REPORT

Mary River Project

2017-2018 Integrated Narwhal Tagging Study - Technical Data Report

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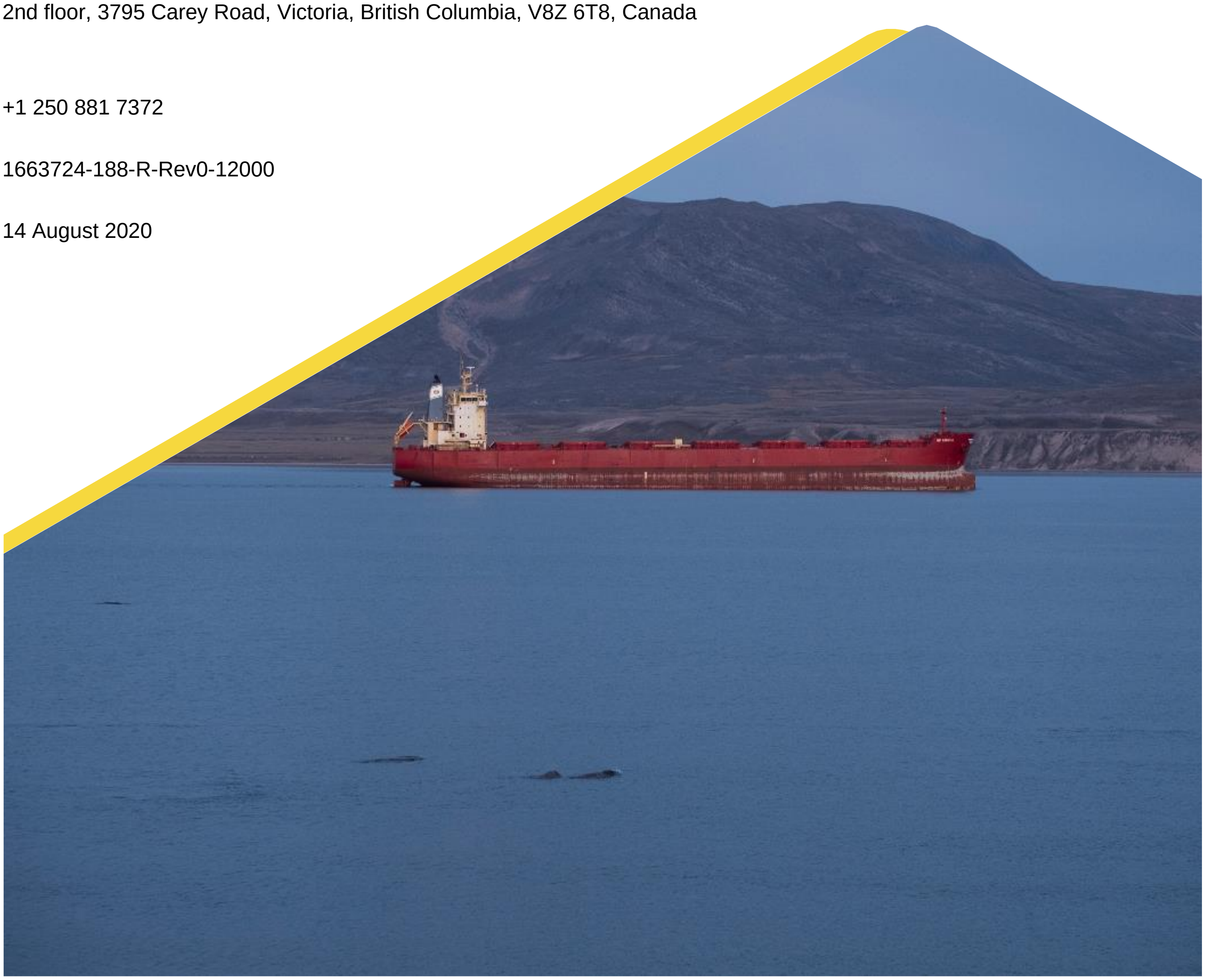

Executive Summary - English

The Mary River Project (hereafter, "the Project") is an operating open pit iron ore mine owned by Baffinland Iron Mines Corporation (Baffinland) and located in the Qikiqtani Region of North Baffin Island, Nunavut. 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. To date, Baffinland has been operating in the Early Revenue Phase (ERP) of the Project and is currently authorized to transport 6.0 million tonnes per annum (Mtpa) of iron ore to global markets until 31 December 2021. The operating mine site is connected to Milne Port, located at the head of Milne Inlet, through which iron ore is transported to chartered ore carrier vessels for shipping along the Project's Northern Shipping Route.

The Project's Northern Shipping Route encompasses Milne Inlet, Eclipse Sound, Pond Inlet, and adjacent water bodies. This coastal fjord system represents important summering grounds for narwhal (*Monodon monoceros*) in the Canadian Arctic, particularly in nearby Koluktoo Bay where individuals are known to spend a large proportion of time milling near the surface, calving, and rearing young (Heide-Jørgensen et al. 2001, Marcoux et al. 2009, Golder 2018). Despite early studies reporting that narwhal spend limited time foraging during the summer months (Mansfield et al. 1975, Laidre et al. 2004), recent analyses of frequent, deep-water dives by narwhal on their summering grounds suggests that foraging does occur during this time (Watt et al. 2015, 2017, Golder 2019a). Therefore, for narwhal summering throughout Milne Inlet, Eclipse Sound, Pond Inlet, and adjacent water bodies, it is unclear how exposure to vessels transiting along the Project's Northern Shipping Route may affect narwhal behaviors. Other cetacean species have been documented to avoid transiting vessels by altering their travel 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). However, information on behavioral response of narwhal to vessel traffic is limited.

To investigate behavioral response of narwhal to vessels transiting the Northern Shipping Route in support of the Project's Environmental Effects Monitoring (EEM), Golder Associates Ltd. (Golder) partnered with Fisheries and Oceans Canada (DFO) to undertake the 2017 and 2018 narwhal tagging programs 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. A total of 24 narwhal were live-captured in Tremblay Sound during summer of 2017 and 2018 (20 narwhal in 2017 and four narwhal in 2018) and instrumented with a combination of biologging tags. Biologging tags monitored the fine-scale lateral movements of narwhal, their dive behavior, and habitat use throughout their summering grounds in the coastal fjord system of northern Baffin Island. A subset of narwhal 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 Project ore carriers and other non-Project related vessel traffic present within the Project's Regional Study Area (RSA) was investigated by comparing animal-borne tag data with Automated Identification System (AIS) vessel-tracking data collected during the 2017 and 2018 shipping seasons. Behavioral responses considered in this study included changes in narwhal surface movement (e.g., horizontal displacement, travel speed, habitat re-occupation) and changes in dive behavior; with the latter component assessing potential changes in surface time, dive rate, bottom dive depth, time at depth, dive duration, and descent speed during encounters with large- (≥100 m in length) and medium-sized vessels (50–99 m in length).

For analysis of narwhal dive behavior, the dataset included high-resolution dive data obtained for six narwhal, each fitted with a backpack tag possessing Fastloc GPS capability and a MiniPAT tow tag (Wildlife Computers). A total of 92 vessel-narwhal interactions were identified in which the closest point of approach (CPA) between individual narwhal and a given vessel was within 3 km. 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 fitted with high resolution dive tags. The dataset used for analysis of surface movement relative to vessel traffic included 14 narwhal fitted with GPS Fastloc location tags (ten SPLASH10 tags and four CTD-SRDL tags). Potential changes in narwhal surface behavior were also examined as a function of distance from transiting vessels within the 10 km exposure zone and compared against periods of non-exposure (> 10 km).

The following is a summary of key findings pertaining to narwhal behavioral response to vessel traffic based on a comparison of animal-borne tag data with AIS vessel-tracking data during the 2017 and 2018 shipping seasons.

- Narwhal positional data from 2017 and 2018 demonstrated that tagged narwhal occurred in all strata during the summer period but were more common in certain areas of the RSA, namely Milne Inlet South, Koluktoo Bay, Milne Inlet North and Tremblay Sound. High use areas in the RSA included the central portion of Tremblay Sound, the western shore of Milne Inlet North, and most of Koluktoo Bay and Milne Inlet South, particularly in areas south of Bruce Head (i.e., entrance to Koluktoo Bay) and in Assomption Harbour (i.e., Milne Port site). These results were consistent with areas of high narwhal concentrations identified during baseline aerial surveys conducted in the RSA during 2007, 2008, 2013, and 2014 (Elliott et al. 2015; Thomas et al. 2015) prior to the commencement of iron ore shipping along the Northern Shipping Route.
- With respect to interactions between tagged narwhal and existing shipping activity in the RSA, the majority of the GPS data collected during 2017 and 2018 occurred when narwhal were >10 km from medium- and large-sized vessels (including both Project and non-Project related vessels). Vessel exposure events (<10 km) occurred throughout the RSA but were more common in the Milne Inlet South and Koluktoo Bay strata due to the confined nature of the channel along this part of the Northern Shipping Route.
- Satellite tag data from 2017 indicated that several of the tagged narwhal moved between Eclipse Sound and Admiralty Inlet during their deployment period. These results support the notion that some degree of mixing occurs between the Eclipse Sound and Admiralty Inlet stocks during the shipping season.
- Narwhal dive behavioral responses that were shown to be significantly influenced by vessel noise and/or close vessel encounters included surface time, dive duration, and bottom dives; the latter only during periods when narwhal were engaged in bottom diving at the initial time of vessel exposure. No significant effects were observed for dive rate, time at depth, descent speed, or bottom dives (during periods when narwhal were not actively diving to the bottom at the initial time of exposure). The distance at which significant changes were observed in dive behavior ranged from 1 to 5 km, dependent on the response variable. This corresponded with an exposure period ranging from 7 to 36 min per vessel transit (based on a 9 knot travel speed), with animals returning to their pre-response behavior following the exposure period (i.e., a temporary effect). The frequency of this effect was considered intermittent given that vessels were within 5 km of a tagged narwhal for <1% of the GPS datapoints collected in the RSA during 2017 and 2018.

- Narwhal surface movement responses that were shown to be significantly influenced by vessel-generated noise included turning angle and orientation relative to vessel (low level severity responses). No significant effects were observed for travel speed, horizontal displacement or habitat re-occupation. The distance at which significant changes were observed in surface movement behavior ranged from 4 to 10 km, dependent on the response variable. This corresponded with an exposure period ranging from 29 to 54 min per vessel transit (based on a 9 knot travel speed), with animals returning to their pre-response behavior following the exposure period (i.e., a temporary effect). The frequency of this effect was considered intermittent given that vessels were within 10 km of a tagged narwhal for <7% of the GPS datapoints collected in the RSA during 2017 and 2018. Although no significant effect was observed for horizontal displacement, a clear spatial gap in narwhal positional data was evident in the immediate proximity of the vessel (within 0.5 km of the vessel's port and starboard beam and within 1 km of its bow and stern). This gap may reflect close-range avoidance behavior but may also be a function of the low-resolution GPS location data available.

Overall, results from the 2017 and 2018 narwhal tagging study support predictions made in the Final Environmental Impact Statement (FEIS) for the ERP, in that vessel-generated noise effects on narwhal will be limited to temporary, short-term avoidance behavior, consistent with low to moderate severity responses as defined in Section 2.6.3 of this report. No evidence was observed of large-scale avoidance behavior, displacement effects, or abandonment of the summering grounds (i.e., high severity responses), which might in turn result in a population or stock-level consequence (consistent with the definition of a non-significant effect used in the FEIS).

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ᓄᓘᔾᓂᑦ ᐱᓕᕆᐊᖅ (ᑖᒃᑯᓂ ᑕᐃᔭᐅᔪᖅ, “ᐱᓕᕆᐊᖅ”) ᐊᐅᓛᖅᑐᖅ ᓄᓇᒥᑦ ᐃᓗᑦᑐᖅᓯᒪᔪᖅ ᐅᒃᑯᐃᖓᐸᓗᓂ ᓴᕕᖕᓄᑦ ᐅᔭᕋᒃᑕᕆᐊᖑᔪᖅ ᓇᖏᓂᕆᔭᐅᐸᓗᓂ ᐹᕝᕋᓛᓐ ᓴᕕᖕᓄᑦ ᐅᔭᕋᒃᑕᕆᓕᕆᓂᒃᑯᓐᓄᑦ (ᐹᕝᕋᓛᓐᑯᑦ) ᐊᒻᒪᓗ ᕿᑭᖅᑖᓗᕐᒥᕕᓂ, ᓄᓇᕗᒻᒥᑦ. ᐱᓕᕆᐊᕐᒧᑦ ᓇᓗᓇᐃᒃᑯᑎ ᓈᓴᐅᑎ 005, ᐋᖅᑭᒋᐊᖅᑕᐅᓚᐅᖅᑐᖅ ᐊᕗᑎᓕᕆᔨᒃᑯᓐᓄᑦ ᓄᕐᕋᐃᑦ 27, 2014-ᒥᑦ, ᐱᔪᓐᓇᖅᑎᑦᑎᔪᖅ ᐹᕝᕋᓛᓐᑯᓂᑦ ᐊᕐᕋᒍᑕᒫᒃᑯᑦ ᐅᔭᕋᒃᑕᐱᓐᓇᕐᓗᑎᒃ 22.2 ᒥᓕᔭᓐ ᑖᓐ ᓴᕕᖕᓂᑦ ᐱᑕᓕᖕᒥᑦ ᓈᓴᐅᑎ 1-ᒥᑦ. ᐅᑉᓗᒥᒧᑦ ᑎᑭᓯᓗ, ᐹᕝᕋᓛᓐᑯᑦ ᐊᐅᓛᕐᓂᖃᓕᖅᑐᑦ ᐱᓕᕆᐊᖅ ᑮᓇᐅᔭᓕᐅᖅᐸᓪᓕᐊᒋᐋᓂᖓᓂᑦ ᐊᒻᒪᓗ ᐊᓯᖅᑐᐃᔪᓐᓇᖅᑎᑕᐅᔪᑦ ᐊᕐᕋᒍᑕᒫᒃᑯᑦ 6 ᒥᓕᔭᓐ ᑖᓐ ᓴᕕᖕᓂᑦ ᓄᓇᕐᔪᐊᕐᒥᑦ ᓂᐅᕕᐊᒃᓴᐅᓂᐊᖅᑐᓂᒃ ᐋᒡᔪᓕᕐᕕᒃ 31, 2021-ᒧᑦ ᑎᑭᒃᓯᓗᒍ. ᐊᐅᓛᖅᑎᑕᐅᔪᖅ ᐅᔭᕋᒃᑕᕆᐊᕐᒥᑦ ᑲᑎᖕᓂᖅᖅᑐᖅ ᕿᙳᐊᓂᑦ ᐃᒃᓴᕐᕕᖕᒧᑦ, ᕿᙳᐊᓂᑦ ᓵᖓᓃᓗᓂ, ᑕᐃᑯᓈᖅᓗᑎᒃ ᓴᕖᑦ ᐊᒡᔭᖅᑐᖅᑕᐅᖃᑦᑕᖅᑐᑦ ᐅᔭᕋᒃᑕᖅᑕᐅᔪᓂᒃ ᐅᓯᖃᑦᑕᖅᑐᓂᒃ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐱᓕᕆᐊᑉ ᐅᐊᖕᓇᖅᐸᓯᐊᓂᑦ ᐅᒥᐊᕐᔪᑦ ᐊᑉᖁᑖᒍᑦ.

ᐱᓕᕆᐊᑉ ᐅᐊᖕᓇᖅᐸᓯᖕᒐᓂᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᑉᖁᑎᖕᒑᑦ ᐊᑉᖁᔮᖃᑦᑕᖅᑕᖕᒋᑦ ᕿᙳᐊ, ᑕᓯᐅᔭᖅ, ᒥᑦᑎᒪᑕᓕᒃ, ᐊᒻᒪᓗ ᖃᓂᑕᖕᒋᑦ ᐃᒪᖃᕐᓂᐅᔪᑦ. ᑕᒪᓐᓇ ᐊᐅᔭᒃᑯᑦ ᐃᒪᖅ ᐱᒻᒪᕆᐅᒋᔭᐅᔪᖅ ᑑᒡᓕᖕᓄᑦ ᑲᓇᑕᐅᑉ ᐅᑭᐅᖅᑕᖅᑐᖓᓂᑦ. ᐱᓗᐊᖅᑐᒥᑦ ᖃᓂᑕᖓᓂᑦ ᖃ (Koluktoo Bay) ᖃᐅᔨᔭᐅᖃᑦᑕᖅᓱᑎᒃ ᐊᑕᐅᓯᐅᑉᓗᑎᒃ ᐊᑯᓂ ᑕᐃᑲᓃᖃᑦᑕᖅᓱᑎᒃ, ᐱᐊᓛᓕᐅᖅᓱᑎᒃ, ᑲᒪᒋᑉᓗᒋᓪᓗ ᐱᐊᓛᖕᒋᑦ (Heide-Jørgensen et al. 2001, Marcoux et al. 2009, Golder 2018). ᖃᐅᔨᓴᐃᓂᐅᖃᑦᑕᖅᓯᒪᔪᓂᑦ ᐅᖃᖅᓯᒪᒐᓗᐊᖅᑎᓪᓗᒍ ᑑᒡᓖᑦ ᐊᑯᓂᐅᖕᒋᑦᑐᖅ ᓂᕆᔭᒃᓴᖅᓯᐅᖃᑦᑕᖅᑐᑦ ᐊᐅᔭᒃᑯᑦ (Mansfield et al. 1975, Laidre et al. 2004), ᒫᓇᓴᖅ ᖃᐅᔨᓴᐃᓂᐅᓚᐅᖅᑐᓂᑦ ᐃᑎᔪᒥᑦ ᐊᖅᑲᕋᔫᑐᓂᒃ ᐃᓱᒪᒋᔭᐅᔪᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ ᓂᕆᔭᒃᓴᖅᓯᐅᖃᑦᑕᖅᑐᕆᔭᐅᑉᓗᑎᒃ (Watt et al. 2015, 2017, Golder 2019a). ᑕᐃᒪᓐᓇᒎᑦ, ᑑᒡᓖᑦ ᐊᐅᔭᒃᑯᑦ ᕿᖑᐊᓃᑦᑐᓂᒃ, ᑕᓯᐅᔭᕐᒥᑦ, ᒥᑦᑎᒪᑕᓕᖕᒥᑦ, ᐊᒻᒪᓗ ᖃᓂᑕᖕᒋᓐᓂᑦ ᐃᒪᕐᓂᑦ, ᓇᓗᓇᖅᑐᖅ ᖃᓄᖅ ᐱᓕᕆᐊᕐᒧᑦ ᐅᒥᐊᕐᔪᐊᓂᑦ ᐅᐊᖕᓇᖅᐸᓯᖕᒐᓂᑦ ᐊᑉᖁᑎᐅᔪᖅ ᐊᒃᑐᖅᓯᓇᔭᕐᒪᖔᑦ ᑑᒡᓖᑦ ᐃᓕᖅᑯᓯᖓᓂᒃ. ᐊᓯᖏᑦ ᑕᕆᐅᕐᒥᐅᑕᐃᑦ ᑎᑎᕋᐅᓯᐅᓯᒪᔪᑦ ᐃᖏᕐᕋᔪᓄᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᖃᓕᑦᑕᐃᓕᖃᑦᑕᕐᓂᖏᓐᓂᒃ ᓇᑭᖅᓴᕐᓂᖏᑦ ᐊᓯᐊᕐᒨᖅᓱᒋᑦ (Williams et al. 2002), ᐊᒻᒪᓗ/ᐅᕝᕙᓘᓐᓃᑦ ᕿᒫᑉᓗᑎᒃ ᖁᒻᒧᖃᑦᑕᖅᓱᑎᒃ ᓴᓂᒧᓪᓗ ᐃᖏᕐᕋᑉᓗᑎᒃ (ᓱᕐᓗ, ᐊᓯᐊᙳᖅᓱᒍ ᐳᐃᖃᑦᑕᕐᓂᖏᑦ, ᐊᖅᑲᖃᑦᑕᕐᓂᖏᑦ, ᐊᒻᒪᓗ ᓯᕗᒻᒧᑦ ᐃᖏᕐᕋᓂᖏᑦ) (Williams and Ashe 2007; Nowacek et al. 2007). ᑭᓯᐊᓂ, ᐃᓕᖅᑯᓯᖏᑦ ᑑᖓᓖᑦ ᖃᓄᐃᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐃᖏᕐᕋᑎᓪᓗᒋᑦ ᐱᑕᖃᓗᐊᖏᑦᑐᖅ.

ᖃᐅᔨᓴᕐᓂᐊᕐᓗᓂ ᑑᒡᓖᑦ ᐃᓕᖅᑯᓯᖏᓐᓂᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐃᖏᕐᕋᑎᓪᓗᒋᑦ ᐅᐊᖕᓇᖅᐸᓯᖕᒐᓂᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᑉᖁᑎᒋᔭᐅᔪᒥᑦ ᐃᑲᔪᐃᓂᐊᕐᓗᓂ ᐱᓕᕆᐊᑉ ᐊᕙᑎᒥᒃ ᖃᓄᐃᙵᓕᖅᑎᑦᑎᓂᕐᒧᑦ ᖃᐅᔨᓴᐃᖓᓄᑦ, ᒎᑐ ᑲᑐᔾᔮᖃᑎᒌᑦ (ᒎᑐᒃᑯᑦ) ᐱᓕᖃᑎᖃᓚᐅᖅᑐᑦ ᑲᓇᑕᒥᑦ ᐃᖃᓗᓕᕆᓃᒃᑯᓐᓂᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ ᑑᒡᓕᖕᓂᒃ ᑖᒃᓕᖅᑐᐃᑉᓗᑎᒃ ᑲᖏᖅᓱᐊᕐᔪᒃ, ᓄᓇᕗᒻᒥᑦ. ᐱᓕᖃᑎᒌᒃᓱᑎᒃ ᖃᐅᔨᓴᐃᓂᕐᒥᑦ ᐃᓚᐃᓚᐅᖅᑐᑦ ᒎᑐᒃᑯᑦ ᐊᖏᒃᓕᒋᐊᕐᓗᒍ ᐃᖃᓗᓕᕆᓃᒃᑯᑦ ᑖᒃᓕᖅᑐᐃᓐᓇᒐᑦ ᑐᓂᓯᑉᓗᑎᒃ ᐊᓯᖏᓐᓂᒃ ᓂᕐᔪᑎᓂᒃ ᑖᒃᓕᖅᑐᐃᖃᑕᐅᓗᑎᒃ ᐋᖅᑭᒃᓯᒪᔪᒥᒃ ᐱᓕᕆᐊᕆᓂᐊᕐᓗᒋᑦ ᐹᕝᕋᓛᓐᑯᑦ ᐱᓕᕆᐊᕐᒧᑦ ᐱᔭᒃᓴᖏᓐᓄᑦ ᑐᑭᓯᐅᓕᕈᒪᓪᓗᒋᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᑦ ᑑᒡᓖᑦ ᐅᒥᐊᕐᔪᑦ ᐃᖏᕐᕋᔭᒃᑎᓪᓗᒋᑦ. ᑲᑎᓯᓗᒋᑦ 24 ᑑᒡᓖᑦ ᐱᔭᐅᓚᐅᖅᑐᑦ ᑲᖏᖅᓱᐊᕐᔪᖕᒥᑦ 2017 ᐊᒻᒪᓗ 2018 ᐊᐅᔭᖓᓂᑦ (20 ᑑᒡᓖᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ ᓯᑕᒪᑦ ᑑᒡᓖᑦ 2018-ᒥᑦ) ᐃᓕᓯᕝᕕᐅᑉᓗᑎᒃ ᑖᒃᓂᒃ. ᑖᒃᓕᖅᓯᒪᔪᓂᒃ ᖃᐅᔨᓴᐃᓂᖃᓚᐅᖅᑐᑦ ᐊᐅᓚᓐᓂᖏᓐᓂᒃ ᑑᒡᓖᑦ, ᐊᖅᑲᐅᒪᖃᑦᑕᕐᓂᖏᓐᓂᒃ, ᐊᒻᒪᓗ ᐃᓂᒥᒃ ᐊᑐᖃᑦᑕᕐᓂᖏᓐᓂᒃ ᐊᐅᔭᒃᑯᑦ ᓯᒡᔭᓄᑦ ᖃᓂᑦᑐᓂᑦ ᐅᐊᖕᓇᖅᐸᓯᖕᒐᓂᑦ ᕿᑭᖅᑖᓘᑉ. ᐃᓚᖏᓐᓄᑦ ᑑᒡᓖᑦ, ᓂᐱᓕᐅᕈᑎᒥᒃ ᐃᓕᓕᕆᔭᐅᓚᐅᖅᑐᑦ ᐊᒻᒪᓗ ᓇᑭᖅᓴᕐᓂᖏᓐᓄᑦ ᐆᒃᑐᕋᕐᓂᐊᕐᓗᒋᑦ ᑐᓵᔭᖏᑦ ᐊᒻᒪᓗ ᓂᑉᓕᐊᓂᖏᑦ; ᑭᓯᐊᓂ, ᖃᐅᔨᓴᐃᓂᖅ ᑖᑉᑯᓂᙵᓪᓚᑦ ᐅᖓᑖᓃᖓᔪᖅ ᒫᓇᐅᔪᖅ ᐅᓂᑉᑲᒧᑦ ᐱᔪᓂᒃ.

ᐃᓕᖅᑯᓯᕆᔭᖏᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐅᔭᕋᒃᑕᖅᑕᐅᔪᓂᒃ ᐅᓯᖃᑦᑕᖅᑐᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᓯᖏᓐᓄᓗ ᐱᓕᕆᐊᕐᔫᖏᑦᑐᖅ ᐅᒥᐊᕐᔪᐊᑦ ᐃᖏᕐᕋᔭᖕᓂᖏᓐᓄᑦ ᑕᐃᒪᐅᖃᑕᐅᔪᑦ ᐱᓕᕆᐊᑉ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᒋᔭᖓᓂᑦ ᖃᐅᔨᓴᖅᑕᐅᓚᐅᖅᑐᖅ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖏᓐᓄᑦ ᓂᕐᔪᑎᓂᒃ ᑖᒃ ᓈᓴᐅᑎᖏᑦ/ᑎᑎᖅᑲᐃᑎᖏᑦ ᐊᐅᓚᔪᒃᑯᑦ ᐃᓕᑕᖅᓯᓂᕐᒧᑦ ᐋᖅᑭᐅᒪᔪᒃᑯᑦ (AIS) ᐅᒥᐊᕐᔪᐊᓂᒃ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ ᑎᑎᖅᑲᐃᑦ/ᓈᓴᐅᑎᐃᑦ ᑲᑎᖅᓯᖅᑕᐅᔪᓂᒃ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᖃᑦᑕᖅᑎᓪᓗᒋᑦ. ᐃᓕᖅᑯᓯᖏᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐃᓱᒪᒋᔭᐅᔪᑦ ᖃᐅᔨᓴᐃᓂᕐᒥᑦ ᐃᓚᐅᔪᑦ ᑑᒡᓖᑦ ᐊᓯᐊᙳᕐᓂᖏᑦ ᐃᒪᐅᑉ ᖄᖓᓂᑦ ᐊᐅᓚᑎᓪᓗᒋᑦ (ᓱᕐᓗ ᐳᐃᑦᑕᕐᓂᖏᑦ, ᐃᖏᕐᕋᓂᖏᑦᑕ ᓇᑭᕐᓂᖏᑦ, ᐃᓂᖓᑦ ᐅᑎᒃᑲᓐᓂᖅᑐᓂᒃ) ᐊᒻᒪᓗ ᐊᓯᐊᙳᕐᓂᐅᔪᑦ ᐊᖅᑲᖃᑦᑕᕐᓂᖏᓐᓂᒃ; ᐃᓚᖅᑲᐅᑎᒃ ᑭᖑᓂᖓᓂᑦ ᐃᓚᒋᔭᐅᔪᖅ ᖃᐅᔨᓴᐃᓂᖅ ᐊᓯᐊᙳᕐᓂᐅᔪᓂᒃ ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᔪᒥᑦ ᐳᐃᓯᒪᖃᑦᑕᕐᓂᖏᓐᓄᑦ, ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᔪᒥᑦ ᐊᖅᑲᐅᒪᖃᑦᑕᕐᓂᖏᑦ, ᖃᓄᖅ ᐃᑎᑎᒋᔪᒧᑦ ᐊᖅᑲᖃᑦᑕᕐᒪᖔᑕ, ᖃᓄᖅ ᐃᑎᑎᒋᓂᖓ, ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᔪᒥᑦ, ᐊᒻᒪᓗ ᐊᖅᑲᕈᑎᒃ ᓇᑭᕐᓂᖓ ᐊᖏᔪᓂᒃ ᐅᒥᐊᕐᔪᐊᕐᓄᑦ ᑎᑭᐅᑎᒃᐸᑕ (≥100 ᒦᑕᐃᑦ ᑕᑭᓂᖓ) ᐊᖏᓗᐊᖏᓐᓂᖅᓴᓄᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ (50–99 ᒦᑕᐃᑦ ᑕᑭᓂᖓ).

ᖃᐅᔨᓴᕐᓂᐊᕐᓗᒋᑦ ᑑᒡᓖᑦ ᐊᖅᑲᐅᒪᑎᓪᓗᒋᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᑦ, ᐃᓚᐅᔪᑦ ᐊᒃᖠᓕᐅᕆᑦᑎᐊᔪᔪᑦ ᐊᖅᑲᐅᒪᑎᓪᓗᒋᑦ ᓈᓴᐅᑏᑦ/ᑎᑎᖅᑲᐃᑦ ᐱᔭᐅᔪᑦ ᐊᕝᕕᓂᓕᖕᓄᑦ ᑑᒡᓕᖕᓄᑦ, ᐊᑐᓂ ᓇᖕᒪᒋᖅᖅᓱᑎᒃ ᕿᐱᐊᒃᖄᖅᑐᒥᒃ ᐊᒻᒪᓗ ᓂᕐᔪᑎᓄᑦ ᑲᒻᐱᐅᑕᓂᒃ. ᑲᑎᓯᓗᒋᑦ 92 ᐅᒥᐊᕐᔪᐊᓄᑦ-ᑑᒡᓖᑦ ᑎᑭᐅᑎᓂᖃᓚᐅᖅᑐᑦ ᖃᓂᓛᖓ ᐊᑕᐅᓯᖅ ᑑᒡᓕᒃ ᐅᒥᐊᕐᔪᐊᕐᒧᑦ 3 ᑭᓛᒥᑕᐅᑉᓗᓂ. ᐃᒪᐅᑉ ᖃᖓᓄᑦ ᖃᓂᕐᓱᑎᒃ ᐊᐅᓚᓐᓂᖏᑦ ᐊᑐᓂ ᓂᕐᔫᑦ ᖃᐅᔨᓴᖅᑕᐅᓕᖅᓱᑎᒃ ᐅᖓᓯᒃᑎᒋᓂᖓᓄᑦ ᐃᖏᕐᕋᔪᓄᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ (CPA 10 ᑭᓛᒥᑕᓄᑦ) ᐅᒥᐊᕐᔪᐊᕐᒧᑦ ᑎᑭᐅᑎᓂᖅᒥᓂᕐᒧᑦ (>10 ᑭᓛᒥᑕᐅᖃᑦᑕᖅᑐᑦ).

ᐊᒥᓲᓂᖅᓴᓄᑦ ᑑᒫᓕᕆᓄᑦ ᓯᐲᐊᓪᓕᕆᓂᑦ ᐃᓚᓯᓚᐅᖅᑐᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ ᑕᒪᓐᓇ ᒥᑭᔪᐃᓐᓇᕐᓄᑦ ᐆᒃᑐᕋᐃᓂᕐᓅᓚᐅᖏᒻᒪᑦ ᐊᑕᐅᓯᐅᔪᓄᑦ ᐃᓕᔭᐅᑦᑎᐊᕈᓐᓇᖅᓱᑎᒃ ᐊᔾᔨᓕᐅᕆᑦᑎᐊᔪᔪᓂᒃ ᑖᓐᓂᒃ ᐊᖃᐅᒪᑎᓪᓗᒋᑦ. ᓈᓴᐅᑏᑦ/ᑎᑎᖅᑲᐃᑦ ᖃᐅᔨᓴᐃᔪᑦ ᐃᒪᐅᑉ ᖄᖓᓂᑦ ᐊᐅᓚᔪᓂᒃ ᐅᒥᐊᕐᔪᐊᑦ ᐃᖏᕐᕋᔭᒃᑎᓪᓗᒋᑦ 14 ᑑᒫᓖᑦ ᐃᓪᓕᕆᔭᐅᓚᐅᖅᑐᑦ ᓯᐲᐊᒃᓯᒃ ᓇᓅᓂᖏᓐᓄᑦ ᖃᐅᔮᔾᔪᑎᓂᒃ ᑖᒃᓯᒃ (ᖁᓖᑦ SPLASH10 ᑖᒃ ᐊᒻᒪᓗ ᓯᑕᒪᐃᑦ CTD-SRDL ᑖᒃ). ᐊᓯᐊᙱᕐᓂᖏᑦ ᑑᒫᓖᑦ ᐃᒪᐅᑉ ᖄᖓᓂᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᖃᐅᔨᓭᑕᐅᓚᐅᕐᒥᔪᑦ 10 ᑭᓖᒥᑕᓂᒃ ᐅᖓᓯᖕᓂᖃᖅᑎᓪᓗᒋᑦ ᐃᖏᕐᕋᔪᓄᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖓᓅᖅᑕᐅᑉᓗᓂ ᐅᒥᐊᕐᔪᐊᓄᑦ ᑎᑭᐅᑎᖃᑦᑕᙱᓐᓂᕆᓴᖏᓐᓄᑦ (> 10 ᑭᓖᒥᑕᐃᑦ).

ᐅᖁᐊ ᓇᐃᓈᖅᓯᒪᔪᑦ ᖃᐅᔨᓴᐅᔪᑦ ᑑᒫᓖᑦ ᖃᓄᐃᓕᐅᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐃᖏᕐᕋᔭᒃᑎᓪᓗᒋᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖓᓅᖅᑕᐅᔪᓂᒃ ᓂᕐᔪᑎᓂᑦ ᑖᒃᑲᖅᓯᒪᔪᓂᑦ ᓈᓴᐅᑎᓄᑦ/ᑎᑎᖅᑲᓄᑦ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ ᖃᐅᔨᓴᐃᓂᕐᒧᑦ ᓈᓴᐅᑎᓂᑦ/ᑎᑎᖅᑲᓂᒃ ᐱᔭᐅᔪᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑎᑭᖃᑦᑕᖅᑎᓪᓗᒋᑦ.

