DFO's existing tagging program by supplying additional biologging tags that were customized to address Baffinland's Project-specific study objectives related to understanding behavioral response of narwhal to vessel traffic. Twenty narwhal were live-captured in Tremblay Sound during the 2017 open-water season and instrumented with a combination of biologging tags for the purpose of monitoring fine-scale lateral movements, dive behavior, and habitat use throughout their summering grounds in the coastal fjord system of northern Baffin Island. A subset of animals was also outfitted with passive acoustic recording tags and accelerometer sensors to measure the animal's acoustic environment and vocal activity; however analysis of these datasets is beyond the scope of the present report.

Behavioral response of narwhal to ore carriers transiting along the Northern Shipping Route was investigated by comparing animal-borne tag data with based Automated Identification System (AIS) ship-tracking data collected during the 2017 open-water season. Behavioral responses analyzed included changes in narwhal surface movement (e.g., horizontal avoidance and habituation) and changes in dive behavior; with the latter component including potential changes in surface time, dive rate, bottom dive depth, time at depth, total dive duration, and descent velocity during encounters with large vessels.

For analysis of narwhal dive behavior, the dataset included high-resolution dive data obtained for four narwhal, each outfitted with a SPLASH-10 backpack tag and a MiniPAT tow tag (Wildlife Computers). A total of 77 vessel-narwhal interactions were identified in which the closest point of approach (CPA) between individual narwhal and a given vessel was within 3km. Subsurface movements of each animal were then analyzed as a function of distance from transiting vessels (CPA to 10 km) in relation to vessel non-exposure (>10 km) periods.

A larger subset of narwhal associated with GPS tag data was incorporated into the surface behavior analysis as this component was not limited by the small sample size of individuals that were successfully outfitted with high resolution dive tags. The dataset used for analysis of surface movement relative to vessel traffic included 12 narwhal fitted with GPS Fastloc location tags (ten SPLASH-10 tags and two CTD-SRDL tags). Potential changes in narwhal surface behavior were examined within a 10 km radius of transiting vessels.

The following is a summary of the key findings pertaining to narwhal behavioral responses to Project-related vessel traffic based on a comparison of animal-borne tag data with AIS ship-tracking data:

Dive behavior:

- Surface time: The effect of distance from a large vessel on narwhal surface time was statistically significant at close distances (P=0.001), with surface time decreasing when narwhal were within 2 km from a vessel.
- Dive rate: The effect of distance from a vessel on narwhal dive rate (dives/hour) was statistically significant at close distances only (≤2 km; *P*=0.002), with the probability of dive rate increasing from 0.443 during non-exposure periods to 0.501 and 0.686 when vessels were at 1 km and 0 km, respectively. Average dive rates were generally similar between exposure and no-exposure periods, while maximum dive rates were higher for all narwhal during non-exposure events (Figure 4-32).
- Bottom dive depth: The effect of distance from a vessel on narwhal dive depth was statistically significant at close distances (≤2 km; Figure 4-37). At distances less than 2 km from the vessel, the probability of deep dives for potentially feeding narwhal increased from 0.627 during non-exposure events to 0.882 at 0 km. At distances of 1 km and 0 km, the probability of deep dives for non-feeding narwhal increased from 0.137 during non-exposure events to 0.357 and 0.888, respectively. That is, both feeding and non-feeding narwhal tended to exhibit deep dives more often when a large vessel was within 2 and 1 km from the narwhal, respectively, indicative of a possible flight response (Figure 4-37).
- Time at depth: The effect of distance from a vessel on narwhal time spent at the bottom of a dive was not statistically significant (*P*≥0.1).
- Total dive duration: The effect of distance from a large vessel on narwhal total dive duration was found to be statistically significant (*P*=0.016), with dive duration decreasing when within 2 km from a vessel. However, limited data were incorporated into the model and results should be interpreted with caution.
- Descent speed: Narwhal descent velocity was determined to depend on dive depth and potential foraging. However, narwhal descent velocity did not significantly change with distance from vessels or between vessel exposure and non-exposure events.

Surface Behavior:

- Rate of direction change: Statistically significant effects of vessel exposure on narwhal travel direction was evident within 4 km ($P<0.05$) compared to when no large vessels were present within 10 km from narwhal. This analysis does not indicate whether narwhal were turning toward or away from the vessels but only that narwhal changed course at different rates depending on distance from vessels.
- Travel orientation relative to vessels: Narwhal travel orientation did not significantly change as a function of distance from vessels, suggesting no horizontal avoidance of vessels. As the dataset focused on the angles between narwhal and large vessels, the dataset available for modeling was restricted to cases where a large vessel was present, therefore no "no exposure" modeling was conducted.
- Horizontal displacement: In plotting locations of tagged narwhal relative to distance from vessels during exposure events, no GPS locations were evident within approximately 0.5 km of vessel's port and starboard, 1 km of the vessel's bow, and 1.5 km astern. Observed and model-predicted densities increased close to the vessel in all four directions relative to densities at distance. However, densities at both port and starboard directions continued increasing up to <1 km from the vessel, whereas densities at forward and astern directions peaked at 1 km and decreased <1 km, in accordance with the gap of recorded positions. Despite the difference in narwhal density astern/forward relative to port/starboard at the immediate vicinity of the vessels, narwhal distance and position relative to a vessel (forward, astern, port, starboard) was found to be not significant ($P=0.066$).
- Seasonal change and horizontal displacement: Temporal changes in distance between narwhal and vessels were found to decrease at close ranges over the course of the study period ($P<0.001$), suggesting potential habituation of narwhal to large vessel traffic.
- Habitat Re-Occupation: Overall, narwhal crossed the vessel track both shortly before and shortly after vessel passage (minimum value of 4 minutes), suggesting no long-term avoidance of the shipping corridor due to vessel passage.
- Travel speed: The analysis of narwhal travel speed indicated that while the effect of vessel exposure on narwhal was statistically significant ($P<0.001$), the effect of distance from vessel was not ($P=0.06$). Therefore, this result may be spurious and should be re-evaluated with supplementary data collected during the 2018 season.

Observed behavioral responses by narwhal, such as decreased surface time and increased dive rate and dive depth at close distance to vessels, supports the theory that narwhal respond to vessel traffic by active avoidance (i.e., flight response) rather than a freeze response. Despite measurable changes observed in surface and dive behavior, the responses of narwhal to vessel encounters were shown to be temporary, variable among individuals, and variable between vessel encounters by the same individual, suggesting that disturbance and/or avoidance reactions were unlikely to lead to abandonment of Milne Inlet and adjacent water bodies. It is important to note that the dive behaviour models were based on a limited amount of near-field distance data, and therefore results should be interpreted with caution. As more data becomes available from future tagging efforts, the relationship between vessel distance and narwhal surface and dive behavior will be re-evaluated.

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ᑮᓇᐅᔭᓕᐅᕈᑎᖃᖅᑐᑦ ᐅᒥᐊᖅᔪᐊᑦ ᐅᓯᑲᖅᑕᖅᑐᑦ ᐊᑕᔪ ᓄᓘᔾᔪᓂ ᐅᔭᕋᖕᓂᐊᕐᕕᒃ (ᐅᔭᕋᖕᓂᐊᕐᕕᒃ), ᓴᕕᕋᔾᔭᒃᓴᓂᒃ ᐅᔭᕋᖕᓂᐊᖅᑐᑦ ᓇᖕᒥᓂᕆᔭᐅᕙᖅ ᐸᕕᓐᓖᓐᑦ ᓴᕕᕋᔾᔭᒃᓴᓂᒃ ᐅᔭᕋᖕᓂᐊᕐᑎᒃᑯᑦ ᑯᐊᐳᕆᓴᓐ (ᐸᕕᓐᓖᓐᑦ) ᐊᒻᒪᓗ ᕿᑭᖅᑕᓂ ᓄᓇᖓᓃᑦᑐᖅ ᓄᓇᕗᒻᒥ (ᓴᕿᔮᖅᑐᖅ 1-1), ᐸᕐᔭᕐᓗᒃᓯᒪᕗᖅ ᓴᕿᑕᐅᓯᒪᔪᓂ ᐊᐅᔭᒥ ᓇᔪᖅᑕᖅᑎᕐᓂ ᑑᒥᓕᑦ ᕿᓚᓗᒐᐃᑦ ᓯᑯᖃᖅᑎᓇᒍ. ᐅᔭᕋᖕᓂᐊᕈᓐᓇᐅᑎᖓᓕᑦ ᓈᓴᐅᑖ 005, ᐋᕿᒋᐊᖅᑕᐅᓯᒪᓕᖅᑐᖅ ᓄᓇᕗᒻᒥ ᐊᕙᑎᓕᕆᔩᑦ ᑲᑎᒪᔨᖏᓐᓂᑦ ᑕᐃᑲᓂ 27 ᒪᐃ 2014, ᐊᔪᖏᑦᑎᑕᐅᕗᑦ ᐸᕕᓐᓖᓐᑦ ᐅᔭᕋᖕᓂᐊᕈᓐᓇᖅᓱᓂ ᑎᑭᓪᓗᒍ 22.2 ᒥᓕᐊᓐ ᑕᓐᓇ ᐊᕐᕌᒍ ᐊᑕᐅᓯᖅ ᓴᕕᕋᔾᔭᒃᓯᒃ ᐅᔭᕋᖕᓂᐊᕈᓐᓇᐅᑎᖓ ᓈᓴᐅᑖ 1. ᑕᒃᑯᖓ 22.2 ᒥᓕᐊᓐ ᑕᓐᓇ ᐊᕐᕌᒍ ᐊᑕᐅᓯᖅ, ᑲᒪᐸᓂ ᒫᓇᐅᔪᖅ ᐊᖏᕐᖅᑕᐅᓯᒪᔪᖅ ᐊᒡᔭᖅᑐᐸᓇᖅᐳᑎᒃ 6.0 ᒥᓕᐊᓐ ᑕᓐᓇ ᐊᕐᕌᒍ ᐊᑕᐅᓯᖅ ᓴᕕᕋᔾᔭᒃᓯᒃ ᕿᑦᑐᐊᑕ ᐃᒃᓴᕐᕕᖓᓄᑦ ᓯᑯᖃᐳᓃᖅᐸᑦ ᐊᐅᔭᒃᑯᑦ ᑕᒪᓐᓇ ᐅᑭᐅᖅᑕᖅᑐᒥ ᐅᒥᐊᖅᔪᐊᑦ ᐊᖅᑯᑎᖏᑦᑎᒍᑦ ᐊᑐᕐᓗᑎᒃ ᐅᓯᑲᖅᑕᐅᑎᕐᔪᐊᓂ ᐅᒥᐊᖅᔪᐊᓂᒃ. ᐅᑭᐅᖅᑕᖅᑐᒥ ᐅᒥᐊᖅᔪᐊᑦ ᐊᕐᑯᑖ ᑕᒪᐅᓈᖅᑐᖅ ᕿᑦᑐᐊ, ᑕᓯᐅᔭᖅ, ᒥᑦᑎᒪᑕᓕᒃ, ᐊᒻᒪᓗ ᖃᓂᒋᔭᖏᓐᓂᑦᑐᑦ ᐃᒪᐃᑦ. ᐃᓱᒫᑑᑕᐅᓗᐊᖅᑐᖅ ᓇᓗᓇᐃᖅᑕᐅᓯᒪᔪᑦ ᑕᒫᓂ ᐅᑭᐅᖅᑕᖅᑐᒧᑦ ᐅᒥᐊᖅᔪᐊᑦ ᐃᓂᖏᑦᑎᒍᑦ ᐃᓚᖃᖅᓴᖅᐸᑦ ᐸᖅᑭᓗᑎᒃ ᐊᒃᑐᐃᓗᑎᒃ ᑑᒥᖏᓐᑦ ᕿᓚᓗᕐᓂᒃ ᐅᓯᑲᖅᑐᓂᑦ ᐅᑯᐊᓗ ᑎᑭᐅᑎᓯᒪᓕᑕ ᓇᓅᓐᓂᖏᓐᓂ, ᐅᓄᕐᓂᖏᓐᓄᑦ, ᓄᑕᖅᓗᑎᒃ ᐃᓂᖏᑦᑎᒍᑦ, ᖃᓄᐃᓕᐅᕈᓯᖏᑦ ᐊᒻᒪᓗ ᐱᑕᖃᐅᖅᐸᑕ ᓯᓕ ᑑᒥᓕᑦ ᕿᓚᓗᖃᖅᓯᑕᐅᖃᑦᑕᖅᑐᑦ ᓄᓇᓕᖕᓂᑦ.

ᐅᖃᐅᓯᕆᓗᒋᑦ ᐅᔭᕋᖕᓂᐊᕐᕕᐅᑉ ᐅᔭᕋᖕᓂᐊᕈᓐᓇᐅᑎᖏᓐᓄᑦ ᐊᑐᐊᓚᐃᑦ ᐊᒻᒪᓗ ᒪᓕᒋᐊᖃᖅᑕᖏᑦ ᐋᑐᑎᖃᖅᑐᑦ ᑑᒥᓕᖕᓄᑦ ᕿᓚᓗᕐᓄᑦ, ᒎᓯᑐ ᐸᓇᓯᐊᖃᑎᕖᑦ ᐸᓇᓯᐊᖃᑎᒌᓗᒋᑦ ᐃᖃᓗᓕᖓᔭᒃᑯᑦ ᐊᒻᒪᓗ ᐃᒪᕙᓕᖓᔭᒃᑯᑦ ᑲᓇᑕ ᐱᓕᖓᓚᐅᖅᑐᑦ 2017 ᑑᒥᓕᖕᓂ ᕿᓚᓗᕐᓂᒃ ᓂᕕᙵᑖᓕᖅᓯᒪᓪᓗᑎᒃ ᐱᓕᖓᑎᑦᑎᔾᔪᑎᖃᖅᑐᑦ ᑲᖏᖅᖢᐊᕐᔪᒃ, ᓄᓇᕗᑦ. ᐃᑲᔪᖃᑎᒌᒃᖢᑎᒃ ᖃᐅᔨᓴᕐᓂᖅ ᐱᓕᖓᑎᑦᑎᔾᔪᑕᐅᔪᖅ ᐃᓚᖃᖅᑐᖅ ᒎᓯᑐ ᐊᖏᕐᕆᓕᕆᐊᖅᑎᓪᓗᒍ ᐃᖃᓗᓕᖓᔭᒃᑯᑦ ᐊᒻᒪᓗ ᐃᒪᕙᓕᖓᔭᒃᑯᑦ ᑲᓇᑕ ᒫᓇᐅᔪᖅ ᓂᕕᙵᑖᓕᖓᔾᔪᑎᖓᓕᑦ ᑐᓂᓯᒪᓪᓗᑎᒃ ᐊᓯᖏᑦᑕᐅᖅ ᐆᒪᔪᓂᒃ ᑎᑎᕋᕈᑎᓕᓪᓗᒋᑦ ᓂᕕᙵᑖᖓᓕᑦᑎᒍᑦ ᐋᑐᑎᒃᓂᐊᕐᒪᑕ ᐸᕕᓐᓖᓐᑦ ᐅᔭᕋᖕᓂᐊᕐᕕᖓᓗᓐ-ᐱᓯᒪᔪᑦ ᐃᓕᑕᐅᓇᓱᒃᑐᑦ ᑐᑭᓕᕈᑕᐅᕙᓪᓕᐊᓂᐊᖅᑐᑦ ᐱᓗᒍ ᑐᑭᓯᓂᐊᕐᒪᑕ ᑭᐅᓯᓂᖅ ᑑᒥᓕᖕᓂᒃ ᑖᒃᑯᓄᖓ ᐅᒥᐊᖅᔪᐊᓄᑦ ᐃᖏᕐᖃᔭᒃᑐᓄᑦ. 20 ᑑᒥᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐆᒪᔪᑦ-ᐱᔭᐅᔪᑦ ᑲᖏᖅᖢᐊᕐᔪᖕᒥ ᑕᐃᑲᓂ 2017 ᓯᑯᖃᖅᑎᓇᖑ ᐊᐅᔭᒃᑯᑦ ᐊᒻᒪᓗ ᓴᓇᕿᑕᐅᔪᑦ ᑲᑎᖓᓪᓗᑎᒃ ᐆᒪᔪᓂᒃ ᑎᑎᕋᖅᐸᓪᓕᐊᔪᑦ ᓂᕕᙵᑖᖏᑦ ᒪᓕᒡᒍᒋᑦ ᐱᔾᔪᑎᒋᓪᓗᒍ ᒥᐊᓂᖃᓂᖓᓪᓚᑦ ᖃᐅᔨᓇᕐᓯᑎᑦᑎᓂᐊᕐᒪᑕ ᓇᒧᑦ ᓄᑦᑕᕐᓂᖏ, ᐊᖃᐅᒪᓂᖏᑦ, ᐊᒻᒪᓗ ᓇᔪᖅᑕᖏᑦ ᐊᐅᔭᓕᒫᖅ ᓯᒡᔭᖏᓐᓂ ᓯᕐᒥᑦ ᐅᐊᖕᓇᖓᓂ ᖁᑦᑎᒃᑐᕐᒥᐅᑦ. ᐊᑕᔪᑦ ᓂᕐᔪᑎᓄᑦ ᑕᑯᔭᐅᓇᓱᒡᔪᐊᕆᕗᑦ ᓂᐹᕿᔪᑦ ᐱᔾᔪᑎᒋᓪᓗᒋᑦ ᐃᒫᓂ ᓂᐱᓕᐅᑎᓪᓗᒋᑦ ᓂᕕᙵᑖᖏᑦ ᐊᒻᒪᓗ ᓴᔾᔭᓯᖅᑐᓗᒃᑐᑦ ᖃᐅᔨᓴᕆᑦ ᐆᒃᑐᖃᖅᑐᑦ ᓂᕐᔪᑎᑦ ᐊᕙᑖᓂ ᓂᐹᕿᔪᑦ ᐊᒻᒪᓗ ᓂᐱᖃᕐᒥᔪᑦ ᐃᒫᓂ ᖃᓄᐃᓕᐅᖅᑐᓂᑦ; ᑕᐃᒪᓐᓇᐅᓚᓗᐊᖅᑎᓪᓗᒍ ᐅᑯᐊ ᖃᐅᔨᓇᓯᒍᑕᐅᔪᑦ ᑕᒪᒃᑯᓂᖓ ᖃᐅᔨᓴᕈᑎᑦ ᑎᑎᖅᓯᒪᔪᑦ ᐊᖏᕐᓂᖅᓴᒥᒃ ᖃᐅᔨᒪᑦᑎᐊᓕᖅᑐᑦ ᒫᓇᐅᔪᖅ ᖃᐅᔨᓇᓱᒃᑕᐅᓯᒪᔪᑎᒍᑦ.

ᐃᓕᖁᓯᕆᔭᕐᒥᑦ ᑭᐅᓯᔾᔪᓯᕆᔭᕐᒥᑦ ᑑᒥᓕᑦ ᕿᓚᓗᒐᐃᑦ ᑕᒻᑯᓄᖕ ᓴᕿᔭᒃᓴᓂᒃ ᐅᓯᒃᖠᑕᖅᑐᑦ ᐅᒥᐊᖃᐅᑦ ᐊᖁᑖᓂ ᑖᒥᓂ ᐅᑭᐅᖅᑕᖅᑐᒧᑦ ᐅᒥᐊᖃᐅᓂᖅ ᐃᓂᒋᔭᐅᔪᑎᒍᑦ ᖃᐅᔨᓴᕆᒃᑕᐅᑦᑎᐊᖅᓯᒪᔪᖅ ᖃᓄᑎᒋᙵᓪᓚᖓᑦ ᓂᕐᔪᑎᓂᑦ ᓂᕕᙵᑖᓕᑦ ᒪᓕᒡᒍᒋᑦ ᓈᓚᐅᑎᑦᑎᒍᑦ ᐅᒥᐊᖃᐅᓂᑦ ᐅᒥᐊᖃᐅᑦ ᓄᓈᖑᐊᑎᒍᑦ ᓇᓃᓕᖓᓪᓚᑦ ᓴᕿᔮᖅᑐᑦ ᑕᐃᑲᓂ 2017 ᐊᐅᔭᒃᑯᑦ ᓯᕗᑲᐱᓐᓃᖅᑎᓇᖁ. ᖃᓄᐃᓕᐅᕐᑎᕐᒥᑦ ᑭᐅᔪᖏᑦ ᖃᐅᔾᔭᓴᖅᑕᐅᑎᓪᓗᒥᑦ ᐃᓚᖃᖅᑐᑦ ᐊᓯᑦᔭᕐᓗᒃ ᑑᒥᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐃᖃᓪᓕᐊᕐᒥᑦ ᓄᑕᕐᓂᕐᒥᑦ (ᓱᕐᓗ ᐊᓯᐊᓄᑦ ᓴᙳᔪᑦ ᕿᒫᓯᒪᔪᑦ ᐊᒻᒪᓗ ᐃᓅᖅᑕᐅᔪᓐᖏᑦᑐᑦ) ᐊᒻᒪᓗ ᐊᓯᑦᔮᖅᑐᑦ ᐊᖃᐅᒪᓂᖏ; ᐃᓯᐊᓂ ᐃᓚᖃᖅᑐᖅ ᐊᓯᑦᔭᖃᓯᖅᑐᑦ ᐃᖃᓪᓕᓈᓂᖓᓪᓚᑦ ᐊᑯᓂᐅᓂᖓᓪᓚ, ᐊᖃᐅᒪᓂᖓᓪᓚᑦ ᓱᑲᓂᖓ, ᐃᖃᓪᓕᓂ ᐊᖃᐅᒪᕙᕆᔭᖓᓪᓚᑦ ᐃᑎᓂᖓ, ᐊᑯᓂᐅᓂᖓ ᖃᓄᖅ ᐃᑎᓂᖓᓕᑎᒍᑦ, ᑲᑎᖕᒍᕐᒥᑦ ᐊᖃᐅᒪᓂᖓᓪᓚᑦ ᐊᑯᓂᐅᓂᖓ, ᐊᒻᒪᓗ ᐃᖃᓪᓕᓄᐊᖅᐸᓪᓕᐊᕚᑦ ᑐᓴᕐᓗᒃ ᐸᓯᖅᔭᕋᖓᒥᒃ ᐅᒥᐊᔪᐊᒥ ᐊᖏᕐᔪᓂᒃ.

ᖃᐅᔨᓴᓯᑎᐊᖅᓱᒋᑦ ᑑᒥᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐊᖃᐅᒪᒃᑯᔨᖏᑦ, ᖃᐅᔨᓴᕆᑎᓪᓛᑦ ᐃᓚᖃᖅᑐᑦ ᓴᕿᑎᓪᓗᒥᑦ ᐊᑲᐅᒪᒃᑯᑎᖏᑦ ᑎᓴᒪᓂᑦ ᑑᒥᓕᖕᓂᑦ ᕿᓚᓗᒐᕐᓂᑦ, ᐊᑐᓂ ᐃᓪᓚᕆᔭᐅᔪᑦ SPLASH-10 ᐊᒫᖕᒍᕐᒥᑦ ᓂᕕᙵᑖᖅ ᐊᒻᒪᓗ MiniPAT ᐊᑕᓪᓗᓂ ᓂᕕᙵᑖᓗᒍᑦ (ᓂᕐᔪᑎᒃᔪᑎᑦ ᖃᓄᓴᐅᔭᑦ). ᑲᑎᓪᓗᒥᑦ 77 ᐅᒥᐊᖅᔪᐊᑦ-ᑑᒥᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐸᕐᓯᒪᔪᑦ ᓇᓗᓇᐃᖅᑕᐅᓯᒪᔪᑦ ᖃᓂᓈᖅᓯᓛᖑᓯᒪᔪᑦ ᐊᕙᑖᓂᑦ ᐊᑕᐅᓯᖅ ᑑᒥᓕᒃ ᐊᒻᒪᓗ ᓇᓕᐊᑐᐃᓐᓇᖅ ᐅᒥᐊᖅᔪᐊᖅ ᐃᓗᐊᓂ 3 ᑭᓛᒥᑕᑦ. ᐊᖃᐅᒪᓪᓗᒥᑦ ᓄᑦᑕᕐᓂᕐᒥᑦ ᐊᑐᓂ ᓂᕐᔪᑎᑦ ᖃᐅᔨᔭᐅᓇᓱᒃᑕᐅᑦᑎᐊᓚᐅᖅᑐᑦ ᖃᓄᖅ ᐅᖓᓯᒃᑎᒋᔪᐊᖃᑦᑕᕐᓕᖓᓪᓚᑦ ᓅᑕᕐᒥ ᐅᒥᐊᖅᔪᐊᓂᑦ (ᖃᐅᔨᓴᖅᑕᐅᕐᒥᓇᕐᓂᐊᖅᑐᖅ ᑕᒪᓇ) ᐊᒻᒪᓗ ᐱᓪᓗᒥᑦ ᐅᒥᐊᖅᔪᐊᓃᖃᑕᐅᓚᐅᖅᑕᐅᓪᓗᒍ (CPA ᑎᑭᓪᓗᒍ 10 ᑭᓛᒥᑕᑦ) ᐊᒻᒪᓗ ᑕᑯᓚᐅᙱᕐᑯᑎᒃ (> 10 ᑭᓛᒥᑕᑦ) (ᑕᐃᒪᐃᓐᓇᕐᓂᐊᖅᑐᖅ ᖃᐅᔨᓴᖅᑕᐅᑲᓂᕋᓗᐊᕈᓂ).

ᐊᖏᓕᖅᓴᒥᑦ ᑕᑯᓪᓗᒋᑦ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᑕᒻᒪᕇᒃᑯᑎᑦᑎᒍᑦ ᓂᕕᖓᓪᓚᑖᓕᖕᓂᑦ ᐃᓚᔭᐅᓯᒪᔪᑦ ᐳᐃᖃᑦᑕᕈᓯᖏᑦ ᖃᐅᔨᔭᐅᓇᓱᒍᑎᒃ ᑕᒪᓐᓇ ᐃᓚᒋᓪᓗᒍ ᐊᓯᖏᑦᑕᐅᖅᑭᓱᐊᓂ ᒥᑭᔪᒃ ᖃᐅᔨᓴᕈᑎᑖᕙᐅᓯᒪᔪᖅ ᐊᑕᐅᓯᕐᒧᑦ ᐋᖅᑎᑕᐅᔪᖅ ᐊᔾᔨᓕᐅᕈᑎᓂᒃ ᐊᖃᐅᒪᓕᕐᖓᓪᓚᑦ ᓂᕕᖓᓪᓚᑦᕐᒥᒍᑦ.
ᐊᑐᖅᑕᐅᔪᑦ ᖃᐅᔨᓇᓱᒃᑕᐅᑦᑎᐊᓚᐅᖅᑐᑦ ᐳᐃᓯᒪᓪᓗᑎᒃ ᖃᓄᖅ ᓅᖃᑦᑕᖅᐸᑦ ᐅᒥᐊᕐᔪᐊᖅᑕᖃᖅᑐᓂ ᐃᓚᕆᔭᐅᓪᓗᑎᒃ 12 ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᓇᖕᒪᖅᑐᑦ ᑕᒻᒪᕇᑯᑎᓂᒃ Fastloc ᓇᓃᒻᒪᖕᖓᑕ ᓂᕕᖓᓪᓚᖅᑎᑦᑎᒍᑦ (ᖁᓕᑦ SPLASH-10 ᓂᕕᖓᓪᓚᖕᖔᓂᑦᑐᑦ ᐊᒻᒪᓗ ᒪᕿᒃ CTD-SRDLᓂᕕᖓᓪᓛᑦ). ᐊᓯᑦᔨᖅᑐᖃᕋᔭᕐᒪᖖᒋᑦ ᑑᒑᓕᖕᓂᒃ ᖃᓄᐃᓕᐅᕈᓯᖏᑦ ᖃᐅᔨᔭᐅᓇᓱᓚᐅᖅᑐᑦ 10 ᑭᓚᒦᑕᒃ ᐊᕙᓗᐊᓂ ᐃᖏᕐᕋᔪᑦ ᐅᒥᐊᕐᔪᐊᑦ.

ᐅᑯᐊ ᐊᑖᓂ ᑎᑎᕋᖅᓯᒪᔮᑦ ᓇᐃᓈᖅᓯᒪᓚᐅᖅᑎᒃ ᖃᐅᔨᔭᐅᔪᓂᒃ ᑕᒪᑐᒨᖓ ᑑᒑᓕᖕᓄᑦ ᖃᓄᐃᓕᐅᕈᓯᖏᑦ ᑭᐅᓯᑎᓚᐅᕐᑦ ᐅᔭᕋᖕᓂᐊᕐᕕᒃ-ᐱᓯᒪᔪᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ ᒪᓕᒃᑯᒍ ᖃᓅᑎᕆᔪᖅ ᓂᕐᔪᑎ-ᐃᖏᕐᕋᔪᓂᑦ ᓂᕕᖓᓪᓚᖅᑐᑦᑎᒍᑦ ᑖᒃᑯᐊᓗ ᖃᐅᔨᔾᔪᑎᒋᒋᓚᐅᕐᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᓈᓚᐅᑎᖏᑦ ᐃᖏᕐᕋᓂᖏᑦᑕ ᖃᐅᔨᒪᑎᑦᑎᔾᔪᑕᐅᔪᓂᑦ:

ᐊᖃᐅᒪᓚᐅᕐᓂ ᐃᒪᓐᓇᐃᓕᐅᖅᑐᖅ ᐃᓕᖁᓯᕐᒥᒍᑦ:

- ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᔪᖅ ᐳᐃᓯᒪᕙ: ᐊᒃᑐᖅᑕᐅᓂᖓ ᐅᖓᓯᖕᓂᖓᑕ ᐊᖕᖏᔪᓂᒃ ᐅᒥᐊᕐᔪᐊᓂᒃ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐳᐃᓯᒪᔪᑦ ᖃᐅᔨᓴᕈᑎᖏᑦᑎᒍᑦ ᖃᓂᓈᖅᑕᐅᓯᒪᔪᓄᑦ (P=0.001), ᐳᐃᓯᒪᓐᖏᑯᑖᒃᑐᖅ ᑑᒑᒃ ᐃᓗᐊᓃᒃᑯᑎᒃ 2 ᑭᓚᒦᑕᒃ ᐅᒥᐊᕐᔪᐊᒥᑦ.
- ᐊᖅᑲᐅᒪᓂᖓᑕ ᐊᑯᓂᐅᑎᒋᓂᖓ: ᐊᒃᑐᖅᑕᐅᓂᖓ ᐅᖓᓯᖕᓂᖓᑕ ᐅᒥᐊᕐᔪᐊᖅ ᑑᒑᒃ ᕿᓚᓗᒐᖅ ᐊᖃᐅᒪᓚᐅᕐᓂ (ᖃᓄᐃᑎᒋᔪᖅ ᐊᖅᑲᐅᒪᕙ/ᐃᑲᕐᖁᒥ) ᓈᓴᖅᓯᒪᔪᑎᒍᑦ ᖃᓂᑦᑐᒻᒪᕆᐋᓘᓚᐅᖅᑎᒃ ᑭᓯᐊᓂ (≤2 ᑭᓚᒦᑕᒃ; P=0.002), ᐃᒻᒪᖄ ᖃᓄᖅ ᓱᒃᑲᑎᒋᓂᖓ ᑕᒫᖓᑦ 0.443 ᑕᑯᓯᒪᓐᖏᓚᐅᖅᑎᓕ ᑎᑭᐅᒪᔩᑦ 0.501 ᐊᒻᒪᓗ 0.686 ᐅᒥᐊᕐᔪᐊᖅᑕᖅᑎᓚᐅᕐᒧᑦ ᐃᒪᓐᓇᐅᓚᐅᕐᓂ ᑕᐃᑲᓂ 1-2 ᑭᓚᒦᑕᒃ ᐊᒻᒪᓗ 0-1 ᑭᓚᒦᑕᒃ, ᒪᓕᒃᑐᖅ. ᑕᐃᒪᖓᓂ ᐊᖃᐅᒪᔾᔪᓯᖏᑦ ᐊᑯᓂᐅᑎᒋᓂᖓ ᑕᐃᒫᑐᐃᓐᓇᖅ ᐊᕙᑖᓂ ᑕᑯᓯᒪᕙᓗᐊᕈᑎᒃ ᐊᒻᒪᓗ ᑕᑯᓯᒪᓐᖏᒃᑲᓗᐊᕈᑎᒃ, ᑕᐃᒪᓕ ᐊᑯᓂᐅᒫᖅ ᐊᖅᑲᐅᒪᔭᖓ ᐊᑯᓂᐅᓂᖅᓴᐅᖃᑦᑕᓚᐅᖅᑐᑦ ᑑᒑᓕᑦ ᕿᓚᓗᑦ ᑕᑯᓯᒪᓐᖏᓚᐅᕐᑎᒃ ᐅᒥᐊᕐᔪᐊᓂᒃ.
- ᐃᖃᖓᓂᑦ ᐊᖃᐅᒪᔪᑦ ᐃᑎᓂᖓᓄᑦ: ᐊᒃᖃᑕᐅᓗᑎᒃ ᐅᖓᓯᓈᖅᑐᒥᑦ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ ᑖᒃᑯᓄᖓ ᑑᒑᓕᖕᓄᑦ ᕿᓚᓗᒐᕐᓄᑦ ᐃᑎᓂᖓᑕ ᐊᖃᐅᒪᕕᕆᔭᖓᑕ ᓈᓴᖅᑕᐅᓯᒪᒧᑎᒍᑦ ᖃᓂᓈᑦᑎᐊᖅᓯᒪᔪᑦ ᖃᓄᖅ ᐅᖓᓯᒃᑎᒋᓂᑐᐊᖏᑦᑎᒍᑦ ᐃᖃᖓᓄᑦ (≤2 ᑭᓚᒦᑕᒃᔪ). ᐅᖓᓯᖕᓂᖓ ᑐᖖᓂ 1 ᑭᓚᒦᑕᒃ ᑕᒫᖓᑦ ᐅᒥᐊᕐᔪᐊᒥᑦ, ᑕᐃᒪᓐᓇᐅᓚᐅᕐᑎᓪᓗᒍ, ᑲᔪᖏᖅᑕᖅ ᐃᑎᓂᖓᓄᑦ ᐊᖅᑲᐅᒪᔩᑦ ᓂᕆᑎᑦᑎᓐᖏᑦᑐᓄᑦ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐃᑎᓂᖅᓴᒍᐊᔩᑦ 0.357 ᐊᒻᒪᓗ 0.888, ᒪᓕᑦᑎᐊᖅᑐᖅ. ᑕᐃᒪᓗ, ᑕᒪᕿᒃ ᓂᕆᑎᑦᑎᔪᑦ ᐊᒻᒪᓗ ᓂᕆᑎᑦᑎᓐᖏᑦᑐᑦ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᑕᑯᓭᕙᒃᑐᑦ ᐃᑎᓂᖅᓴᒥᒃ ᐊᖅᑲᐅᒪᔩᑦ ᑕᐃᒪᖓᓂ ᐅᒥᐊᕐᔪᐊᖅᑕᖅᑎᓚᐅᕐᒧᑦ ᐃᓗᐊᓂ 1 ᐊᒻᒪᓗ 2 ᕿᓚᒦᑕᒃ ᑕᒫᖓᑦ ᑑᒑᓕᖕᓂᑦ ᑭᓚᓗᖏᓐᓂᑦ, ᒪᓕᑦᑎᐊᖅᑐᖅ, ᖃᐅᔨᓇᕋᔭᖅᑐᖅ ᐃᖋᔪᓂᑦ ᑕᐃᒪᓐᓇᐃᓕᕈᑎᑦᔭᖓ.
- ᐃᑎᓂᖓᒍᑦ ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᓂᖃᓚᐅᖅᐸ: ᐊᒃᑐᖅᑕᐅᓂᖓ ᐅᖓᓯᒃᑎᒋᓂᖓᓂᑦ ᐅᒥᐊᕐᔪᐊᖅ ᑖᒃᑯᓇᖓ ᑑᒑᓕᖕᓄᑦ ᕿᓚᓗᒐᕐᓄᑦ ᐊᑯᓂᐅᑎᒋᓂᖓ ᐊᖅᑲᐅᒪᓂᖓᑕ ᓈᓴᐅᓯᓇᔾᔭᑎᖏᑦᑎᒍᑦ ᖃᐅᔨᓇᖅᓯᓯᒪᔭᖃᓚᐅᖏᑦᑐᖅ ᑎᑭᐅᑎᓯᒪᖏᓐᓂᖓᓄ (P≥0.1).
- ᐊᑯᓂᐅᑎᒋᓂᖓ ᐊᖅᑲᐅᒪᓂᖓᑕ ᑲᑎᓪᓗᒋᑦ: ᑕᒪᓐᓇᐅᓚᐅᕐᑎᓪᓗᒍ ᐊᒃᑐᖅᑕᐅᔪᓐᓇᕐᓂᖓ ᐅᖓᓯᒃᑐᒥᑦ ᐊᖏᔪᓂᑦ ᐅᒥᐊᕐᔪᐊᓂᑦ ᑖᒃᑯᓇᖓ ᑑᒑᓕᖕᓄᑦ ᑲᑎᓪᓗᒍ ᐊᑯᓂᐅᑎᒋᓂᖓ ᐅᖃᐅᒪᓪᓗᑎᒃ ᑲᑎᓪᓗᒋᑦ ᖃᐅᔨᕙᐅᒪᔪᖅ ᐊᑯᓂᒃᓪᓚᐅᔪᓇᕐᓂᖓᓂᒃ (P=0.016), ᐊᖅᑲᐅᒪᓂᖓᑕ ᐊᑯᓂᐅᓂᖓ ᐊᑯᓂᐅᓗᐊᕋᓂ ᐃᓗᐊᓂ 2 ᑭᓚᒦᑕᒃ ᐅᒥᐊᕐᔪᐊᒥᑦ, ᖃᐅᔨᓴᖅᓯᒪᔪᓂᒃ ᐱᑕᖃᓗᐊᓐᖏᑦᑐᖅ ᐃᓚᓕᐅᑎᓯᒪᔾᔪᑎᔪᓇᖅᑐᓄᑦ ᐊᒻᒪᓗ ᖃᐅᔨᔭᐅᔪᓂᒃ ᑐᑭᓕᐅᕆᑕᐅᓯᒪᔪᓄᑦ ᐱᑦᑎᐊᕙᐅᕆᐊᓕᖕᓄᑦ.
- ᑲᔪᓰᓐᓇᖏᔭᕐᓂᖓᑦ ᑐᓗᕐᕕᕆᓇᔭᖅᑕᒥᑦ: ᑑᒑᓕᑦ ᓱᑲᓂᖏᑦ ᐃᖏᕐᖁᓪᓗᑎᒃ ᖃᐅᔨᔭᐅᓇᓱᓚᐅᖅᑐᖅ ᑕᒪᓕᒫᖅ ᐊᖃᐅᒪᓪᓗᑎᒃ ᐃᑎᓂᖓᓂ ᐊᒻᒪᓗ ᓂᕿᒃᓴᖅᓯᐅᖅᓱᑎᒃ. ᑕᐃᒪᓐᓇᐅᓚᐅᕐᑎᓪᓗᒍ, ᑑᒑᒃ ᓱᒃᑲᓗᐊᓘᖏᑦᑐᖅ ᐊᓯᐊᒍᐊᓘᖏᑦᑐᖅ ᐊᕙᑖᓂᑦ ᐅᒥᐊᕐᔪᐊᖅᑕᖃᕈᐊᕆᓂ ᐅᒥᐊᕐᔪᐊᖅᑕᖃᖏᒃᑲᓗᐊᕆᓂ.

ᐃᖅᑲᓐᓂ ᖃᓄᐃᓕᐅᖅᐸᑦ:

- ᓱᑲᓂᖕ ᐊᓯᐊᓄᑦ ᓵᖑᓪᓗᓂ: ᓈᓴᖅᑕᐅᓯᒪᔪᓂ ᐊᒃᑐᖅᑕᐅᑎᓪᓗᒋᑦ ᐅᒥᐊᕐᔪᐊᓂ ᑑᒑᓕᑦ ᐃᖏᕐᕋᓪᓗᑎᒃ ᐊᓯᐊᓄᑦ ᓵᖑᔾᔨᑦ ᐃᓗᐊᓂ 4-ᒥᑦ 4-ᒧᑦ ᑭᓚᒦᑕᒃ (P<0.05) ᖃᓃᑎᒋᖕᒪᖕᓛᑕᓕ ᐊᖕᖏᔪᓂᒃ ᐅᒥᐊᕐᔪᐊᑦ ᐱᑕᖃᖕᒋᓪᓗᑎᒃ ᐃᓗᐊᓂ 10 ᑭᓚᒦᑕᒃ ᑑᒑᓕᖕᓂᑦ ᕿᓚᓗᒐᕐᓂᑦ. ᐅᓇ ᖃᐅᔨᓴᐅᓇᓱᒃᓯᒪᓂᖕ ᐅᖃᖅᓯᒪᔪᖃᖕᒋᑦᑐᖅ ᖃᓄᖅ ᓵᖑᑎᒋᕙᖕᒪᖕᓚᑦ ᐅᐸᑎᓇᓱᐊᖅᓱᓂ ᐅᕝᕙᓘᓐᓃᑦ ᕿᓖᓪᓗᓂ ᐅᒥᐊᕐᔪᐊᓂᒃ ᑭᓯᐊᓂ ᐅᓇ ᑑᒑᓕᒃ ᕿᓚᓗᒐᖅ ᐊᓯᐊᓄᖅ ᓵᖑᔾᔨᖅ ᐊᔾᔨᒋᖕᒋᑕᖕᓚᓂ ᐊᑯᓂᐅᑎᒋᓂᖕ ᐅᖕᒐᓯᒃᑎᒋᓂᖕᒐᓄ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ.

- ᐃᖏᕐᕋᓪᓗᑎᒃ ᓇᒧᖕᒐᐅᔭᓇᐊᒃᓴᖅ ᓇᓗᓕᐅᖃᖃᑦᑕᖅᐹᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ: ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐃᖏᕐᕋᓪᓗᑎᒃ ᐊᓯᐅᖃᖃᑦᑕᓐᖏᑦᑐᑦ ᐊᖕᖏᕚᓐᖏᑦᑐᖅ ᐊᓯᑦᔨᑎᖕ ᑕᐃᑲᓂ ᐅᒥᐊᕐᔪᐊᖅᑕᖃᖅᑎᓪᓗᒍ, ᐃᓱᒪᓕᕈᑕᐅᓯᒪᔪᖅ ᑐᓗᖅᓯᓂᐊᓐᖏᑦᑐᑦ ᐅᒥᐊᕐᔪᔪᐊᑦ. ᑕᐃᒪᓗ ᖃᐅᔨᓴᕈᑎᑖᕐᑎᒧᑦ ᐊᐅᓪᓗᑎᔭᐅᔪᑦ ᓴᓂᐊᒍᑦ ᐊᕙᑖᓂ ᑑᒑᓕᒃ ᕿᓚᓗᒐᖅ ᐊᒻᒪᓗ ᐊᖕᖏᔪᑦ ᐅᒥᐊᕐᔪᐊᑦ, ᖃᐅᔨᓴᕈᑎᖂᔨᒪᔪᑎᒧᑦ ᑕᑯᑦᑎᑦᔪᑎᒋᓂᐊᕐᓗᒍ ᑕᐃᒪᓐᓇᐃᑦᑐᖃᕋᔭᕈᓂ ᐊᖏᔪᓂᒃ ᐅᒥᐊᕐᔪᐊᓂ ᐱᑕᖃᖅᑎᓪᓗᒍ, ᑕᐃᒪᐃᒻ, ᐋᒃᑲ "ᑕᐃᒪᓐᓇ ᑕᑯᑦᑎᔪᓂᒃ" ᐊᑐᕈᑎᖃᕐᓗᑕ ᖃᐅᔨᓴᖅᓯᔪᖃᓚᐅᓐᖏᑦᑐᖅ.

- ᐊᓪᓚᕕᓇᐊᖅᑐᑦ ᐊᖁᑎᖕᒐᓃᑉᐸᑦ: ᓇᒧᖕᒐᖅᐸᖕᒪᖕᓛᑕ ᓂᕕᖕᒐᑖᖃᖅᑐᑦ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᖃᓄᖅ ᐅᖕᒐᓯᓈᖃᑦᑕᖅᐸᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᓴᕿᔮᖅᑎᓪᓗᒋᑦ, ᑕᒪᓃᑯᑎᓂᑦ ᓴᕿᑦᑐᓇᖃᓕᐅᖕᒋᑦᑐᑦ ᐃᓗᐊᓂ 0.5 ᑭᓚᒦᑕ ᐅᒥᐊᕐᔪᐊᑉ ᓴᐅᒥᐊᓂ ᐊᒻᒪᓗ ᑕᓕᕐᐱᐊᓂ ᑎᒥᐊᑕ, 1 ᑭᓚᒦᑕᒃ ᐅᒥᐊᕐᔪᐊᑉ ᓯᕗᓂᐊᓂᑦ, ᐊᒻᒪᓗ 1.5 ᑭᓚᒦᑕᒃ ᐃᖁᐊᓂᑦ. ᑕᑯᔪᑦ ᐊᒻᒪᓗ ᖃᓄᐃᓕᖕᒐᓇᔾᓂᖕᒐᓂ ᓂᕆᐅᒋᔭᑎᒧᑦ ᐅᓄᖅᓯᕙᓪᓕᐊᓚᔭᖅᐸᑕ ᖃᓂᓪᓗᑎᒃ ᐅᒥᐊᕐᔪᐊᕐᒧᑦ ᓇᓂᑐᐃᓐᓇᖅ ᐊᕙᓗᓯᒪᓗᑎᒃ ᐊᒻᒪᓗ ᐅᓄᓗᐋᕐᕈᓐᖏᓪᓗᑎᒃ ᐅᖕᒐᓯᒋᔭᖕᒐᓂ. ᑕᐃᒪᓐᓇᐅᓚᓗᐊᖅᑎᓪᓗᒍ, ᐅᓄᖅᓯᓯᒪᓂᖕᒋ ᑕᒪᐃᓐᓂᑦ ᓴᐅᒥᐊᓂ ᑎᒥᐊᑕ ᐅᒥᐊᕐᔪᐊᖅ ᐊᒻᒪᓗ ᐅᒥᐊᕐᔪᐊᑉ ᑕᓕᕐᐱᐊᓂ ᓴᓂᐊᓂ ᐅᓄᖅᓯᕙᓪᓕᐊᖕᒋᓐᓇᕐᓗᑎᒃ ᑎᑭᓪᓗᒍ 1 ᑭᓚᒦᑕᒃ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ, ᐃᒪᐃᒻᒪᑦ ᐅᓄᖅᓯᒍᑎᒃ ᓯᕗᓂᐊᓂ ᐊᒻᒪᓗ ᐃᖁᖕᒐᓂ ᓴᓂᐊᓂ 1 ᑭᓚᒦᑐᒦᓪᓗᑎᒃ ᐊᒻᒪᓗ ᐅᓄᕈᓂᕐᒥᓗᑎᒃ 1 ᑭᓚᒦᑕᒥᑦ, ᒪᓕᒡᓗᒍ ᐃᖅᐸᖅᓯᒪᓂᖕ ᓇᓗᓇᐃᓕᐅᖅᑐᑦ ᓇᓐᓂᓐᖏᓐᓂᒃ ᖃᓄᐃᓕᖕᒐᓂᖕᒋᓐᓂᒃ. ᑕᒪᓐᓇᐅᓚᓗᐊᖅᑎᓪᓗᒍ ᐊᔾᔨᓐᖏᓐᖏᓂᖕ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐅᓄᖅᓯᓯᒪᑎᓪᓗᒋᑦ ᓯᕗᓂᐊᓂ ᐱᓂᖅᓴᐅᓪᓗᑎᒃ ᓴᐅᒥᐊᓂ ᑕᓕᕐᐱᐊᓂᓪᓗ ᐅᒥᐊᖅ ᓴᓂᖕᒋᓐᓂᑦ ᑕᐃᑲᓂ ᑕᓖᓐᑎᓪᓗᒋᑦ ᐅᒥᐊᕐᔪᐊᓂ, ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐅᖕᒐᓯᖕᓂᖕᒋᑦ ᐊᒻᒪᓗ ᐃᓂᒋᔭᖕᒋᑦ ᑖᒃᑯᓄᖕ ᐅᒥᐊᕐᔪᐊᓄᑦ (ᓯᕗᓂᖕ, ᐃᖁᐊ, ᓴᐅᒥᐊ, ᑕᓕᕐᐱᖕ ᑎᒥᖕᒐᓂ) ᖃᐅᔨᓴᐅᓚᒥ ᐊᖕᖏᓂᓕᐅᖕᒋᑦᑐᖅ (P=0.066).

- ᐊᖅᑯᓂ ᐊᒃᑭᖅᑕᖕᒋᓂᖕᒋᑦ ᐊᒻᒪᓗ ᑐᓗᖅᑕᐅᓚᔭᖅᓴᖕᓕᑕ: ᐊᓯᑦᔨᖃᑦᑕᖅᑐᑦ ᐅᖕᒐᓯᒋᔭᖕᒐᖑᖅᒪᑕ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐊᒻᒪᓗ ᐅᒥᐊᕐᔪᐊᑦ ᖃᐅᔨᐅᕗᑦ ᐅᓄᓗᐊᕿᓐᓕᖅᑐᑦ ᖃᓂᒋᔭᖕᒐᒨᒪᐅᖅᑐᑦ ᐃᓕᑕᐅᓇᓱᖕᓇᐅᑎᓪᓗᒍ (P<0.001), ᖃᐅᔨᑎᑦᑎᔪᖅ ᐃᓕᑦᑎᖁᔭᕿᓇᖅᑐᑦ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᑖᒃᑯᓄᖕ ᐊᖕᖏᔪᓄᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐃᖏᖁᔭᒃᑐᓄᑦ.

- ᓇᔪᖅᑕᖕᒋᑦ ᐊᓯᐊᓃᓕᖅᑐᑦ: ᑕᒪᐃᓐᓄᑦ, ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐹᖅᓯᕗᒃᑐᑦ ᐅᒥᐊᕐᔪᐊᑉ ᐊᖁᑖᓂ ᑕᒪᐅᓐᓇᑦᑎᐊᖅ ᐊᓂᒍᕐᓂᐋᖓᖅᑎᓪᓗᒍ ᐊᒻᒪᓗ ᐊᓂᒍᖓᑦᑎᐊᖅᑎᓪᓗᒍ ᐅᒥᐊᕐᔪᐊᖅ (ᐊᑦᑎᓛᖕ 4 ᒥᓂᒥᒃ), ᐃᓱᒪᓕᖅᓯᓯᒪᔪᖅ ᑕᒪᓐᓇ ᐅᐸᑐᑎᑦᑕᐃᓕᒪᓂᖕᒋᑦ ᐊᑯᓂᐅᓗᐊᕿᓗᓐᖏᑦᑐᑦ ᐅᒥᐊᕐᔪᐊᑉ ᐅᓯᑲᖅᑕᖅᑐᑦ ᐊᖁᑖᓂ ᐱᔪᑎᒋᓪᓗᒍ ᐅᒥᐊᕐᔪᐊᕐᓂᑦ ᓴᓂᖁᖅᑕᐅᖃᑦᑕᕐᓂᒃ.

- ᐃᖏᕐᕋᓪᓗᑎᒃ ᓱᒃᑲᓵᕐᓂᖕᒋᑦ: ᖃᐅᔨᓴᖅᑕᐅᓯᒪᕗᖅ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᓱᒃᑲᓵᕐᓂᖕᒋᑦ ᓇᓗᓇᐃᖅᑕᐅᖅᑐᑦ ᐊᒃᑐᖅᑕᐅᒍᑎᒃ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ ᐱᑕᖃᖅᑎᓪᓗᒋᑦ ᑑᒑᓕᖕᓄᑦ ᓈᓴᖅᓯᒪᔪᑎᒧᑦ ᐊᓯᑦᔨᖅᓯᒪᓂᖅᓴᐅᓚᐅᖅᑐᑦ (P=0.005), ᐊᒃᑐᖅᑕᐅᓚᐅᖕᒋᑦᑐᖅ ᐅᒥᐊᕐᔪᐊᓂᑦ(P=0.5). ᑕᐃᒪᐃᒻᒪᑦ, ᐅᓇ ᐋᕿᐅᑎᓂᖕ ᑕᒪᖅᓯᒪᔫᓇᖅᑐᖅ ᐊᒻᒪᓗ ᖃᐅᔨᓴᖅᑕᐅᑦᑎᐊᑲᓐᓂᕆᐊᓕᒃ ᐊᓯᖕᒋᑦᑎᒍᑦᑕᐅᖅ ᖃᐅᔨᓴᕈᑎᑖᕈᑎᒃᓴᑎᒍᑦ ᑕᐃᑲᓂ ᔪᐊᑦᑎᓪᓗᑎᒃ 2018-ᒥ.

ᑕᒪᒃᑯᐅᓚᓗᐊᖅᑎᓪᓗᒋᑦ ᐆᒃᑐᕋᓚᒃᓴᐅᔪᑦ ᐊᓯᑦᔨᐅᑎᓯᒪᔪᑦ ᐳᐃᓯᒪᔪ ᐊᒻᒪᓗ ᐊᖅᑲᐅᒪᔪᑦ ᖃᓄᐃᓕᐅᕈᓯᖕᒋᑦ ᑕᑯᔭᐅᓯᒪᔪᑦ, ᑭᐅᔾᔪᑕᐅᔪᑦ ᑑᒑᓕᒃ ᕿᓚᓗᒐᖅ ᑕᑯᔭᐅᓯᒪᔪᑦ ᐅᒥᐊᖅᑐᖅᑐᓂᑦ ᐊᒃᑭᖅᑕᖕᒋᑦᑐᑦ ᐊᕙᑖᓂᑦ ᐊᑐᓂ ᐊᒻᒪᓗ ᐊᕙᑖᓂᑦ ᖃᓄᖅ ᐸᖅᔭᖅᑰᑎᓂᖕᒋᑦ ᑖᓇᑦᑕᐃᓐᓇᐅᓚᔭᕈᓂ. ᖃᐅᔨᓴᐅᓯᒪᔪᑦ ᓱᖅᓗ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐳᐃᓯᒪᓐᖏᓂᖅᓴᐅᕝᕕᒃᑐᑦ ᐊᒻᒪᓗ ᐅᖃᐅᒪᓂᖕᓕᑕ ᐊᑯᓂᐅᓂᖕ ᐊᒻᒪᓗ ᐊᖅᑲᐅᒪᕕᒋᔭᖕᓕᑕ ᐃᑎᓂᖕ ᑖᑉᐱᑐᖕᓕᑦᓴᐃᓐᓇᖅ. ᓇᓂᔭᐅᓯᒪᔪᑦ ᓱᖅᓗ ᑑᒑᓕᑦ ᕿᓚᓗᒐᐃᑦ ᐳᐃᓚᐅᖃᑐᐃᓐᓇᖅᐸᖕᓂᖕᒋ ᐊᒻᒪᓗ ᐊᖅᑲᐅᒪᓂᖕᓕᑕ ᐊᑯᓂᐅᓂᖕ ᐊᒻᒪᓗ ᖃᓄᖅ ᐃᑎᑎᕆᔪ ᐊᖅᑲᐅᒪᕙ ᖃᒡᓕᕝᓕᓕᐊᔪ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᒃᑭᖅᑕᖕᓕ ᑭᐅᔾᔪᑎᖕᓕᑕ ᖁᐊᕈᑎᑦᑎᓪᓗᒋᑦ ᓅᑦᑐᐃᓐᓇᐃᓕᓇᓯᕆᔭᐅᕙᑦ ᐊᒻᒪᓗ ᐃᑲᔪᖅᓯᕙᖅ ᕿᒪᒍᑎᓂᖕᓕᑕ ᐃᖏᕐᖁᓂᖕ ᒪᓕᒡᓗᒍ. ᑕᐃᒪᓐᓇᐅᓚᓗᐊᖅᑎᓪᓗᒍ, ᖃᓂᓈᖅᑐᕕᓂᕐᓂᑦ ᖃᐅᔨᓴᕈᑏᑦ ᐃᓚᓕᐅᑎᔭᐅᓪᓗᑎᒃ ᐊᑐᖅᑕᐅᔪᑦ ᐳᐃᓯᓪᓗᑎᒃ ᐃᓕᖁᓯᓇᕝᕕᒃᑕᖕᒋᓐᓂᒃ ᐅᓄᓗᐊᓚᐅᖕᒋᒻᒪᑕ ᐊᒻᒪᓗ ᐋᕿᐅᑎᔪ ᑕᐃᒪᐃᒻᒪᑦ ᑐᕿᓕᐅᕈᑎᕆᔭᓇᐊᖅᑐᑦ ᐱᑎᐊᓕᓗᑕ. ᑕᐃᒪᓗ ᖃᐅᔨᓴᕈᑏᑎᐊᑲᓐᓂᖅᓯᒪᓕᕈᑎᒃ ᓯᕗᓂᑎᓂ ᓂᕕᖕᒐᑖᓕᖅᓯᖃᑦᑕᕐᓂᒃᑯᑦ, ᐃᓚᒌᒍᓯᖕᒋᑦ ᐊᕙᑖᓂᑦ ᐅᒥᐊᕐᔪᐊᖅ ᐅᖕᒐᓯᓈᖅᑐᖅ ᐊᒻᒪᓗ ᑑᒑᓕᒃ ᐳᐃᓯᒪᔪᖅ ᐊᒻᒪᓗ ᐊᖅᑲᐅᒪᔾᔨᖕᒐᑕ ᖃᓄᐃᓕᐅᕐᓂᖕ ᖃᐅᔨᓇᓱᒃᑕᐅᑦᑎᐊᑲᓐᓂᕆᐊᓕᒃ.

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Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

The potential effects of vessel-generated noise on cetaceans has become an increasingly recognized management issue worldwide (Williams et al. 2015). As cetaceans rely on the transmission and reception of sound in order to carry out the majority of critical life functions (i.e., communication, navigation, reproduction, and foraging) (Holt et al. 2013), persistent exposure to vessel noise may limit their ability to carry out such functions. Recent studies have indicated that certain cetacean species exposed to vessel-generated noise may be at elevated risk of physiological stress (Rolland et al. 2012), vessel strike (Nowacek et al. 2004), and may attempt to avoid a transiting vessel by altering their swim speed (Williams et al. 2002), and/or using evasive tactics consistent with horizontal (and/or vertical) avoidance (e.g., changing surfacing, diving, and heading patterns) (Williams and Ashe 2007; Nowacek et al. 2007). Depending on the resources that a given habitat provides and the availability of suitable habitat nearby, cetaceans may or may not be able to leave ‘noisy’ areas to seek new, quieter habitat.

The narwhal (*Monodon monoceros*) is a cetacean species endemic to the Arctic that is currently subject to a changing acoustic environment due to increased industrial activity in the Arctic including commercial shipping. Narwhal occur in deep Arctic waters, rarely south of 61º N (COSEWIC 2004), and show high levels of site fidelity as they return to well-defined summering and wintering areas each year (Laidre et al. 2004). Of the two narwhal populations that occur in Canadian waters, the Baffin Bay (BB) population is known to rely on Eclipse Sound, Milne Inlet, and adjacent waterbodies as important summering habitat (Koski and Davis 1994; Dietz and Heide-Jørgensen 1995; Dietz et al. 2001). Of note, mating and calving are known to occur in Eclipse Sound, Milne Inlet, Koluktoo Bay, Pond Inlet, and Navy Board Inlet each year during the open water season (Remnant and Thomas 1992; Marcoux et al. 2009; Smith et al. 2017). Although it remains contested whether narwhal utilize this region for foraging during summer months (Mansfield et al. 1975; Finley and Gibb 1982; Martin et al. 1994; Laidre et al. 2003; Laidre et al. 2004; Laidre and Heide-Jørgensen 2005; Watt et al. 2017), it is thought that the presence of ice and resultant refuge from killer whales (*Orcinus orca*) likely influence the local distribution of narwhal (Koski and Davis 1994; COSEWIC 2004). It has also been suggested that these deep-water inlets provide preferred protection from wind (Kingsley et al. 1994; Richard et al. 1994; COSEWIC 2004).

Commercial shipping operations associated with the Mary River Project (the Project), an iron ore mining project owned by Baffinland Iron Mines Corporation (Baffinland) and located in the Qikiqtani region of Nunavut (Figure 1-1), overlap with established summering grounds for the Eclipse Sound summer stock of narwhal during the open-water season. Project Certificate No. 005, amended by the Nunavut Impact Review Board (NIRB) on 27 May 2014, authorizes the Company to mine up to 22.2 million tonnes per annum (Mtpa) of iron ore from Deposit No. 1. Of this 22.2 Mtpa, the Company is currently authorized to transport 18 Mtpa of ore by rail to Steensby Port for year-round shipping through the Southern Shipping Route (via Foxe Basin and Hudson Strait), and 4.2 Mtpa of ore by truck to Milne Port for open water shipping through the Northern Shipping Route using chartered ore carrier vessels. A Production Increase to ship 6.0 Mtpa from Milne Port was approved for 2018 and 2019. The Northern Shipping Route encompasses Milne Inlet, Eclipse Sound, Pond Inlet, and adjacent water bodies. Therefore, primary concerns identified along the Project’s Northern Shipping Route include potential acoustic disturbance effects from shipping that may lead to changes in narwhal distribution, abundance, migration patterns, and subsequent availability of narwhal for harvesting by local communities. Mother-calf pairs are present along the shipping corridor (e.g. Marcoux et al. 2009) and may be particularly susceptible to potential acoustic disturbance effects given a calf’s close association with its mother in the echelon position, thus potentially reducing the pair’s travel speed and ability to manoeuvre away from vessel traffic.