- ᑑᒫᓖᑦ ᓇᓅᓂᖏᓐᓄᑦ ᓈᓴᐅᑏᑦ/ᑎᑎᖅᑲᐃᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ ᑕᑯᒃᓴᐅᑎᑦᑎᔪᑦ ᑖᒃᑲᖅᓯᒪᔪᑦ ᑕᐃᒪᐅᖃᑦᑕᖅᑐᑦ ᑕᒪᐃᓐᓄᑦ ᐊᐅᔭᐅᑎᓪᓗᒍ ᑭᓯᐊᓂ ᑕᐃᒪᐅᓚᔪᖕᓂᖅᓴᐅᕙᓪᓗᑎᒃ ᐃᓚᖏᓐᓂᒃ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᐅᔪᒥᑦ, ᐱᓗᐊᖅᑐᒥᑦ ᕿᙱᐊ ᓂᕆᐊᓂᑦ, ᖃ (Koluktoo Bay), ᕿᙱᐊ ᐅᐊᖕᓇᖕᒐᓂᑦ ᐊᒻᒪᓗ ᑲᖏᖅᓘᐊᕐᔪᖕᒥᑦ. ᐊᑐᖅᑕᐅᑦᑎᐊᕐᓂᖕᒐ ᐃᓂᐅᔪᖅ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᓂᕐᒥᑦ ᐃᓚᐅᔪᑦ ᑲᖏᖅᓘᐊᕐᔪᒃ, ᐱᖕᒐᖕᓇᖕᒐᓂᑦ ᓯᓪᔭᖅᐸᓯᖕᒐᓂᑦ ᕿᙱᐊ ᐅᐊᖕᓇᖕᒐᓂᑦ, ᐊᒻᒪᓗ ᑕᒪᓗᒃᑖᖅᑲᔭᖅ ᖃ (Koluktoo Bay) ᐊᒻᒪᓗ ᕿᙱᐊ ᓂᕆᐊᓂᑦ, ᐱᓗᐊᖅᑐᒥᑦ ᐃᓂᐅᔪᓂᑦ ᓂᕆᐊᓂᑦ ᐃᓗᕕᓕᐅᑉ (ᓲᕐᓗ, ᖃ-ᒨᐊᓇᐊᕐᓂᐊᕐᓗᓂ (Koluktoo Bay)) ᐊᒻᒪᓗ Assomption Harbour-ᒥᑦ (ᓲᕐᓗ, ᕿᙱᐊᓂᑦ ᐃᒃᓴᕝᕕᐅᑉ ᐃᓂᖕᒐᓂᑦ). ᖃᓄᐃᖕᒐᓂᐅᔪᑦ ᐊᔾᔨᓕᐅᖅᑕᖕᒋᑦ ᑑᒫᓕᖃᖅᑐᓂᑦ ᖃᐅᔨᔭᐅᔪᑦ ᖃᖕᒐᑕᓲᒃᑯᑦ ᖃᐅᔨᓴᐃᓂᖃᖅᑎᓪᓗᒋᑦ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᐅᔪᒥᑦ 2007-ᒥᑦ 2008-ᒥᑦ, 2013-ᒥᑦ ᐊᒻᒪᓗ 2014-ᒥᑦ (Elliott et al. 2015; Thomas et al. 2015) ᓯᕗᓂᐊᒍᑦ ᐅᔭᖁᑕᖅᑕᐅᔪᑦ ᐊᐅᓪᓚᖅᑎᑕᐅᖃᑦᑕᕐᓂᐊᕕᖅᑎᓪᓗᒋᑦ ᐅᐊᖕᓇᖅᐸᓯᖕᒐᓂᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᕐᖁᑎᒃᑯᑦ.
- ᐱᔾᔪᑎᒋᐸᓗᒋᑦ ᑎᑭᐅᑎᖃᑦᑕᐅᑎᓂᖏᑦ ᑖᒃᑲᖅᓯᒪᔪᑦ ᑑᒫᓖᑦ ᐊᒻᒪᓗ ᐅᒥᐊᕐᔪᐊᓕᕆᓃᑦ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᐅᔪᒥᑦ, ᑕᒪᓗᒃᑖᖅᑲᔭᖅ ᓯᐲᐊᒃᒥᑦ ᓈᓴᐅᑏᑦ/ᑎᑎᖅᑲᐃᑦ ᑲᑎᑕᐅᔪᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ ᐱᓕᕆᐊᖑᓚᐅᖅᑐᑦ ᑑᒫᓖᑦ >10 ᑭᓖᒥᑕᓂᒃ ᐅᖓᓯᒃᑎᒋᑎᓪᓗᒋᑦ ᐊᖏᓗᐊᖏᓐᓂᖅᓴᐅᔪᓂᒃ ᐊᒻᒪᓗ ᐊᖏᓂᖅᓴᓂᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ (ᐃᓚᐅᑉᓗᑎᒃ ᑕᒪᐃᓐᓂᑦ ᐱᓕᕆᐊᕐᒧᑦ ᐊᒻᒪᓗ ᐱᓕᕆᐊᕐᒨᙱᑦᑐᑦ ᐅᒥᐊᕐᔪᐊᑦ). ᐅᒥᐊᕐᔪᐊᓄᑦ ᑎᑭᐅᑎᖃᑦᑕᕐᓃᑦ (<10 ᑭᓖᒥᑕᐃᑦ) ᑕᐃᒪᐅᓚᐅᖅᑐᑦ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᐅᔪᒥᑦ ᑭᓯᐊᓂ ᐱᑕᖃᕋᔪᖕᓂᖅᓴᐅᑉᓗᓂ ᕿᖕᒍᐊ ᓂᕆᐊᓂᑦ ᐊᒻᒪᓗ ᖃ-ᒥᑦ (Koluktoo Bay) ᐃᒪᖕᒐᓂᑦ ᐃᓂᑭᕐᓚᑑᓂᖕᒐᓄᑦ ᓱᐸᔅᐸ ᐃᓚᖕᒐᓂᑦ ᐅᐊᖕᓇᖅᐸᓯᖕᒐᓂᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᕐᖁᑎᒋᔭᐅᔪᒥᑦ.
- ᖃᖕᒐᑦᑕᖅᑎᑕᐅᓯᒪᔫᒃᑯᑦ ᑖᒃᓄᑦ ᓈᓴᐅᑏᑦ/ᑎᑎᖅᑲᐃᑦ 2017-ᒥᑦ ᓇᓗᓇᐃᖅᓯᔪᑦ ᖃᑉᓯᐊᕐᔪᐃᑦ ᑖᒃᑲᖅᓯᒪᔪᑦ ᓅᑦᑕᖅᑐᑦ ᐊᑯᓂᖕᒋᓂᑦ ᑕᓯᐅᔭᖅ ᐊᒻᒪᓗ Admiralty Inlet. ᖃᓄᐃᖕᒐᓃᑦ ᐃᑲᔪᐃᔪᑦ ᐃᓱᒪᒋᔭᐅᔪᒥᑦ ᐃᓚᖕᒋᑦᑎᒍᑦ ᐊᑯᑉᓕᖅᓯᒪᖃᑦᑕᖅᑐᑦ ᐊᑯᓂᖕᒋᓂᑦ ᑕᓯᐅᔭᖅ ᐊᒻᒪᓗ Admiralty Inlet-ᒦᑦᑐᓂᒃ ᐅᒥᐊᕐᔪᐊᑦ ᐃᖏᕐᕋᔭᒃᑎᓪᓗᒋᑦ.
- ᑑᒫᓖᑦ ᐊᖅᑲᐅᒪᖃᑦᑕᕐᓂᖏᑦ ᑕᑯᒃᓴᐅᔪᑦ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᕐᓂᖏᑦ ᐱᔾᔪᑎᒋᐸᓗᒋ ᐊᒻᒪᓗ/ᐅᕝᕙᓘᓐᓃᑦ ᖃᓂᖓᓂᖏᓐᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐃᓚᐅᔪᑦ ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᔪᖅ >ᐃᖕᒐᖃᑦᑕᕐᓂᖏᑦ, ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᔪᖅ ᐊᖅᑲᐅᒪᖃᑦᑕᕐᓂᖏᑦ, ᐊᓗᐊᓄᓪᓗ ᐊᖅᑲᐅᒪᖃᑦᑕᕐᓂᖏᑦ; ᑭᙱᓂᐊᒍᑦ ᑑᒫᓖᑦ ᐃᒪᐅᑉ ᐊᓗᐊᓄᐊᖃᑦᑕᖅᑐᑦ ᐅᒥᐊᕐᔪᐊᖅᑕᖅᑎᓪᓗᒍᑐᐃᓐᓇ. ᐊᖏᔫᒥᒃ ᖃᓄᐃᖕᒐᓕᖅᑎᑦᑎᓂᖃᓚᐅᖅᑐᖅ ᖃᓄᖅ ᐊᑯᓂᐅᑎᒋᔪᖅ ᐊᖅᑲᐅᒪᓂᖏᓐᓄᑦ, ᐊᖅᑲᖅᐸᓪᓕᐊᑉᓗᑎᒃ ᓇᑭᖅᓴᕐᓂᖏᓐᓄᑦ, ᐅᕝᕙᓘᓐᓃᑦ ᐃᒪᐅᑉ ᐊᓗᐊᓄᑦ ᐊᖅᑲᐅᒪᓕᑎᓪᓗᒋᑦ (ᑑᒫᓖᑦ ᐊᖅᑲᖃᑦᑕᙱᑎᓪᓗᒋᑦ ᐊᓗᐊᓄᑦ ᑎᑭᐅᑎᔭᕆᐊᖕᒐᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ). ᐅᖓᓯᒃᑎᒋᖕᒋᑦ ᐊᓯᐊᙱᕐᓂᖃᖅᑎᓪᓗᒍ ᖃᐅᔨᔭᐅᔭᕆᐊᖕᒐᑦ ᐊᖅᑲᐅᒪᖕᒋᓄᑦ 1-ᒥᑦ 5-ᒧᑦ ᑭᓖᒥᑕᓅᖃᑦᑕᓚᐅᖅᑐᖅ, ᒪᓕᒃᓗᑎᒃ ᖃᓄᐃᓕᓂᖕᒋᓄᑦ ᐊᔾᔨᙳᖕᒋᓂᖕᒋᑦ. ᐊᔾᔨᒋᔭᖕᒐ ᑎᑭᐅᑎᓂᖕᒋᓄᑦ 7-ᓂᒃ 36-ᒥᓂᑦᓄᑦ ᐊᑕᐅᓯᖅ ᐅᒥᐊᕐᔪᐊᖅ ᐃᖏᕐᕋᑎᓪᓗᒍ (9 ᓈᑦᓂᒃ (knot) ᓇᑭᖅᓴᕐᓂᖅᑯᑎᒃ), ᓂᕐᔪᑏᑦ ᐅᑎᖅᑯᑎᒃ ᐱᖁᓯᑐᖃᓚᐅᖅᑕᕆᓄᑦ ᐅᒥᐊᕐᔪᐊᓄᑦ ᑎᑭᐅᑎᓯᒪᖅᑳᖅᑯᑎᒃ (ᓲᕐᓗ ᐊᑯᓂᐅᖕᒋᑦᑐᖅ ᐊᒃᑐᖅᑕᐅᓯᒪᓂᖅ). ᖃᔾᔮᖅᑕᖃᑦᑕᕐᓂᖕᒋᑦ ᐊᒃᑐᖅᓯᓂᐅᑉ ᐃᓱᒪᒋᔭᐅᓚᐅᖅᑐᖅ ᖁᑎᒃᑯᖃᑦᑕᕐᓂᖕᒐᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ 5 ᑭᓖᒥᑕᓂᒃ ᐅᖓᓯᒃᑎᒋᖃᑦᑕᕐᒪᑕ ᑖᒃᑲᖅᓯᒪᔪᖅ ᑑᒫᓕᕆᒧᑦ <1%-ᖑᔪᖅ ᓯᐲᐊᒃᒥᑦ ᓈᓴᐅᑏᑦ/ᑎᑎᖅᑲᐃᑦ ᑲᑎᑕᐅᔪᓂᑦ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᐅᔪᒥᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ.
- ᑑᒫᓖᑦ >ᐃᑦᑕᕐᓂᖏᓐᓄᑦ ᑕᑯᒃᓴᐅᓚᐅᖅᑐᑦ ᐱᔾᔪᑕᐅᓂᖕᒐᓄᑦ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ ᓂᐱᖃᕐᓂᖕᒐᓄᑦ ᐃᓚᐅᔪᑦ ᓴᖑᓂᖏᑦ ᐊᒻᒪᓗ ᓇᓅᓂᕆᓴᖏᑦ ᐅᒥᐊᕐᔪᐊᕐᒥᑦ (ᐊᑦᑎᒃᑐᖅ ᖃᓄᐃᓕᐅᕐᓂᕆᓴᖏᑦ). ᐊᖏᔫᒥᒃ ᐊᒃᑐᖅᑕᐅᓂᖏᓐᓄᑦ ᖃᐅᔮᓇᓚᐅᖏᑦᑐᖅ ᐃᖏᕐᕋᓂᖏᑦᑕ ᓇᑭᖅᓂᖏᓐᓄᑦ, ᓴᓂᒧᑦ ᐊᐅᓚᓂᖏᓐᓄᑦ 4-ᒥᑦ 10 ᑭᓖᒥᑕᓄᑦ, ᖃᓄᐃᓕᓂᕆᓴᖏᓐᓄᑦ ᐊᔾᔨᙱᖏᓐᓂᖅ ᐊᑐᖅᓗᒍ. ᐊᔾᔨᓕᐅᖅᑕᖕᒐ ᑎᑭᐅᑎᓯᒪᓂᖏᑦ ᐊᑐᓂ ᐅᒥᐊᕐᔪᐊᓄᑦ 29-ᒥᑦ 54 ᒥᓂᑦᓄᑦ (9 ᓈᑦᓂᒃ (knot) ᓇᑭᖅᓴᕐᓂᖅ), ᓂᕐᔪᑏᑦ ᐅᑎᖅᑯᑎᒃ ᐊᖅᑯᓯᓇᖅᑲᐅᑕᐅᓚᐅᖅᑕᕆᓄᑦ (ᓲᕐᓗ ᐊᑯᓂᐅᖕᒋᑦᑐᖅ ᖃᓄᐃᖕᒐᓂᖅᑯᕐᓂᖅ). ᖃᔾᔮᖅᑕᖃᑦᑕᕐᓂᖕᒋᑦ ᐊᒃᑐᖅᑕᐅᓂᐅᑉ ᐃᓱᒪᒋᔭᐅᓚᐅᖅᑐᖅ ᖁᑎᒃᑯᖃᑦᑕᕐᓂᖕᒐᓄᑦ ᐅᒥᐊᕐᔪᐊᑦ ᖁᓖᑦ ᑭᓖᒥᑕᓂᒃ ᐅᖓᓯᒃᑎᒋᖃᑦᑕᕐᒪᑖ ᑖᒃᑲᖅᓯᒪᔪᖅ ᑑᒫᓕᕆᒧᑦ <7%-ᖑᔪᖅ ᓯᐲᐊᒃᒥᑦ ᓈᓴᐅᑏᑦ/ᑎᑎᖅᑲᐃᑦ ᑲᑎᑕᐅᔪᓂᑦ ᖃᓂᑦᑐᒥᑦ ᖃᐅᔨᓴᐃᕝᕕᐅᔪᒥᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ. ᐊᖏᔫᒥᒃ ᖃᓄᐃᖕᒐᓕᖅᑎᑦᑎᓂᖃᕐᓂᕐᒥᒃ ᖃᐅᔨᔭᐅᓚᐅᖏᑎᓪᓗᒍ ᓴᓂᒨᖕᒐᔪᒧᑦ, ᓇᓗᓇᓚᐅᖏᑦᑐᖅ ᐃᓂᐅᔫᑦᑐᖃᙱᑦᑐᓂᒃ

> ᓈᓴᐅᑎᓂᑦ/ᑎᑎᖅᑲᓂᑦ ᖃᓂᑕᖓᓂᑦ ᐅᒥᐊᕐᔪᐊᑉ (0.5 ᑭᓛᒥᑕᓂᒃ ᐅᖓᓯᒃᑎᒋᔪᑦ ᐅᒥᐊᕐᔪᐊᑉ ᐃᒃᓴᕿᖓᓂᑦ ᐊᒻᒪᓗ 1 ᑭᓛᒥᑕᒥᒃ ᐅᒥᐊᕐᔪᐊᑉ ᓯᕗᓂᐊᓂᑦ). ᐱᑕᖃᖕᒋᓐᓂᐅᔪᖅ ᖃᒡᓕᔪᒪᖕᒋᓐᓂᕐᒨᔪᖕᓇᖅᑐᖅ ᑭᓯᐊᓂᑦᑕᐅᖅ ᓅᐲᐊᕐ ᑕᑯᒃᓴᐅᑎᑦᑎᑦᑎᐊᖏᓐᓂᖓᓄᑦ ᐃᓂᐅᔪᒥᑦ ᓈᓴᐅᑎᓂᒃ/ᑎᑎᖅᑲᓂᒃ ᒪᓂᒪᔪᖃᖕᒋᕐᓘᓂ.

ᑕᒪᐃᓐᓅᖓᔪᒃᑯᑦ, ᖃᓄᐃᖓᓂᐅᔪᑦ 2017-ᒥᑦ ᐊᒻᒪᓗ 2018-ᒥᑦ ᑑᒫᓕᖕᓂᒃ ᑖᒡᓕᖅᑐᐃᓂᕐᒧᑦ ᖃᐅᔮᓴᐃᓃᑦ ᐃᑲᔪᐃᔪᑦ ᓇᓚᐅᑦᑖᕆᓂᕐᓂᒃ ᑭᖑᓪᓕᖅᐸᐅᖅ ᐊᕙᑎᒥᒃ ᐊᒃᑐᖅᓯᓂᕐᒧᑦ ᑎᑎᖅᑲᒦᑦᑐᓂᒃ ᑮᓇᐅᔭᓕᐅᖅᐸᓪᓕᐊᓕᓵᕐᓂᕐᒧᑦ, ᐅᒥᐊᕐᔪᐊᕐᒥᑦ ᓂᐱᖃᕐᓂᕐᒥᒃ ᖃᓄᐃᖓᓕᖅᑎᑦᑎᓂᐅᔪᑦ ᑑᒫᓕᖕᓄᑦ ᐊᑯᓂᐅᔾᔫᖕᒋᕐᓘᓂ, ᓇᐃᑦᑑᓗᓂ ᑎᑭᐅᑎᑦᑕᐃᓕᓂᕐᒧᑦ, ᐊᔾᔨᑉᓗᒍ ᐊᑦᑎᒃᑐᒥᑦ ᖁᑦᑎᖕᓂᖅᓵᕐᔪᖕᒧᑦ ᖃᓄᐃᓕᐅᕈᑎᖃᕐᓂᖏᑦ ᑐᑭᓕᐅᖅᓯᒪᓂᖓᑐᑦ ᐊᕕᒃᑐᖅᓯᒪᔪᖅ 2.6.3-ᒥᑦ ᐅᓂᒃᑳᒥᑦ. ᖃᐅᔨᓇᖅᑐᖃᓚᐅᖏᑦᑐᖅ ᑎᑭᐅᑎᑦᑕᐃᓕᓂᐅᔪᓂᒃ, ᐊᓯᐊᓄᐊᖅᑐᓂᒃ, ᕿᒪᐃᔪᓂᒡᔫᓃᑦ ᐊᐅᔭᒃᑯᑦ ᐃᓂᒋᖃᑦᑕᖅᑕᖏᓐᓂᑦ (ᓰᕐᓗ ᖃᓄᐃᓕᐅᕐᓂᖃᕐᔪᐊᕐᓂᖏᑦ), ᐊᒥᓲᓂᖏᓐᓂᒃ ᐱᔾᔪᑎᖃᕈᓐᓇᖅᓘᓂ (ᐊᔾᔨᒋᔭᖓ ᑐᑭᓕᐅᖅᓯᒪᔫᑉ ᐅᔾᔨᕐᓇᖕᒋᑦᑐᖅ ᖃᓄᐃᖓᓕᖅᑎᑦᑎᓂᕐᒧᑦ ᐊᑐᖅᑕᐅᔪᖅ ᑭᖑᓪᓕᖅᐹᖅ ᐊᕙᑎᒥᒃ ᐊᒃᑐᖅᓯᓂᕐᒧᑦ ᑎᑎᖅᑲᒥᑦ).

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APPENDIX D
Comments

APPENDIX D
Comments

ACRONYMS / ABBREVIATIONS

AIS	Automated Identification System
Baffinland	Baffinland Iron Mines Corporation
BB	Baffin Bay
COSEWIC	Committee on the Endangered Wildlife in Canada
CPA	Closest Point of Approach
DFO	Fisheries and Oceans Canada
EEM	Environmental Effects Monitoring
ERP	Early Revenue Phase
FEIS	Final Environmental Impact Statement
Golder	Golder Associates Ltd.
h	hour
H_0	null hypothesis
Hz	hertz
IQ	Inuit Qaujimajatuqangit
JASCO	JASCO Applied Sciences
kHz	kilohertz
km	kilometres
LOESS	Locally Estimated Scatterplot Smoothing
m	metres
min	minutes
Mtpa	million tonnes per annum
No.	number
NHB	Northern Hudson Bay
NIRB	Nunavut Impact Review Board
NR	Tag not recovered
PAM	Passive Acoustic Monitoring
PAT	pop-up archival transmitting
the Project	Mary River Project
RSA	Regional Study Area
SARA	*Species at Risk Act*
SEL	Sound exposure level
SMRU	Sea Mammal Research Unit
SPL_{rms}	Sound pressure level (root mean square)

1.0 INTRODUCTION

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 strikes (Nowacek et al. 2004) and may attempt to avoid a transiting vessel by altering their travel speed (Williams et al. 2002) 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). The present study investigates the specific behavioral responses of narwhal (*Monodon monoceros*) to vessel noise and close vessel encounters along an existing shipping corridor in the Eastern Canadian Arctic. Narwhal behavioral responses evaluated in this study included changes in surface (e.g., horizontal displacement) and subsurface movements (i.e., dive behavior).

The narwhal 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 that includes commercial shipping. Narwhal occur in 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). Two of three recognized populations of narwhal occur in Canada (Baffin Bay and Hudson Bay), with the third population occurring in East Greenland. The populations are distinguished by their summering distributions, which may not reflect the degree of interchange between them (COSEWIC 2004). Narwhal from the Baffin Bay (BB) population winter in Baffin Bay and Davis Strait (Koski and Davis 1994; Dietz et al. 2001; Heide-Jørgensen et al. 2003) and summer in traditional coastal and inshore areas of West Greenland and the Canadian High Arctic. For management purposes, Fisheries and Oceans Canada (DFO) has partitioned the Baffin Bay population into six distinct summering stock areas (Jones Sound, Smith Sound, Somerset Island, Admiralty Inlet, Eclipse Sound and East Baffin Island), based on narwhal tracking data indicating geographic segregation of these narwhal stocks during summer (and year-round segregation from the Hudson Bay population), and evidence from genetic and contaminants studies that support this stock partitioning (Doniol-Valcroze et al. 2015a).

Narwhal from the Eclipse Sound and Admiralty Inlet stocks are known to rely on the inshore fjord waterways of North Baffin Island 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 during the summer season in Milne Inlet, Koluktoo Bay, Eclipse Sound, Navy Board Inlet and Admiralty Inlet (Remnant and Thomas 1992; Marcoux et al. 2009; Smith et al. 2017). Although it remains contested whether narwhal utilize these summering areas for foraging (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), the sheltered deep-water inlets are thought to provide them with protection from wind (Kingsley et al. 1994; Richard et al. 1994; COSEWIC 2004) and with refuge from their main predator the killer whale (*Orcinus orca*) (Koski and Davis 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/the Company) 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 summer 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, Baffinland is authorized to transport 6.0 Mtpa of ore to Milne Port using chartered ore carrier vessels along the Northern Shipping Route until 31 December 2021. The Northern Shipping Route encompasses marine waters of Milne Inlet, Eclipse Sound, Pond Inlet and Baffin Bay. 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 during summer (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, thus potentially reducing the pair's travel speed and ability to manoeuvre away from vessel traffic.

In this study, fine-scale movements of narwhal during close encounters with large- (≥100 m in length) and medium- (50 - 99 m in length) sized vessels (Project and non-Project related) throughout the 2017-2018 shipping seasons were analyzed to understand and characterize behavioral responses of narwhal to vessel traffic and associated noise along the Northern Shipping Route. Narwhal vertical and horizontal movement data collected from animal-borne biologging tags were analyzed in relation to vessel movements derived from available Automated Identification System (AIS) vessel-tracking data to investigate the following research questions:

- Do narwhal alter their movements at the surface during close vessel 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 vessel 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 behavioral responses observed?
- Do narwhal demonstrate habituation to Project-related vessel traffic following repeated exposure?

The above research questions informed the development of null hypotheses outlined in Section 3.5.2 to 3.5.4, used to test predictions made in the Final Environmental Impact Statement (FEIS) that vessel noise impacts on narwhal will be limited to temporary and localized disturbance effects, with no anticipated large-scale displacement effects or abandonment of narwhal from their summering grounds which could result in a population or stock-level consequence (consistent with the definition of a significant effect used in the FEIS).

1.1 Overview of Narwhal Tagging Program

Terms and Conditions contained within 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 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 assessing effects of Project-related shipping operations on marine mammals, including 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 No. 005 terms and conditions applicable to narwhal, Golder Associates Ltd. (Golder) partnered with Fisheries and Oceans Canada (DFO) to undertake the 2017 and 2018 Narwhal Tagging Program in Tremblay Sound, Nunavut. The collaborative research study expanded on DFO’s existing narwhal 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 behavioral response of narwhal to vessel traffic. A total of 24 narwhal were live-captured in Tremblay Sound during the 2017 and 2018 open-water seasons and instrumented with a combination of tags that recorded the animal’s 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 to measure the animal’s acoustic environment and vocal activities in tandem with other narwhal behaviors.

1.2 Study Objective

The objective of the 2017 – 2018 Integrated Narwhal Tagging Study was to investigate narwhal behavioral response to large- (≥ 100 m in length) and medium- (50-99 m in length) sized vessels transiting along the Northern Shipping Route by comparing animal-borne tag data with vessel movement data collected during the 2017 and 2018 shipping seasons. Behavioral responses considered in this study included changes in narwhal movement behavior at the surface (e.g., horizontal displacement) and in the subsurface (i.e., dive behavior).

1.3 Study Area

The study area assessed herein includes the full spatial extent of the Project’s Regional Study Area (RSA) for North Baffin Island (Figure 1-1) and includes marine waters of Milne Inlet, Eclipse Sound, Navy Board Inlet, Tremblay Sound and adjacent waterbodies (Figure 1-2). To capture potential variation in narwhal movement in relation to the animal’s habitat, waterbodies within the RSA were partitioned into substrata based on bathymetric features.

LEGEND

- PROJECT SITE
- COMMUNITY
- FUTURE SOUTH RAILWAY
- MILNE INLET TOTE ROAD
- NUNAVUT SETTLEMENT AREA
- SHIPPING ROUTE
- MARINE MAMMAL REGIONAL STUDY AREA
- 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

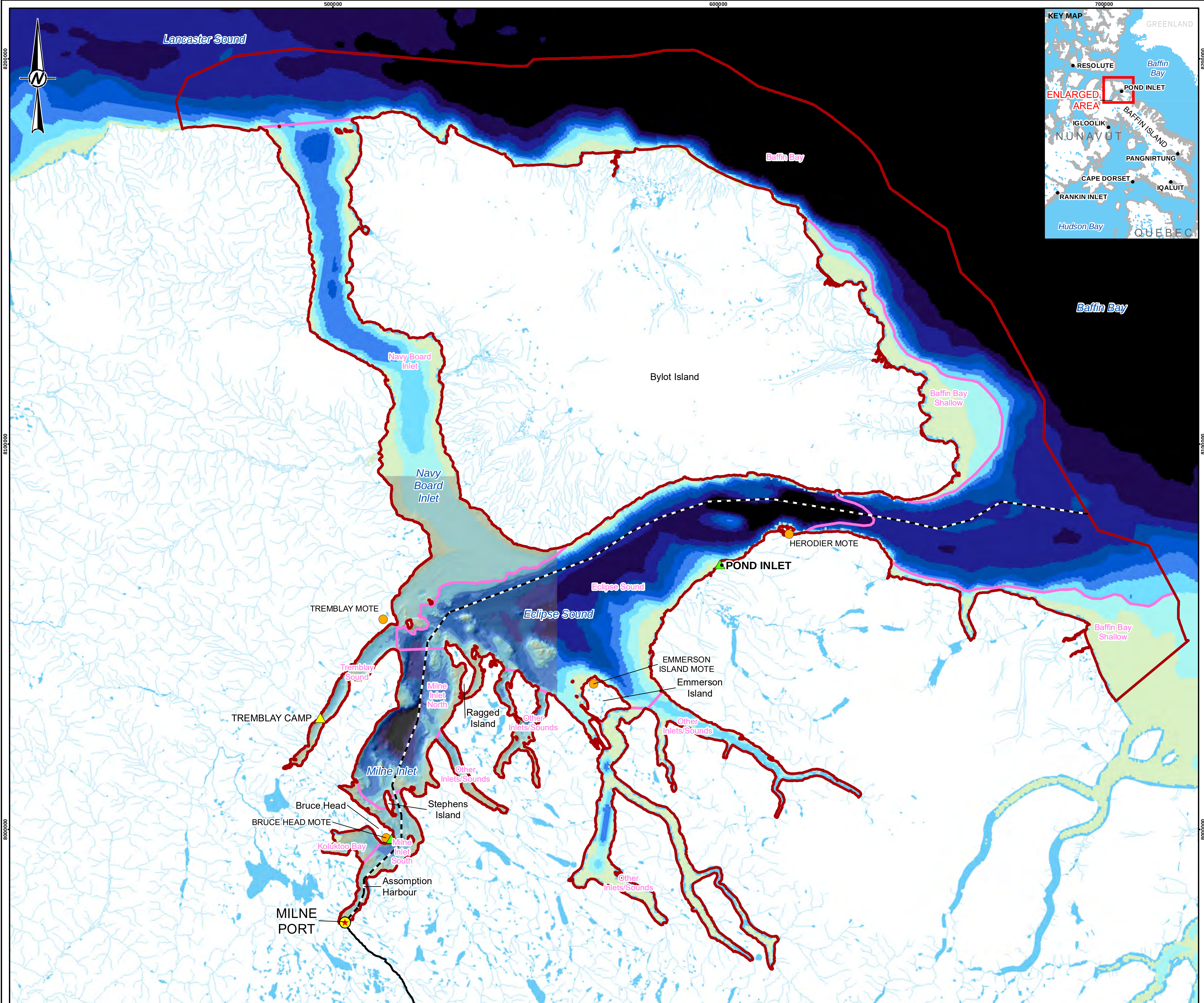
PROJECT
MARY RIVER PROJECT

TITLE
PROJECT LOCATION

CONSULTANT
GOLDER

YYYY-MM-DD	2020-08-07
DESIGNED	AA
PREPARED	AJA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	12000-4	0	1-1



LEGEND

- AIS SHORE-BASED STATION
- COMMUNITY
- MILNE PORT
- TAGGING LOCATION
- MOTE LOCATION
- MILNE INLET TOTE ROAD
- SHIPPING ROUTE (APPROXIMATE)
- WATERCOURSE
- GEOGRAPHIC STRATA
- MARINE MAMMAL REGIONAL STUDY AREA
- WATERBODY

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

0 25 50

1:1,000,000 KILOMETRES

REFERENCE(S)

MILNE PORT INFRASTRUCTURE DATA BY HATCH, JANUARY 25, 2017, RETRIEVED FROM KNIGHT PIESOLD LTD. FULCRUM DATA MANAGEMENT SITE MAY 19, 2017. GEOGRPAHIC NAMES, 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. CHART 3380, 3395, 3477, 1200024, 2301836, 4012380, 4013646, 4013647, AND 4013648 OBTAINED FROM THE CANADIAN HYDROGRAPHIC SERVICE AND PURSUANT TO CHS DIRECT USER LICENCE NO. 2017-0531-1260-G. ENJI CHART 10-044 OBTAINED FROM ENTREPRISES NORMAND JUNEAU INC. ADDITIONAL BATHYMETRY COVERAGE PROVIDED BY IBCAO V3.0 OBTAINED FROM NOAA. PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

TITLE
GEOGRAPHIC STRATA FOR NARWHAL TAGGING PROGRAM (2017-2018)

CONSULTANT

GOLDER

YYYY-MM-DD	2020-08-07
DESIGNED	AA
PREPARED	AJA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	12000-4	0	1-2

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm

2.0 SPECIES BACKGROUND

2.1 Population Status and Abundance

Narwhal are endemic to the Arctic, occurring primarily in Baffin Bay, the eastern Canadian Arctic, and the Greenland Sea (Reeves et al. 2012). According to NAMMCO (2017), an approximate estimate of global abundance is 85,000 to 100,000 narwhal. Seldom present south of 61º N latitude (COSEWIC 2004), two populations are recognized in Canadian waters; the Baffin Bay (BB) population and the northern Hudson Bay (NHB) 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, 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 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). Both narwhal populations in Canada are not presently considered at risk and are not listed under the federal *Species at Risk Act* (*SARA*).

The Canadian High Arctic Cetacean Survey conducted by DFO in August 2013 represents the most complete survey conducted to date of six major narwhal summering aggregations in the Canadian Arctic (Doniol-Valcroze et al. 2015). The current abundance estimate for the Baffin Bay population, corrected for diving and observer bias, is 141,909 individuals (Doniol-Valcroze et al. 2015). Although narwhal stocks tend to segregate in the summer months, annual variation in stock estimates between Eclipse Sound and Admiralty Inlet suggests that there is movement between these two summering ground locations (Thomas et al. 2015). The corrected estimate for the Eclipse Sound stock is 10,489 narwhal (CV = 0.24) while the corrected estimate for the Admiralty Inlet stock is 35,043 (CV = 0.42) (Doniol-Valcroze et al. 2015).

Results from aerial surveys conducted by Golder in 2019 indicated an abundance estimate of 38,771 narwhal for the combined Eclipse Sound and Admiralty Inlet stocks (Coefficient of Variation (CV) = 0.12, 95% confidence interval CI = 30,667– 49,016; Golder 2020b), which falls within the 95% CI of DFO's 2013 abundance estimate of the combined stock (45,532 narwhals, CV=0.33, CI = 22,440–92,384; Doniol-Valcroze et al. 2015). For the Eclipse Sound stock alone, the 2019 abundance estimate was 9,931 narwhal (CV = 0.05, 95% CI = 9,009–10,946; Golder 2020b) which falls within the 95% confidence interval of all previous DFO abundance estimates for the Eclipse Sound stock, including the last survey undertaken in 2016 (12,093 narwhal, CV = 0.23, CI = 7,768–18,660; Marcoux et al. 2019).

2.2 Geographic and Seasonal Distribution

Narwhal show high levels of site fidelity, annually returning to well-defined summering and wintering areas (Laidre et al. 2004; Richard et al. 2010). During summer, narwhal tend to remain in inlet 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-water offshore areas and the continental slope where water depths are 1,000 to 1,500 m, and where upwelling increases biological productivity and supports abundant prey species (Dietz and Heide-Jørgensen 1995; Dietz et al. 2001; Richard et al. 2010).

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). According to Inuit traditional knowledge (Inuit qaujimajatuqangit; IQ), narwhal first enter Eclipse Sound in July through leads in the ice, with large males typically entering ahead of females and calves (JPCS 2017). Throughout the summer months, narwhal remain in western Eclipse Sound and associated inlets during which time calves are born and reared (Koski and Davis 1994; Dietz and Heide-Jørgensen 1995; Dietz et al. 2001; Doniol-Valcroze et al. 2015). The distribution of narwhal in Eclipse Sound, Milne Inlet, Koluktoo Bay, and Tremblay Sound during summer is thought to be influenced 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). Individuals exiting Eclipse Sound and Pond Inlet migrate down the east coast of Baffin Island toward overwintering areas in Baffin Bay and Davis Strait (Dietz et al. 2001; JPCS 2017). Depending on ice conditions, specific migratory routes may change from year to year (JPCS 2017). Individuals summering near Somerset Island typically 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 1,000 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 (JPCS 2017). Narwhal tracking data have identified two distinct wintering areas for the Baffin Bay population (Richard et al. 2010, Laidre and Heide-Jørgensen 2005). 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 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 (Laidre and Heide-Jørgensen 2005).

2.3 Life History and Reproduction

Narwhal are one of the longest-lived of the toothed whales, living for more than 100 years according to research that assessed chemical changes in the eye lens (Garde et al. 2007; NAMMCO 2017). 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 typically occurs 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 et al. 2018). Typically, newborn calves travel less than one body length away from their mother and in larger group sizes while in Eclipse Sound (mean group size = 5) compared to smaller group sizes along the east coast of Baffin Island (mean group size = 2) (Charry et al. 2018). 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 and reported food 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 (Finley and Gibb 1982). 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).

Deep diving is energetically costly to marine mammals and requires lipid-rich prey or abundant food sources to support this activity (Bluhm and Gradinger 2008; Davis 2014; 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). However, recent studies that have analyzed the spatial and seasonal patterns in narwhal dive behavior (using targeted deep dives as a proxy for benthic foraging) suggest that, although the majority of dives recorded in Eclipse Sound during the summer occurred near the surface, deep-water dives were also frequently observed, suggesting the occurrence of important benthic foraging areas (Watt et al. 2015; 2017). This finding is supported by stable isotope analysis conducted for the Baffin Bay population, in which Greenland halibut and Northern shrimp (*Pandalus borealis*) were identified as the major constituents (>50%) of their summer diet (Watt et al. 2013).

2.5 Locomotive Behavior

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 behavior 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 min; 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 m; 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 that offered 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-Jørgensen 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-Jørgensen 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 upper 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-Jørgensen et al. (2001).

Heide-Jørgensen et al. (2001) evaluated dive rate (number of dives per hour) of 25 narwhal tagged in Tremblay Sound between 1997 and 1999 and in Melville Bay, West Greenland between 1993 and 1994. According to this study, the 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-Jørgensen 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 an older study that tracked the dive behavior 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 behavior is variable based on parameters such as sex, life stage, location, season, and activity state (Heide-Jørgensen 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-Jørgensen 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 behavior, given the aerobic limitations of the young and its reliance on maintaining an echelon position with its mother (Watt et al. 2015), though studies conducted by Heide-Jørgensen and Dietz (1995) found no difference in dive behavior 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 on their summering grounds (with depths often limited by the seabed bathymetry), increasing their dive depth and duration in the fall months (Heide-Jørgensen 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-Jørgensen 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 behavior but does influence narwhal spatial distribution at the surface (Watt et al. 2017).

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-Jørgensen 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 region 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[1] averaging 3.5 individuals (range: 1 to 25), and in herds[2] 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; Golder 2018).

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

[2] Herd = an aggregation of clusters.

Understanding confounding effects such as the presence of predators in a system is important when assessing movement behavior 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 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 normal spatial distribution), beached themselves in sandy areas, and shifted their distribution away from the attack site. Normal (pre-exposure) behavior was said to resume shortly (< 1 hour) after the killer whales departed the area (Laidre et al. 2006). This shift in spatial distribution is supported by Breed et al. (2017), who suggested that behavioral 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 Behavior

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-Jørgensen et al. 2013b, Hauser et al. 2018).

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 behavioral 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

Behavioral responses of marine mammals exposed to vessel traffic and associated noise have been documented for several species, however limited information is available for cetaceans inhabiting Arctic waters and for narwhal specifically. Vessel disturbance may elicit several different behavioral responses in cetaceans, including a shift in travel speed or dive behavior, freeze or flight (avoidance) response, and short- or long-term displacement from optimal habitat, all of which have the potential to affect subpopulation viability. Of note, narwhal have been shown to react at relatively low received sound levels to distant icebreaking vessels actively breaking ice (Finley et al. 1990; Cosens and Dueck 1993).

In comparing the proposed hearing range of narwhal to the sound output of transiting vessels, the majority of underwater sound generated by 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 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 is likely concentrated below the peak hearing sensitivity of narwhal (>1 kHz).

Sound level (or ‘intensity’) must also be considered when assessing the behavioral response of narwhal to vessel-generated noise. 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 behavioral disturbance effects, though the specific behavioral 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 at 9 knots along the Northern Shipping Route was undertaken by JASCO Applied Sciences (JASCO) in 2017 that considered the spectral content for vessel operations up to 25 kHz (Quijano et al. 2017). Modeling results predicted that ore carriers transiting through Milne Inlet would not reach the SEL_{24h} injury threshold[3] at ranges beyond 20 m from the center of the vessel. However, the 120 dB re 1µPa (SPL_{rms}) disturbance threshold[4] 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), though model estimates were later shown to be overly conservative compared to sound levels measured via passive acoustic recording in 2018 (Frouin-Mouy et al. 2019). 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-Jørgensen et al. 2013a).

Based on behavioral response research to date, marine mammal responses to anthropogenic sound sources are categorized using a severity scale ranking system (Southall et al. 2007; Finneran and Jenkins 2012; Finneran et al. 2017). Finneran et al. (2017) categorize marine mammal behavioral responses to anthropogenic sound sources using a severity scale described as low, moderate, or high, derived from Southall et al. (2007). Low severity responses are described as being within an animal's range of typical (baseline) behaviors and are unlikely to disrupt an individual to a point where natural behavior patterns are significantly altered or abandoned.

Low severity responses would include:

- Orientation response
- Startle response
- Change in respiration
- Change in heart rate
- Change in group spacing or synchrony

Moderate severity responses would not be considered significant behavioral responses if they lasted for a short duration (e.g., partial duration of vessel passage) and the animal immediately returned to their pre-response behavior. Moderate severity responses would be considered significant behavioral responses if they were sustained for a long duration. What constitutes a long-duration response is different for each situation and species, although it is likely dependent upon the magnitude of the response and species characteristics such as body size, feeding strategy, and behavioral state at the time of the exposure. In general, a response would be considered 'long-duration' if it lasted up to several hours, or enough time to significantly disrupt an animal's daily routine. For the derivation of behavioral criteria in this study, a long duration was defined as a response that lasted for the full duration of vessel exposure or longer. This assumption was made because examination of behavioral response data suggests that had the vessel exposure continued, the behavioral responses would have continued as well.

[3] 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).

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

Moderate severity responses would include:

- Altering migration path, locomotion (speed, heading), dive profiles
- Stopping/altering nursing, breeding, feeding/foraging, sheltering/resting, vocal behavior
- Avoiding area near sound source
- Displays of aggression or annoyance (e.g., tail slapping)

High severity responses include those with immediate consequences to growth, survival, or growth, and those affecting animals in vulnerable life stages (i.e., calf, yearling). High severity responses are therefore always considered to be significant.

High severity responses would include:

- Long-term or permanent abandonment of area
- Prolonged separation of females and dependent offspring
- Panic, flight, or stampede
- Stranding

3.0 METHODS

3.1 Field Tagging

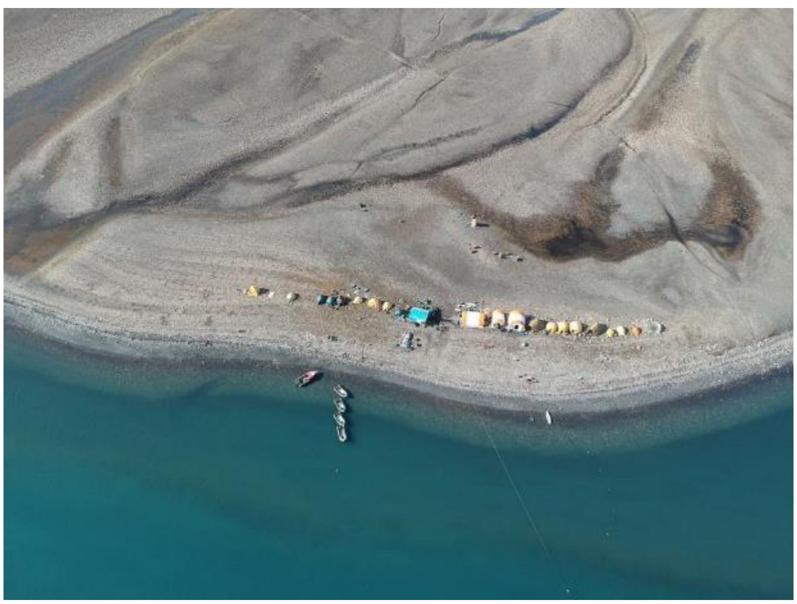
A total of 20 narwhal were live-captured during the 2017 open-water season (31 July to 11 September) from a remote field camp located in Tremblay Sound, Nunavut (72° 22' N, 81° 06' W) (Figure 1-2 and Photograph 3-1). Four additional narwhal were live-captured during the 2018 open-water season at the same location. During both field programs, 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 for Scientific Purposes (S-17/18 1017-NU and S-18/19-1029-NU) and program approval was obtained from the Freshwater Institute Animal Care Committee (Animal Use Permits FWI-ACC-2017-40 and FWI-ACC-2018-22).

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 SPLASH10 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. Additionally,13 of the live-captured narwhal (i.e., nine in 2017; four in 2018) were 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). Fourteen of the satellite tags deployed on narwhal (i.e., 12 satellite tags in 2017; two satellite tags in 2018) were equipped with a Fastloc[5] 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 RSA during the 2017 shipping season and an additional two stations were deployed in 2018 (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 Milne Inlet (including Koluktoo Bay). The addition of the two MOTE systems resulted in approximately double the number of data messages received from each narwhal compared to messages received by satellite alone.



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

[5] 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.

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: Tags shown from left to right are Greenridge Sciences Acousonde 3B, Wildlife Computers (WC) MiniPat, and the WC SPLASH10.

3.2 Tag Specifications

3.2.1 Wildlife Computers SPLASH10

The SPLASH10 is an Argos satellite tag that contains 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 SPLASH10 is summarized, compressed and stored for transmission during a subsequent surfacing event. In addition to providing ARGOS locations, the SPLASH10 can incorporate Fastloc GPS which enables high-resolution GPS location data to be acquired. Depth data provided by the SPLASH10 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 SPLASH10 tags used in 2017 included Fastloc GPS, while the five remaining SPLASH10 tags relied on conventional ARGOS positioning and were of insufficient resolution to be included in this analysis. All SPLASH10 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 contains 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, four of the five CTD-SRDL tags deployed on narwhal in 2017 and 2018 also included Fastloc GPS capability and were of sufficient resolution to be included in this analysis. 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 SPLASH10 tags. The five 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 SPLASH10 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 SPLASH10 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 behaviors. 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. In 2017, 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. In 2018, each of the four units were deployed on separate animals, for a total of four independent deployments. All four Acousonde units 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 (≥ 100 m) and medium (50-100 m) Project and non-Project related vessels transiting throughout the RSA during the 2017 and 2018 study periods were tracked and recorded using a combination of shore-based and satellite-based Automated Identification System (AIS) data. 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. AIS transponders are mandatory on all commercial vessels >300 gross tonnage and on all passenger vessels. Small vessels (< 50 m in length) are not typically equipped with AIS transponders and were therefore not included in this study.

A shore-based AIS station was installed at Bruce Head in 2017 which provided a continuous record of vessel positions within line-of-sight of the station, inclusive of Milne Inlet (north and south) and portions of Eclipse Sound and Navy Board Inlet. The Bruce Head shore-based AIS data were limited to between 29 July and 30 August during 2017 and between 23 July and 15 September during 2018. A second shore-based AIS station was installed near Pond Inlet in 2018 which provided a continuous record of vessel positions within line-of-sight of the station, inclusive of Eclipse Sound and portions of Milne Inlet and Navy Board Inlet. The Pond Inlet shore-based AIS data were limited to between 20 July and 21 October during 2018. Satellite-based AIS data, acquired from exactEarth Ltd[6], were 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 had 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 RSA 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 (SPLASH10 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), hereafter referred to as ‘clean’ GPS positions. Since narwhal are known to modify their normal behavioral activities immediately following live capture and tag attachment (Blackwell et al. 2018), the initial 36 h of positional data post tagging were removed from the dataset.

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. An equivalent correction was also performed for the SMRU GPS data.

For visualization of all tagged narwhal movements throughout the full duration of tag deployment, raw narwhal GPS data were shown for the full spatial 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 the spatial extent of the RSA.

Narwhal tracks were corrected manually so that they did not cross land by adding the smallest number of points that allowed avoidance of land while providing a plausible track (usually near shore). Added points that were within 20 min from a raw GPS point were flagged as equivalent to a raw GPS point, whereas filled-in points > 20 min from a raw GPS point were not considered raw GPS data. The 20 min cut-off value was chosen based

[6] 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.

on the use of the 20 min cut-off for use of interpolated GPS data (see below). Following the manual correction, positional data were interpolated at 1 min intervals, however only raw data and interpolated data <20 min of a raw GPS position were retained for this report, as described in Golder (2019). In addition, manually added points that were within 20 min from a raw GPS position were also retained for analysis. Since more than 80% of the raw GPS records were within 40 min of each other, the <20 min cut-off allowed for retention of the majority of the interpolated data. Raw and interpolated GPS data were used to extract the narwhal's distance from shore, the bottom depth at narwhal position using available bathymetric data for the region, and which substratum the narwhal was in (where substrata were defined based on bathymetry and physical habitat differences, such as bathymetry and channel width; Figure 1-2).

In 2017, SPLASH10 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 SPLASH10 tag buffer programming, older data were 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 skewed decrease of daily GPS points following tag deployment (Golder 2019a). If SPLASH10 tags were still active in November and December 2017, GPS collection effort was reduced to one day in seven (e.g., NW12), while no GPS collection was attempted after December. Although the four Fastloc-enabled CTD-SRDL tags deployed on narwhal could theoretically collect GPS locations every eight minutes, other programming requirements and environmental limitations resulted in an actual recovery of GPS locations at a lower rate than the SPLASH10 tags (NW11, NW15, NW21 and NW22). 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.

In order to evaluate the spatial distribution of narwhal in the RSA, a custom R function developed by Binder et al. (2018) was used to divide the RSA into a grid of 500 x 500 m cells. For each 500 x 500 m cell, two values were then calculated:

1) total number of tagged individuals (of the 14 available) which occupied the cell at least once during the 2017 and 2018 deployment period.

2) mean daily number of tagged narwhal (of the 14 total) in each cell - calculated as the sum of the number of narwhal in each cell within a 24-hour period, divided by the total number of narwhal actively transmitting in the RSA. For this calculation, multiple positions of a single narwhal within the same cell and time interval were considered to be a single position. The resulting value represented "relative habitat use" within a cell.

Plotting the spatial distribution of narwhal only incorporated raw GPS positions from the combined 2017-2018 dataset. The output consisted of color-coded heat maps depicting the total number of narwhal and narwhal habitat use within each 500 m × 500 m cell in the RSA, as detailed above. Heat maps were plotted using the package 'ggmap' (Kahle and Wickham 2013) in R (R Core Team 2019).

3.4.2 Raw Dive Data

Dive data from pop-up archival transmitting tow tag (MiniPAT; Wildlife Computers) were corrected for surface bias – for each narwhal, minimum recorded depth was calculated for each hour of the MiniPAT tag deployment. The resulting values were plotted relative to time, to examine possible drifts in logged surfacing depths over time or due to water temperature changes. Hourly surface bias ranged from -2 m to 1 m. To correct the surface bias, an hourly offsetting depth was calculated and used, so that the 5th quantile of hourly depth for each MiniPAT-tagged narwhal was 0 m.

Dive data from SPLASH10 tags were also corrected for surface bias. However, since the resolution of the data collected by SPLASH10 tags was only 75 s, only daily minimum depths were calculated for these tags to evaluate the surface bias. Since less and less data were transmitted over time due to tag settings, daily minimum depths increased over time, from approximately 0.5 m in the beginning of the deployment to approximately 5 m by the end of deployment (for most tags except for NW06, where daily minimum depth was >15 m). The median daily surface bias for SPLASH10 tags was 0.5 m for all tags other than NW08, which had a median surface bias of 1.5 m due to an early onset of reduced data transmission. Since it was not possible to use each day's minimum depth to correct for surface bias and since median surface bias was 0.5 m for nine out of the 10 deployed SPLASH10 tags, a simple 0.5 m correction factor was applied across the board for all SPLASH10 tags.

On rare occasions, MiniPAT dive data had spurious depth recordings. These were identified as an increase in depth ≥3 m between two consecutive 1 s records, followed by a decrease in depth ≥3 m in the subsequent 1 s time stamp. These cases (535 cases out of the 14,972,840 cases of compiled MiniPAT records) were removed from the dataset.

Since narwhal have been documented to change their behavior immediately following tagging (Blackwell et al. 2018), the first 36 h post tagging were removed from the dive database. This resulted in a clean dive dataset of 14,178,788 records, which consisted of 13,841,375 MiniPAT records and 337,413 SPLASH10 records (though some of these records were obtained from narwhal that were also equipped with MiniPAT tags).

3.4.3 Bathymetric Data

For each raw and interpolated narwhal GPS position, a bathymetry depth value was calculated using linear interpolation of available data obtained for the region (Figure 1-2). Due to the limited horizontal 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), some misalignment of narwhal dive depths and the estimated available bathymetry was evident. In certain cases, narwhal appeared to dive deeper than the available bathymetry; in other cases, deep dives (likely feeding behavior) 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 AIS data, which provided accurate real-time data on all large- and medium-size vessel passages through the RSA during the 2017 and 2018 shipping seasons. Information provided by 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 (in 2017 and 2018) and at Pond Inlet (in 2018 only) provided higher temporal resolution positional data, but only for line-of-sight spatial coverage. The satellite-based AIS data offered lower temporal resolution, but covered the entire Northern Shipping Route and beyond.

Due to the higher resolution of the shore-based AIS data, the AIS data included in the analyses were primarily shore-based, with satellite data points included only where gaps in the shore-based AIS coverage were evident. Travel speeds were calculated using the recorded AIS positions and time stamps. Cases where travel speeds exceeded 50 m/s over two consecutive records were assumed to be erroneous and were removed from the dataset. Following data clean-up, vessel positions were interpolated to 1 min resolution where gaps in the AIS coverage occurred.

Vessels were classified into three size categories and only large- and medium-sized vessels were used in subsequent analyses. AIS data were also filtered to retain only moving vessels (speed ≥ 1 knot), to avoid representing interactions between narwhal and stationary vessels. Vessel AIS data were not restricted geographically, so that possible encounters between narwhal within the Project's RSA and vessels outside of the RSA were captured.

3.5 Data Analysis

3.5.1 Identification of Narwhal Encounters with Vessels

For the purpose of this study, horizontal movements of narwhal fitted with GPS Fastloc tags (SPLASH10 or CTD-SRDL) were analyzed in relation to the combined AIS vessel track dataset to determine the location and time of narwhal-vessel interactions within the RSA. Using customized functions in R v. 3.6.1 (R Core Team 2019), the closest point of approach (CPA) was then identified for all 'events[7]' in which a vessel transiting through the RSA (speed ≥1 knot) came within 3 km of a tagged narwhal.

Only raw GPS data or manually corrected/interpolated data within 20 min from a raw GPS point were used in this analysis (Section 3.4.1). For each retained narwhal GPS position, all vessel AIS positions recorded within the preceding or following 30 min of the timestamp were retrieved and the nearest AIS position to a given narwhal location was identified. Of these, the points in time when the distance between the narwhal and the vessel decreased and then increased were flagged as potential CPA points. Each of these "potential" CPA points was then compared to other "potential" CPA points for that narwhal-vessel combination, so that only a single CPA point within each 6 h time period was retained. An "event" was then defined as the ±3 h time window around each narwhal-vessel encounter where the CPA ≤3 km.

For each CPA event, vessel AIS data, narwhal GPS data, narwhal dive data, and bathymetric data were retained in order to visualize trends in narwhal surface and subsurface movements in relation to the surrounding environment. Two plots were then generated; the first included a map depicting the horizontal relocations of individual narwhal and vessels during the 6 h time period, while the second plot showed the corresponding dive profile for the same narwhal during that time, relative to bathymetry. All analyses and plotting were performed in R v. 3.6.1 (R Core Team 2019).

Surface and dive behavior of individual narwhal was then 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 knots through Milne Inlet, according to acoustic modeling results (Quijano et al. 2017).

[7] Event = the 6 h time period (3 h before CPA, 3 h after CPA) associated with each narwhal-vessel encounter where the CPA ≤3km.

According to measured sound levels obtained in 2018 via passive acoustic monitoring (Frouin-Mouy et al. 2019), it was determined that model estimates were overly conservative in predicting the distance to which the disturbance threshold would propagate from a vessel. Therefore, ten kilometres was deemed a conservative distance to delineate periods when narwhal are “exposed” to vessels, or not. 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 Dive Behavior

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

1) increase in surface time (reflective of a freeze response)
2) decrease in surface time (reflective of avoidance behavior)
3) increase in dive rate (reflective of avoidance behavior)
4) decrease in dive rate (reflective of potential freeze response)
5) increase in the occurrence of bottom dives[8] (reflective of avoidance behavior)
6) decrease in the occurrence of bottom dives (reflective of decreased foraging effort and/or freeze response)
7) increase in ‘time at depth’[9] (reflective of avoidance behavior)
8) decrease in ‘time at depth’ (reflective of decreased foraging effort and/or freeze response)
9) increase in dive duration (reflective of avoidance behavior)
10) decrease in dive duration (reflective of decreased foraging effort and/or freeze response)
11) increase in descent speed (reflective of avoidance behavior)

Based on information from the literature regarding possible whale responses to vessel traffic, the following null hypotheses were developed in 2017 (Golder 2018) and again tested herein to identify potential effects of vessel traffic on narwhal within the RSA:

$H1_0$: Surface time does not significantly change in the presence of vessel traffic
$H1_A$: Surface time significantly changes in the presence of vessel traffic

$H2_0$: Dive rate does not significantly change in the presence of vessel traffic
$H2_A$: Dive rate does change significantly in the presence of vessel traffic

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[8] 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.

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

H3$_0$: The occurrence of bottom dives does not significantly change in the presence of vessel traffic
H3$_A$: The occurrence of bottom dives significantly changes in the presence of vessel traffic

H4$_0$: Time at depth does not significantly change in the presence of vessel traffic
H4$_A$: Time at depth significantly changes in the presence of vessel traffic

H5$_0$: Dive duration does not significantly change in the presence of vessel traffic
H5$_A$: Dive duration significantly changes in the presence of vessel traffic

H6$_0$: Descent speed does not significantly change in the presence of vessel traffic
H6$_A$: Descent speed significantly changes in the presence of vessel traffic

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 the analysis of subsurface movements based on meeting the following criteria: (1) narwhal was fitted with ARGOS satellite tag including Fastloc GPS (SPLASH10; Wildlife Computers); (2) narwhal was fitted with tow tag and tow tag was retrieved, providing 1 s dive resolution data (MiniPAT; Wildlife Computers); and (3) narwhal was present within the RSA during the time that the tags collected data. With the primary objective being to incorporate the highest resolution data possible, these selection criteria resulted in six narwhal from the broader 2017 and 2018 datasets being included in the analysis of dive response to vessel traffic. Specifically, four narwhal tagged in 2017 (i.e., NW1, NW2, NW3, NW4) and two narwhal tagged in 2018 (i.e., NW21, and NW22) met the above-stated criteria.

For the analyses of narwhal surface time and dive rate, dive data obtained from additional animals outfitted with only the SPLASH10 tag but not the MiniPAT tag were incorporated. A preliminary examination of concurrent data collected by MiniPAT and SPLASH10 tags attached to the same individuals indicated that while SPLASH10 data were not reliable in resolving the other dive parameters, the data performed well for recording overall dive and surface behaviors (where “dive” is a narwhal recorded deeper than 7 m from surface). Therefore, SPLASH10 data obtained from NW5, NW6, NW7, NW8, NW12, and NW13 were incorporated in the analyses of both surface time and dive rate in order to increase the sample size from six to 12 tags.

The MiniPAT tags detached from narwhal considerably earlier than the GPS backpack tags, providing high-resolution dive data between 02 August and 09 September 2017 and between 18 August and 05 September 2018. The temporal extent of low-resolution dive data provided from SPLASH10 tags ranged between 3 August and 14 October 2017 and no SPLASH10 dive data were collected in 2018.

All dive depth data were separated into individual dives using the Python package DiveBomb (Nunes 2018). The DiveBomb algorithm identified the beginning of a dive as the time when an individual dove deeper than 1 m (for MiniPAT data) or deeper than 7 m (for SPLASH10 data, where resolution was lower). For each dive, the algorithm output included the following:

- maximum dive depth (m)
- bottom duration – the duration of time the narwhal remained at the bottom (where the Divebomb algorithm defines bottom as reaching 80% of maximum depth and levelling out or starting to ascend; min)

- descent speed (m/s)
- dive duration (min)

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 behavior throughout the tag deployment period, and to characterize diving behavior as a function of time, location, and distance from vessels. The separated dives were related to GPS positions by the time stamp associated with the beginning of a new dive. That is, the time stamp of the start of a dive was used to allocate a GPS position, interpolated to 1 s (but within 20 min from a raw GPS point).

For visualization of spatial trends, each response variable was summarized within each individual narwhal tag using 4 h bins within each day. A 4 h window was selected as an appropriate resolution to provide sufficient data for visualization while not compromising the comparison of spatial distribution with dive behavior. 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 min from another GPS point). These maps were used to visualize the spatial extent of narwhal activity, the variability in behaviors between narwhal, and the variability in activity of the same narwhal in different areas.

A plot showing the response variable (e.g., surface time or dive duration) in response to distance from vessels was constructed using the raw data for each analyzed response variable. For this plot, distance from vessel was examined as a directional value – negative values prior to the closest point of approach (CPA) and positive values following the CPA. That is, distance between narwhal and vessel was expressed as negative as long as the distance between them was decreasing, but positive once distance started increasing. The plot included a locally estimated scatterplot smoothing (LOESS) line to visualize potential trends, and a boxplot of non-exposure data (i.e., values of the response variable when there were no vessels within 10 km) for a visual comparison of exposure to non-exposure data. These plots were used to identify whether the response variable should be analyzed using directional distance (i.e., if a strong difference was identified in narwhal response to an approaching vessel in comparison to a vessel moving away). Usually, the modeling framework (detailed below for each response variable) used a non-directional distance from a vessel to maximize sample sizes, especially in near proximity of vessels where data were sparse. However, when a strong directionality was identified in the preliminary plots, the models were modified to include the directionality.

In cases where narwhal were exposed to more than one vessel at a time, only the event involving the closer vessel was retained (i.e., the event involving the more distant vessel was omitted from the dataset). Analysis of exposure to multiple vessels was performed separately (see Section 3.5.4). All data were analyzed using mixed effects linear and generalized linear models, as applicable based on the response variable of interest. All continuous predictor variables were standardized prior to analysis. All polynomial predictor variables were modeled as orthogonal, rather than raw polynomials, to assist with numerical stability; hence, the coefficients reported for polynomial model effects are not directly interpretable. All random effects were simple random intercepts by tag. Random slopes were not considered due to convergence issues. Model fit was assessed via diagnostic and residual plots using the DHARMa package (Hartig 2019) in R v. 3.6.1 (R Core Team 2019). 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.

When constructing models, the approach to variable selection was intended to include the main shipping-related predictors of interest, while accounting for biological or habitat variables that can influence narwhal behavior.

Therefore, all models contained effects of vessel distance from narwhal and whether the data were recorded during exposure to vessel traffic or not. The exact structure of the effect (i.e., the degree of the polynomial, and whether distance effect differed before or after CPA) was defined based on preliminary data exploration and visualization. Models also included habitat effects, such as substratum and bathymetry, as applicable, to account for possible differences in behavior. In addition, several biological effects were explored in relation to each response variable, to account for difference in dive behavior between bottom dives (>75% of available bathymetry) and non-bottom dives (≤75% of available bathymetry). These included variables such as whether the current dive was a bottom dive, time since the last bottom dive, and whether the previous dive was a bottom dive. Models also contained autocorrelative variables, such as the response variable in the previous dive; for example, in the analysis of dive duration, the model contained the effect of the duration of the previous dive. These variables were added to account for the narwhal feeding behavior, where individuals perform a series of long, bottom dives to feed. Interactions were added only where exploratory plots indicated a difference in behavior between different states. For example, in the analysis of dive duration, the model contained an interaction between distance from vessel and whether the current dive was a bottom dive, to account for the difference in dive behavior between bottom and non-bottom dives under exposure to vessel traffic.

Variable significance was assessed using type II *P* values (Langsrud 2003). Type III *P* values, which are commonly used in statistical analysis, allow for testing the statistical significance of main effects in the presence of significant interactions. However, when the interactions are significant, the effect sizes associated with the effects are of more interest than the *P* values of the main effects (e.g., Matthews and Altman 1996). In contrast, when the interactions are not significant, the type II tests have more power than type III tests (Lewsey et al. 2001). That is, a model with type II *P* values provides a more powerful test for main effects in the absence of a significant interaction, and no loss of information in the presence of a significant interaction, since the *P* values of the main effects are of no interest.

Plots were made to visualize model predictions in relation to all statistically significant terms, as well as in relation to the effects of distance and exposure, even if they were not statistically significant. All prediction plots included the data (raw whenever possible, summarized in other cases) to visualize the fit of the model relative to the data. If significant effects of distance from vessel were found, multiple comparisons (with Dunnett-adjusted *P* values) were performed to estimate at which distance the estimated response values became significantly different from values predicted when no vessels were present within 10 km. All models were fit using the package `glmmTMB` (Brooks et al. 2017) in R v. 3.6.1 (R Core Team 2019).

3.5.2.1 Surface Time

The effects of vessels on narwhal dive behavior were assessed by identifying which dives occurred during vessel exposure (narwhal-vessel distance ≤10 km) vs. non-exposure (narwhal-vessel distance >10 km) events. Narwhal occurring 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 the upper 7 m of the water column.

For the analysis of surface time (narwhal depth ≤7 m), positions obtained from 12 narwhal using both MiniPAT and SPLASH10 tags were allocated based on the timestamps of the dive data and on GPS positions. Each position was classified as either `exposure` or `non-exposure`, based on distance of the narwhal to the nearest vessel. 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 s to 1 min was done because of dataset size (original dataset at 1 s intervals had over 14 million rows), as well as to decrease the temporal autocorrelation associated with the data. The resulting data were analyzed using a mixed effect generalized linear model, where the response variable was whether the 1 min period was at surface or not (i.e., binary response), and the independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable, 3rd degree polynomial)
- Exposure = whether there was a vessel within 10 km from the narwhal (categorical variable)
- PreviousSurface = whether the previous 1 min period was considered to be “at surface” (categorical variable). This variable was included to control for the high level of autocorrelation associated with behavioral data
- Substratum = substratum within the RSA (categorical variable)
- TimeSinceLastSurface = time from last 1 min surface event (min; continuous variable, 2nd degree polynomial)
- TagType = tag type (MiniPAT vs SPLASH10; categorical variable)

The mixed model’s structure was as follows:

$$\begin{aligned} logit(\mu_{i,j}) = \beta_0 + \beta_1 \times Distance_i + \beta_2 \times Distance_i^2 + \beta_3 \times Distance_i^3 + \beta_4 \times Exposure_i \\ + \beta_5 \times PreviousSurface_i + \beta_{6,S} \times Substratum_i + \beta_7 \times TimeSinceLastSurface_i \\ + \beta_8 \times TimeSinceLastSurface_i^2 + \beta_9 \times TagType_i + b_{oj} \end{aligned}$$

where $\mu_{i,j}$ is the expected probability of being at surface, estimated at the *i*-th 1 min interval for *j*-th narwhal, β_0 is the intercept of each equation (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the effect of distance from a vessel, β_2 is the quadratic effect of distance from a vessel, β_3 is the cubic effect of distance from a vessel, β_4 is the effect of vessel presence within 10 km from a narwhal, β_5 is the effect of whether the previous 1 min period was at surface, $\beta_{6,S}$ is the effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal is found at the *i*-th 1 min interval, β_7 is the effect of the time since the last 1 min interval at surface, β_8 is the quadratic effect of time since the last 1 min interval at surface, β_9 is the effect of tag type (SPLASH10 vs MiniPAT), and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of dives performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data).

3.5.2.2 Dive Rate

The analysis of dive rate (as number of dives per hour) was performed using the summarized dive data provided by the DiveBomb algorithm, where dives were only retained if maximum dive depth exceeded 7 m, thereby removing very shallow dives and porpoising behavior. Like the analysis of surface time, data obtained from 12 narwhal using both MiniPAT and SPLASH10 tags were incorporated. The allocation of each dive event to a GPS position was performed using the timestamp associated with the point when a narwhal initiated the dive.

The GPS positions (interpolated to 1 s resolution within 20 min 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 time, each position was classified as either `exposure` or `non-exposure`, based on distance of the narwhal to the nearest vessel.

The calculation of dive rate requires that the number of dives undertaken by an individual be assessed over a prolonged period of time (i.e., one hour) to yield reliable results. Therefore, it is difficult to relate dive rate of narwhal to distance from vessels as the distance between the two changes substantially over a one-hour period. Instead, dive rate was calculated only for exposure and non-exposure periods. Hourly dive rates were calculated as the number of dives undertaken within that hour, divided by the length of time for which data were available during that hour (e.g., in cases where GPS data were missing for part of the hour). Dive rates were calculated separately for each narwhal on each day of collected data. If an exposure event commenced partway through an hour, two dive rates were calculated for that hour – one for the portion of the hour prior to the exposure event (‘non-exposure’ dive rate) and the other for the portion of the hour during which exposure occurred (‘exposure’ dive rate). Since dive rates were corrected for the length of time that data were available within each hour, short periods of available data resulted in highly inflated dive rates (e.g., a 5 min period with two short dives would result in an unlikely dive rate of 24 dives/h). Therefore, only periods of time longer than 15 min were considered for this assessment in order to avoid inflation of dive rate. Since more than 90% of the dives were shorter than 15 min, this cut-off value both reduced dive rate inflation and the occurrence of cases where the period of time was shorter than the undertaken dive, resulting in under-representation of dive rate.

The estimated dive rates were used to construct box plots of dive rates in the overall dataset, and in exposure and non-exposure periods for each narwhal. In addition, a map was produced, showing maximum dive rate in 4 h periods within each day for each narwhal, as described above for surface time.

Because dive rate could not be analyzed in relation to distance from vessel, a formal modeling analysis was not performed for this variable. Instead, qualitative assessment of dive rate in relation to the overall exposure and non-exposure periods was performed.

3.5.2.3 Performing Bottom Dives

As narwhal must target lipid-rich prey in order to support the energy requirements of deep diving, individuals likely focus on diving to specific areas of the water column and this can indicate where foraging is focused (Laidre et al. 2003; Hauser et al. 2015). Furthermore, 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% of available bathymetry depth) were used as a proxy for regions that are important to narwhal for foraging.

In the analysis of narwhal performing bottom dives, the response variable was whether the dive was considered a “bottom” dive, defined as a dive that was more than 75% of the available bathymetry depth (Golder 2018). The analysis of bottom dives was performed using the summarized MiniPAT dive data provided by the DiveBomb algorithm, where dives were only retained if maximum dive depth was >7 m. Allocation of each dive to a GPS position was performed using the time stamp associated with the beginning of a dive. Each position was classified as either `exposure` (narwhal -vessel distance ≤10 km) or `non-exposure` (narwhal -vessel distance >10 km), based on distance of the narwhal to the nearest vessel. Where no GPS data were available, the dives were removed from analysis.

If the maximum depth of a dive was more than 75% of the available bathymetry, the dive was characterized as a “bottom” dive, whereas if the maximum depth was equal to or shallower than 75% of the available bathymetry, the dive was characterized as “not bottom”. The resulting data were analyzed using a mixed effect generalized linear model, where the response variable was whether the dive was a bottom dive or not (i.e., binary response), and the independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable, 2nd degree polynomial)
- Exposure = whether there was a vessel within 10 km from the narwhal (categorical variable)
- PreviousBottom = whether the previous dive was a bottom dive (>75% of the available bathymetry depth; categorical variable). This variable was included to control for the high level of autocorrelation associated with behavioral data
- Bathymetry = available bathymetry at dive location (m; continuous variable)
- TimeSinceLastBottom = time from last bottom dive (min; continuous variable)
- Substratum = substratum within the RSA (categorical variable)
- Interaction between distance from vessel and whether the previous dive was a bottom dive
- Interaction between whether there was a vessel within 10 km from the narwhal and whether the previous dive was a bottom dive

The mixed model’s structure was as follows:

$$\begin{aligned} logit(\mu_{i,j}) = \beta_0 + \ & \beta_1 \times Distance_i + \beta_2 \times Distance_i^2 + \beta_3 \times Exposure_i + \beta_4 \times PreviousBottom_i \\ & + \beta_5 \times Bathymetry_{\ i} + \beta_6 \times TimeSinceLastBottom_i + \beta_{7,S} \times Substratum_i \\ & + \beta_{14} \times Distance_i \times PreviousBottom_i + \beta_{24} \times Distance_i^2 \times PreviousBottom_i \\ & + \beta_{34} \times Exposure_i \times PreviousBottom_i + b_{oj} \end{aligned}$$

where $\mu_{i,j}$ is the expected probability of the *i*-th dive being a bottom dive for *j*-th narwhal, β_0 is the intercept of each equation (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the main effect of distance from a vessel, β_2 is the quadratic main effect of distance from a vessel, β_3 is the main effect of vessel presence within 10 km from a narwhal, β_4 is the main effect of whether the previous dive was a bottom dive, β_5 is the effect of bathymetry, β_6 is the effect of the time elapsed since the last bottom dive, $\beta_{7,S}$ is effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal was during the *i*-th dive, β_{14} is the interaction between the linear effect of distance from a vessel and whether the previous dive was a bottom dive, β_{24} is the interaction between the quadratic effect of distance from a vessel and whether the previous dive was a bottom dive, β_{34} is the interaction between the effect of vessel presence within 10 km from a narwhal and whether the previous dive was a bottom dive, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of dives performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). Due to persistent autocorrelation issues, an autocorrelation term using the Ornstein–Uhlenbeck covariance structure (required due to the unequal time steps between dives) was added to the model.

3.5.2.4 Time at Depth

For the analysis of ‘time at depth’, the response variable of interest was the period of time (in minutes) a narwhal spent in the bottom 20% of its dive depth. This analysis was performed using the summarized MiniPAT dive data provided by the DiveBomb algorithm. Allocation of dives to “exposure” and “non-exposure” events followed the description provided in Section 3.5.2.3. To address residual heteroscedasticity that was apparent during preliminary modeling, the time at depth values were square-root transformed prior to analysis. The resulting data were analyzed using a mixed effect linear model, where the response variable (time at depth) was square root-transformed and the independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable, 3rd degree polynomial)
- Exposure = whether there was a vessel within 10 km from the narwhal (categorical variable)
- Bottom = whether the dive was a bottom dive (>75% of the available bathymetry depth; categorical variable)
- PreviousBottom = whether the previous dive was a bottom dive (>75% of the available bathymetry depth; categorical variable)
- MaxDepth = maximum dive depth (m; continuous variable, 2nd degree polynomial)
- Substratum = substratum within the RSA (categorical variable)
- Interaction between distance from vessel and whether the previous dive was a bottom dive
- Interaction between whether there was a vessel within 10 km from the narwhal and whether the previous dive was a bottom dive
- Interaction between maximum dive depth and whether the dive was a bottom dive
- Interaction between whether the current dive was a bottom dive and whether the preceding dive was a bottom dive

The mixed model’s structure was as follows:

$$\begin{aligned}\sqrt{\mu_{i,j}} = \beta_0 + \beta_1 \times Distance_i + \beta_2 \times Distance_i^2 + \beta_3 \times Distance_i^3 + \beta_4 \times Exposure_i + \beta_5 \times Bottom_i \\ + \beta_6 \times PreviousBottom + \beta_7 \times MaxDepth_i + \beta_8 \times MaxDepth_i^2 + \beta_{9,S} \times Substratum_i \\ + \beta_{15} \times Distance_i \times Bottom_i + \beta_{25} \times Distance_i^2 \times Bottom_i \\ + \beta_{35} \times Distance_i^3 \times Bottom_i + \beta_{45} \times Exposure_i \times Bottom_i + \beta_{56} \times PreviousBottom_i \times Bottom_i \\ + \beta_{57} \times MaxDepth_i \times Bottom_i + \beta_{58} \times MaxDepth_i^2 \times Bottom_i + b_{oj}\end{aligned}$$

where $\mu_{i,j}$ is the expected time spent at depth of the *i*-th dive for *j*-th narwhal, β_0 is the intercept (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the main effect of distance from a vessel, β_2 is the quadratic main effect of distance from a vessel, β_3 is the cubic main effect of distance from a vessel, β_4 is the main effect of vessel presence within 10 km from a narwhal, β_5 is the main effect of whether the current dive was a bottom dive, β_6 is the effect of whether the previous dive was a bottom dive, β_7 is the effect of the maximum dive depth, β_8 is the quadratic effect of maximum dive depth, $\beta_{9,S}$ is the effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal was during the *i*-th dive, β_{15} is the interaction between the linear effect of distance from a vessel and whether the dive was a bottom dive, β_{25} is the interaction between the quadratic effect of distance from a vessel and whether the dive was a bottom dive, β_{35} is the interaction between the cubic effect of distance from a vessel and whether the dive was a bottom dive, β_{45} is the interaction between the effect of vessel presence within 10 km from a narwhal and whether the previous dive was a bottom dive, β_{56} is the interaction between whether the dive was a bottom dive and whether the preceding dive was a bottom dive, β_{57} is the interaction between the linear effect of maximum dive depth and whether the dive was a bottom dive, β_{57} is the interaction between the quadratic effect of maximum dive depth and whether the dive was a bottom dive, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of dives performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). Due to persistent autocorrelation issues, an autocorrelation term using the Ornstein–Uhlenbeck covariance structure (required due to the unequal time steps between dives) was added to the model.