In this study, fine-scale narwhal movements (horizontal and vertical) during close interactions with large vessels transiting the shipping lane were analyzed to understand and characterize narwhal behavioural responses to ship noise and close ship encounters along the Northern Shipping Route. Narwhal movement data collected from animal-borne biologging tags were analyzed in relation to ship movements derived from available Automated Identification System (AIS) ship-tracking data to investigate the following questions:

- Do narwhal alter their movements at the surface during close ship encounters?
  - Lateral displacement
  - Change in surface travel speed
  - Change in body orientation and direction of travel
- Do narwhal alter their movements in the sub-surface during close ship encounters?
  - Change in dive rate
  - Change in dive depth
  - Change in dive duration
  - Change in proportional time at the surface (surface time)
  - Change in dive descent speed
- If changes in narwhal movement do occur, at what range are individual behavioural responses observed?
- Do narwhal demonstrate habituation to Project-related vessel traffic following repeated exposure?

1.1 Overview of Narwhal Tagging Program

Terms and Conditions attached to Baffinland's Project Certificate No. 005 applicable to narwhal include requirements for the collection of additional baseline data along the Northern Shipping Route on narwhal abundance, distribution and habitat use, as well as implementation of a narwhal monitoring program along the Northern Shipping Route to evaluate predictions in the Final Environmental Impact Statement (FEIS) with respect to potential disturbance effects on narwhal from vessel-generated noise (over a sufficient period to determine the extent to which habituation may occur). Specific terms and conditions attached to Project Certificate No. 005 relevant to narwhal include the following:

- Condition No. 109 - "The Proponent shall conduct a monitoring program to confirm the predictions in the FEIS with respect to disturbance effects from ships noise on the distribution and occurrence of marine mammals. The survey shall be designed to address effects during the shipping seasons, and include locations in Hudson Strait and Foxe Basin, Milne Inlet, Eclipse Sound and Pond Inlet. The survey shall continue over a sufficiently lengthy period to determine the extent to which habituation occurs for narwhal, beluga, bowhead and walrus".
- Condition No. 110 - "The Proponent shall immediately develop a monitoring protocol that includes, but is not limited to, acoustical monitoring, to facilitate assessment of the potential short term, long term, and cumulative effects of vessel noise on marine mammals and marine mammal populations".

- Condition No. 111 - "The Proponent shall develop clear thresholds for determining if negative impacts as a result of vessel noise are occurring".

To address Project Certificate terms and conditions applicable to narwhal, Golder Associates (Golder) partnered with Fisheries and Oceans Canada (DFO) to undertake the 2017 Narwhal Tagging Study in Tremblay Sound, Nunavut (Figure 1-2). The collaborative research program in 2017 expanded on DFO's existing tagging program by deploying specialized biologging tags tailored to address DFO's research objectives related to habitat use, stock delineation and mixing, as well as Baffinland's Project-specific study objectives related to understanding behavioural response of narwhal to vessel traffic. Twenty narwhal were live-captured in Tremblay Sound during the 2017 open-water season and instrumented with a combination of tags for the purpose of monitoring fine-scale lateral movements, dive behaviour, and habitat use throughout their summering grounds in the coastal fjord system of northern Baffin Island. A subset of animals was also outfitted with passive acoustic recording tags to measure the animal's acoustic environment and vocal activities in tandem with other narwhal behaviours.

1.2 Study Objective

The objective of the Narwhal Tagging Study was to investigate narwhal behavioural response to Project-related vessels transiting along the Northern Shipping Route by comparing animal-borne tag data with ship-tracking data collected during the 2017 open-water season. Behavioural responses considered in this study included changes in narwhal movement behaviour at the surface (e.g., horizontal displacement) and in the subsurface (dive behaviour); with the latter component including potential changes in surface time, dive rate, dive duration, bottom time, descent velocity and proportional time spent at the surface (surface time).

1.3 Study Area

The Study Area was defined based on the full spatial extent that narwhal fitted with dive tags travelled, and included Milne Inlet, Eclipse Sound, southern Navy Board Inlet, Tremblay Sound, and adjacent water bodies (Figure 1-2).

To capture potential variation in narwhal movement in relation to the animal's habitat, Milne Inlet and surrounding waterbodies were divided into multiple substrata based on geographic areas having similar bathymetry. Milne Inlet Northern and Southern substrata are discussed throughout the report to qualitatively assess differences in narwhal behaviour that may stem from physical habitat differences, such as water depth and channel width. As bathymetry and distance from shore were incorporated into the models for a quantitative analysis, substrata depicted in Figure 1-2 are presented as a qualitative visualization of the collected data.

LEGEND

- PROJECT SITE
- COMMUNITY
- FUTURE SOUTH RAILWAY
- MILNE INLET TOTE ROAD
- NUNAVUT SETTLEMENT AREA
- SHIPPING ROUTE
- SIRMILIK NATIONAL PARK
- WATER

0 125 250

1:5,000,000 KILOMETRES

REFERENCE(S)

BASE MAP: © ESRI DATA AND MAPS (ONLINE) (2016). REDLANDS, CA: ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

TITLE
PROJECT LOCATION

CONSULTANT

GOLDER

YYYY-MM-DD	2018-11-21
DESIGNED	AO
PREPARED	AA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	9000-904	0	1-1

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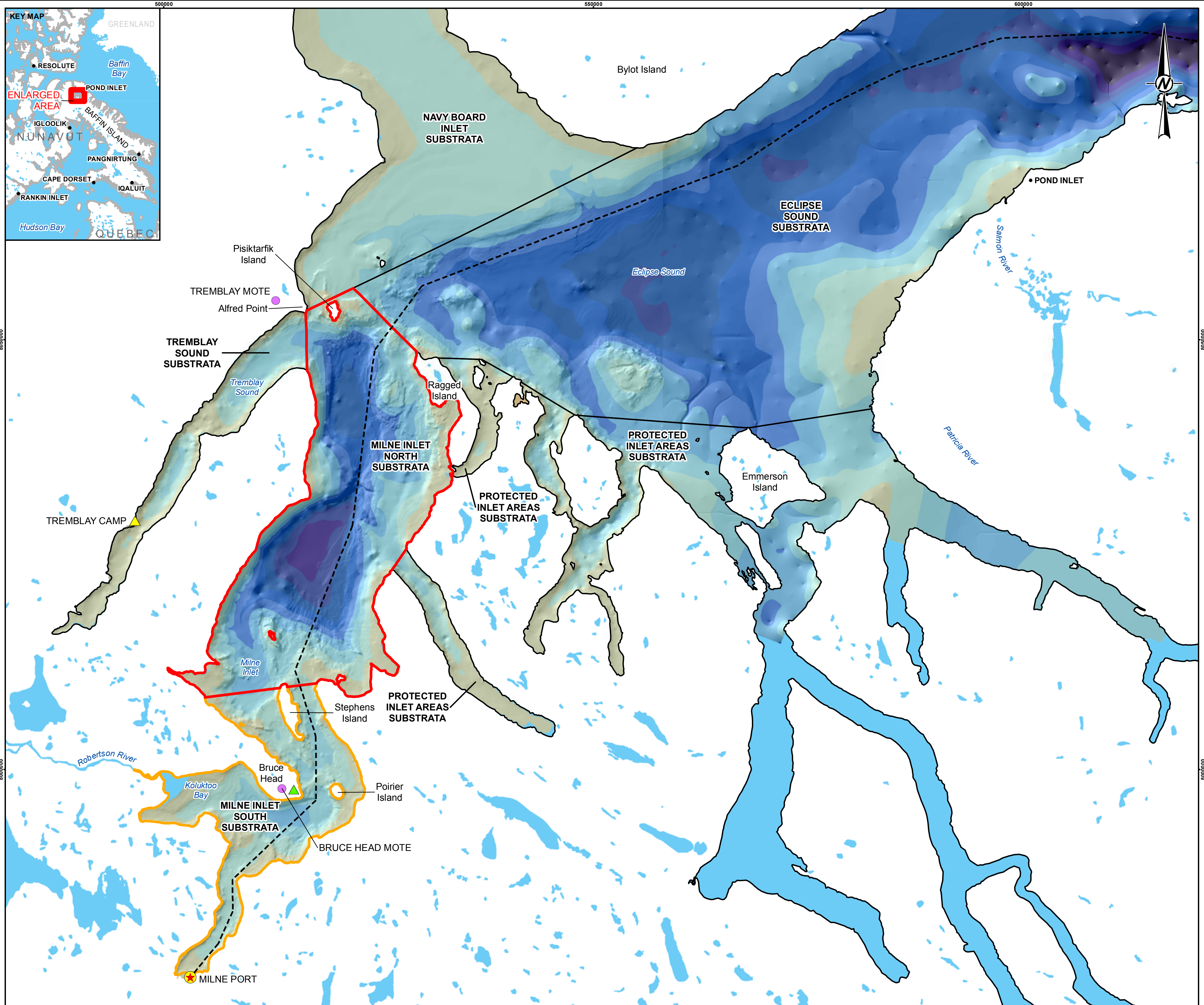

LEGEND

- AIS ANTENNA
- COMMUNITY
- MILNE PORT
- MOTE LOCATION
- TAGGING LOCATION
- SHIPPING ROUTE (APPROXIMATE)
- WATERBODY

NARWHAL SUBSTRATA

- MILNE INLET NORTH
- MILNE INLET SOUTH
- OTHER SUBSTRATA

ELEVATION (masl)

- ≥ 0 TO < 100
- ≤ 0 TO > -100
- ≤ -100 TO > -200
- ≤ -200 TO > -300
- ≤ -300 TO > -400
- ≤ -400 TO > -500
- ≤ -500 TO > -600
- ≤ -600 TO > -700
- ≤ -700 TO > -800
- ≤ -800 TO > -900
- ≤ -900 TO > -1000
- <-1000

0 10 20

1:450,000 KILOMETRES

NOTE(S)

MASL = METRES ABOVE SEA LEVEL

REFERENCE(S)

HYDROGRAPHY, POPULATED PLACE, AND PROVINCIAL BOUNDARY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
BATHYMETRY CREATED BY GOLDER FROM MULTIPLE DATA SOURCES.
PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

TITLE
STUDY AREA INCLUDING MILNE INLET NORTHERN AND SOUTHERN SUBSTRATA

CONSULTANT

GOLDER

YYYY-MM-DD	2019-05-14
DESIGNED	SU
PREPARED	AA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	9000-904	0	1-2

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2.0 SPECIES BACKGROUND

2.1 Population Status and Abundance

Narwhal are endemic to the Arctic, occurring in deep Arctic waters, primarily in Baffin Bay, the eastern Canadian Arctic, and the Greenland Sea (Reeves et al. 2012). Seldom present south of 61º N latitude (COSEWIC 2004), two populations are recognized in Canadian waters; the Baffin Bay population and the northern Hudson Bay population (Watt et al. 2017). Of these, only the Baffin Bay population occurs seasonally along the Northern Shipping Route for the Project (Koski and Davis 1994; Dietz et al. 2001; Richard et al. 2010). A third recognized population of narwhal occurs in East Greenland and is not thought to enter Canadian waters (COSEWIC 2004). The populations are distinguished by their summering distributions, as well as a significant difference in nuclear microsatellite markers indicating limited mixing of the populations (DFO 2011).

For management purposes, Fisheries and Oceans Canada (DFO) has defined seven narwhal stocks (i.e., resource units subject to hunting) in Nunavut: Jones Sound, Smith Sound, Somerset Island, Admiralty Inlet, Eclipse Sound, East Baffin Island, and Northern Hudson Bay (Doniol-Valcroze et al. 2015). These stocks were selected based on satellite tracking data indicating geographic segregation in summer (year-round segregation from the others in the case of the northern Hudson Bay stock) and also on evidence from genetic and contaminants studies that supported this stock partitioning. Subdividing the management units was recommended as a precautionary approach that would reduce the risk of over-exploitation of a segregated unit with site fidelity in summer (Richard et al. 2010).

Narwhal are identified as a species of Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2004) and are currently being considered for listing under the federal *Species at Risk Act* (*SARA*). There have been multiple attempts to estimate the abundance of narwhal in the Canadian Arctic either in total or for specific populations, but until recently no survey had covered the entire distribution range of narwhal in Canada. One of the earliest assessment attempts was that of Koski and Davis (1994) in which an estimated 34,363 (± SE 8,282) narwhal were found to be present in offshore areas of Baffin Bay from May to July 1979. This survey did not, however, account for submerged animals and did not cover eastern Baffin Bay. Specific to the Eclipse Sound area, Kingsley et al. (1994) reported on replicate aerial surveys of narwhal conducted from 1987 to 1993, in which approximately 600 animals were detected annually. This estimate, also, was not corrected for submerged animals and, after including a correction for narwhal diving behaviour, it is likely that more than 1,500 narwhal could have been present (Kingsley et al. 1994). A re-analysis of 2002 to 2004 summer aerial surveys of narwhal estimated that there were more than 63,000 narwhal in the Canadian High Arctic (NAMMCO 2010a) and approximately 20,211 individuals in the Eclipse Sound area. DFO (2015) also provided abundance estimates of narwhal based on aerial surveys with diving correction conducted in the Canadian Arctic. DFO estimated that narwhal abundance in Eclipse Sound was approximately 20,000 individuals between 2002 and 2004. Confidence intervals for these years were large, however, and an abundance estimate of approximately half as many narwhal in 2013 (n = 10,489) was likely not representative of a change in the actual stock size, but of year to year variation in distribution of the stock.

The Canadian High Arctic Cetacean Survey conducted by DFO in August 2013 was the first complete survey of six major narwhal summering aggregations in the Canadian High Arctic (DFO 2015). The total abundance estimate, corrected for diving and observer bias, was 141,909 narwhal. Coefficients of variation ranged from 20%-65% for the different stocks and the corrected estimate for the Eclipse Sound area was 10,489 narwhal with a coefficient of variation of 24%. Annual variation in narwhal stock estimates between adjacent summering areas, Eclipse Sound and Admiralty Inlet, indicate that there is movement between these two summering ground locations (Thomas et al. 2015). Inuit Qaujimajatuqangit (IQ)[1] collected in northern Baffin Island communities suggests that narwhal numbers may be increasing (Stewart 2001). For example, it was reported that, until the 1970's, narwhal in Clyde River were predominantly limited to fall migrants (during the Ukiaksak and Ukia seasons) (JPCS 2017). In more recent years, narwhal have been reported in this area starting in spring (Upingoaksak and Upingoa) and extending into the fall (Stewart 2001). Community workshop participants from Pond Inlet did not note any visible change to narwhal populations from year to year or changes to the abundance of narwhal in Eclipse Sound during the open-water season (JPCS 2017). IQ information indicates that narwhal first enter Eclipse Sound in the spring from either Navy Board Inlet or Baffin Bay through leads in the ice, with large males entering ahead of females and calves (JPCS 2017).

2.2 Geographic and Seasonal Distribution

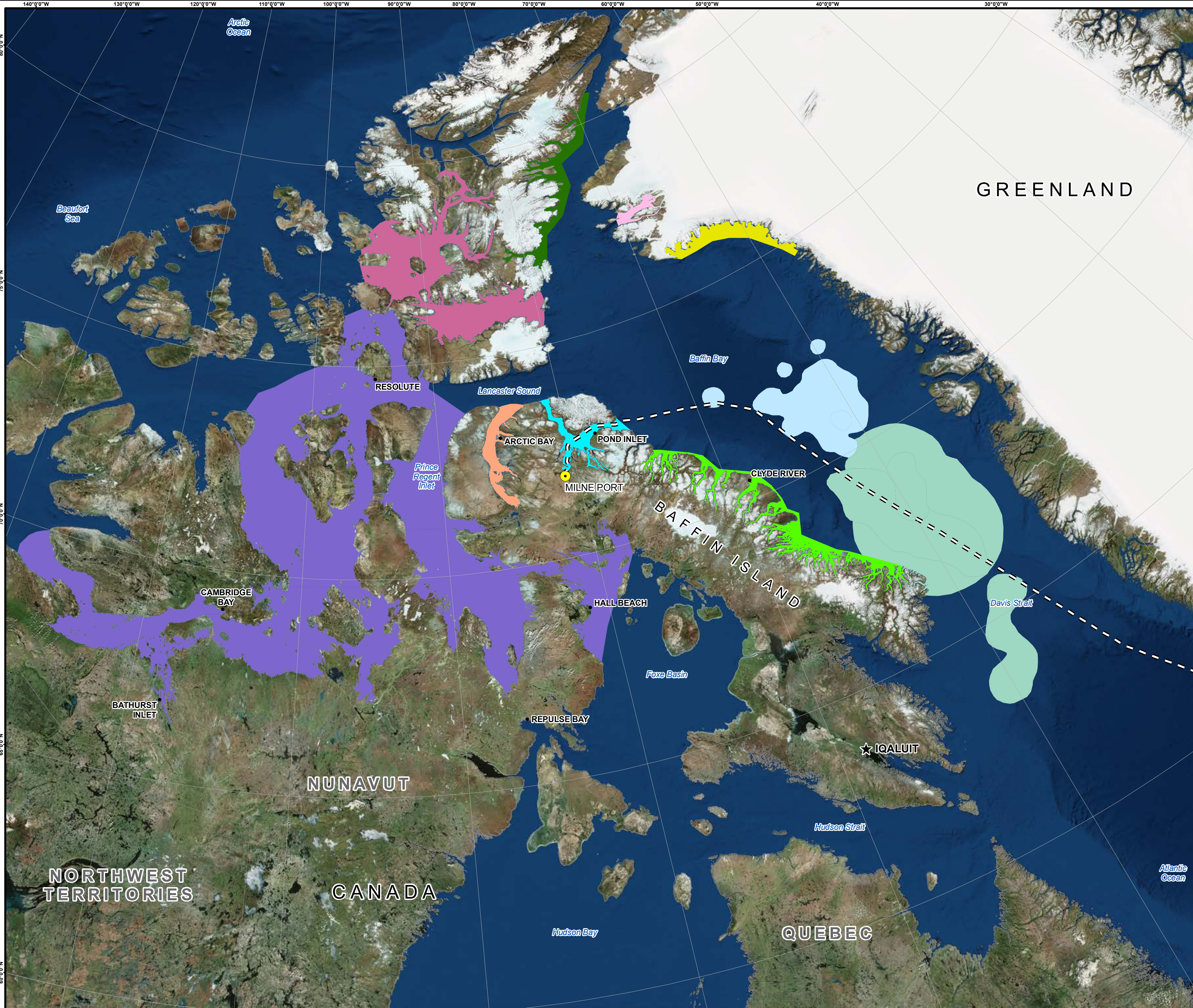
Narwhal show high levels of site fidelity, annually returning to well-defined summering and wintering areas (Figure 2-1) (Laidre et al. 2004; Richardson et al. 2014). During summer, narwhal tend to remain in deep-water coastal areas that are thought to provide protection from the wind (Kingsley et al. 1994; Koski and Davis 1994; Richard et al. 1994). In winter, narwhal move onto feeding grounds located in deep fjords and the continental slope where water depths are 1000 to 1500 m, and where upwelling increases biological productivity and supports abundant prey species including squid, flatfish, and Greenland halibut (Dietz and Heide-Jørgensen 1995; Dietz et al. 2001; Richard et al. 2014). IQ indicates that narwhal enter into Eclipse Sound in July through leads in the ice, with large males ahead of females and calves (JPCS 2017). Eclipse Sound is considered a particularly important summering area (Koski and Davis 1994; DFO 2015) and satellite tracking studies of narwhal summering in Tremblay Sound have shown that summering narwhal remain in a relatively small area including western Eclipse Sound and associated inlets during August (Dietz and Heide-Jørgensen 1995; Dietz et al. 2001). The distribution of narwhal in Eclipse Sound, Milne Inlet, Koluktoo Bay, and Tremblay Sound during summer is thought to be determined by the presence and distribution of ice and by the presence of killer whales (Kingsley et al. 1994).

Narwhal generally begin migrating out of their summering areas in late September (Koski and Davis 1994). IQ indicates that narwhal migrate in October and November through Eclipse Sound and Pond Inlet to overwintering areas in Baffin Bay and Davis Strait. Narwhal migratory routes to their overwintering grounds will change from year to year depending on ice conditions (JPCS 2017). Individuals exiting Eclipse Sound and Pond Inlet migrate down the east coast of Baffin Island in late September (Dietz et al. 2001). Individuals summering near Somerset Island enter Baffin Bay north of Bylot Island in mid- to late October (Heide-Jørgensen et al. 2003). By mid- to late October, narwhal leave Melville Bay and migrate southward along the west coast of Greenland in water depths of 500 to 1000 m (Dietz and Heide-Jørgensen 1995). Narwhal generally arrive at their wintering grounds in Baffin Bay and Davis Strait during November (Heide-Jørgensen et al. 2003) where they associate closely with heavy pack ice comprised of 90 to 99% ice cover (Koski and Davis 1994). Elders have indicated that while the majority of narwhal overwinter in Baffin Bay, some animals remain along the floe edges at Pond Inlet and Navy Board Inlet (DEIS 2010). Narwhal tracking data have identified two distinct wintering areas for the Baffin Bay population. One wintering area is located in northern Davis Strait / southern Baffin Bay (referred to as the southern wintering area) and is frequented by Canadian narwhal summering stocks from

[1] Inuit Qaujimajatuqangit (IQ) refers to Inuit "Traditional Knowledge" that includes local and community-based knowledge, and ecological knowledge that encompasses the daily life of Inuit people (NIRB 2018).

Admiralty Inlet and Eclipse Sound, and the Greenland narwhal stock from Melville Bay. The second wintering area is located in central Baffin Bay (referred to as the northern wintering area) and is used by narwhal from the Somerset Island summering stock (Richard et al. 2014).

IQ indicates that between April and June, narwhal migrate from their Baffin Bay wintering areas to the Pond Inlet floe edge, northern coast of Bylot Island, Navy Board Inlet floe edge, and eastern Lancaster Sound (JPCS 2017). As ice conditions permit (usually late June and July), narwhal move into summering areas in Barrow Strait, Peel Sound, Prince Regent Inlet, Admiralty Inlet, and Eclipse Sound (Cosens and Dueck 1991; Remnant and Thomas 1992; Kingsley et al. 1994; Koski and Davis 1994; Richard et al. 1994).



LEGEND

- ★ TERRITORY CAPITAL
- • COMMUNITY
- MILNE PORT
- SHIPPING ROUTE (APPROXIMATE)

SUMMER AGGREGATION AREA

- ADMIRALTY INLET
- EAST BAFFIN ISLAND
- ECLIPSE SOUND
- INGLEFIELD BREDNING
- JONES SOUND
- MELVILLE BAY
- SMITH SOUND
- SOMERSET ISLAND

WINTER AGGREGATION AREA

- NORTHERN WINTERING AREA
- SOUTHERN WINTERING AREA

0 200 400
1:10,000,000 KILOMETRES

REFERENCE(S)

NARWHAL POPULATION RANGES DIGITIZED FROM DFO FIGURE 1 'MAP OF HIGH ARCTIC NARWHAL SUMMER AGGREGATIONS' (SOURCE: AMMCO/SC/21-JCNB/SWG/14-05). NARWHAL WINTERING AREAS DIGITIZED FROM RICHARD ET AL. (2014) FIGURE 3 PUBLISHED WINTER HOME RANGES OF TRACKED BAFFIN BAY NARWHAL. SHYDROGRAPHY, POPULATED PLACE, AND PROVINCIAL BOUNDARY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. COUNTRY BASE DATA © ESRI AND ITS LICENSORS. USED UNDER LICENSE, ALL RIGHTS RESERVED. SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY
PROJECTION: CANADA ALBERS EQUAL AREA CONIC DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

TITLE
NARWHAL SUMMERING AND WINTERING AREAS – BAFFIN BAY POPULATION

CONSULTANT
GOLDER

YYYY-MM-DD	2019-05-14
DESIGNED	SU
PREPARED	AA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	9000-904	0	2-1

2.3 Reproduction

Female narwhal are believed to mature at 8 to 9 years of age and produce their first young at 9 to 10 years of age while males mature at 12 to 20 years of age (Garde et al. 2015). Pond Inlet hunters reported that narwhal mating activity occurs in areas off the north coast of Bylot Island and at the floe edge east of Pond Inlet and at the north end of Navy Board Inlet. Eclipse Sound, Tremblay Sound, Milne Inlet, and Koluktoo Bay have also been reported as mating areas (Remnant and Thomas 1992). Conception is generally thought to occur between late March and late May, although mating has been observed in June at the Admiralty Inlet floe edge and in August in western Admiralty Inlet (Stewart 2001). At least one presumed mating event was observed from the Bruce Head observation platform in southern Milne Inlet during the 2016 open-water season (Smith et al. 2017). Calving has been reported in Pond Inlet, Eclipse Sound, Navy Board Inlet, Milne Inlet, and Koluktoo Bay (Remnant and Thomas 1992; JPCS 2017); which is consistent with IQ information indicating that calving has been observed in all areas of North Baffin Island (Furgal and Laing 2012). On average, females are thought to produce a single calf approximately once every two to three years and have a generation time of approximately 30 years (Garde et al. 2015). However, many Inuit believe that narwhal give birth more frequently, perhaps annually (COSEWIC 2004). Gestation for narwhal is on the order of 14-15 months (COSEWIC 2004) with IQ suggesting 15 months based on fetuses observed (Furgal and Laing 2012). Newborn calves are primarily born between May and August each year and measure 140 to 170 cm in length, approximately 1/3 the body length of an adult female (Charry 2017). Typically, newborn calves travel less than one body length away from their mother. Mother/calf pairs travel in mean group sizes of five individuals (5.0 ± 3.03 Standard Deviation [SD]) in Eclipse Sound and two individuals (2.0 ± 0.0 SD) along the east coast of Baffin Island (Charry 2017). Calves are generally weaned at 1–2 years of age (COSEWIC 2004).

2.4 Diet

Current understanding on narwhal diet is based on studies focusing on stomach content analysis (Finley and Gibb 1982; Laidre and Heide Jørgensen 2005), satellite-based tagging studies (Watt et al. 2015; 2017) and fatty acid and stable isotope analysis (Watt et al. 2013; Watt and Ferguson 2015).

Finley and Gibb (1982) analyzed the diet of 73 narwhal near Pond Inlet from June through September (1978-1979) through stomach content analysis. Food remains were reported in 92% of the stomachs analyzed. Feeding was found to be most intensive during spring when narwhal occurred near the floe edge and within open leads. Limited feeding was reported during late summer in the Northern fjord areas. Diet consisted of pelagic and benthic species including Arctic cod (*Boreogadus saida*) (identified in 88% of analyzed stomachs), Greenland halibut (*Reinhardtius hippoglossoides*), squid (*Gonatus fabricii*), redfish (*Sebastes marinus*), and polar cod (*Arctogadus glacialis*), with foraging occurring at depths greater than 500 m (Finley and Gibb 1982; Watt et al. 2017).

Satellite-tracking of GPS-tagged narwhal show differences in narwhal diet and dive behaviour between summering and wintering areas as well as between the two established wintering areas in Baffin Bay. Surface dives (0 to 50 m) and ‘proportional time at surface’ was shown to be higher in summering areas than wintering areas (Richard et al. 2014). In the northern wintering area, where narwhal dive to depths exceeding 1000 m, Greenland halibut represents a high proportion of the narwhal diet. In the southern wintering area, where narwhal dive to depths between 200 and 400 m, halibut represents a much lower proportion of narwhal diet (Richard et al. 2014). As narwhal travel to the floe edge during the late spring migration, stomach contents consisted primarily of Arctic cod, although a shift toward Greenland halibut was observed as narwhal moved through Pond Inlet (Finley and Gibb 1982).

Deep diving is energetically costly to marine mammals and requires lipid-rich prey or abundant food sources to support this activity (Watt et al. 2017). Narwhal are well adapted to deep diving and are known to prey on deep-water fish species (Finley and Gibb 1982; Watt et al. 2015) to meet their dietary requirements. Early studies reported that narwhal spend limited time feeding while present on their summering grounds, compared to winter or spring (Mansfield et al. 1975; Finley and Gibb 1982; Laidre et al. 2004; Laidre and Heide-Jørgensen 2005). More recent studies analyzing spatial and seasonal patterns in narwhal dive behaviour (using targeted deep dives as a proxy for benthic foraging) indicates that the majority of dives recorded during summer in Eclipse Sound occurred near the surface; although deep-water dives were also observed during this time, suggesting the occurrence of important benthic foraging areas in Eclipse Sound during summer (Watt et al. 2015; 2017). This is supported by stable isotope analysis conducted for the Baffin Bay population, which identified Greenland halibut and northern shrimp (*Pandalus borealis*) as the major constituents (>50%) of their summer diet (Watt et al. 2013).

2.5 Locomotive Behaviour

Like many cetacean species that inhabit patchy and/or dynamic environments (Laidre et al. 2003), narwhal surface and dive behavior varies depending on where they are distributed throughout their summering grounds (Watt et al. 2017). The following sections (Section 2.5.1 and 2.5.2) provide context regarding the current understanding of narwhal vertical and horizontal movements while summering throughout Milne Inlet and adjacent water bodies.

2.5.1 Subsurface Movements (Dive Behavior)

Narwhal are specially adapted for sustained, deep submergence (Martin et al. 1994, Watt et al. 2017). Although data on narwhal dive behaviour throughout Milne Inlet is relatively limited, it is generally accepted that depth and duration of narwhal dives are positively correlated given the longer travel time required to reach deeper depths (Laidre et al. 2002). Dive data collected in Tremblay Sound revealed a maximum recorded dive duration of 26.2 minutes for one narwhal tagged during August 1999 (mean = 4.9 minutes; Laidre et al. 2002). Despite this event representing one of the longest dives recorded for narwhal to date, the maximum depth to which this animal dove was only 256 m (mean = 50.8; Laidre et al. 2002), likely a result of the dive being limited by bathymetry. Narwhal tagged in Tremblay Sound during August 2010 and August 2011 made the majority of dives to between 400 and 800 m depths (Watt et al. 2017), indicating that these dives took place in adjacent water bodies with deeper bathymetry (i.e., Milne Inlet/Eclipse Sound).

During the summer months, narwhal spend a large proportion of time near the surface, milling and socially interacting with one another (Pilleri 1983, Heide-Jorgensen et al. 2001). Narwhal (n = 23) tagged near Baffin Island between 2009 and 2012 were estimated to spend approximately 31.4% of their time within 2 m of the surface during the month of August (Watt et al. 2015). Innes et al. (2002) reported a similar value of 38% of time that narwhal spend within 2 m of the surface based on aerial surveys. The proportion of time that narwhal spend within 5 m of the surface is slightly greater; Heide-Jorgensen et al. (2001) reported narwhal (n = 21) spend approximately 45.6% of time within the top five metres of the water column, while Laidre et al. (2002) reported a range of 30-53% of time that narwhal (n = 4) spend within this depth. Although mother-calf pairs have been predicted to spend a greater proportion of time at the surface given the limited diving ability of calves (Watt et al. 2015), no obvious pattern between surface time and body length, sex, and/or presence/absence of calves was observed in a study conducted by Heide-Jorgensen et al. (2001).

Heide-Jorgensen et al. (2001) evaluated dive rate (number of dives per hour) of 25 narwhal tagged in Tremblay Sound, Canada between 1997 and 1999 and Melville Bay, Greenland between 1993 and 1994. According to this study, mean dive rate of all narwhal outfitted with tags during the month of August was 7.4 dives/hour below 8 metres depth, with narwhal from Tremblay Sound having a significantly lower dive rate overall (7.2 dives/hour) compared to animals tagged in Melville Bay (8.6 dives/hour). No diurnal difference was found in narwhal dive rate from either tagging site (Heide-Jorgensen et al. 2001). Furthermore, increasing number of dives (dive rate) had no effect on narwhal surfacing times (0-5 m). Laidre et al. (2002) reported similar dive rates for two narwhal tagged in Tremblay Sound, ranging from 6.0 dives/hour to 10.9 dives/hour.

In regard to descent and ascent speeds, one study conducted by Laidre et al. (2002) determined that a typical dive profile for two narwhal tagged in Tremblay Sound consisted of a steep descent, followed by a short bottom interval, a gradual ascent, and a relatively slow approach to the surface. The two narwhal in this study exhibited mean descent rates of 0.8 m/s and 1.3 m/s and mean ascent rates of 0.7 m/s and 1.5 m/s, respectively (Laidre et al. 2002). According to a less recent study that tracked the dive behaviour of three narwhal tagged in Tremblay Sound (Martin et al. 1994), the maximum rates of ascent and descent for each dive ≥ 20m depth were positively correlated to the depth and duration of the dive. This finding was loosely supported by Laidre et al. (2002), who observed mean descent rates to be strongly correlated with destination depth for only one of two narwhal tagged in Tremblay Sound and found no correlation between destination depth and ascent rates for either whale.

It is important to note that narwhal dive behaviour is variable based on parameters such as sex, life stage, location, season, and activity state (Heide-Jorgensen et al. 2001). For example, differences in dive rates (number of dives per hour) and dive depth have been found to vary between size and sex of narwhal tagged, with female narwhal generally diving shallower and having lower dive rates than males (Heide-Jorgensen and Dietz, 1995). Surprisingly, female narwhal have also been found to spend more time at depth compared to males (Watt et al. 2015), despite hypotheses that those with larger body size (i.e., males) would have enhanced ability to dive deeper and for greater periods of time. Whether a female is with or without a calf may also influence dive behaviour, given the aerobic limitations of the young (Watt et al. 2015), though studies conducted by Heide-Jorgensen and Dietz (1995) found no difference in dive behaviour between female narwhal with and without calves. The depths to which narwhal dive are also known to vary with season (Watt et al. 2015, Watt et al. 2017). In general, narwhal make relatively short, shallow dives while at their summering grounds (with depths often limited by the seabed bathymetry), increasing their dive depth and duration in the fall months (Heide-Jorgensen et al. 2002), and making the deepest dives while over-wintering in the pack ice in Baffin Bay (Laidre et al. 2003). Tidal and circadian cycles are not thought to influence narwhal movement patterns (Martin et al. 1994, Born 1986, Dietz and Heide-Jorgensen 1995, Marcoux et al. 2009) and, as will be discussed in the Section 2.5.2, predation by killer whales is not a significant predictor of narwhal dive behaviour but does influence narwhal space use patterns (Watt et al. 2017).

Differences in foraging behaviour in males and females have been found in a number of marine mammals (Le Boeuf et al. 2000; Beck et al. 2003; Baird et al. 2005). Narwhal display sexual size dimorphism, where adult males are significantly larger than adult females (Garde 2011). Increased size enhances an individual's ability to dive and stay at depth for longer periods of time (Schreer & Kovacs 1997; Irvine et al. 2000; Noren & Williams 2000; Mori 2002). Due to the size differences, males potentially have the ability to dive longer and deeper than females and may have an increased dive effort if they have greater energy requirements than non-pregnant and non-lactating females (Kleiber 1932). Within the Baffin Bay population, Heide-Jørgensen & Dietz (1995) reported that female narwhal had lower dive rates than their male counterparts. However, Laidre et al. (2003) found no differences between the sexes. Watt et al. (2015) were unable to detect differences between males and females in the number of dives to the bottom (deep zone), although they may have not captured this difference because males and females captured in that study were of similar body size (males = 4.1 m, females = 4.0 m). The fact that population-wide male and female body size was not captured in their small tagged sample may have limited their ability to detect differences in dive performances between sexes.

2.5.2 Surface Movements

Narwhal are a migratory species, travelling large distances between high Arctic summering grounds and low Arctic wintering grounds annually (Laidre and Heide-Jorgensen 2005). Ice conditions permitting, narwhal typically move into summering grounds in Eclipse Sound and adjacent inlets (e.g., Milne Inlet) during late June/July (Remnant and Thomas 1992; Kingsley et al. 1994; Koski and Davis 1994; Richard et al. 1994). Once at their summering grounds, narwhal are widely distributed throughout the open-water fjord complexes and bays (Laidre et al. 2003) and rely on the area for important mating and calving activities (Mansfield et al. 1975; Remnant and Thomas 1992; Marcoux et al. 2009; Smith et al. 2017). Following a summer spent in Milne Inlet and adjacent water bodies, narwhal then begin their migration eastward out of Eclipse Sound during mid to late September (Koski and Davis 1994), where they make their way from Pond Inlet, down the east coast of Baffin Island (Dietz et al. 2001), toward winter feeding areas in Baffin Bay (Koski and Davis 1994; Heide-Jørgensen et al. 2002; Laidre et al. 2004).

Narwhal are highly gregarious and are closely associated with one another by nature (Marcoux et al. 2009). Although knowledge regarding the context and function (if any) of narwhal aggregations is incomplete (Marcoux et al. 2009), they have been observed throughout Milne Inlet and Koluktoo Bay in small groups or clusters[2] averaging 3.5 individuals (range: 1 to 25), and in herds[3] of up to hundreds of clusters (Marcoux et al. 2009). According to Marcoux et al. (2009), herds observed from the Bruce Head Peninsula were composed of 1 to 642 clusters, with a mean of 22.4 clusters/herd. Observations from the Bruce Head Peninsula also reveal that narwhal generally enter Milne Inlet and Koluktoo Bay in larger clusters than when they exit, and show strong site fidelity to Koluktoo Bay specifically (Marcoux et al. 2009; Smith et al. 2017).

Understanding confounding effects such as the presence of predators in a system is important when assessing movement behaviour of cetaceans in relation to vessel traffic. Killer whales, for example, are well known to prey on narwhal and may affect narwhal space use patterns (Campbell et al. 1988; Cosens and Dueck 1991). In one report by Laidre et al. (2006), an attack was observed in which multiple narwhal were killed by a pod of killer

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[2] Cluster = a group with no individual more than 10 body lengths apart from any other (Marcoux et al. 2009).

[3] Herd = an aggregation of clusters. A 'herding event' was considered finished when no narwhal were observed for 30 minutes.

whales over six hours. In the immediate presence of killer whales, narwhal moved slowly, travelling in very shallow water close to shore, and in tight groups at the surface (Laidre et al. 2006). Once the attack commenced, narwhal dispersed widely (approximately doubling their space-use), beached themselves in sandy areas, and shifted their distribution away from the attack site. Normal (pre-exposure) behaviour was said to resume shortly after the killer whales departed the area (Laidre et al. 2006). This observation is supported by Breed et al. (2017), who suggested that behavioural changes in narwhal extend beyond discrete predation/attack events, with space use patterns being highly influenced by the mere presence of killer whales in an area. Of note, simultaneous satellite tracking of narwhal and killer whales revealed that narwhal constrained themselves to a narrow band close to shore (≤500 m) when killer whales were present within approximately 100 km (Breed et al. 2017).

2.6 Acoustic Behaviour

Like all cetaceans, narwhal depend on the transmission and reception of sound in order to carry out the majority of critical life functions (i.e., communication, reproduction, navigation, detection of prey, and avoidance of predators) (Holt et al. 2013). For Arctic cetaceans that are closely associated with sea ice (e.g., narwhal), they are also likely dependant on sound for locating leads and polynyas in the ice for breathing (Richardson et al. 1995; Heide-Jorgensen et al. 2013).

2.6.1 Vocalizations

Narwhal are a highly vocal species that produce a combination of pulsed calls, clicks, and whistles (Ford and Fisher 1978; Marcoux et al. 2011). Pulsed calls are the predominant form of narwhal vocalization and are comprised of pulsed tones and click series (Ford and Fisher 1978). Pulsed tones emitted by narwhal possess pulsed repetition rates that have distinct tonal properties and are generally concentrated between 500 Hz and 5 kHz (Ford and Fisher 1978; Shapiro 2006). Click series are broadband and are concentrated between 12 and 24 kHz, though many click series with low repetition rates are concentrated at lower frequencies between 500 Hz and 5 kHz (Ford and Fisher 1978). High frequency broadband echolocation clicks emitted by narwhal extend up to and beyond 150 kHz (Miller et al. 1995; Rasmussen et al. 2015). Finally, whistles are typically emitted between 300 Hz and 10 kHz, though some whistles have been found to reach frequencies as high as 18 kHz (Ford and Fisher 1978; Marcoux et al. 2011). More recent studies that include recordings at higher sampling rates have allowed for a more complete description of narwhal vocalizations (Rasmussen et al. 2015; Koblitz et al. 2016).

2.6.2 Hearing

Depending on the level and frequency of the sound signal, marine mammal groups with similar hearing capability will experience sound differently than other groups (Southall et al. 2007; Southall et al. 2019). According to updated marine mammal noise exposure criteria by Southall et al. (2019), narwhal, like a selection of other toothed whales previously considered mid-frequency cetaceans, are now considered high-frequency cetaceans whose functional hearing range likely occurs between 150 Hz and 160 kHz (Southall et al. 2007; Southall et al. 2019). Although no behavioural or electrophysiological audiograms are currently available for narwhal specifically (Rasmussen et al. 2015), auditory response curves for this grouping of cetaceans suggest maximum hearing sensitivity in frequencies between 1 kHz and 20 kHz (corresponding to social sound signals) and between 10 kHz and 100 kHz (corresponding to echolocation signals) (Tougaard et al. 2014; Veirs et al. 2016; Southall et al. 2019).

2.6.3 Narwhal and Vessel Noise

Behavioural responses by marine mammals to vessels have been documented for several marine mammal species, however limited information is available for Arctic species and there are no studies directly assessing potential impacts of vessels or anthropogenic noise on narwhal. Vessel disturbance may induce several different behavioural responses, including a shift in swim speed or dive rate, fleeing, freeze response, avoidance, or displacement from optimal habitat, all of which ultimately have the potential to affect subpopulation viability. Narwhal have been shown to react at long distances to ice-breaking vessels even at relatively low received sound levels (Finley et al. 1990; Cosens and Dueck 1993). Low sighting rates of narwhal recorded during vessel-based surveys undertaken in areas known to support high densities of narwhal suggests that animals may actively avoid or be displaced by vessels (Heide-Jorgensen et al. 2010; 2013).

The majority of underwater sound generated by large vessel traffic is concentrated in the lower frequencies between 20 and 200 Hz (Veirs et al. 2016). Propeller cavitation accounts for peak spectral power between 50-150 Hz while propulsion noise (from engines, gears, and other machinery) generates noise below 50 Hz (Veirs et al. 2016). Broadband noise generated by propeller cavitation has, however, been found to radiate into the higher frequencies up to 100 kHz (Arveson and Vendittis 2000; Veirs et al. 2016), overlapping with the range of maximum hearing sensitivity of narwhal. Therefore, while large vessels associated with the Project would generate some broadband noise in the proposed hearing range of narwhal and other high-frequency cetaceans, the majority of sound energy produced by large vessels is likely concentrated below the peak hearing sensitivity of narwhal (>1 kHz).

Sound level (or 'intensity') must also be considered when assessing the behavioural response of narwhal to vessel-generated noise. Of note, two metrics commonly used to describe and evaluate the effects of non-impulsive sound on marine mammals are sound pressure level (SPL_{rms}; dB re: 1µPa) and sound exposure level (SEL; dB re: $1µPa^{2}$·s). Sound pressure level (SPL_{rms}) refers to the average of the squared sound pressure over some duration, while sound exposure level (SEL) is a cumulative measure of sound energy that takes into account the duration of exposure (Southall et al. 2007; NMFS 2018; Southall et al. 2019). It is generally accepted that cetaceans exposed to received sound levels above 120 dB re: 1µPa (SPL_{rms}) will begin to experience behavioural disturbance effects, though the specific behavioural responses exhibited is highly variable depending on the context of species, populations, and/or individuals exposed to the sound source (Southall et al. 2007; Ellison et al. 2012; Williams et al. 2014; NMFS 2018; Southall et al. 2019). For high-frequency cetaceans exposed to non-impulsive received sound levels exceeding 198 dB re: $1µPa^{2}$·s (SEL_{24h}) , they may begin to experience auditory injury effects (i.e., permanent hearing loss) (NMFS 2018; Southall et al. 2019).

Acoustic modeling of ore carriers transiting traveling at 9 knots along the Northern Shipping Route was undertaken by JASCO Applied Sciences (JASCO) in 2018 (Quijano et al. 2017). Modeling results predicted that ore carriers transiting through Milne Inlet would not reach the SEL_{24h} injury threshold[4] at ranges beyond 20 m from the vessel. However, the 120 dB re 1µPa (SPL_{rms}) disturbance threshold[5] was predicted to be exceeded at distances up to 19 km for Post-Panamax carriers (9.82 km < R_{max} < 19.24 km), and up to 29 km for Cape size carriers (12.34 km < R_{max} < 29.29 km). These modeling results, together with studies suggesting that narwhal respond to vessel traffic by huddling in groups, ceasing sound production, exhibiting a “freeze response”, becoming displaced, or generally altering their behavior, warrant further investigation into the potential effects of vessel traffic on narwhal behavior (Cosens and Dueck 1988, Finley et al. 1990, Cosens and Dueck 1993, Heide-Jorgensen et al. 2013).

[4] Injury thresholds reported have auditory weighting functions applied, meaning that the frequencies in which the animal hears well are emphasized and the frequencies that the animal hears less well or not at all are de-emphasized, based on the animal’s audiogram (NMFS 2018; Southall et al. 2019).

[5] The disturbance threshold is broadband, meaning that the total sound pressure level (SPL) is measured over the specified frequency range (25 kHz).

3.0 METHODS

3.1 Field Tagging

A total of 20 narwhal were live-captured during the 2017 open-water season (31 July to 11 September) from a remote field camp located in Tremblay Sound, Nunavut (72° 22’ N, 81° 06’ W) (Figure 1-2 and Photograph 3-1). Individual animals were caught using a shore-anchored net (100-m in length and 6-m in height) set perpendicular to shore (Photograph 3-2). The net was kept under continuous surveillance by shore-based observers in order to quickly respond to narwhal entanglements. Animals caught in the net were initially brought to the surface by a boat-based team and then pulled into shore by personnel stationed on the beach. Once the narwhal was removed from the net, it was re-positioned and secured in shallow water with the fluke oriented towards the beach (Photograph 3-3). Handling of animals was conducted by a team of local Inuit, marine mammal scientists, and veterinarians. All field work was conducted under a DFO License to Fish (DFO LFSP S-17/18 1036-NU) and program approval was obtained from the Freshwater Institute Animal Care Committee (AUP# ACC-2017-44).

Once the animal was stabilized, measurements of animal length, girth, fluke width and tusk length were taken, along with observations of overall animal health and condition. Blood and tissue samples were collected for gender identification and body burden analysis. Narwhal were then fitted with a satellite tag using a ‘backpack’ style tag design with three nylon pins inserted subdermally on the back of the animal (just anterior of the dorsal ridge), along with a pop-up archival transmitting (PAT) tag that was pre-programmed to release off the animal after several weeks (Photograph 3-4). Two different types of satellite tags (Wildlife Computers SPLASH-10 and SMRU Instrumentation CTD-SRDL) and two different type of PAT tags (Wildlife Computers MiniPAT and Mk10-PAT) were employed, as described further in Section 3.2. Nine narwhal were also instrumented with an acoustic and orientation tag (Greeneridge Sciences Acousonde 3B™) attached adjacent to the dorsal ridge using suction cup attachments.

All of the tags described above relayed positional data through the Argos satellite network. Tag data transmissions include the tag identification number and a data package (i.e., depth, temperature or GPS information). Argos location estimates are derived from the number of satellites that receive data from an individual tag and the number of tag messages received in quick succession (accuracy typically between 226 and 757 m; Vincent et al. 2006). Twelve of the 18 satellite tags deployed on narwhal were equipped with a Fastloc[6] GPS receiver for improved position accuracy compared to conventional Argos tracking. Fastloc location estimates are derived from GPS satellite pseudoranges that are relayed from the tag to the Argos satellite system, and are subsequently post-processed by the tag manufacturer to determine location estimates (accuracy typically between 18 and 70 m; Dujon et al. 2014).

Ground-based receiver stations (Wildlife Computers MOTE stations) were also used to augment the number of received data package transmissions from the GPS tags. Two MOTE stations were deployed in the Study Area (Figure 1-2). MOTE data reception is based on line-of-sight coverage, which, as realized by two the MOTE locations, provided coverage of Tremblay Sound, Western Eclipse Sound, Southern Navy Board Inlet and

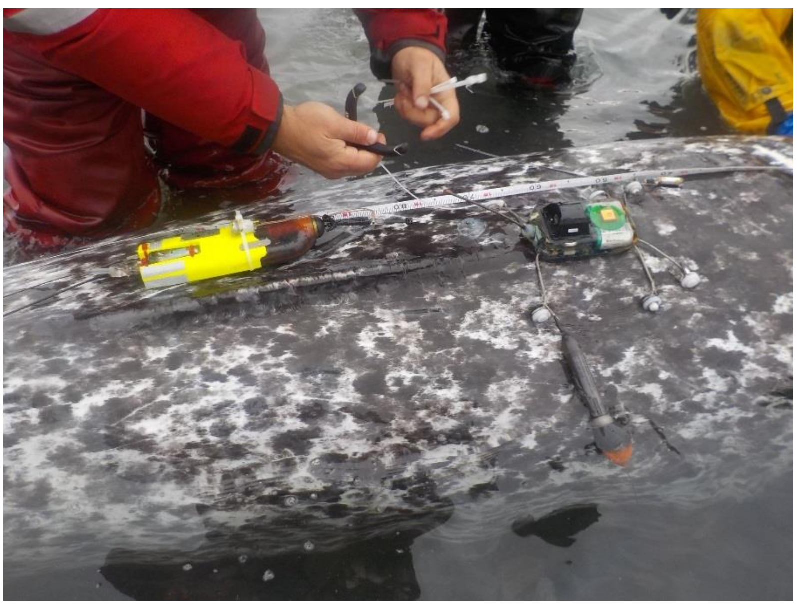
[6] Fastloc® technology, developed by Wildtrack Telemetry Systems Ltd, is ideal for species that only surface briefly. The Fastloc-GPS receiver achieves this by taking a quick (i.e. fraction of a second) snapshot of the radio signals produced by overhead GPS satellites. These signals are processed onboard the tag and compressed into a snapshot containing just the satellite ID numbers, their respective pseudo ranges, and a timestamp. The processing and compression takes approximately 12 s and continues after the animal has dived. Up to ten GPS satellites can be processed to provide location accuracies from 18 to 70 m.

Milne Inlet (including Koluktoo Bay). The addition of the two MOTE systems resulted in approximately double the number of data messages received from each whale compared to messages received by satellite alone.

Photograph 3-1: Aerial view of shore-based narwhal tagging camp in Tremblay Sound, Nunavut

Photograph 3-2: Narwhal capture net set perpendicular to beach

Photograph 3-3: Narwhal secured in shallow water during tag attachment



Photograph 3-4: Attachment locations for tag instrumentation on live-captured narwhal

Notes: Acousonde, MiniPat, SPLASH-10 shown from left to right.

3.2 Tag Specifications

3.2.1 Wildlife Computers SPLASH-10

The SPLASH-10 is an Argos satellite tag that includes sensors to measure horizontal (X/Y location) and vertical (Z or depth) movement, temperature, light level, and wet/dry periods to decipher surfacing events. Data collected by a SPLASH-10 is summarized, compressed and stored for transmission during a subsequent surfacing event. In addition to providing ARGOS locations, the SPLASH-10 can incorporate Fastloc GPS which enables high-resolution GPS location data to be acquired. Depth data provided by the SPLASH-10 is of poorer temporal resolution (75-s), compared to 1-s resolution depth data provided by the MiniPAT tag upon retrieval (Section 3.2.3). Ten of the SPLASH-10 tags used in 2017 included Fastloc GPS, while the five remaining SPLASH-10 tags relied on conventional ARGOS positioning. All SPLASH-10 tags were attached to narwhal using a 'backpack' style tag design with three nylon pins inserted subdermally on the back of the animal (just anterior of the dorsal ridge).

3.2.2 SMRU Instrumentation CTD-SRDL with Fastloc

The CTD-SRDL tag is an Argos satellite tag manufactured by Sea Mammal Research Unit (SMRU) Instrumentation that includes sensors to measure horizontal and vertical animal movements, temperature, conductivity, and wet/dry periods to decipher surfacing events. Data obtained on CTD-SRDL tags are summarized and compressed for transmission each time the animal surfaces. In addition to providing ARGOS locations, two of the three CTD-SRDL tags deployed on narwhal included Fastloc GPS capability. Depth data collected by the CTD-SRDL is associated with individual dives and predetermined depth intervals, not recorded at specific time intervals as in the MiniPAT, Mk10-Pat and Splash-10 tags. All three CTD-SRDL tags were attached to narwhal using a 'backpack' style tag design with three nylon pins inserted subdermally on the back of the animal.

3.2.3 Wildlife Computers MiniPAT

The MiniPAT tag is a high-resolution PAT tag (tow tag design) that measures depth, temperature, and light level. MiniPATs are pre-programmed by the user to release from the animal on a specified date via a corrodible wire. Upon release of the animal, the tag floats to the surface and begins to transmit its position to ARGOS to allow for instrument recovery. If recovery is not possible, data borne on the tag will be transmitted to satellite at 75 s resolution. If the tag is recovered, data is available for download at 1-s resolution. Each MiniPAT was tethered to the SPLASH-10 backpack tag via a wire cable coupled to the releasable portion of the MiniPAT tag.

3.2.4 Wildlife Computers Mk10-PAT

The Mk10-PAT tag is another PAT tag (tow tag design) that measures depth, temperature, and light level. Mk10-PATs are pre-programmed by the user to release from the animal via a corrodible wire on a specified date at which time the tag floats to the surface and transmits the data. The Mk10-PAT tag must be retrieved upon release from the animal in order to obtain the full resolution of data collected (e.g., 1 s resolution for depth data). Each Mk10-PAT was tethered to the SPLASH-10 backpack tag via a wire cable coupled to the releasable portion of the Mk10-PAT tag.

3.2.5 Greeneridge Sciences Acousonde™ 3B

The Acousonde 3B is an autonomous acoustic/ultrasonic recorder that incorporates hydrophones as well as depth, attitude, orientation and temperature sensors. When attached to an animal subject, the Acousonde measures the acoustic environment of the subject as well as its vocalization activity and potentially associated behaviours. The Acousonde is a reusable tag that may be deployed, retrieved, and then re-deployed on multiple animals. Prior to each deployment, the user may re-program the Acousonde, modifying parameters such as the recording duty cycle, sampling rate, and acoustic gain, depending on the data that the user wishes to collect.

Four Acousonde units were purchased for the program. Three of the four units were deployed twice (each on two separate animals) and one was deployed three times, for a total of nine independent deployments. All four Acousondes were outfitted with two hydrophones (one high-frequency and one low-frequency), allowing the unit to be pre-programmed prior to each deployment to duty cycle between high and low frequency channels and collect data from a broader frequency spectrum.

3.3 AIS Vessel Tracking

Large vessel transits along the Northern Shipping Route during the 2017 study period were tracked and recorded using a combination of shore-based and satellite-based Automated Identification System (AIS) data. AIS transponders are mandatory on all commercial vessels >300 gross tonnage and on all passenger ships. Information provided by the AIS includes vessel name and unique identification number, vessel size and class, position and heading, course, speed of travel, and destination port.

A shore-based AIS station was installed on a high cliff near Bruce Head which provided a continuous record of ship positions within line-of-sight of the station, inclusive of Milne Inlet (north and south) and portions of Eclipse Sound and Navy Board Inlet. Shore-based AIS data was limited to between 29 July and 30 August. Satellite-based AIS data, acquired from exactEarth Ltd[7], was used to supplement vessel position information during periods when there were gaps in the shore-based data. The temporal resolution of the shore-based AIS data was approximately five seconds, whereas the satellite-based AIS data exhibited longer interposition times (ten minutes on average), resulting in a comparatively lower spatial and temporal resolution with respect to vessel position. To best represent vessel movement in the SSA during periods when only satellite-based AIS was available, vessel position was interpolated at one-minute intervals.

3.4 Data Management

3.4.1 Narwhal GPS Data

Narwhal positional data were available from two types of GPS Fastloc location tags (SPLASH-10 and CTD-SRDL). To reduce erroneous locations, GPS data were filtered to remove all narwhal positions calculated from less than six satellite positions and for which the residual value was ≤30 (Dujon et al. 2014). Narwhal travel speeds between consecutive GPS points were examined to identify obvious outliers. For the analysis of narwhal travel speed only, GPS locations that resulted in speeds >3.5 m/s were removed (n = 5). It is assumed that

[7] exactEarth Ltd. Is a data services company that leverages advanced microsatellite technology and globally deployed ground systems to deliver exactAIS™, a global vessel tracking and monitoring system based on world leading space-based advanced AIS detection technology.

unrealistic travel speeds were an artefact of a larger GPS error occurred in combination with consecutive locations that were close in time. A time offset value was provided as part of Wildlife Computers' analysis of Fastloc GPS pseudorange data and was used to correct the Fastloc GPS data, where the correct date/time stamp is the sum of the recorded date/time stamp and the estimated time offset. No equivalent correction was performed for the SMRU GPS data.

For visualization of all tagged narwhal movements throughout the full duration the overall spatial dataset, narwhal GPS data were shown for the full extent of the dataset, which ranged from Lancaster Sound in the north to Cumberland Sound in the south. For all subsequent analyses, the narwhal GPS dataset was restricted geographically to extend between Milne Port in the south (72º 53' N), Navy Board Inlet in the north (72º 55' N), Tremblay Sound in the west (81º 22' W), and Pond Inlet in the east (77º 57' W).

Narwhal positional data were interpolated at 1 min intervals and then classified to one of the following categories for analytical purposes:

1) raw GPS data.
2) interpolated data within 20 min of a raw GPS position.
3) interpolated data ≥20 min from a raw GPS position but within 60 min of a raw GPS position.
4) interpolated data ≥60 min of a raw GPS position.

Interpolated data in Category 4 were excluded from analysis. The remaining GPS data were used to estimate bottom depth at narwhal position using available bathymetric data for the region (Figure 1-2). In eight cases, high-quality GPS data resulted in narwhal tracks extending overland (e.g., when one position was on the north side of the Bruce Head peninsula, and another, a short time later, was on the south side of the peninsula). In these eight cases, one or two points were added manually to force the track line.

3.4.2 Dive Data

Dive data from pop-up archival transmitting tow tag (MiniPAT; Wildlife Computers) were corrected for surface bias – for each whale, minimum recorded depth was calculated for each hour of the MiniPAT tag deployment. The resulted values were plotted relative to time and relative to temperature (also recorded by the MiniPAT), to examine possible drifts in logged surfacing depths over time or due to water temperature changes. For each whale, an offsetting depth was calculated, so that the sum of the recorded depths and the offset value resulted in a depth of 0 m during surfacing events. These offsets were 0.75 m for NW01, 1.0 m for NW02, -0.5 m for NW03, and 1.0 m for NW04.

3.4.3 Bathymetric Data

Each raw and interpolated narwhal GPS position was correlated with bathymetry obtained for the region using linear interpolation of available data (Figure 1-2). Due to the limited resolution of the bathymetric data (100 m) and the error associated with the raw narwhal GPS positions (which is then propagated through interpolation of narwhal GPS positions), these sources of error resulted in some misalignment of narwhal dive depths and the estimated available bathymetry. In some cases, narwhal appeared to dive deeper than the available bathymetry; in other cases, deep dives (likely feeding behaviour) did not appear to reach the full estimated available depth. Therefore, results discussing narwhal dive behavior in relation to bottom depth should be interpreted with caution.

3.4.4 AIS Data

Vessel GPS data used in this study were a combination of shore-based and satellite-based Automated Identification System (AIS) data, which provided accurate real-time data on all large vessel passages through Milne Inlet during the 2017 Bruce Head Shore-based Monitoring Program. AIS is mandatory for all commercial vessels >300 gross tonnage and passenger ships. Information provided by the AIS includes vessel name and unique identification number, vessel size and class, position and heading, course, and speed of travel. The two datasets were used to complement one another as the AIS base station at Bruce Head provided higher temporal resolution positional data, but only provided line-of-sight spatial coverage. The satellite-based AIS data had lower temporal resolution, but covered the entire Northern Shipping Route and beyond. To prioritize the high-resolution shore-based AIS data, satellite AIS points recorded within 5 minutes of shore-based AIS data were removed. The cutoff was based on a visual examination of time periods between AIS data points where a satellite-based AIS data point was preceded or followed by a shore-based AIS point. Where gaps in the AIS coverage did exist, vessel AIS data were interpolated to 1 minute resolution.

Vessels were classified into three categories – small vessels (<50 m in length), medium vessels (≥50 m but <100 m in length), and large vessels (≥100 m in length). Only large vessels (≥100 m in length) were used in subsequent analyses. AIS data were also filtered to retain only moving vessels (speed ≥2 knots), to avoid representing interactions between narwhal and stationary vessels. Vessel AIS data were restricted geographically to extend between Milne Port in the south (72º 53’ N), Navy Board Inlet in the north (72º 55’ N), Tremblay Sound in the west (81º 22’ W), and Pond Inlet in the east (77º 57’ W).