3.5.2.5 Dive Duration

For the analysis of narwhal ‘dive duration’, the response variable of interest was the period of time (in minutes) to undertake a dive (i.e., the time between when an animal dove below 1 m and when the animal re-surfaced). While the 7 m cut-off was used to define what constitutes a dive (in the case on MiniPAT tags; Section 3.5.1), the onset of the actual dive was when the individual reached a depth of 1 m. The analysis of dive duration was performed using the summarized MiniPAT dive data provided by the DiveBomb algorithm. Allocation of dives to “exposure” and “non-exposure” events followed the description in Section 3.5.2.3. To address residual heteroscedasticity that was apparent during preliminary modeling, the dive duration values were square-root transformed prior to analysis. The resulting data were analyzed using a mixed effect linear model, where the response variable (dive duration) was square root-transformed and the independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable, 3rd degree polynomial)
- Exposure = whether there was a vessel within 10 km from the narwhal (categorical variable)
- Bottom = whether the dive was a bottom dive (>75% of the available bathymetry depth; categorical variable)
- PreviousBottom = whether the previous dive was a bottom dive (>75% of the available bathymetry depth; categorical variable)
- MaxDepth = maximum dive depth (m; continuous variable, 5th degree polynomial)
- PreviousDuration = dive duration of the preceding dive (min; continuous variable)
- Substratum = substratum within the RSA (categorical variable)
- Interaction between distance from vessel and whether the current dive was a bottom dive
- Interaction between whether there was a vessel within 10 km from the narwhal and whether the current dive was a bottom dive
- Interaction between duration of previous dive and whether the current dive was a bottom dive
- Interaction between duration of previous dive and whether the preceding dive was a bottom dive

- Interaction between whether the current dive was a bottom dive and whether the preceding dive was a bottom dive
- Interaction between duration of previous dive, whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive

The mixed model's structure was as follows:

$$\begin{aligned}\sqrt{\mu_{i,j}} = \beta_0 + \ & \beta_1 \times Distance_i + \beta_2 \times Distance_i^2 + \beta_3 \times Distance_i^3 + \ \beta_4 \times Exposure_i + \ \beta_5 \times Bottom_i \\ & + \beta_6 \times PreviousBottom + \ \beta_7 \times MaxDepth_i + \beta_8 \times MaxDepth_i^2 + \ \beta_9 \times MaxDepth_i^3 \\ & + \ \beta_{10} \times MaxDepth_i^4 + \ \beta_{11} \times MaxDepth_i^5 + \ \beta_{12} \times PreviousDuration_i + \ \beta_{13,S} \times Substratum_i \\ & + \beta_{15} \times Distance_i \times Bottom_i + \beta_{25} \times Distance_i^2 \times Bottom_i \\ & + \ \beta_{35} \times Distance_i^3 \times Bottom_i + \ \beta_{45} \times Exposure_i \times Bottom_i \\ & + \beta_{58} \times PreviousDuration_i \times Bottom_i + \ \beta_{68} \times PreviousDuration_i \times PreviousBottom_i \\ & + \beta_{56} \times PreviousBottom_i \ \times Bottom_i + \beta_{568} \times PreviousDuration_i \times PreviousBottom_i \times Bottom_i \\ & + \ b_{oj}\end{aligned}$$

where $\mu_{i,j}$ is the expected dive duration of the *i*-th dive for *j*-th narwhal, β_0 is the intercept (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the main effect of distance from a vessel, β_2 is the quadratic main effect of distance from a vessel, β_3 is the cubic main effect of distance from a vessel, β_4 is the main effect of vessel presence within 10 km from a narwhal, β_5 is the main effect of whether the current dive was a bottom dive, β_6 is the effect of whether the previous dive was a bottom dive, β_7 to β_{11} are the effects of the 5th degree polynomial of maximum dive depth, β_{12} is the effect of the duration of the previous dive, $\beta_{13,S}$ is the effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal was during the *i*-th dive, β_{15} is the interaction between the linear effect of distance from a vessel and whether the dive was a bottom dive, β_{25} is the interaction between the quadratic effect of distance from a vessel and whether the dive was a bottom dive, β_{35} is the interaction between the cubic effect of distance from a vessel and whether the dive was a bottom dive, β_{45} is the interaction between the effect of vessel presence within 10 km from a narwhal and whether the previous dive was a bottom dive, β_{58} is the interaction between the duration of the preceding dive and whether the current dive was a bottom dive, β_{68} is the interaction between the duration of the preceding dive and whether the preceding dive was a bottom dive, β_{56} is the interaction between whether the preceding dive was a bottom dive and whether the current dive was a bottom dive, β_{568} is the three-way interaction between the duration of the preceding dive, whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of dives performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). Due to persistent autocorrelation issues, an autocorrelation term using the Ornstein–Uhlenbeck covariance structure (required due to the unequal time steps between dives) was added to the model.

3.5.2.6 Descent Speed

The response variable of interest in this analysis was descent speed (m/s) of narwhal during a dive. The analysis of descent speed was performed using the summarized MiniPAT dive data provided by the DiveBomb algorithm. Allocation of dives to "exposure" and "non-exposure" events followed the description provided in Section 3.5.2.3.

To address residual heteroscedasticity that was apparent during preliminary modeling, the descent speed values were square-root transformed prior to analysis. The resulting data were analyzed using a mixed effect linear model, where the response variable (descent speed) was square root-transformed and the independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable, 2nd degree polynomial)
- Exposure = whether there was a vessel within 10 km from the narwhal (categorical variable)
- Bottom = whether the dive was a bottom dive (>75% of the available bathymetry depth; categorical variable)
- PreviousBottom = whether the previous dive was a bottom dive (>75% of the available bathymetry depth; categorical variable). This variable was included to control for the high level of autocorrelation associated with behavioral data
- Substratum = substratum within the RSA (categorical variable)
- TimeDepth = time at depth during the dive (min; continuous variable, 3rd degree polynomial)
- PreviousSpeed = descent speed during the preceding dive (m/s; continuous variable)
- MaxDepth = maximum dive depth (m; continuous variable, 3rd degree polynomial)
- Interaction between distance from vessel and whether the current dive was a bottom dive
- Interaction between whether there was a vessel within 10 km from the narwhal and whether the current dive was a bottom dive
- Interaction between descent speed of previous dive and whether the current dive was a bottom dive
- Interaction between descent speed of previous dive and whether the preceding dive was a bottom dive
- Interaction between whether the current dive was a bottom dive and whether the preceding dive was a bottom dive
- Interaction between descent speed of previous dive, whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive
- The mixed model's structure was as follows:

$$\begin{aligned}\sqrt{\mu_{i,j}} = \beta_0 + \beta_1 \times Distance_i + \beta_2 \times Distance_i^2 + \beta_3 \times Exposure_i + \beta_4 \times Bottom_i + \beta_5 \times PreviousBottom_i \\ + \beta_6 \times PreviousSpeed_i + \beta_7 \times MaxDepth_i + \beta_8 \times MaxDepth_i^2 + \beta_9 \times MaxDepth_i^3 \\ + \beta_{10} \times Substratum_i + \beta_{14} \times Distance_i \times Bottom_i + \beta_{24} \times Distance_i^2 \times Bottom_i \\ + \beta_{34} \times Exposure_i \times Bottom_i \\ + \beta_{46} \times PreviousSpeed_i \times Bottom_i + \beta_{56} \times PreviousSpeed_i \times PreviousBottom_i \\ + \beta_{45} \times PreviousBottom_i \times Bottom_i + \beta_{456} \times PreviousSpeed_i \times PreviousBottom_i \times Bottom_i \\ + b_{oj}\end{aligned}$$

where $\mu_{i,j}$ is the expected descent speed of the *i*-th dive for j-th narwhal, β_0 is the intercept (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the main effect of distance from a vessel, β_2 is the quadratic main effect of distance from a vessel, β_3 is the main effect of vessel presence within 10 km from a narwhal, β_4 is the main effect of whether the current dive was a bottom dive, β_5 is the effect of whether the previous dive was a bottom dive, β_6 is the effect of the descent speed of the preceding dive, β_7 is the effect of maximum dive depth, β_8 is the quadratic effect of maximum dive depth, β_9 is the cubic effect of maximum dive depth, $\beta_{10,S}$ is the effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal was during the *i*-th dive, β_{14} is the interaction between the linear effect of distance from a vessel and whether the dive was a bottom dive, β_{24} is the interaction between the quadratic effect of distance from a vessel and whether the dive was a bottom dive, β_{34} is the interaction between the effect of vessel presence within 10 km from a narwhal and whether the previous dive was a bottom dive, β_{46} is the interaction between the descent speed of the preceding dive and whether the current dive was a bottom dive, β_{56} is the interaction between the descent speed of the preceding dive and whether the preceding dive was a bottom dive, β_{45} is the interaction between whether the preceding dive was a bottom dive and whether the current dive was a bottom dive, β_{456} is the three-way interaction between the descent speed of the preceding dive, whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive, and b_{0j} is a random effect of the j-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of dives performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). Due to persistent autocorrelation issues, an autocorrelation term using the Ornstein–Uhlenbeck covariance structure (required due to the unequal time steps between dives) was added to the model.

3.5.3 Narwhal Surface Behavior

A review of the literature suggests that normal surface behavior of whales may be altered when individuals are exposed to vessel traffic and associated noise (Finley et al. 1990; Cosens and Dueck 1993; Finley and Greene 1993; Heide-Jørgensen et al. 2013). Common behavioral responses of marine mammals to vessel traffic may include the following:

1) change in turning angle during travel, where an angle of 0° indicates a whale that is travelling in a straight line relative to its previous location, while an angle of 180° indicates a whale that has turned back (reflective of avoidance behavior)

2) change in travel orientation relative to vessel path, where an angle of 0° indicates a whale that is heading toward a vessel (regardless of the orientation of the vessel), and an angle of 180° indicates a whale that is heading away from a vessel (reflective of avoidance behavior)

3) horizontal displacement from the vessel path, where if whales maintain a certain distance from vessels (relative to vessel bow, aft, port, and starboard), it may be reflective of avoidance behavior

4) decrease in distance at CPA between whale and vessel over time (reflective of habituation)

5) increase in distance at CPA between whale and vessel over time (reflective of avoidance behavior)

6) decrease in habitat re-occupation, where whales avoid the vessel track (reflective of avoidance behavior); this behavior is assessed qualitatively herein, therefore no formal hypotheses are listed below

7) increase in travel speed (reflective of avoidance behavior)

8) decrease in travel speed (reflective of a freeze response)

Based on this information, the following null hypotheses were developed in 2017 (Golder 2018) and again tested herein to identify potential effects of vessel traffic on narwhal within the RSA:

$H7_0$: Turning angle during travel does not significantly change in the presence of vessel traffic

$H7_A$: Turning angle during travel does significantly change in the presence of vessel traffic

$H8_0$: Travel orientation relative to vessels does not significantly change with distance from vessel traffic

$H8_A$: Travel orientation relative to vessels does significantly change with distance from vessel traffic

$H9_0$: Narwhal do not exhibit significant horizontal displacement in the presence of vessel traffic

$H9_A$: Narwhal exhibit significant horizontal displacement in the presence of vessel traffic

$H10_0$: CPA distance between narwhal and vessels does not significantly change throughout the shipping season

$H10_A$: CPA distance between narwhal and vessels significantly changes throughout the shipping season

$H11_0$: Narwhal do not exhibit significant seasonal habituation to vessel passage

$H11_A$: Narwhal exhibit significant seasonal habituation to vessel passage

$H12_0$: Travel speed does not significantly change in the presence of vessel traffic

$H12_A$: Travel speed significantly changes in the presence of vessel traffic

Associated analyses related to the length of time that an identified surface behavioral 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 14 narwhal outfitted with GPS Fastloc location tags (ten SPLASH10 tags and four CTD-SRDL tags). Twelve narwhal were tagged in Tremblay Sound between 31 July 2017 and 3 September 2017 and two narwhal were tagged in Tremblay Sound on 17 August 2018. The temporal extent of the compiled GPS datasets incorporated into the analysis ranged between 02 August and 15 October in 2017 and between 18 August and 18 October in 2018.

Only large and medium vessels (≥50 m in length) were considered in this analysis as AIS vessel tracking data were not available for smaller vessels (<50 m in length). 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 vessel 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 vessel 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.

To assess narwhal horizontal avoidance of vessels, narwhal headings were used to calculate two values – 1) turning angles of narwhal relative to their own travel path, and 2) travel orientation of narwhal relative to transiting vessels, calculated as the angle between the narwhal track and the vessel position. In the analysis of narwhal turning angles (regardless of orientation to vessel), a value of 0º represented no change in the animal's heading (i.e., continuation of travel in a straight line), a value of 90º represented a right angle turn, and a value of 180º represented a complete reversal of narwhal course. In of the analysis of narwhal travel orientation relative to the vessel, 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/left) of the narwhal path, and a value of 180º indicated that the vessel was directly behind the narwhal.

To quantify horizontal displacement, narwhal positional data relative to vessels (within the 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.

In cases where narwhal were exposed to more than one vessel at a time, only the event with the nearest vessel was retained and the event with the vessels further away were omitted from the dataset. Analysis of exposure to multiple vessels was performed separately (see Section 3.5.4). Aside from horizontal displacement, all surface movement variables (i.e., turning angles, travel orientation relative to vessel, distance between narwhal and vessel at CPA, and travel speed) were analyzed using mixed effects linear models. All continuous predictor variables were standardized prior to analysis. All polynomial terms were modeled as orthogonal, rather than raw polynomials, to assist with numerical stability; hence, the coefficients reported for polynomial model effects are not directly interpretable. All random effects were simple random intercepts by tag. Random slopes were not considered due to convergence issues. 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. The marginal pseudo-R^2 values estimate the variability explained by the fixed effects only, whereas the conditional pseudo-R^2 values estimate the variability explained by both fixed and random effects. Plots were made to visualize model predictions in relation to all statistically significant terms, as well as in relation to the effects of distance and exposure, even if they were not statistically significant. 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. If significant effects of distance from vessel were found, multiple comparisons (with Dunnett-adjusted *P* values) were performed to estimate at which distance the estimated response values became significantly different from values predicted when no vessels were present within 10 km. All analyses were performed using the package `glmmTMB` (Brooks et al. 2017) in R v. 3.6.1 (R Core Team 2019).

For the analysis of surface behavior, variable selection was based on inclusion of the main shipping-related predictors of interest and accounted for biological or habitat variables that may influence narwhal behavior. Therefore, all models contained effects of vessel distance from narwhal and whether the data were recorded during exposure to vessel traffic or not. The exact structure of the effect (i.e., the degree of the polynomial, and whether distance effect differed before or after CPA) was defined based on preliminary data exploration and visualization. Models also included habitat effects, such as substratum and distance from shore, as applicable, to account for possible differences in behavior. Furthermore, models contained autocorrelative variables, such as the response variable at the previous GPS point; for example, in the analysis of travel speed, the model contained the effect of travel speed at the previous GPS point. These variables were added to account for narwhal existing behavior, where if an individual was previously moving fast, it was likely to do so at the following GPS position as well.

Typically, 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. That is, angle data were modeled as a simple continuous response variable with values ranging from 0 to 180.

3.5.3.1 Turning Angle

Unlike the following section (Section 3.5.3.2) that assesses narwhal orientation relative to vessels, the analysis of turning angle does not examine whether narwhal turn toward or away from a given vessel but only that narwhal turning angles changes, and whether that change is related to distance from a vessel. That is, a small turning angle by a narwhal is indicative of a linear travel mode, whereas a large turning angle may indicate avoidance (e.g., turning away from vessel) or simply nondirectional travel.

Turning angles were analyzed using a mixed effect linear model. To address residual heteroscedasticity that was apparent during preliminary modeling, the turning angle values were square-root transformed prior to analysis. The independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable, 3rd degree polynomial)
- Exposure = whether there was a vessel within 10 km from the narwhal (categorical variable)
- PreviousAngle = turning angle at the preceding GPS point (°; continuous variable, 3rd degree polynomial)
- ShoreDistance = distance from shore (km; continuous variable)
- Substratum = substratum within the RSA (categorical variable)

The mixed model's structure was as follows:

$$\sqrt{\mu_{i,j}} = \beta_0 + \beta_1 \times Distance_i + \beta_2 \times Distance_i^2 + \beta_3 \times Distance_i^3 + \beta_4 \times Exposure_i + \beta_5 \times ShoreDistance_i + \beta_6 \times PreviousAngle_i + \beta_7 \times PreviousAngle_i^2 + \beta_{8,S} \times Substratum_i + b_{oj}$$

where $\mu_{i,j}$ is the expected turning angle at the *i*-th GPS point for *j*-th narwhal, β_0 is the intercept (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the effect of distance from a vessel, β_2 is the quadratic effect of distance from a vessel, β_3 is the cubic effect of distance from a vessel, β_4 is the effect of vessel presence within 10 km from a narwhal, β_5 is the effect of distance from shore, β_6 is the effect of the turning angle at the preceding GPS point, β_7 is the quadratic effect of the turning angle at the preceding GPS point, $\beta_{8,S}$ is the effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal is found at the *i*-th GPS point, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of movements performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). Due to persistent autocorrelation issues, an autocorrelation term using the Ornstein–Uhlenbeck covariance structure (required due to the unequal time steps between dives) was added to the model.

3.5.3.2 Travel Orientation Relative to Vessels

In assessing narwhal travel orientation relative to vessels, mean values less than 90° are expected if vessel exposure has no effect on narwhal travel orientation relative to vessels. That is, an angle less than 90° would be indicative of narwhal heading toward a vessel (regardless of the orientation of the vessel itself), while an angle larger than 90° would be indicative of a narwhal heading away from, or avoiding, a vessel.

Narwhal travel orientation relative to vessels was analyzed using a mixed effect linear model. Preliminary data visualization and modeling indicated a strong directional response to distance from vessel, which could not be successfully modeled using a polynomial. Hence, the data were modeled using different slopes for the effect of distance from vessel for before and after the CPA. Since the dataset focuses on the orientation of narwhal relative to vessels, the dataset available for modeling was restricted to cases where a vessel was present. The independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable)
- BeforeAfter = whether the data point was before CPA (i.e., vessel approaching) or after CPA (i.e., vessel moving farther away; categorical variable)
- Substratum = substratum within the RSA (categorical variable)

The mixed model's structure was as follows:

$$\mu_{i,j} = \beta_0 + \beta_1 \times Distance_i + \beta_2 \times BeforeAfter_i + \beta_3 \times Substratum_i + \beta_{12} \times Distance_i \times BeforeAfter_i + b_{oj}$$

where $\mu_{i,j}$ is the expected relative angle between narwhal and vessel at the *i*-th GPS point for *j*-th narwhal, β_0 is the intercept (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the effect of distance from a vessel, β_2 is the effect of whether the *i*-th GPS point was recorded before or after the CPA, $\beta_{3,S}$ is the effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal is found at the *i*-th GPS point, β_{12} is the effect of interaction between distance and whether the data point was before or after CPA, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of movements performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). Due to persistent autocorrelation issues, an autocorrelation term using the Ornstein–Uhlenbeck covariance structure (required due to the unequal time steps between dives) was added to the model.

3.5.3.3 Horizontal Displacement

To quantify horizontal displacement, narwhal positional data relative to vessels (within the 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 Core Team 2019).

3.5.3.4 Seasonal Change and Horizontal Displacement

To identify potential habituation or seasonal changes in narwhal surface behavior, temporal trends in values of CPA 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 CPA distance between narwhal and vessel (the response variable) over time, while accounting for the repeated measures nature of the data.
To address residual heteroscedasticity that was apparent during preliminary modeling, the CPA distances were square-root transformed prior to analysis. The independent fixed variables were as follows:

- DateTime = decimal day of year, where 1 is the earliest day of available data for both years (2 August continuous variable)
- Year = year of study (categorical variable)

The mixed model's structure was as follows:

$$\sqrt{\mu_{i,j}} = \beta_0 + \beta_1 \times DateTime_i + \beta_2 \times Year_i + b_{oj}$$

where $\mu_{i,j}$ is the expected distance at CPA at the *i*-th CPA point for *j*-th narwhal, β_0 is the intercept (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the effect of time elapsed since beginning of the study, β_2 is the effect of year of study, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of movements performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). The analysis was performed in the statistical environment R v. 3.6.1 (R Core Team 2019) using the package 'nlme' (Pinheiro et al. 2018).

3.5.3.5 Habitat Re-Occupation

To assess narwhal habitat re-occupation following vessel passage, events where individual narwhal crossed vessel tracks were identified. For each crossing, the GPS position of the point where the narwhal crossed the vessel track and the associated time stamp were estimated. The difference in time from when the vessel was at a given GPS point and when the narwhal reached it was then recorded. The distance that the vessel then travelled until the narwhal intersected that same point was also estimated. These calculations were performed for vessel tracks post vessel passage and pre-vessel passage. In the latter cases, the future track that the vessel will travel was used.

The resulting data were plotted as a scatterplot of distance the vessel has traveled before narwhal crossed the track vs. the time elapsed since the vessel was at the point of crossing. The plot provided a visual of the length of time and distance associated with narwhal absence from the vessel track before and after vessel passage. Overall, this provided information on re-occupation of the shipping corridor in relation to vessel traffic.

The portion of the dataset that pertained to narwhal crossing behind vessels (rather than the full dataset, which also included narwhal crossing in front of vessels) was used to examine temporal changes of habitat re-occupation. Linear mixed effects models were used to estimate the change in time elapsed between vessel passage and narwhal crossing, and between distance accumulated along the vessel track between vessel passage and narwhal crossing. The independent fixed variables were as follows:

- Day of study = decimal day of year, where 1 is the earliest day of available data for both years (August 2; continuous variable)
- Year = year of study (categorical variable)
- Interaction between day of study and year

The mixed model's structure was as follows:

$$\sqrt{\mu_{i,j}} = \beta_0 + \beta_1 \times DayStudy_i + \beta_2 \times Year_i + \beta_{12} \times DayStudy_i \times Year_i + b_{oj}$$

where $\mu_{i,j}$ is the expected value of the response variable (time elapsed or distance along vessel track between vessel passage and narwhal crossing) at the *i*-th point for *j*-th narwhal, β_0 is the intercept (corresponding to the year 2017 and the mean value of day of study), β_1 is the effect of time elapsed since beginning of the study, β_2 is the effect of year of study, β_{12} is the interaction between day of study and year, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of movements performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). The analysis was performed in the statistical environment R v. 3.6.1 (R Core Team 2019) using the package `glmmTMB` (Brooks et al. 2017).

3.5.3.6 Travel Speed

The response variable in this analysis was narwhal travel speed (m/s) between consecutive raw GPS points. The data were analyzed using a mixed effect linear model, where the independent fixed variables were as follows:

- Distance = distance from vessel (km; continuous variable)
- BeforeAfterExposure = whether the data point was before CPA (i.e., vessel approaching), after CPA (i.e., vessel moving farther away; categorical variable), or in the absence of vessels within 10 km from the narwhal (categorical variable)
- ShoreDistance = distance from shore (km; continuous variable, 4th degree polynomial)
- Substratum = substratum within the RSA (categorical variable)
- PreviousSpeed = travel speed at the preceding GPS point (m/s; continuous variable, 2nd degree polynomial)

The mixed model's structure was as follows:

$$\begin{aligned}\mu_{i,j} = \beta_0 + \beta_1 \times Distance_i + \beta_2 \times BeforeAfterExposure_i + \beta_3 \times ShoreDistance_i + \beta_4 \times ShoreDistance_i^2 \\ + \beta_5 \times ShoreDistance_i^3 + \beta_6 \times ShoreDistance_i^4 + \beta_{7,S} \times Substratum_i + \beta_8 \times PreviousSpeed_i \\ + \beta_9 \times PreviousSpeed_i^2 + b_{oj}\end{aligned}$$

where $\mu_{i,j}$ is the expected travel speed at the *i*-th GPS point for *j*-th narwhal, β_0 is the intercept (corresponding to the reference level of each categorical variable and the mean value of each continuous variable), β_1 is the effect of distance from a vessel, β_2 is the effect of whether the *i*-th GPS point was recorded before or after the CPA or in the absence of a vessel within 10 km from the narwhal, β_3 is the effect of distance from shore, β_4, β_5, β_6, are the coefficients of the quadratic, cubic, and 4th degree polynomials of distance from shore, $\beta_{7,S}$ is the effect of the *s*-th substratum (where *s* is any substratum that is not the reference level) where the narwhal is found at the *i*-th GPS point, β_8 is the coefficient of travel speed at the preceding GPS, and β_9 is the coefficient of the quadratic effect of travel speed at the preceding GPS point, and b_{0j} is a random effect of the *j*-th narwhal tag. The random intercept by narwhal tag (b_{0j}) was included to account for lack of independence of movements performed by the same individual narwhal (i.e., accounting for lack independence in repeated measures data). Due to persistent autocorrelation issues, an autocorrelation term using the Ornstein–Uhlenbeck covariance structure (required due to the unequal time steps between GPS points) was added to the model.

3.5.4 Dive and Surface Behavior During Exposure to Multiple Vessels

To assess the effects of multiple vessels present at the same time within a 10 km radius from a single narwhal, a subset of the dive and surface behavior analyses detailed above were selected and repeated with an additional predictor variable of number of vessels present within the 10 km exposure zone. The analyses selected were those where the effect of distance from vessel was statistically significant. These included models with the following response variables: surface time, bottom dive depth, dive duration, rate of direction change, and travel orientation relative to vessels. A separate analysis of narwhal interactions with multiple vessels including icebreaking vessels is presented in a technical memorandum on 2018 shoulder season shipping (Golder 2019b).

Based on information presented in Sections 3.5.2 and 3.5.3 regarding possible whale responses to vessel traffic, the following null hypotheses were developed to identify potential responses of narwhal to exposure to multiple vessels present at the same time:

$H12_0$: Surface time does not significantly change in the presence of multiple vessels
$H12_A$: Surface time significantly changes in the presence of multiple vessels

$H13_0$: The occurrence of bottom dives does not significantly change in the presence of multiple vessels
$H13_A$: The occurrence of bottom dives significantly changes in the presence of multiple vessels

$H14_0$: Dive duration does not significantly change in the presence of multiple vessels
$H14_A$: Dive duration significantly changes in the presence of multiple vessels

$H15_0$: Turning angle during travel does not significantly change in the presence of multiple vessels
$H15_A$: Turning angle during travel does significantly change in the presence of multiple vessels

$H16_0$: Travel orientation relative to vessels does not significantly change with distance from multiple vessels
$H16_A$: Travel orientation relative to vessels does significantly change with distance from multiple vessels

To focus the analysis on the effect of multiple vessels in comparison to a single vessel, the dataset was restricted to only “exposure” events, removing data where no vessels were present within 10 km from a given individual. The full temporal extent of the exposure data was included, ranging from 2 August to 30 September 2017 and from 20 August to 4 September 2018 for analysis of the dive data, and from 2 August to 27 September 2017 and from 20 August to 15 October 2018 for analysis of the surface movement data. The majority of the dataset comprised exposure of a narwhal to a single vessel (e.g., 91% of exposure events in raw dive data, used in analysis of surface time), followed by exposure to two vessels (8.2% in surface time data) and exposure to three vessels (0.6% in surface time data). Since three vessels were present only rarely, the predictor variable of number of vessels was coded as a categorical variable of whether there was a single vessel or two or more vessels within 10 km from the narwhal.

The effect of multiple vessel presence on narwhal dive and surface behavior was modeled by including the following two predictor variables – 1) the number of vessels present within 10 km from the narwhal (as a categorical variable), and 2) distance from the nearest vessel. The expectation was to see an increased effect with a diminishing distance (as was seen in the original analysis using a single vessel dataset). In addition, if the number of vessels present does affect narwhal behavior, it is assumed that the data and models should indicate a larger effect in the presence of two or more vessels than in the presence of a single vessel.

For each analysis of exposure to multiple vessels, the model described in the original analysis was used, with two changes – 1) the effect of “exposure” was removed and replaced with the effect of number of vessels present (categorical variable), and 2) distance was considered as non-directional only (i.e., the models did not account for whether the data were collected before or after CPA). The latter change was introduced to simplify the analysis (since each vessel had its own CPA, directionality of distance is not straightforward) and to maximize sample size. The change to non-directional distance affected only the analysis of travel orientation relative to vessels, since the remaining analyses used non-directional distance in the original models.

For each dataset, a bubble plot of the response variable in relation to distance was constructed, showing the sample size for each distance (rounded to nearest 1 km), by number of vessels. The plots also included a LOESS curve to visualize the overall trend, not accounting for any of the other explanatory variables.

Following modeling (which was performed via the same methods as described in earlier sections for dive and surface movements), a single prediction plot was constructed, showing mean observed data and predicted curves for a single vessel and two or more vessels present within a 10 km distance from narwhal. Tables of significance and coefficient values are provided in Appendix B.

3.5.5 Power Analysis

To assess the statistical power of the analyses performed in this report, a separate power analysis was performed for each model. The power analysis was performed using simulations that quantified the relevant model’s statistical power to detect various effect sizes. The resulting power curves were presented for each model. Refer to Appendix C for detailed methods and results of the power analysis.

4.0 RESULTS

4.1 Data Collection

4.1.1 Tag Deployment

A total of 20 narwhal were live-captured during the 2017 field season, of which 18 animals were successfully outfitted with satellite location tags (Table 4-1 and Table 4-2), with deployments ranging from 33 to 97 days (mean = 63 days). Additionally, four narwhal were live-captured during the 2018 field season, of which two animals were successfully outfitted with satellite location tags, with deployments of 54 and 79 days. PAT tags were deployed on 16 of the narwhal tagged in 2017 and on two of the narwhal tagged in 2018. Of these, four of the five high-resolution MiniPAT tags deployed in 2017 were successfully recovered (deployments ranging from 27 to 38 days), providing one second resolution data, while the fifth MiniPAT unit deployed in 2017 was not, providing 14 days of 75 second resolution data. Only one of the 11 MK10-PAT tags deployed in 2017 was recovered which yielded a total of six days of one second resolution data. In 2018, both MiniPAT satellite location tags deployed were recovered, providing 20 and 24 days of one second resolution data.

Acousonde units were successfully deployed on a total of nine narwhal in 2017 and on all four narwhal in 2018. However, none of these animals entered the Northern Shipping Route before the Acousonde units released off the animals, therefore direct measurements of vessel-generated noise relative to the receiver, and characterization of narwhal vocal and movement behavior in relation to received noise levels, was not possible in the current analysis.

NW22 (an adult female) and NW23 (a juvenile male) were live-captured at the same time on 17 August 2018. Following tag attachment, NW22 was released back into the water. Upon its release, it swam back to the beach and only departed the area once NW23 was released. No backpack or PAT tags were deployed on NW23 as it was deemed undersized for subdermal tagging.

Table 4-1: Summary of tag instrumentation deployed on narwhal during the 2017 and 2018 field seasons

Narwhal ID	Deployment Date	Location Tags		PAT Tags		Greeneridge Sciences Acousonde 3B
		Wildlife Computers SPLASH10	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)
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)
NW21	08-17-18	-	✓ (54 days)	✓ (24 days)	-	✓ (78 h)
NW22	08-17-18	-	✓ (79 days)	✓ (20 days)	-	✓ (116 h)
NW23	08-17-18	-	-	-	-	✓ (520 h)
NW24	08-18-18	-	-	-	-	✓ (460 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 the 2017 and 2018 field seasons

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	172070	425	100	240	N	N/A	F
NW13	172071	298	65	N/A	Y	27	M (juv)
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
NW21	174726/ 174727	360	82	124**	N	N/A	F
NW22	174728/ 174729	357	81	114**	N	N/A	F w/ juv, also tagged (NW23)
NW23	N/A	303	65	99**	Y	25	M (juv)
NW24	N/A	382	93	123**	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.

** Girth index recorded by DFO that measures distance from pectoral insertion to pectoral insertion.

4.1.2 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 status updates from the tags indicated that battery life was sufficient at the time of last tag transmission, it was assumed that tag demise was due to either adverse environmental conditions, animal behavior or tag detachment (or a combination thereof). The loss of GPS Fastloc positional data did not always coincide with ‘tag death’, as Argos data continued transmitting on some tags for extended periods.

SPLASH10 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 2017. Due to a fault in the SPLASH10 tag buffer programming in 2017, older positional data was transmitted more frequently than newly acquired 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 in daily GPS fixes following tag deployment (Figure 4-1). In 2017, the SPLASH10 tags were pre-programmed to limit the amount of data collected during the latter stages of deployment, with daily positional data collected once every seven days during November (e.g., NW12; Figure 4-1), and no positional data collected during December. Although CTD-SRDL tags deployed on NW11 and NW15 in 2017 and NW21 and NW22 in 2018 could theoretically collect GPS locations every 8 min, other programming requirements and environmental limitations resulted in an actual recovery of GPS locations at a lower rate than the SPLASH10 tags (Figure 4-1). 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 clear of the water.

Interpolation of the 2017-2018 GPS data to 1 min resolution resulted in an increase in the size of the dataset from 28,478 to 873,406 data points. Of these, 3.3% (28,478 cases) were raw GPS points, 0.7% (655 cases) were GPS points manually added to force tracks from running over land, 69% (601,995 cases) were interpolated to within 20 min from a raw GPS point, and 28% (242,278 cases) were interpolated to within 20 to 60 min from a raw GPS point.

The spatial distribution of narwhal movements in 2017 and 2018 are presented over two-week intervals in Figure 4-2 to Figure 4-5. Summer and early fall distribution varied by time and by individual, with certain tagged animals associating with one another more frequently than others. Although both CTD-SRDL tags deployed on NW21 and NW22 in 2018 included Fastloc capability, Fastloc data transmissions from NW21 terminated prematurely (while Argos-based positions remained available), providing only 11 days worth of high-resolution location data for this individual.