3.5 Data Analysis

Analysis of narwhal tag and vessel track data was adapted from previous works that examined the vertical and horizontal movements of blue whales (*Balaenoptera musculus*) in relation to large vessel traffic in the Santa Barbara Channel, California (McKenna et al. 2015). In the study by McKenna et al. (2015), nine individual blue whales were tagged with GPS Fastloc location tags (TDR10-F; Wildlife Computers) and two types of acoustic recording tags (Bioacoustic Probe and Acousonde; Greeneridge Sciences) and analyzed in relation to 20 large vessel passages that transited within 3.6 km of the animals. Data on large vessels was collected via a shore-based AIS station that provided the full extent of each vessel transit through the region. Following interpolation of both vessel and whale track datasets, the closest point of approach (CPA) between the two was determined. The following behavioural variables were then analyzed for each whale for the entire duration of the tag deployment, allowing for comparison of normal dive behaviour and dive behaviour in the presence of large vessels: (1) surface duration between deep dives (and number of breaths); (2) descent time, angle, and speed; (3) bottom time, maximum dive depth (and number of lunges); and (4) ascent time, angle, and speed (Goldbogen et al. 2006, 2011; McKenna et al. 2015).

3.5.1 Identification of Closest Point of Approach (CPA) Events

For the purpose of this study, horizontal movements of narwhal outfitted with GPS Fastloc tags (SPLASH-10 or CTD-SRDL) were analyzed in relation to the combined AIS vessel track dataset to determine the location and time of narwhal-vessel interactions. Using customized functions in R v. 3.5.1 (R Core Team 2018), the closest point of approach (CPA) was identified for all 'events[8]' in which a vessel transiting through the Study Area came within 3 km of the animal.

Only raw GPS data or interpolated data within 20 min from a raw GPS point were used. For each narwhal GPS position, all AIS positions recorded within the preceding or following 30 mins were retrieved. For each vessel within those AIS positions, the distance between narwhal and every AIS position in the subset was calculated. If the same narwhal encountered the same vessel following a 3 h or longer break, the encounter was considered to be a new event. This allowed for encounters with vessels that performed more than one passage within the same day (for example, entering Milne Inlet in the morning and exiting in the evening, or vice versa). The 3 h cutoff value was based on visual examination of the time periods between subsequent narwhal GPS positions in this analysis. For each individual encounter, the minimum distance between narwhal and vessel was calculated, and is referred to as the closest point of approach (CPA).

Only events with CPA ≤3 km and with at least 3 points of raw GPS data were retained for visualizing the trends in narwhal dive behaviour. For these events, narwhal GPS data, vessel AIS data, and dive data recorded in the three hours preceding and following the CPA timestamp were retained. For each CPA event (i.e., each narwhal-vessel interaction), two plots were generated. The first plot included a map depicting the horizontal relocations of individual narwhal and vessel in the 1 h preceding and 1 h following the CPA timestamp. The second plot showed the dive profiles for the same narwhal during the same time period, relative to the bathymetry (as based on interpolated GPS positions). All analyses and plotting were performed in R v.3.5.1 (R 2018).

Behavior of individual narwhal was analyzed in relation to periods when vessels were present or absent, based on defined exposure (CPA to 10 km) and non-exposure (>10 km) zones. Ten kilometres was selected as an appropriate distance to delineate exposure vs non-exposure zones as the 120 dB re: 1µPa (SPL_{rms}) disturbance threshold was predicted to propagate 9.82 km < R_{max} < 19.24 km from a Post-Panamax vessel transiting at 9 kts through Milne Inlet, according to acoustic modeling results (Quijano et al. 2017). Distance within the exposure zone was examined as a continuous variable (0-10 km) while animals outside of the exposure zone (10+ km) were assigned to a discrete non-exposure bin.

3.5.2 Narwhal Subsurface Movements (Dive Behaviour)

A review of the literature suggests that normal dive behaviour of marine mammals may be altered when individuals are exposed to close ship encounters and associated noise (Wartzok et al. 2003; Williams and Ashe 2007; Williams et al. 2014; Williams et al. 2015). Dive responses of narwhal to vessel traffic may include the following:

1) increase in surface time (reflective of a freeze response)

[8] Event = the CPA associated with any whale-vessel encounter ≤3km within the Study Area. Events more than 3 h apart, even of the same narwhal with the same vessel, are considered to be different encounters.

2) decrease in surface time (reflective of avoidance behaviour)

3) change in dive rate (reflective of avoidance behaviour and/or potential freeze response)

4) increase in the occurrence of bottom dives[9] (reflective of avoidance behaviour and/or flight behaviour)

5) decrease in the occurrence of bottom dives (reflective of decreased foraging effort and/or freeze response)

6) increase in ‘time at depth’[10] (reflective of avoidance behaviour)

7) change in dive duration (reflective of decreased foraging effort and/o ship avoidance)

8) increase in descent speed (reflective of a flight response)

Based on this information, the following null hypotheses were developed as part of the dive response analyses with respect to large vessel transits along the Northern Shipping Route:

$H1_0$: Surface time does not significantly change in the presence of Project-related shipping
$H1_A$: Surface time significantly increases in the presence of Project-related shipping

$H2_0$: Surface time does not significantly change in the presence of Project-related shipping
$H2_A$: Surface time significantly decreases in the presence of Project-related shipping

$H3_0$: Narwhal dive rate does not significantly change in the presence of Project-related shipping
$H3_A$: Narwhal dive rate does change significantly in the presence of Project-related shipping

$H4_0$: The occurrence of bottom dives does not significantly change in the presence of Project-related shipping
$H4_A$: The occurrence of bottom dives significantly increases in the presence of Project-related shipping

$H5_0$: The occurrence of bottom dives does not significantly change in the presence of Project-related shipping
$H5_A$: The occurrence of bottom dives decreases in the presence of Project-related shipping

$H6_0$: Time at depth does not significantly change in the presence of Project-related shipping
$H6_A$: Time at depth significantly increases in the presence of Project-related shipping

$H7_0$: Dive duration does not significantly change in the presence of Project-related shipping
$H7_A$: Dive duration significantly increases in the presence of Project-related shipping

$H8_0$: Dive duration does not significantly change in the presence of Project-related shipping
$H8_A$: Dive duration significantly decreases in the presence of Project-related shipping

[9] Defined as a dive that had a maximum dive depth of >75% of the available bathymetry. Due to available bathymetry limitations (see Section 3.4.3), the use of 75% of available bathymetry was selected to handle cases where available bathymetry data may not accurately represent true available bathymetry.

[10] Defined as time narwhal spend in the bottom 20% of their dive depth (per qualifying dive), irrespective of bottom bathymetry.

$H9_0$: Descent speed does not significantly change in the presence of Project-related shipping
$H9_A$: Descent speed significantly increases in the presence of Project-related shipping

Given the spatial and temporal constraints presented by the shore-based and satellite AIS datasets, together with the variable resolution of data associated with the different tag combinations deployed, individual narwhal were included in this part of the analysis based on meeting the following criteria: (1) narwhal was outfitted with ARGOS satellite tag including Fastloc GPS (SPLASH-10; Wildlife Computers); (2) narwhal was outfitted with tow tag and tow tag was retrieved, providing 1 s dive resolution data (MiniPAT; Wildlife Computers); (3) deployment of tags coincided with the timeframe that high-resolution vessel track data was collected via the shore-based AIS station (29 July 2017 – 20 August 2017); and (4) narwhal entered the Eclipse Sound / Milne Inlet region during the time that it was outfitted with biologging tags. With the primary objective being to incorporate the highest resolution data possible, this selection criteria resulted in four narwhal from the broader dataset being included in the analysis herein.

Specifically, the first four narwhal tagged during the 9-week field program met the above-stated criteria. All four animals were outfitted with a SPLASH-10 backpack tag and a MiniPAT tow tag that was retrieved. The four narwhal were tagged in Tremblay Sound between 31 July 2017 and 3 August 2017 and all entered Milne Inlet by 7 August 2017, with the first arriving earlier on 1 August 2017.

For analysis purposes, corrected dive depth data were separated into individual dives using the Python package DiveBomb (Nunes 2018). The separated dives underwent a data filtration process, where dives with ≤5 data points were removed from analysis. The DiveBomb algorithm identified the beginning of a dive as the time when the whale dove deeper than its surface threshold (calculated as whale length multiplied by cosine of 45º).
For each dive, the algorithm output included the following:

- maximum dive depth (m)
- the duration of time the whale remained at the bottom (where the Divebomb algorithm defines bottom as reaching 80% of maximum depth and levelling out or starting to ascend; mins)
- descent velocity (m/s)
- dive duration (mins)

These variables, as well as the proportion of time spent at surface and the number of dives per hour (dive rate), were used to analyze narwhal diving behaviour throughout the tag deployment period, and to characterize diving behaviour as function of time, location, and distance from large vessels. For visualization of spatial and temporal trends, each response variable was averaged within each individual narwhal tag using 4 h bins within each day. 4 h was selected as an appropriate resolution to provide sufficient data for visualization while not compromising the comparison of spatial distribution with dive behaviour. The resulting mean values were mapped using calculated centroid values within each 4 h bin (based on raw or interpolated GPS data up to 20 mins from another GPS point). The maps were also paneled by study period (31 July to 14 Aug, 15 Aug to 09 Sept). Overall, these maps visualized the spatial extent of narwhal activity, the variability within period, and shifts between the early and late study period.

The effect of large vessels on dive behaviour of individual narwhal was assessed by identifying which dives occurred during vessel exposure vs. non-exposure events. Narwhal that were at depths <7 m were considered to be “at surface”, following the results presented by Blackwell et al. (2018), in which the majority (54%) of narwhal calls were recorded when animals were within 7 m from the water surface. For the analysis of surface time (narwhal depth ≤7 m), which was performed using the full dive dataset (to 1 s resolution), narwhal positions were allocated based on the timestamps of the dive data and GPS positions (interpolated to 1 s resolution within 20 mins from a raw GPS position). Each position was assigned to either `Exposure` or `Non-exposure` bin, based on distance of the narwhal to the nearest large vessel (exposure events were defined as any vessel encounters within 10 km of a narwhal). Where no GPS data were available, the dives were removed from analysis. For modeling, raw data were summarized to 1 min resolution, where if the minimum depth during the 1 min was ≤7 m, the full minute was assigned a “surface” value, whereas if no depths ≤7 m were recorded during the minute, it was assigned a “not surface” value. The reduction of data resolution from 1 sec to 1 min was done due to dataset size (original dataset at 1 s intervals had over 10 million rows), as well as to decrease the temporal autocorrelation associated with the data. The resulting data were analyzed using a mixed logistic regression, where the dependent variable was whether the 1 min period was at surface or not, the independent variables were distance from vessel (as 3rd-degree polynomial), whether there was a large vessel within 10 km from narwhal position, and whether the narwhal was at surface in the preceding 1 min period. The latter variable was included to control for the high level of autocorrelation associated with behavioural data. To account for lack of independence of time series data, the model also included a random intercept by narwhal ID and data event, where “events” were dive data separated by more than 1 min.

In the analysis of the DiveBomb outputs (i.e., maximum dive depth, duration of time spent at the bottom of the dive, descent velocity, and dive duration), the allocation of each dive event to a GPS position was performed using the timestamp associated with the point when a whale initiated the dive. The GPS positions (interpolated to 1 sec resolution within 20 mins from a raw GPS position) were used to assign coordinates to each dive event. If no GPS data were available at the time of dive initiation, the dive was removed from analysis. Similar to the analysis of surface use, each position was assigned to either `Exposure` or `Non-exposure` bin, based on distance of the narwhal to the nearest large vessel (exposure events were defined as any vessel encounters within 10 km of a narwhal)

All dive behaviour response variables (presence/absence ≤7 m, maximum dive depth, duration of time at bottom of dive, and descent velocity) were analyzed using linear or generalized linear mixed models, where the models had fixed effects of day of year (where applicable), distance from large vessel (as 3rd-degree polynomial), and whether there was a large vessel within 10 km from narwhal position. Where autocorrelation was suspected, variables accounting for behaviour in the preceding dive were included. For example, in the analysis of maximum dive depth (as proportion of available bathymetry), the model included a variable of whether the preceding dive was a deep dive (>75% of available bathymetry). Due to convergence issues, all random effects were simple random intercepts by tag.

In cases where narwhal were exposed to more than one vessel at a time, only the event with the closer vessel was retained and the event with the farther vessel was omitted from the dataset. Model fit was assessed using diagnostic and residual plots. The pseudo R^2 values (Nakagawa et al. 2017) were reported for both marginal (i.e., fixed effects only) and conditional (both fixed and random effects) portions of the model. All prediction plots included the data (raw whenever possible, summarized in other cases) to visualize the fit of the model relative to the collected data. All analyses were performed using the package `glmmTMB` (Brooks et al. 2017) in R v. 3.5.1 (R 2018).

3.5.3 Narwhal Surface Movements

A review of the literature suggests that normal surface behaviour of narwhal may be altered when animals are exposed to ship noise and to close ship encounters (Finley et al. 1990; Cosens and Dueck 1993; Finley and Greene 1993; Heide Jorgensen et al. 2013). Common behavioral responses of marine mammals to vessel traffic may include the following:

1) change in direction of travel (reflective of ship avoidance)
2) horizontal displacement from the vessel path (reflective of ship avoidance)
3) increase in swim speed reflective of flight behaviour
4) decrease in swim speed reflective of a freeze response

Based on this information, the following null hypotheses were developed as part of the surface response analyses with respect to large vessel transits along the Northern Shipping Route:

$H10_0$: Narwhal travel direction does not significantly change in the presence of Project-related shipping
$H10_A$: Narwhal travel direction does significantly change in the presence of Project-related shipping

$H11_0$: Narwhal distribution at the surface does not significantly change in the presence of Project-related shipping
$H11_A$: Narwhal distribution at the surface does change significantly in the presence of Project-related shipping

$H12_0$: Narwhal swim speed does not significantly change in the presence of Project-related shipping
$H12_A$: Narwhal swim speed significantly increases in the presence of Project-related shipping

$H13_0$: Narwhal swim speed does not significantly change in the presence of Project-related shipping
$H13_A$: Narwhal swim speed significantly decreases in the presence of Project-related shipping

Associated analyses related to the length of time that an identified surface behavioural response was shown to persist (if present) were undertaken to determine whether habituation occurs over time.

The dataset used for the analysis of horizontal movements relative to vessel traffic included 12 narwhal outfitted with GPS Fastloc location tags (ten SPLASH-10 tags and two CTD-SRDL tags). The twelve narwhal were tagged in Tremblay Sound between 31 July 2017 and 3 September 2017, with the first arriving in Milne Inlet on 1 August and the last on 6 September 2017. Only large vessels were considered in this analysis (defined as vessels ≥100 m in length) as AIS ship tracking data were not available for smaller vessels. The distance between narwhal and vessel, as well as the relative angle between the vessel and the narwhal were calculated (taking into account the vessel’s heading throughout the interaction event). In cases where land was present between a narwhal and a vessel during a qualifying interaction event, these data were removed from analysis. All narwhal-vessel paired interactions, where the distance between a narwhal and vessel was ≤10 km, were plotted to visualize the relative position of narwhal during all ship interaction events relative to the nominal shipping route and the shoreline. The 10 km data plots identified animal position relative to all aspects (i.e., 360º) of the ship during active transits. In addition, 3 km data plots were produced to highlight close encounters; in this case, narwhal positional data from either side of the vessel (port or starboard) were combined to focus on the gap in narwhal distribution relative to the vessel during active transits.

Narwhal positional data relative to vessels (on the full 10 km range) were used to create a spatial model of narwhal densities relative to vessel. The model included an effect of distance (in km) and direction relative to vessel, as well as an interaction between distance and direction. Directions were assigned based on angle between narwhal and vessel, where angles between 315° and 45° (relative to straight ahead of the vessel) were considered “Forward”, angles between 45° and 135° were considered “Starboard”, angles between 135° and 225° were considered “Astern”, and angles between 225° and 315° were considered “Port”. The model was fitted using a Poisson point process model from the package `spatstat` (Baddeley et al. 2015) in R (R 2018).

To assess narwhal horizontal avoidance of vessels, narwhal headings were used to calculate two values – 1) change in narwhal heading over time, and 2) relative angle between narwhal and vessel over time. For change in narwhal heading over time, a value of 0º represented no change in heading (i.e., continuation of travel in a straight line), a value of 90º represented a right angle turn to the right of the vessel, and a value of 180º represented a complete reversal of course. In the case of the relative angle, a value of 0º indicated that the narwhal was headed toward the vessel, a value of 90º indicated that the vessel was immediately abeam (to the right) of the narwhal path, and a value of 180º indicated that the vessel was directly behind the narwhal. Both variables were plotted as a function of time during the 1 h periods both preceding and following the CPA event.

Generally, angle data are analyzed using circular modeling methods (Pewsy et al. 2013). However, both turning and relative angles were only expressed as extending between 0° and 180°, as opposed to the full 0-359° range. Therefore, circularity did not have to be accounted for and both variables were analyzed using non-circular methods. Turning angles were analyzed using a mixed model, where the fixed variables were whether there was a large vessel within 10 km of the narwhal, a second-degree polynomial of distance between narwhal and large vessel (if present; km), distance of narwhal from shore (km), and an interaction between whether a large vessel was present and distance from shore. The random effects only included a random intercept by narwhal, to account for the repeated measures character of the data. If significant effects were found, multiple comparisons (with Dunnett-adjusted *P* values) were performed to estimate at which distance turning angles became significantly different from turning angles predicted when no large vessels were present within 10 km.

Angles relative to vessels were analyzed using a mixed model, where the fixed variable was a third-degree polynomial of distance between narwhal and large vessel (km). Since the dataset focuses on the angles between narwhal and large vessels, the dataset available for modeling was restricted to cases where a large vessel was present, therefore no “no exposure” modeling was available. The random effects only included a random intercept by encounter, to account for the repeated measures character of the data. If significant effects were found, multiple comparisons (with Dunnett-adjusted *P* values) were performed to estimate at which distance narwhal relative angles became significantly different from relative angles predicted at 10 km away from a large vessel (i.e., on the boundary of the exposure zone).

To identify potential habituation or seasonal changes in narwhal surface behaviour, temporal trends in distance between narwhal and vessels during interaction events were examined (narwhal-vessel distance ≤10 km). Linear mixed effects models were used to estimate the change in distance between narwhal and vessel over time. The models contained a single fixed effect of time (expressed as decimal days from beginning of the study). The random effects differed between the models – one model had only a random intercept, whereas the other included both a random intercept and a random slope by individual tag, to account for individual variability in the relationship. The two models were compared using likelihood ratio tests, and the better model (based on alpha level of 0.05) was selected for interpretation. Since the data had a high degree of autocorrelation (as confirmed by autocorrelation plots of the initial model residual), an autocorrelation structure was added to the models. All analyses were performed in the statistical environment R v. 3.5.1 (R 2018) using the package 'nlme' (Pinheiro et al 2018).

4.0 RESULTS

4.1 Data Collection

4.1.1 Tag Deployment

A total of twenty narwhal were live-captured during the 2017 study period. Satellite location tags were successfully deployed on 18 animals (Table 4-1 and Table 4-2), with deployments ranging from 33 to 97 days (mean = 63 days). PAT tags were deployed on 16 animals. Four of the five high-resolution MiniPAT units were successfully recovered (deployments ranging from 27 to 38 days), providing 1 s resolution data. The fifth MiniPAT unit was unrecovered, providing 14 days of 75 s resolution data. Only one of the 11 MK10-PAT tag was recovered which yielded a total of 6 days of 1 s resolution data.

Acousonde units were successfully deployed on nine animals in total, with deployments ranging from 12 to 98 hours. None of the narwhal fitted with Acousondes entered the Northern Shipping Route before the units released off the animal, therefore the aural component of shipping interactions could not be assessed as part of this analysis.

Table 4-1: Summary of tag instrumentation deployed on narwhal during summer 2017 with total length of deployment

Narwhal ID	Deployment Date	Location Tags		PAT Tags		Greeneridge Sciences Acousonde 3B
		Wildlife Computers SPLASH-10	SMRU CTD-SRDL	Wildlife Computers MiniPAT	Wildlife Computers MK10-PAT	
NW01	07-31-17	✓F (94 days)	-	✓ (33 days at 1 s)	-	-
NW02	07-31-17	✓F (63 days)	-	✓ (33 days at 1 s)	-	-
NW03	08-01-17	✓F (46 days)	-	✓ (27 days at 1 s)	-	-
NW04	08-03-17	✓F (68 days)	-	✓ (38 days at 1 s)	-	-
NW05	08-03-17	✓F (81 days)	-	-	✓NR (4 days at 75 s)	-
NW06	08-03-17	✓F (97 days)	-	✓NR (14 days at 75 s)		-
NW07	08-05-17	✓F (52 days)	-	-	✓NR (no data)	-
NW08	08-12-17	✓F (65 days)	-	-	✓NR (1 day at 75 s)	✓ (98 h)
NW09	08-16-17	-	✓ (50 days)	-	✓NR (no data)	✓ (82 h)
NW10	08-18-17	-	-	-	✓NR (no data)	-
NW11	08-30-17	-	✓F (62 days)	-	✓NR (no data)	✓ (12 h)
NW12	09-02-17	✓F (62 days)	-	-	✓NR (no data)	✓ (24 h)

Narwhal ID	Deployment Date	Location Tags		PAT Tags		Greeneridge Sciences Acousonde 3B
		Wildlife Computers SPLASH-10	SMRU CTD-SRDL	Wildlife Computers MiniPAT	Wildlife Computers MK10-PAT	
NW13	09-02-17	✓F (33 days)	-	-	-	✓ (42 h)
NW14	09-03-17	-	-	-	-	✓ (24 h)
NW15	09-03-17	-	✓F (38 days)	-	✓ (6 days at 1 s)	-
NW16	09-03-17	✓ (67 days)	-	-	✓NR (no data)	-
NW17	09-10-17	✓ (54 days)	-	-	-	-
NW18	09-11-17	✓ (82 days)	-	-	✓NR (<1 day at 75 s)	✓ (21 h)
NW19	09-11-17	✓ (67 days)	-	-	✓NR (no data)	✓ (15 h)
NW20	09-11-17	✓ (51 days)	-	-	-	✓ (30 h)

Notes: F = tag with Fastloc GPS capability. NR = Tag not recovered, so only 75 s resolution available. Grey cells identify data excluded from present analysis due to poor data resolution or because tag was not recovered.

Table 4-2: Morphometric data for narwhal tagged during summer 2017

Narwhal ID	PTT	Body length (cm)	Fluke width (cm)	Girth (cm)	Tusk (Y/N)	Tusk length (cm)	Sex (M/F)
NW01	172062	466	116	N/A	Y	183	M
NW02	172063	400	90	N/A	N	N/A	F
NW03	172064	400	90	218	N	N/A	F
NW04	172066	432	110	282	Y	113	M
NW05	172067	488	110	N/A	Y	221	M
NW06	172065	458	131	N/A	N	N/A	M
NW07	172069	430	100	251	Y	124	M
NW08	172068	375	N/A	235	N	N/A	F
NW09	164370	385	95	N/A	N	N/A	F
NW10	N/A	400	115	N/A	Y	0.7*	M
NW11	172253/172254	390	No data	No data	N	N/A	F w/calf
NW12	WC 172070	425	100	240	N	N/A	F
NW13	WC 172071	298	65	N/A	Y	27	M (juv)

Narwhal ID	PTT	Body length (cm)	Fluke width (cm)	Girth (cm)	Tusk (Y/N)	Tusk length (cm)	Sex (M/F)
NW14	N/A	250	61	162	N	N/A	M (juv)
NW15	172081/172082	380	90	N/A	Y	78	M
NW16	148687	370	82	N/A	N	N/A	F
NW17	148688	360	95	N/A	Y	92	M
NW18	148690	370	82	N/A	N	N/A	F
NW19	148696	380	90	210	N	N/A	F
NW20	148694	408	90	231	N	N/A	F

Notes: *tusk broken at base (remnant tusk <1 cm long). Grey cells identify data excluded from present analysis due to poor data resolution or because tag was not recovered.

4.1.2 Large Vessel Traffic

Large vessels transiting ≥2 knots[11] within the broader Study Area (i.e. Milne Inlet, Eclipse Sound, and Navy Board Inlet) were recorded on 76 days between 2 August and 17 October 2018. Of these, the most prevalent were ore carriers, with vessels present on 72 of the total 76 days and up to 7 vessels present per day (Figure 4-1 and 4-2). Passenger and service vessel traffic was limited, with vessels present on only nine days and never more than one vessel transiting through the Study Area per day. General cargo and fuel tanker vessels were present on 33 days of the overall period, and up to three vessels transited within the Study Area per day (recorded on three days).

[11] Two knots was selected as a minimum vessel speed required to qualify as a 'vessel transit'. Vessels recorded under this speed were presumed to be anchored or drifting.

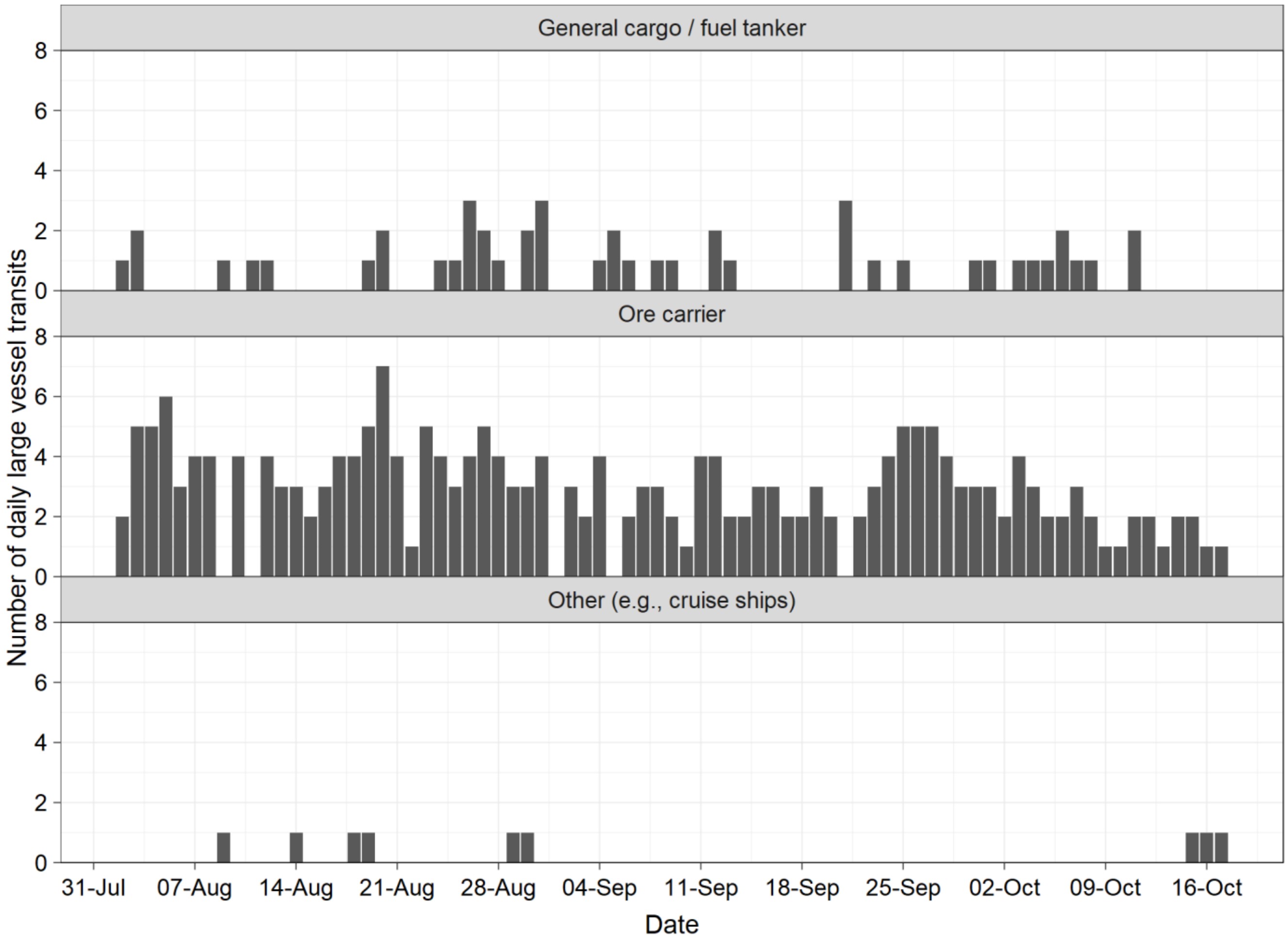
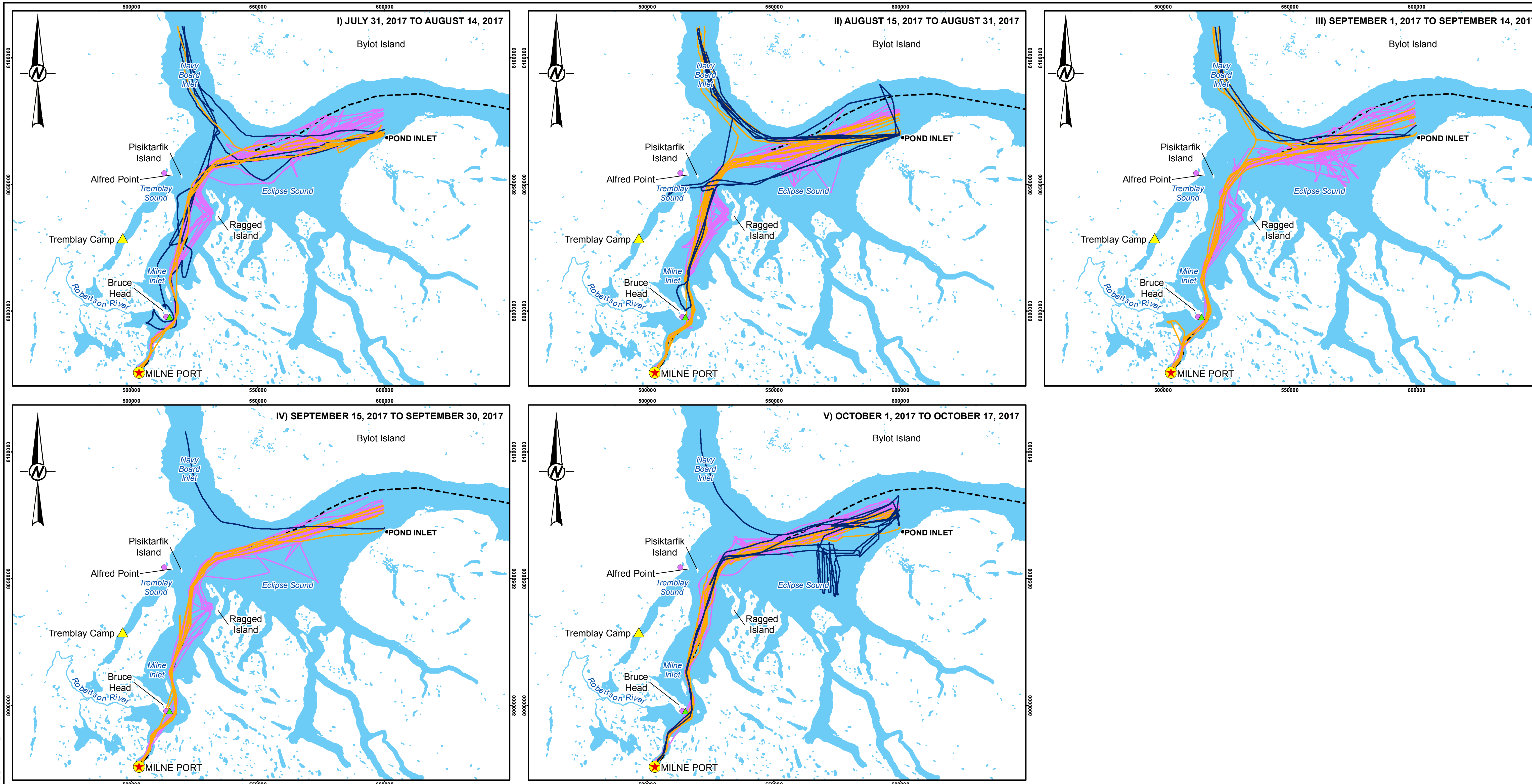


Figure 4-1: Daily number of large vessel transits (>100 m) within the Study Area



LEGEND

- AIS ANTENNA
- COMMUNITY
- MILNE PORT
- MOTE LOCATION
- TAGGING LOCATION
- SHIPPING ROUTE (APPROXIMATE)
- WATERBODY

VESSEL TRANSIT ROUTES BY CLASS

- BULK (ORE) CARRIER
- GENERAL CARGO/FUEL TANKER
- OTHER (e.g., CRUISE SHIP)

0 25 50
1:1,500,000 KILOMETRES

REFERENCE(S)
HYDROGRAPHY, POPULATED PLACE, AND PROVINCIAL BOUNDARY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

CONSULTANT
GOLDER

YYYY-MM-DD	2019-05-14
DESIGNED	SU
PREPARED	AA
REVIEWED	PR
APPROVED	PR

TITLE
TRACKLINES OF LARGE VESSEL TRANSITS (LVTS) IN THE STUDY AREA BY BI-WEEK AND VESSEL TYPE; 2017

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	9000-904	0	4-2

4.1.3 Narwhal GPS Location Data

The total number of GPS locations recovered from the backpack tags was directly related to the total time that tags were active, while the lifespan of the tags appeared to be related to season (Table 4-3). Since tag status updates indicated that battery life was sufficient, it was assumed that the cessation of GPS location recovery was due to a combination of adverse environmental or behavioural conditions, buffer programming in the case of Splash-10 tags, or the possibility of tag detachment. The lack of GPS location data did not always coincide with ‘tag death’ and Argos transmissions may have continued for some time.

Splash-10 tag programming limited the collection of GPS locations to a maximum of four transmissions per hour and 72 transmissions per day, from July through October. Due to a fault in the Splash-10 tag buffer programming, older data was transmitted more times than newer data (each unique GPS collection point is transmitted multiple times to increase the likelihood of Argos or MOTE reception), resulting in a predictable skewed decrease of daily GPS points following tag deployment (Figure 4-3). If Splash 10 tags were still active into November and December, GPS collection effort was reduced to one day in seven (e.g., NW12; Figure 4-3), while no GPS collection was attempted after December. Although CTD-SRDL tags deployed on whales NW11 and NW15 could theoretically collect GPS locations every 8 minutes, other programming requirements and environmental limitations resulted in an actual recovery of GPS locations at a lower rate than the Splash-10 tags (NW11 and NW15; Figure 4-3). Sea state and animal behavior also had the potential to reduce the number of GPS locations recovered from backpack tags as GPS data collected could only be transmitted to satellite when the wet-dry sensor indicated that the tag was dry.

Interpolation of GPS data to 1 min resolution resulted in an increase in the size of the dataset from 27,702 data points to a total of 798,764 data points. Of these, 3.5% (27,702 cases) were raw GPS points, 71% (564,923 cases) were interpolated within 20 mins from a raw GPS point, and 26% (206,139 cases) were interpolated but 20-60 mins from a raw GPS point.

Table 4-3: Summary statistics of narwhal GPS tag deployment

Narwhal No.	Deployment Period				Number of GPS Positions	
	Start Date	Last GPS Location	Last Argos Transmission	Tag Duration (days)	Total	Clean
NW01	07-31-17	01-Nov	3-Dec	94	4,012	3,937
NW02	07-31-17	15-Oct	17-Oct	63	3,322	3,269
NW03	08-01-17	16-Sep	3-Oct	46	1,942	1,920
NW04	08-03-17	10-Oct	31-Oct	68	2,857	2,647
NW05	08-03-17	22-Oct	25-Oct	81	2,644	2,523
NW06	08-03-17	08-Dec	8-Mar	97	4,256	4,098
NW07	08-05-17	26-Sep	7-Oct	52	2,274	2,210
NW08	08-12-17	16-Oct	27-Oct	65	2,346	2,291
NW11	08-30-17	31-Oct	3-Nov	62	1,346	1,320
NW12	09-02-17	08-Nov	24-Nov	62	1,953	1,934
NW13	09-02-17	05-Oct	12-Oct	33	1,004	986
NW15	09-03-17	11-Oct	16-Oct	38	577	568

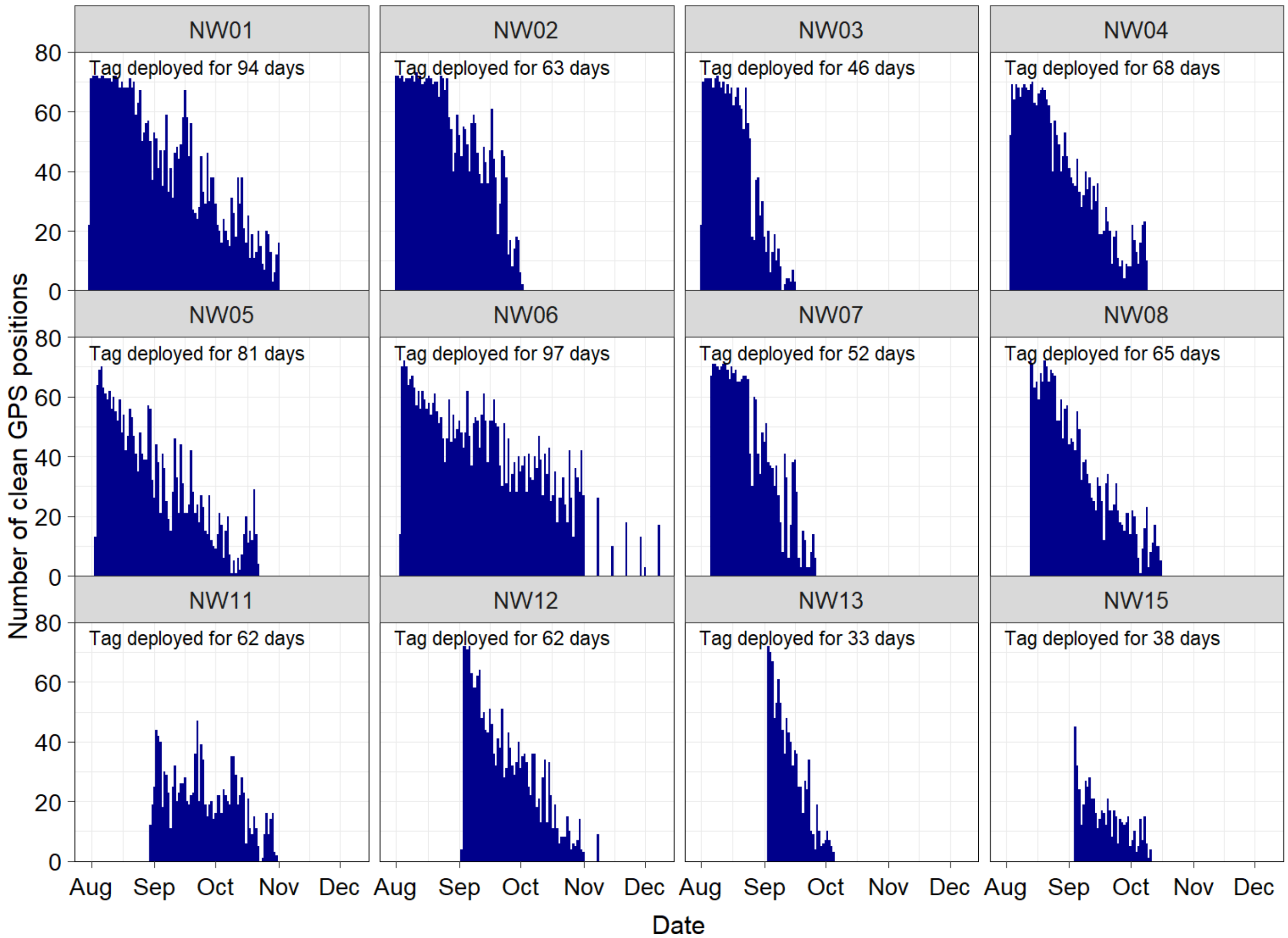
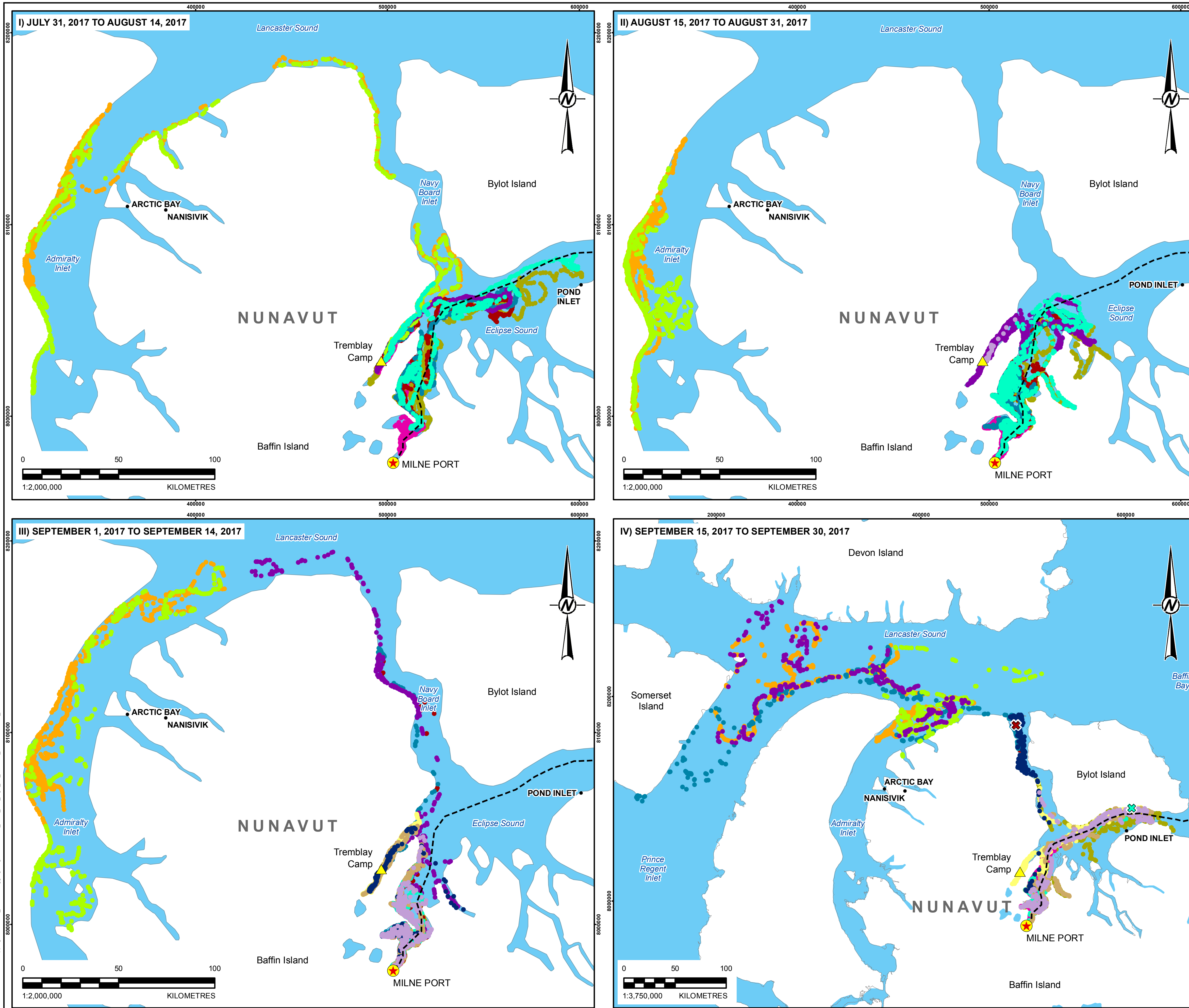


Figure 4-3: Daily number of clean GPS positions per narwhal with total deployment period (days)

Throughout the deployment period of GPS tags (July 31 to December 8), narwhal utilized and traveled around the north and east shores of Baffin Island, ranging from Lancaster Sound to Leopold Island (Figure 4-4). The spatial distribution of narwhal varied by animal. For example, NW08 and NW04 were found predominantly in the western portion of the overall utilized area – from Lancaster Sound to near Pond Inlet. In comparison, NW01, NW06, and NW12 (the three tags that recorded the latest within the dataset) were recorded farthest east, with only NW06 ever entering Lancaster Sound. Narwhal NW05, NW06, and NW11 were recorded farthest off shore in Baffin Bay, with NW11 recorded approximately 290 km from the nearest Baffin Island shoreline. Narwhal NW01 and NW06 generally travelled near one another until the second half of September, when NW06 was still recorded in Lancaster Sound and NW01 travelled to the mouth of Admiralty Inlet.

Within the Study Area (i.e. Eclipse Sound, Milne Inlet, Tremblay Sound, and southern Navy Board Inlet), narwhal distribution varied over time and by animal (Figure 4-5). During the first two weeks of August, narwhal NW05 and NW06 traveled together from Tremblay Sound into Navy Board Inlet, while NW01, NW03, NW04, NW07, and NW08 traveled throughout Eclipse Sound. In comparison, NW02 was recorded only within Tremblay Sound and south of the Bruce Head peninsula. During the second half of August, narwhal remained largely within Tremblay Sound and Milne Inlet, with only NW07 and NW08 recorded in the western portion of Eclipse Sound. During early September, NW03, NW04, and NW08 were recorded traveling north through Navy Board Inlet and spent the remainder of the study period in Lancaster Sound and Baffin Bay (except for NW03, whose tag expired while in the mouth of Navy Board Inlet). During the second half of September, narwhal NW11, NW12, and NW01 were recorded throughout Eclipse Sound and Navy Board Inlet while NW13, NW02, and NW07 were recorded throughout Milne Inlet. In early October, narwhal NW12 and NW11 departed the Study Area through Navy Board Inlet, and the tag associated with NW02 expired in Eclipse Sound. No tagged narwhal remained in the Study Area for the remainder of the study period.



LEGEND

- COMMUNITY
- MILNE PORT
- NARWHAL FINAL TRACKED LOCATION
- TAGGING LOCATION
- SHIPPING ROUTE (APPROXIMATE)
- WATERBODY

NARWHAL ID

- NW1
- NW2
- NW3
- NW4
- NW5
- NW6
- NW7
- NW8
- NW11
- NW12
- NW13
- NW15

REFERENCE(S)

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PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

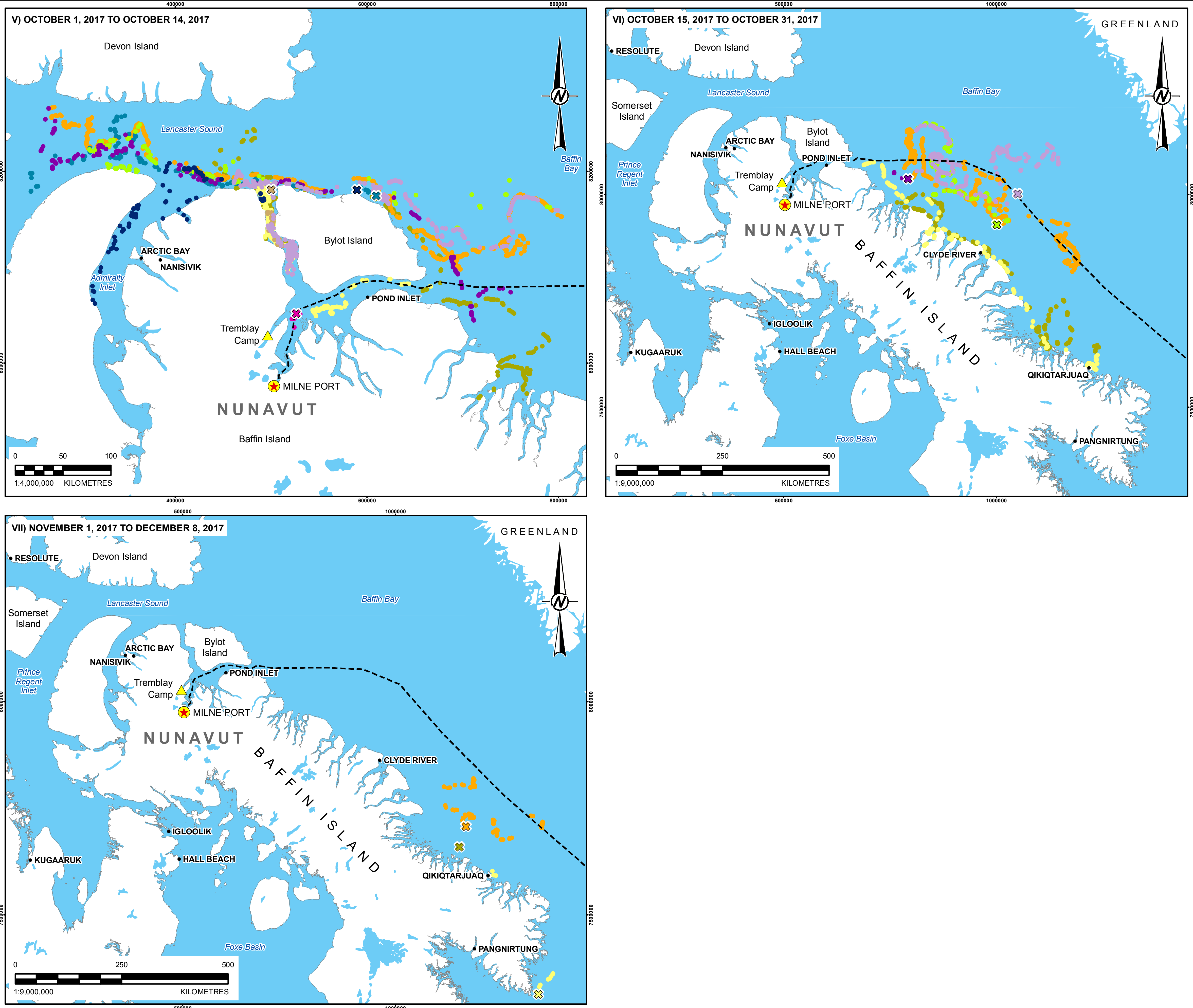
TITLE
FULL SPATIAL DISTRIBUTION OF GPS-TAGGED NARWHAL; JULY-DECEMBER 2017

CONSULTANT

GOLDER

YYYY-MM-DD	2019-05-14
DESIGNED	SU
PREPARED	AA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	9000-904	0	4-4A



LEGEND

- COMMUNITY
- MILNE PORT
- NARWHAL FINAL TRACKED LOCATION
- TAGGING LOCATION
- SHIPPING ROUTE (APPROXIMATE)
- WATERBODY

NARWHAL ID

NW1, NW2, NW3, NW4, NW5, NW6, NW7, NW8, NW11, NW12, NW13, NW15

REFERENCE(S)
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PROJECTION: UTM ZONE 17 DATUM: NAD 83

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DESIGNED	SU
PREPARED	AA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
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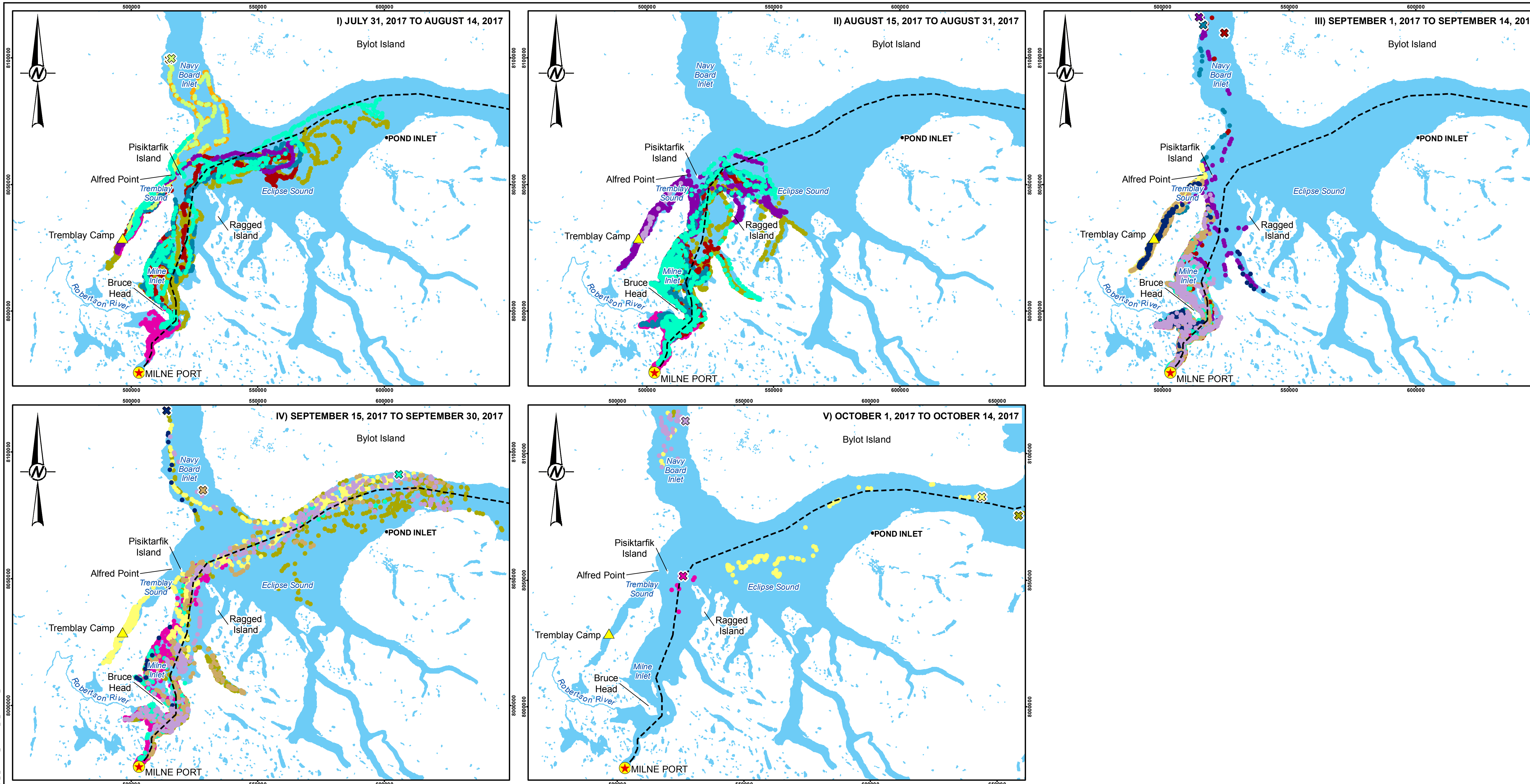

LEGEND

COMMUNITY	NW7
MILNE PORT	NW8
NARWHAL FINAL TRACKED LOCATION	NW11
TAGGING LOCATION	NW12
	NW13
	NW15
	SHIPPING ROUTE (APPROXIMATE)
	WATERBODY

NARWHAL ID

- NW1
- NW2
- NW3
- NW4
- NW5
- NW6

0 25 50

1:1,500,000 KILOMETRES

REFERENCE(S)

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PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT

BAFFINLAND IRON MINES CORPORATION

PROJECT

MARY RIVER PROJECT

CONSULTANT

GOLDER

YYYY-MM-DD	2019-05-14
DESIGNED	SU
PREPARED	AA
REVIEWED	PR
APPROVED	PR

TITLE

SPATIAL DISTRIBUTION OF GPS-TAGGED NARWHAL BETWEEN MILNE PORT AND POND INLET; JULY-OCTOBER 2017

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	9000-904	0	4-5

4.2 Narwhal Interactions with Large Vessel Traffic

Narwhal behavioral response to Project-related vessel traffic was analyzed as a function of distance from vessels (CPA to 10 km) in relation to vessel non-exposure (>10 km) events.

The majority of narwhal GPS data was collected when no large vessels were within 10 km of the narwhal (i.e., no exposure zone [96.1% of the 542,787 raw and interpolated GPS points]; Figure 4-6). Narwhal were positioned within 10 km of a large vessel (i.e., exposure events) throughout Milne Inlet, as well as north of Ragged Island, and with one exposure event in Tremblay Sound (when the passenger vessel *Le Boreal* approached the mouth of Tremblay Sound on 30 August). In many of the exposure events, narwhal were recorded traveling along the shoreline and were exposed to vessel traffic events due to the confined nature of the narrow channel. Exposure events were frequent within Koluktoo Bay and the south portion of Milne Inlet due to the high incidence of narwhal and the close proximity to the shipping route.

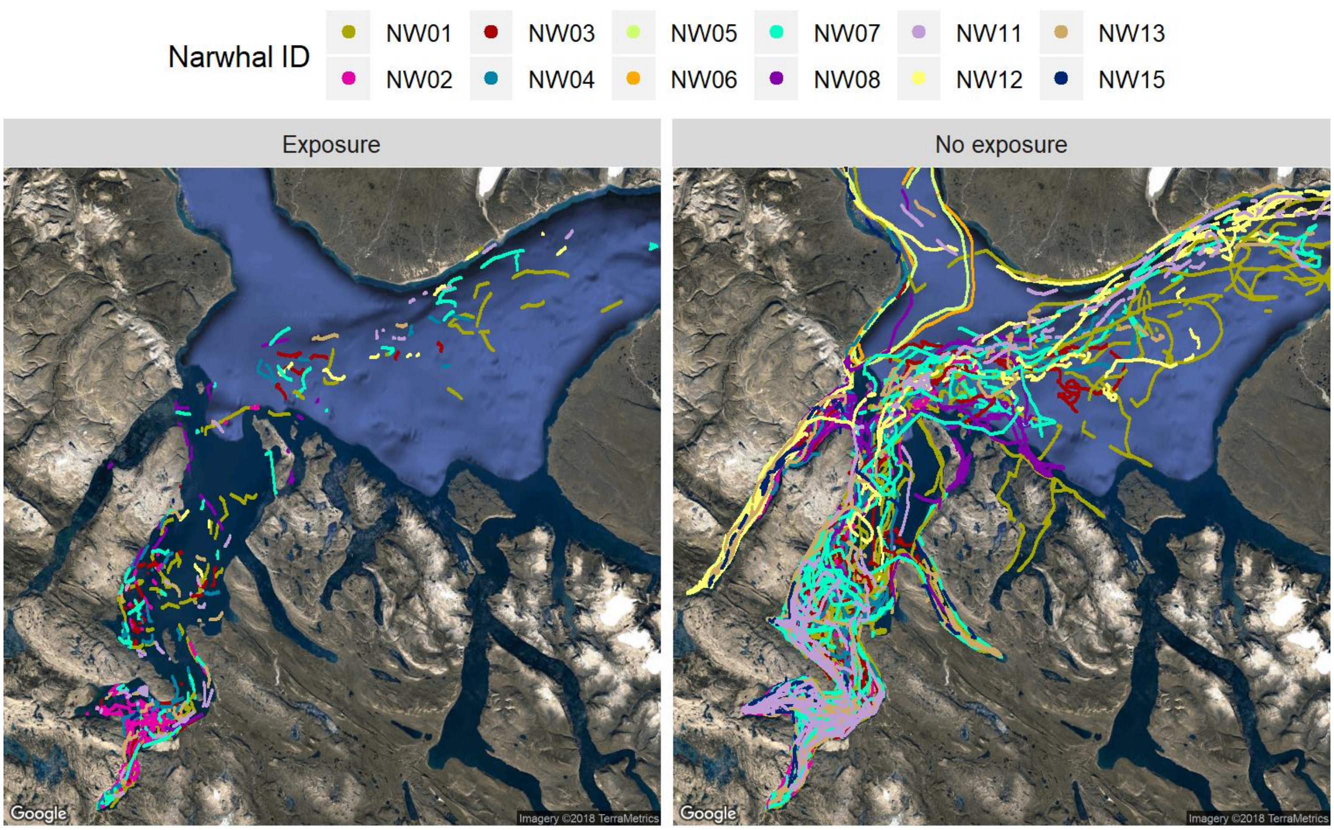

Figure 4-6: Spatial distribution of narwhal GPS positions during vessel exposure (CPA to 10 km) and non-exposure (>10 km) events

4.2.1 Dive Behaviour in Relation to Vessel Traffic

4.2.1.1 Close Encounters with Large Vessel Traffic (CPA Events)

A total of 77 events were identified in which the closest point of approach (CPA) between narwhal and a transiting vessel was ≤3 km and included ≥3 raw GPS points (Figure 4-7 through Figure 4-26). Of these, 21 events were identified for NW01, 25 events were identified for NW02, 8 events were identified for NW03, and 23 events were for identified NW04. The distance between whale and vessels at CPA ranged between 0.1 km and 3.0 km, with a mean of 1.3 km (SD=0.8 km). Drifting/anchored vessels (i.e. speed <2 knots) and vessels less than 100 m in length were not included in this analysis (e.g., 2 active tugs, 2 cargo vessels, and one bulk carrier stationed at port).

Of the 77 events identified, six were considered paired vessel transits in which a narwhal was exposed to two Project-related vessels concurrently, with one vessel transiting north-bound and the other transiting south-bound. The following events were considered paired vessel transits but were not depicted on the same diagram due to complexity: NW01- 12 and 13; NW02- 17 and 18; NW02– 19 and 20; NW02- 23 and 24; NW04- 12 and 13; and NW04- 20 and 21. Paired vessel transits were not included in the present analysis due to the limited sample size. Effects of paired vessel transits on narwhal behaviour will be evaluated in the 2018 Narwhal Tagging Report using combined 2017 and 2018 datasets.

Often, ‘V’ shaped dives appeared to be initiated when the vessel was within 2 km of narwhal (e.g., NW01-11, CPA=0.33 km; NW02-1, CPA=1.27 km; NW02-4, CPA=1.98 km; NW02-11, CPA=0.62 km; NW02-12, CPA=1.17 km; NW02-23, CPA=0.24 km; NW03-1, CPA=0.31 km; NW03-8, CPA=0.92 km; NW04-9, CPA=0.28 km; and NW04-12, CPA= 1.23 km). These flight response dives may temporarily interrupt sustained ‘U’ shaped dives (presumably foraging behaviour) or sustained shallow dives. In many cases, the depth of V shaped dives corresponded to available bathymetry but occasionally to mid-water depths as well (e.g., NW02-16 CPA=1.21 km; NW03-5, CPA=0.26 km and NW04-6, CPA = 0.53 km); this may be due to the limitations of the available bathymetry values, estimated for each narwhal GPS position (see Section 3.4.3). The initiation of such dives often occurred in advance of the CPA, thereby causing the CPA to represent an underestimate of the distance at which this behaviour is initiated. Temporary suspension of dive activity by narwhal appeared to be initiated for certain vessel transits when near the CPA, even in the absence of an obvious flight response dive (e.g., NW02-5, CPA=1.83 km; NW03-3, CPA = 1.81 km and NW04-1 CPA=0.47 km). There are exceptions to these trends as in NW02-21 (CPA=0.98 km) and NW04-14 (CPA=0.47 km) where close vessel passage did not illicit a flight dive nor a dive cessation response but only a slight extension in the surface interval. When consistent foraging activity was presumed (U-shaped dives) and appeared to be interrupted by vessel passage, the amount of time until the resumption of U-shaped dives varied from approximately 20 minutes to 2 hours (e.g., NW02-4, ~2 h; NW02-5, ~20 min; NW02-11, ~50 min; NW03-1 ~40 min; and NW03-8, ~35 min).

Spatial behavioural responses (i.e. displacement or change in travel path) to vessel transits can also be interpreted for some vessel transits, but this is more problematic than the dive data given the temporal limitations of the narwhal GPS data. Regardless, all possible iterations of potential spatial behaviours in response to vessel transits appeared to be illustrated in the figures. There were many examples where narwhal were not displaced from a small geographic area even when in close proximity to a vessel transit (e.g., NW01-1, CPA=0.68 km; NW01-11, CPA=0.33 km; NW01-20, CPA=1.53 km; NW02-5, CPA=1.83 km; NW02-12, CPA=1.17 km; NW04-14, CPA=0.47 km; NW04-18, CPA=0.29 km; and NW04-23, CPA=0.15 km). There were also examples where narwhal appear to stop in an area (e.g., NW02-15, CPA=1.13 km; and NW04-1, CPA=0.47 km) or, alternatively, leave an area (e.g., NW04-15, CPA=0.81 km; and NW04-22, CPA=0.34 km) in response to vessel transits. In some instances, narwhal appeared to maintain their travel path, even when on a head-on' approach with a vessel (e.g., NW01-10, CPA=1.43 km; NW04-17, CPA=1.25 km; NW04-20, CPA=0.89 km). There also were examples that appeared to show narwhal path deflection as influenced by vessel transits (e.g., NW02-22, CPA=0.4 km). It should be noted that even when no change in dive behaviour was evident, the narwhal path could appear to change in response to vessel proximity (e.g., NW01-3 CPA=1.68 km).

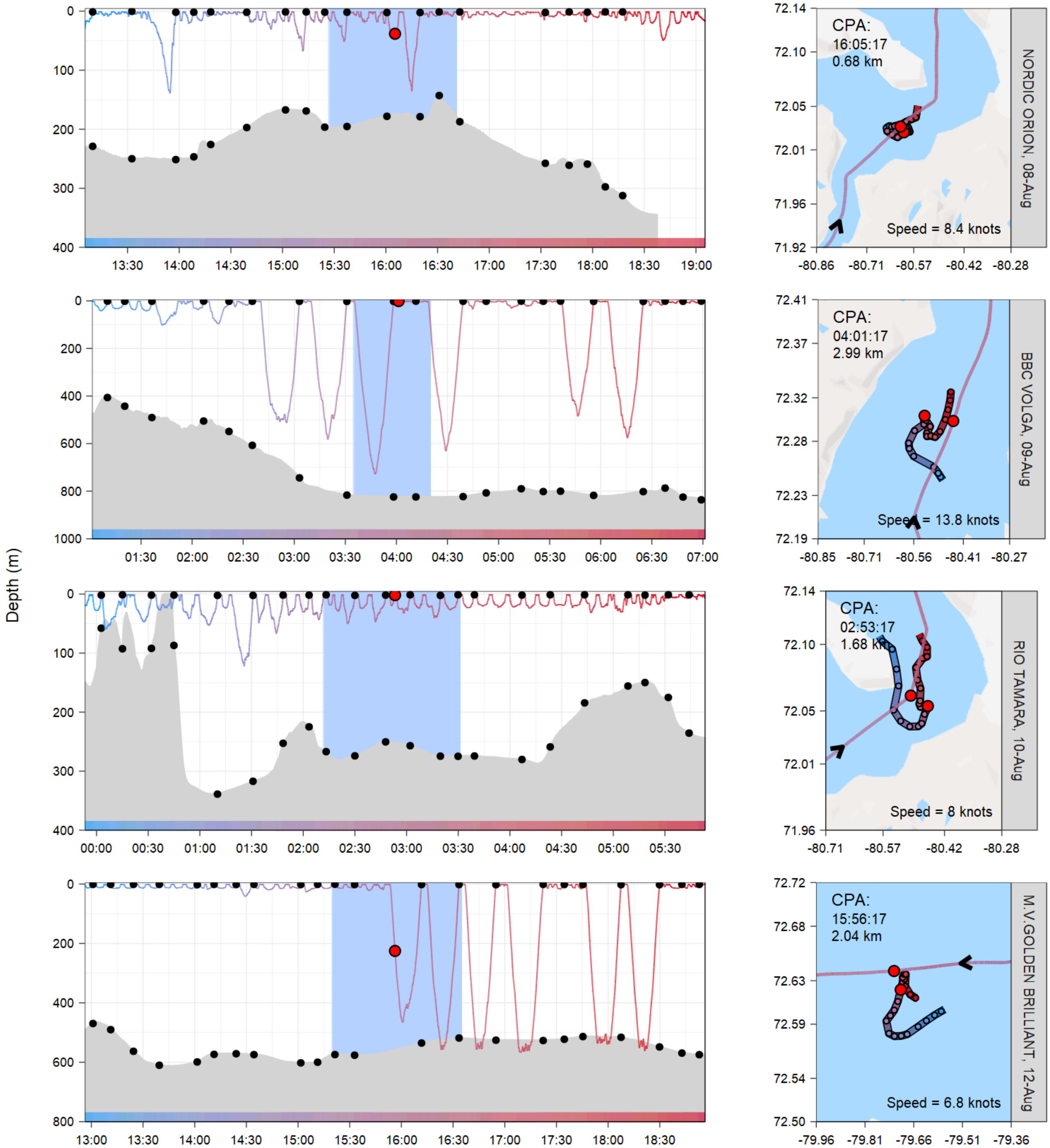

Figure 4-7: Movement and dive depths of NW01 relative to Project-related vessel transits 1-4

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines respectively, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

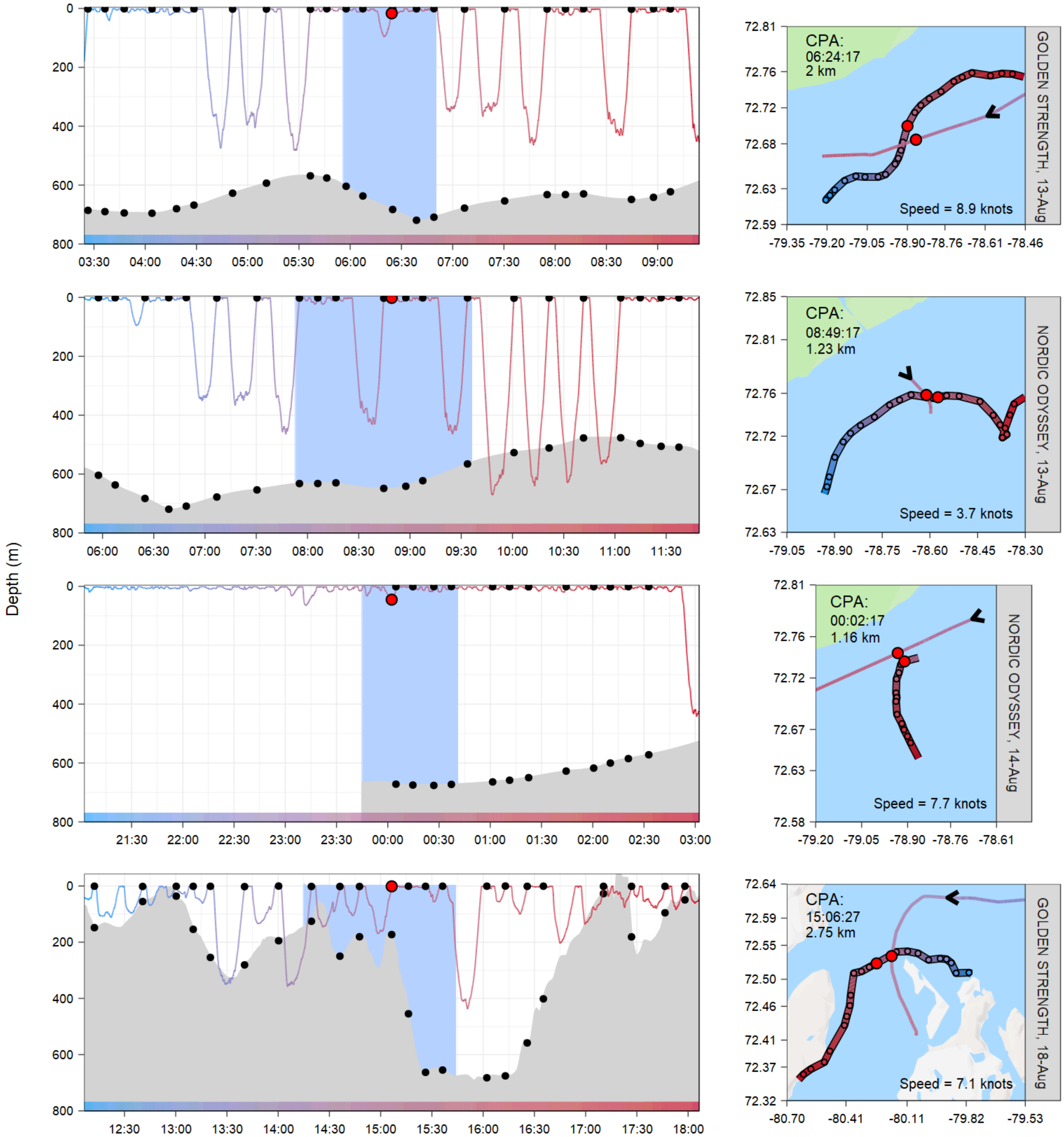

Figure 4-8: Movement and dive depths of NW01 relative to Project-related vessel transits 5-8

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel. Note that land depicted as green is part of Sirmilik National Park.

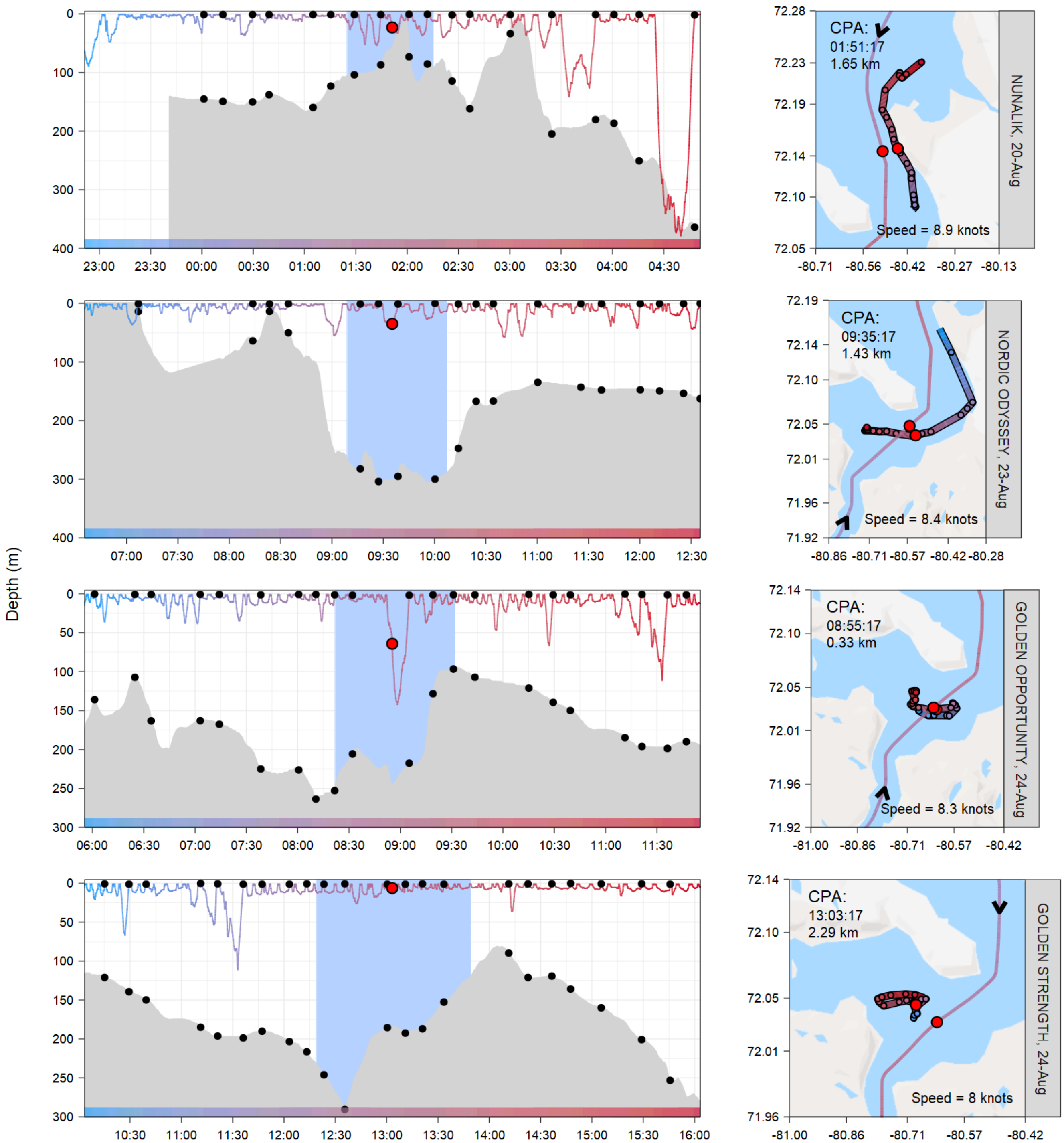

Figure 4-9: Movement and dive depths of NW01 relative to Project-related vessel transits 9-12

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

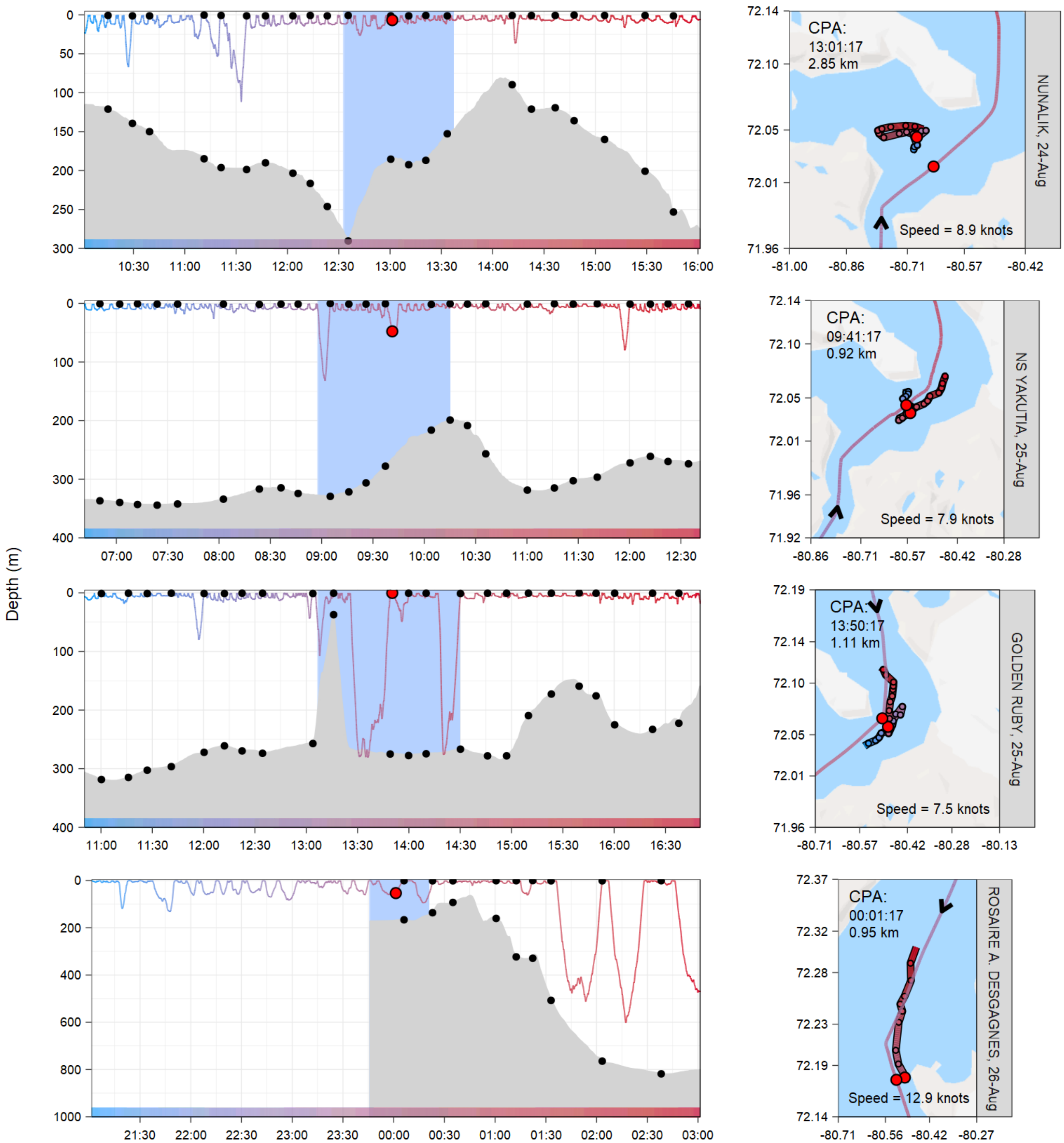

Figure 4-10: Movement and dive depths of NW01 relative to Project-related vessel transits 13-16

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

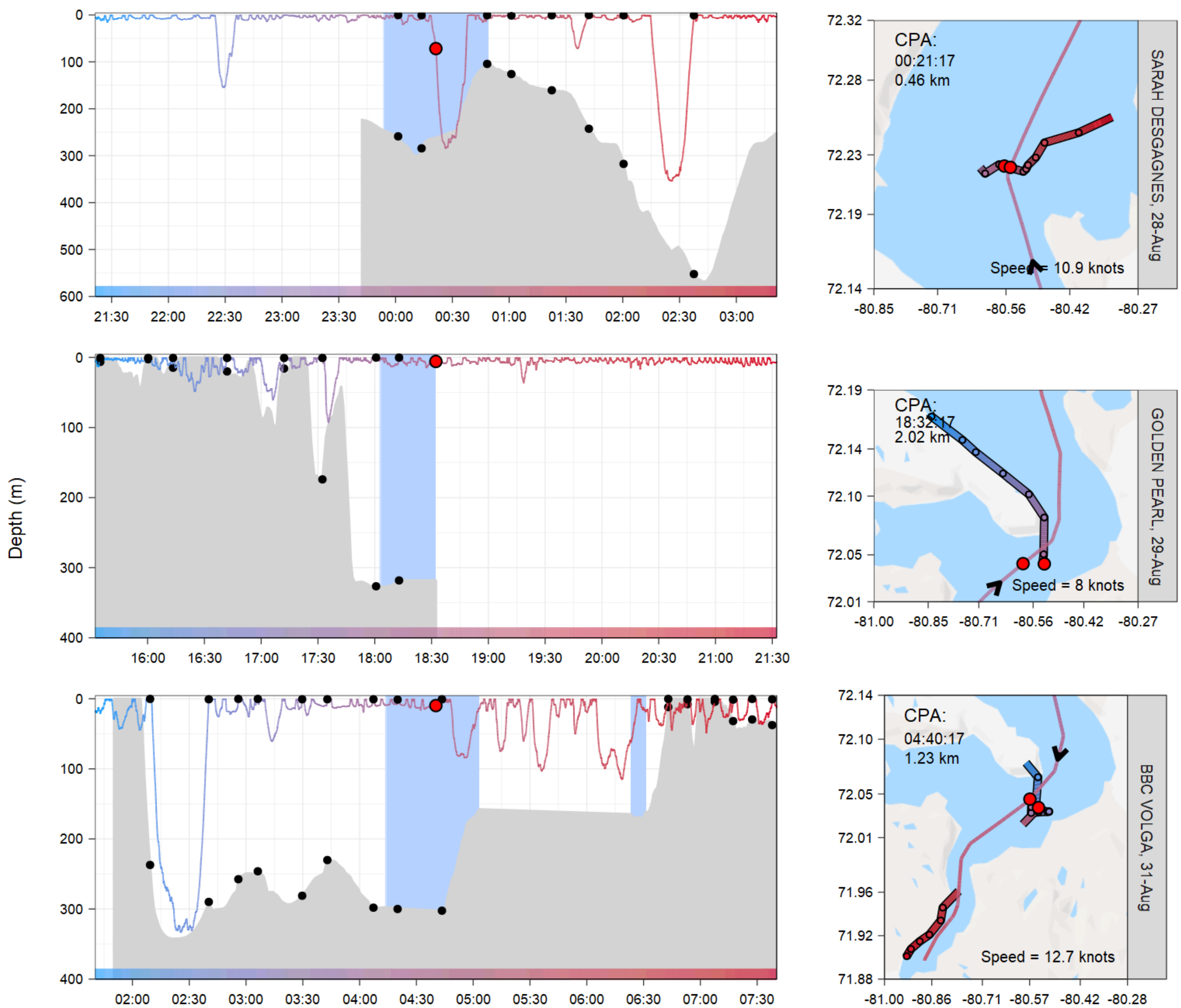

Figure 4-11: Movement and dive depths of NW01 relative to Project-related vessel transits 17-19

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel. Note that a 2 h gap in GPS location data is evident for NW01- 19.

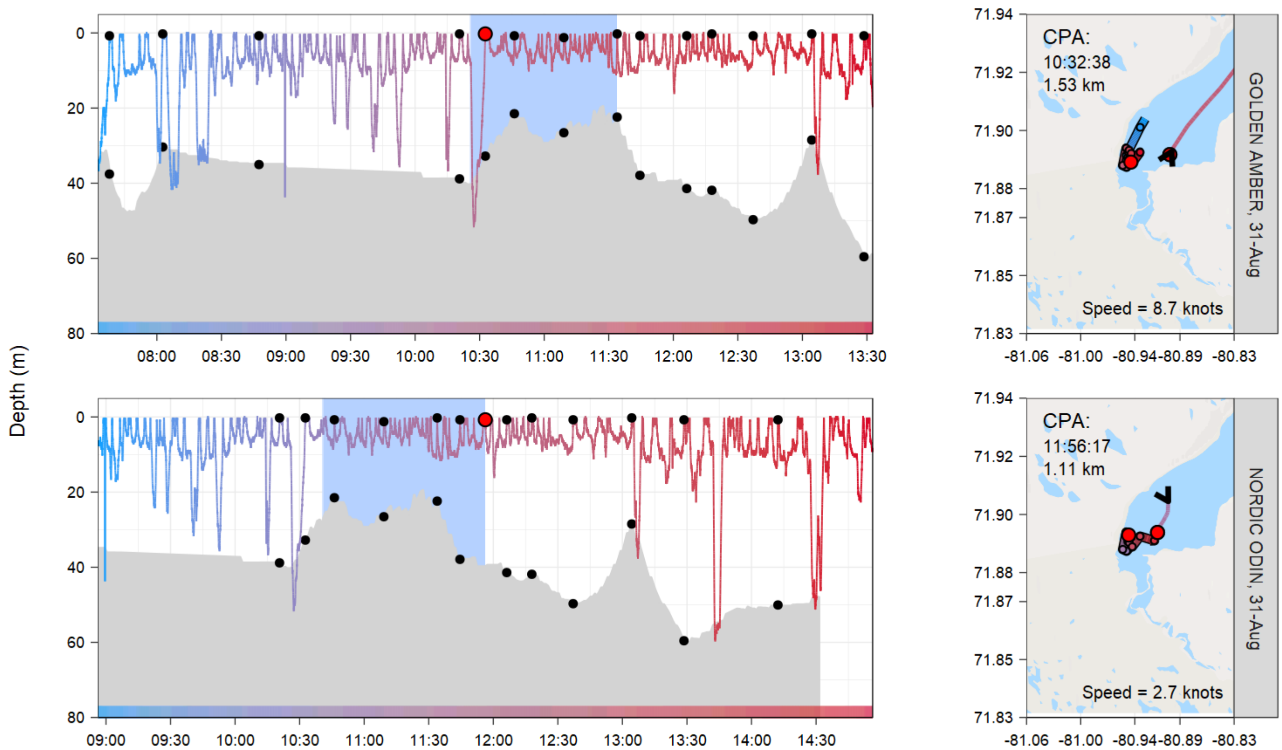

Figure 4-12: Movement and dive depths of NW01 relative to Project-related vessel transits 20-21

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

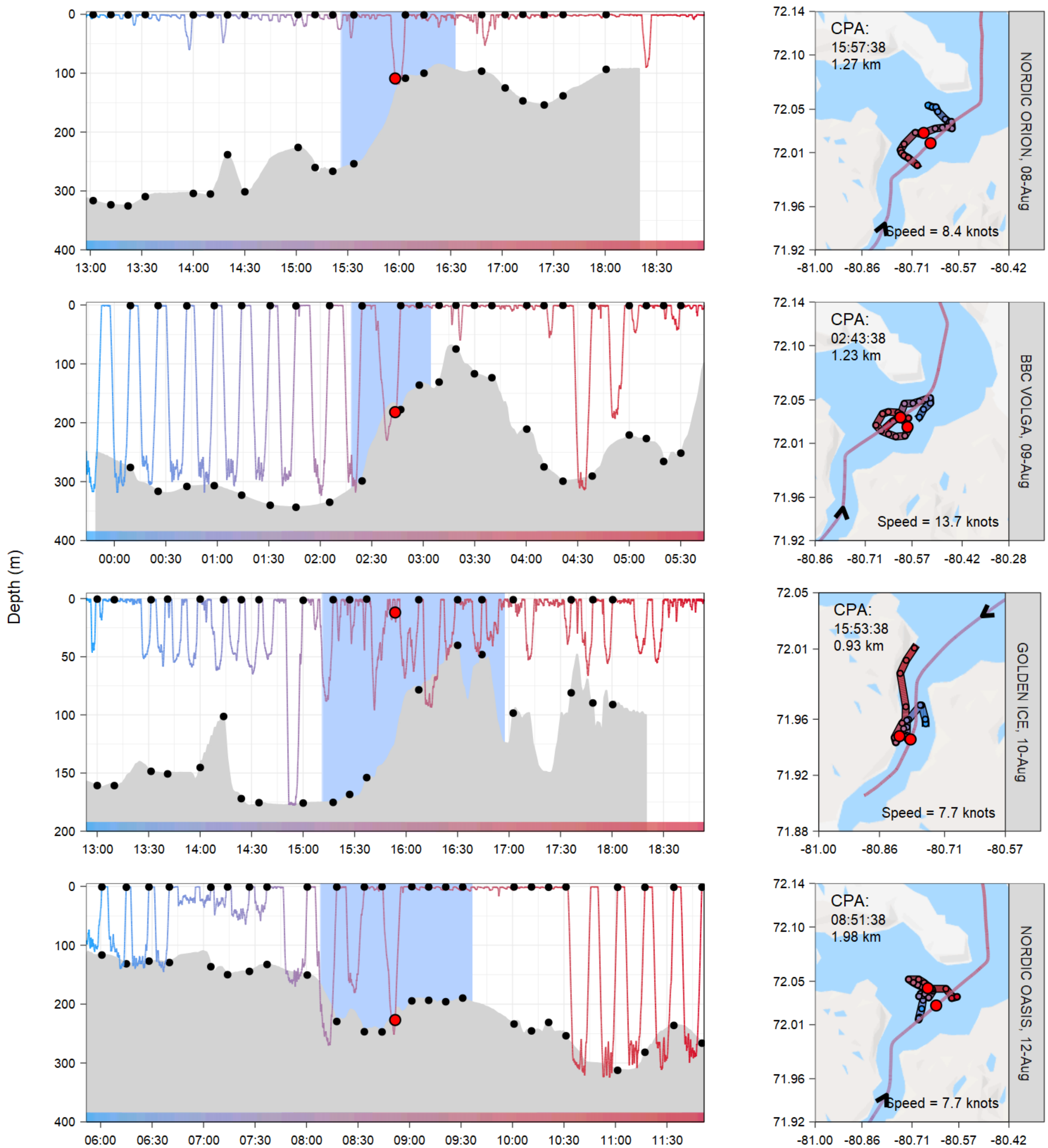

Figure 4-13: Movement and dive depths of NW02 relative to Project-related vessel transits 1-4

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

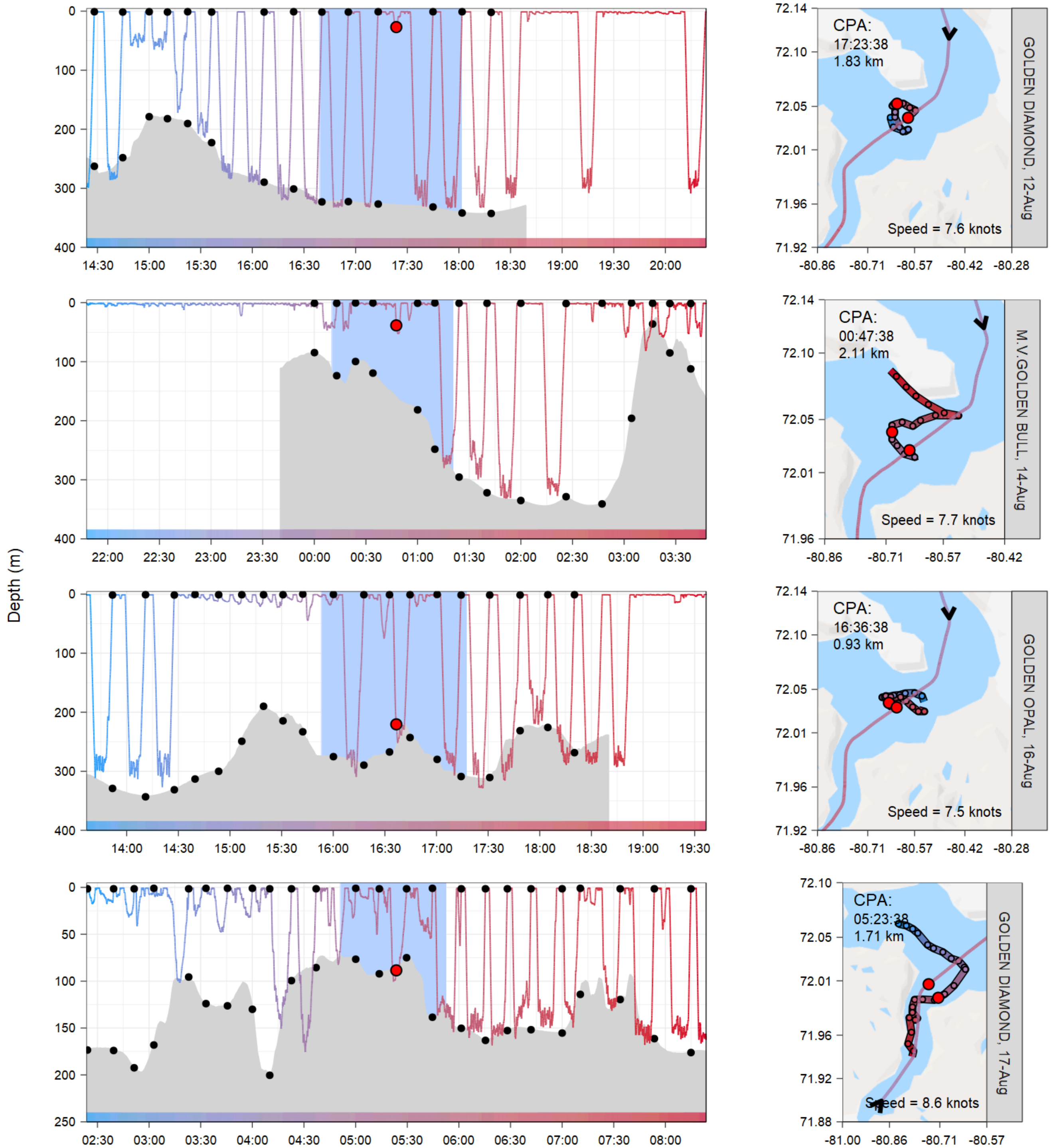

Figure 4-14: Movement and dive depths of NW02 relative to Project-related vessel transits 5-8

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

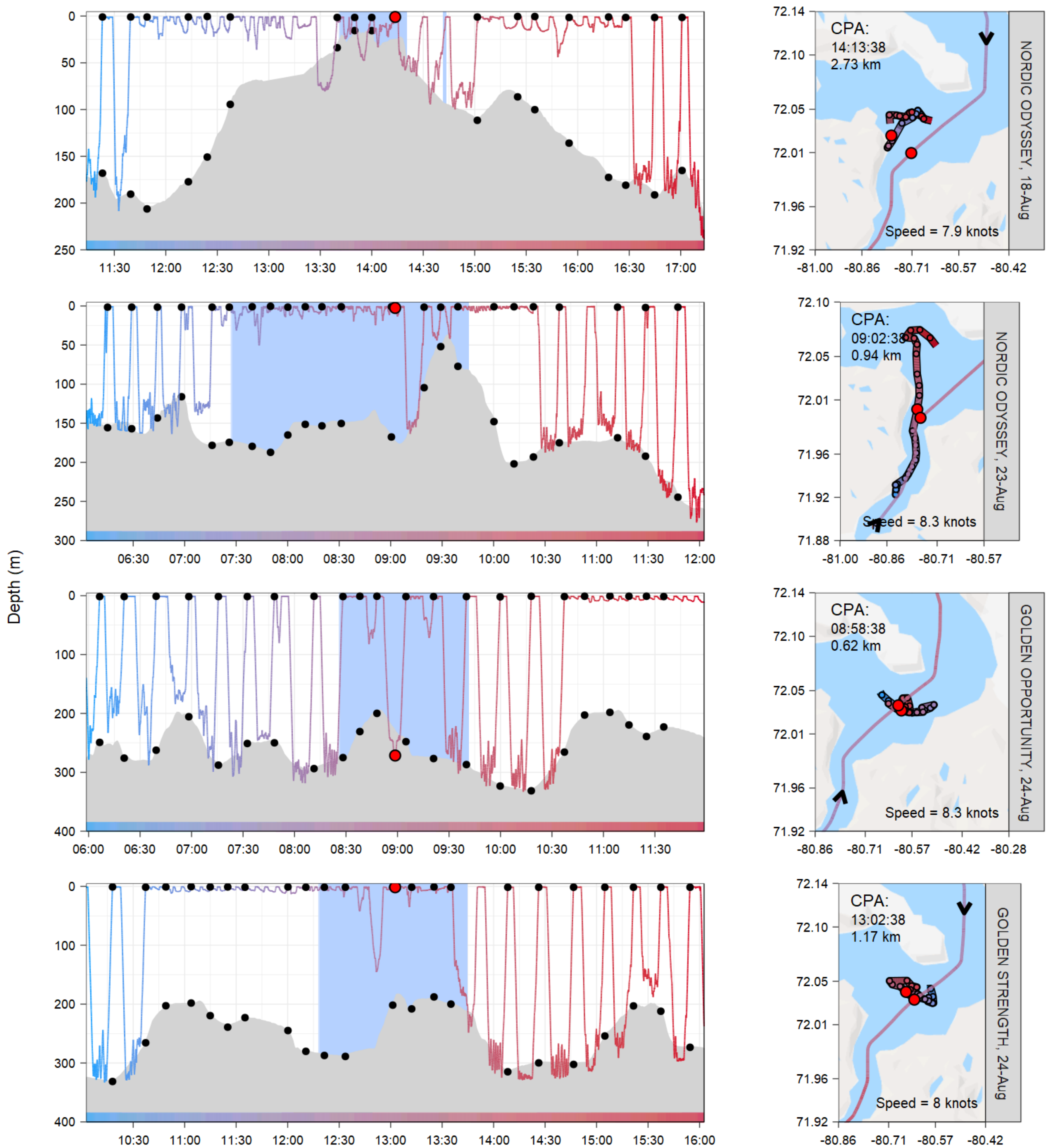

Figure 4-15: Movement and dive depths of NW02 relative to Project-related vessel transits 9-12

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

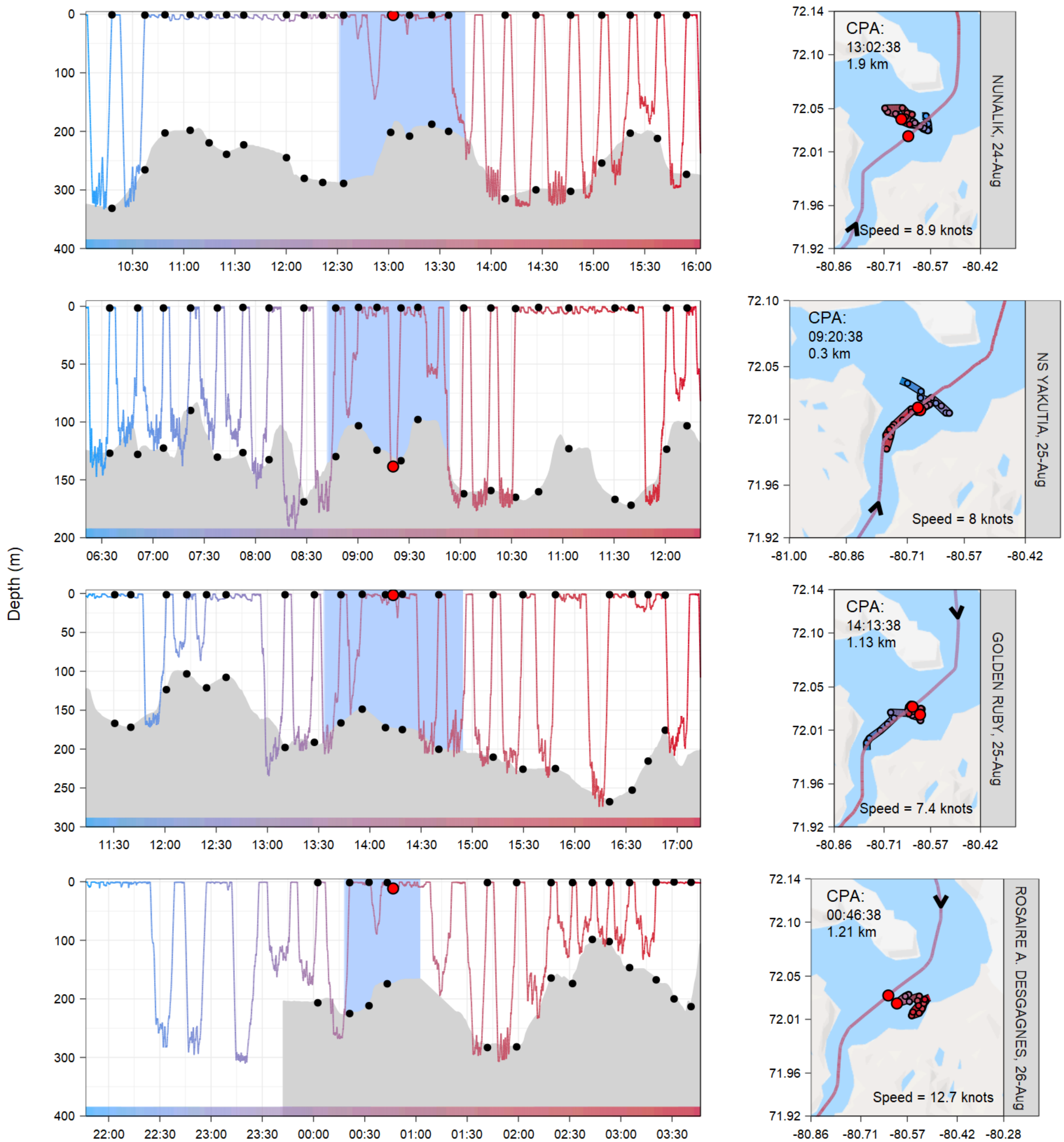

Figure 4-16: Movement and dive depths of NW02 relative to Project-related vessel transits 13-16

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

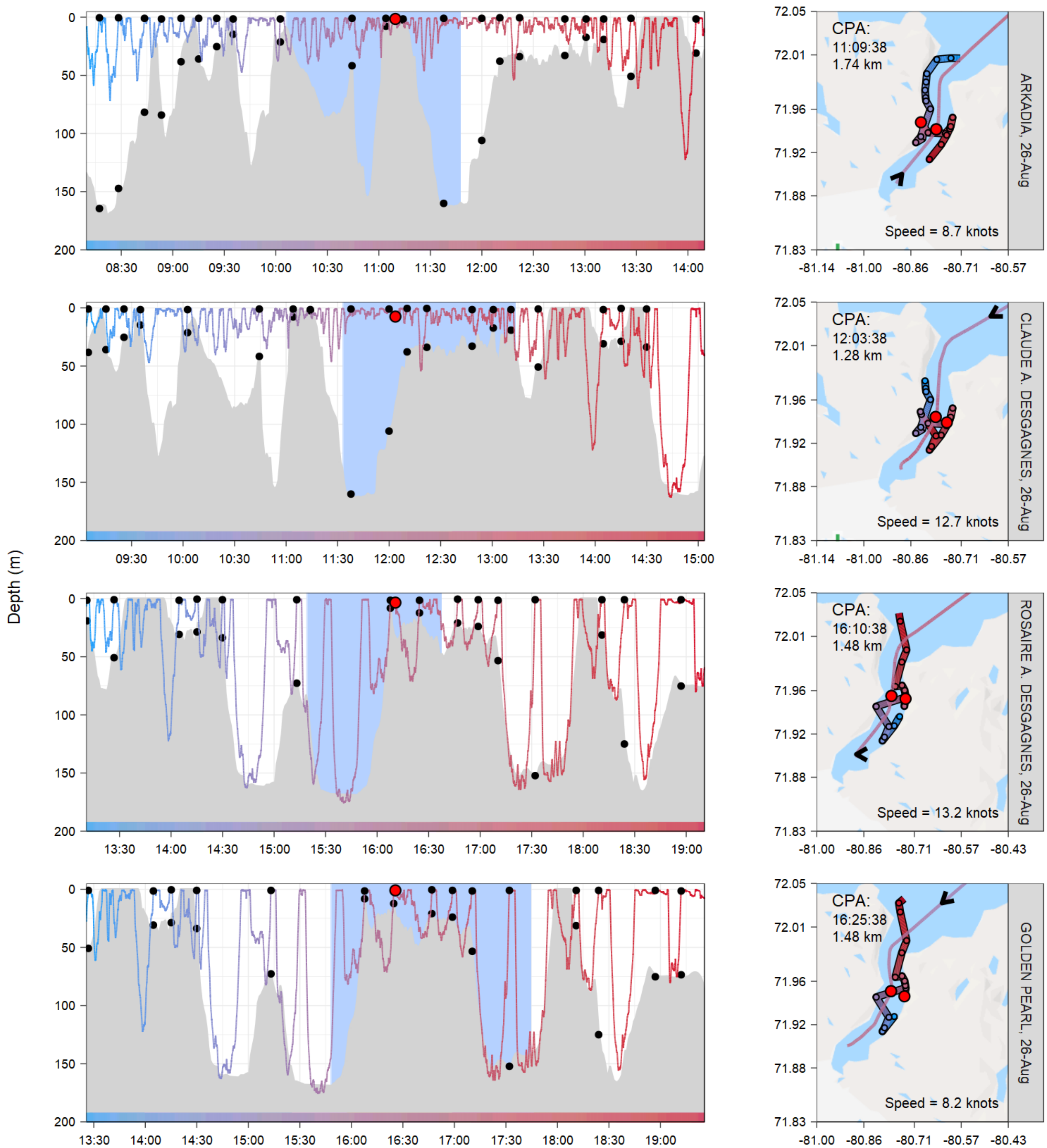

Figure 4-17: Movement and dive depths of NW02 relative to Project-related vessel transits 17- 20

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

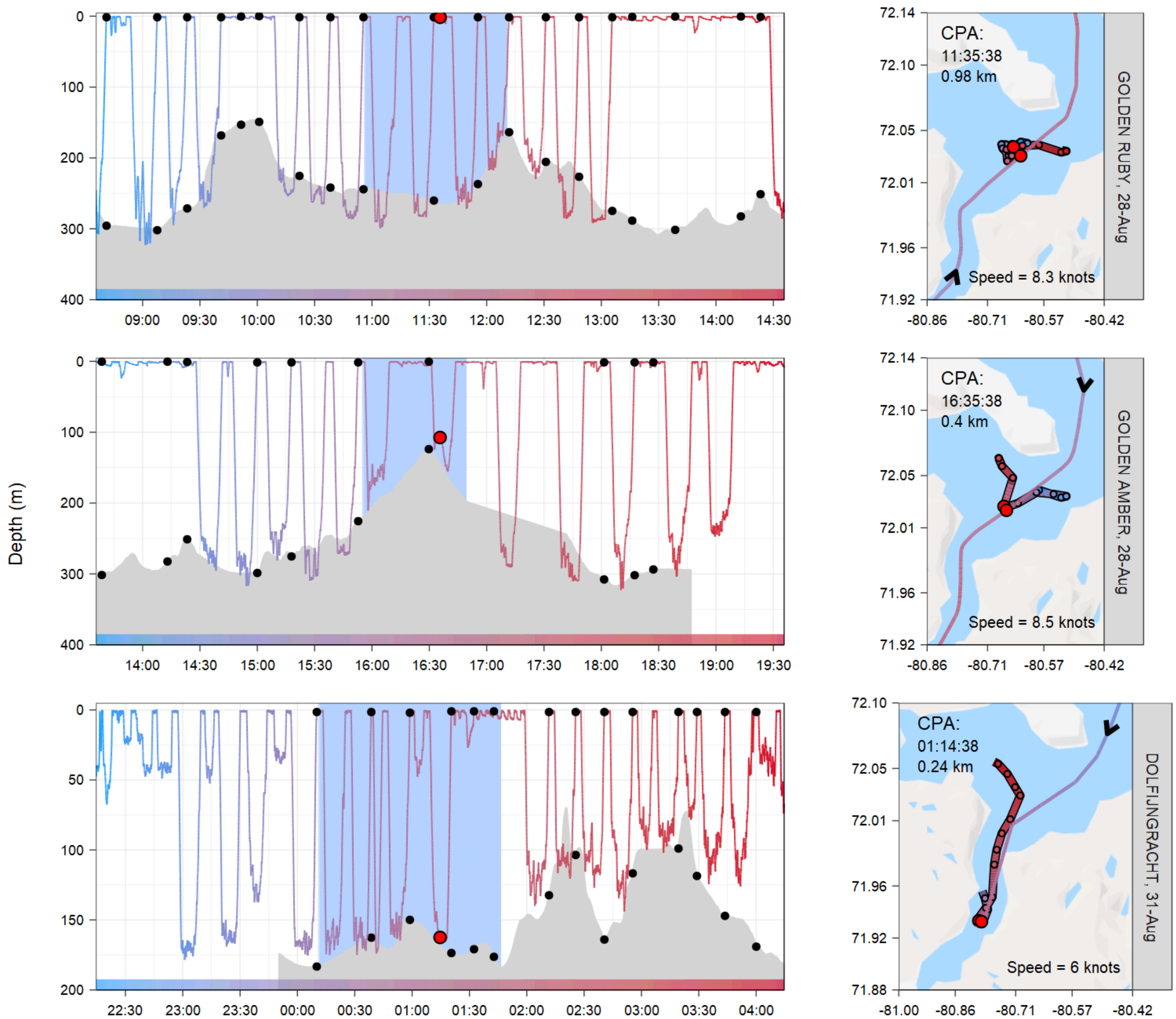

Figure 4-18: Movement and dive depths of NW02 relative to Project-related vessel transits 21- 23

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

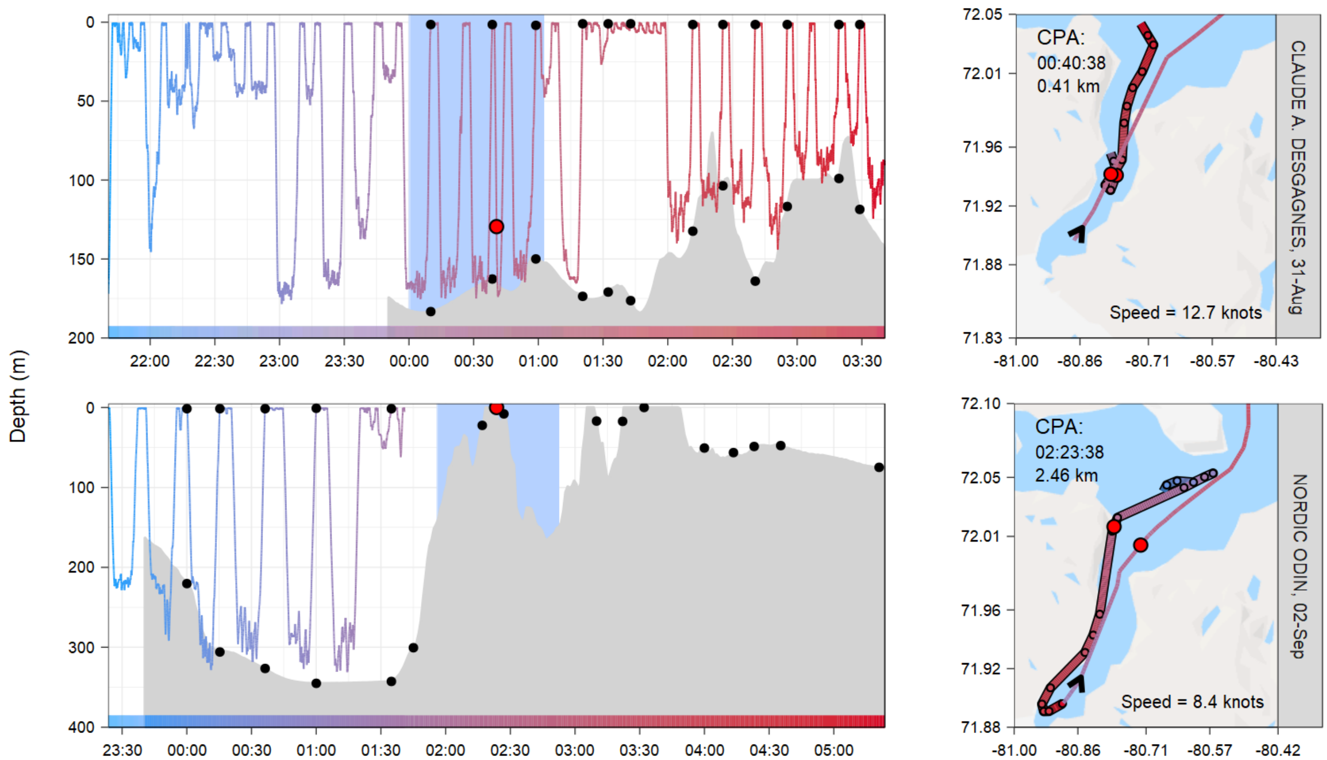

Figure 4-19: Movement and dive depths of NW02 relative to Project-related vessel transits 24-25

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

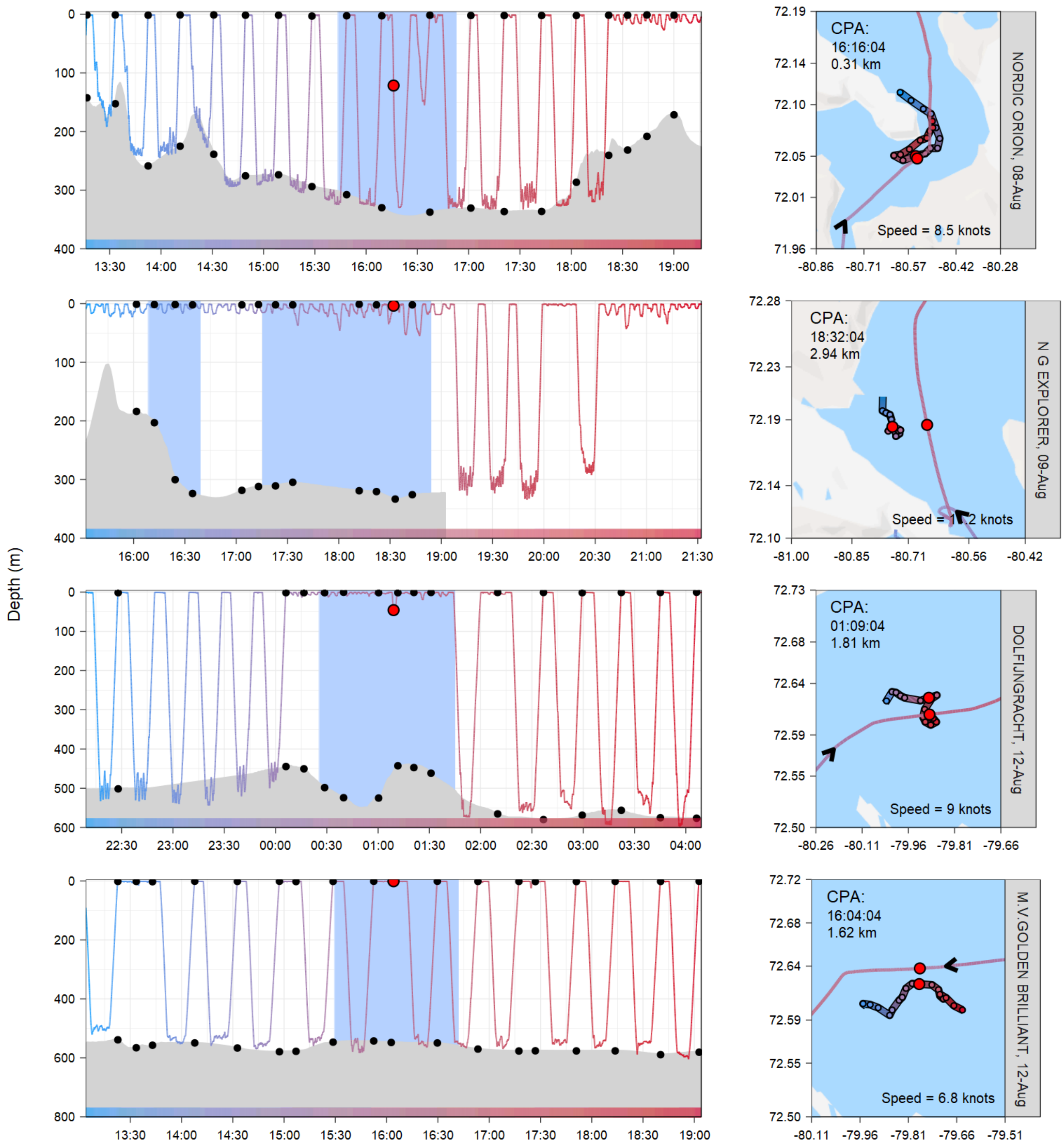

Figure 4-20: Movement and dive depths of NW03 relative to Project-related vessel transits 1-4

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

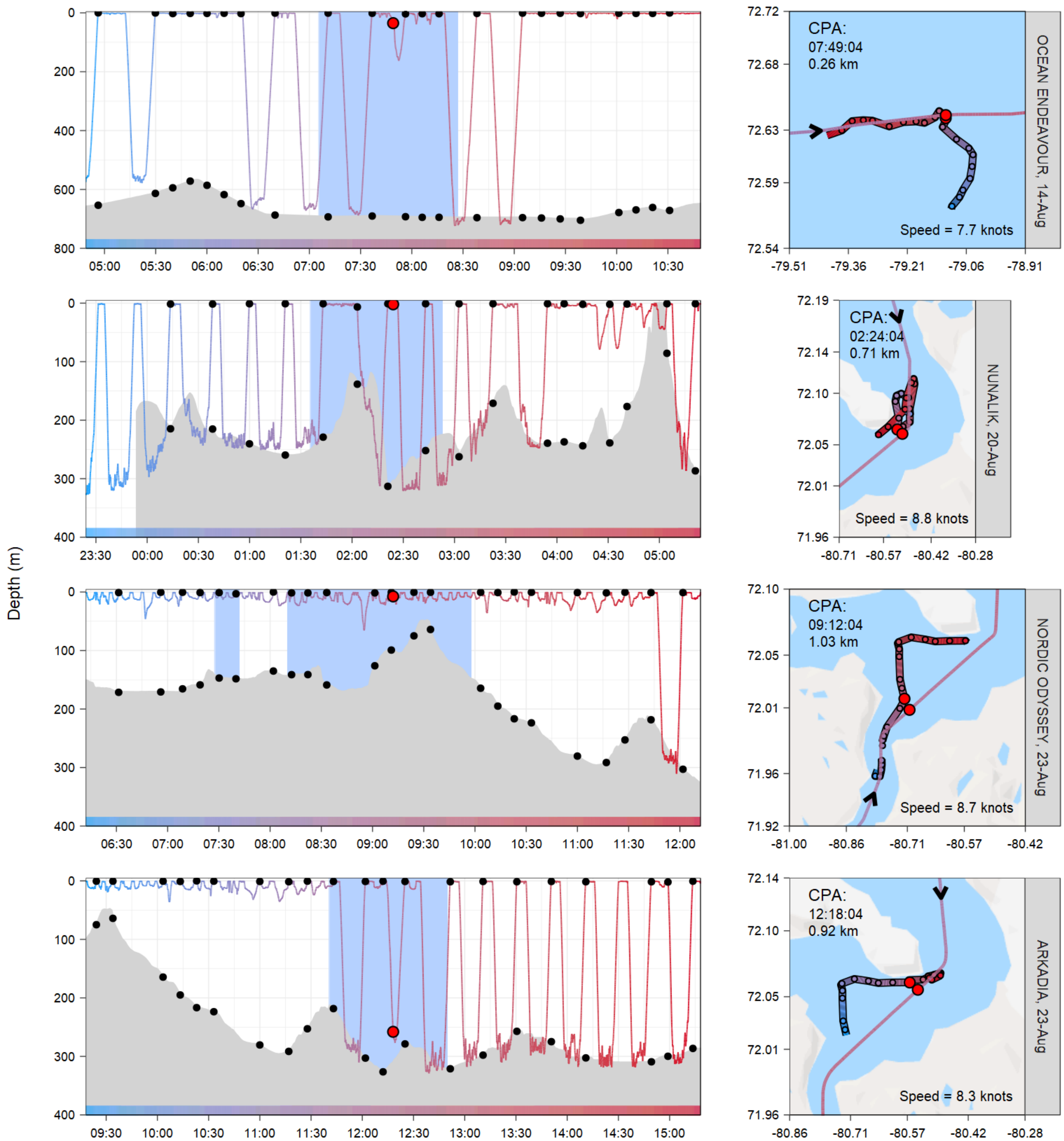

Figure 4-21: Movement and dive depths of NW03 relative to Project-related vessel transits 5-8

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

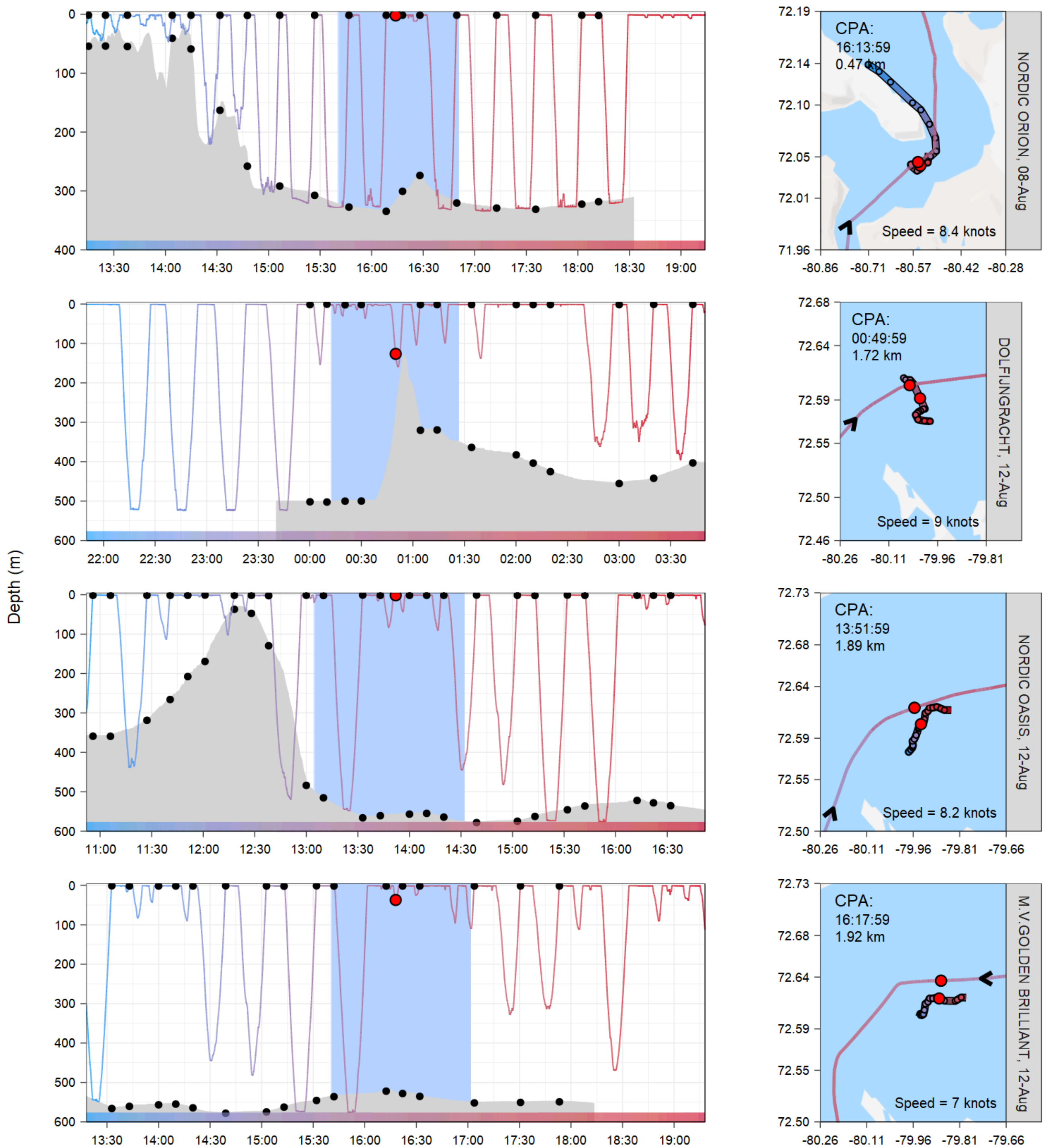

Figure 4-22: Movement and dive depths of NW04 relative to Project-related vessel transits 1-4

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

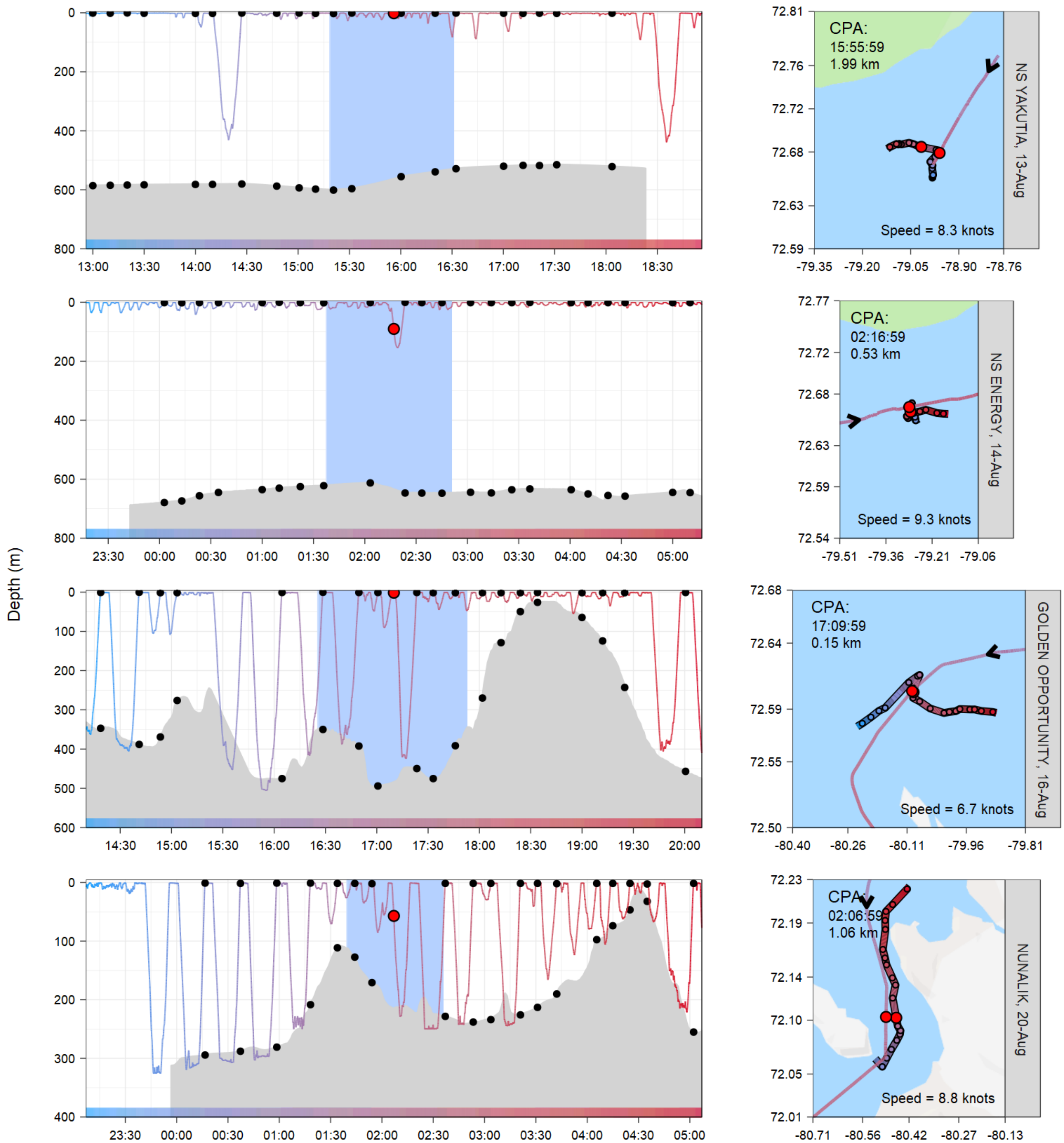

Figure 4-23: Movement and dive depths of NW04 relative to Project-related vessel transits 5-8

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel. Note that land depicted as green is part of Sirmilik National Park.