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	3,824
NW02	07-31-17	15-Oct	17-Oct	63	3,322	3,127
NW03	08-01-17	16-Sep	3-Oct	46	1,942	1,804
NW04	08-03-17	10-Oct	31-Oct	68	2,857	2,524
NW05	08-03-17	22-Oct	25-Oct	81	2,644	2,412
NW06	08-03-17	08-Dec	8-Mar	97	4,256	3,982
NW07	08-05-17	26-Sep	7-Oct	52	2,274	2,091
NW08	08-12-17	16-Oct	27-Oct	65	2,346	2,177
NW11	08-30-17	31-Oct	3-Nov	62	1,346	1,286
NW12	09-02-17	08-Nov	24-Nov	62	1,953	1,814
NW13	09-02-17	05-Oct	12-Oct	33	1,004	856
NW15	09-03-17	11-Oct	16-Oct	38	577	500
NW21	08-17-18	28-Aug	09-Oct	54	534	428
NW22	08-17-18	02-Nov	03-Nov	79	1,730	1,653

Notes: * Total GPS positions following removal of lower precision datapoints (i.e., those based on <6 satellites with residual value >30)

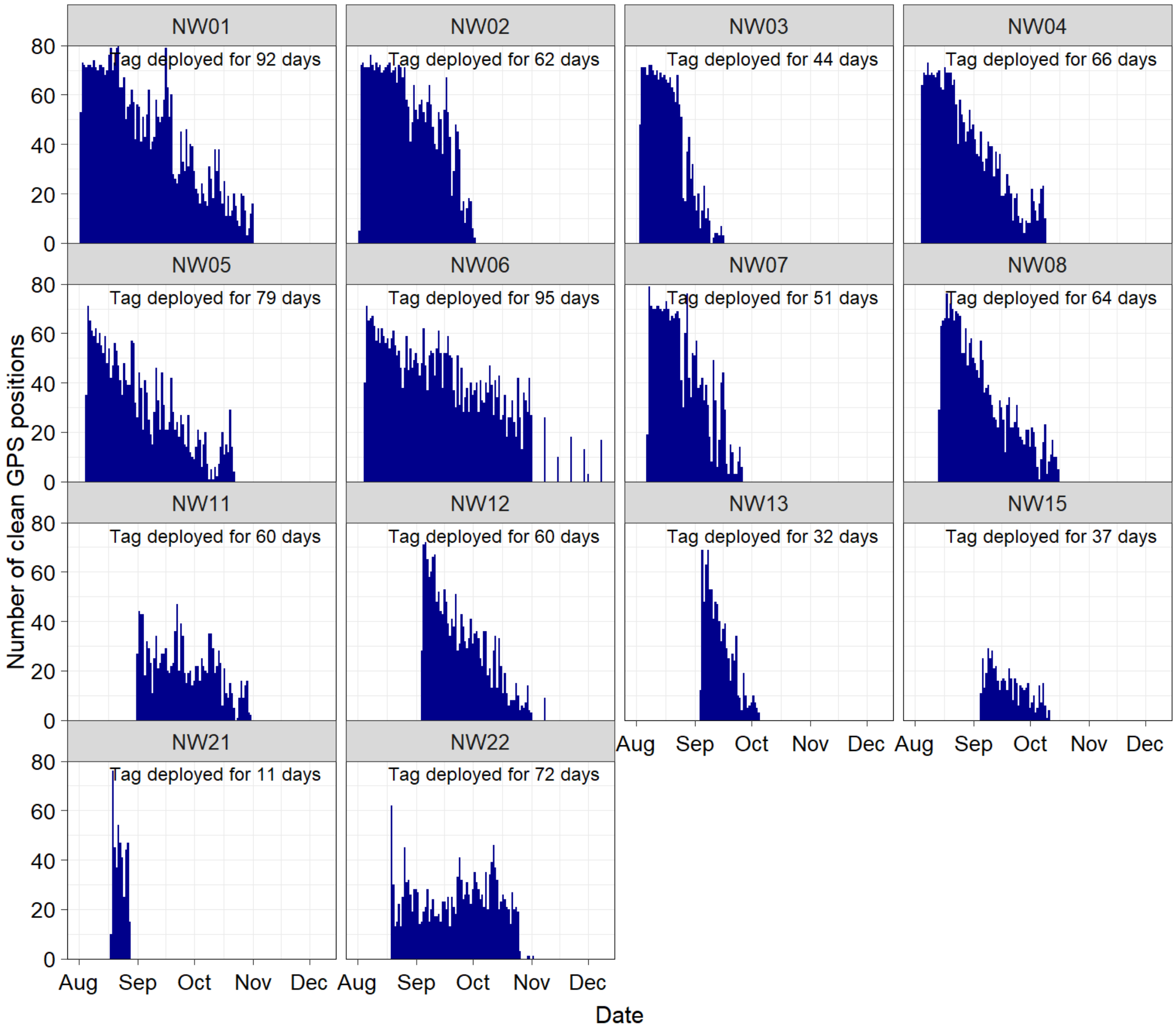
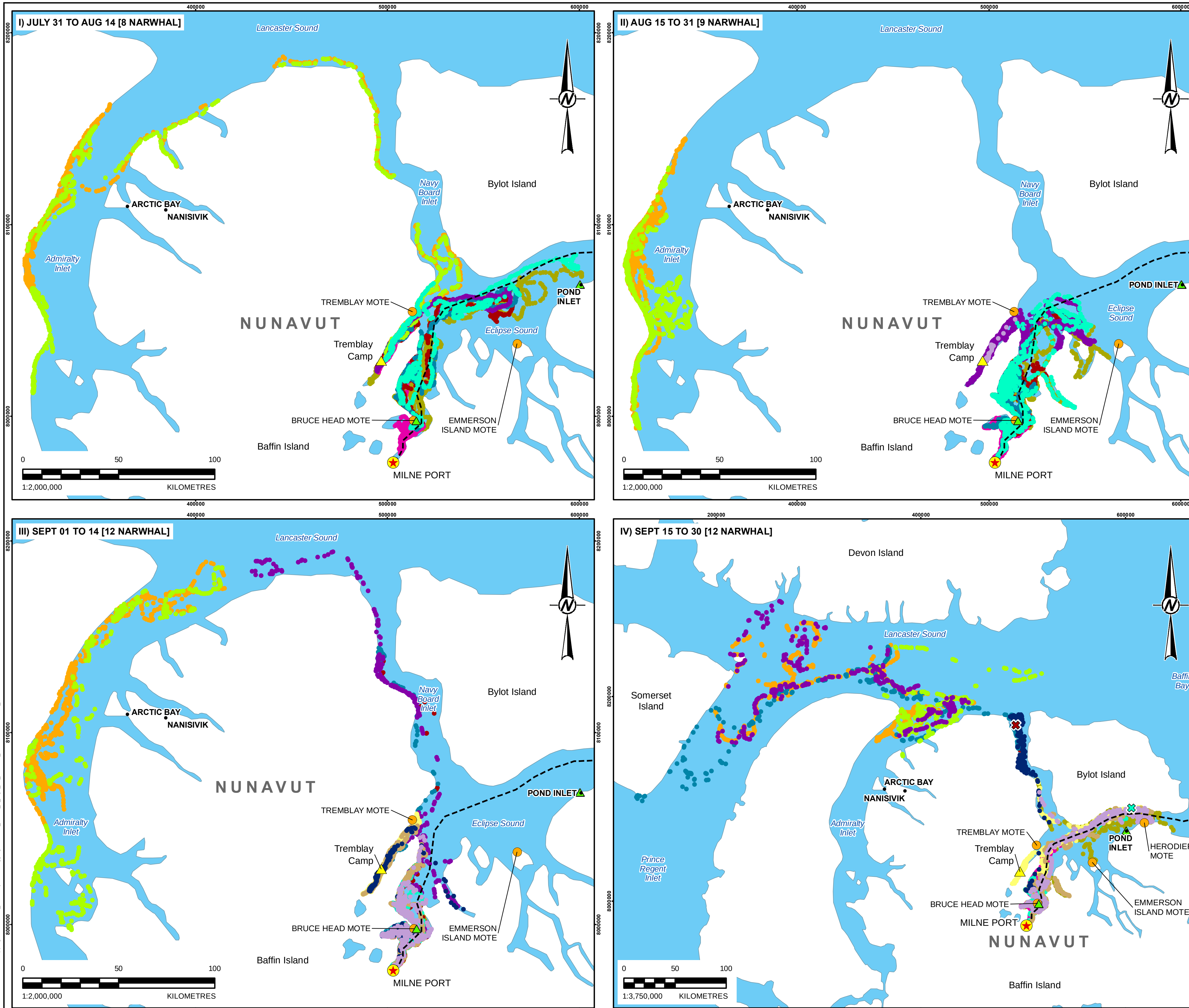


Figure 4-1: Daily number of clean GPS positions per narwhal over total deployment period (days)



LEGEND

- AIS SHORE-BASED STATION
- COMMUNITY
- MILNE PORT
- MOTE RECEIVER STATION
- 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

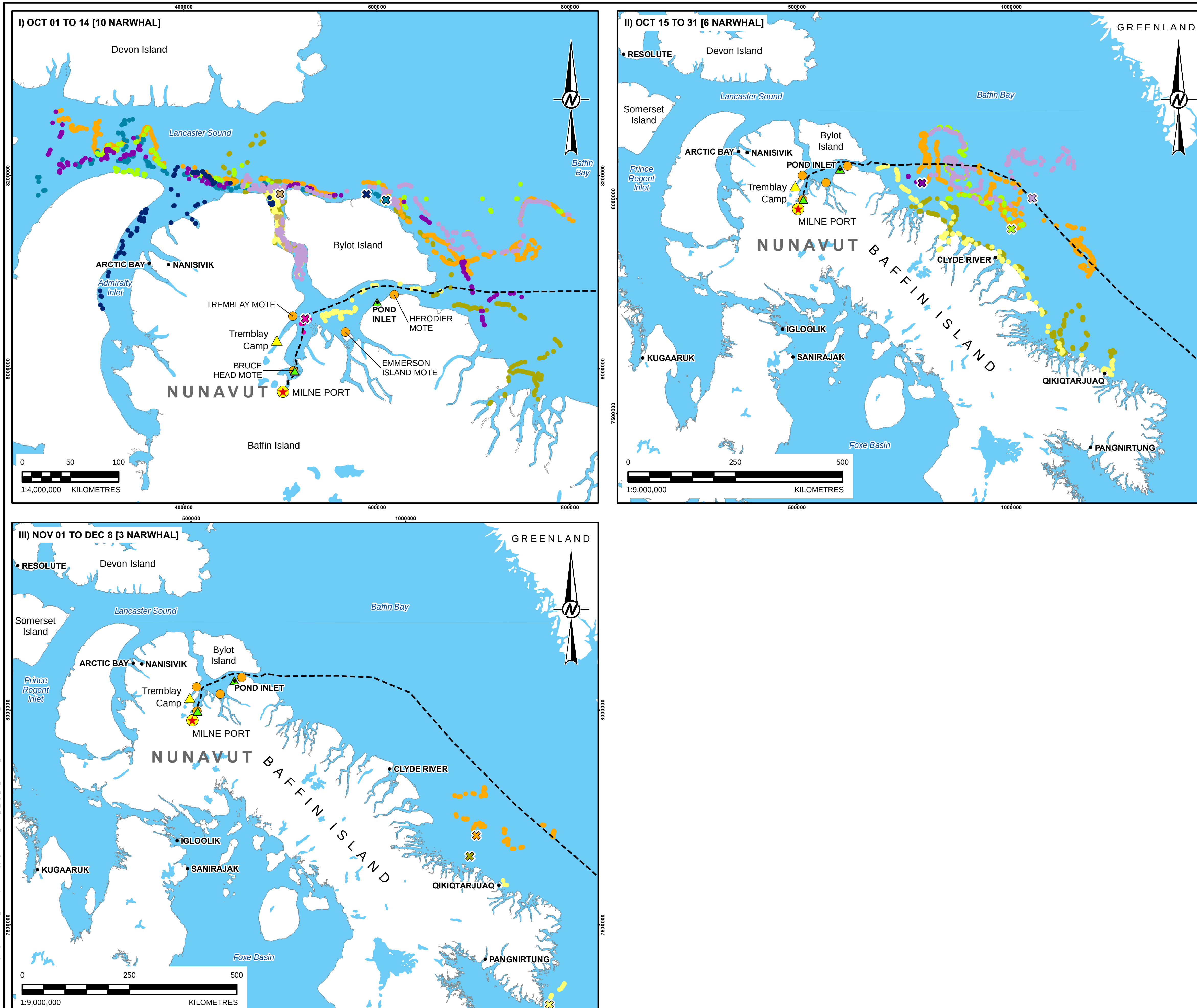
TITLE
SPATIAL DISTRIBUTION OF GPS-TAGGED NARWHAL (31 JULY – 30 SEPTEMBER 2017)

CONSULTANT

GOLDER

YYYY-MM-DD	2020-08-07
DESIGNED	SU
PREPARED	AJA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	12000-4	0	4-2



LEGEND

- AIS SHORE-BASED STATION
- COMMUNITY
- MILNE PORT
- MOTE RECEIVER STATION
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- TAGGING LOCATION
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NARWHAL ID

- NW1
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- NW7
- NW8
- NW11
- NW12
- NW13
- NW15

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CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

TITLE
SPATIAL DISTRIBUTION OF GPS-TAGGED NARWHAL (1 OCTOBER – 8 DECEMBER 2017)

CONSULTANT
GOLDER

YYYY-MM-DD	2020-08-07
DESIGNED	SU
PREPARED	AJA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	12000-4	0	4-3

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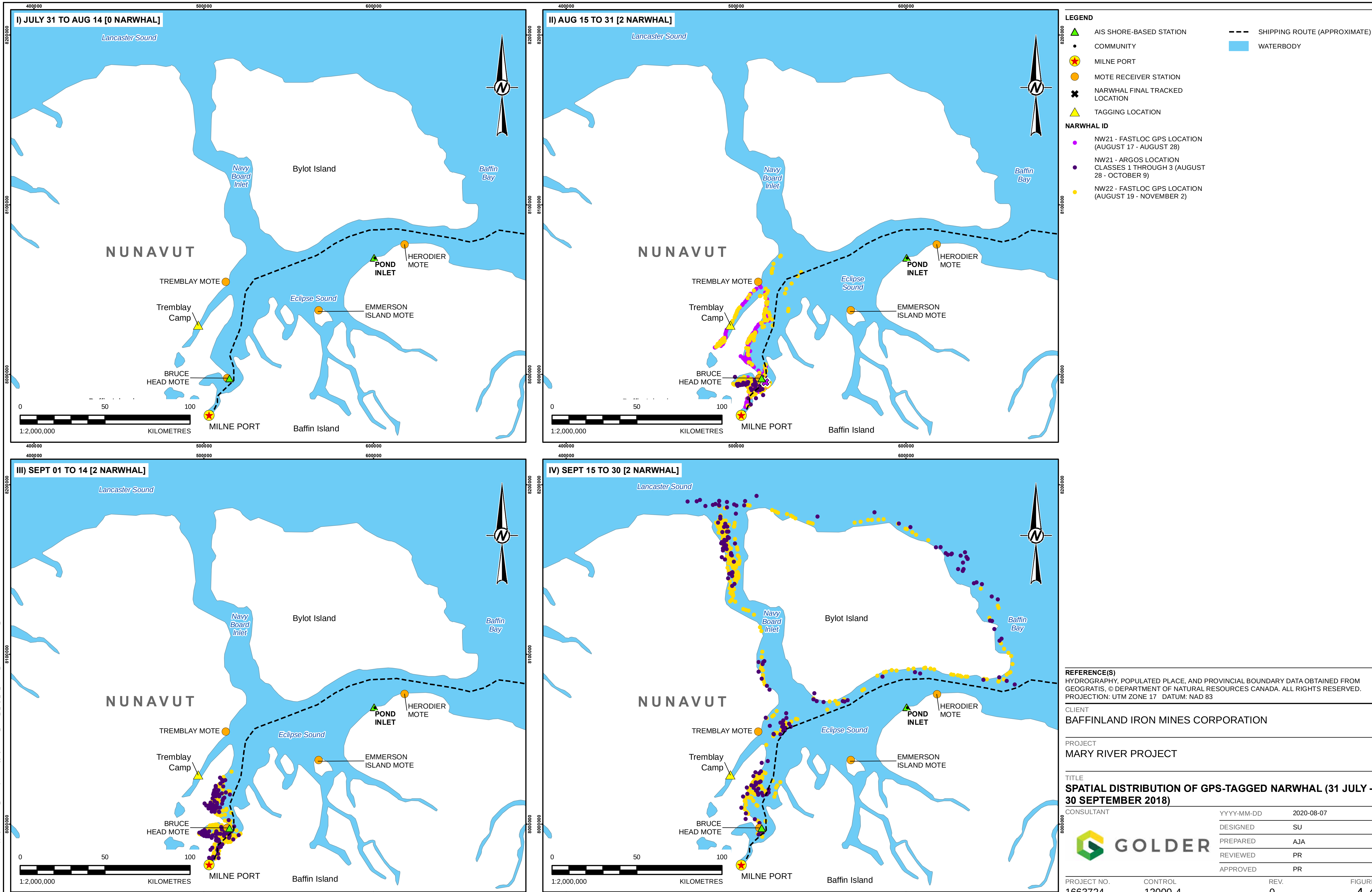
I) JULY 31 TO AUG 14 [0 NARWHAL]
II) AUG 15 TO 31 [2 NARWHAL]
III) SEPT 01 TO 14 [2 NARWHAL]
IV) SEPT 15 TO 30 [2 NARWHAL]
Lancaster Sound
Bylot Island
Navy Board Inlet
Baffin Bay
NUNAVUT
TREMBLAY MOTE
Tremblay Camp
Eclipse Sound
POND INLET
HERODIER MOTE
EMMERSON ISLAND MOTE
BRUCE HEAD MOTE
MILNE PORT
Baffin Island
0 50 100
1:2,000,000
KILOMETRES
400000
500000
600000
8000000
8100000
8200000
LEGEND
AIS SHORE-BASED STATION
COMMUNITY
MILNE PORT
MOTE RECEIVER STATION
NARWHAL FINAL TRACKED LOCATION
TAGGING LOCATION
SHIPPING ROUTE (APPROXIMATE)
WATERBODY
NARWHAL ID
NW21 - FASTLOC GPS LOCATION (AUGUST 17 - AUGUST 28)
NW21 - ARGOS LOCATION CLASSES 1 THROUGH 3 (AUGUST 28 - OCTOBER 9)
NW22 - FASTLOC GPS LOCATION (AUGUST 19 - NOVEMBER 2)
REFERENCE(S)
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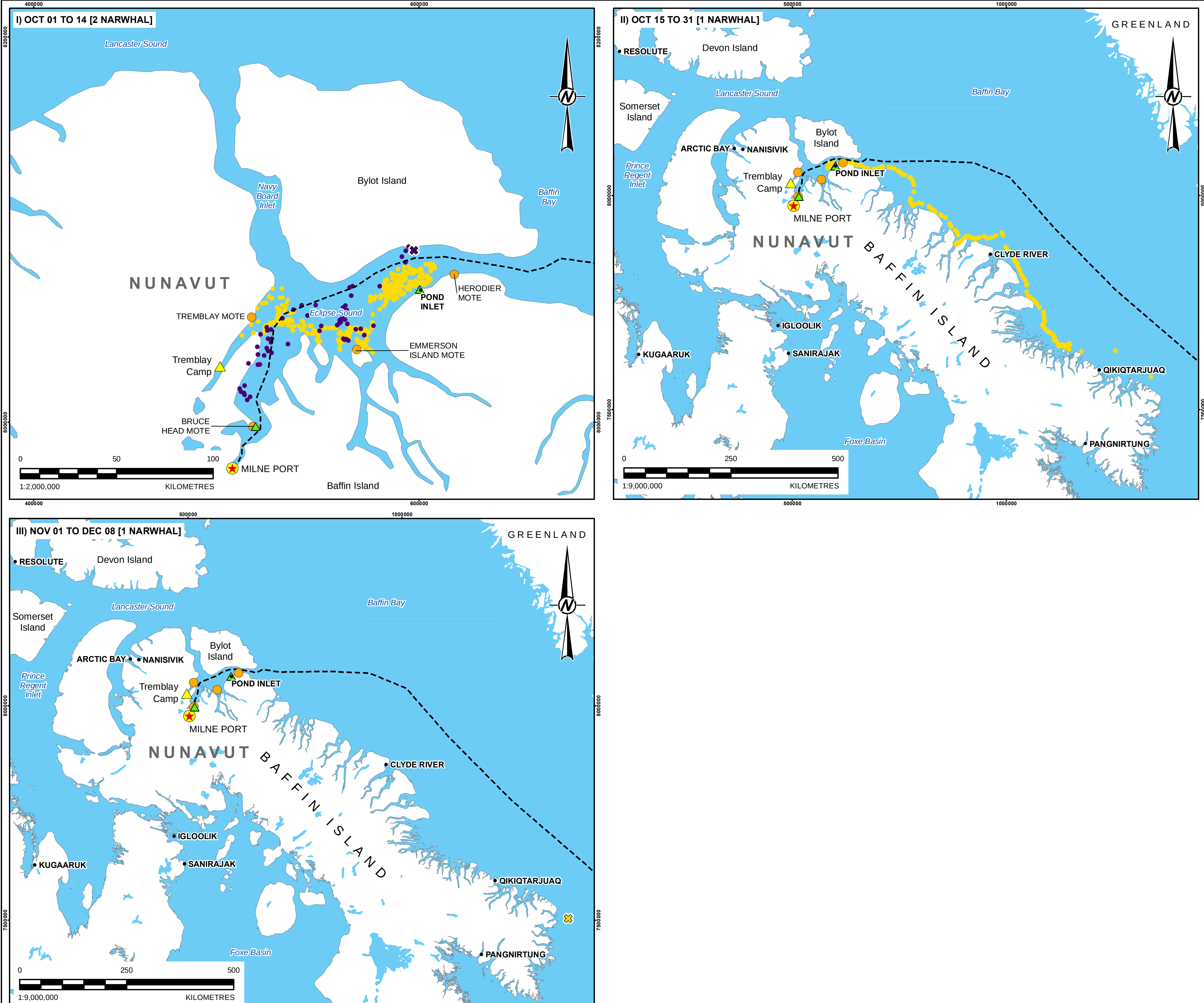
PROJECTION: UTM ZONE 17 DATUM: NAD 83
CLIENT
BAFFINLAND IRON MINES CORPORATION
PROJECT
MARY RIVER PROJECT
TITLE
SPATIAL DISTRIBUTION OF GPS-TAGGED NARWHAL (31 JULY – 30 SEPTEMBER 2018)
CONSULTANT
GOLDER
YYYY-MM-DD 2020-08-07
DESIGNED SU
PREPARED AJA
REVIEWED PR
APPROVED PR
PROJECT NO. 1663724
CONTROL 12000-4
REV. 0
FIGURE 4-4



LEGEND

- AIS SHORE-BASED STATION
- COMMUNITY
- MILNE PORT
- MOTE RECEIVER STATION
- NARWHAL FINAL TRACKED LOCATION
- TAGGING LOCATION
- SHIPPING ROUTE (APPROXIMATE)
- WATERBODY

NARWHAL ID

- NW21 - ARGOS LOCATION CLASSES 1 THROUGH 3 (AUGUST 28 - OCTOBER 9)
- NW22 - FASTLOC GPS LOCATION (AUGUST 19 - NOVEMBER 2)

REFERENCE(S)

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PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

TITLE
SPATIAL DISTRIBUTION OF GPS-TAGGED NARWHAL (1 OCTOBER – 8 DECEMBER 2018)

CONSULTANT
GOLDER

YYYY-MM-DD	2020-08-07
DESIGNED	SU
PREPARED	AJA
REVIEWED	PR
APPROVED	PR

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	12000-4	0	4-5

Overall, narwhal positional data from 2017 and 2018 demonstrated that tagged narwhal occurred in all strata during the summer period, but were more common in certain areas of the RSA, namely Milne Inlet South, Koluktoo Bay, Milne Inlet North and Tremblay Sound (Figure 4-6). High use areas in the RSA included the central portion of Tremblay Sound, the western shore of Milne Inlet North, and most of Koluktoo Bay and Milne Inlet South, particularly in areas south of Bruce Head (i.e., entrance to Koluktoo Bay) and in Assomption Harbour (i.e., Milne Port site) (Figure 4-6; Figure 4-7). These results were consistent with areas of high narwhal concentrations identified during baseline aerial surveys conducted in the RSA during 2007, 2008, 2013, and 2014 (Elliott et al. 2015; Thomas et al. 2015) prior to the commencement of iron ore shipping along the Northern Shipping Route.

Satellite tag data from 2017 indicated that several of the tagged narwhal moved between Eclipse Sound and Admiralty Inlet during their deployment period. Two of the 12 individuals tagged in early August (NW05 and NW06) travelled west to Admiralty Inlet and remained there for the remainder of the summer. Two additional tagged animals (NW04 and NW08) arrived in Admiralty Inlet by mid-September. Another five tagged individuals (NW03, NW11, NW12, NW13 and NW15) travelled up Navy Board Inlet in late September arriving in Lancaster Sound and Admiralty Inlet in early October. The majority of the 2017 instrumented animals began their eastward migration to Baffin Bay via Lancaster Sound, with only one individual tagged in 2017 (NW12) confirmed to have exited the RSA via Pond Inlet (after returning from Lancaster Sound). In 2018, both tagged narwhal (NW21 and NW22) remained in the RSA for the full duration of the open-water period. Interestingly, the pair generally traveled together throughout their entire deployment period, including during a full clockwise circumnavigation of Bylot Island undertaken over an 11 day period in late September (20-30 Sept), after which point the pair returned to the North Milne Inlet / Eclipse Sound area for over a week prior to starting their out-migration to Baffin Bay via Pond Inlet (note: positional information for NW21 ceased on 09 October along the south shore of Bylot Island (Northeast of Pond Inlet). These results support the notion that some degree of mixing occurs between the Eclipse Sound and Admiralty Inlet stocks during the open-water and late shoulder seasons.

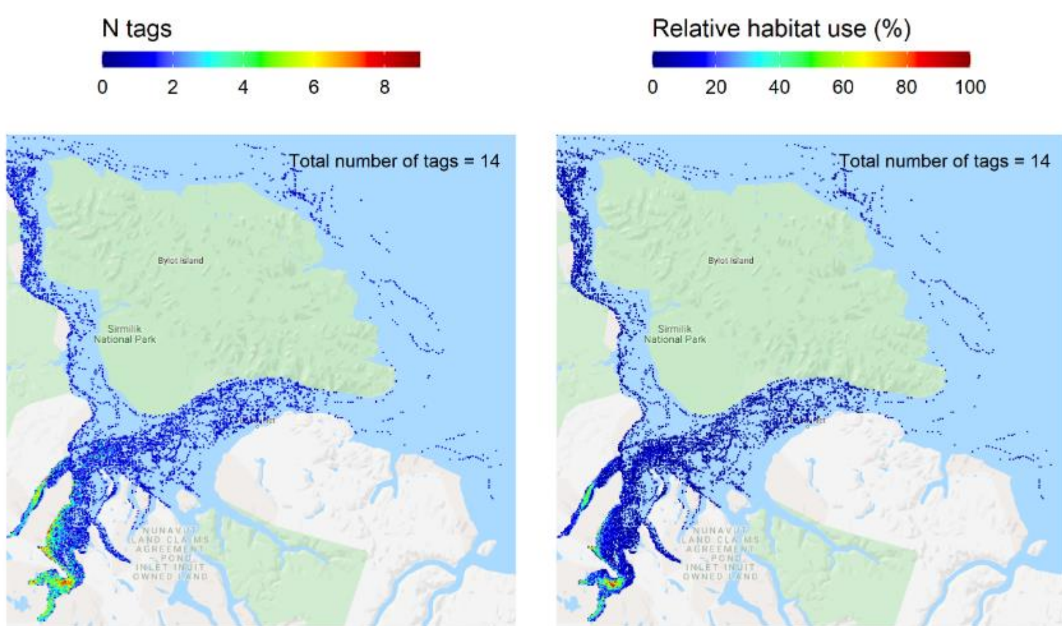


Figure 4-6: Spatial distribution of tagged narwhal in the RSA (2017 and 2018). In left plot, colour scale indicates the total number of tagged individuals (no. of unique tags) recorded in each grid cell of 500 x 500 m. In right plot, colour scale represents relative habitat use in each grid cell.

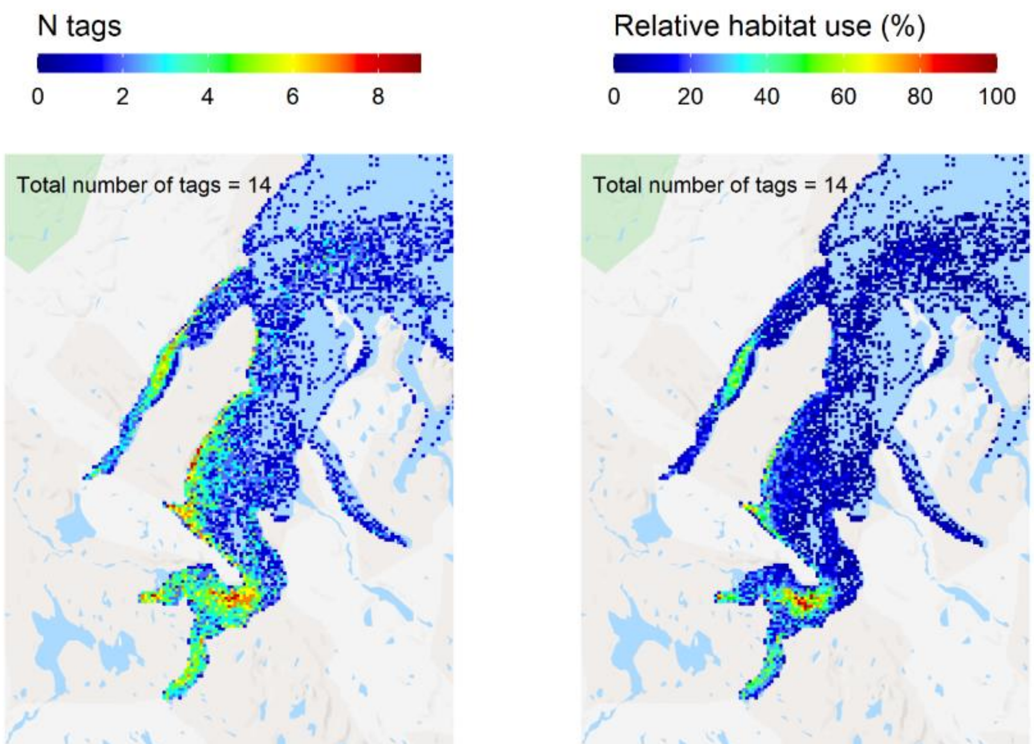


Figure 4-7: Spatial distribution of tagged narwhal in Milne Inlet North, Milne Inlet South, Koluktoo Bay, and Tremblay Sound substrata. In left plot, colour scale indicates the total number of tagged individuals recorded in each grid cell of 500 x 500 m. In right plot, colour scale represents relative habitat use in each grid cell.

4.1.3 Narwhal Dive Data

Dive data were recorded on three of the different tag types deployed on narwhal, including the MiniPAT/MK10-PAT tags (1 s resolution), SPLASH10 tags (75 s resolution), and SMRU tags (dive summary data). Narwhal that were equipped with both a SPLASH10 tag and a MiniPAT/MK10-PAT tag (NW01, NW02, NW03, and NW04; Table 4-1) provided an opportunity to compare dive data between the two tags. Both tags presented similar results regarding the proportion of time narwhal spent at the surface (<7m) vs. on a dive (>7m) (Table 4-4) which allowed for inclusion of the SPLASH10 tag data in the analysis of surface time (Section 4.2.2.1).

Table 4-4: Proportion of time tagged narwhal engaged in a qualifying dive (>7 m depth)

Narwhal	Depth tag	
	MiniPAT / MK10-PAT	SPLASH10
NW01	53.3%	52.3%
NW02	50.7%	50.4%
NW03	52.1%	52.2%
NW04	54.5%	54.1%

Conversely, all other dive response variables derived from the dive data time series using the DiveBomb algorithm differed strongly between MiniPAT and SPLASH10 tags (Figure 4-8). For example, while dive duration was similar overall between the two data sources, maximum dive depth and time spent at the bottom 20% of the dive were generally underestimated by the SPLASH10 data when compared to the full, 1 s resolution of MiniPAT data. In addition, the DiveBomb algorithm did not always correctly identify all dives based on the SPLASH10 dataset when compared to the MiniPAT dataset, resulting in fewer dives overall. In the example provided in Figure 4-8, the DiveBomb algorithm identified 21 dives based on MiniPAT data exclusively, but only 16 dives based on SPLASH10 data (76% relative to MiniPAT). Given that the SPLASH10 data often resulted in an underestimation of the number of dives completed by narwhal, along with associated response variables, these data were excluded from the dataset when analyzing changes in bottom dives, time at depth, dive duration, and descent speed in relation to vessel exposure.

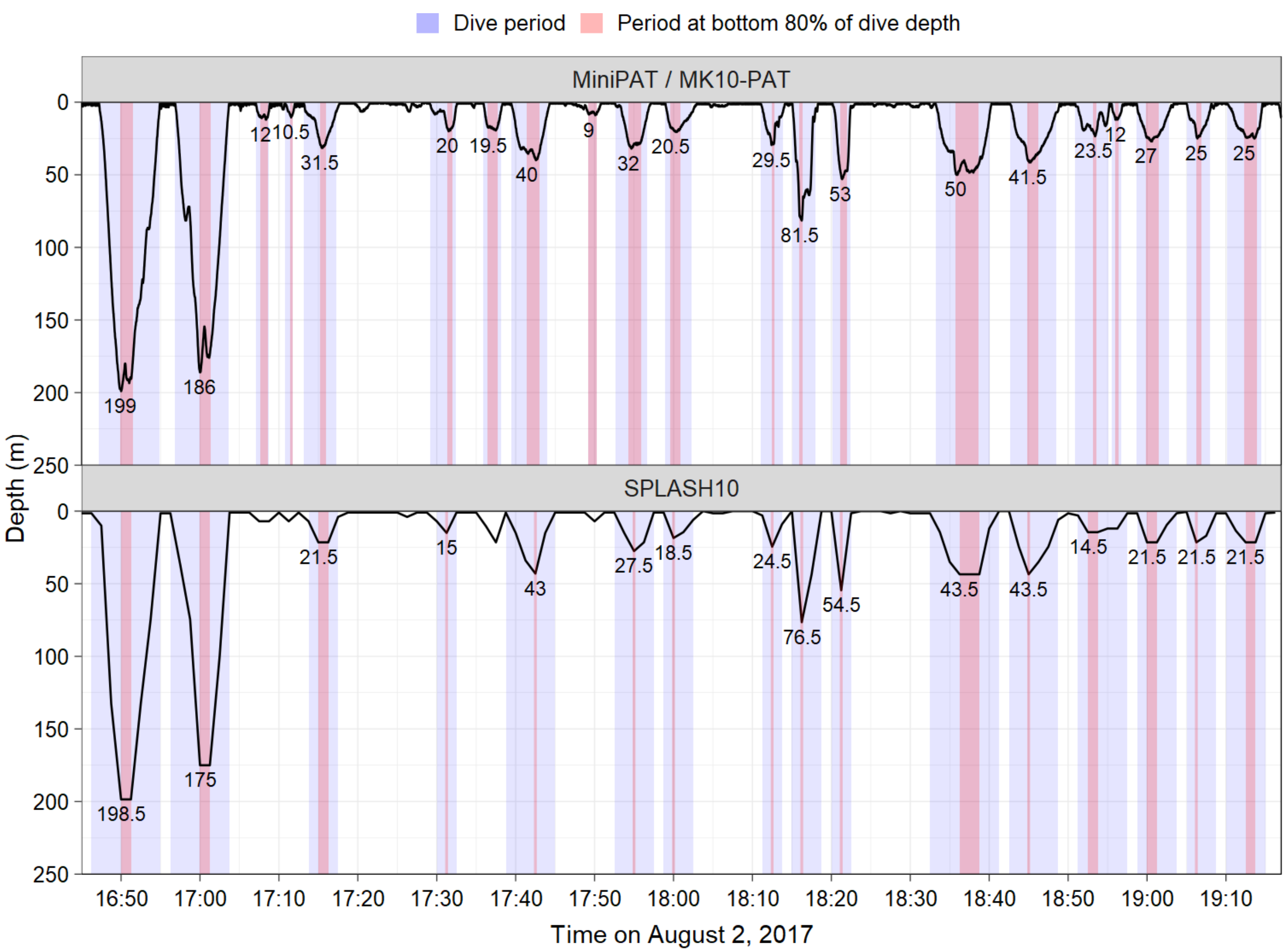


Figure 4-8: Comparison of MiniPAT and SPLASH10 dive data collected on 02 August 2017 from NW02. DiveBomb dive summary information provided for both tags. Values indicate maximum dive depths (in m) associated with each dive characterized by DiveBomb.

NW21 and NW22 were equipped with both SMRU tags and MiniPAT / MK10-PAT tags, which also allowed for a comparison of dive data recorded by the two tag types. Overall, the low-resolution binned SMRU data only captured a fraction of the dives recorded by the MiniPAT tags (Figure 4-9). In addition, the binned depth data provided by the SMRU tags provided adequate description of the dive profile for some dives (first two dives with SMRU data in Figure 4-9) but not others (all remaining dives). Therefore, dive data from the SMRU tags were excluded from the present analyses and further consideration in this report.

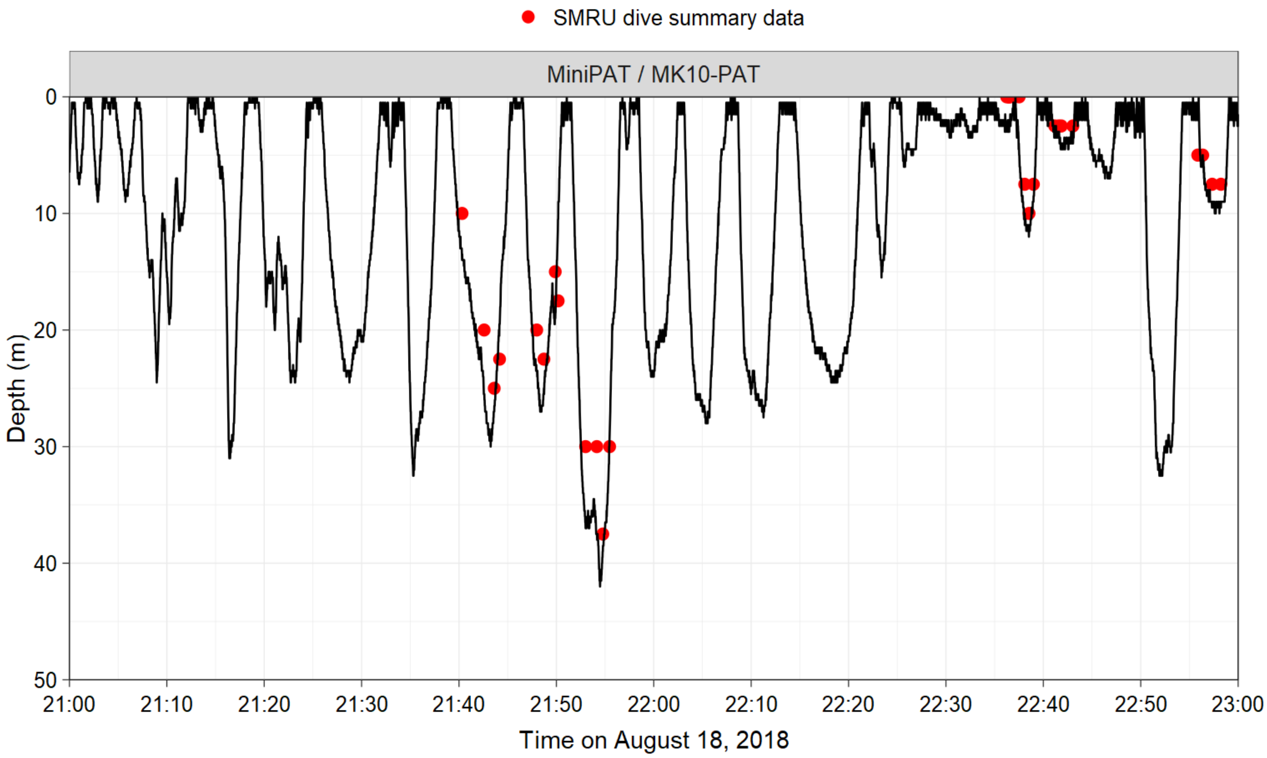


Figure 4-9: Comparison of dive data collected using MiniPAT / MK10-PAT and SMRU dive tags on 18 August 2018 from NW21

4.1.4 Vessel Traffic

AIS data were collected over 81 days in 2017 (between 29 July and 17 October) and 95 days in 2018 (between 20 July and 22 October). During this period, vessels traveling at a speed of ≥1 knots[10] in the RSA were recorded on 79 days and 94 days in 2017 and 2018, respectively. Ore carriers were the most common vessel type recorded in the RSA, present during 78 of 79 days in 2017 and during 90 of 94 days in 2018 (Figure 4-10). General cargo and fuel tanker vessels (including community re-supply vessels) were present on 68 days and 78 days in 2017 and 2018, respectively, and vessels categorized as “Other” (e.g., passenger vessels, Canadian Coast Guard vessels, fishing vessels) were present on 39 and 45 days in 2017 and 2018, respectively. In comparing with vessel numbers previously reported in Golder (2019), the increase is attributed to the larger spatial extent assessed as part of this analysis (i.e., the full extent of the RSA) and the incorporation of medium-sized vessels (50 – 99 m in length).