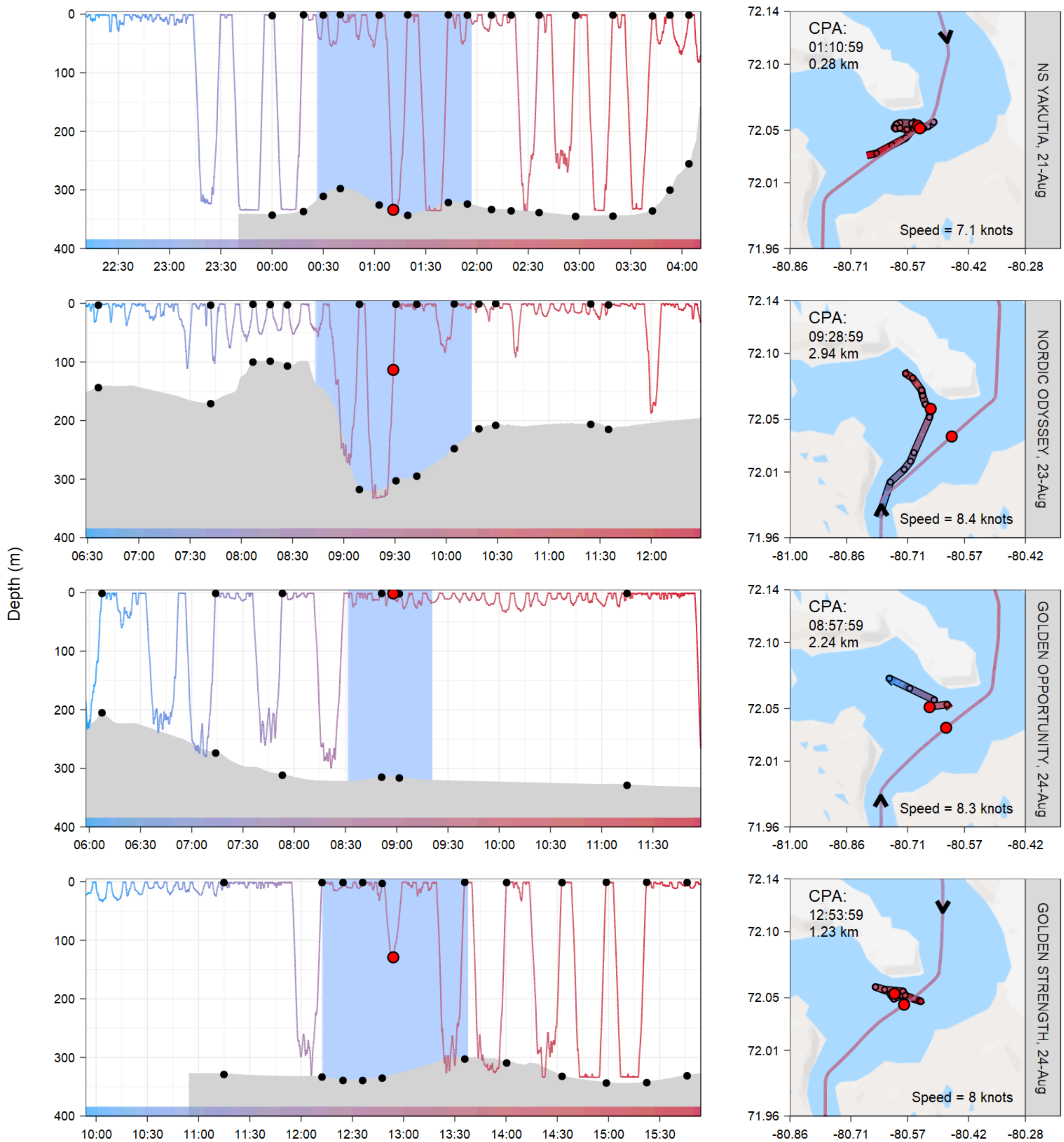

Figure 4-24: Movement and dive depths of NW04 relative to Project-related vessel transits 9-12

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

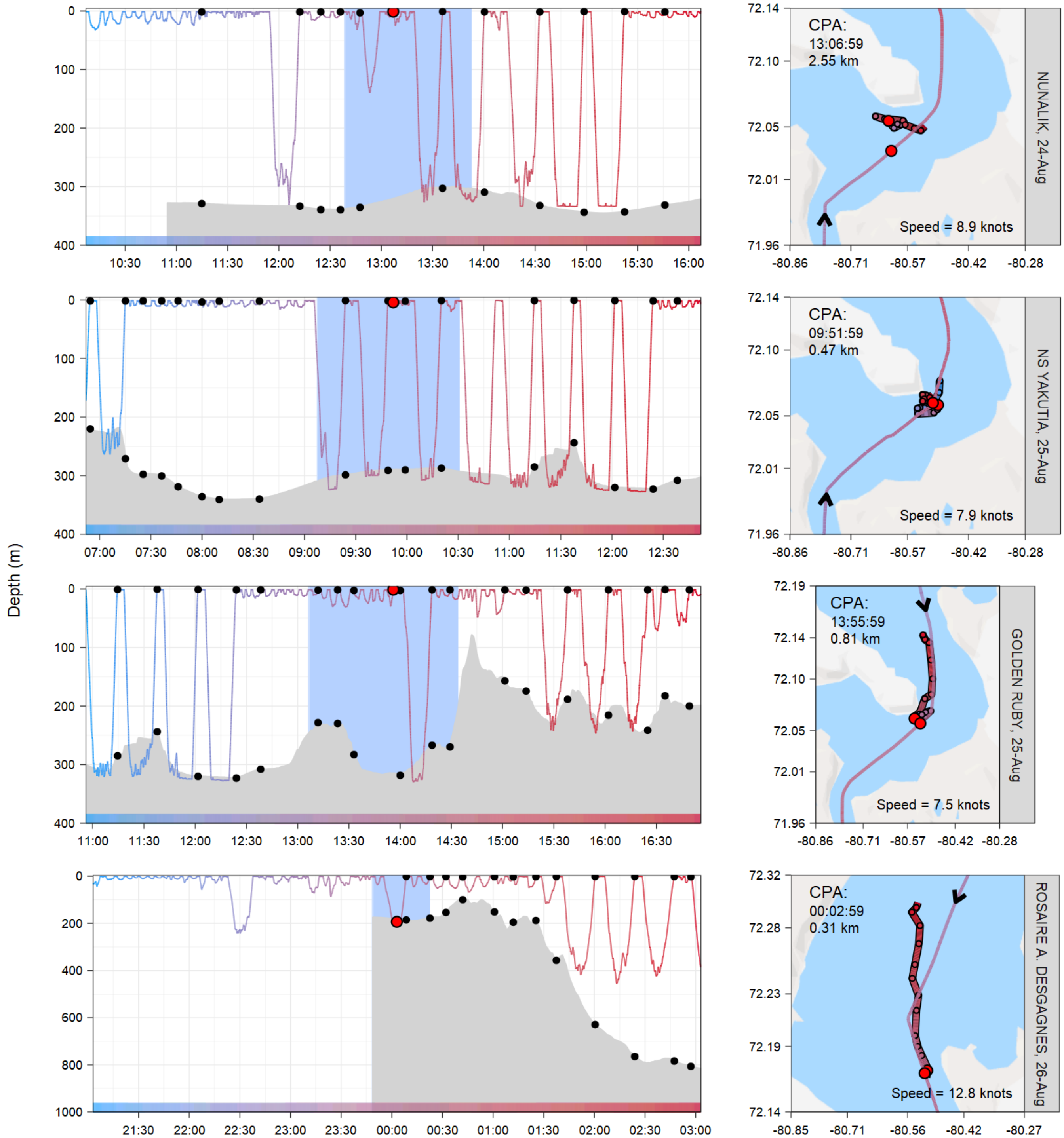

Figure 4-25: Movement and dive depths of NW04 relative to Project-related vessel transits 13-16

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

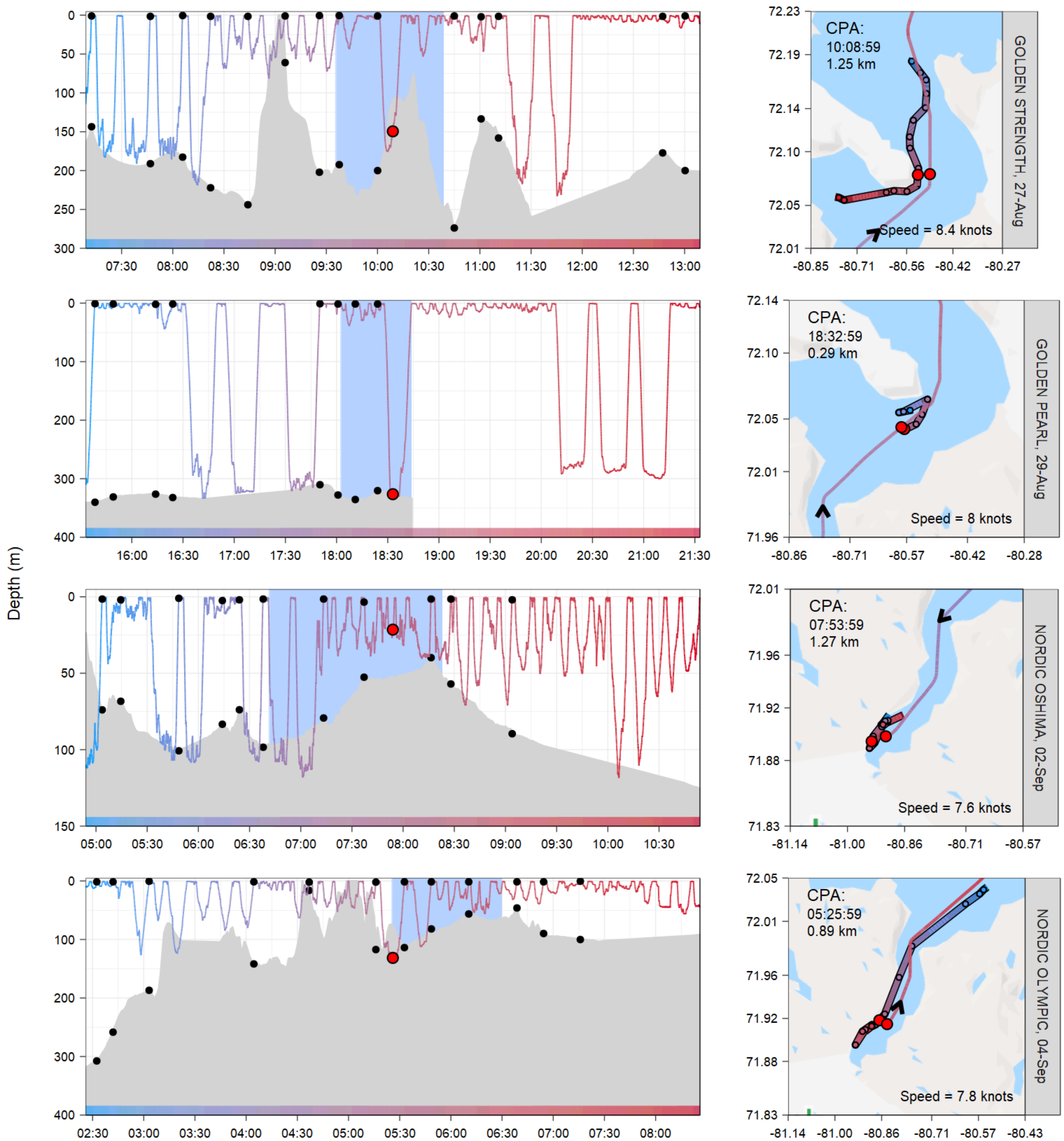

Figure 4-26: Movement and dive depths of NW04 relative to Project-related vessel transits 17-20

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

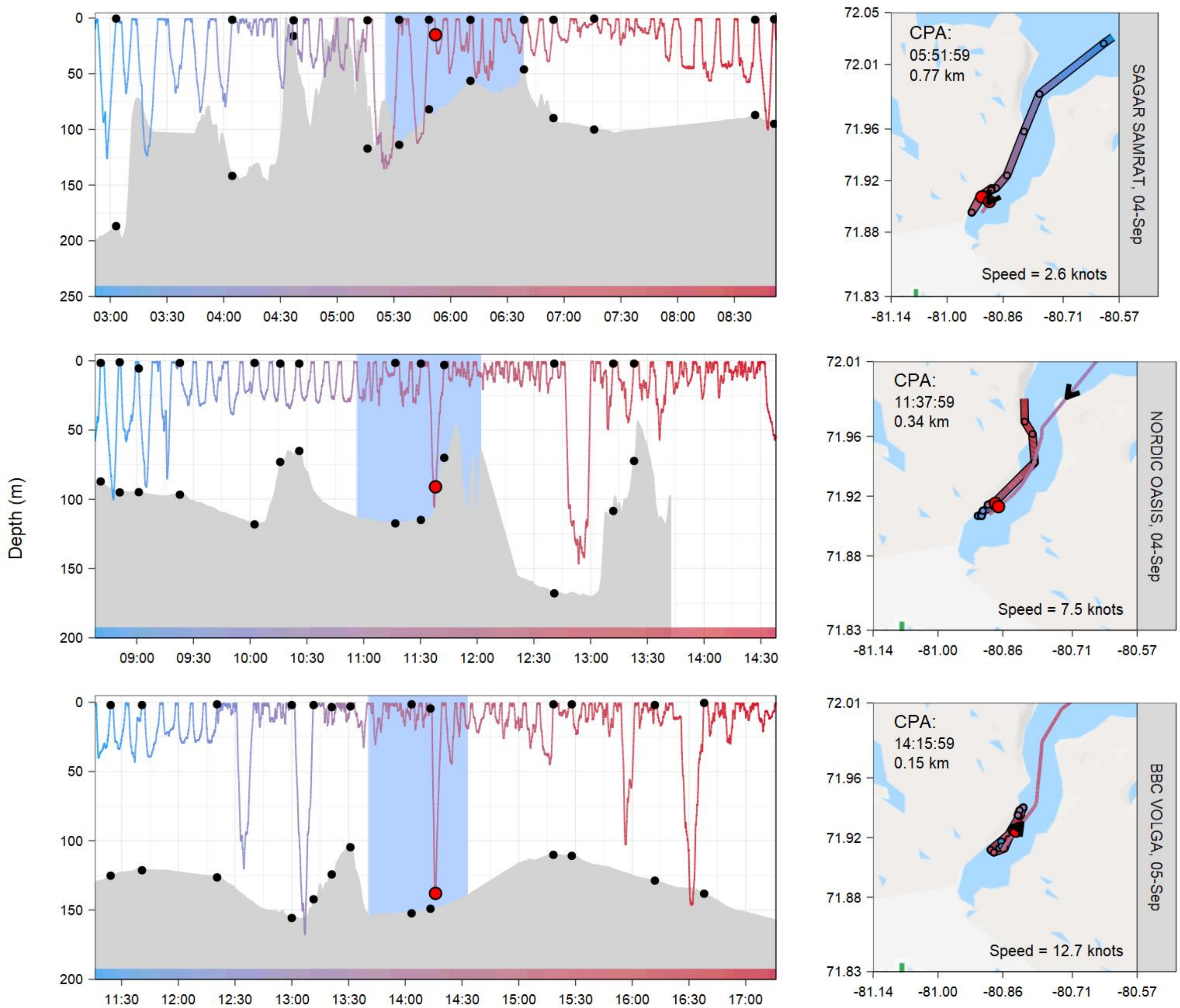

Figure 4-27: Movement and dive depths of NW04 relative to Project-related vessel transits 21-23

Note: Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position (grey ribbon) in the 3 h preceding and following the CPA. Black points show the timing of raw GPS time stamps, and red point identifies the timing of the CPA. Right panels depict narwhal and vessel tracks as thick and thin lines, also colour-coded as function of time. Black points on the narwhal track identify location of raw GPS data, and red dots identify narwhal and vessel locations at CPA. Blue ribbon on left panels identifies periods of time when narwhal were ≤10 km from the large vessel.

4.2.1.2 Surface Time

Of the four tagged narwhal, the two females (NW02 and NW03) spent higher percentages of time at the surface (≤7 m depth) overall when compared to the two males (median of 44% and 41% vs 39% and 40% respectively, Figure 4-28; Table 4-4). The proportion of time spent at the surface during non-exposure events (narwhal >10 km from vessel) was less than or equal to exposure events for all four narwhal tagged (Table 4-4).

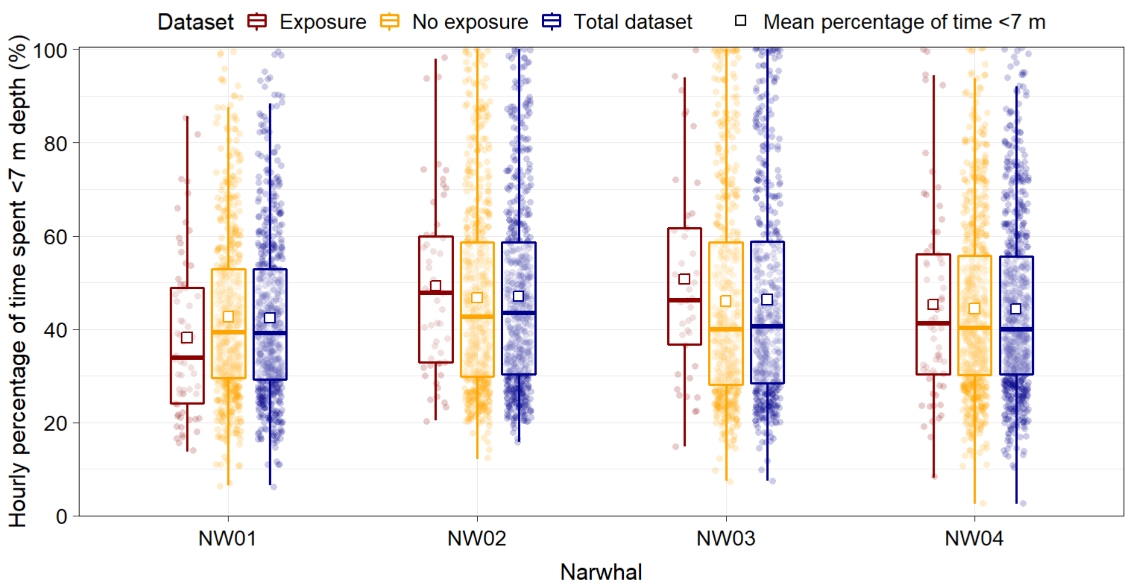

Figure 4-28: Observed proportion of time spent by narwhal at surface (0-7 m) under exposure, no exposure, and in the full dataset. Summary statistics (minimum, maximum, and median) are provided in Table 4-4.

Table 4-4: Summary statistics of narwhal surface time (percent of time spent ≤7 m out of each hour)

Dive Parameter	NW01	NW02	NW03	NW04
Total dataset				
Minimum	6	16	8	3
Median	39	44	41	40
Maximum	100	100	100	100
Exposure Zone (≤10 km):				
Minimum	14	21	15	8
Median	34	48	46	41
Maximum	86	98	100	100
Non-exposure Zone (>10 km):				
Minimum	6	12	8	3
Median	39	43	40	40
Maximum	100	100	100	100

Temporal differences were observed in the extent of surface time by individual narwhal (Figure 4-29). NW02 spent more time than average at the surface in Koluktoo and Milne South during the first two weeks of August, but less time than average during the last three weeks of the study period (15 Aug to 09 Sept). Surface time in Eclipse Sound was shown to be highly variable between individuals during the first two weeks of August.

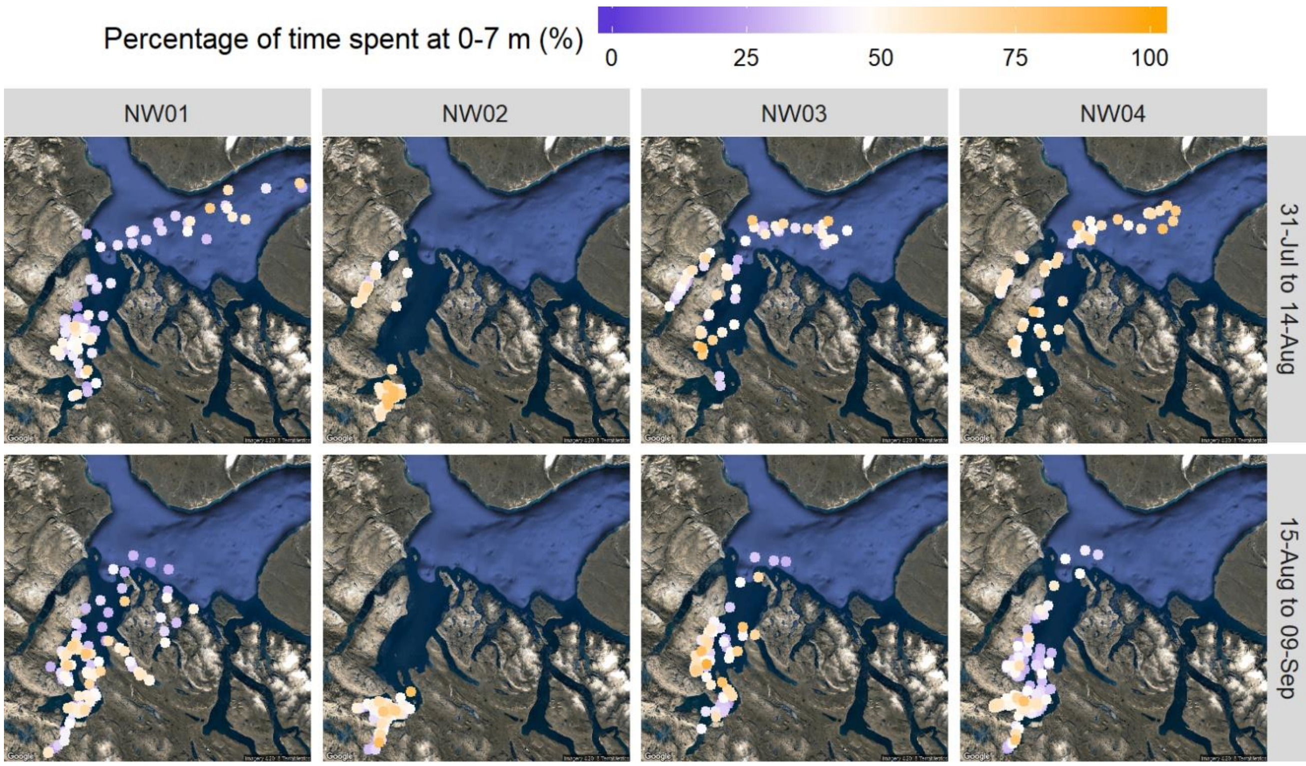

Figure 4-29: Percentage of time spent at 0-7 m depth, by tagged narwhal (and averaged by 4 h time periods). White colour represents mean time spent at 0-7 m depth across all animals.

The presence/absence of narwhal at surface (≤7 m) was analyzed using mixed generalized linear models. In the analysis, fixed effects included in the model were whether the narwhal was within an exposure zone (≤10 km from a large vessel), distance from large vessel if present (4th-degree polynomial), and whether the narwhal was at surface in the preceding 1 min period. The random effect was a random intercept by dive event, where events were dive data by each narwhal separated by 1 min or more. The effect of distance from a large vessel was statistically significant (P<0.001), while the overall effect of exposure was not (P=0.5). This result was due to the fact that the effect of exposure was only evident at close distances (≤2 km; Figure 4-30), whereas "Exposure" was associated with the full 10 km spatial extent. The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.434 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.454. Test statistics and coefficients estimates for the model are provided in Appendix B.

The estimated population-level probability of narwhal presence at surface when no large vessels were present within 10 km was 0.557, with individual-level predictions ranging between 0.512 and 0.589. This result was not significantly different from probabilities predicted when large vessels were within 2-10 km from narwhal (≥0.05 for all distances). At distances of 1 km and 0 km, the population-level prediction of probability of narwhal presence at surface decreased to 0.499 and 0.314, respectively. Both values were significantly different from predictions when no vessel was present within 10 km (P<0.001 at 0 km and P=0.004 at 1 km).

In summary, the 2017 dive data reject the null hypothesis that surface time does not significantly change during vessel-exposure events. The effect is only evident within 2 km from the vessels, where the probability of narwhal presence at surface decreases significantly (contradicting the freeze response theory and supporting the flight behaviour theory at close vessel distances).

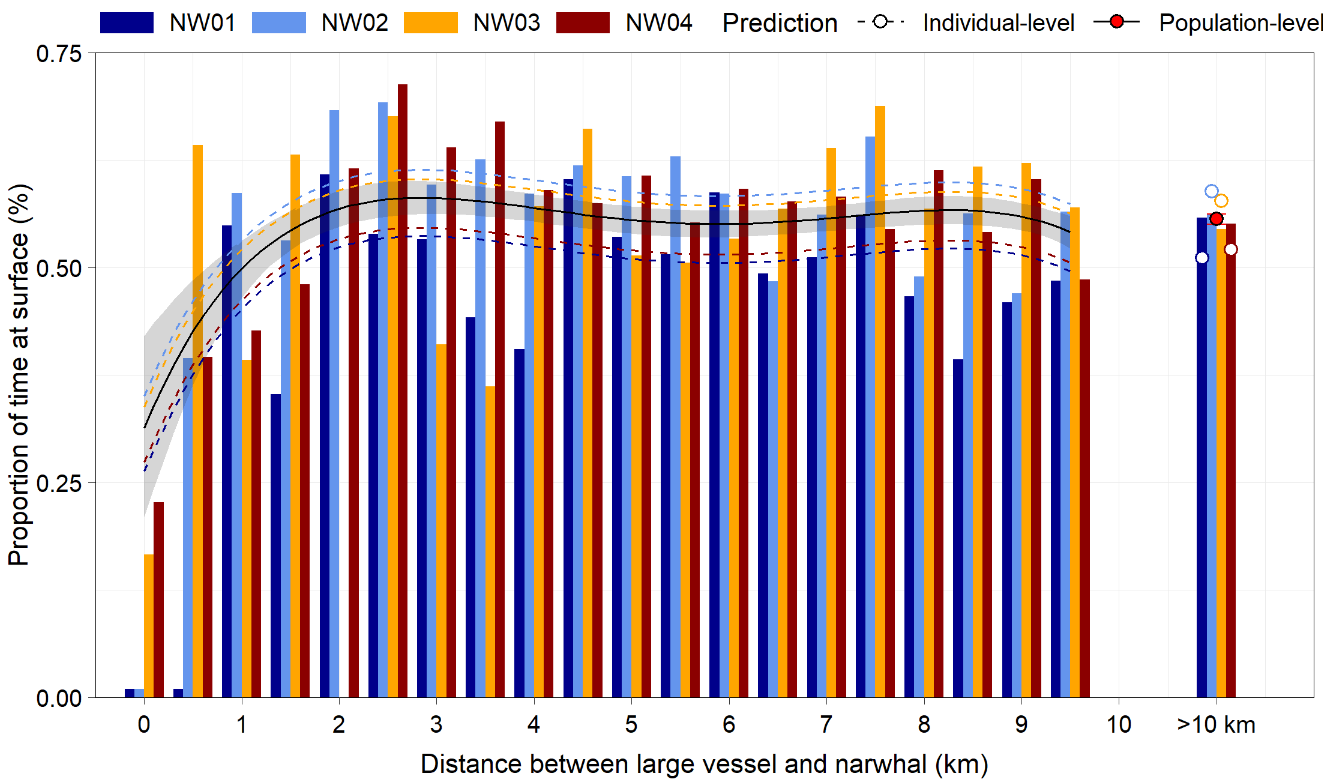

Figure 4-30: Proportion of narwhal depths at surface (0-7 m) relative to distance from large vessels in transit

4.2.1.3 Dive Rate

Tagged females (NW02 and NW03) demonstrated lower dive rates than males (NW01 and NW04; Figure 4-31; Table 4-5), with average dive rate in females ranging between 6.0 and 6.3 dives/h, and between 7.2 and 8.5 dives/h in males. NW01 generally had the highest dive rate across the four tagged individuals, with zero instances of ‘no diving’ (0 dives/h). Hourly periods of ‘no diving’ were observed for NW02 (n = 2), NW03 (n = 8), and NW04 (n = 3). Average dive rates observed during exposure events compared to non-exposure events were lower for NW01 and NW02, and higher for NW03 and NW04 (Figure 4-32).

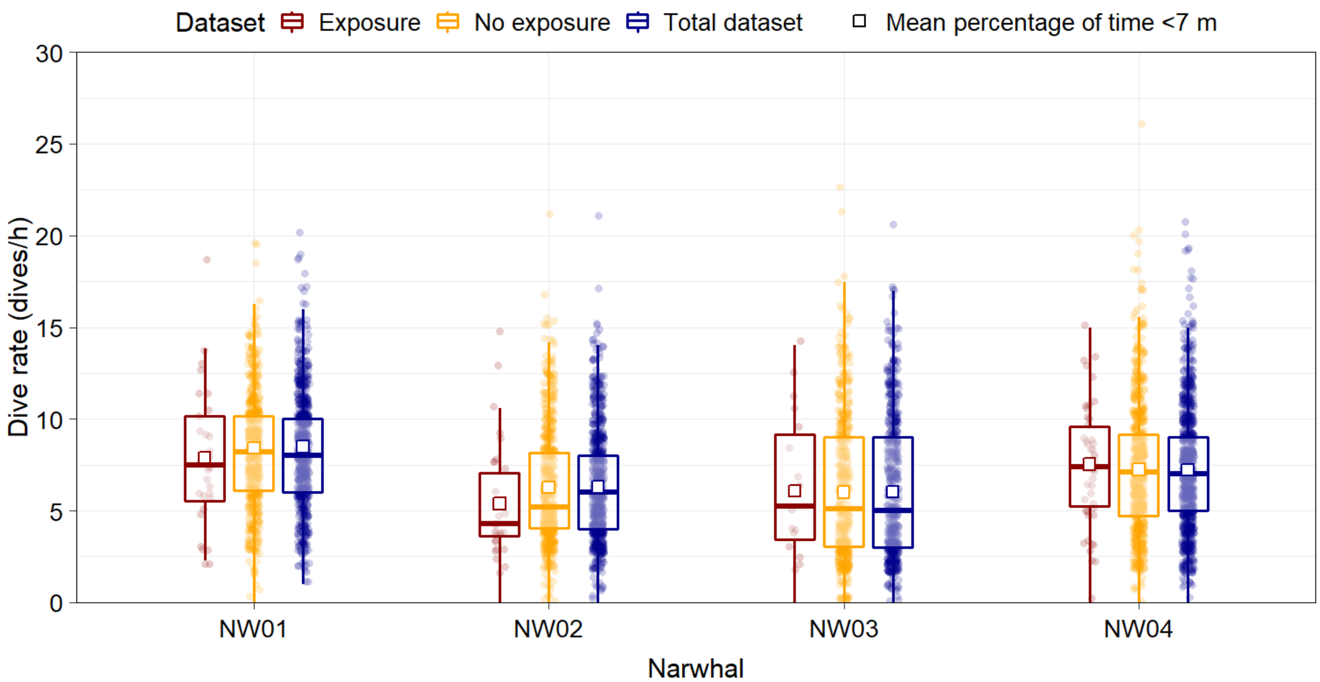

Figure 4-31: Observed hourly diving rate values (dives/h) by tagged narwhal. under exposure, no exposure, and in the full dataset. Summary statistics (minimum, maximum, and mean) are provided in Table 4-5.

Table 4-5: Summary statistics of narwhal dive rate (dives/h)

Dive Parameter	NW01	NW02	NW03	NW04
Total dataset				
Minimum	1.0	0.0	0.0	0.0
Average	8.5	6.3	6.0	7.2
Maximum	20.0	21.0	21.0	21.0
Exposure Zone (≤10 km):				
Minimum	2.3	0.0	0.0	2.3
Average	7.9	5.4	6.1	7.5
Maximum	19.0	14.5	14.0	15.0
Non-exposure Zone (>10 km):				
Minimum	0.0	0.0	0.0	0.0
Average	8.4	6.3	6.0	7.3
Maximum	19.3	21.4	22.5	26.0

Note: Exposure and non-exposure statistics were calculated on values that were pro-rated to capture hourly dive rate after removal of dive data with no associated GPS positions. In some cases, this may result in an average dive rate that is inconsistent with the overall (total) dataset statistics (e.g., NWO1).

Maximum dive rate within a 4 h period was shown to be variable between individuals, strata, and study period (Figure 4-32). Highest values were observed in the vicinity of Bruce Head and Koluktoo Bay, and primarily during the latter weeks of the study period. Dive rates in Eclipse Sound were low compared to other strata. This was likely due to the higher occurrence of deep dives in this area (Figure 4-35).

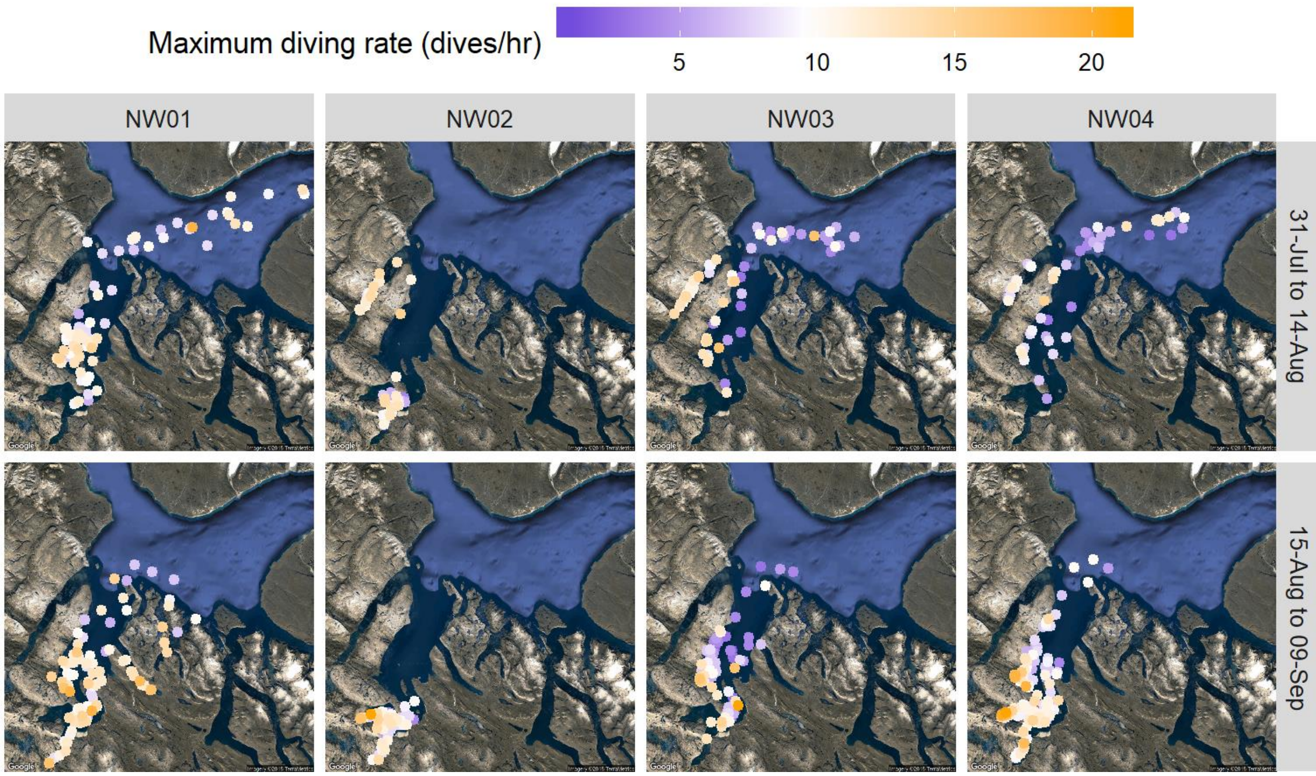

Figure 4-32: Maximum dive rate (dives/h) presented by 4-h period. White circles represent mean values for maximum dive rate for all four tagged narwhal

To assess the effect of distance between large vessels and narwhal on diving rate, the analysis of dive rate would have to be performed as a logistic regression of presence/absence of narwhal below diving depth (i.e., 7 m). As such, it would be the exact inverse of the analysis performed to assess the effect of large vessels on surface time (Section 4.2.1.1). Therefore, the inverse of the findings detailed for surface time analysis holds true for dive rate. Specifically, the effect of distance from a large vessel has a statistically significant effect on dive rate (P=0.002). The effect of exposure on dive rate is only evident at close distances (Figure 4-33). The estimated population-level probability of narwhal presence below minimum diving depth (i.e., 7 m) when no large vessels were present within 10 km was 0.443 (calculated as 1.0 - 0.557, where 0.557 is the probability of observing narwhal at surface, as detailed in Section 4.1). This result was not significantly different from probabilities predicted when large vessels were within 2-10 km from narwhal (P≥0.05 for all distances). At distances of 1 km and 0 km, the population-level prediction of probability of narwhal diving increased to 0.501 and 0.686, respectively. Both values were significantly different from predictions when no vessel was present within 10 km (P<0.001 at 0 km and P=0.004 at 1 km).

In summary, the 2017 dive data reject the null hypothesis that diving rate does not significantly change during vessel-exposure events. The effect is only evident within 2 km from the vessels, where the probability of narwhal presence at surface decreases significantly (contradicting the freeze response theory and supporting the flight response theory).

4.2.1.4 Bottom Dive Depth

Deep-diving marine mammals are limited in their foraging time because of oxygen requirements at the surface. In general, surface time increases with dive duration. Longer dives increase the likelihood of animals locating and capturing prey (Kooyman and Ponganis 1998). Thus, diving marine mammals must offset the high costs of diving by foraging on lipid-rich and/or abundant prey in order to optimize their energy budget (Bluhm and Gradinger 2008; Davis 2014). Because of this selectivity, animals may focus on specific areas of the water column and this can indicate where foraging is focused (Laidre et al. 2003; Hauser et al. 2015). Narwhal are specially adapted for deep diving (Laidre et al. 2003) and are known to forage heavily on Greenland halibut (Laidre and Heide-Jørgensen 2005; Watt et al. 2013), which are lipid-rich benthic prey (Lawson et al. 1998). Because deep diving is so energetically expensive, it is often assumed that targeted deep dives indicate foraging by narwhal (Laidre et al. 2003; Robinson et al. 2012). Therefore, dives close to the bottom (75%–100% of total bottom depth) were used as a proxy for regions important for narwhal foraging.

The most common dives demonstrated by tagged narwhal overall were shallow dives (<25% of the available depth), followed by bottom dives (≥75% of the available depth) (Figure 4-33). The proportional use of different dive depths varied between individuals, with shallow dives observed more frequently in NW01 (male) and NW03 (female) (~65% of all dives) than in NW02 (female) and NW04 (male) (~43% of all dives). Of the four tagged narwhal, NW01 demonstrated the lowest proportion of bottom dives (~18% of all dives) while NW02 demonstrated the highest proportion of bottom dives (~37%). For all tagged narwhal, use of the mid-water column (25-49% and 50-74% depth intervals) was least common, ranging from 4% to 16% of total dives.

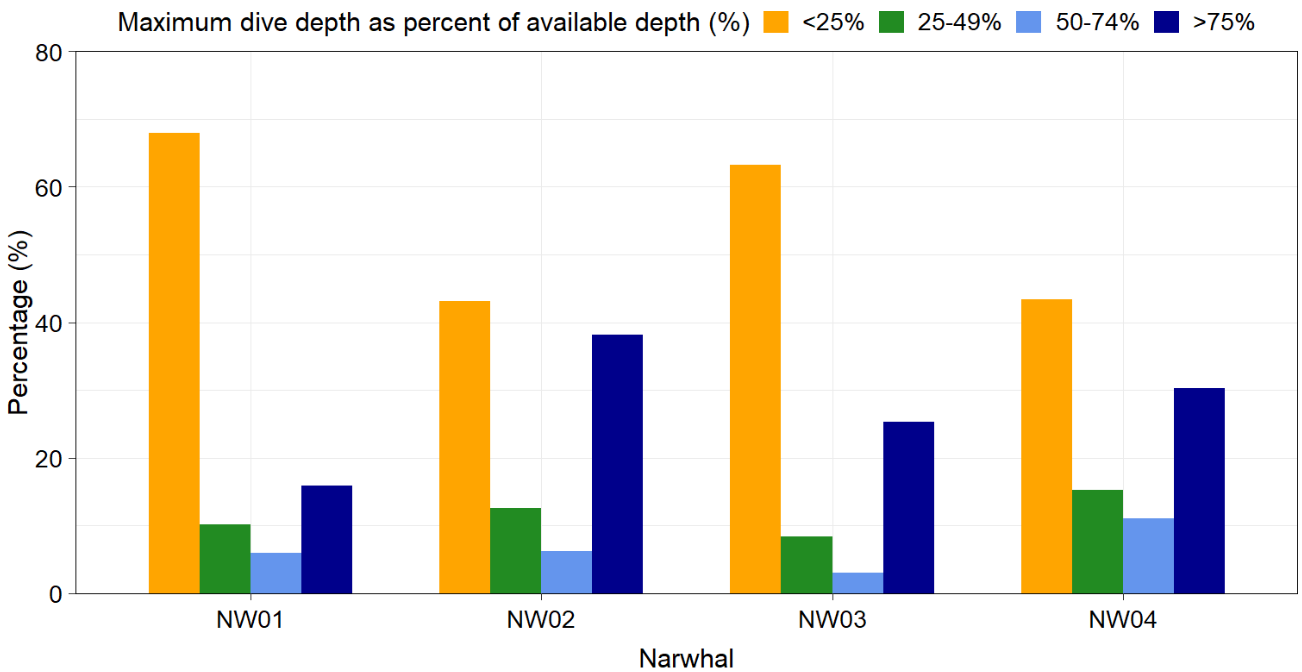

Figure 4-33: Observed maximum dive depth in proportion to available depth (%)

Of the four tagged individuals, NW02 (female) demonstrated the lowest maximum dive depth (335 m) throughout the study period. Maximum depth for the other three narwhal ranged from 745 to 881 m (Table 4-6). The lower observed maximum dive depth for NW02 was likely due to its movements being largely restricted to Tremblay Sound and south of Bruce Head (Figure 4-35), where available depths are generally shallower. Median dive depths were slightly greater for all whales during non-exposure events with the exception of NW04 (Table 4-6). However, when looking at the proportion of available depth, median dive depth was consistently greater for non-exposure events (Figure 4-34).

Maximum dive depth relative to available depth (averaged over 4 h periods) indicated that narwhal conducted bottom dives throughout the Study Area, suggesting that deep water foraging occurs throughout the Eclipse Sound summering ground (Figure 4-35). Bottom dives varied substantially amongst individuals both temporally and geographically. For instance, NW01 was unique in that it did not conduct a single bottom dive during its first two weeks of deployment despite occupying most strata during this time. It then undertook deep dives in all strata for the remainder of its deployment period. NW04 performed bottom dives in all strata visited during its first two weeks of deployment, but then restricted bottom dives to areas around Bruce Head and Koluktoo Bay for the remainder of the study period. NW03 engaged in bottom dives in all strata visited throughout the entire study period. In Tremblay Sound, narwhal remained close to the surface, with few dives to the bottom. Deep dives were recorded for NW01 in Eskimo Inlet after 15 August.

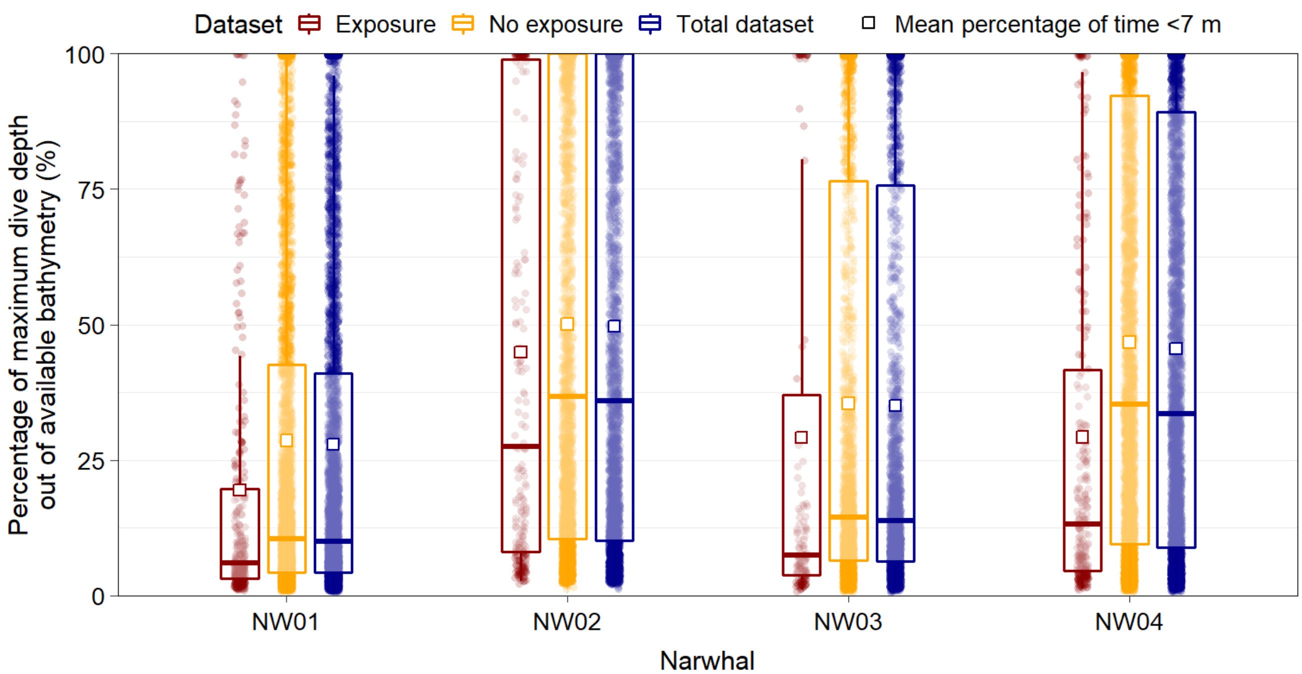

Figure 4-34: Observed maximum dive depth in proportion to available depth under exposure, no exposure, and in the full dataset. Summary statistics (minimum, maximum, and median) are provided in Table 4-6.

Table 4-6: Summary statistics of maximum dive depth (m), where (%) identifies percentage of available depth

Dive Parameter	NW01	NW02	NW03	NW04
Total dataset				
Median	14.8 (10%)	30.5 (36%)	19.5 (14%)	25.0 (34%)
Maximum	764.8 (100%)	335.0 (100%)	880.5 (100%)	745.5 (100%)
Exposure Zone (≤10 km):				
Median	14.2 (6%)	24.5 (27%)	16.2 (7%)	25.0 (13%)
Maximum	728.8 (100%)	334.0 (100%)	723.5 (100%)	576.5 (100%)
Non-exposure Zone (>10 km):				
Median	14.8 (10%)	31.0 (37%)	19.5 (14%)	25.0 (35%)
Maximum	764.8 (100%)	335.0 (100%)	880.5 (100%)	745.5 (100%)

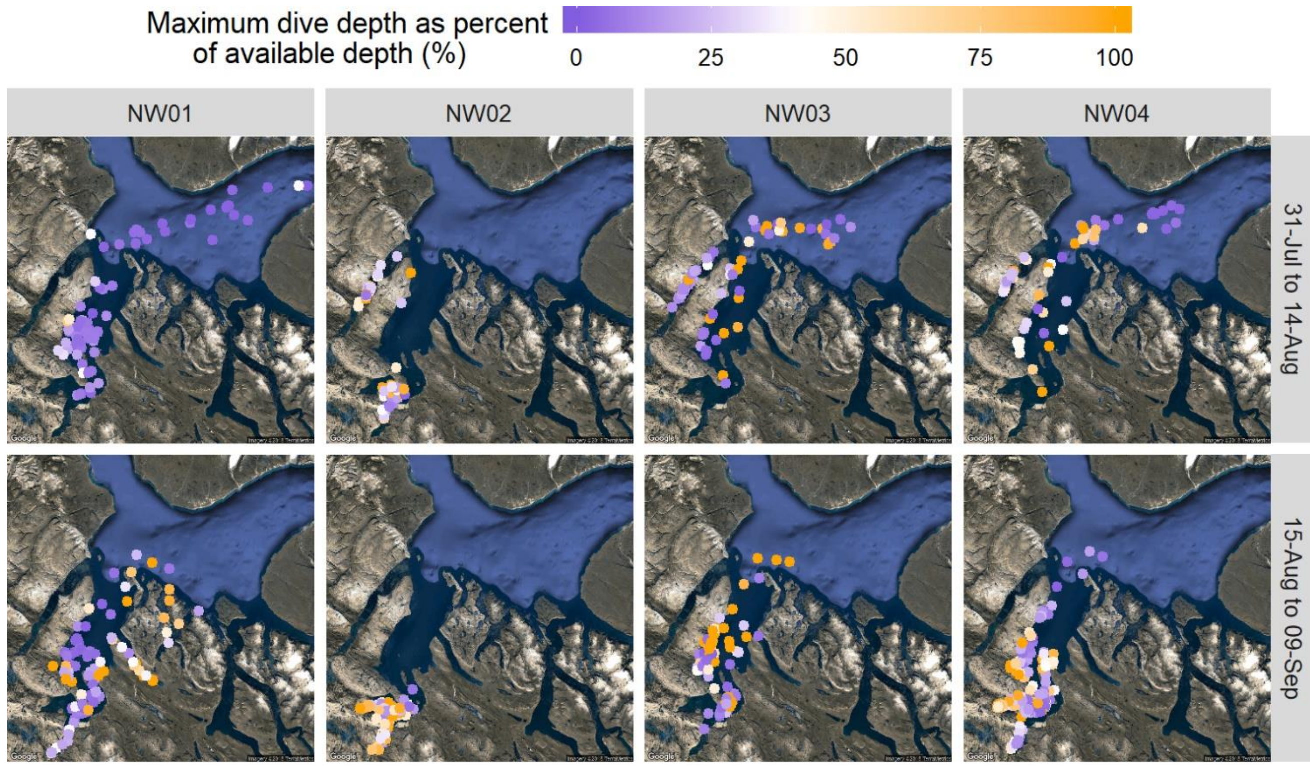

Figure 4-35: Maximum dive depth relative to available depth (%). Mean proportion of available depth across all animals is shown in white

Maximum dive depth was analyzed using mixed logistic models as a presence/absence of deep dives (i.e., whether the dive was deeper than 75% of the available bathymetry depth; Figure 4-36). In the analysis, fixed effects included in the model were whether the narwhal was within an exposure zone (≤10 km from a large vessel), distance from a large vessel if present (km; 4th-degree polynomial), distance from shore (m), available bathymetry depth (m), whether the preceding dive was deep, and an interaction between distance from large vessel and whether the preceding dive was deep. The random effect was a random intercept by narwhal. As deep dives are assumed to be foraging dives in which narwhal dive to the bottom in search of bottom-dwelling fish (Laidre et al. 2003; Robinson et al. 2012), the effect of whether the preceding dive was deep allowed separating the data into two types of behaviour – 1) repeated deep dives (i.e., potentially feeding behaviour) and 2) a deep dive following a non-deep dive (potentially escape behaviour). The fixed-effect interaction between distance from a large vessel and whether the preceding dive was deep was found to be significant (*P*<0.001). The effects of bathymetry and distance from shore were also significant (*P*<0.001 and *P*=0.014, respectively). The main effect of exposure was not significant (*P*=0.3), due to the fact that the effect of exposure was only evident at close distances (Figure 4-37), whereas "Exposure" was associated with the full 10 km spatial extent. The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.261 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.277. Test statistics and coefficients estimates for the model are provided in Appendix B.

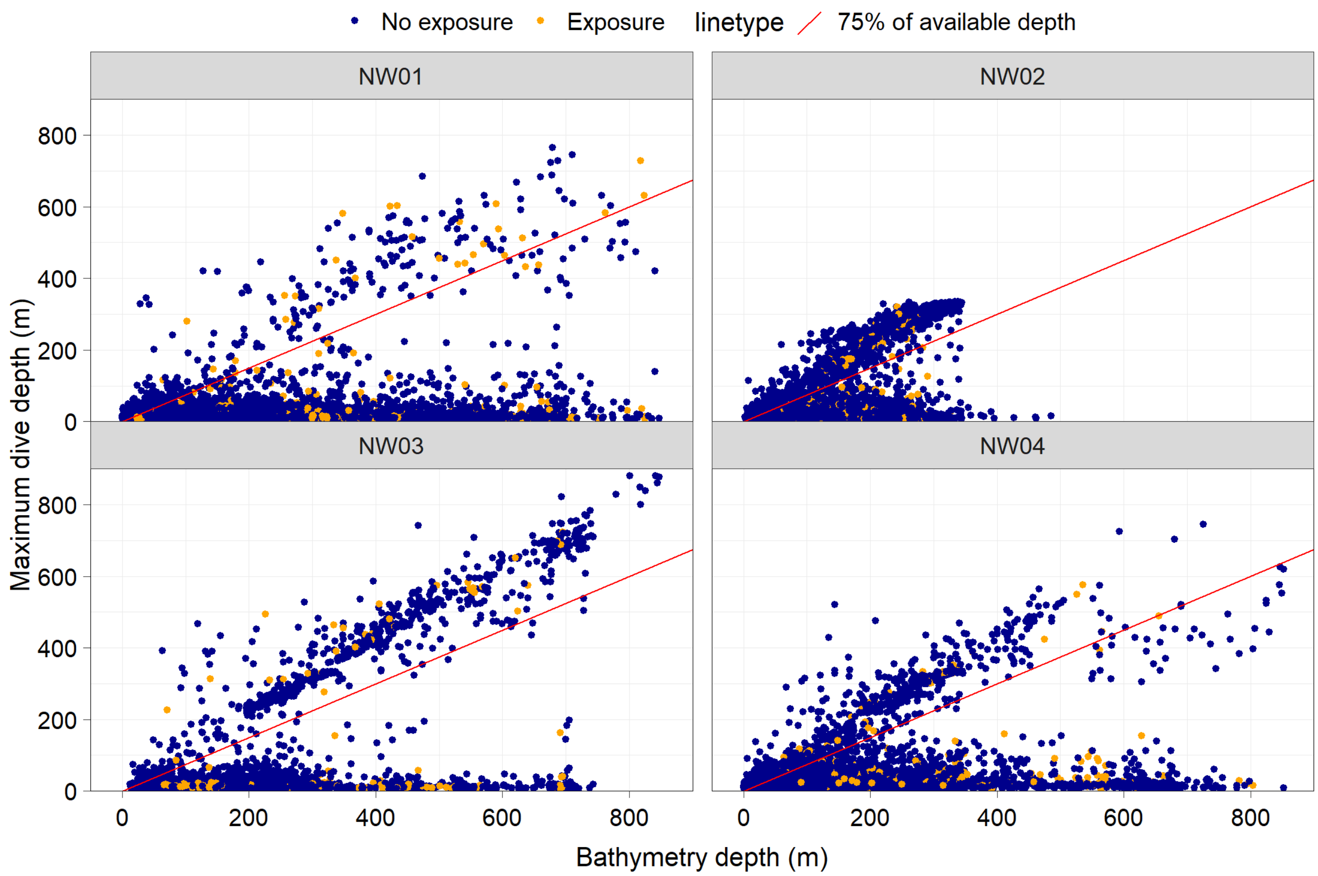

Figure 4-36: Maximum dive depth relative to available depth, with the cutoff for 75% of available depth

At representative values of mean distance from shore (2 km) and mean available bathymetry depth (200 m), the estimated population-level probabilities of deep dives when no large vessels were present within 10 km were 0.627 and 0.137 when preceding dive was deep and not deep, respectively (Figure 4-37). When narwhal were not feeding (i.e., preceding dive was not deep), the probability of a deep dive when no vessels were present within 10 km from the narwhal (0.137) was not significantly different from probabilities predicted when large vessels were within 2-10 km from narwhal ($P \geq 0.4$ for all distances; Table 4-7). At distances of 1 km and 0 km, the population-level prediction of probability of deep dives increased to 0.357 and 0.888, respectively. That is, non-feeding narwhal had a low probability of exhibiting deep dives, unless a large vessel was within 2 km from the narwhal (possible flight response; Figure 4-37).

When narwhal exhibited feeding behaviour (i.e., preceding dive was also deep), the probability of a deep dive when no vessels were present within 10 km from the narwhal (0.627) was not significantly different from probabilities predicted when large vessels were within 6-10 km from narwhal ($P > 0.8$ for all distances; Figure 4-37; Table 4-7). At distance of 1-5 km from a large vessel, the probability of a deep dive following another deep dive decreased significantly ($P \leq 0.041$), to a low of 0.131 at 2 km from the vessel. When the vessel was closer than 2 km to the narwhal, the probability of a deep dive increased, with a predicted value of 0.882 at 0 km from the vessel. That is, feeding narwhal generally ceased the pattern of sequential deep dives when a vessel was at an intermediate distance (2-5 km), but were likely to perform a deep dive when the vessel was in close proximity (<2km), supporting both freeze and flight response theories (Figure 4-37).

Note that the model was based on limited data at close distances between narwhal and large vessels, especially when preceding dives were deep. Much of the data informing the model at these close distances came from narwhal NW02 and NW04, with very little information available from the other two tagged narwhal. Therefore, model results should be interpreted with caution.

In summary, the 2017 dive data support the alternate hypothesis that the occurrence of bottom dives changes significantly during vessel-exposure events. However, deep dive data within the 10 km exposure zone were limited, resulting in high uncertainty and possible noise when relating deep dive behaviour to distance from vessels.

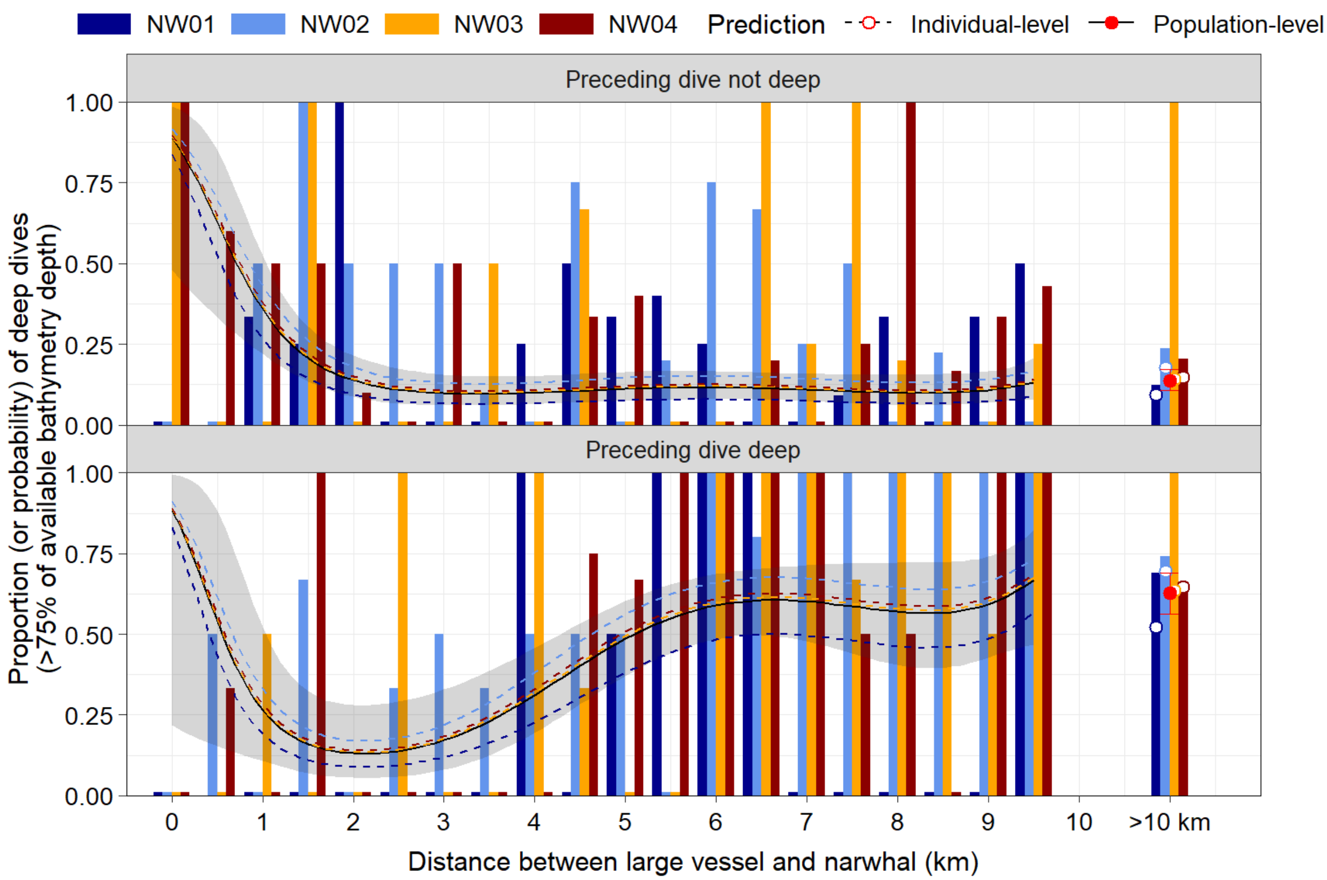

Figure 4-37: Proportion of observed bottom dives as a function of bathymetry (in 500 m bins; bars) and predicted probability of deep dives (lines) for individual narwhal (dashed) and for an average narwhal (solid line). The ribbon represents 95% confidence interval for population-level predictions

Table 4-7: Multiple comparisons between no-exposure predictions and predictions at specific distances between narwhal and large vessels; statistically significant values are shown in bold

Distance from Large Vessel (km)	*P* values of Multiple Comparisons to No-exposure	
	Preceding Dive not Deep	Preceding Dive Deep
0	**0.003**	0.908
1	**0.001**	**0.041**
2	1.000	**<0.001**
3	0.521	**<0.001**
4	0.402	**<0.001**
5	0.711	**0.031**
6	0.785	0.878
7	0.581	0.988
8	0.513	0.946
9	0.732	0.992

4.2.1.5 Time at Depth

On average, tagged females (NW02 and NW03) spent longer periods on the bottom of each dive (within 20% of maximum dive depth) than males (NW01 and NW04; Figure 4-38; Table 4-8), with mean bottom time ranging from 2.4 to 2.5 min for females, and from 1.8 to 1.9 min for males. Conversely, the maximum period spent on the bottom of a dive was higher in males than females, with maximum bottom time ranging from 15.0 to 17.1 min in males, and from 12.8 to 13.0 min for females (Table 4-8). Overall, mean time spent at the bottom of each dive was similar between exposure and non-exposure events for each tagged animal (Table 4-8). Maximum time spent at the bottom of each dive was higher during non-exposure events for all four whales.

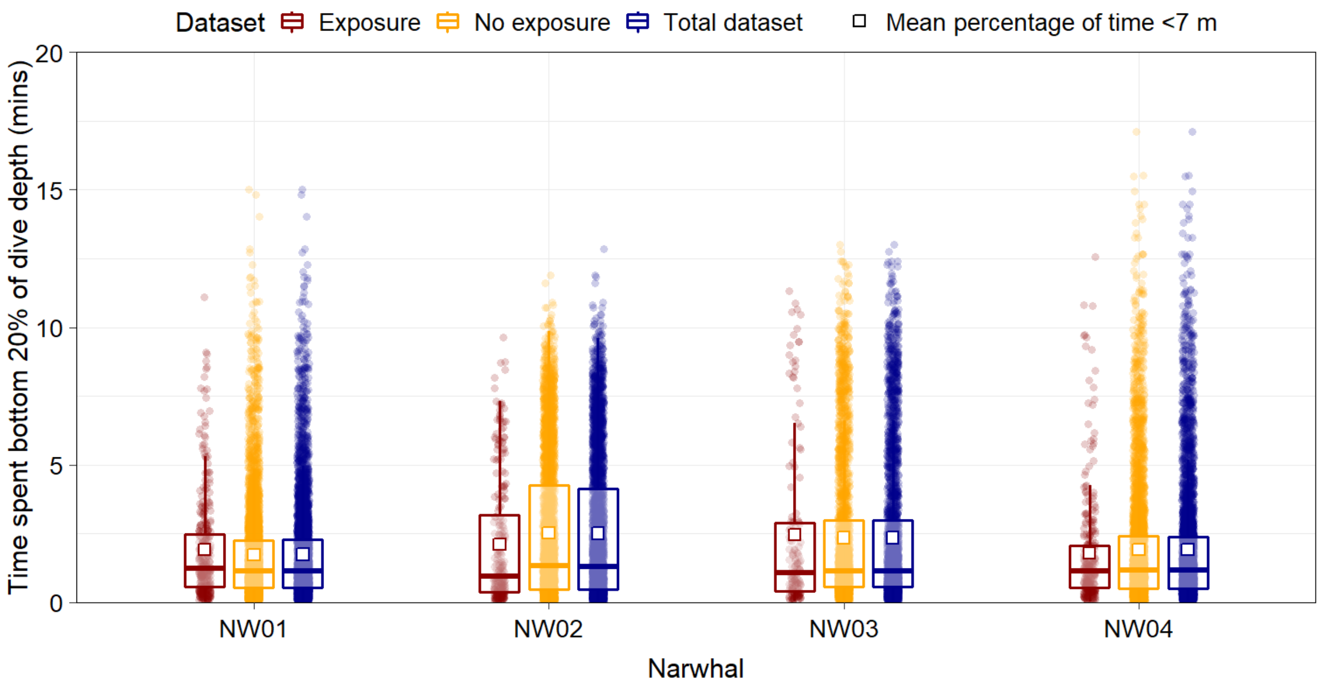

Figure 4-38: Observed time (min) spent at bottom of dive (within 20% of maximum dive depth), under exposure, no exposure, and in the full dataset. Summary statistics (minimum, maximum, and mean) are provided in Table 4-8.

Table 4-8: Summary statistics of time (min) spent at bottom of dive (within 20% of maximum dive depth)

Dive Parameter	NW01	NW02	NW03	NW04
Total dataset				
Minimum	0.03	0.02	0.02	0.02
Mean	1.8	2.5	2.4	1.9
Maximum	15.0	12.8	13.0	17.1
Exposure Zone (≤10 km):				
Minimum	0.03	0.03	0.05	0.03
Mean	1.9	2.1	2.5	1.8
Maximum	11.0	9.6	11.3	12.6
Non-exposure Zone (>10 km):				
Minimum	0.03	0.02	0.02	0.02
Mean	1.7	2.5	2.4	1.9
Maximum	15.0	11.9	13.0	17.1

In general, dives made by narwhal close to Milne Port and throughout Tremblay Sound had short bottom duration (Figure 4-39). Dives made by narwhal near Koluktoo and Bruce Head often had longer bottom duration (e.g., NW02 and NW04), and those made in Eclipse Sound often (but not always) had longer bottom duration (e.g., NW01 and NW03). For NW03, this coincided with deep dives, where maximum dive depth was 100% of the available bathymetry depth (Figure 4-35) and lower dive rate (Figure 4-32).

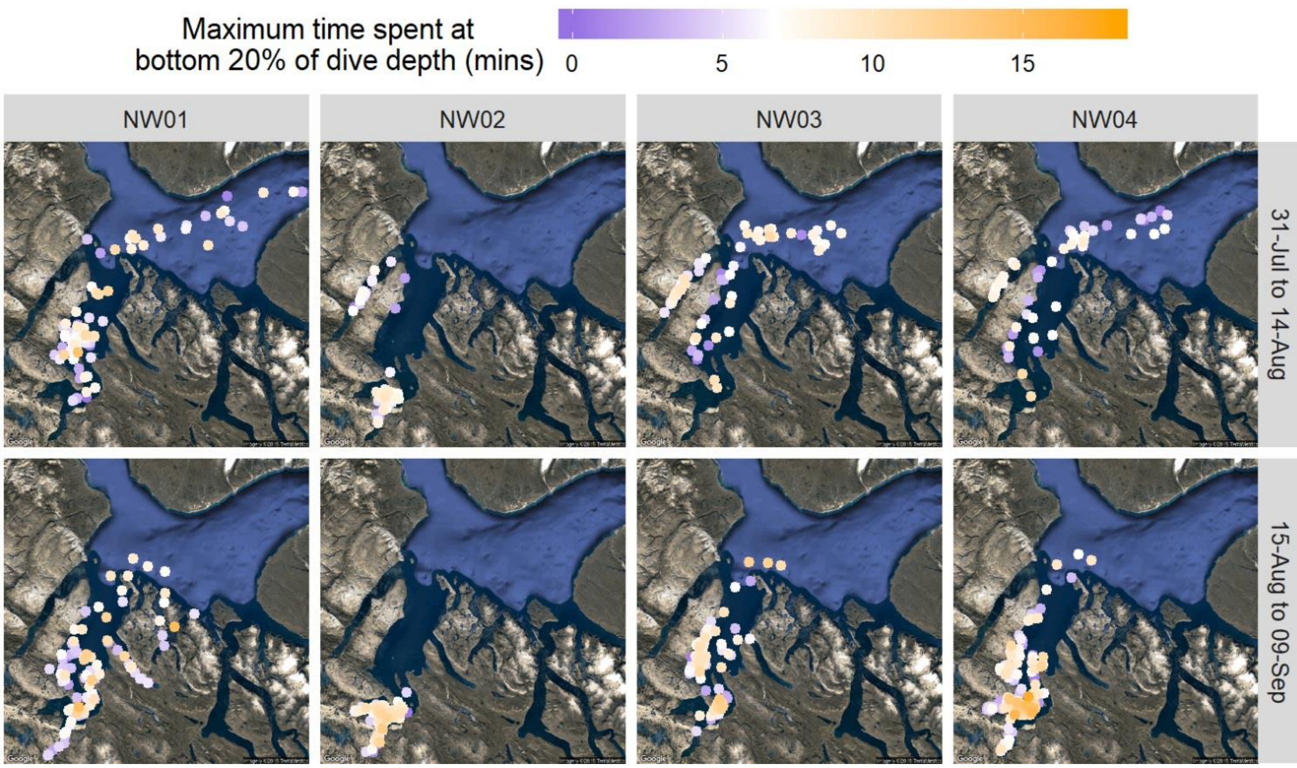

Figure 4-39: Maximum time (min) spent at bottom of dive (within 20% of maximum dive depth) within each 4 h period

Note: Mean values across all animals shown in white.

Time spent at bottom of dive (within 20% of maximum dive depth) was analyzed using mixed linear models. In the analysis, fixed effects included in the model were whether the narwhal was within an exposure zone (≤10 km from a large vessel), distance from a large vessel if present (km; 3rd-degree polynomial), maximum dive depth (m; second-degree polynomial), whether the dive was deep (>75% of the available bathymetry), and whether the preceding dive was deep (>75% of the available bathymetry). In addition to the main effects, the model included an interaction between whether the dive was deep and maximum dive depth and an interaction between whether the dive was deep and whether the preceding dive was deep. The random effects consisted of a random intercept by narwhal.

The main effects of distance from vessel and whether a vessel was within 10 km from narwhal were not statistically significant (*P*>0.1 for both; Figure 4-40). All other effects included in the model were significant (*P*<0.001). Overall, the model indicated that time spent at the bottom 20% of dive depths depended on the depth of the dive, whether the dive was deeper than 75% of the available bathymetry depth, and whether the preceding dive was deep. The model indicated that time spent at the bottom of the dive increased with maximum depth until a peak at approximately 450 m, followed by a decrease in estimated time spent at bottom (Figure 4-40). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.598 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.603.

In summary, the 2017 dive data support the null hypothesis that time at depth does not significantly change during vessel-exposure events. Test statistics and coefficients estimates for the model are provided in Appendix B.

Figure 4-40: Time spent at bottom 20% of the dive relative to maximum dive depth (top) and distance from large vessel (bottom)

Note: Solid points and bars are observed data; lines are predicted means, and grey ribbons are 95% confidence intervals around population-level predictions.

4.2.1.6 Total Dive Duration

The dive duration of the two female narwhal (NW02 and NW03) was on average higher than that of the two male narwhal (NW01 and NW04; Figure 4-41; Table 4-9). Individual differences were also apparent within sex, where NW02 had the narrowest range of dive durations, while NW01 had the lowest mean and widest range of dive duration values. No differences in mean dive duration values were apparent between exposure and non-exposure events based on summary statistics, although maximum dive duration values were higher during non-exposure events (Table 4-9).

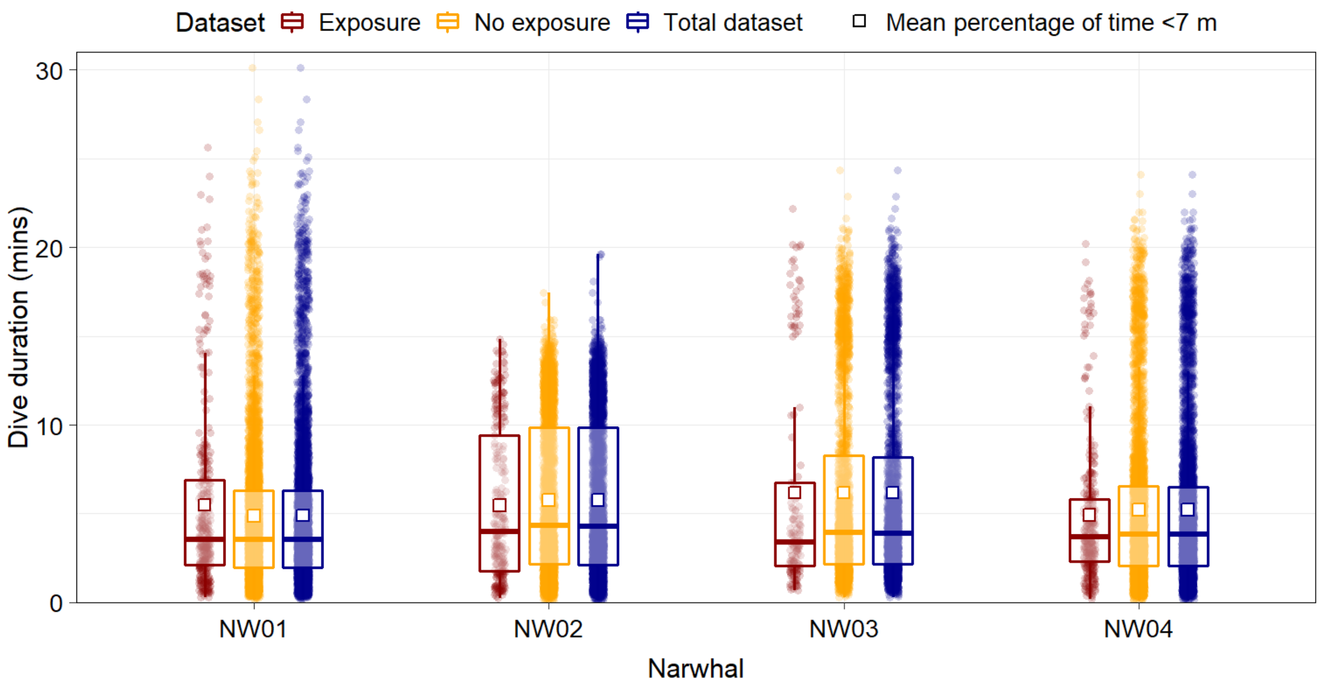

Figure 4-41: Dive duration (min) within each dive, by tagged narwhal under exposure, no exposure, and in the full dataset. Summary statistics (minimum, maximum, and mean) are provided in Table 4-9.

Table 4-9: Summary statistics of narwhal dive duration (mins)

Dive Parameter	NW01	NW02	NW03	NW04
Total dataset				
Minimum	0.15	0.08	0.30	0.08
Mean	4.91	5.77	6.19	5.21
Maximum	30.10	19.6	24.40	24.10
Exposure Zone (≤10 km):				
Minimum	0.28	0.23	0.67	0.20
Mean	5.49	5.48	6.19	4.92
Maximum	25.60	14.90	22.20	20.20

Dive Parameter	NW01	NW02	NW03	NW04
Non-exposure Zone (>10 km):				
Minimum	0.15	0.08	0.30	0.08
Mean	4.87	5.77	6.19	5.22
Maximum	30.10	17.40	24.40	24.10

The dive duration values of narwhal (summarized over 4 h periods) differed by area and tagged individual (Figure 4-42). For example, NW02 had no dives longer than 20 mins, which were recorded for other tagged narwhal, but had a relatively high average dive duration overall (Figure 4-41), low to intermediate dive duration when in Tremblay Sound, and longer dive durations when south of Bruce Head peninsula. NW03 had relatively long dives when in Eclipse Sound (Figure 4-42), often to the full extent of the available bathymetry depth (Figure 4-35), leading to a low dive rate (Figure 4-32).

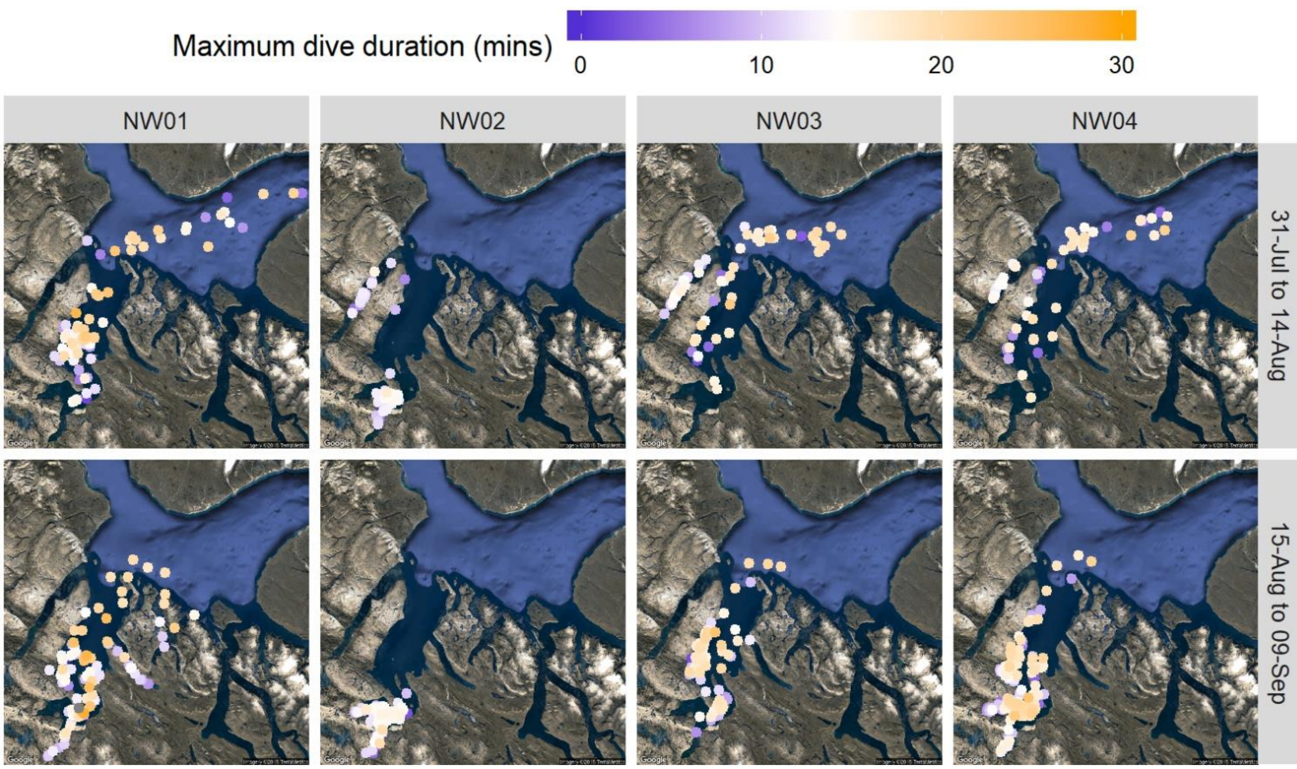

Figure 4-42: Maximum dive duration (min) within each 4 h period, by tagged narwhal

Note: Average values of maximum dive duration across all animals is shown in white.

Dive duration (mins) was analyzed using mixed linear models. In the analysis, fixed effects included in the model included whether the narwhal was within an exposure zone (≤10 km from a large vessel), distance from large vessel if present (km; 3rd-degree polynomial), maximum dive depth (m; 3rd-degree polynomial), whether the current dive was deep (>75% of the available bathymetry), whether the preceding dive was deep (>75% of the available bathymetry), and the interaction between the two latter effects. The random effect was a random intercept by narwhal.

The effect of distance from a large vessel on total dive duration was statistically significant ($P=0.016$). The effect of maximum dive depth was found to be statistically significant ($P<0.001$), as was the interaction between whether the current and previous dives were deep ($P=0.046$). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.813 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.825. Test statistics and coefficients estimates for the model are provided in Appendix B.

The model predicted a slight decrease in dive duration in the immediate vicinity of large vessels, where mean predicted dive duration decreased from ~5.7 mins when no vessels were within 10 km of the narwhal and at maximum dive depth of 50 m, to 5.1 mins at 1 km from a vessel, and 4.3 mins at 0 km from a vessel (Figure 4-43). However, the estimates in the vicinity of the vessel were potentially spurious, especially considering the limited data at distances <1 km and that patterns of the relationship differed by individual, where NW01 and NW02 had reduced dive duration values in the vicinity of vessels, whereas NW02 and NW03 had slightly increased dive durations (data not shown).

Dive duration depended on maximum dive depth (Figure 4-43). Mean predicted dive durations increased from ~2.5 mins when dives were shallow (≤20 m) to ~15 mins for dives at 300 m depth. Subsequent increases in dive depths resulted in a slight increase in mean predicted dive duration, up to ~20 mins for dives at 700 m depth.

Although the 2017 dive data support the alternate hypothesis that dive duration changes significantly during vessel-exposure events, we do not have confidence in the model given the limited and contradictory data for close vessel distances. As more data become available from future tagging programs, the relationship between vessel distance and narwhal dive duration will be re-evaluated.

Figure 4-43: Dive duration (mins) relative to maximum dive depth (m; top) and distance between narwhal and large vessels (km; bottom)

Note: Solid points and bars are observed data; lines, open points, and red point are predicted means, and grey ribbons are 95% confidence intervals around population-level predictions.

4.2.1.7 Descent Speed

The descent speed of the two female narwhal (NW02 and NW03) was on average higher than that of the two male narwhal (NW01 and NW04; Figure 4-44; Table 4-10). Individual differences were also apparent within sex, where NW02 had the highest and most variable record of descent speeds, whereas NW01 had the lowest and least variable descent speeds. No differences in mean descent speeds were apparent between exposure and no-exposure events, although maximum descent speeds were higher in no-exposure events (Table 4-10).

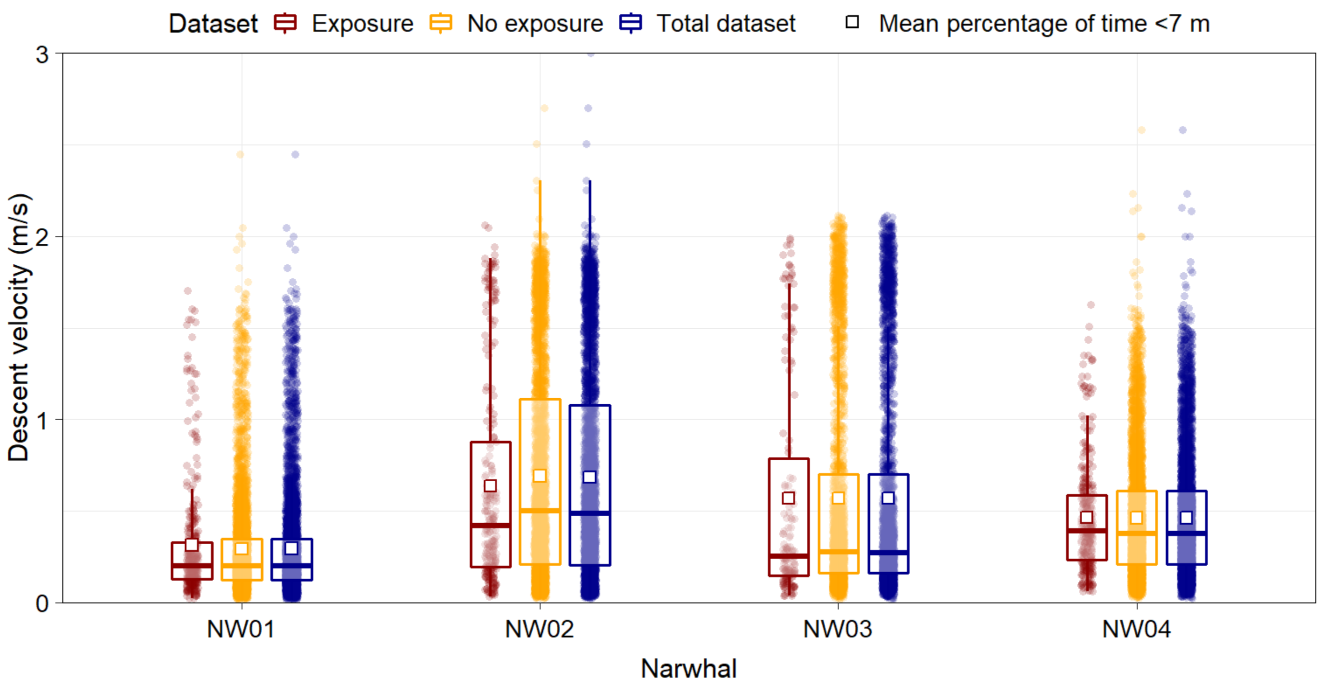

Figure 4-44: Descent speed (m/s) within each dive, by tagged narwhal under exposure, no exposure, and in the full dataset. Summary statistics (minimum, maximum, and mean) are provided in Table 4-10.

Table 4-10: Summary statistics of narwhal descent speed (m/s)

Dive Parameter	NW01	NW02	NW03	NW04
Total dataset				
Minimum	0.01	0.02	0.01	0.02
Mean	0.29	0.69	0.57	0.46
Maximum	2.45	2.70	2.11	2.58
Exposure Zone (≤10 km):				
Minimum	0.02	0.03	0.04	0.06
Mean	0.32	0.64	0.57	0.46
Maximum	1.70	2.06	1.99	1.63
Non-exposure Zone (>10 km):				
Minimum	0.01	0.02	0.01	0.02
Mean	0.29	0.69	0.57	0.46
Maximum	2.45	2.70	2.11	2.58

The descent speeds of narwhal (summarized over 4 h periods) differed by area and tagged individual (Figure 4-45). Narwhal NW02, which had generally high descent speeds (Figure 4-44), had low to intermediate descent speeds when recorded in Tremblay Sound, but higher speeds when diving south of Bruce Head peninsula. NW03 had high descent speeds when it was recorded in Eclipse Sound (Figure 4-45), and these dives were often to the full extent of the available bathymetry depth (Figure 4-35), leading to a low dive rate (Figure 4-32). NW04 had generally low to intermediate descent speed throughout the Study Area.

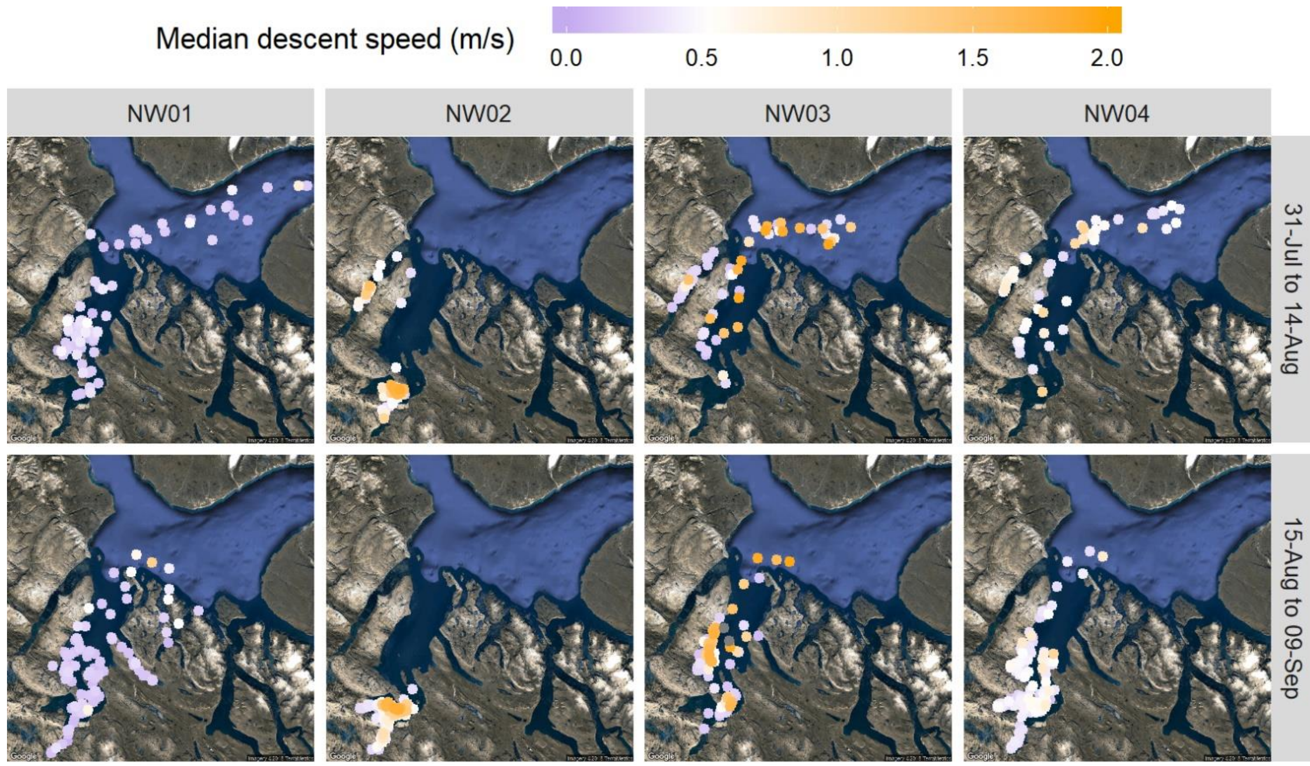

Figure 4-45: Median descent speed (m/s) within each 4 h period, by tagged narwhal

Note: Average values of median descent speed across all animals is shown in white.

Descent velocity (m/s) was analyzed using mixed linear models. In the analysis, fixed effects included in the model were whether the narwhal was within an exposure zone (≤10 km from a large vessel), distance from large vessel if present (km; 3rd-degree polynomial), maximum dive depth (m; 3rd-degree polynomial), whether the current dive was deep (>75% of the available bathymetry), and whether the preceding dive was deep (>75% of the available bathymetry). The random effect was a random intercept by narwhal.

The effects of maximum dive depth and whether the previous dive was deep were found to be statistically significant (P<0.001 for both). The effects of exposure and whether the current dive was deep were not significant (P=0.5 and P=0.8, respectively). The effect of distance on descent speed was not significant (P=0.1). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.605 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.626.

The model predicted a slight increase in descent velocity in the immediate vicinity of large vessels, where mean descent speed increased from ~0.46 m/s when no vessels were within 10 km from the narwhal, to 0.53 m/s at 1 km from a vessel, and 0.61 m/s at 0 km from a vessel (Figure 4-46). However, the relationship overall was not significant (P=0.1) and the multiple comparisons indicated no significant differences between mean descent speed when no vessel was within 10 km from the narwhal or any of the examined distances (P=0.2 for comparison at 0 km from vessel). The lack of significance is likely a result of the high data variability and paucity of data in the immediate vicinity of vessels (Figure 4-46).

Descent speed depended on dive depth (Figure 4-47). Mean predicted speeds increased from ~0.5 m/s when dives were shallow (~100 m) to ~1.3 m/s for dives at 300 m depth. Subsequent increases in dive depths resulted in a slower increase in mean predicted descent speed, up to ~1.6-1.8 m/s for dives at 700 m depth, depending on whether the preceding dive was also a bottom dive. Descending speeds were slightly and not significantly higher when the preceding dive was also deep (e.g., 0.57 m/s vs 0.46 m/s when no vessels were within 10 km from narwhal, at mean dive depth of 70 m), indicating that narwhal may be diving faster when exhibiting feeding behaviour (Figure 4-47). Test statistics and coefficients estimates for the model are provided in Appendix B.

In summary, the 2017 dive data supports the null hypothesis that descent velocity does not significantly change during vessel-exposure events. As more data become available from the additional tagging programs, the relationships will be re-evaluated.

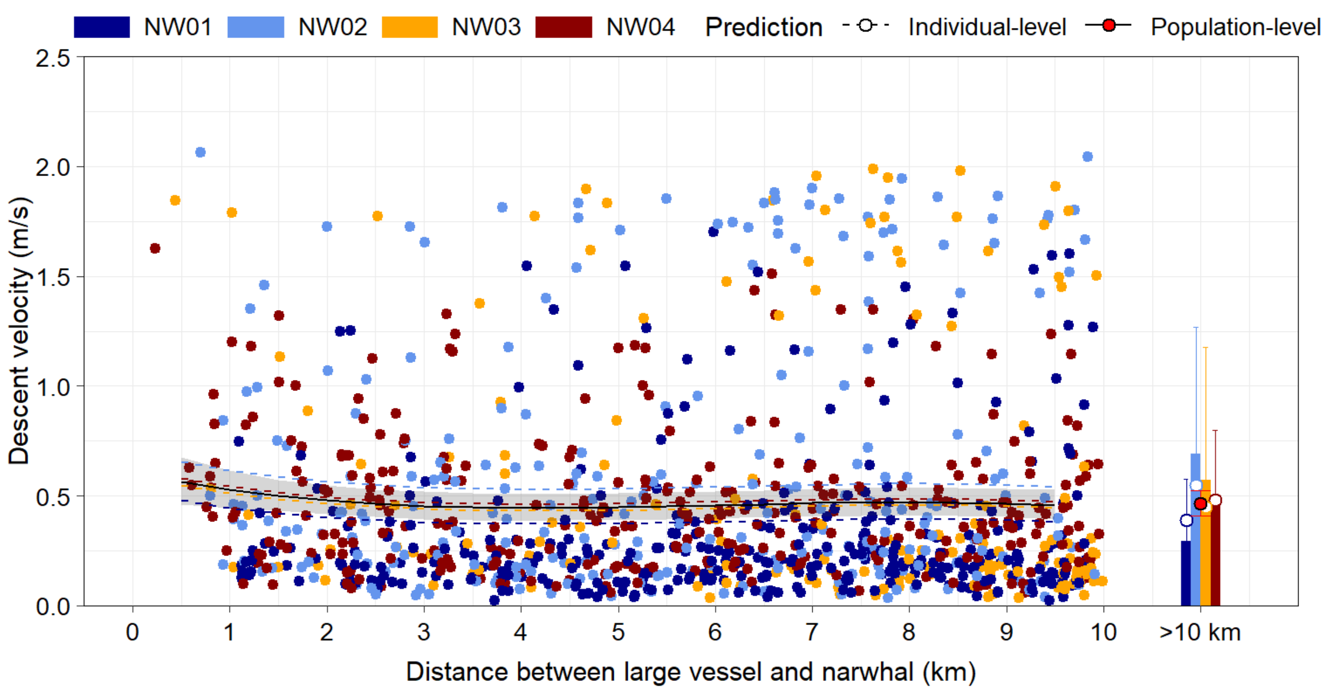

Figure 4-46: Descent velocity (m/s) relative to distance between narwhal and large vessels (km)

Note: Solid points and bars are observed data; lines, open points, and red point are predicted means, and grey ribbons are 95% confidence intervals around population-level predictions.

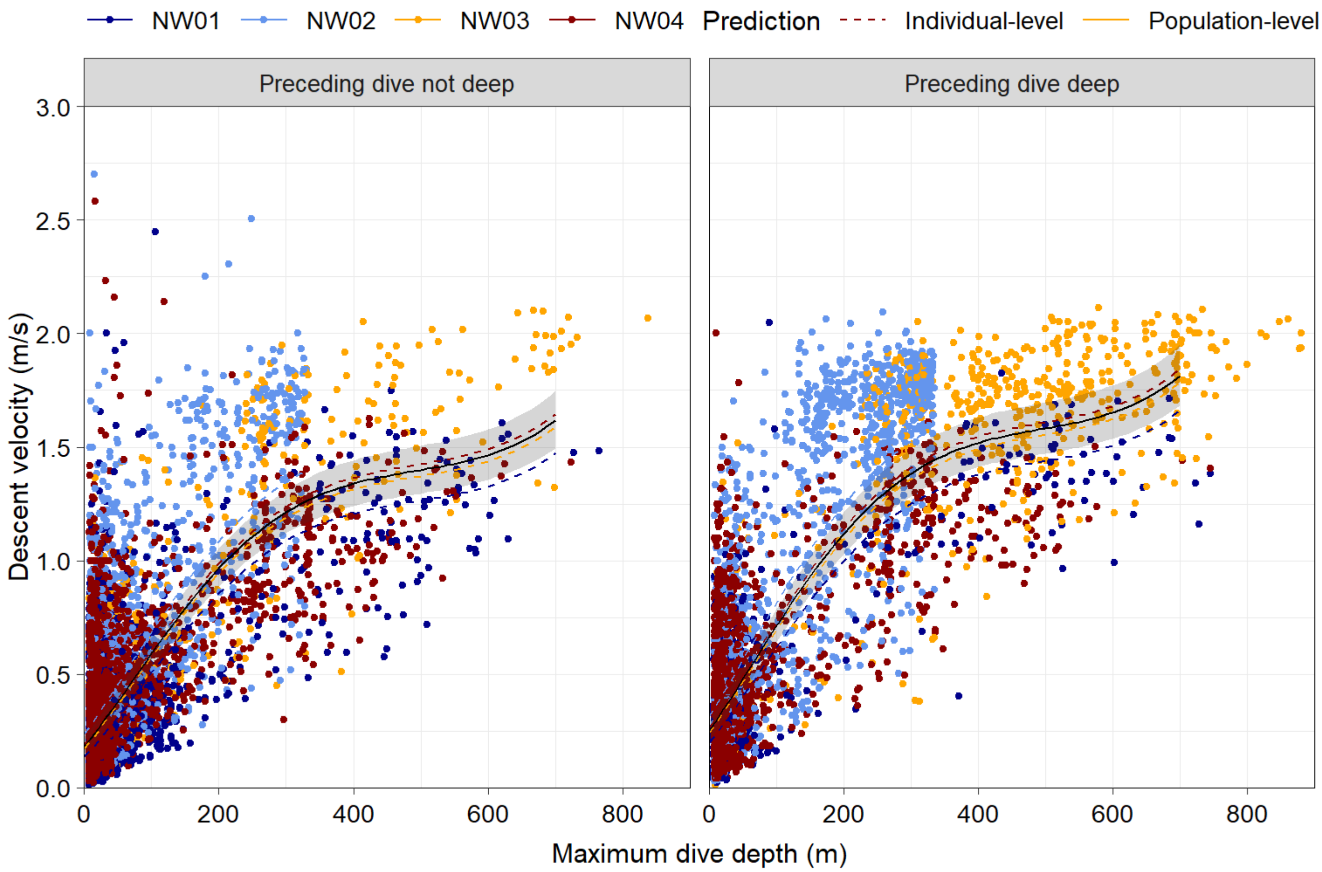

Figure 4-47: Descent velocity (m/s) relative to maximum dive depth and whether the preceding dive was deep (i.e., >75% of available bathymetry depth)

Note: Solid points and bars are observed data; lines, open points, and red point are predicted means, and grey ribbons are 95% confidence intervals around population-level predictions.

4.2.2 Surface Behaviour in Relation to Large Vessel Traffic

4.2.2.1 Rate of Direction Change

A total of eight narwhal with GPS tag data were recorded within 10 km of a large vessel and had sufficient data to estimate turning angles. The analysis of turning angle indicated a significant effect of distance from vessel and narwhal distance from shore ($P<0.001$ for both). It was hypothesized that the effect of vessel exposure would increase with decreasing distance, which was the statistically significant trend suggested based on the modeled turning angle (Figure 4-50). Alternatively, if vessel distance had no effect on narwhal turning angle, the slope of the relationship would have been flat. Narwhal GPS data indicated that narwhal had an affinity for linear travel along shorelines, and the model estimated higher turning rates with increasing distance from shore in narwhal that were within the exposure zone but not for narwhal outside of the exposure zone. The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.004 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.030. Test statistics and coefficients estimates for the model are provided in Appendix B.

Multiple comparisons performed on model predictions indicated that turning angles were significantly ($P<0.05$) higher when large vessels were within 4 km from the narwhal relative to when no large vessels were within 10 km from narwhal. That is, the effect of vessel presence on narwhal turning rates is only evident within 4 km from the large vessel. This analysis does not indicate whether the narwhal were turning toward or away from the vessels but only that narwhal changed course at different rates depending on distance from vessels. During vessel exposures, narwhal were generally close to shore (Figure 4-6 and Figure 4-48). This is likely related to a paucity of data in wide-channel areas such as Eclipse Sound. Another confounding factor is that the Fastloc GPS tags opportunistically collect locations depending on the availability of longer surfacing events. Since analysis in subsequent sections will indicate that a surface freeze response is possible at intermediate distances, the higher densities of GPS locations present there may skew the analysis in this section. As more data become available from additional tagging programs, the relationships will be re-evaluated.

In summary, the 2017 location data analysis rejects the null hypothesis that travel direction does not significantly change during vessel-exposure events. Statistically significant effects of vessel exposure on travel direction of narwhal was evident within 4 km of the vessel.

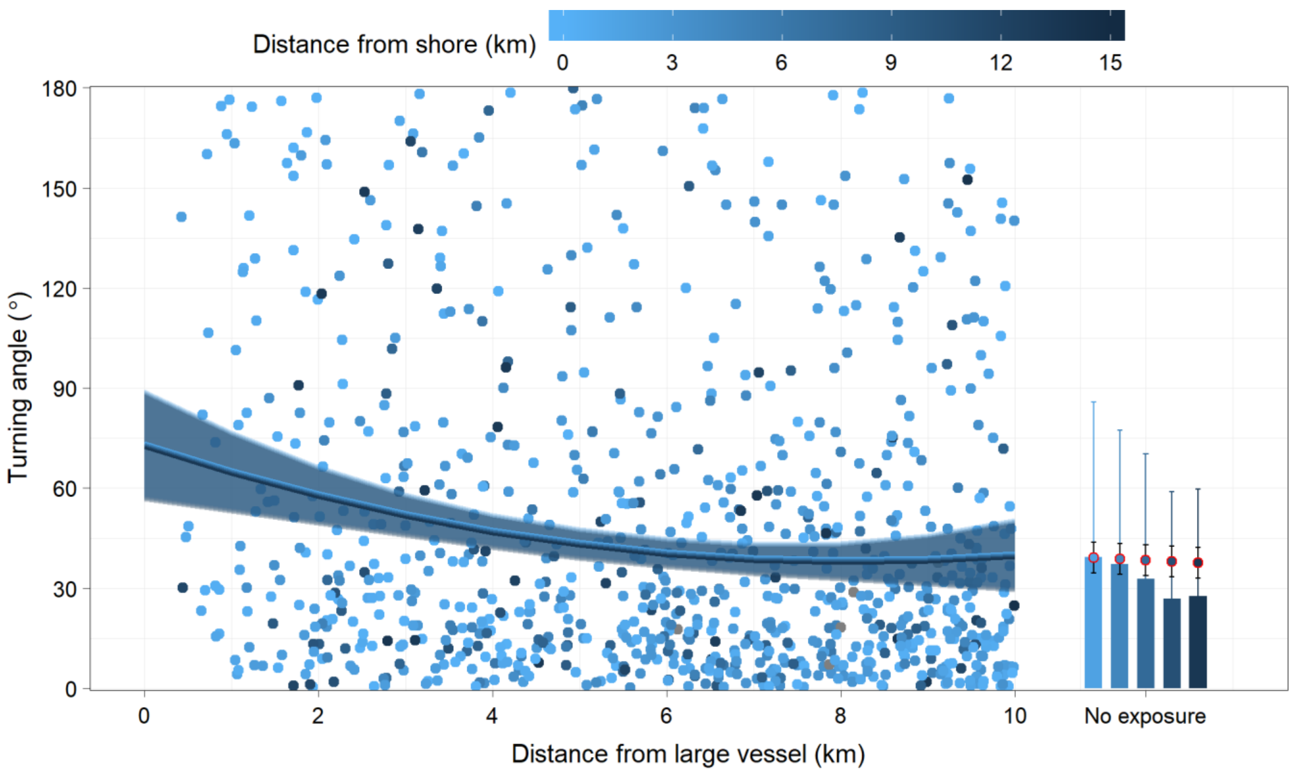

Figure 4-48: Observed and predicted turning angles by narwhal relative to distance from large vessels during exposure (<10 km; lines) and non-exposure events (>10 km; bars)

Note: Points and bars depict raw data; lines and ribbons show predicted mean and 95% confidence intervals for turning angles within exposure zone, and points and error bars show mean and 95% confidence intervals outside of exposure zone. Colour-coded error bars represent 1 SD. Distance between narwhal and shore (km) is also shown using colour-coding.

4.2.2.2 Travel Orientation relative to Vessels

A total of eight narwhal with GPS tag data were recorded within 10 km of a large vessel and had sufficient data to analyze narwhal travel orientation relative to large vessels. Since the dataset focused on the angles between narwhal and large vessels, the dataset available for modeling was restricted to cases where a large vessel was present, therefore no “no exposure” modeling was available. Instead, travel orientation was modeled as a function of distance between vessel and narwhal (as third-degree polynomial). The effect of distance was found to not be significant (*P*=0.08). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.019 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.083. Test statistics and coefficients estimates for the model are provided in Appendix B.

It was hypothesized that the effect of vessel distance would increase with decreasing distance, which was observed as a slight (but not significant) increase in relative angles at close distances (≤4 km) relative to when vessels were farther away (Figure 4-49). Alternatively, if vessel distance had no effect on narwhal angle relative to vessels, the slope of the relationship would have been flat.

In summary, a slight (not significant) effect of vessel distance on narwhal travel orientation was estimated, which may suggest that a relationship may be identified once additional tagging data are analyzed.

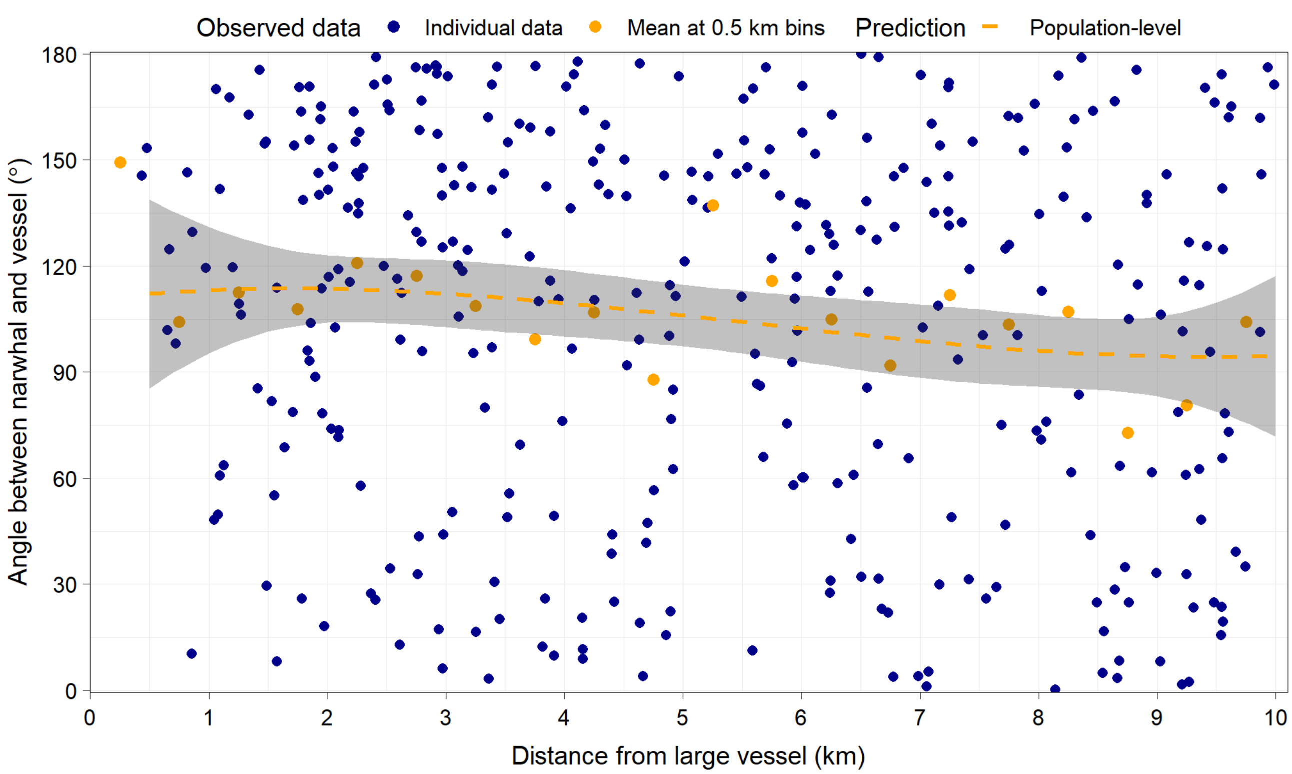

Figure 4-49: Observed and predicted angles between narwhal and large vessels during exposure (≤10 km)

Note: line and ribbon show predicted mean and 95% confidence interval.

4.2.2.3 Horizontal Displacement

A total of ten narwhal with GPS tag data were recorded within 10 km of a large vessel (Figure 4-50 and Figure 4-51). These points represent snapshots in time of narwhal locations relative to the vessel heading and not the vessel track. Although the horizontal distribution of narwhal around the vessels had the lowest point density at the farther distances from the sides of the vessels, this is likely an artifact of geography of Milne Inlet, since the inlet is relatively narrow, and land is often within 10 km of the vessel sides. A gap without narwhal GPS locations was evident within approximately 0.5 km of vessel port and starboard, 1 km of the vessel bow, and 1.5 km astern (Figure 4-51). This gap in distribution in close proximity to vessels may indicate movement away from the vessel by narwhal (i.e. avoidance) but may also be a function of the low resolution GPS location data available.

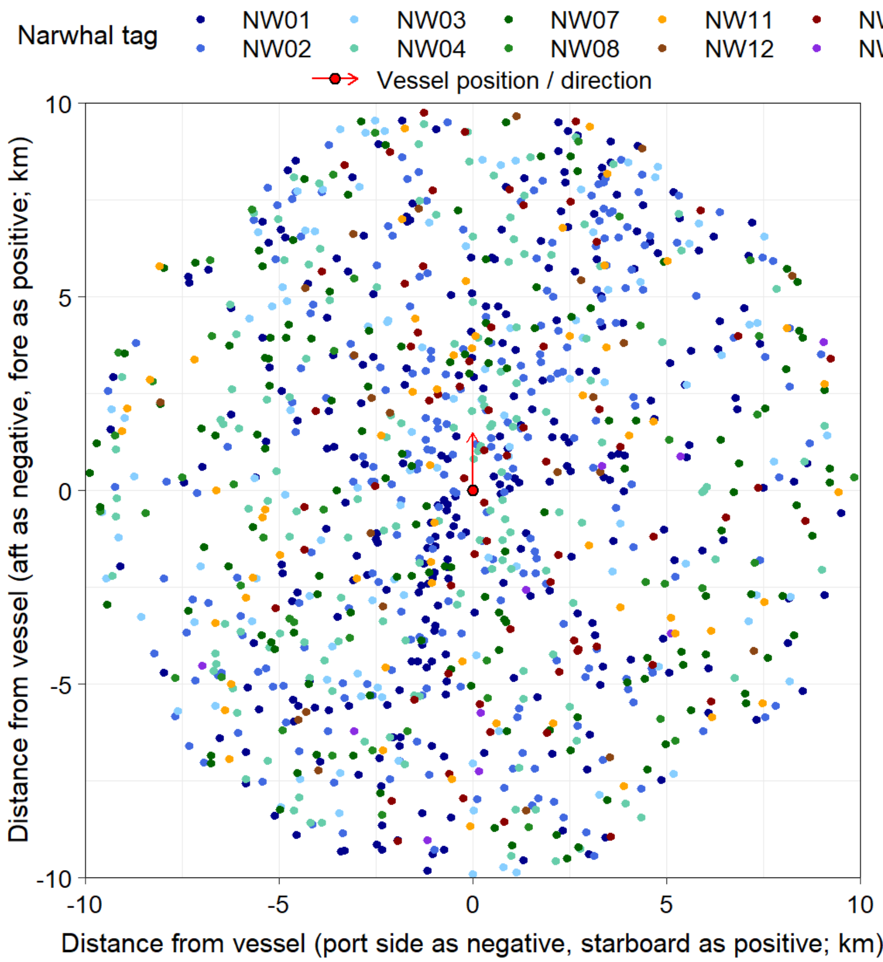

Figure 4-50: Relative distance between large vessels and narwhal (limited to 10 km) during August and September 2017

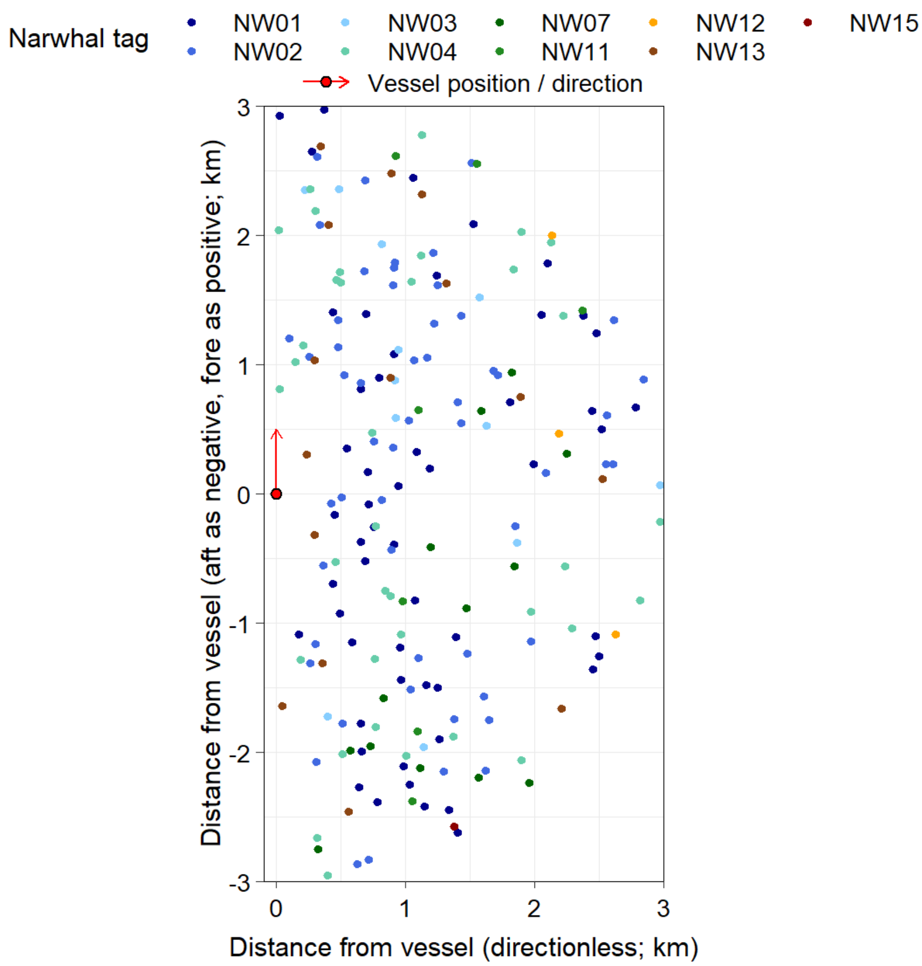

Figure 4-51: Distance between large vessels and narwhal (limited to 3 km) throughout August and September 2017

Note: Data were combined for both port and starboard sides of vessel

Narwhal location as a function of distance and direction relative to the vessel (forward, astern, port, starboard) were used to create a spatial model. Observed and model-predicted densities increased close to the vessel in all four directions relative to densities at distance (Figure 4-52). However, densities at both port and starboard directions continued increasing up to <1 km from the vessel, whereas densities at forward and astern directions peaked at 1 km and decreased <1 km (Figure 4-52), in accordance with the gap of recorded positions (Figure 4-51). There was no significant difference between an interaction model that used all four directions relative to the vessel (forward, astern, port, starboard) and an interaction model that combined the four directions into two classes (forward/astern and port/starboard; P=0.1), suggesting no significant difference between forward and astern densities and between port and starboard densities relative to distance from vessel. The interaction between distance and direction (i.e. narwhal position relative to the vessel) was also found to be not significant (P=0.066), despite the observed difference in narwhal density astern/forward relative to port/starboard at the immediate vicinity of the vessels.