[10] One knot 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.

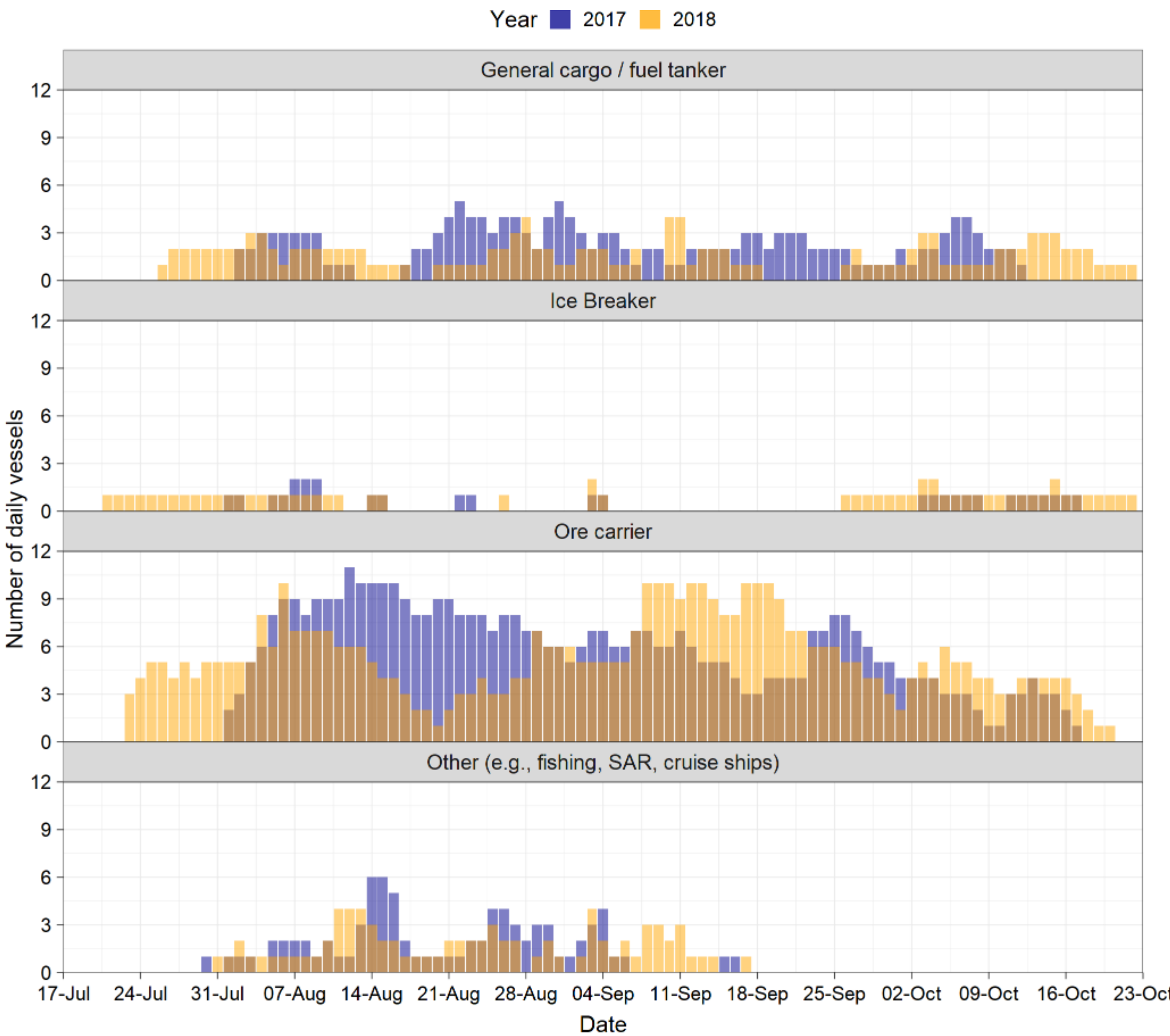
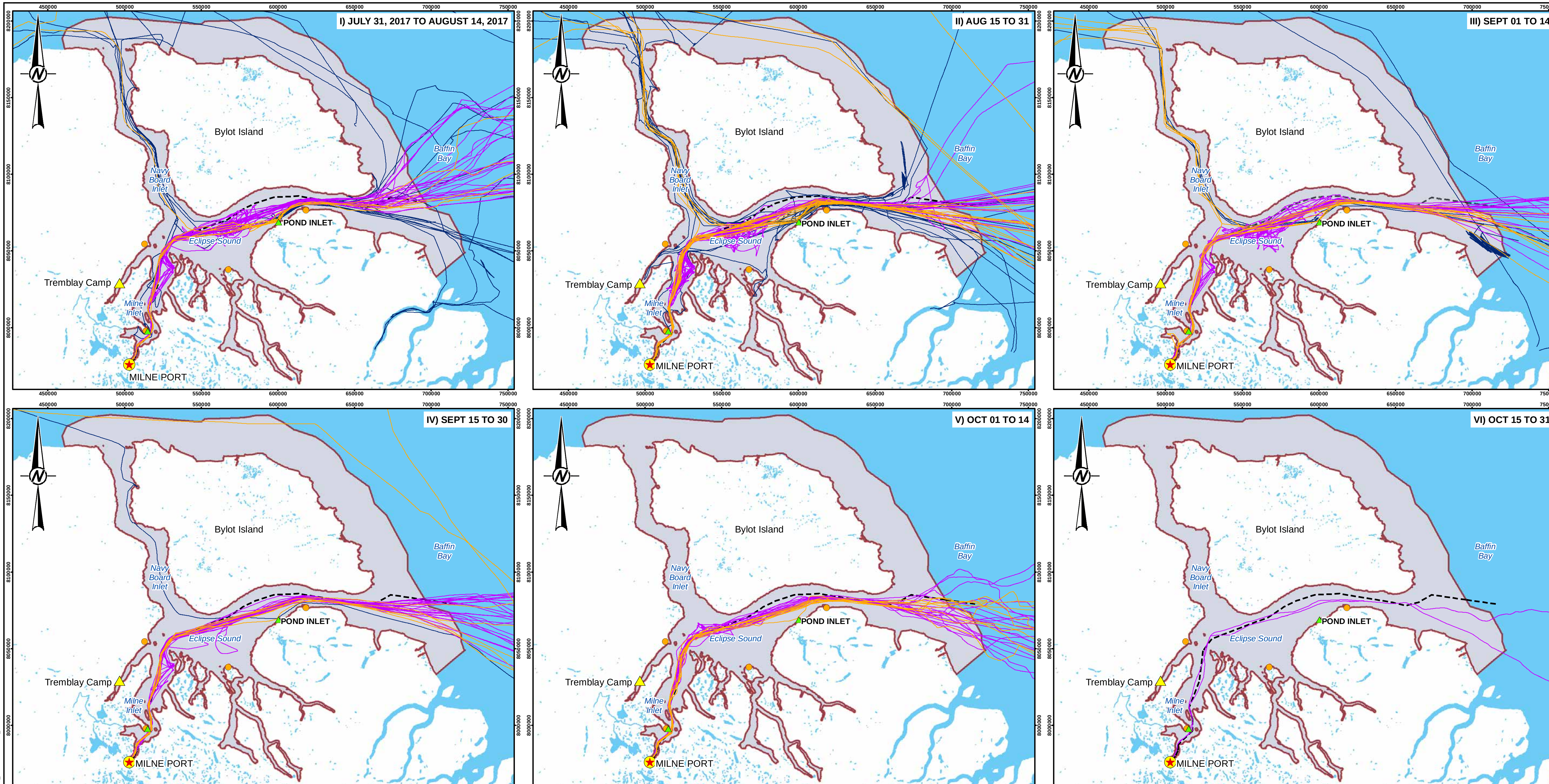


Figure 4-10: Daily number of vessels in RSA during 2017 and 2018 - presented by vessel type (Project and non-Project vessels combined).



LEGEND

- AIS SHORE-BASED STATION
- COMMUNITY
- MILNE PORT
- MOTE RECEIVER STATION
- TAGGING LOCATION
- SHIPPING ROUTE (APPROXIMATE)
- MARINE MAMMAL REGIONAL STUDY AREA
- WATERBODY

VESSEL TRANSIT ROUTES BY CLASS

- BULK (ORE) CARRIER
- GENERAL CARGO
- OTHER

0 50 100
1:2,500,000 KILOMETRES

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

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT

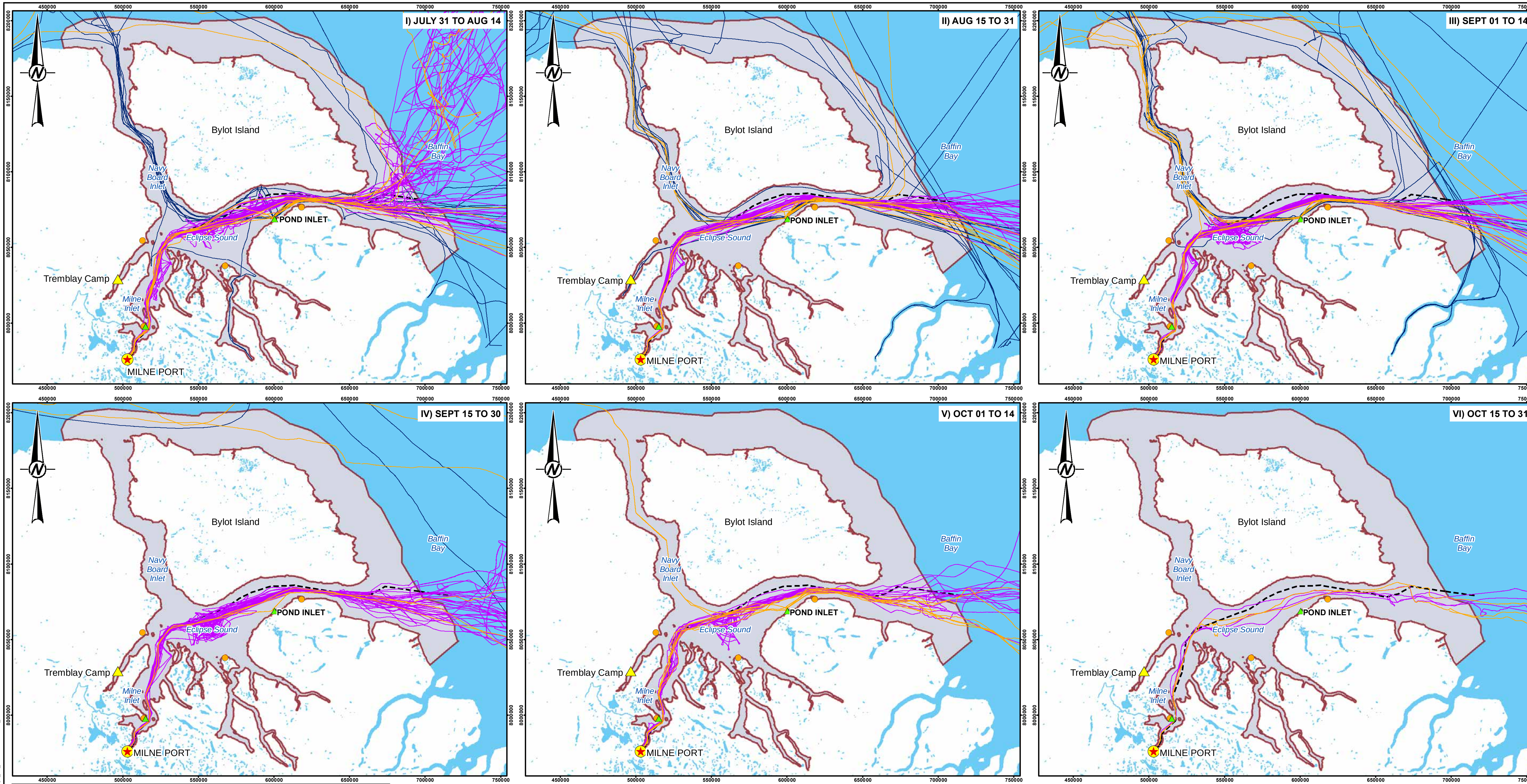
CONSULTANT
GOLDER

YYYY-MM-DD	2020-08-07
DESIGNED	SU
PREPARED	AJA
REVIEWED	PR
APPROVED	PR

TITLE
TRACKLINES OF LARGE (>100 M) AND MEDIUM (>50 M) SIZED VESSELS (PROJECT AND NON-PROJECT RELATED) - 2017 NARWHAL TAGGING PROGRAM

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	12000-4	0	4-11

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm



LEGEND

- AIS SHORE-BASED STATION
- COMMUNITY
- MILNE PORT
- MOTE RECEIVER STATION
- TAGGING LOCATION
- SHIPPING ROUTE (APPROXIMATE)
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VESSEL TRANSIT ROUTES BY CLASS

- BULK (ORE) CARRIER
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0 50 100
1:2,500,000 KILOMETRES

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PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
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PROJECT
MARY RIVER PROJECT

CONSULTANT
GOLDER

YYYY-MM-DD	2020-08-07
DESIGNED	SU
PREPARED	AJA
REVIEWED	PR
APPROVED	PR

TITLE
TRACKLINES OF LARGE (≥100 M) AND MEDIUM (50-99 M) SIZED VESSELS (PROJECT AND NON-PROJECT RELATED) - 2018 NARWHAL TAGGING PROGRAM

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	12000-4	0	4-12

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

4.2 Narwhal Interactions with Vessel Traffic

Narwhal behavioral responses to vessel traffic were 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 were collected when narwhal were not exposed to vessel traffic (i.e., no vessels were within 10 km of the animal [93.2% of the 442,334 raw and interpolated GPS points]; Figure 4-13). Narwhal were exposed to vessel traffic (i.e., positioned within 10 km of a vessel) throughout the RSA, but this was more common in the Milne Inlet South and Koluktoo Bay strata due to the confined nature of the channel along this part of the Northern Shipping Route (Table 4-5).

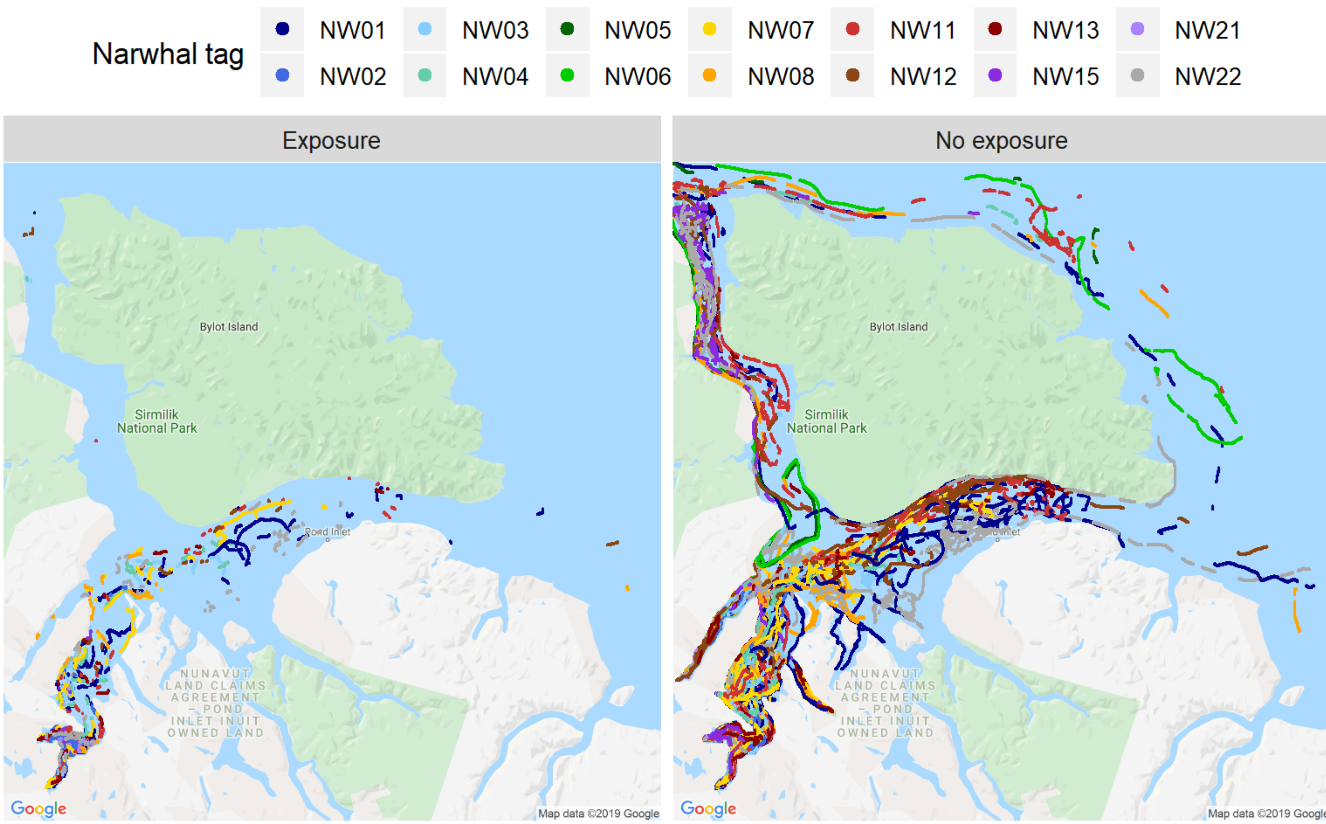

Figure 4-13: Spatial distribution of narwhal during vessel exposure (CPA to 10 km) and non-exposure (>10 km) events

Within each substratum, the majority of GPS data were collected when narwhal were not exposed to vessel traffic (>10 km away), with periods of non-exposure comprising 89% of data collected in Eclipse Sound and 100% of data collected in the ‘Baffin Bay Shallow’ and ‘Other Inlets / Sounds’ substrata (Table 4-5). The substrata that contributed the majority of the data to the overall GPS dataset were Milne Inlet South (29% of data), Milne Inlet North (18% of the data), Eclipse Sound (16% of the data), and Tremblay Sound (14% of the data). In Milne Inlet South, 9% of the data were collected when a vessel was present within 10 km from narwhal, with 2% of the data collected when vessels were within 2 km from narwhal. In comparison, in all other substrata, vessels were within 2 km from narwhal in less than 1% of the collected data, with zero instances recorded in Navy Board Inlet, Other Inlets / Sounds, Baffin Bay Shallow, or Baffin Bay. Overall, narwhal occurred within 10 km of a vessel for approximately 7% of the total deployment period in the RSA (i.e., 6.8% of all GPS locations).

Table 4-5: Proportion of GPS data collected from tagged narwhal at 0-10 km distance gradients from vessel, and when no vessels were present within 10 km from narwhal, by substratum. Note that proportions are additive as distance from vessel increases

Distance from Vessel	Substratum									Total RSA
	Milne Inlet South	Koluktoo Bay	Milne Inlet North	Tremblay Sound	Eclipse Sound	Other Inlets / Sounds	Navy Board Inlet	Baffin Bay Shallow	Baffin Bay	
≤1 km	0.003	0.001	<0.001	0	0.001	0	0	0	0	**0.001**
≤2 km	0.016	0.006	0.001	<0.001	0.003	0	0	0	0	**0.006**
≤3 km	0.027	0.010	0.002	<0.001	0.012	0	0	0	0	**0.011**
≤4 km	0.038	0.016	0.007	0.001	0.021	0	0.001	0	0	**0.017**
≤5 km	0.045	0.022	0.014	0.001	0.032	0	0.001	0	0.002	**0.023**
≤6 km	0.053	0.030	0.026	0.001	0.044	0	0.001	0	0.002	**0.030**
≤7 km	0.062	0.034	0.038	0.001	0.061	0	0.001	0	0.002	**0.038**
≤8 km	0.071	0.044	0.054	0.001	0.078	0	0.002	0	0.002	**0.048**
≤9 km	0.080	0.054	0.067	0.001	0.101	0	0.004	0	0.005	**0.057**
≤10 km	0.092	0.064	0.086	0.002	0.114	0	0.004	0	0.005	**0.068**
No vessels within 10 km	0.908	0.936	0.914	0.998	0.886	1.000	0.996	1.000	0.995	**0.932**
No. of narwhal	**11**	**11**	**12**	**13**	**12**	**6**	**12**	**3**	**9**	**14**
No. of data points	**6,041**	**2,089**	**3,717**	**2,941**	**3,222**	**354**	**1,626**	**22**	**562**	**20,574**
Relative proportion of data in substratum	**0.294**	**0.102**	**0.181**	**0.143**	**0.157**	**0.017**	**0.079**	**0.001**	**0.027**	**1.000**

4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events)

A total of 92 events were identified in which CPA between narwhal and a transiting vessel was ≤3 km, included ≥3 raw GPS points, and for which both narwhal dive and GPS data were available (Figure 4-14 through Figure 4-39). Of these, 23 events were identified for NW01 (2017), 25 events were identified for NW02 (2017), 10 events were identified for NW03 (2017), 24 events were for identified NW04 (2017), 5 events were identified for NW21 (2018), and 5 events were identified for NW22 (2018). The distance between narwhal and vessels at CPA ranged between 0.1 km and 3.0 km, with a mean of 1.4 km (SD=0.78 km). Drifting/anchored vessels (i.e., speed <1 knot for the duration of the exposure event) and vessels less than 50 m in length were not included in this analysis. Plots depict both Project and non-Project related vessels transiting throughout the RSA.

Of the 92 events identified, 20 were considered paired vessel transits in which a narwhal was exposed to two or more vessels concurrently. The following events were examples of paired vessel transits but were not depicted on the same diagram due to complexity: NW01- 2 and 3, 5 and 6, 13 and 14, and 22 and 23; NW02- 12 and 13, 17 and 18, 19 and 20, and 23 and 24; NW04- 13 and 14, and 21 and 22. Paired vessel transits were not included in the main analyses. Instead, effects of paired vessel transits on narwhal behavior are assessed in Section 4.2.4.

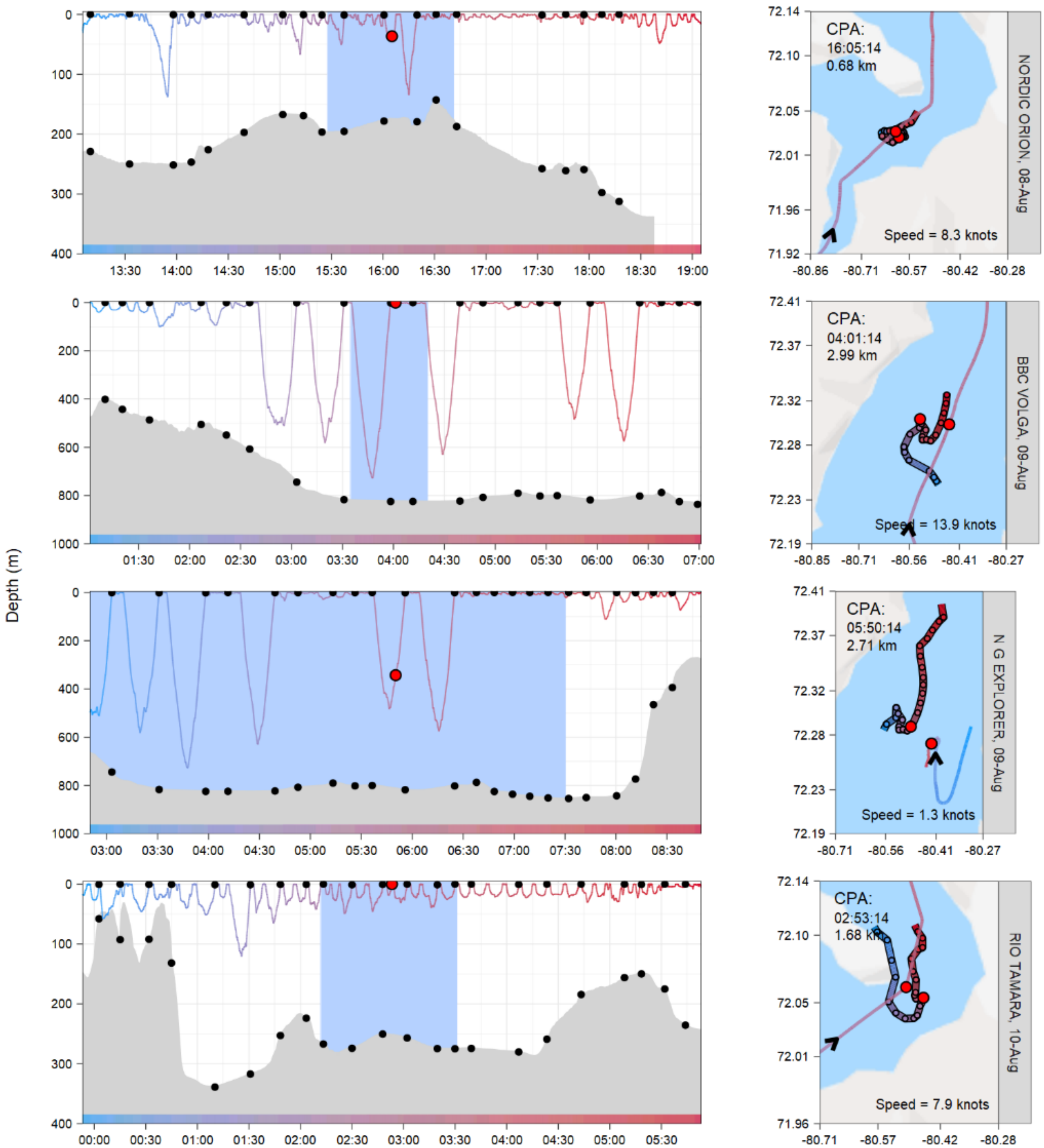

Figure 4-14: Movement and dive depths of NW01 relative to vessel transits 1-4. All vessels shown are Project-related, except for *NG Explorer*

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 vessel.

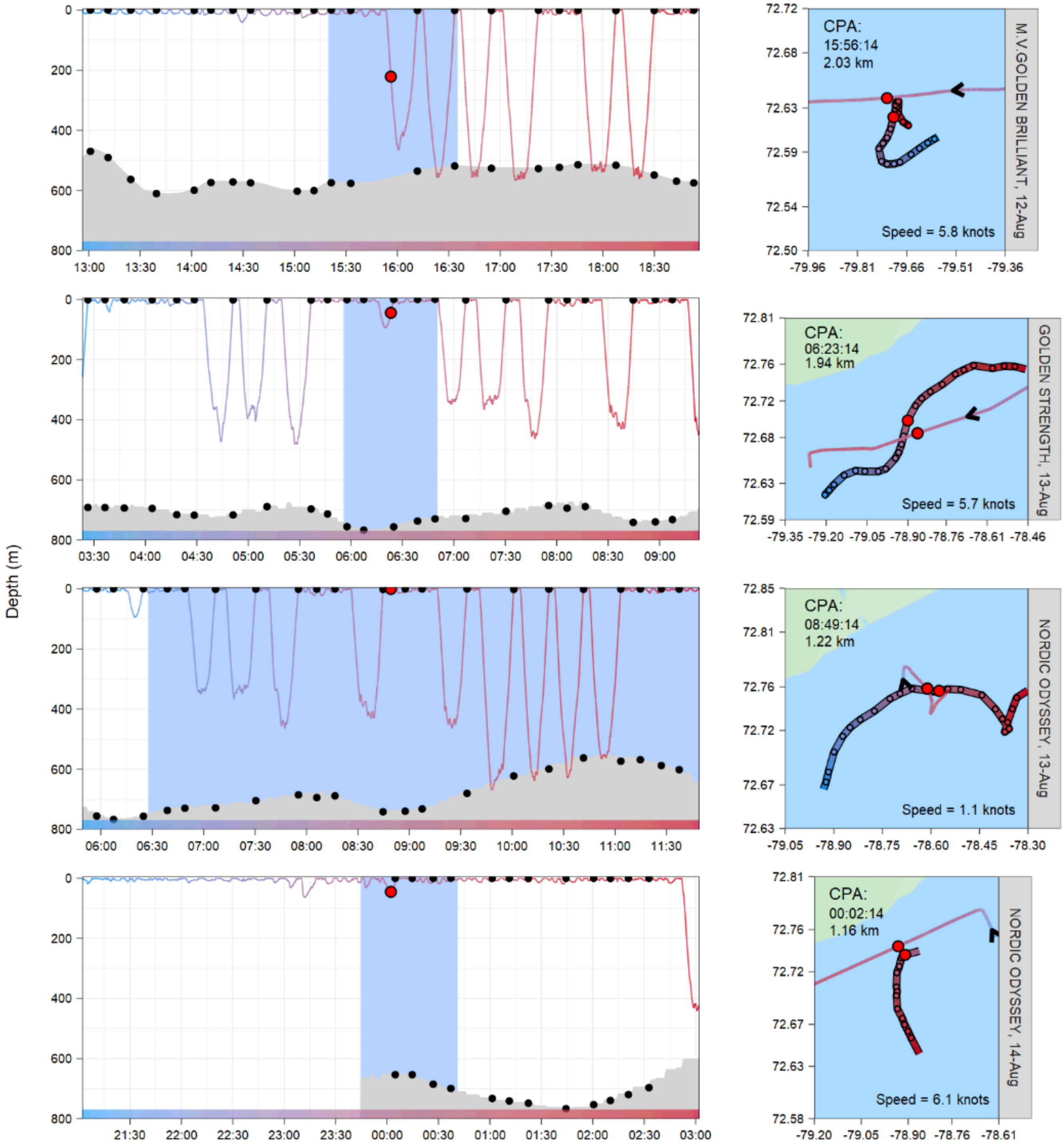

Figure 4-15: Movement and dive depths of NW01 relative to vessel transits 5-8. All vessels shown are Project-related

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 vessel. Note that land depicted as green is part of Sirmilik National Park.

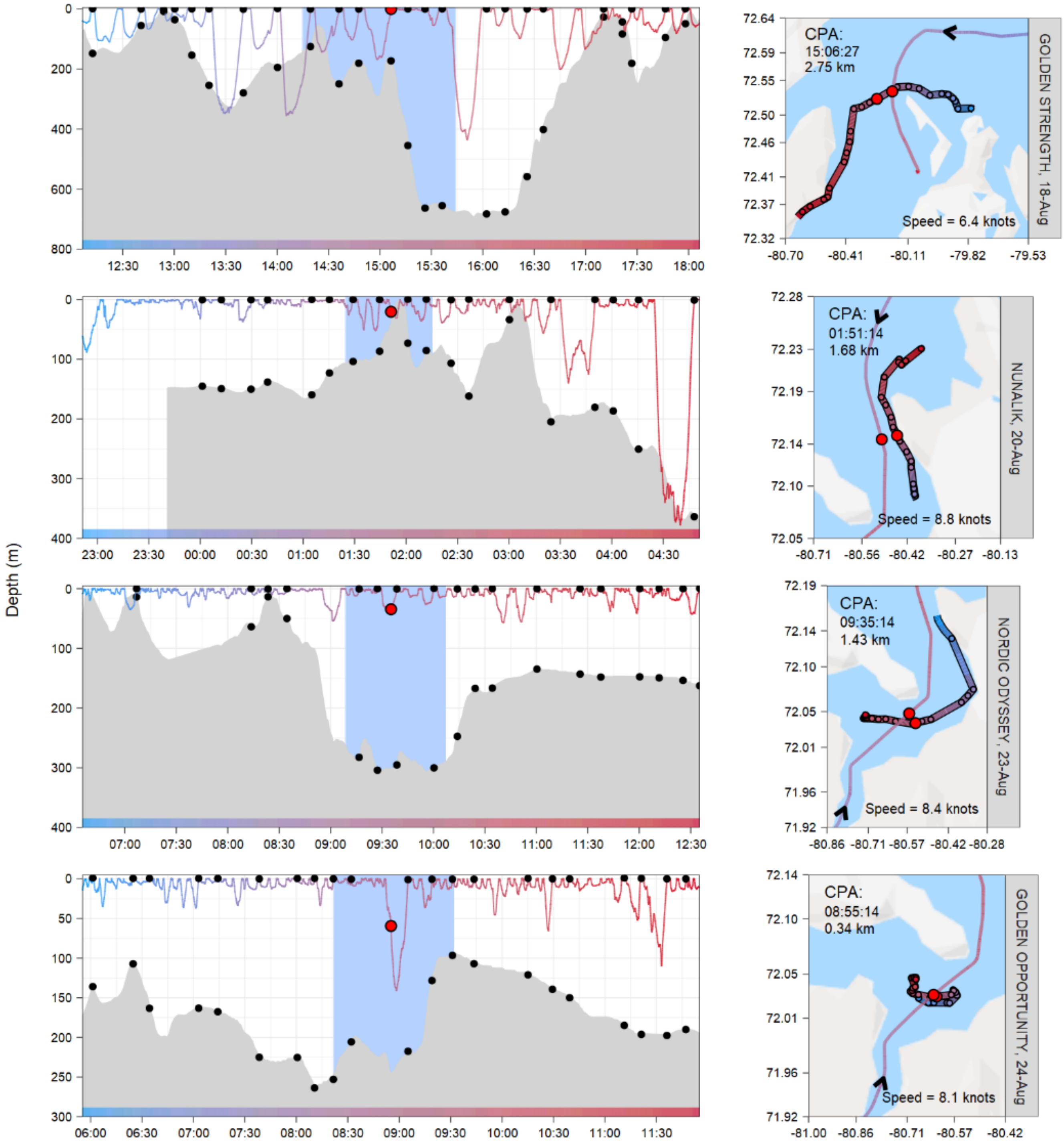

Figure 4-16: Movement and dive depths of NW01 relative to vessel transits 9-12. All vessels shown are Project-related

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 vessel.

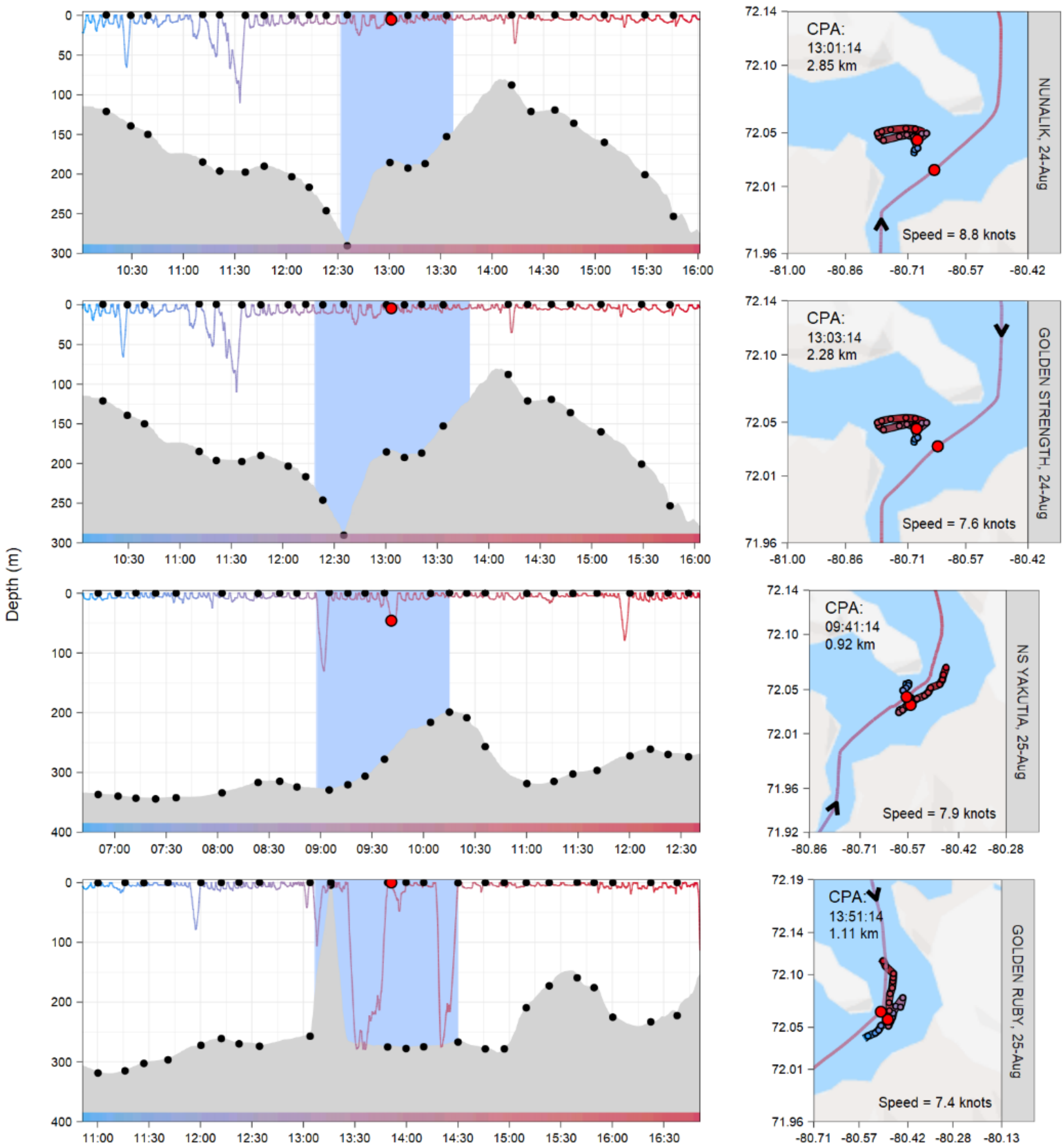

Figure 4-17: Movement and dive depths of NW01 relative to vessel transits 13-16. All vessels shown are Project-related

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 vessel.