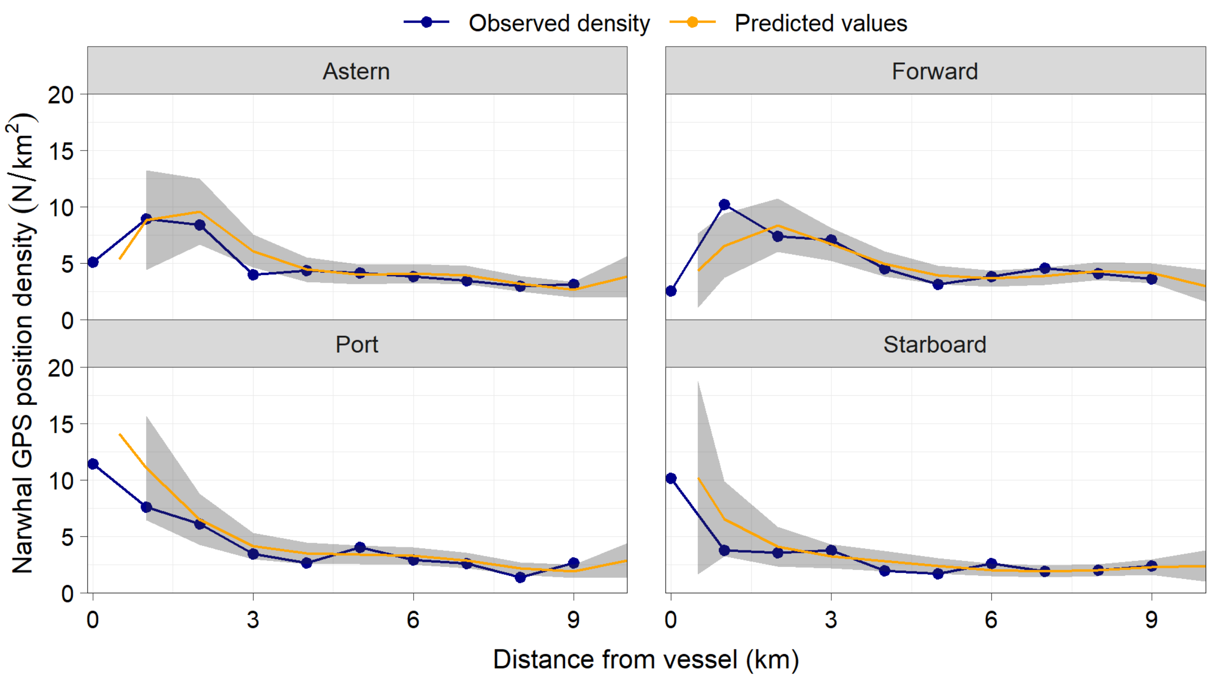

Figure 4-52: Observed (blue points) and predicted (orange lines) narwhal density at distance and position relative to the vessel (data shown in Figure 4-50)

4.2.2.4 Seasonal Change and Horizontal Displacement

As an indication of narwhal habituation to large vessel traffic, temporal changes to the time series of distances between narwhal and vessels were modeled (Figure 4-53) and included a significant slope (estimate of -39 m/day, SE of 9 m/day; *P* value <0.001). The model did not support random slopes (*P* value = 0.4), suggesting no extensive individual variability in the change of distance from vessels. In the beginning of the study, mean distance between narwhal and vessel (for cases where narwhal were within 10 km from vessels) was estimated to be 7.6 km. The model results indicated that with every passing day, the mean distance between narwhal and large vessels decreased by 39 m, resulting in a mean estimated distance of 5.6 km by 22 September 2017. Note that not all narwhal were present for the entire duration of the August-September study period due to intermittently leaving the Study Area and returning. Test statistics and coefficients estimates for the model are provided in Appendix B.

In summary, the 2017 narwhal location data rejects the null hypothesis that narwhal distribution at the surface does not significantly change during vessel-exposure events, although this pattern appears to be limited to close ranges of the vessel (and more pronounced when animals were astern), and the effect appears to occur over a limited period (animals are shown to re-enter the shipping lane shortly following a vessel transit).

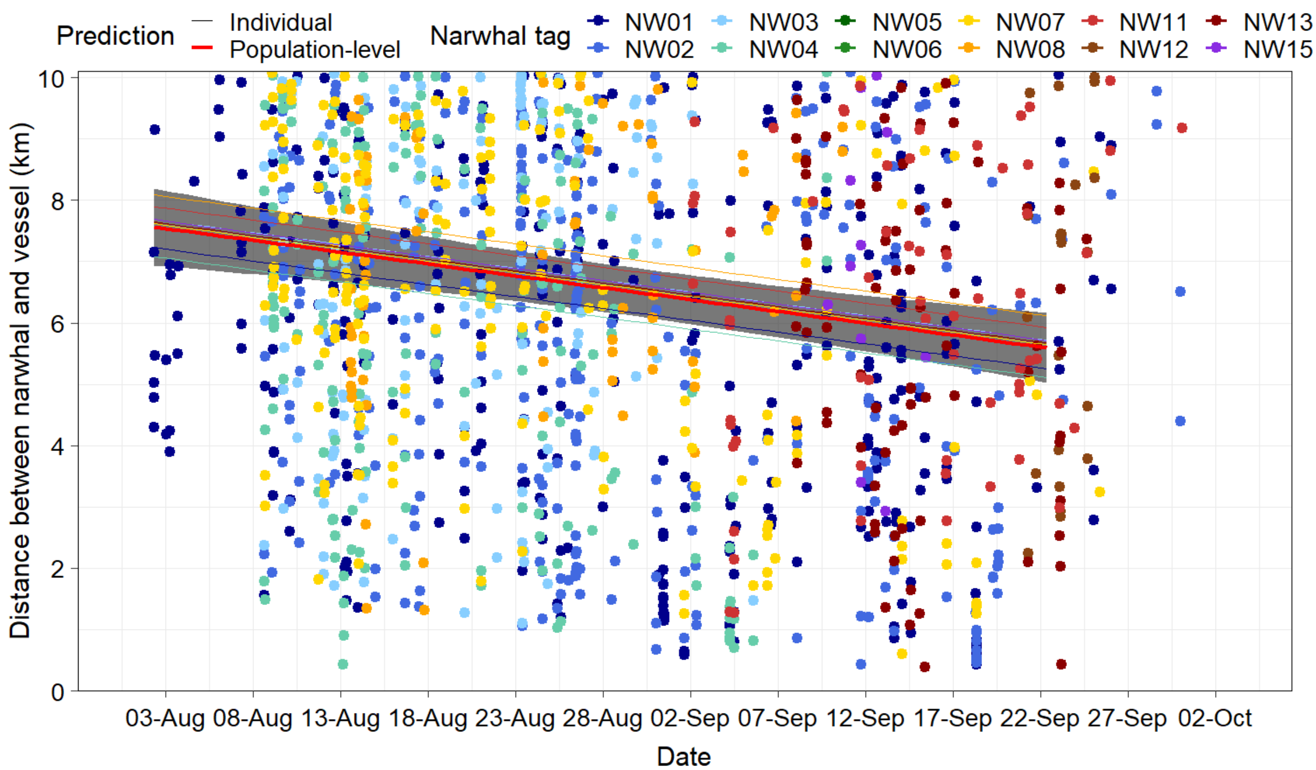

Figure 4-53: Distance between narwhal and vessel (km) relative to date of study

Note: Thin lines are individual-level predictions of mixed model; thick red line and the grey ribbon are the population-level prediction and the corresponding 95% confidence band. Three points (NW12) recorded in min-October at 7-8.5 km from vessels were removed to avoid extending the x-axis.

4.2.2.5 Habitat Re-Occupation

Instances where narwhal crossed vessel tracks, as indicated by GPS locations either in front of or behind a vessel, are presented in (Figure 4-54). For crossing events ahead of the vessel, the realized (future) vessel track was used. As expected, the faster a vessel was moving, the faster the distance to the vessel was likely to accumulate before the narwhal crossed the vessel track. No obvious difference is present between crossing events before or after vessel passage, with each scenario essentially being a ‘mirror image’ of the other. Although narwhal crossing vessel tracks is only a subset of the total narwhal interactions with vessels, it does inform the amount of time an animal is displaced from the habitat by the vessel passage. The extent of the temporal lag between vessel passage and the animal’s crossing of the track should be positively correlated to the level of disturbance presented by vessel passage.

Overall, narwhal crossed the vessel track both shortly before and shortly after vessel passage (minimum value of 4 mins), suggesting no long-term avoidance of the shipping route due to vessel passage.

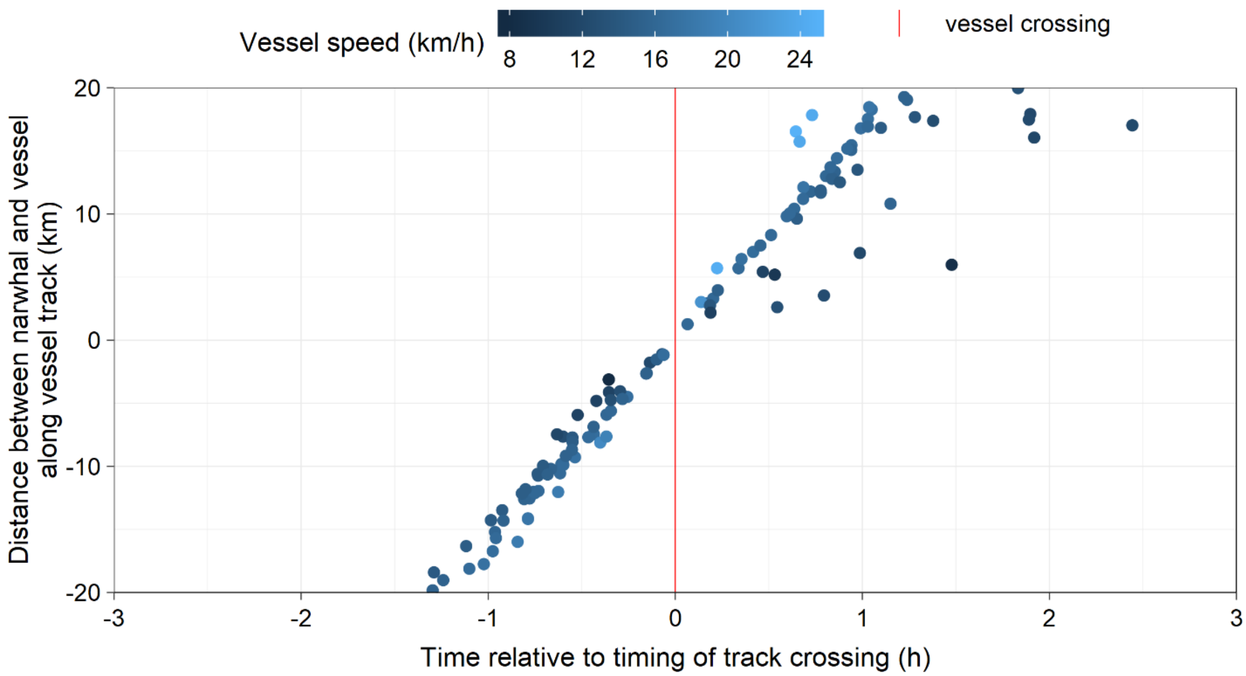

Figure 4-54: Time elapsed and distance travelled by large vessels before narwhal cross ship track; points colour-coded by vessel speed

Note: Negative values represent narwhal crossing the ship track before the vessel transits.

4.2.2.6 Travel Speed

Mean narwhal travel speeds ranged between 0.8 m/s (NW03) and 1.2 m/s (NW06; Table 4-11). Mean travel speeds were generally similar between exposure and non-exposure events, while maximum travel speeds were generally higher during non-exposure events.

The analysis of travel speed indicated that while the effect of exposure was statistically significant ($P<0.001$), the effect of distance from vessel was marginally not significant ($P=0.06$). In addition, the effect size of exposure on travel speed was limited, with mean estimated travel speed decreasing from 0.98 m/s during non-exposure events to 0.79 m/s at 0 km from a vessel (Figure 4-56). Since it is expected that the effect of shipping would increase with decreasing distance, the lack of significance of slope likely suggests that the significant effect of exposure may be a spurious finding, especially considering the lack of data in close proximity to vessels. Coupled with the small effect size, these results suggest that vessel traffic had little effect on narwhal travel speed. The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.002 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.025. Test statistics and coefficients estimates for the model are provided in Appendix B.

In summary, the 2017 horizontal relocation data reject the null hypothesis that swim speed does not significantly change during vessel-exposure events. However, for reasons described above, this result may be spurious and should be re-evaluated with supplementary data collected during the 2018 season.

Table 4-11: Summary statistics of narwhal travel speed (m/s)

Narwhal	Full dataset			Exposure Zone (≤10 km)			Non-exposure Zone (> 10 km)		
	Min	Average	Max	Min	Average	Max	Min	Average	Max
NW01	0.0	1.1	2.9	0.0	1.0	2.4	0.0	1.1	2.9
NW02	0.0	1.0	3.1	0.0	0.9	2.9	0.0	1.0	3.1
NW03	0.0	0.8	2.9	0.1	0.8	2.1	0.0	0.9	2.9
NW04	0.0	0.9	2.5	0.1	0.7	2.2	0.0	0.9	2.5
NW05	0.1	1.0	2.8	X	X	X	0.1	1.0	2.8
NW06	0.0	1.2	3.1	X	X	X	0.0	1.2	3.1
NW07	0.0	1.0	2.9	0.1	0.9	2.4	0.0	1.0	2.9
NW08	0.0	0.9	3.1	0.3	1.1	2.0	0.0	0.9	3.1
NW11	0.0	0.9	2.7	0.1	0.9	1.6	0.0	0.9	2.7
NW12	0.0	0.9	2.6	0.0	0.8	1.9	0.0	0.9	2.6
NW13	0.0	1.0	2.4	0.0	0.8	1.9	0.0	1.0	2.4
NW15	0.0	0.9	3.0	0.0	0.9	1.2	0.0	0.9	3.0

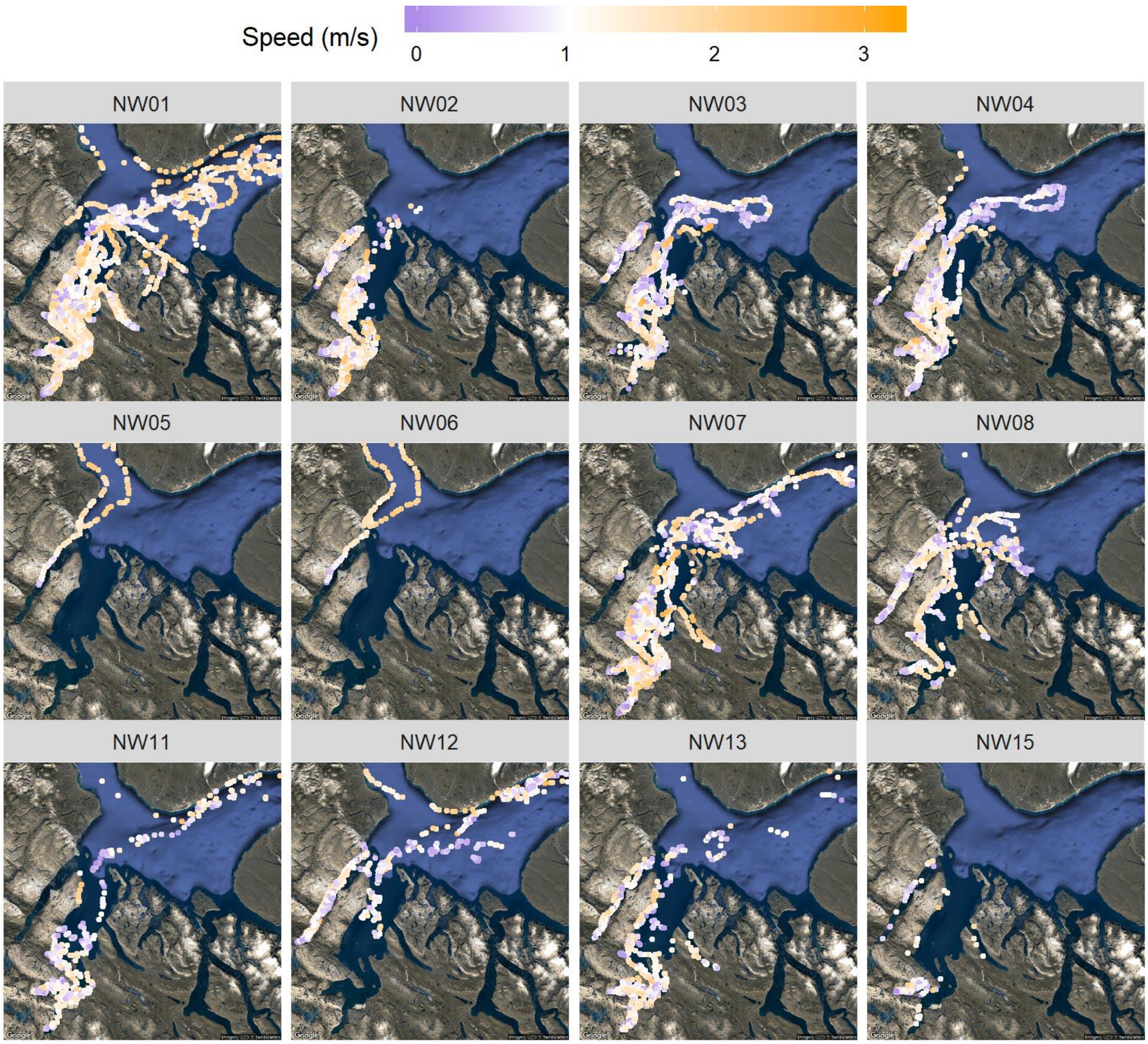

Figure 4-55: Spatial distribution of narwhal GPS positions, colour-coded by travel speed (m/s) between August and October 2017

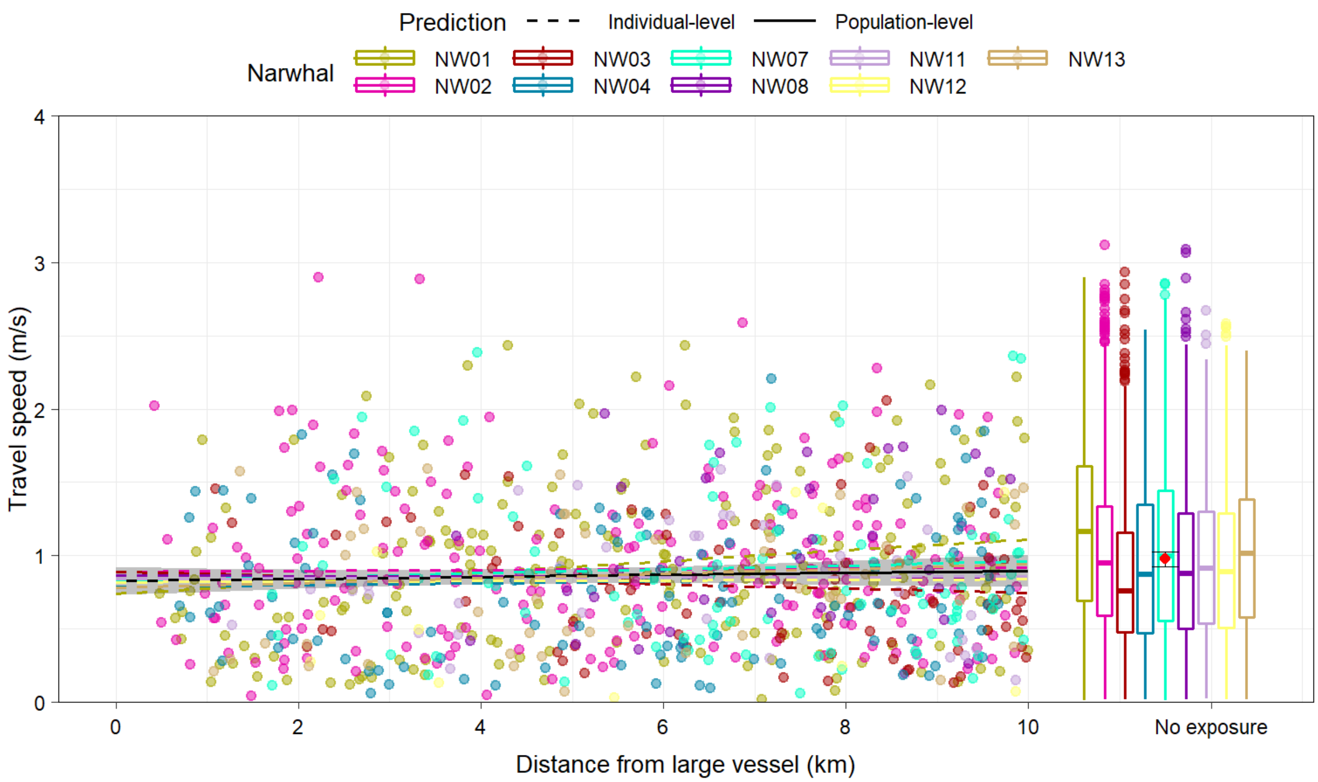

Figure 4-56: Observed and predicted narwhal travel speed relative to distance from large vessels during vessel exposure periods (<10 km; lines) and non-exposure periods (boxplots)

Note: Colour-coded by individual narwhal; lines and ribbons show predicted mean and 95% confidence intervals for travel speed within exposure zone, and points and error bars show mean and 95% confidence intervals outside of exposure zone.

4.3 Dive Behaviour in Relation to Shore-based Hunting

The Bruce Head Shore-based Monitoring Program recorded shore-based hunting (i.e. gunshot) events in the vicinity of the Bruce Head peninsula during August 2017(Golder 2018). On August 22, NW03 and NW04 approached Bruce Head from the north in close proximity to the shoreline as several gunshots were fired from the hunting camp at the base of Bruce Head. The distance of narwhal from the hunting camp was measured using GPS point location data and interpolated for points in between, assuming a constant speed for narwhal movement. For narwhal within 2 km of the Bruce Head hunting camp, dive initiation for NW03 and NW04 was often correlated with gunshot events (Figure 4-57 and Figure 4-58). For example, NW03 appeared to initiate a dive following a gunshot event at approximately 19:14, and an even deeper dive following a second gunshot event at approximately 19:20. Hunting activity at camps further north of Bruce Head were likely not captured due to in-air sound propagation constraints and may coincide with the initiation of dives as by NW03 and NW 04 as both animals would have been in close proximity to those camps at the time. Narwhal NW03 was observed to consistently dive deeper than NW04, however this may be related to available depth below each animal’s path of travel.

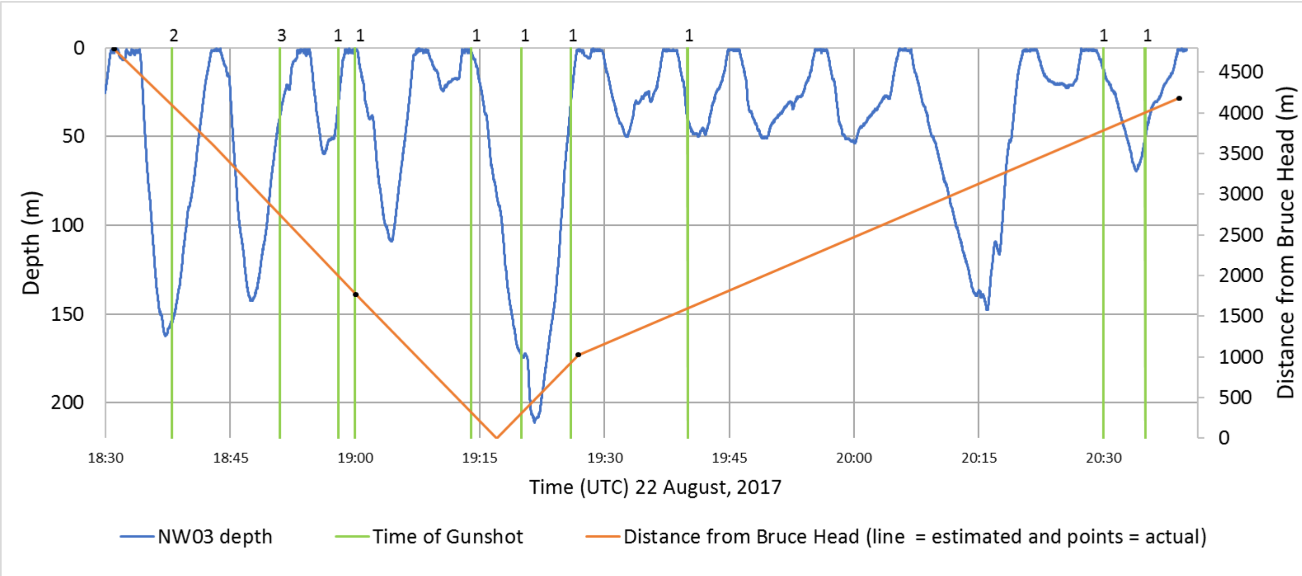

Figure 4-57: Dive behaviour of NW03 in relation to gunshot events recorded at Bruce Head with distance from Bruce Head hunting camp

Note: The number presented above each grey vertical line represents number of gunshots.

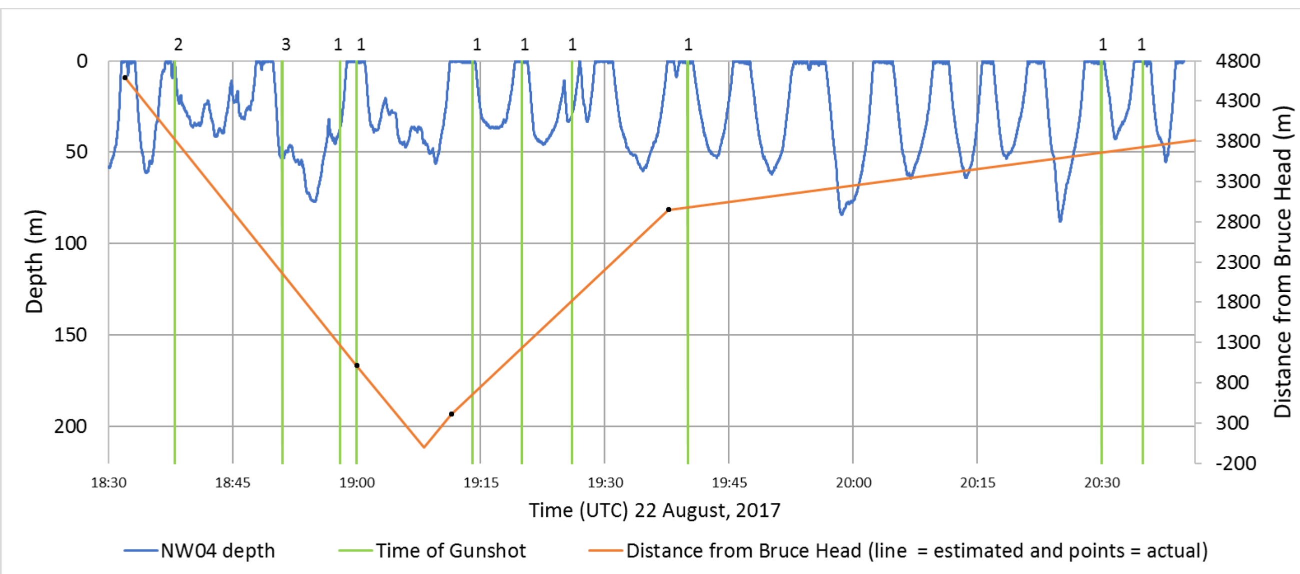

Figure 4-58: Dive behaviour of NW04 in relation to gunshot events recorded at Bruce Head with distance from Bruce Head hunting camp

Note: The number presented above each grey vertical line represents number of gunshots.

4.4 Summary of Key Findings

The following is a summary of key findings pertaining to narwhal behavioral response to Project-related vessel traffic based on a comparison of animal-borne tag data with AIS ship-tracking data:

Dive behavior:

- Surface time: The effect of distance from a large vessel on narwhal surface time was statistically significant at close distances (P=0.001), with surface time decreasing when narwhal were within 2 km from a vessel.
- Dive rate: The effect of distance from a vessel on narwhal dive rate (dives/hour) was statistically significant at close distances only (≤2 km; *P*=0.002), with the probability of dive rate increasing from 0.443 during non-exposure periods to 0.501 and 0.686 when vessels were at 1 km and 0 km, respectively. Average dive rates were generally similar between exposure and no-exposure periods, while maximum dive rates were higher for all narwhal during non-exposure events (Figure 4-32).
- Bottom dive depth: The effect of distance from a vessel on narwhal dive depth was statistically significant at close distances (≤2 km; Figure 4-37). At distances less than 2 km from the vessel, the probability of deep dives for potentially feeding narwhal increased from 0.627 during non-exposure events to 0.882 at 0 km. At distances of 1 km and 0 km, the probability of deep dives for non-feeding narwhal increased from 0.137 during non-exposure events to 0.357 and 0.888, respectively. That is, both feeding and non-feeding narwhal tended to exhibit deep dives more often when a large vessel was within 2 and 1 km from the narwhal, respectively, indicative of a possible flight response (Figure 4-37).
- Time at depth: The effect of distance from a vessel on narwhal time spent at the bottom of a dive was not statistically significant (*P*≥0.1).
- Total dive duration: The effect of distance from a large vessel on narwhal total dive duration was found to be statistically significant (*P*=0.016), with dive duration decreasing when within 2 km from a vessel. However, limited data were incorporated into the model and results should be interpreted with caution.
- Descent speed: Narwhal descent velocity was determined to depend on dive depth and potential foraging. However, narwhal descent velocity did not significantly change with distance from vessels or between vessel exposure and non-exposure events.

Surface Behavior:

- Rate of direction change: Statistically significant effects of vessel exposure on narwhal travel direction was evident within 4 km ($P<0.05$) compared to when no large vessels were present within 10 km from narwhal. This analysis does not indicate whether narwhal were turning toward or away from the vessels but only that narwhal changed course at different rates depending on distance from vessels.
- Travel orientation relative to vessels: Narwhal travel orientation did not significantly change as a function of distance from vessels, suggesting no horizontal avoidance of vessels. As the dataset focused on the angles between narwhal and large vessels, the dataset available for modeling was restricted to cases where a large vessel was present, therefore no “no exposure” modeling was conducted.
- Horizontal displacement: In plotting locations of tagged narwhal relative to distance from vessels during exposure events, no GPS locations were evident within approximately 0.5 km of vessel’s port and starboard, 1 km of the vessel’s bow, and 1.5 km astern. Observed and model-predicted densities increased close to the vessel in all four directions relative to densities at distance. However, densities at both port and starboard directions continued increasing up to <1 km from the vessel, whereas densities at forward and astern directions peaked at 1 km and decreased <1 km, in accordance with the gap of recorded positions. Despite the difference in narwhal density astern/forward relative to port/starboard at the immediate vicinity of the vessels, narwhal distance and position relative to a vessel (forward, astern, port, starboard) was found to be not significant ($P=0.066$).
- Seasonal change and horizontal displacement: Temporal changes in distance between narwhal and vessels were found to decrease at close ranges over the course of the study period ($P<0.001$), suggesting potential habituation of narwhal to large vessel traffic.
- Habitat Re-Occupation: Overall, narwhal crossed the vessel track both shortly before and shortly after vessel passage (minimum value of 4 minutes), suggesting no long-term avoidance of the shipping corridor due to vessel passage.
- Travel speed: The analysis of narwhal travel speed indicated that while the effect of vessel exposure on narwhal was statistically significant ($P<0.001$), the effect of distance from vessel was not ($P=0.06$). Therefore, this result may be spurious and should be re-evaluated with supplementary data collected during the 2018 season.

5.0 DISCUSSION

An overview of narwhal surface and dive behavioural responses observed as part of the 2017 Tagging Study are presented in Table 5-1. Measurable changes in surface behaviour (e.g., increased turning rate in the presence of vessels) and certain dive behaviours (e.g., decreased likelihood of a bottom dive in the presence of vessels) were observed at distances up to 5 km from a ship. Other observed changes in narwhal dive behaviour were observed at distances under 2 km. This included a higher likelihood of deep dive behaviour in the presence of vessels, as depicted in the CPA figures as 'V' shaped dives (which typically are bottom dives). Narwhal tagging data suggest that most dive behavioural responses by narwhal are elicited at relatively close distances (<2 km) to a passing vessel, although several behavioral responses are observed at intermediate distances (up to 5 km), such as increased turning rate and decreased bottom dives, suggesting potential foraging effects are possible within this range. Depictions of vessel and narwhal location information in combination with narwhal dive data provide a unique opportunity to visually interpret narwhal behavioural responses to vessel traffic.

Table 5-1: Narwhal surface and dive behavioral responses to shipping events

Validated Hypotheses	Vessel Effects (or Non-Effects)	Report Section	Examples of CPA diagrams that potentially illustrate a significant effect
$H1_0$	Surface time does not significantly increase in the presence of Project-related shipping	4.2.1.2	
$H2_A$	The likelihood of narwhal presence at surface decreases at vessel distances <2 km.	4.2.1.2	NW01-11, NW02-1, NW02-12
$H3_A$	The probability of a narwhal diving increases at vessel distances <2 km.	4.2.1.3	
$H4_A$	For narwhal previously engaged in either shallow or bottom dives, the probability of a bottom dive increases at vessel distances <2 km.	4.2.1.4	
$H5_A$	For narwhal previously engaged in a bottom dive, the probability of a bottom dive decreases at vessel distances between 2 and 5 km.	4.2.1.4	NW02-10, NW03-3 NW04-3, NW04-15, NW04-18
$H6_0$	Time at depth is not significantly affected by vessel distance.	4.2.1.5	
$H7_0$	Dive duration does not significantly increase during vessel exposure (as a function of distance from vessel).	4.2.1.6	
$H8_A$	Dive duration significantly decreases at vessel distances <2 km. Confidence in this prediction is low due to limited data at close vessel distances.	4.2.1.6	

Validated Hypotheses	Vessel Effects (or Non-Effects)	Report Section	Examples of CPA diagrams that potentially illustrate a significant effect
$H9_0$	Descent speed is not significantly affected by vessel distance. The ability of the model to detect a change in descent speed may be hindered by limited data at close vessel distances.	4.2.1.7	
$H10_A$	Narwhal turning rates significantly increase at vessel distances up to 4 km.	4.2.2.1 4.2.2.2	Turning rates: NW01-2, NW01-14, NW02-17, NW04-7
$H11_A$	At close ranges (~1 km), the observed distribution of animals fore/aft of vessels decreases in relation to animal density on either side of vessel, although the models indicated that the difference is not significant. Mean narwhal distance from vessel is shown to decrease over the course of the study period which may suggest some level of habituation. Horizontal displacement from the shipping lane appears to be temporary, as narwhal are shown to reoccupy vessel corridor within several minutes following a vessel passage.	4.2.2.3 4.2.2.4 4.2.2.5	Temporary displacement: NW01-11, NW01-17, NW02-7, NW02-14, NW04-9
$H12_0$	Narwhal swim speed does not significantly increase in the presence of vessel traffic.	4.2.2.6	
$H13_A$	Narwhal swim speed decreases from 1.0 m/s to 0.8 m/s during vessel exposure (within 10 km). The difference in swim speed is slight and potentially spurious given that vessel distance was not significant.	4.2.2.6	

The indicator threshold (i.e., trigger for adaptive management) established in the FEIS for narwhal disturbance from Project vessel noise was identified as ≥10% of narwhals in the RSA exhibiting a strong disturbance and/or avoidance reaction that leads to (seasonal) abandonment of areas identified as important habitat. Observed behavioural responses of narwhal to Project-related vessel traffic and vessel noise were shown to be in agreement with impact predictions made in the FEIS, which stated that ‘narwhal are expected to exhibit temporary and localized avoidance behavior when encountering Project vessels along the shipping route’. Of note, the finding that no tagged narwhal occurred within 0.5 km of a vessel’s port and starboard side, 1 km of its bow, and 1.5 km of its stern suggests that narwhal likely actively avoid close encounters with ships and would be subject to localized horizontal displacement effects if the individual(s) occurred within close proximity to the shipping lane during an active vessel passage. Observed behavioral responses by narwhal, such as decreased surface time and increased dive rate and dive depth at close distance to vessels, also supports the flight response theory and contradicts the freeze response theory. Despite measurable changes observed in surface and dive behavior, the responses of narwhal to vessel encounters were shown to be temporary, variable among individuals, and variable between vessel encounters by the same individual, suggesting that disturbance and/or avoidance reactions were unlikely to lead to abandonment of Milne Inlet and adjacent water bodies. It is important to note that the dive behaviour models were based on a limited amount of near-field distance data, and therefore results should be interpreted with caution. In addition, dive behaviour and surface behaviour analyses were based on movement data from four and 12 tagged narwhal, respectively, both collected over a single season. As more data become available from future tagging efforts, the relationship between vessel distance and narwhal surface and dive behavior will be re-evaluated.

The indicator threshold established in the FEIS for narwhal hearing impairment from Project vessel noise was identified as ≥ 10% of narwhals in the RSA being exposed to ship noise levels exceeding 175 dB re: 1 µPa (rms) over a duration of 100 s (BIM 2013). While one of the initial objectives of the Tagging Study was to assess the response of narwhal to Project-related vessel noise and fluctuations in the ambient sound field, none of the narwhal fitted with acoustic recording tags (Acousonde 3B) travelled within 10 km of the Northern Shipping Route during the period that the tags remained fastened to the animal. Therefore, sound levels received by narwhal in the vicinity of Project-related vessel traffic could not be evaluated as part of this study. The contribution of vessel noise to the acoustic environment throughout Milne Inlet and adjacent water bodies was, however, monitored during the 2018 open-water season using five autonomous recorders deployed along the shipping corridor near Bruce Head by JASCO Applied Sciences (Frouin-Mouy et al. 2019). During the two-month recording period, sound levels did not exceed the established injury threshold for high-frequency cetaceans (198 dB re: 1 $\mu Pa^{2} \cdot s$; SEL_{24h}) at any of the five recorders and exceedances of the marine mammal disturbance threshold (120 dB re 1 µPa; SPL_{rms}) were shown to be rare at all five recording stations (<1% of the deployment period).

Distances at which behavioural responses were observed in the Tagging Study are generally smaller than the zones of acoustic disturbance predicted through acoustic modelling in which disturbance was predicted to occur at ranges extending from 9 km to 19 km for a Post-Panamax vessel transiting at 9 knots through Milne Inlet. The discrepancy between measured and modelled disturbance distances relevant to vessel noise may be due to a variety of factors including animal habituation to vessel noise, site-specific noise propagation limitations, overly conservative model assumptions, and/or the lack of weighting applied to the disturbance threshold to account for species-specific hearing abilities. This is particularly relevant for narwhal, given that the majority of sound generated by large vessels is concentrated in lower frequencies between 20 and 200 Hz, which is well below the main frequency range used by narwhal for communication (1 kHz to 20 kHz) and echolocation (10 to 100 kHz) (Tougaard et al. 2014; Veirs et al. 2016), and is therefore assumed to be outside their sensitive hearing range.

The present study results are not directly comparable to narwhal behavioural patterns observed as part of the Bruce Head Shore-based Monitoring Program given differences in study design and data collection methods. The Bruce Head Shore-based Monitoring Program did not measure individual dive responses in narwhal, was limited in spatial scale (Bruce Head specific) and applied several different analytical parameters such as vessel travel direction. The 2017 Narwhal Tagging Study did not account for vessel direction and was not tied to a specific geographic location. That said, *ad lib* observations recorded by observers at Bruce Head were in close agreement with behavioural responses observed in the current Study, where the response of narwhal to ore carriers was shown to be variable, ranging from ‘no obvious response’ (animals remained in close proximity to ore carriers as they transited through the Study Area), to temporary and localized displacement and related changes in behaviour (Golder 2018). This highlights the value of remote sensing (i.e., tagging) technologies in providing insight into animal behavior that would otherwise be difficult to detect and/or quantify. Although land-based observers can track narwhal activity at the surface, their ability to link subsequent sightings to the same individuals is limited and impedes the ability to interpret dive behaviour.

6.0 RECOMMENDATIONS

The following are recommendations for future monitoring efforts with respect to the Narwhal Tagging Study:

- The temporal distribution of narwhal positions based on GPS data is coarse and somewhat irregular which can lead to less precise estimates of narwhal-vessel distances and subsequently introduce noise when attempting to link distance effects with narwhal behaviours. Additionally, the sparse temporal resolution of the GPS data impedes the ability to detect fine scale geographic movements of the animal to a vessel passage. For future tagging efforts, we recommend increasing the frequency of GPS transmissions when setting up programming for the tags.
- Hunting activities (i.e., noise from gunshots or small vessel passage) are well known to have a significant effect on narwhal behaviour (e.g., Golder 2018). Hunting effects were not accounted for in the present analysis. It was assumed that many of the tagged whales likely encountered hunting activities at some point during the tag deployment period. Narwhal responses specific to hunting events are likely to contribute noise into the dataset and potentially obscure any vessel-specific effects (or non-effects). Ongoing monitoring efforts at Bruce Head will attempt to better document hunting activities in this region, with this information potentially used as a covariate in future analyses of the tagging data.
- The present dive response analysis was based on four of the 20 narwhal tagged in 2017, focusing on those individuals with the highest resolution dive data. Future analysis of the dive data may benefit from inclusion of dive data from the broader 2017 tagging dataset, in addition to dive data yielded from two narwhal tagged in 2018.
- Future investigations may benefit from alternate approaches for analyzing narwhal dive and location datasets. An analysis may be possible akin to the hidden Markov model approach developed by Ngo et al. (2018) for narwhal in Greenland. A benefit of this analysis methodology is the potential to incorporate a detailed analysis of dive types (e.g. analyzing dive shape, etc.).
- Unfortunately, none of the narwhal fitted with acoustic recording tags (Acousonde 3B; Greeneridge Sciences) ever entered Milne Inlet or Eclipse Sound during the period tags remained on the animal. For this reason, the acoustic behavior of narwhal in relation to large vessel traffic and associated noise could not be assessed. Like all cetaceans, narwhal rely on the transmission and reception of sound in order to carry out the majority of critical life functions. They are a highly vocal species that produce a combination of pulsed calls, clicks, and whistles in order to communicate, navigate, and forage (Ford and Fisher 1978; Marcoux et al. 2011; Rasmussen et al. 2015). Relatively little is known however on specific call characteristics of narwhal and the potential context-specific variation among individuals and groups given their remote Arctic distribution (Marcoux et al. 2012). Therefore, future work will explore whether the frequency, intensity, and duration of different narwhal call types changes in the presence of large vessel traffic. By analyzing the data from acoustic recording tags deployed on narwhal during the 2018 open-water season, potential thresholds above which received sound levels correspond to a change in narwhal vocalizations and/or locomotive behavior may also be explored. This analysis is currently in process through a collaborative study between Golder, JASCO, the University of New Brunswick and Baffinland.
- Although two of the focal animals in this study were outfitted with MBLog Mini acceleration data loggers (Maritime Biologgers), both tags released from the narwhal before they entered into Milne Inlet in early August. As described in previous studies (Goldbogen et al. 2006, 2011; McKenna et al. 2015), the angle and speed of ascents and descents is a valuable metric to analyze when assessing locomotive response of

cetaceans to vessel traffic. Future work will therefore incorporate the deployment of acceleration data loggers on a greater number of narwhal during tag deployments.

- Future analyses of the tagging data will attempt to include variables that may assist in identification of adaptive management measures, including:
  - Consideration of multiple vessels (i.e. convoys) interactions in the model.
  - Consideration of vessel direction relative to the narwhal in the model (i.e., testing for potential differences between approaching and departing vessels - before or after CPA; facilitating the measurement of the duration of behavioural effects).
  - Consideration of vessel direction – i.e., north- or southbound, which could be important due to differences in load status and associated noise output.
  - Consideration of different vessel speeds in the model.

7.0 CLOSURE

We trust that this report provides sufficient information for your present needs. If you have any questions, please do not hesitate to contact the undersigned.

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APPENDIX A

Turning Angle Plots

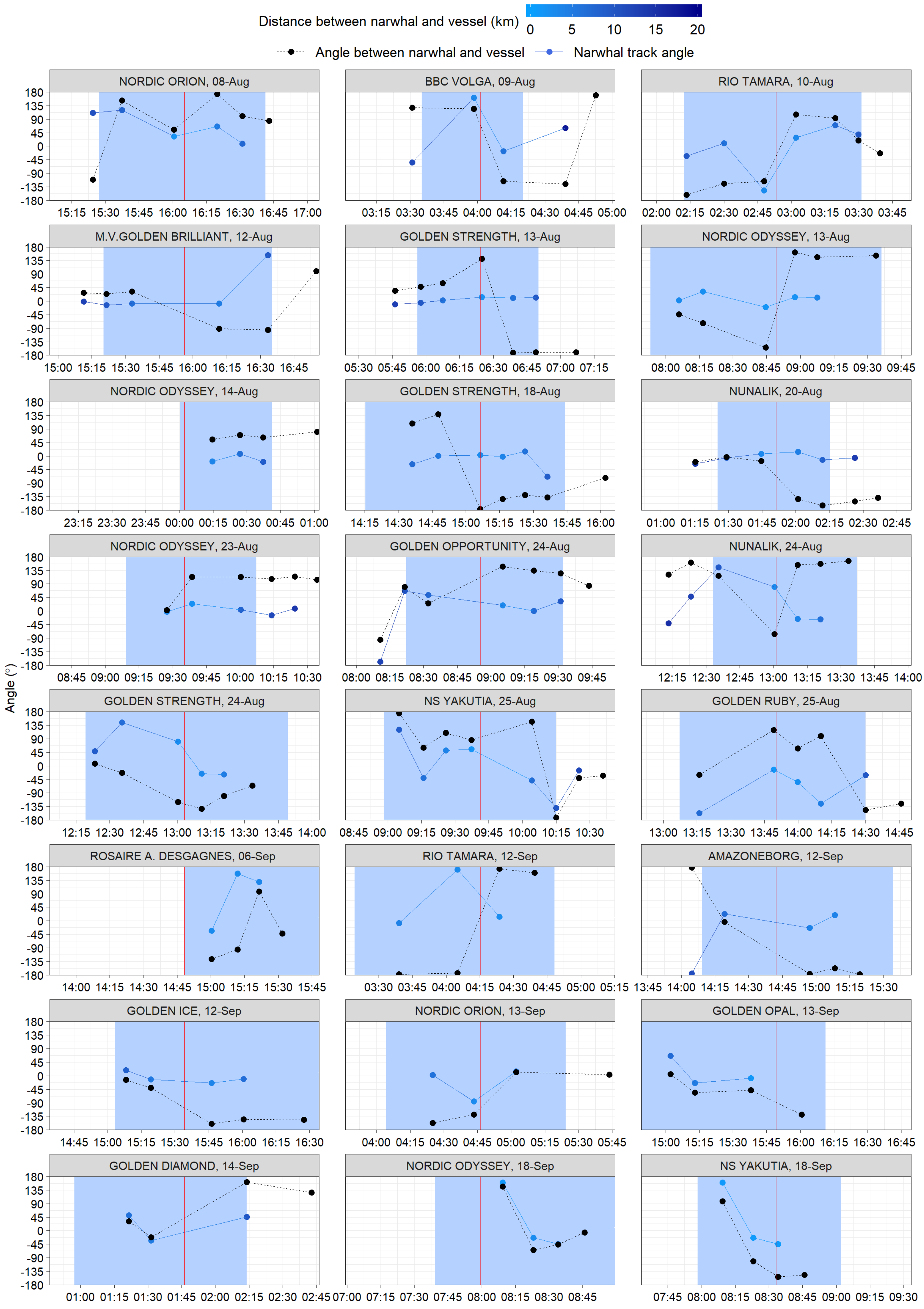

Figure A1. Angle between NW01 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤ 10 km from vessel) is depicted as a blue rectangle.

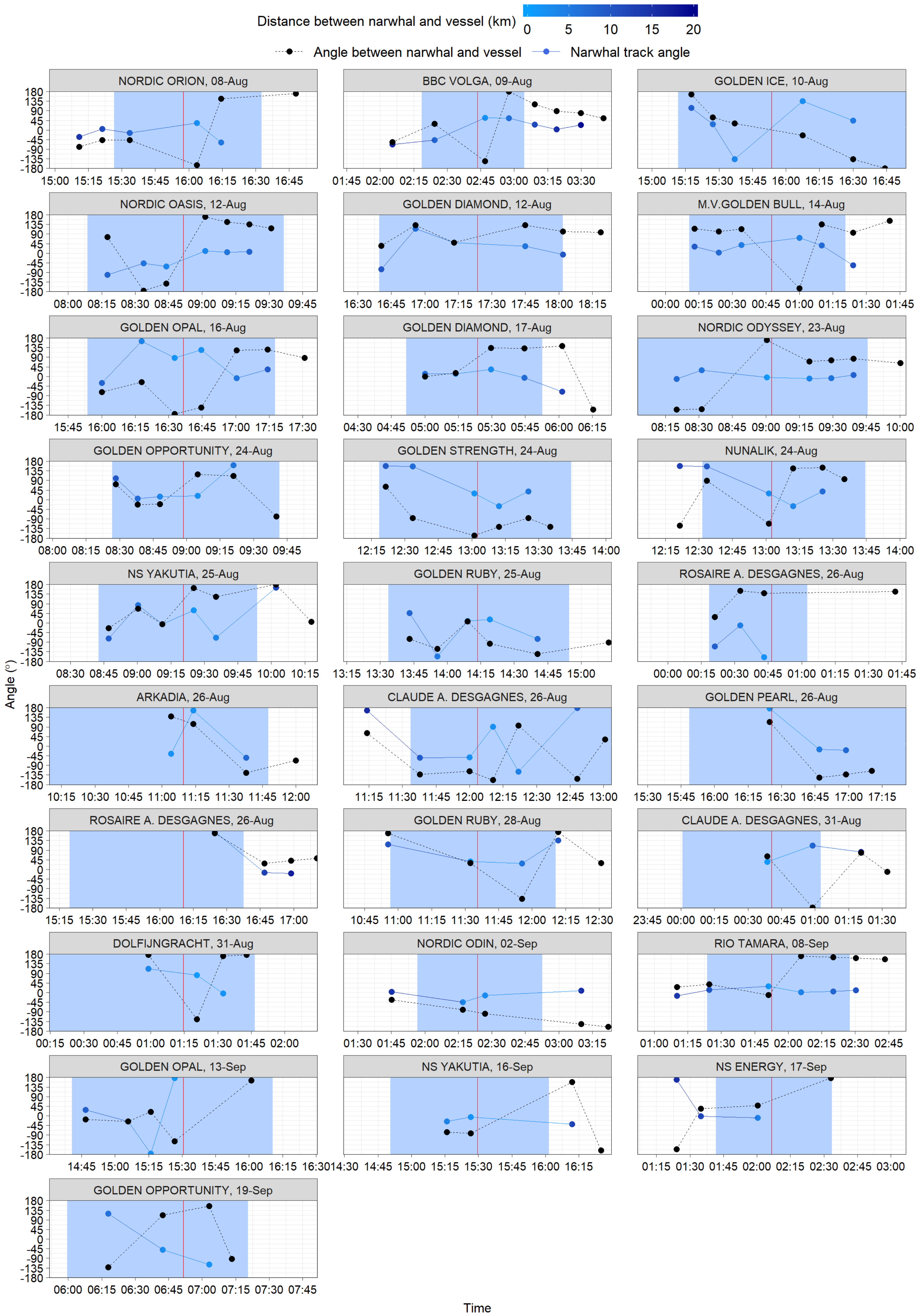

Figure A2. Angle between NW02 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤10 km from vessel) is depicted as a blue rectangle.

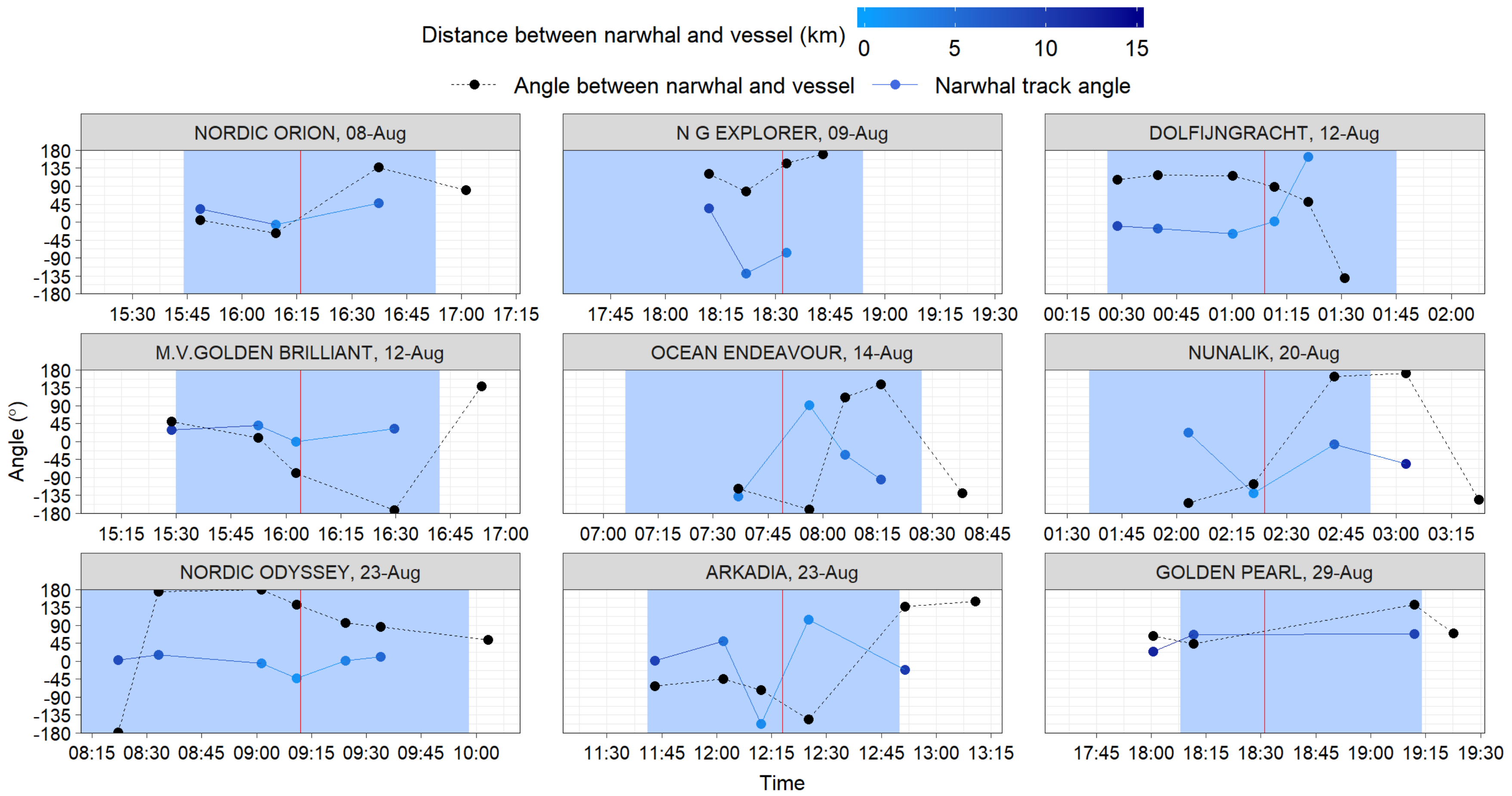

Figure A3. Angle between NW03 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤10 km from vessel) is depicted as a blue rectangle.

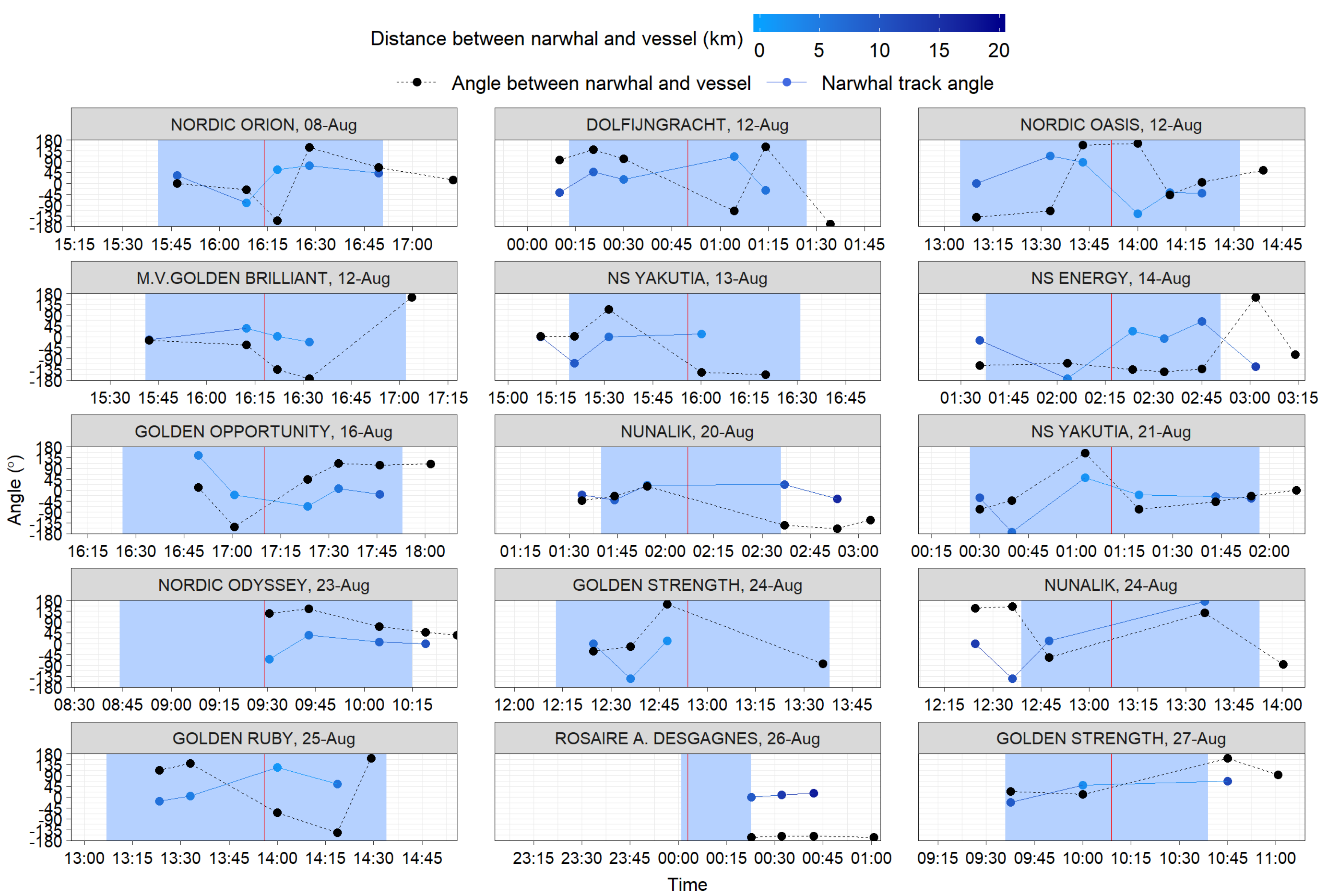

Figure A4. Angle between NW04 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤ 10 km from vessel) is depicted as a blue rectangle.