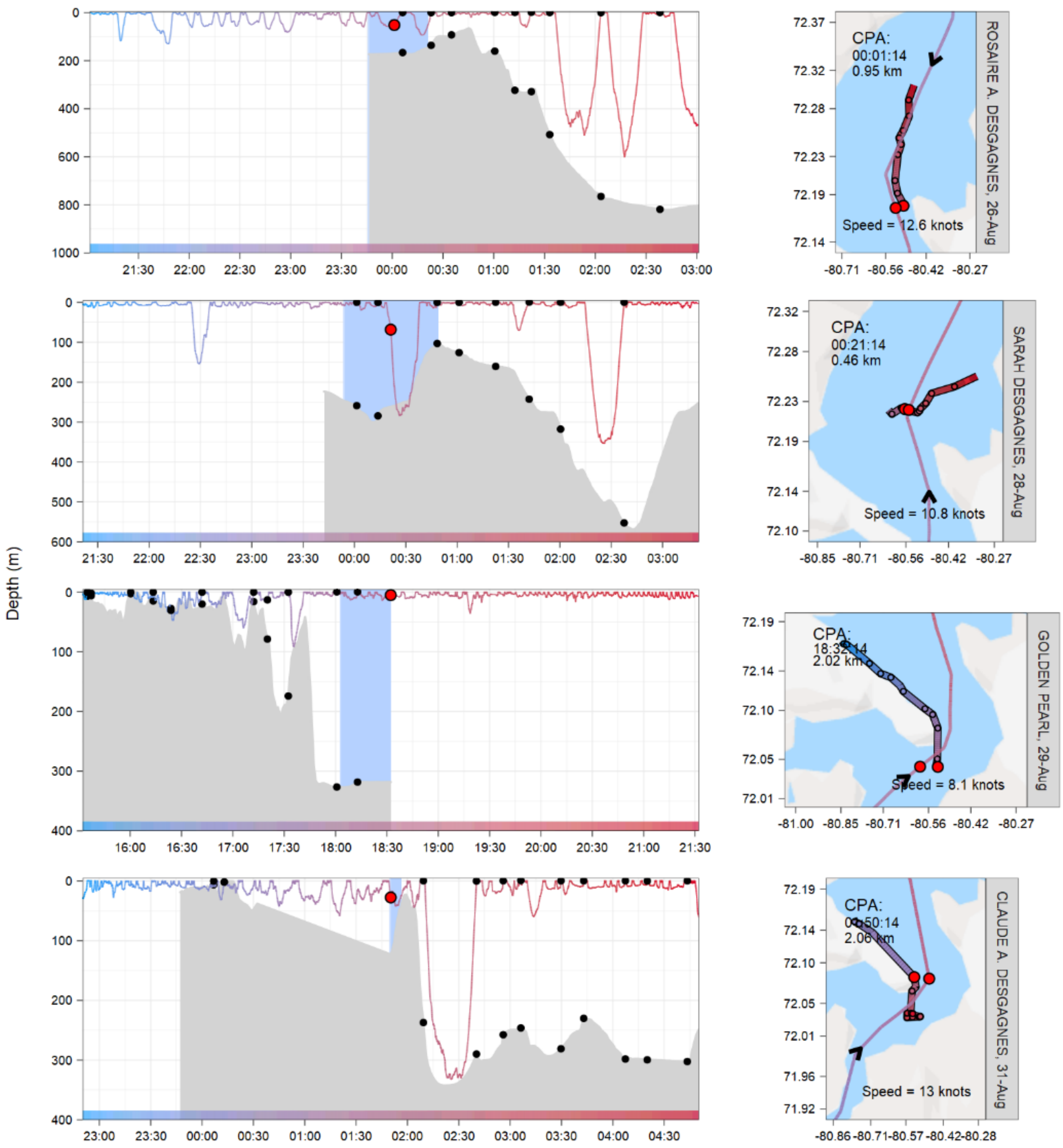

Figure 4-18: Movement and dive depths of NW01 relative to vessel transits 17-20. All vessels shown are Project-related

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 vessel.

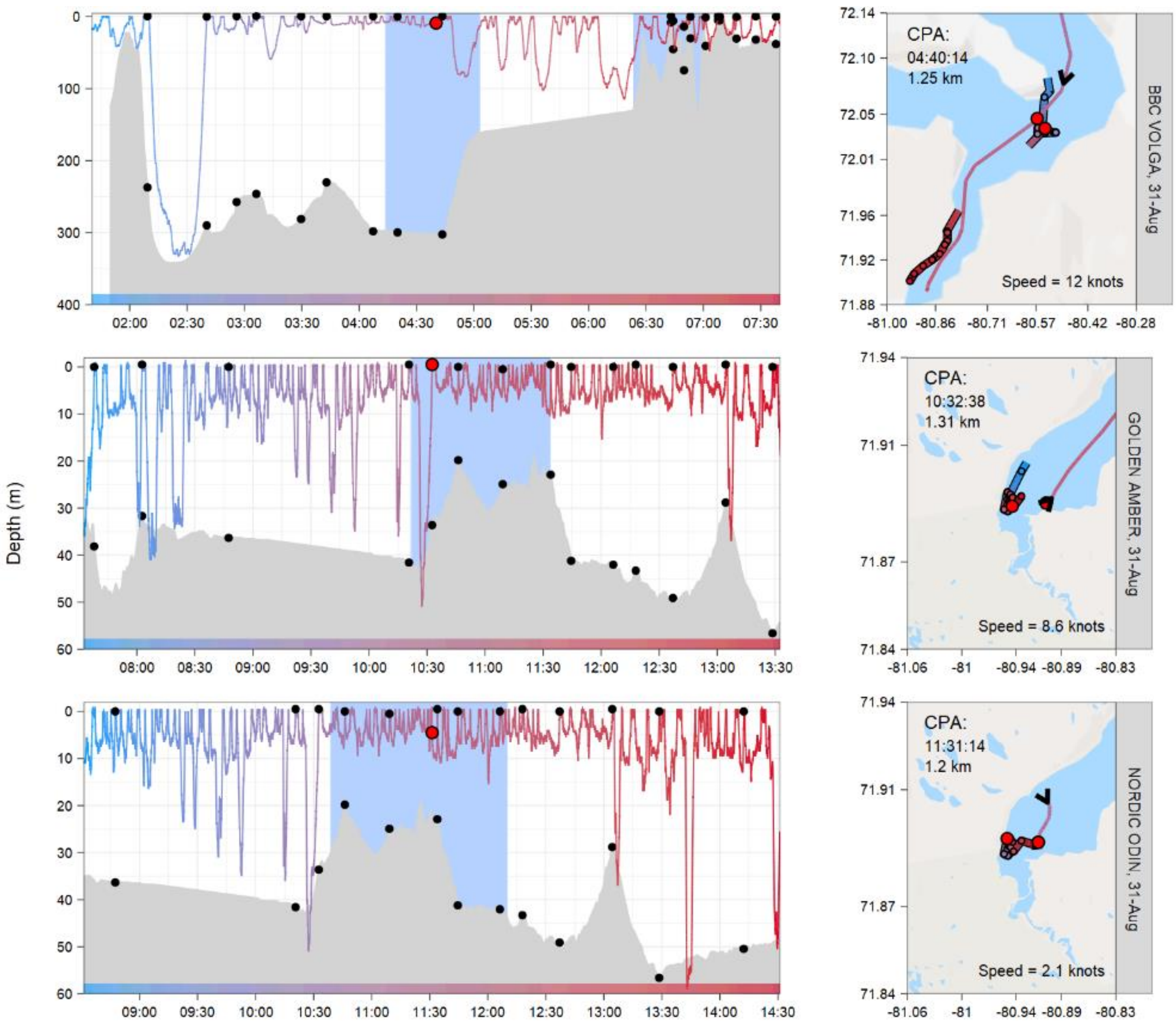

Figure 4-19: Movement and dive depths of NW01 relative to vessel transits 21-23. All vessels shown are Project-related

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 vessel.

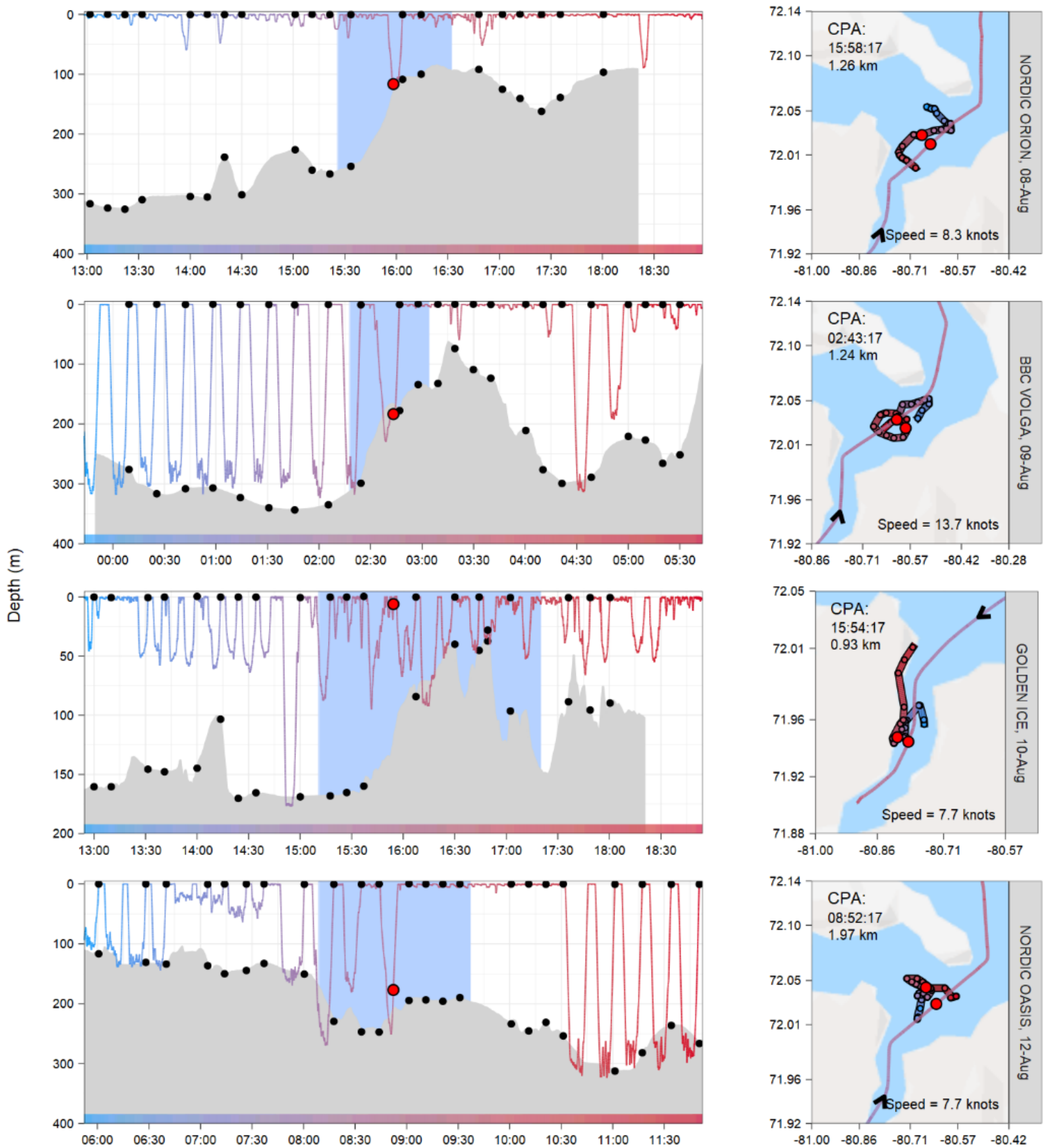

Figure 4-20: Movement and dive depths of NW02 relative to vessel transits 1-4. All vessels shown are Project-related

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 vessel.

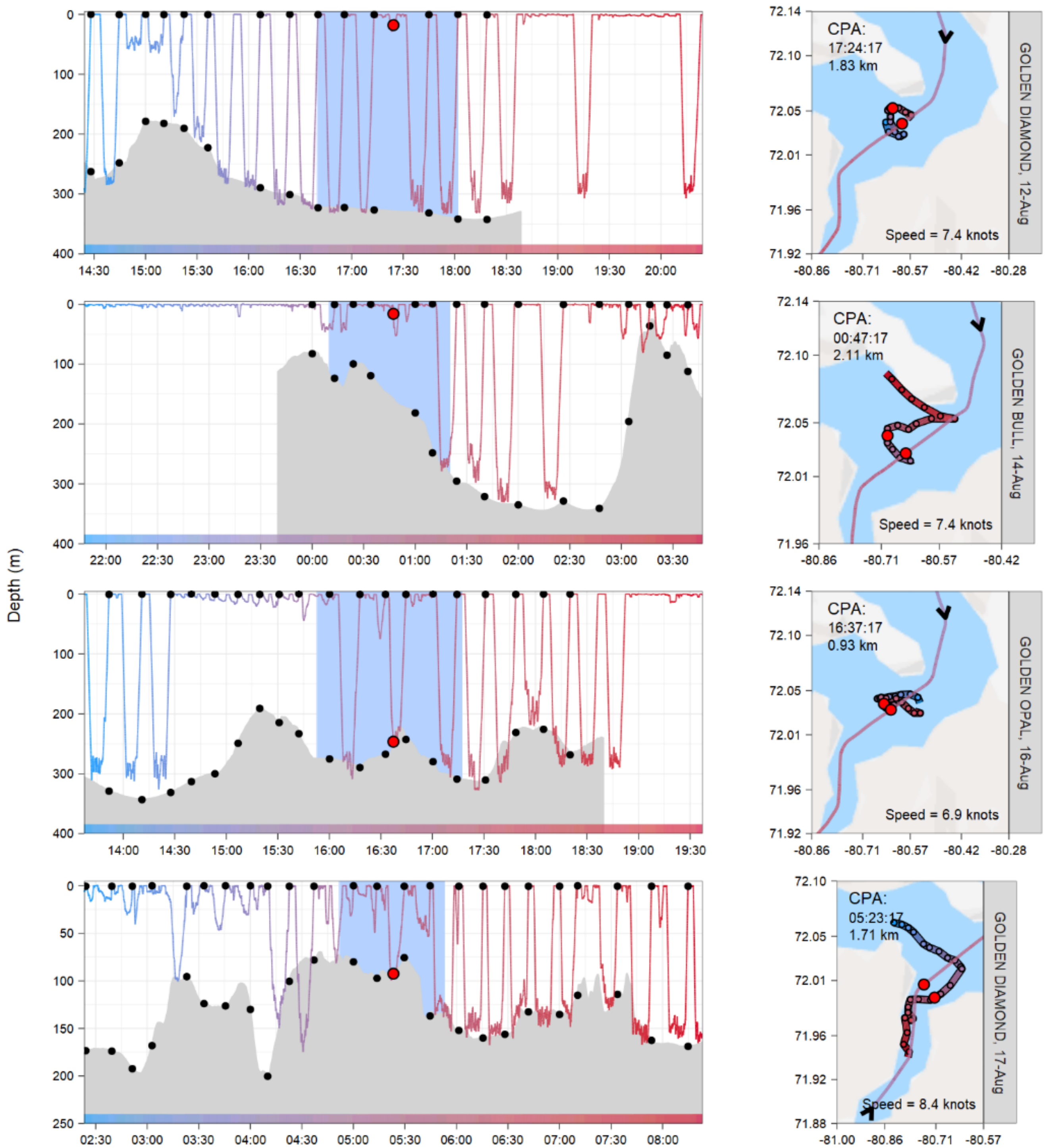

Figure 4-21: Movement and dive depths of NW02 relative to vessel transits 5-8. All vessels shown are Project-related

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 vessel.

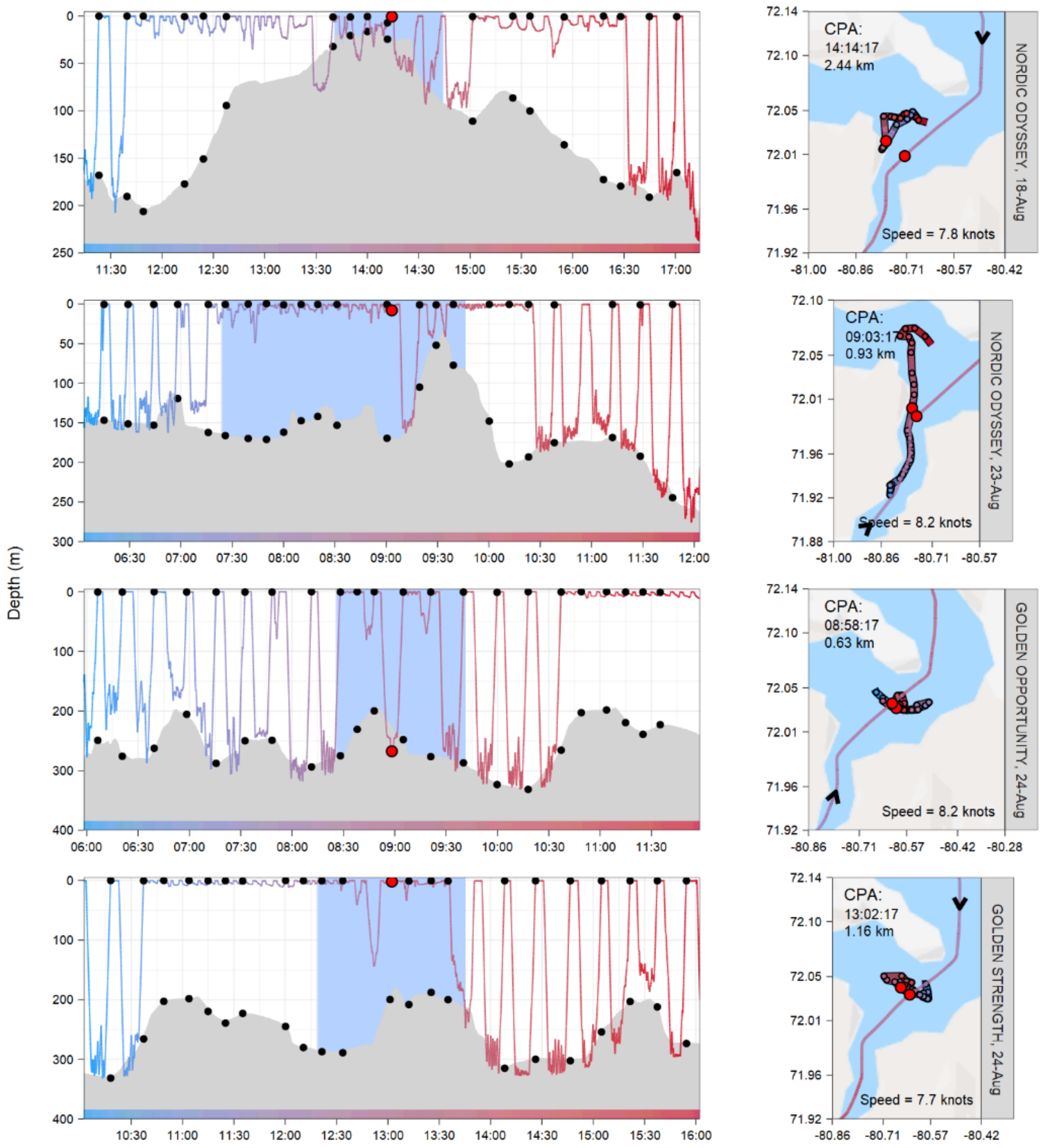

Figure 4-22: Movement and dive depths of NW02 relative to vessel transits 9-12. All vessels shown are Project-related

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 vessel.

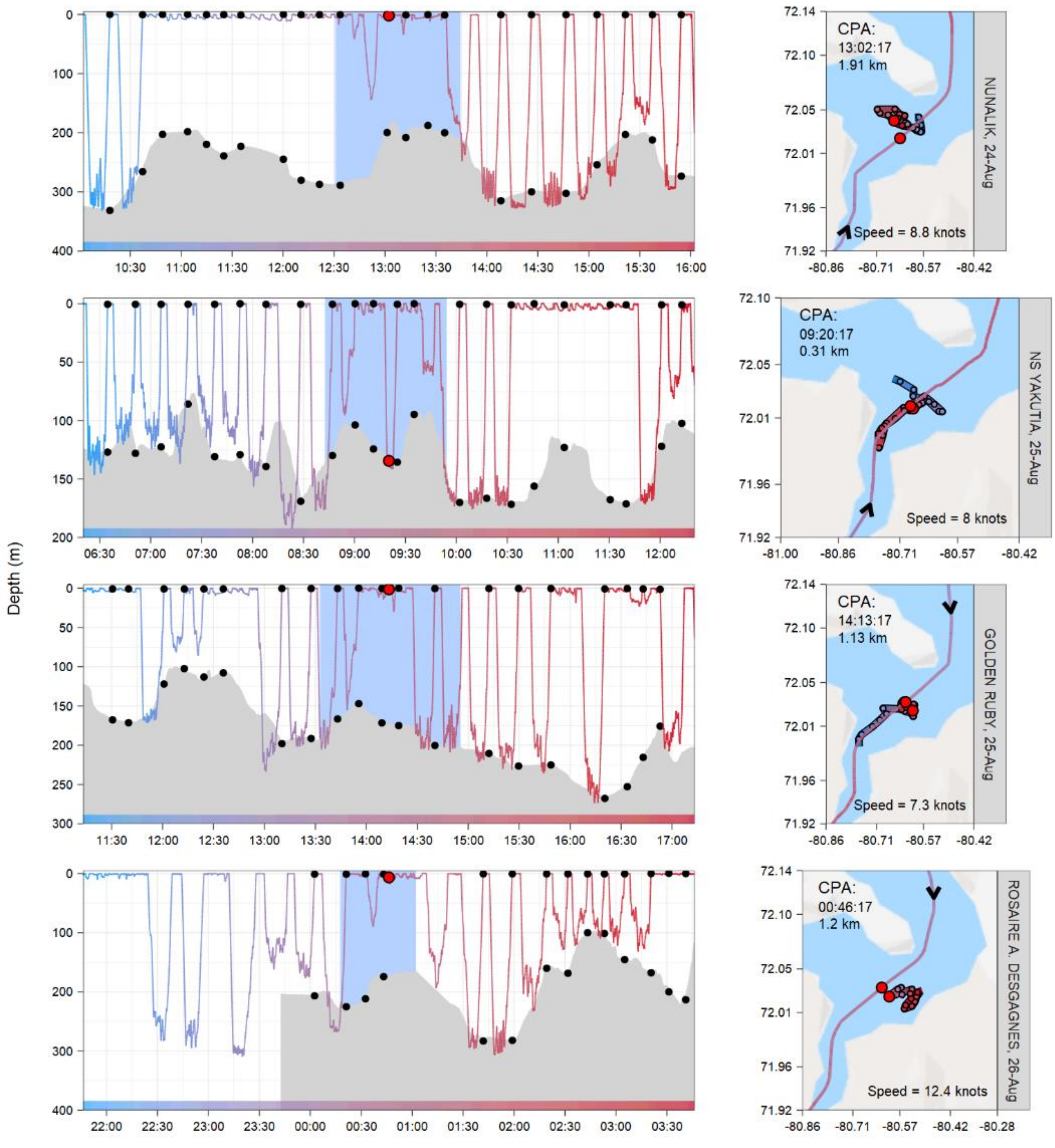

Figure 4-23: Movement and dive depths of NW02 relative to vessel transits 13-16. All vessels shown are Project-related

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 vessel.

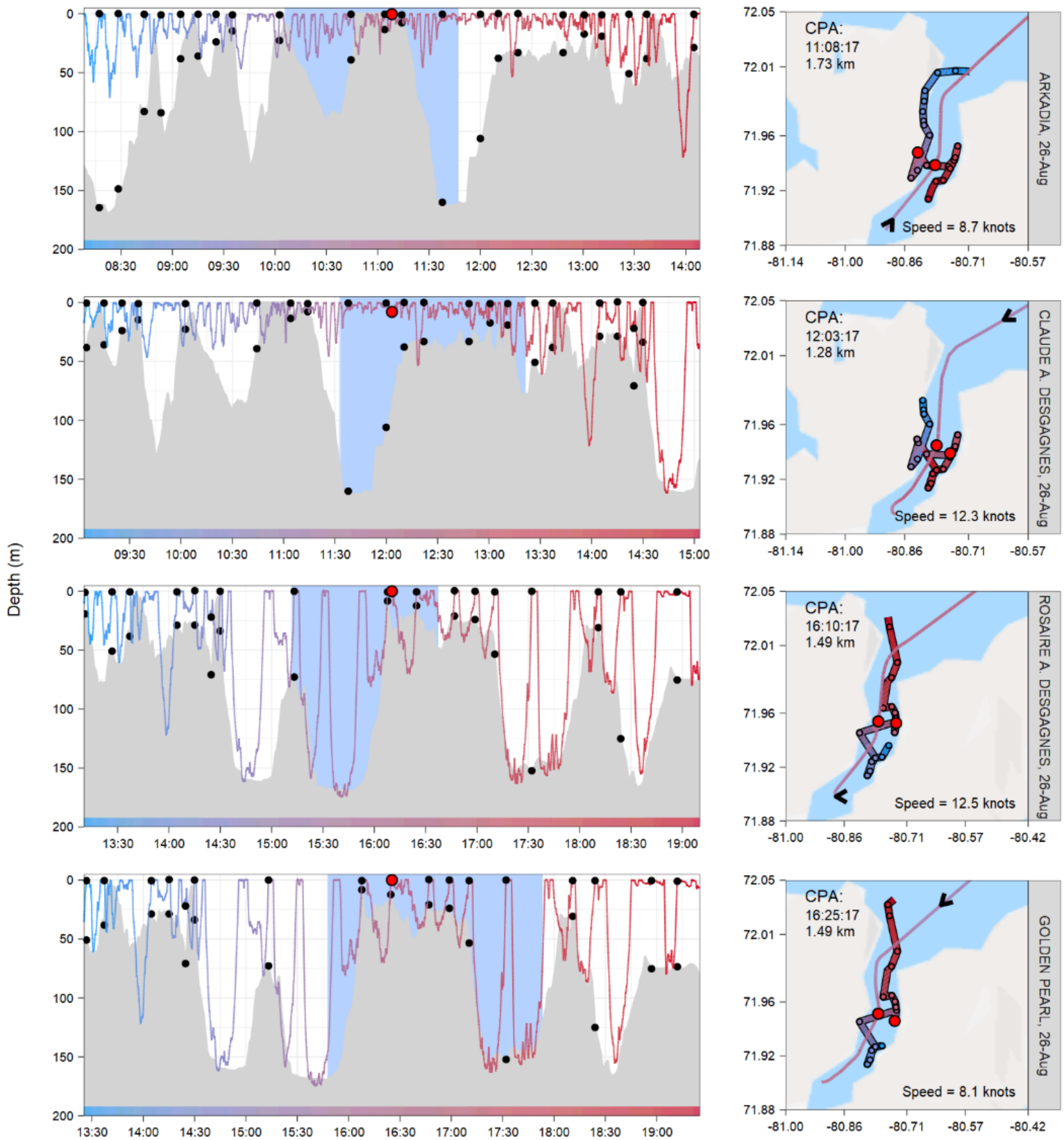

Figure 4-24: Movement and dive depths of NW02 relative to vessel transits 17-20. All vessels shown are Project-related

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 vessel.

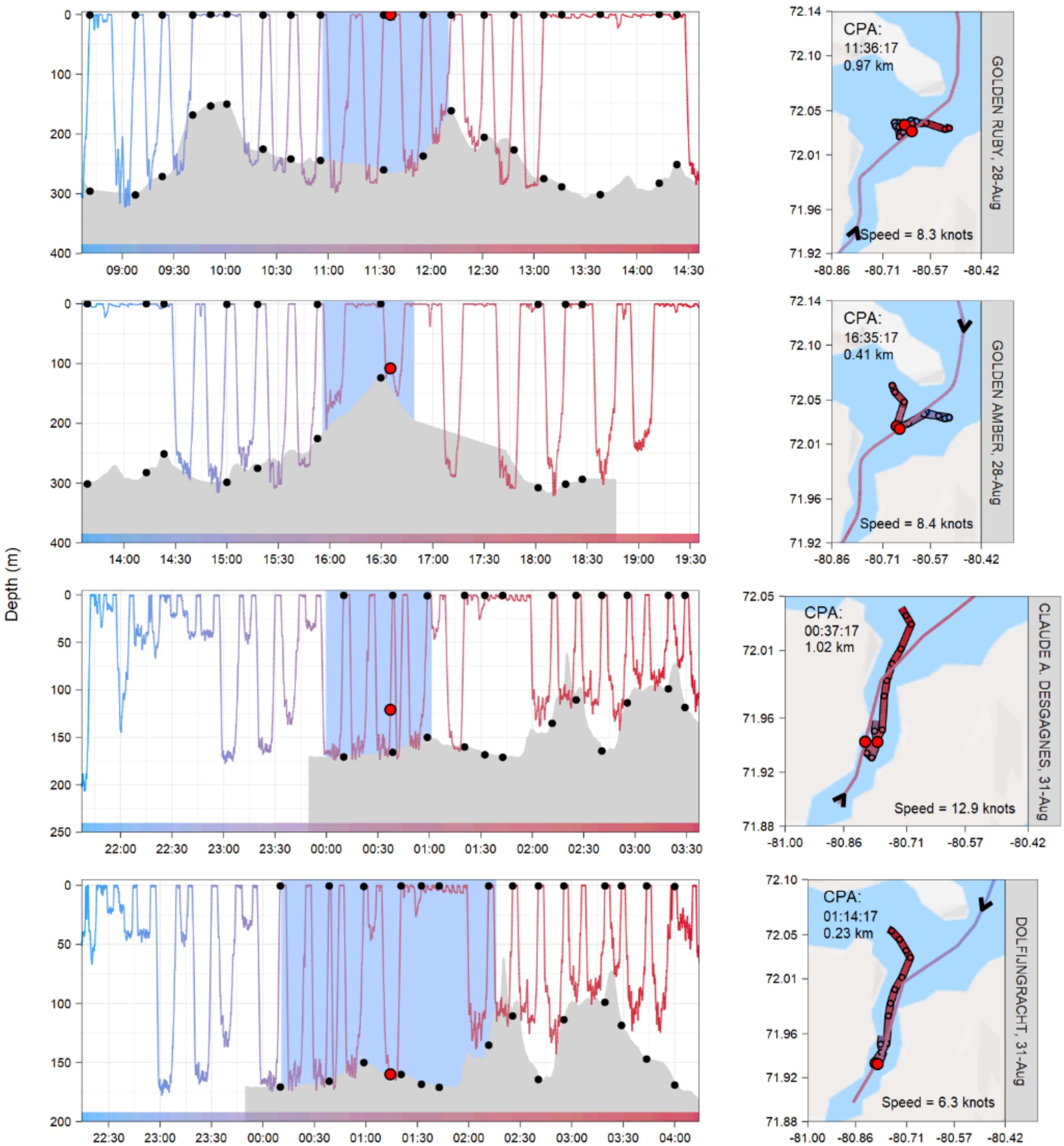

Figure 4-25: Movement and dive depths of NW02 relative to vessel transits 21- 24. All vessels shown are Project-related

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 vessel.

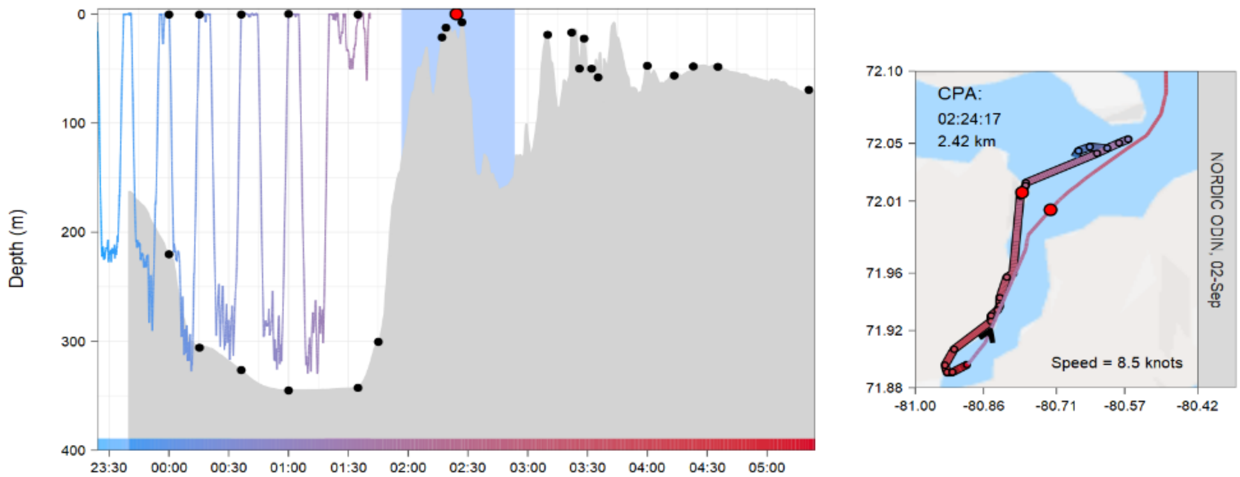

Figure 4-26: Movement and dive depths of NW02 relative to vessel transit 25. Vessel shown is Project-related

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 vessel.

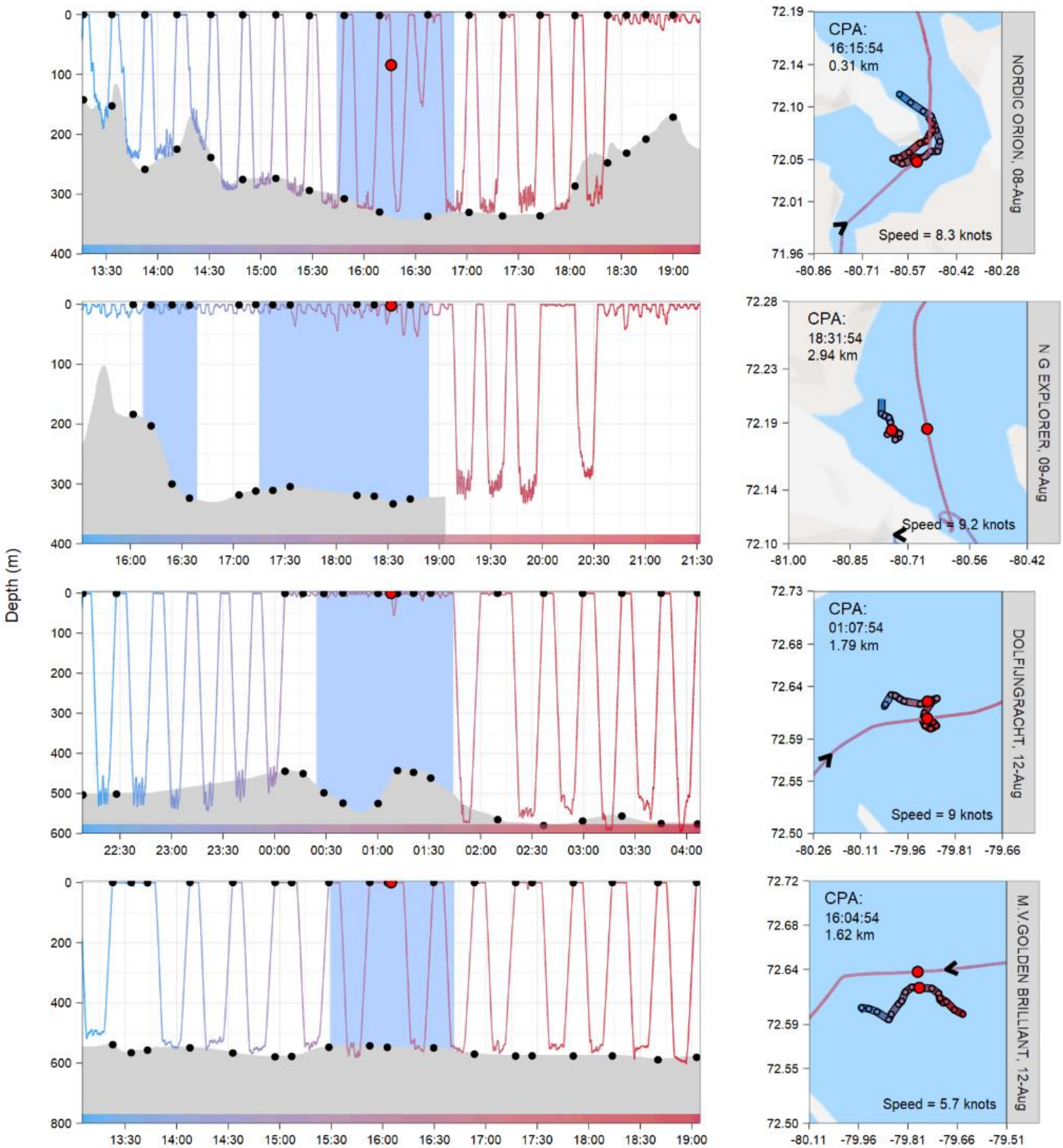

Figure 4-27: Movement and dive depths of NW03 relative to vessel transits 1-4. All vessels shown are Project-related, except the *NG Explorer*

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 vessel.