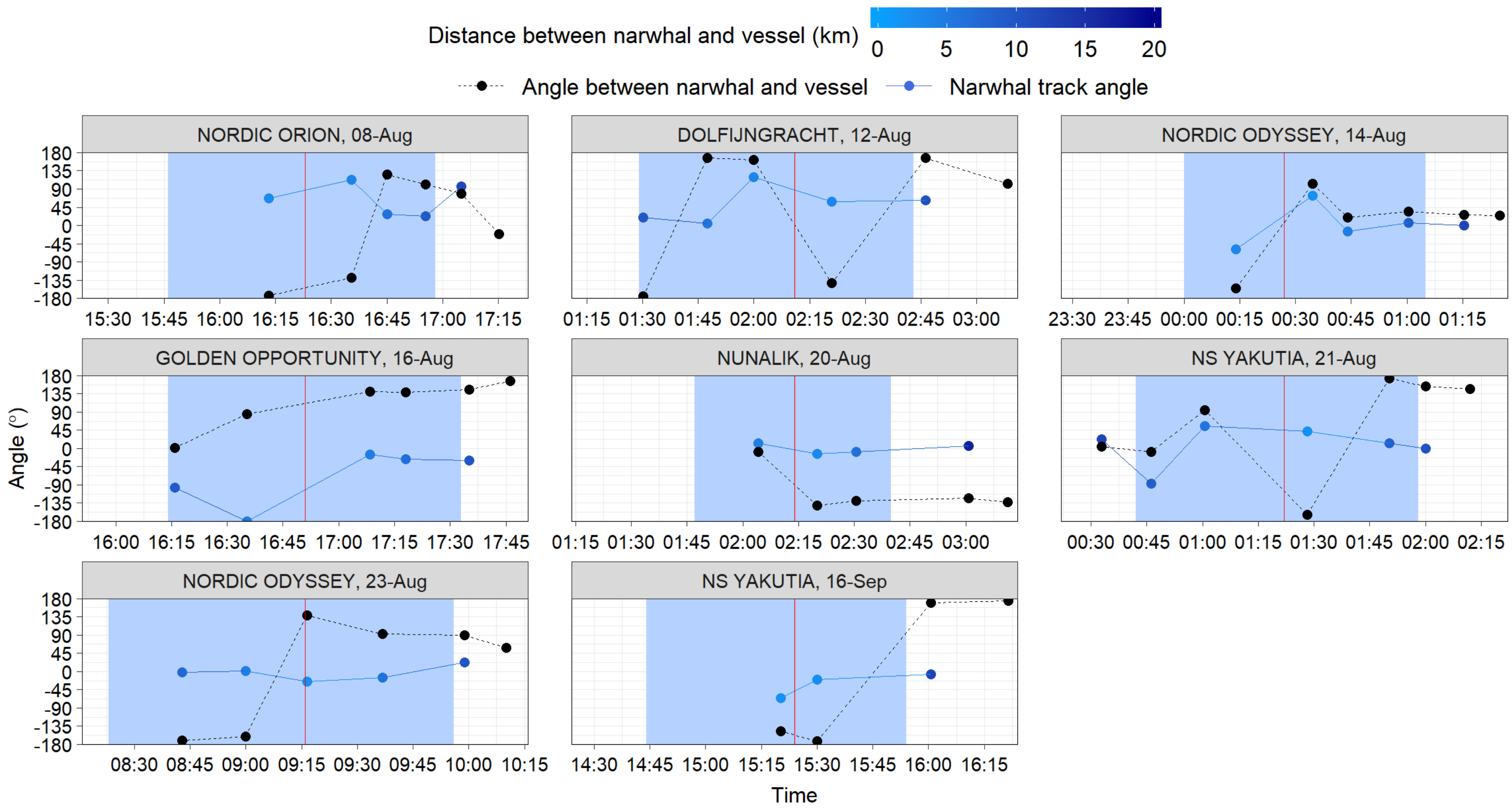

Figure A5. Angle between NW07 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤ 10 km from vessel) is depicted as a blue rectangle.

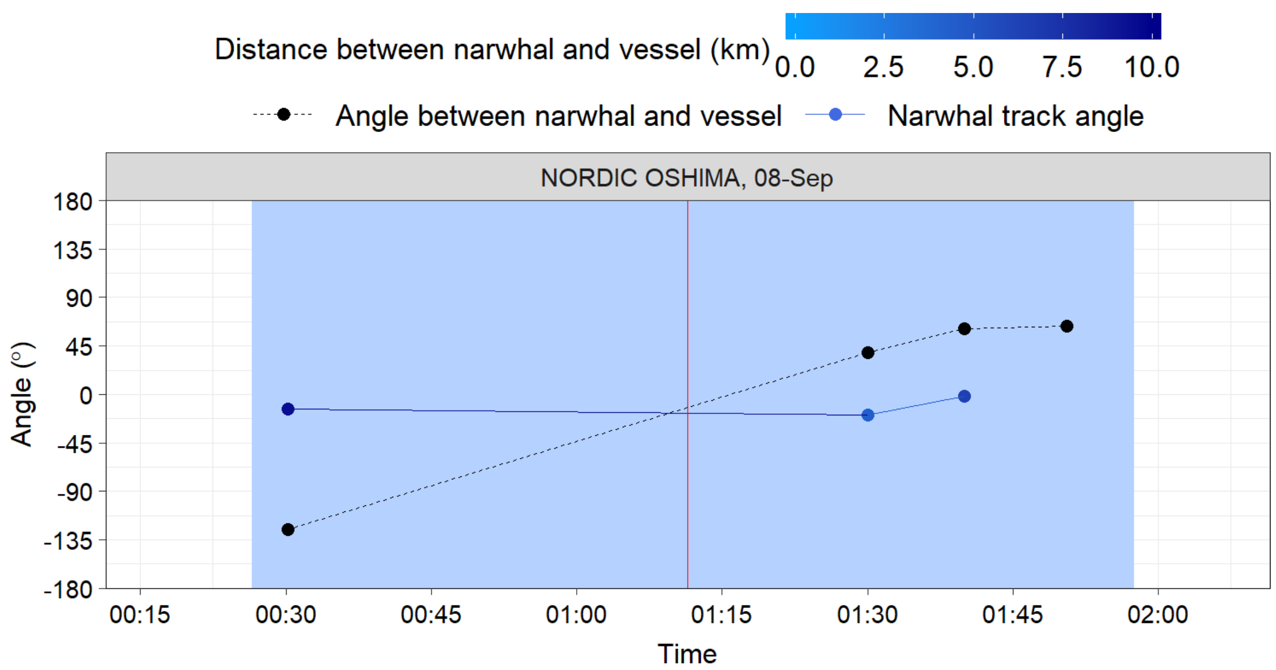

Figure A6. Angle between NW08 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤ 10 km from vessel) is depicted as a blue rectangle.

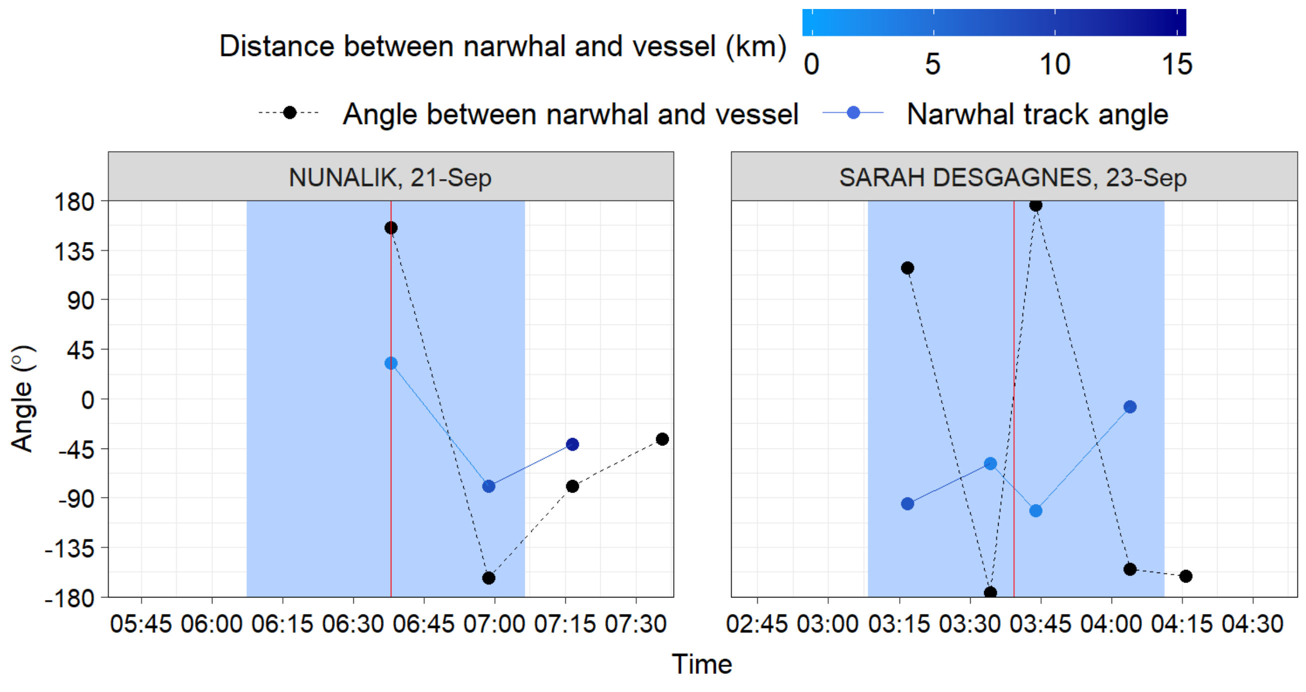

Figure A7. Angle between NW09 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤ 10 km from vessel) is depicted as a blue rectangle.

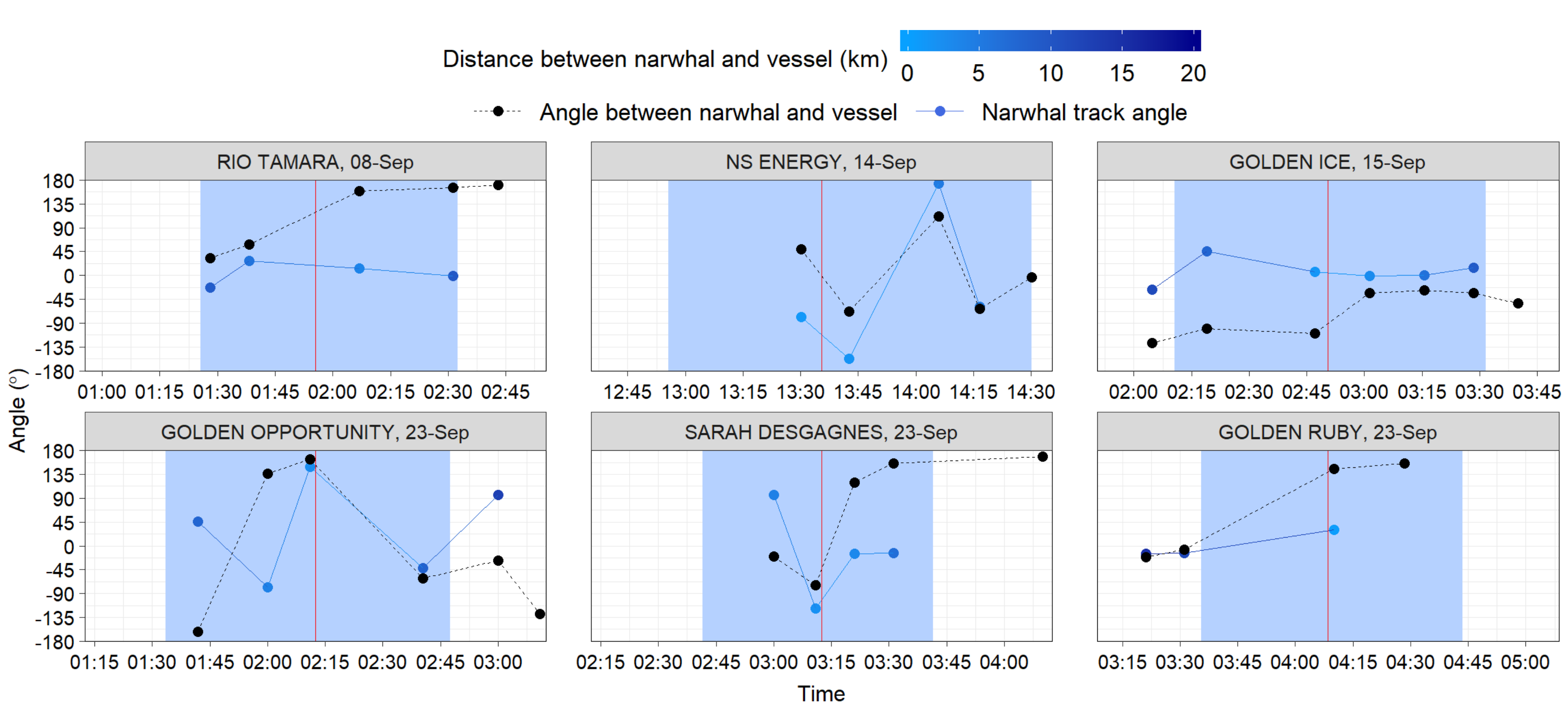

Figure A8. Angle between NW13 and Project-related vessels (black dashed line) and turning angles on narwhal track (solid line, coloured by distance from vessel). Time of CPA is indicated by a red vertical line, and exposure period (narwhal ≤ 10 km from vessel) is depicted as a blue rectangle.

APPENDIX B

Model Test Statistics and Coefficient Summaries

Dive Behaviour in Relation to Vessel Traffic

Surface Time

Table B-1: Test statistics of logistic model of presence/absence of narwhal at surface

Parameter	Chi squared	Df	*P* value
Distance from vessel (4th degree polynomial)	25.533	4	<0.001
Effect of exposure	0.560	1	0.454
Effect of narwhal presence at surface in the preceding 1 min interval	44249.2	1	<0.001

Table B-2: Coefficient estimates for fixed effects in a mixed logistic model of presence/absence of narwhal at surface

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, narwhal not at surface in the preceding 1 min interval)	0.131	0.031	4.200	<0.001
Distance from vessel[1]	-0.384	2.859	-0.130	0.893
Distance from vessel squared[1]	-3.443	4.420	-0.780	0.436
Distance from vessel cubed[1]	6.584	2.951	2.230	0.026
Distance from vessel to the fourth[1]	-12.870	3.281	-3.920	<0.001
Exposure	0.020	0.027	0.750	0.454
Narwhal at surface in the preceding 1 min interval	-1.625	0.008	-210.350	<0.001

[1] = Variable was standardized prior to modeling; in addition, orthogonal polynomials were used, hence the coefficients cannot be interpreted simply as change in response variable with 1 SD change in predictor variable.

Bottom Dive Depth

Table B-3: Test statistics of logistic model of presence/absence of bottom dives

Parameter	Chi squared	Df	*P* value
Distance from vessel (4th degree polynomial)	15.876	4	0.003
Effect of whether the preceding dive was deep	2869.559	1	<0.001
Effect of bathymetry	57.195	1	<0.001
Effect of exposure	1.321	1	0.250
Effect of distance from shore	5.992	1	0.014
Interaction between distance from vessel and whether the preceding dive was deep	31.043	4	<0.001

Table B-4: Coefficient estimates for fixed effects in a mixed logistic model of presence/absence of bottom dives

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive)	-0.778	0.155	-5.010	<0.001
Distance from vessel [1]	10.290	3.291	3.130	0.002
Distance from vessel squared [1]	-3.784	5.048	-0.750	0.454
Distance from vessel cubed [1]	-5.908	3.000	-1.970	0.049
Distance from vessel to the fourth [1]	10.319	3.706	2.780	0.005
Preceding dive was a bottom dive	-1.162	0.022	-52.940	<0.001
Effect of bathymetry [2]	-0.242	0.032	-7.560	<0.001
Exposure	0.095	0.083	1.150	0.250
Effect of distance from shore [2]	0.076	0.031	2.450	0.014
Interaction between distance from vessel [1] and whether the preceding dive was deep	-14.738	3.293	-4.470	<0.001
Interaction between distance from vessel squared [1] and whether the preceding dive was deep	10.403	3.161	3.290	0.001
Interaction between distance from vessel cubed [1] and whether the preceding dive was deep	0.705	2.959	0.240	0.812
Interaction between distance from vessel to the fourth [1] and whether the preceding dive was deep	-2.803	3.159	-0.890	0.375

[1] = Variable was standardized prior to modeling; in addition, orthogonal polynomials were used, hence the coefficients cannot be interpreted simply as change in response variable with 1 SD change in predictor variable. [2] Variable was standardized prior to modeling.

Time at Depth

Table B-5: Test statistics of model of time spent at bottom 80% of each dive

Parameter	Chi squared	Df	*P* value
Distance from vessel (3rd degree polynomial)	5.550	3	0.136
Effect of exposure	0.447	1	0.504
Effect of whether the preceding dive was a bottom dive	25.794	1	<0.001
Effect of maximum dive depth	10470.645	2	<0.001
Effect of whether the current dive was a bottom dive	176.241	1	<0.001
Interaction between maximum dive depth and whether the dive was a bottom dive	18.502	2	<0.001
Interaction between whether the preceding dive was a bottom dive and whether the current dive was a bottom dive	100.190	1	<0.001

Table B-6: Coefficient estimates for fixed effects in a mixed model of time spent at bottom 80% of each dive

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive, current dive not bottom dive)	1.240	0.028	44.000	<0.001
Distance from vessel [1]	1.026	0.450	2.280	0.023
Distance from vessel squared [1]	-0.126	0.657	-0.190	0.848
Distance from vessel cubed [1]	-0.264	0.455	-0.580	0.562
Exposure	0.007	0.011	0.670	0.504
Preceding dive was a bottom dive	0.017	0.005	3.500	<0.001
Effect of maximum dive depth [1]	52.646	1.065	49.450	<0.001
Effect of maximum dive depth squared [1]	-31.134	0.841	-37.010	<0.001
Effect of whether the current dive is a bottom dive	-0.094	0.006	-14.720	<0.001
Interaction between maximum dive depth [1] and whether the current dive is a bottom dive	-3.761	1.069	-3.520	<0.001
Interaction between maximum dive depth squared [1] and whether the current dive is a bottom dive	-3.237	0.836	-3.870	<0.001
Interaction between whether the current dive is a bottom dive and whether the preceding dive was a bottom dive	0.049	0.005	10.010	<0.001

[1] = Variable was standardized prior to modeling; in addition, orthogonal polynomials were used, hence the coefficients cannot be interpreted simply as change in response variable with 1 SD change in predictor variable.

Total Dive Duration

Table B-7: Test statistics of model of total dive duration

Parameter	Chi squared	Df	*P* value
Distance from vessel (3rd degree polynomial)	10.266	3	0.016
Effect of exposure	0.031	1	0.861
Effect of maximum dive depth (3rd degree polynomial)	36377.813	3	<0.001
Effect of whether the current dive was a bottom dive	62.756	1	<0.001
Effect of whether the preceding dive was a bottom dive	123.950	1	<0.001
Interaction between whether the preceding dive was a bottom dive and whether the current dive was a bottom dive	3.991	1	0.046

Table B-8: Coefficient estimates for fixed effects in a mixed model of total dive duration

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive, current dive not bottom dive)	5.321	0.269	19.750	<0.001
Distance from vessel [1]	3.389	1.971	1.720	0.086
Distance from vessel squared [1]	-1.847	2.879	-0.640	0.521
Distance from vessel cubed [1]	5.056	1.993	2.540	0.011
Effect of exposure	-0.008	0.047	-0.180	0.861
Effect of maximum dive depth [1]	482.700	2.608	185.110	<0.001
Effect of maximum dive depth squared [1]	-167.900	2.179	-77.080	<0.001
Effect of maximum dive depth cubed [1]	78.140	2.008	38.920	<0.001
Effect of whether the current dive is a bottom dive	-0.220	0.027	-8.060	<0.001
Effect of whether preceding dive was a bottom dive	0.230	0.022	10.690	<0.001
Interaction between whether the current dive is a bottom dive and whether the preceding dive was a bottom dive	0.043	0.021	2.000	0.046

[1] = Variable was standardized prior to modeling; in addition, orthogonal polynomials were used, hence the coefficients cannot be interpreted simply as change in response variable with 1 SD change in predictor variable.

Descent Speed

Table B-9: Test statistics of model of descent speed

Parameter	Chi squared	Df	*P* value
Distance from vessel (3rd degree polynomial)	5.413	3	0.144
Effect of exposure	0.520	1	0.471
Effect of whether the preceding dive was a bottom dive	373.903	1	<0.001
Effect of whether the current dive was a bottom dive	0.074	1	0.786
Effect of maximum dive depth	11636.398	3	<0.001

Table B-10: Coefficient estimates for fixed effects in a mixed model of descent speed

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive, current dive not bottom dive)	0.644	0.021	29.980	<0.001
Distance from vessel [1]	-0.133	0.180	-0.740	0.458
Distance from vessel squared [1]	0.306	0.263	1.160	0.244
Distance from vessel cubed [1]	-0.314	0.182	-1.730	0.084
Exposure	0.003	0.004	0.720	0.471
Effect of whether preceding dive was a bottom dive	-0.038	0.002	-19.340	<0.001
Effect of whether the current dive is a bottom dive	0.001	0.002	0.270	0.786
Effect of maximum dive depth [1]	25.117	0.238	105.550	<0.001
Effect of maximum dive depth squared [1]	-8.311	0.198	-41.950	<0.001
Effect of maximum dive depth cubed [1]	3.238	0.184	17.620	<0.001

[1] = Variable was standardized prior to modeling; in addition, orthogonal polynomials were used, hence the coefficients cannot be interpreted simply as change in response variable with 1 SD change in predictor variable.

Surface Behaviour in Relation to Large Vessel Traffic

Rate of Direction Change

Table B-11: Test statistics of mixed model of turning rates

Parameter	Chi squared	Df	*P* value
Effect of exposure	1.006	1	0.316
Effect of distance from shore	26.825	1	<0.001
Effect of distance from vessel	28.488	2	<0.001

Table B-12: Coefficient estimates for fixed effects in a mixed model of turning rates

Parameter	Coefficient	SE	t value	*P* value
Intercept (no exposure)	39.909	2.331	17.119	<0.001
Effect of exposure	-1.092	1.089	-1.003	0.316
Effect of narwhal distance from shore [2]	-1.648	0.318	-5.179	<0.001
Effect of distance from large vessel [1]	-207.712	43.113	-4.818	<0.001
Effect of distance from large vessel squared [1]	145.051	63.106	2.299	0.022

[1] = Variable was standardized prior to modeling; in addition, orthogonal polynomials were used, hence the coefficients cannot be interpreted simply as change in response variable with 1 SD change in predictor variable. [2] = Variable was standardized prior to modeling.

Table B-13: Test statistics of mixed model of travel orientation relative to vessels

Parameter	Chi squared	Df	*P* value
Effect of distance from vessel	6.875	3	0.076

Table B-14: Coefficient estimates for fixed effects in a mixed model of travel orientation relative to vessels

Parameter	Coefficient	SE	t value	*P* value
Intercept (no exposure)	104.989	3.118	78.128	<0.001
Effect of distance from large vessel [1]	-135.169	52.596	341.822	0.011
Effect of distance from large vessel squared [1]	-6.416	52.498	338.225	0.903
Effect of distance from large vessel cubed [1]	23.694	52.919	349.394	0.655

[1] = Variable was standardized prior to modeling; in addition, orthogonal polynomials were used, hence the coefficients cannot be interpreted simply as change in response variable with 1 SD change in predictor variable.

Seasonal Change and Horizontal Displacement

Table B-15: Test statistics of mixed model of habituation (distance between narwhal and vessel over time)

Parameter	Chi squared	Df	*P* value
Day-time of study (where 1 is Aug 2, 2018 at 08:00)	18.291	1	<0.001

Table B-16: Coefficient estimates for fixed effects in a mixed model of habituation

Parameter	Coefficient	SE	t value	*P* value
Intercept	7.618	0.329	23.167	<0.001
Day-time of study (where 1 is Aug 2, 2018 at 08:00)	-0.039	0.010	-4.277	<0.001

Travel Speed

Table B-17:Test statistics of mixed model of travel speed

Parameter	F value	Df	*P* value
Exposure	10.313	1, 17376	<0.001
Distance	1.055	1, 17372	0.059

Table B-18: Coefficient estimates for fixed effects in a mixed model of travel speed

Parameter	Coefficient	SE	t value	*P* value
Intercept (no exposure)	0.921	0.029	31.500	<0.001
Effect of exposure	0.054	0.009	5.906	<0.001
Effect of distance from large vessel	0.033	0.018	1.889	0.059

[2] = Variable was standardized prior to modeling

golder.com

Baffinland

Name: Laura Watkinson

Agency / Organization: DFO Science

Date of Comment Submission: April 2, 2019

#	Document Name	Section Reference	Comment	Baffinland Response
1	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 25	BIM states that "*For the analysis, it was hypothesized that the effect of large vessels on Narwhal behaviour will be within 10 km from the vessel. This value was selected as an appropriate distance to delineate exposure vs non-exposure zones as the 120 dB re: 1µPa (SPLrms) disturbance threshold was predicted to propagate 9.82 km < Rmax < 19.24 km from a Post-Panamax vessel transiting at 9 kts through Milne Inlet, according to acoustic modeling results (Quijano et al. 2017). The area within the 10 km distance from any large vessel was termed an exposure zone, and Narwhal behaviour was compared relative to whether they were within or outside of exposure zones*". DFO Science is concerned that Narwhal can probably hear a vessel when the received sound levels are > 100 dB re: 1 µPa (SPL_{rms}). DFO Science suggests to explore the reaction of Narwhals beyond 10 km, particularly for avoidance behavior.	Although narwhal are likely exposed to vessel sound > 100 dB re: 1 µPa, the threshold for behavioral disturbance is 120 dB re 1 µPa and there is no evidence in the literature that suggests that narwhal would be adversely affected by sound levels below this. Furthermore, the behavioral threshold commonly referred to in the literature is not 'weighted' to account for the frequency range in which marine mammals are most sensitive to hearing. Of note, the majority of underwater sound generated by vessel traffic is concentrated below 200 Hz (Veirs et al. 2016), which is well below the assumed peak hearing sensitivity of narwhal (>1 kHz). The distance used to delineate exposure vs non-exposure zones (i.e. 10 km) is supported by acoustic modelling conducted by JASCO in which the majority of the disturbance noise field falls within 10 km of the source. Based on passive acoustic monitoring undertaken in 2018, 10-km appears to be an overestimate of the disturbance zone for narwhal (see

#	Document Name	Section Reference	Comment	Baffinland Response
				revised 2018 Passive Acoustic Monitoring Report).
2	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 25	DFO Science notes that a lot of the analysis conducted by Golder assess the difference in behavior of 4 Narwhals when they were in close proximity of a ship (< 10m) and when they were not. DFO Science suggests to explore the difference in movement and dive behavior between Narwhals that were exposed to shipping and Narwhals that were not. Since there was a vessel present everyday, the entire study could be considered as an impact study with no control.	As stated in the response to DFO Comment #1 (above), 10 km is considered a conservative distance to delineate exposure vs. non-exposure of narwhal to vessel sound, based on acoustic modeling results, 2018 acoustic monitoring results, and in consideration of the 120 dB threshold not being weighted to account for variable hearing sensitivities amongst different marine mammal hearing groups. Distance within the exposure zone was examined as a continuous variable (0-10 km) while animals outside of the exposure zone (10+ km) were assigned to a discrete non-exposure bin. Therefore, this approach was deemed appropriate for determining distances at which behavioral changes may occur for those exposed to vessel traffic and for assessing behavioral changes in narwhal exposed to shipping and those that are not. Based on the above points, Baffinland does not agree with the statement that 'the entire study could be considered as an impact

#	Document Name	Section Reference	Comment	Baffinland Response
				study with no control'; however, Baffinland will consider evaluating alternate exposure zone distances in the 2018 Narwhal Tagging Report, which will incorporate both 2017 and 2018 narwhal tagging data.
3	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 26	In the model to assess horizontal avoidance of vessels, the distance between Narwhals and vessel was entered as a second-degree polynomial. Also, in the model to assess the relative angles to vessels, the distance between Narwhals and vessel is entered as a third-degree polynomial. DFO Science requests the Proponent provide justification for entering the distance to the vessel as polynomial.	The relationship between narwhal response and distance from vessels is not linear. Even if it was linear within a certain distance from the vessel, it is not possible to identify prior to the analysis at what distance within the 10 km range the narwhal will commence the response. For example, significant effects on surface time were observed at <2 km from vessels, whereas significant effects on the probability of deep dives were observed at <5 km from vessels. The lack of linearity within the variable-specific effect zone and the differences in the distance at which effects are observed require the use of models that can fit these trends, such as polynomial, spline, or non-linear models. In all cases, preliminary data plots were used to identify the form of the modeled relationships relative to the predictor variables.
4	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 29	Surface time is defined as Narwhal depth < 7 m. DFO Science request precision on how the 7 m threshold was decided upon. DFO Science requests clarification if this definition corresponds to Narwhal length multiplied by cosine of 45°.	The choice of < 7 m for the surface cutoff was based on an existing study (Blackwell et al. 2018) where vocal behaviour was analyzed as a function of animal depth. The methods section of the 2017 narwhal tagging report has been revised to reflect this. Reference: Blackwell S.B., M. Tervo Outi, A.S. Conrad, M.H.S., Sinding,

#	Document Name	Section Reference	Comment	Baffinland Response
				R.G. Hansen, S. Ditlevsen, and M.P. Heide-Jørgensen M.P. 2018. Spatial and temporal patterns of sound production in East Greenland narwhals. PLoS ONE 13(6): e0198295.
5	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 41	DFO Science notes that Golder only reports p-values for the factors of the different analyses. DFO Science recommends that Golder report the value of the test statistics and an indication of the fit of the data. Golder should not make any statement on significance of the results without discussing how the fit of the data was inspected and how well the data fit the model. Furthermore, DFO Science recommends that Golder report the coefficient of each factor of the model, standard error, and degrees of freedom so proper assessment can be conducted.	P values were provided for both continuous and factor variables throughout the report. The fit of each model was assessed using diagnostic and residual plots following the modeling. The pseudo R^2 values were also reported for the models. All prediction plots also included data (raw whenever possible, summarized in other cases) to visualize the fit of the model relative to the collected data. Following DFO Science's comment, summary tables were added to the report for each modeling section (presented in Appendix B).
6	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 42	Golder models the angle between the vessel and Narwhals as a continuous variable. DFO Science is concerned with this methodology as angles are difficult to model because they are not linear and are instead on a circular axis. DFO Science recommends that Golder should revisit how the angle between the boat and the Narwhal is modeled and explore other model options. DFO Science suggests that a circular analysis would be ideal but might be hard to perform.	Yes, angle data are usually analyzed using circular models. However, since angles (both direction and angle relative to vessel) were only expressed as extending between 0° and 180° (as opposed to 0-359°), the circularity did not pose a problem for this analysis. The methods section in the report was edited to reflect this.

#	Document Name	Section Reference	Comment	Baffinland Response
7	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 50	(Figures 4-14 and subsequent figures): DFO Science has an issue with the color scale for ship speed that is green and red and suggests that Golder change the scale to accommodate color-blind individuals.	Figures were updated to blue-orange scale.
8	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 54-72	(Figures 4-16 to 4-34): DFO Science notes that these figures are very informative. DFO Science suggests putting the direction of the ship in the right of the figures since it is not clear from the color coding being used.	Noted. The direction of vessel travel has been incorporated into the figures.
9	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 73	Summary statistics for Narwhal surface time are presented in Table 4-5. DFO Science recommends putting the data of the table in the format of a figure.	As requested, the figures associated with each table were updated to provide the breakdown by exposure.
10	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg 97	Narwhal surface and dive behavior response to shipping events are presented in Table 5-1. DFO Science notes that this table is very useful to summarize the findings.	Noted.

#	Document Name	Section Reference	Comment	Baffinland Response
11	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Table 99	BIM states "*Observed behavioral responses in Narwhal during interactions with ships were shown to be in agreement with impact predictions made in the FEIS, which stated that "Narwhal are expected to exhibit temporary and localized avoidance behavior when encountering Project vessels along the shipping route: and that 'no abandonment or long-term displacement behavior is anticipated*'". DFO Science notes that this study does not investigate the displacement or abandonment of Narwhals. This study did not attempt to generate an estimate of the number of Narwhals present in the study area. This study only investigates the changes in behavior of Narwhals that stayed in the area. As mentioned by Golder ("*response to Narwhal to ore carries was shown to be variable*", Page 99), individual Narwhals are reacting differently to the presence of shipping. It is possible that some Narwhals' reactions to shipping was to avoid the Project area altogether. This study only investigated Narwhals that stayed within the Project area. As a result, it is not possible to extrapolate the results to Narwhals that were not tagged and might have been displaced by the Project. As previously mentioned, DFO Science recommends comparing the general behavior of Narwhals that stayed within the Project area with the ones that left.	Noted. The report has been edited to reflect that abandonment and long-term displacement could not be assessed by this study alone. However, of the 18 narwhal fitted with GPS location and dive tags, 16 (i.e., 89%) of these remained in the Regional Study Area (RSA) within vicinity of the shipping corridor during the majority of the open water season. Tagging data from these animals does not suggest abandonment or large-scale displacement due to shipping. The two whales that did not remain in the RSA traveled directly to Admiralty Inlet via Navy Board Inlet three days after being tagged. It is possible that these individuals left the RSA due to disturbance from shipping, due to disturbance from being tagged, or alternatively they travelled to Admiralty Inlet because this represented part of their normal summer range and summer habitat (acknowledging that there is known exchange between Eclipse Sound and Admiralty Inlet summering areas).

Name: Parks Canada – Natural Resource Conservation Branch (via Jacquie Bastick)

Agency / Organization: Parks Canada

Date of Comment Submission: March 29, 2019

#	Document Name	Section Reference	Comment	Baffinland Response
5	*2017 Narwhal Tagging Program Report*	5.0 Discussion	Results are not compared back to the thresholds established by Baffinland (FEIS 2013). These thresholds should be restated in each report (e.g.: in an appendix) and all results should be related back to them as well as compared (e.g.: trends) to all previous monitoring data.	Noted. New text has been added to the report which discusses thresholds in relation to results. The threshold identified in the FEIS (Baffinland 2012, 2013), which is defined as a 10% change in population, is not testable using a remote tagging study approach because not all animals in the population are tagged, and the sample size (n=18) is insufficient to extrapolate results to the broader Baffin Bay narwhal population. Early warning indicators and corresponding thresholds are currently being developed, in collaboration with the Marine Environmental Working Group (MEWG). Once these thresholds are established, results of monitoring programs will be assessed in relation to them.

#	Document Name	Section Reference	Comment	Baffinland Response
6	*2017 Narwhal Tagging Program Report*	4.3.7 Closest Point of Approach (CPA) Events	Paired vessels transits seem to result in longer disturbance periods than single vessel passages. With the proposed increase in shipping does Baffinland have estimates on the amount of paired vessels transits and the resulting estimated disturbance to narwhal?	In 2017, there was a total of 6 paired vessel transits in the vicinity (<10km) of tagged narwhal. The effect of paired vessel transits on narwhal behavior was not assessed in the current report. Therefore, it is unclear how Parks Canada has postulated that conclusion from the report. Baffinland is looking at incorporating paired vessel transits in the 2018 Narwhal Tagging Report which will incorporate both 2017 and 2018 narwhal tagging data.
7	*2017 Narwhal Tagging Program Report*	3.5.2 Horizontal Movement Relative to Distance from Vessel	Horizontal displacement and disturbance of narwhal does not take in to account the changing geography of Milne Inlet. Analysis of horizontal displace should consider the limitations of animals to move in pinch points such as Milne Inlet.	Comment noted. Future analyses may consider incorporation of geographical differences into the models by using additional covariates, such as channel width across vessel track.

Baffinland

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Agency / Organization: Qikiqtani Inuit Association

Date of Comment Submission: 31 March 2019

#	Document Name	Section Reference	Comment	Baffinland Response
1	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 1, s. 1.0 Introduction	Suggest replacing "summering herd" with "summer stock" (as used by DFO), or "summer aggregation", etc., as "herd" is used differently in other reports (e.g., Bruce Head project) ((and on pg. 7, 12 in this report)	Comment noted. Reference to "summering herd" in introduction replaced with "summer stock".
2	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 3, s. 1.1 Overview of Narwhal Tagging Program	Re: Condition 111, how can the work described here contribute to the development of "clear thresholds for determining if negative impacts as a result of vessel noise are occurring"?	Baffinland is in the process of re-evaluating how to best identify thresholds for determining if negative impacts to narwhal are occurring as a result of vessel noise exposure. This has been identified as a discussion point for upcoming meetings with the MEWG.
3	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 5, s. 2.1 Population Status and Abundance	There is no "Eastern High Arctic - Baffin Bay" narwhal stock recognized by COSEWIC (2004). This name is used for the beluga whale population that resides in the area, and COSEWIC uses "Baffin Bay" for the narwhal population. There is a typo in the 2010 DFO CSAS Research Document on odontocete stock structure (by P. Richard) which is presumably where this error is coming from.	Comment noted. Reference to "Eastern High Arctic - Baffin Bay" narwhal stock removed.

#	Document Name	Section Reference	Comment	Baffinland Response
4	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 5, s. 2.1 Population Status and Abundance	"... and an abundance estimate of approximately half as many narwhal in 2013 (n = 10,489) was likely not representative of actual numbers." What evidence is there to support this statement re: the estimate, given that narwhal are known to move between ES and Admiralty Inlet (AI) and the corresponding AI estimate was ca. 10,000 higher than the previous survey estimate?	Text has been revised for clarity: "The 2013 Eclipse Sound population estimate is not likely representative of a change in the actual stock size, but of year to year variation in the geographic distribution of that stock."
5	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 6, s. 2.1 Population Status and Abundance	There isn't "possible movement" between these two putative summer stocks, as tagging studies have confirmed it. The degree to which it occurs in uncertain, but it definitely happens.	Comment noted. Text has been revised to reflect this.
6	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 6, s. 2.2 Geographic and Seasonal Distribution	In regards to Canadian Arctic and West Greenland waters, turbot and Greenland halibut refer to the same species - *Reinhardtius hippoglossoides*. There is another flatfish known as turbot (*Scophthalmus maximus*) but it occurs in the northeast Atlantic (and is presumably consumed by East Greenland narwhals).	Comment noted. Text has been revised to reflect this.
7	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 7, s. 2.2 Geographic and Seasonal Distribution	Breed et al. 2017b - there is no "a", should be 2017 only (it's correctly cited on pg. 13).	Comment noted. Reference has been edited.

#	Document Name	Section Reference	Comment	Baffinland Response
8	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 7, s. 2.2 Geographic and Seasonal Distribution	Polar bears have been recorded successfully preying on ice-entrapped narwhals, both in the study area and elsewhere. For example: 1) Near Pond Inlet, ca. 1918 - Carcasses found by Inuit, 21 young narwhal caught and dragged onto ice by polar bears (Munn 1932; Mitchell and Reeves 1981) 2) north of Kugaaruk, Nov. 2014 - "Found 2 narwhal tusks frozen in the ice, must have been trapped and the polar bear ate them"; "Where Lionel found a dead narwhal and tusk, it was stranded in the ice and polar bears ate it" (GN 2015) <u>References</u> Government of Nunavut (GN). 2015. Nunavut Coastal Resource Inventory – Kugaaruk. Fisheries and Sealing Division, Department of Environment, Iqaluit, NU. Mitchell, E., and R.R. Reeves. 1981. Catch history and cumulative catch estimates of initial population size of cetaceans in the eastern Canadian Arctic. Report of the International Whaling Commission 31: 645-682. Munn, H. T. 1932. Prairie Trails and Arctic By-Ways. Hurst and Blackett Ltd, London. 288 pp.	Point noted but was not included in background information as intention is to keep it high-level.

#	Document Name	Section Reference	Comment	Baffinland Response
9	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 9, s. 2.3 Reproduction	More recent information on narwhal reproductive biology and life history is available (e.g., Garde et al. 2015) which should be used to update this section. The 2004 COSEWIC status assessment is now outdated in some regards. Garde, E., S.H. Hansen, S. Ditlevsen, K.B. Tvermosegaard, J. Hansen, K.C. Harding, and M.P. Heide-Jørgensen. 2015. Life history parameters of narwhals (*Monodon monoceros*) from Greenland. Journal of Mammalogy 96(4): 866-879.	Comment noted. Garde et al (2015) has been incorporated into the baseline section.
10	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 9, s. 2.4 Diet	Fatty acids have also been used in diet studies (e.g., Watt and Ferguson 2015). Watt, C.A., and S.H. Ferguson. 2015. Fatty acids and stable isotopes (δ13C and δ15N) reveal temporal changes in narwhal (*Monodon monoceros*) diet linked to migration patterns. Marine Mammal Science 31(1): 21-44.	Comment noted. Reference has been incorporated into the report.
11	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 12, s. 2.5.2 Surface Movement	"Understanding confounding effects such as the presence of predators in a system is important when assessing movement behaviour of cetaceans in relation to vessel traffic. Killer whales, for example, are well known to prey on narwhal and may affect narwhal space patterns..." This is an important point as speaks to a deficiency in the 2018 PAM analyses, as noted in QIA's comments on that draft report.	Comment noted. Future monitoring efforts will consider how best to incorporate behavioural responses mediated by non-vessel related causes.

#	Document Name	Section Reference	Comment	Baffinland Response
12	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 13, s. 2.6.1 Vocalizations	Koblitz et al. 2016 is cited twice. Should this be a, b, or one deleted? There's also no citation in the References section.	Comment noted. Koblitz et al. 2016 has been added to the references section.
13	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 13, s. 2.6.2 Hearing (more of a general comment)	Southall et al. (2007) has recently been updated (Southall et al. 2019). There may not be much "new" information in respect to narwhals but it could be reviewed to check. Southall, B.L. et al. 2019. Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. Aquatic Mammals 45(2): 125-232.	Comment noted. Southall et al. 2019 has been reviewed and cited within the report where appropriate.
14	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 15, s. 3.1 Field Tagging	What is meant by "certified marine mammal handlers"? Certified how?	Noted that this is not clear. Text has been edited to reflect that animals were handled by local Inuit, marine mammal scientists, and veterinarians.
15	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 17, Figure 3.1	Figure caption is incorrect.	Comment noted. Figure caption has been corrected.

#	Document Name	Section Reference	Comment	Baffinland Response
16	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 20, s. 3.2.2 SMRU Instrumentation	The fact that 2 of 3 CTD-SRDL tags incorporated Fastloc GPS is stated twice in the paragraph.	Comment noted. Text has been edited accordingly.
17	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 20, s. 3.2.3 MiniPAT and 3.2.4 Mk10-PAT	How many MiniPAT and Mk10-PAT tags were deployed? On every animal outfitted with a SPLASH-10 backpack tag? What was breakdown on numbers?	The breakdown of tags deployed is presented in the results section of the report (4.1.1 Tag Deployment).
18	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 21, s. 3.2.3 Acousonde	"All four Acousonde tags were outfitted with two hydrophones (one high-frequency and one low-frequency), allowing the unit to jump between the two channels and collect data from a broader frequency spectrum." How does this work? Tag programmed to switch between hydrophone, or automatic? More details would be useful.	Acousonde tags were pre-programmed to duty cycle between high and low frequency channels. Text has been edited to reflect this.
19	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 21, s. 3.3 AIS Vessel Tracking	Was all AIS data analyzed at one minute intervals (i.e., including the shore-station data recorded at shorter intervals)? A subset of AIS tracking data from both ground and satellite sources could be used to test the several intervals for interpolation.	No. Only where positions were recorded less often than once per minute were interpolated to a 1 min grid. AIS data available in sub-minute intervals (higher resolution data) was kept as is.

#	Document Name	Section Reference	Comment	Baffinland Response
20	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 23, s. 3.4.3 Dive Data	Re: the 0.75 m surface bias offset, isn't the depth sensor resolution for MiniPATs 0.5 m (e.g., Hagihara et al. 2018)? The Mk9 TDRs have the same resolution, is it different for the Mk10? Hagihara, R., R.E. Jones, S. Sobtzick, C. Cleguer, C. Garrigue, and H. Marsh. 2018. Compensating for geographic variation in detection probability with water depth improves abundance estimates of coastal marine megafauna. PLoS ONE 13(1): e0191476. https://doi.org/10.1371/journal.pone.0191476	The 0.75 m offset was used for one of the four MiniPATs (NW01) since data plots indicated that the surface bias was 0.5 m for about 2/3 of the deployment and 1 m for the remaining 1/3 of the deployment. The use of 0.75 m was therefore chosen to reduce the bias throughout the deployment period. Since there was a long overlap in the periods of 0.5 m and 1.0 m bias, a single correction factor was used for the entire deployment period, instead of applying two different correction factors.
21	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 24, s. 3.5 Data Analysis	Rather than "qualitatively assess differences in narwhal behaviour that may stem from physical habitat differences, such as water depth and channel width", why not quantitatively assess it using bathymetric and shoreline data linked to locations?	Water depth and distance from shore were incorporated into several analyses, where preliminary data exploration indicated possible relationships with these variables. Substrata were defined and presented based mainly on a visual examination of bathymetry plots and, at this point, do not provide information beyond the data already incorporated in the models. They are only presented as a qualitative visualization of the collected data.
22	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	General - Methods/Results	For many of the models, some variables were expressed as polynomials (quadratic, e.g., pg. 26; cubic, e.g., pg. 26, 29, 42, etc.; 4th-degree polynomial, e.g. pg. 80-81). In these cases a curvilinear expression may be the most appropriate, but it would be useful to have justification for selection. For example, are there theoretical relationships that are hypothesized to be curvilinear? Did univariate and bivariate visual inspections reveal curvilinear relationships? Or	As per DFO Science comment #3 – The relationship between narwhal response and distance from vessel is not linear. Even if it were linear within a certain distance from the vessel, it is not possible to identify prior to the analysis at what distance within the 10 km range the narwhal will commence the response. For example, significant effects on surface time were observed at <2 km from vessels, whereas significant effects on the probability of deep dives were

#	Document Name	Section Reference	Comment	Baffinland Response
			inspection of residuals from preliminary models?	observed at <5 km from vessels. The lack of linearity within the variable-specific effect zone and the differences in the distance at which effects are observed require the use of models that can fit these trends, such as polynomial, spline, or non-linear models. In all cases, preliminary data plots were used to identify the form of the modeled relationships relative to the predictor variables.
23	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	General - Methods/Results	It would be useful to see mapping/analysis of associations between individuals (using both n = 4 and n = 12 data sets). Did certain individuals more closely associate than others? For example, NW01 and NW02 were captured on the same day, were they captured together? Did whales captured closer together in time more closely associate with one another?	This specific question is outside of our current scope for analyzing vessel/whale interactions (i.e., Project-related effects).
24	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 24, s. 3.5.1 CPA Events	Why use 3 km? What was the justification in McKenna et al. (2015) for using 3.6 km in their blue whale study? Why use a 3 hour window to define separate encounters - "visual examination" doesn't provide much justification to support the selection, some data should be plotted to provide more information.	The 3 km cutoff for the closest point of approach (CPA) analysis was set to provide a set of encounters at a close range, since the strongest effects of the vessel on narwhal behavior are expected to be observed when vessels are close to the narwhal. An increase in CPA value would quickly inflate the number of plots produced for this analysis. For example, at a CPA of 3 km, a total of 67 encounters were plotted, whereas for a CPA of 5 km, a total of 98 encounters would have been produced. The larger number of plots and the farther distance, leading to a lesser effect (as per the models presented in the report), would make it harder to interpret the CPA plots. The full dataset, with CPAs up to 10 km,

#	Document Name	Section Reference	Comment	Baffinland Response
				was included in the models described further in the report; that is, these encounters were presented elsewhere.
25	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 25, s. 3.5.1 CPA Events	The disturbance threshold was predicted to propagate up to almost 20 km from a Post-Panamax vessel, so the sensitivity of the exposure zone selection (10 km) should be tested using alternate definitions (e.g., 15 km, 18 km) (15 km interactions were plotted, pg. 26).	Yes, the maximum disturbance distance (R_{Max} - or the maximum range to 120 dB re 1 µPa SPL over all azimuths) for a Post-Panamax carrier transiting at 9 knots along the Northern Shipping Route ranged from 9.82 to 19.24 km (depending on location along the shipping corridor). However, the $R_{95\%}$ disturbance distance (distance to 120 dB re 1 µPa SPL after the 5% farthest modelled points were excluded) was ≤10 km of the vessel at all modelled locations. $R_{95\%}$ was considered to provide a more realistic estimation of the total disturbance zone by an ore carrier, because modelled sound footprints were shown to be irregular in shape with anomalous fringes and protrusions that applied only to specific directions. Using R_{max} as a radius for the purpose of this analysis was considered unrepresentative as it yielded unrealistically conservative estimates of the total ensonified area of disturbance (see Figures E7 through E9 in Appendix B of TSD 24 – Marine Mammal Effects Assessment, FEIS for Phase 2 Proposal; Baffinland 2018). Based on the above rationale, 10 km was considered an appropriate distance to delineate exposure vs. non-exposure of narwhal to vessel sound. This was further supported from sound propagation and vessel noise monitoring results from

#	Document Name	Section Reference	Comment	Baffinland Response
				JASCO's 2018 acoustic monitoring program at Bruce Head, and in consideration of the 120 dB threshold not being weighted to account for variable hearing sensitivities amongst different marine mammal hearing groups. Also see response to DFO #1 and 2. Baffinland will consider evaluating alternate exposure zone distances in the 2018 Narwhal Tagging Report, which will incorporate both 2017 and 2018 narwhal tagging data.
26	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 25, s. 3.5.2 Horizontal Movement	What literature was reviewed?	Citations have been incorporated.
27	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 26, s. 3.5.2 Horizontal Movement	Re: no "no exposure" modelling, a sensitivity analysis using alternate definitions (e.g., 15 km) for defining vessel presence could provide useful information.	Baffinland is considering this in its future analyses, as per response to QIA Comment #25.
28	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 27, s. 3.5.2 Horizontal Movement	Re: identifying habituation, why is 15 km used here for defining interactions, versus 10 km elsewhere?	This was an error in the report and is now resolved – all results are presented for an exposure zone of 10 km.

#	Document Name	Section Reference	Comment	Baffinland Response
29	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 27, s. 3.5.3 Subsurface Movement	What literature was reviewed?	Citations have been incorporated.
30	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 27, s. 3.5.3 Subsurface Movement	Why were the specific values used to define "bottom dives" and "time at depth" chosen?	The 80% value used for the definition of "time at depth" is built into the Divebomb algorithm and cannot be changed without modifying the Divebomb program. The 75% cutoff selected for the bottom dives was to allow for uncertainty in assigned available bathymetry data (due to animal GPS position uncertainty, bathymetry measurement uncertainty, and bathymetry interpolation). Text was added to the section for clarity.
31	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 28, s. 3.5.3 Subsurface Movement	Why are 4 hour bins used?	The maps simply provide a spatial reference of narwhal behavior. The total dataset had to be summarized for this visualization. Due to movement and changes in habitat, very low resolution (e.g., daily summary) may not prove useful. The choice of 4-h bins was made as it offered low-enough resolution to provide an informative visual and high-enough resolution to link spatial distribution with dive behavior.

#	Document Name	Section Reference	Comment	Baffinland Response
32	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 29, s. 3.5.3 Subsurface Movement	What is the justification for splitting the study period into two subsets (31 July to 14 Aug., 15 Aug. to 09 Sept.)? Elsewhere data are plotted in bi-weekly segments (e.g., Figure 3, Figures 4-4A, 4-4B and 4-5).	These maps were intended for simple data visualization. The figures referred to have GPS data presented; the GPS dataset continues well beyond September 9 (when the dive dataset ends), which results in informative, biweekly plots. The dive data only extend to September 9, which results in one set of the panels depicting 3 weeks of data, as opposed to adding a new set of mostly empty panels that would cover the period between September 01 and 09.
33	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 29, s. 3.5.3	Subsurface Movement Why use 7 m to define "surface" behaviour? Justification?	The choice of < 7 m for the surface cutoff was based on an existing study (Blackwell et al. 2018) where vocal behavior was analyzed as a function of animal depth. The methods section of the 2017 narwhal tagging report has been revised to reflect this. Blackwell S.B., M. Tervo Outi, A.S. Conrad, M.H.S., Sinding, R.G. Hansen, S. Ditlevsen, and M.P. Heide-Jørgensen M.P. 2018. Spatial and temporal patterns of sound production in East Greenland narwhals. PLoS ONE 13(6): e0198295.
34	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 29, s. 3.5.3	Why use a 1 minute summary resolution for data available at 1-second resolution? How sensitive are results to the chosen time step?	This was done to reduce the dataset to a more manageable size (the original 1-sec dataset is more than 10 million rows), as well as to reduce some of the temporal autocorrelation. Text was added to the methodology section for clarification.

#	Document Name	Section Reference	Comment	Baffinland Response
35	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 30, s. 4.1.1 Tag Deployment	Why were two whales not instrumented with satellite tags?	Inuit team members decide if a captured whale is suitable for placement of backpack tag depending on the animal's size, health, and body condition. Two live-captured whales did not meet these criteria.
36	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 32, s. 4.1.1 Tag Deployment	Was whale sex confirmed using genetics or external morphology, or based solely on tusk presence/absence? The fact that NW06 and NW14 are listed as male without a tusk would suggest sex was confirmed using additional methods, but this could be noted.	Whale sex was confirmed using genetic testing. The report has been revised to clarify this in the report table.
37	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 32, s. 4.1.2 Large Vessel Traffic	Re: assumption that vessels moving under 2 knots were anchored or drifting, couldn't this be tested using vessel logs and AIS positions (i.e., check vessel speeds between AIS positions for vessels known at the time to be anchored or drifting)?	Yes, vessel speed could be tested against AIS messages that include vessel status. However, the 'vessel status' field is often not complete or accurate in the AIS dataset and so this assumption was deemed appropriate.
38	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 35, Figure 3	Why are no vessel trackline data plotted east of Pond Inlet? Satellite AIS data should provide coverage.	The study area extends from Milne Port to Pond Inlet and includes the following strata: Milne Inlet North, Milne Inlet South, Tremblay Sound, Protected Inlet Areas, Navy Board Inlet and Eclipse Sound. The eastern border of the Eclipse Sound strata was 77.96° W, consistent with the longitude of the community of Pond Inlet. The spatial limits of the study area were based on areas where high-resolution dive data was available for narwhal (1 s data from Minipat tags). All 1 s resolution dive data from 2017 were limited to areas west of 77.96° W. No vessel trackline data were plotted east of Pond Inlet because this area falls outside the defined Study Area.

#	Document Name	Section Reference	Comment	Baffinland Response
				Text has been included in the revised report to clarify.
39	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 40, s. 4.2.2 Narwhal Exposure	Figure 4-6 and text - summarize number of raw versus interpolated points	The summary info was added to the GPS data section (section 4.1.3)
40	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 46, s. 4.3.4 Seasonal Change	Figure 12 - a lot less data later in the season, how does variability change over time?	Variability remained the same throughout the season. This was assessed in post-modeling diagnostics.
41	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 48, s. 4.3.5 Habitat Re-Occupation	Figure 4-13 shows vessels moving at speeds in excess of 13.5 knots (ca. 25 km), are these all resupply vessels and tankers? The scale for vessel speed extends down to 0 km/h, but presumably all vessels plotted here would have been moving at speeds > 3.7 km/h (2 knots)? It's difficult to interpret the point colour in the pdf file, but the darkest ones look to be slower than the threshold noted in s. 4.1.2 (pg. 32).	Yes, the vessels that were recorded transiting at speeds >10 knots along the Northern Shipping Route in 2017 were either freight (re-supply) vessels (n=5; BBC Volga, Amazoneborg, Sedna Desgagnes, Rosaire A. Desgagnes, Claude A. Desgagnes), tankers (n=1; Sarah Desgagnes) or cruise ships (n=1; National Geographic Explorer). Baffinland can only provide oversight on vessels associated with its Project, and thus not all vessels traveling through the LSA and/or RSA. The original figures did erroneously include vessel transits traveling at

#	Document Name	Section Reference	Comment	Baffinland Response
				<2 knots. These were removed from the updated report and the figure has been updated.
42	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 52, s. 4.3.7 CPA Events	The report interpreted animal behaviour for 3 of 6 paired transits. What were the reasons for not doing the other three?	When dive behavior was not consistent and/or bathymetry changed significantly during the CPA event, this precluded a simple interpretation of the data for half of the paired vessel events.
43	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 52, s. 4.3.7 CPA Events	Re: "all possible iterations of potential spatial behaviours in response to vessel transits appeared to be illustrated in the figures." It would be useful to see some summary figures quantifying these different response categories. Table 5.1, pg. 97-98 (s. 5.0) provides some information, but graphical summaries would aid in interpretation of results.	Comment noted. Summary figures will be considered for addition during future reporting efforts (as applicable).
44	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 54-72, Figures 4-16 to 4-34	It would be useful to see some summary information on patterns by vessel type/class, etc. (e.g., carriers versus tanker s and re-supply).	The majority of the interactions between narwhal and large vessels were with ore carriers (55 of 77 CPA plots; 71%). However, for the 2018 narwhal tagging report, the vessel type will be indicated on the figures.

#	Document Name	Section Reference	Comment	Baffinland Response
45	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 54-72, Figures 4-16 to 4-34	What is the blue background shading in the left panels? I didn't see it explained in the text or figure captions. Is it the exposure period, as in the figures in Appendix A?	The blue shading defines the periods of time when narwhal were within 10 km from the vessel. The explanation was added to the notes section under each figure.
46	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 57, Figure 4-19	Assuming the blue shading in the left panel represents the exposure period, how did the analysis handle situations such as that shown in the bottom left panel where there were two bouts within a 3-hour window? Presumably that would have been considered a single exposure period? What happens with the data that occurs between the two bouts?	Yes, the blue shading defines the exposure period; the explanation was added to the figures. For modeling, exposure was defined solely based on distance and the association of each case with a specific bout was not represented. Therefore, cases where narwhal were >10 km from the vessel were considered “no exposure”, even if they were between two exposure periods.
47	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 57, Figure 4-19	A number of these figures show dives that extend down past the bottom. What's going on there? For e.g., Figure 4-30, pg. 68 - one dive on the third left panel extends down to > 500 m depth when the grey ribbon showing bathymetry shows a slope from ca. 150 m to ca. 350 m depth.	These are due to the uncertainty in bathymetry and narwhal GPS position. Each GPS position has an error associated with it; further, interpolation of GPS positions introduces a new source of error. In addition, the bathymetry data were interpolated from the original 100 m resolution. In cases where bathymetry and animal location data did not correspond (e.g., narwhal diving into a crevasse that isn’t captured in the interpolated bathymetry data) or cases where animal GPS data positioned the animal a few meters away from its true position (with deeper water), the dataset resulted in cases where narwhal dives were deeper than the estimated available bathymetry.

#	Document Name	Section Reference	Comment	Baffinland Response
48	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 71, Figure 4-33	Why is there missing bathymetric data in some plots. For e.g., the third left panel in Figure 4-33 is missing bathymetric data near Bruce Head, shouldn't there be data available, as other plots show bathymetry for this part of the study area?	These were cases where no raw GPS data were available for more than 20 min. An explanation was added to the footnote for each figure.
49	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 73, s. 4.4.1 Surface Time	Based on the percentile distributions in Figure 4-35, female NW03 doesn't seem to have spent more time on the surface then the males	The two females (NW02 and NW03) spent higher percentages of time at the surface (≤7 m depth) when compared to the two males (median of 44% and 41% vs. 39% and 40% respectively).
50	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 77, s. 4.4.2 Dive Rate (and elsewhere as noted in comment)	Pg. 72 For a number of map figures that show colour-coded point data, it would be useful to see strata-level summary statistics, as the figures are not easy to interpret. For example, Figure 4-39 (pg. 77), Figure 4-45 (pg. 86), Figure 4-48 (pg. 89), Figure 4-51 (pg. 93).	This will be considered for incorporation during future reporting efforts, if applicable at the time. The two females (NW02 and NW03) spent higher percentages of time at the surface (≤7 m depth) when compared to the two males (median of 44% and 41% vs. 39% and 40% respectively).
51	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 95, s. 4.5 Shore-based Hunting	"For narwhal within 2-km m of the hunting camp..." The "m" after "km" is presumably a typo "... gunshot at 19:14... second gunshot at 19:00" Either a typo or the times are reversed?	Noted. This was a typo and has been edited in the revised report.
52	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 95, s. 4.5 Shore-based Hunting	Moving forward, PAM could assist with detection of hunting events.	Underwater PAM and in-air sound level monitoring will be conducted near Bruce Head to record gunshots (as a proxy for hunting event) during the 2019 field season whenever feasible to do so.

#	Document Name	Section Reference	Comment	Baffinland Response
53	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 5.0 Discussion	One year of data on a small subset of animals cannot show that no long-term displacement behaviour has occurred, as it hasn't been a sufficiently lengthy period of time.	Agreed. The text was expanded to reflect this.
54	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 5.0 Discussion	Monitoring needs to be scaled further as well, i.e., from individuals (tags) to Bruce Head to the summering region	The purpose of this Study was to assess narwhal response to Project-related vessel traffic specifically.
55	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 6.0 Recommendations	What kind of trade-offs can be expected between GPS transmission frequency and tag battery life? Anything of consequence to monitoring?	There are significant consequences on tag battery life when increasing attempts to collect and transmit GPS location data. Tag programming (battery life) is a collaborative decision with DFO, with agreement made through balancing the differing research objectives and risks of the respective research programs.
56	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 6.0 Recommendations	I don't recall seeing anything about hunting activity in the 2018 Bruce Head (vessel-based study) draft. Given that no narwhal were recorded, presumably no hunting activity was recorded (for seals, etc.)?	No hunting activity of any marine mammals was observed during the 2018 vessel-based pilot study.

#	Document Name	Section Reference	Comment	Baffinland Response
57	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 6.0 Recommendations	PAM should be considered as a way to monitor hunting activity at a larger spatial scale than the Bruce Head observation study.	Comment noted.
58	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 6.0 Recommendations	Presumably this report will be updated for the 2018 season with analyses of the 2018 tag data? A subset of the 2017 analyses could be conducted on the larger dataset (i.e., the other whales with lower resolution dive data) to see if results are comparable.	Yes, 2017 and 2018 tag data will be integrated in subsequent analyses and included in the 2018 narwhal tagging report. However, any tagged data collected during 2017 having sufficient resolution for the analyses conducted herein were already incorporated.
59	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 6.0 Recommendations	Were Acousonde tags deployed on both whales captured in 2018?	Yes
60	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 6.0 Recommendations	What are anticipated tag numbers (for the various tag types) that the field team hopes to deploy in 2019?	Neither DFO or Golder/Baffinland will be undertaking a tagging program in 2019.
61	2017 Narwhal Tagging Study - Technical Data Report draft ((file name "2017 Narwhal tagging study DRAFT FOR MEWG.pdf")	Pg. 99, s. 6.0 Recommendations	Vessel direction could be important for ore carriers given potential differences with load status.	Agreed. Added this to the recommendations section.