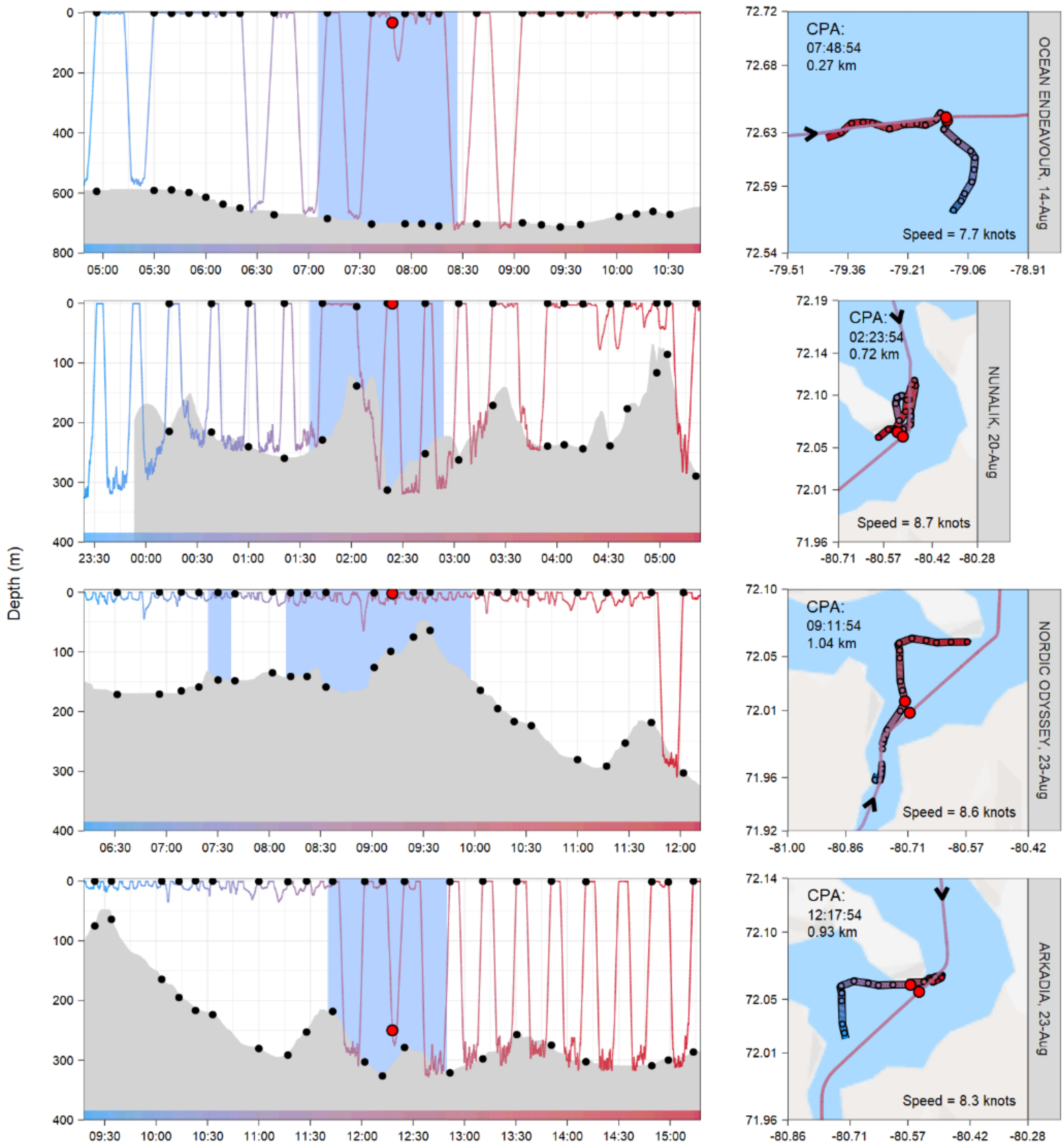

Figure 4-28: Movement and dive depths of NW03 relative to vessel transits 5-8. All vessels shown are Project-related, except the *Ocean Endeavor*

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 vessel.

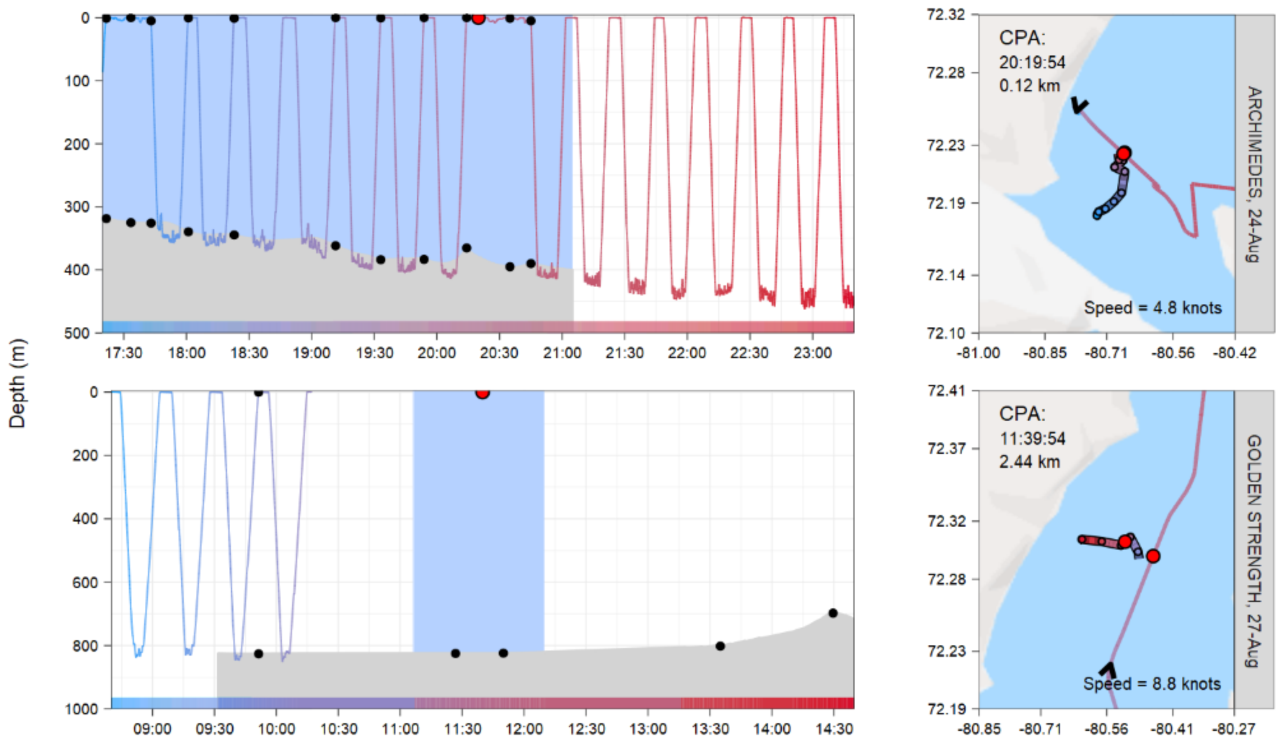

Figure 4-29: Movement and dive depths of NW03 relative to vessel transits 9-10. All vessels shown are Project-related, except the *Archimedes*

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 vessel.

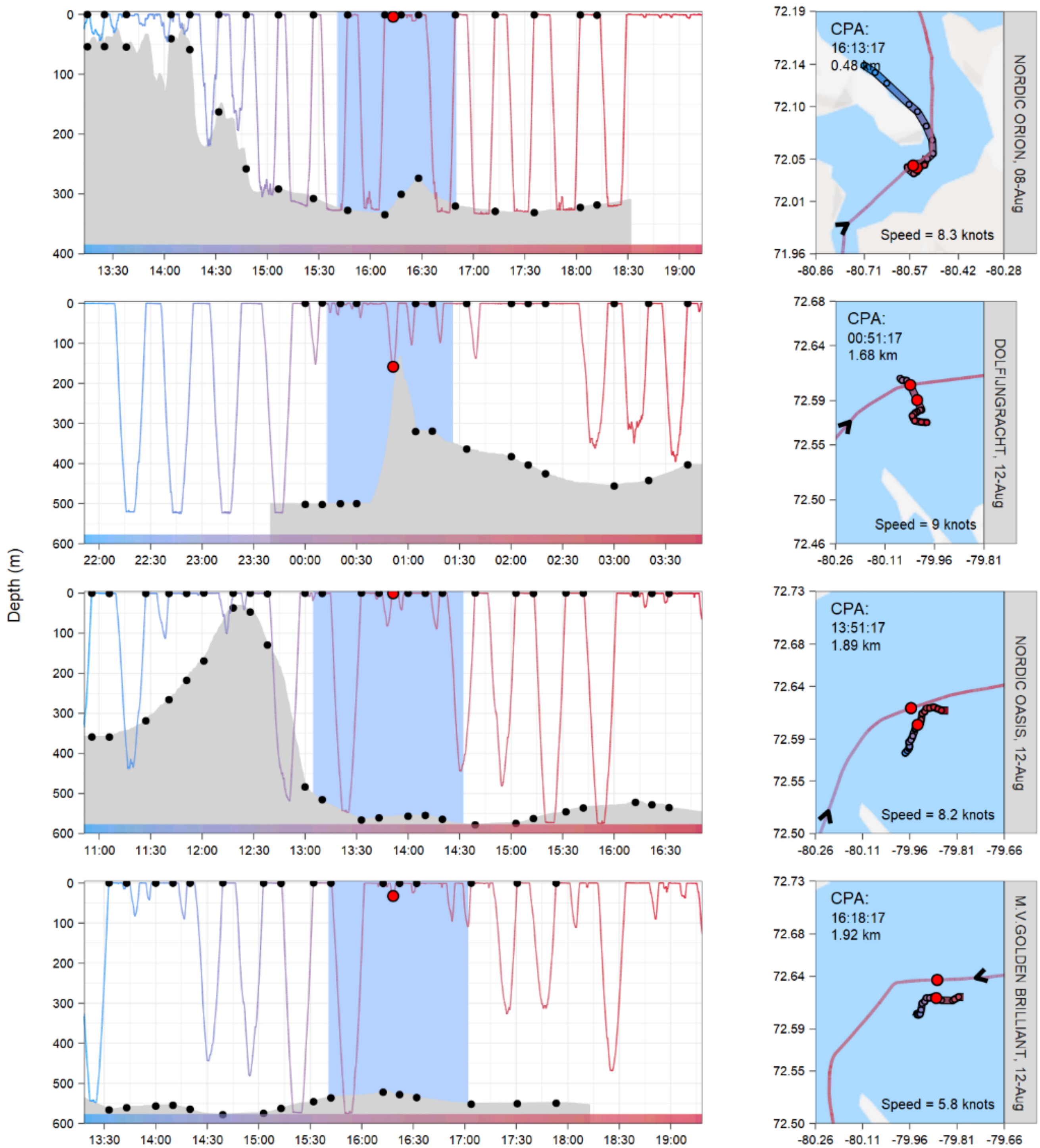

Figure 4-30: Movement and dive depths of NW04 relative to vessel transits 1-4. All vessels shown are Project-related

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 vessel.

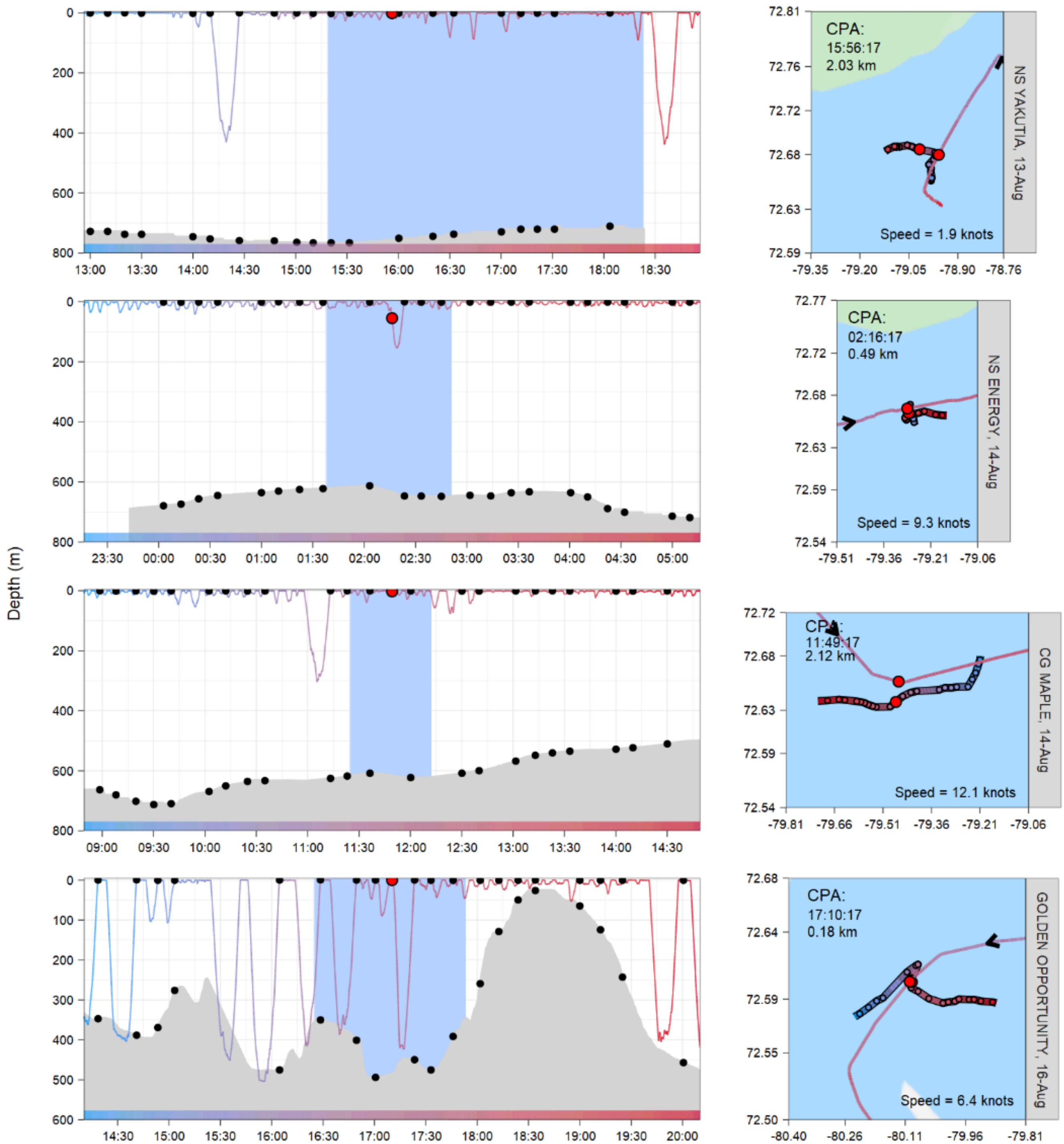

Figure 4-31: Movement and dive depths of NW04 relative to vessel transits 5-8. All vessels shown are Project-related, except the *CG Maple*

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 vessel. Note that land depicted as green is part of Sirmilik National Park.

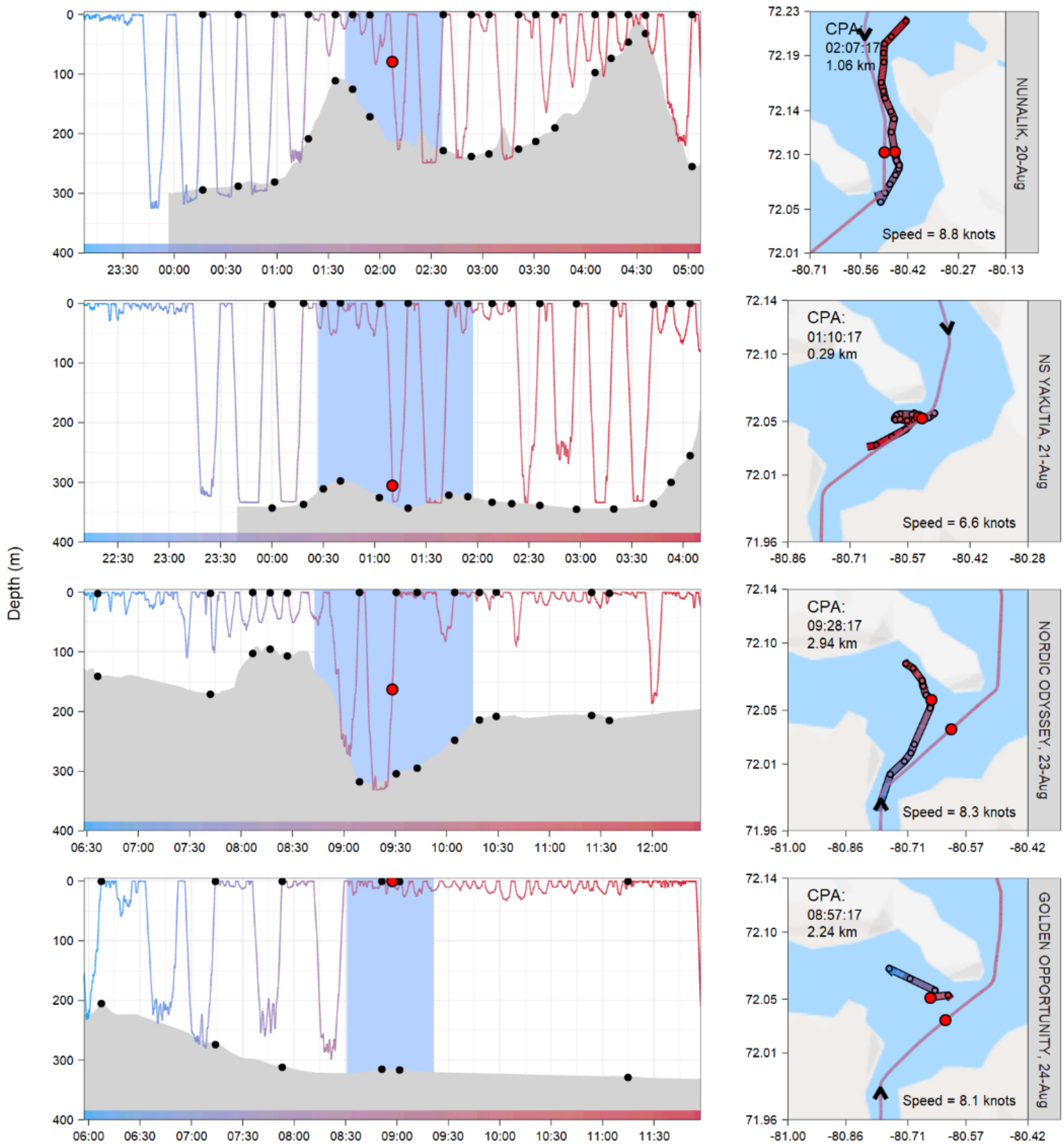

Figure 4-32: Movement and dive depths of NW04 relative to vessel transits 9-12. All vessels shown are Project-related

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 vessel.

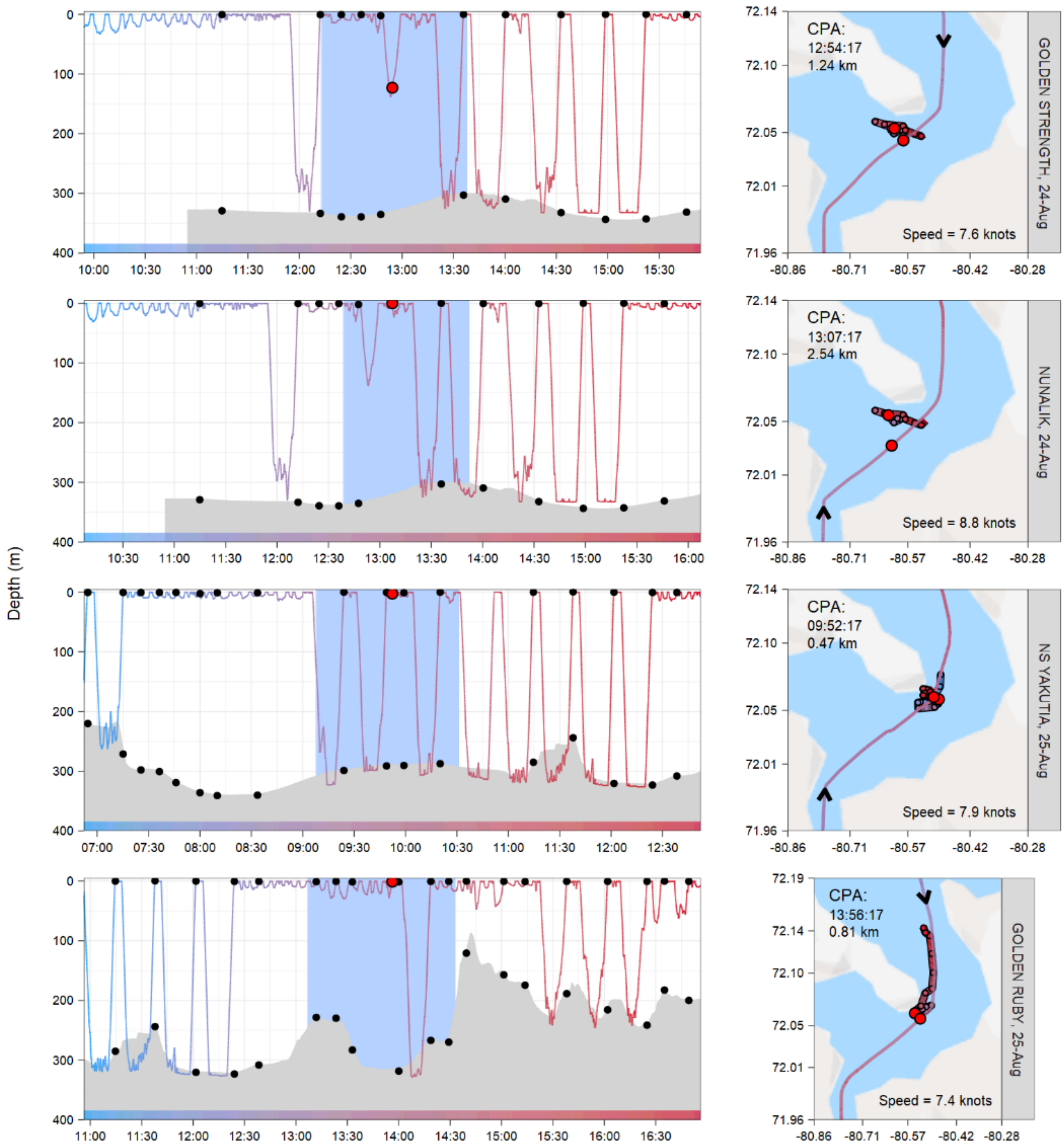

Figure 4-33: Movement and dive depths of NW04 relative to vessel transits 13-16. All vessels shown are Project-related

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 vessel.

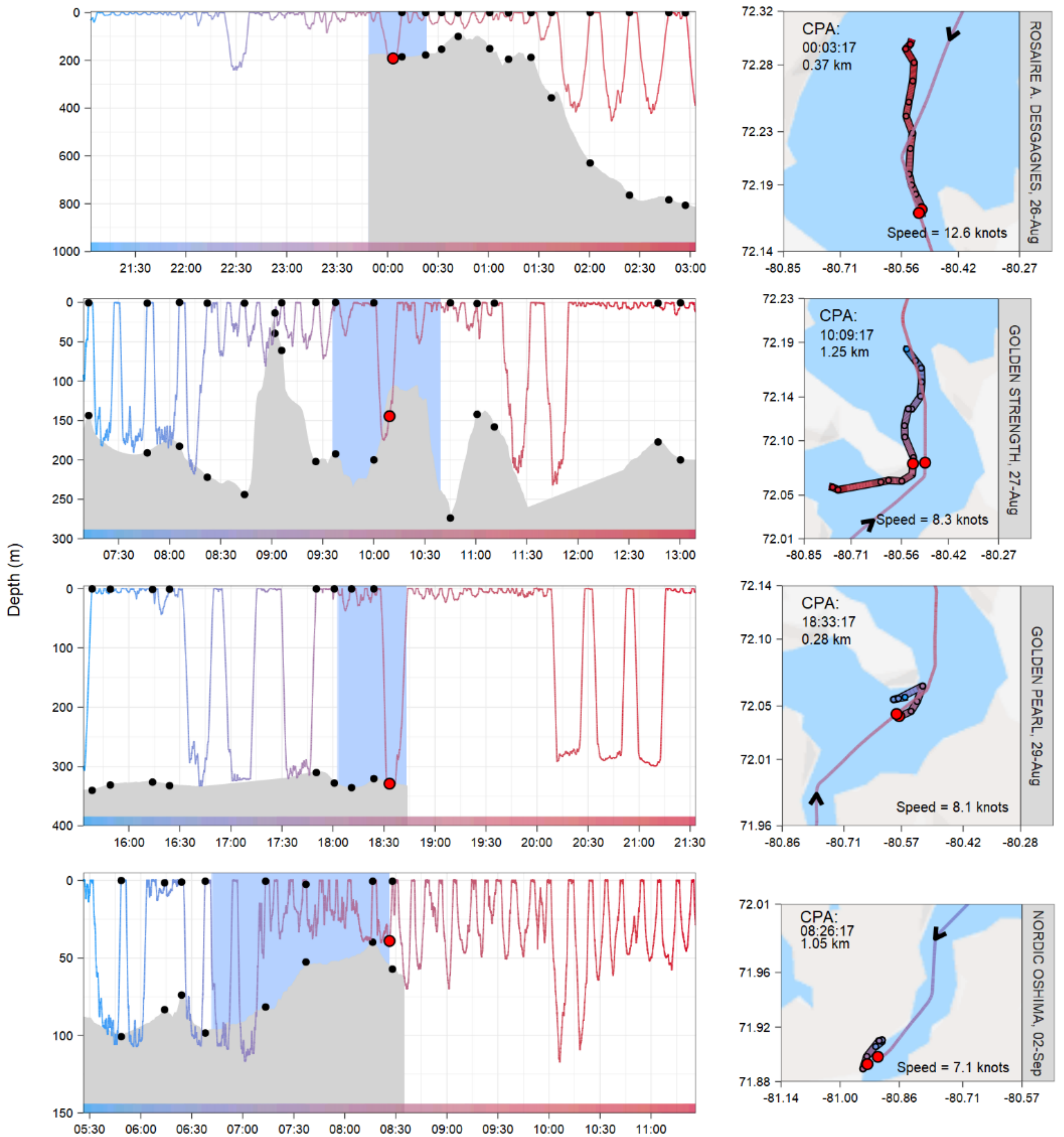

Figure 4-34: Movement and dive depths of NW04 relative to vessel transits 17-20. All vessels shown are Project-related

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 vessel.

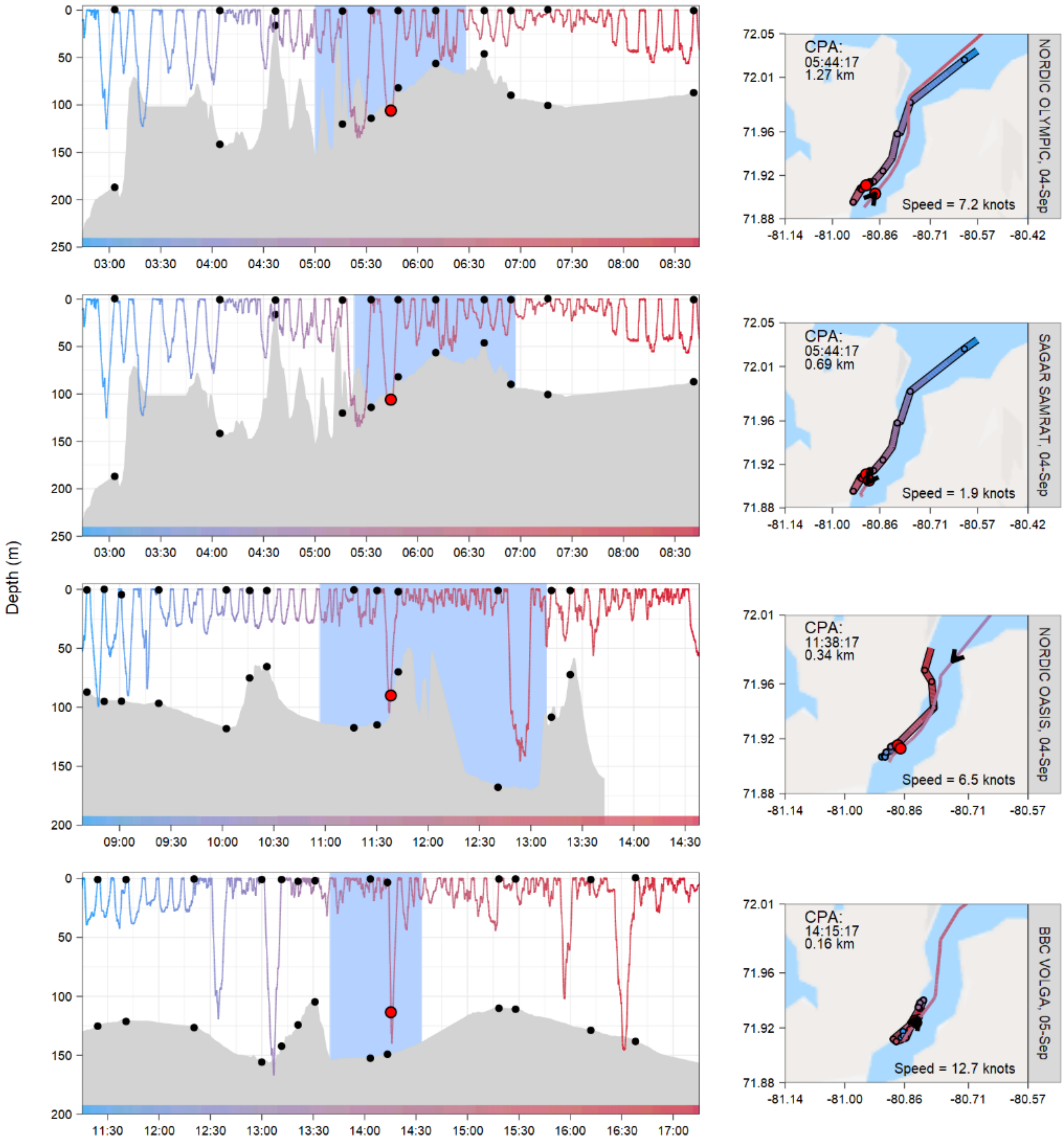

Figure 4-35: Movement and dive depths of NW04 relative to vessel transits 21-24. All vessels shown are Project-related

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 vessel.

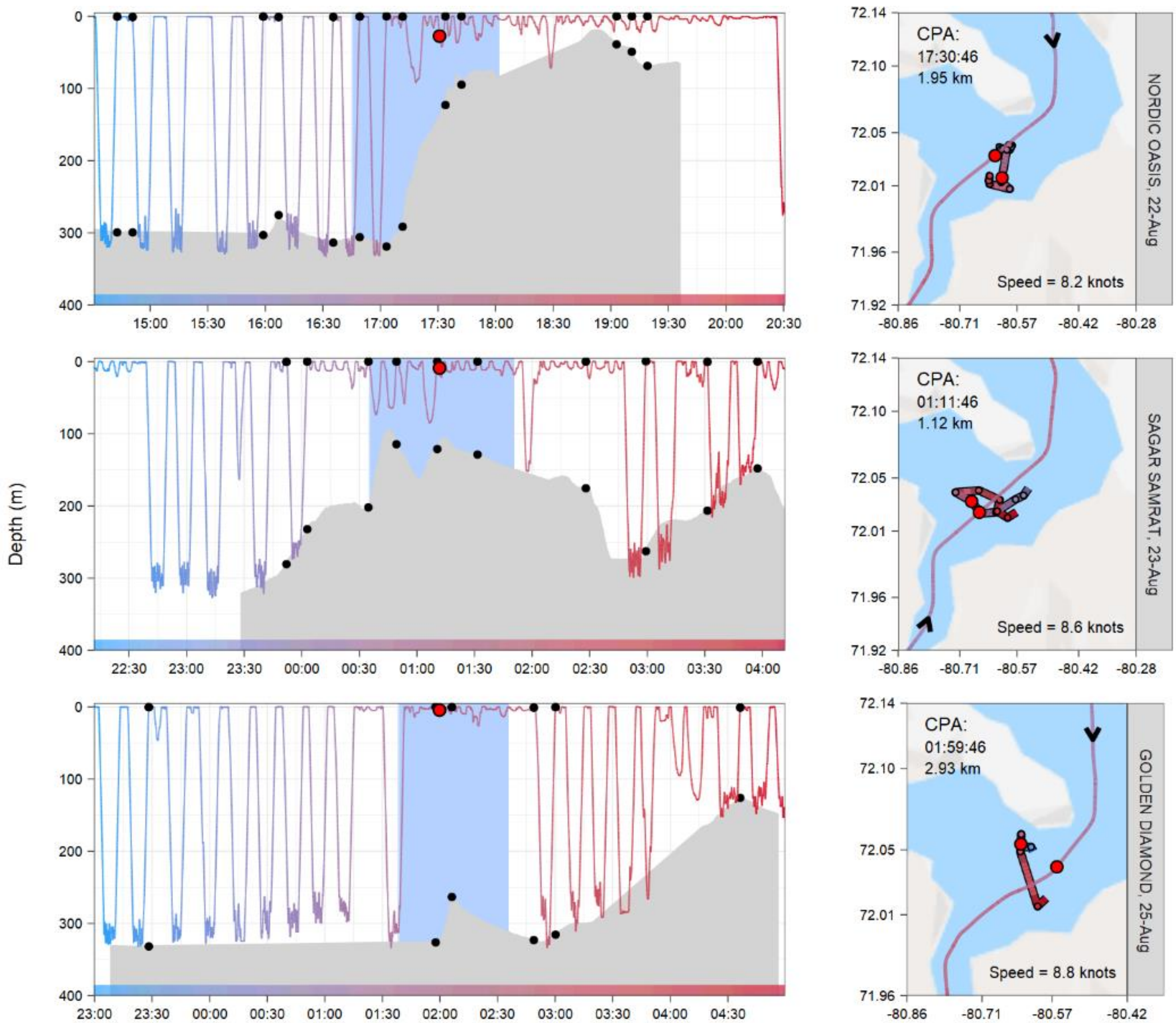

Figure 4-36: Movement and dive depths of NW21 relative to vessel transits 1-3. All vessels shown are Project-related

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 vessel.

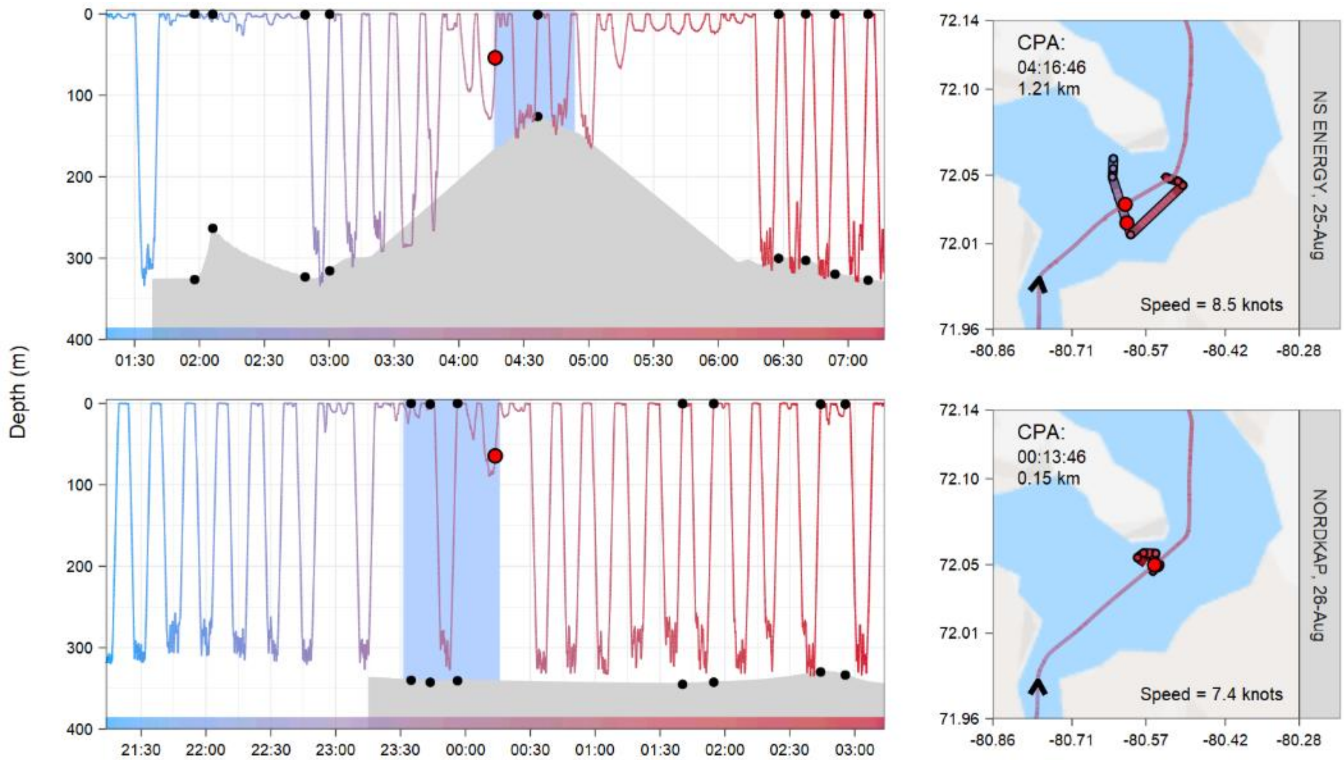

Figure 4-37: Movement and dive depths of NW21 relative to vessel transits 4-5. All vessels shown are Project-related

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 vessel.

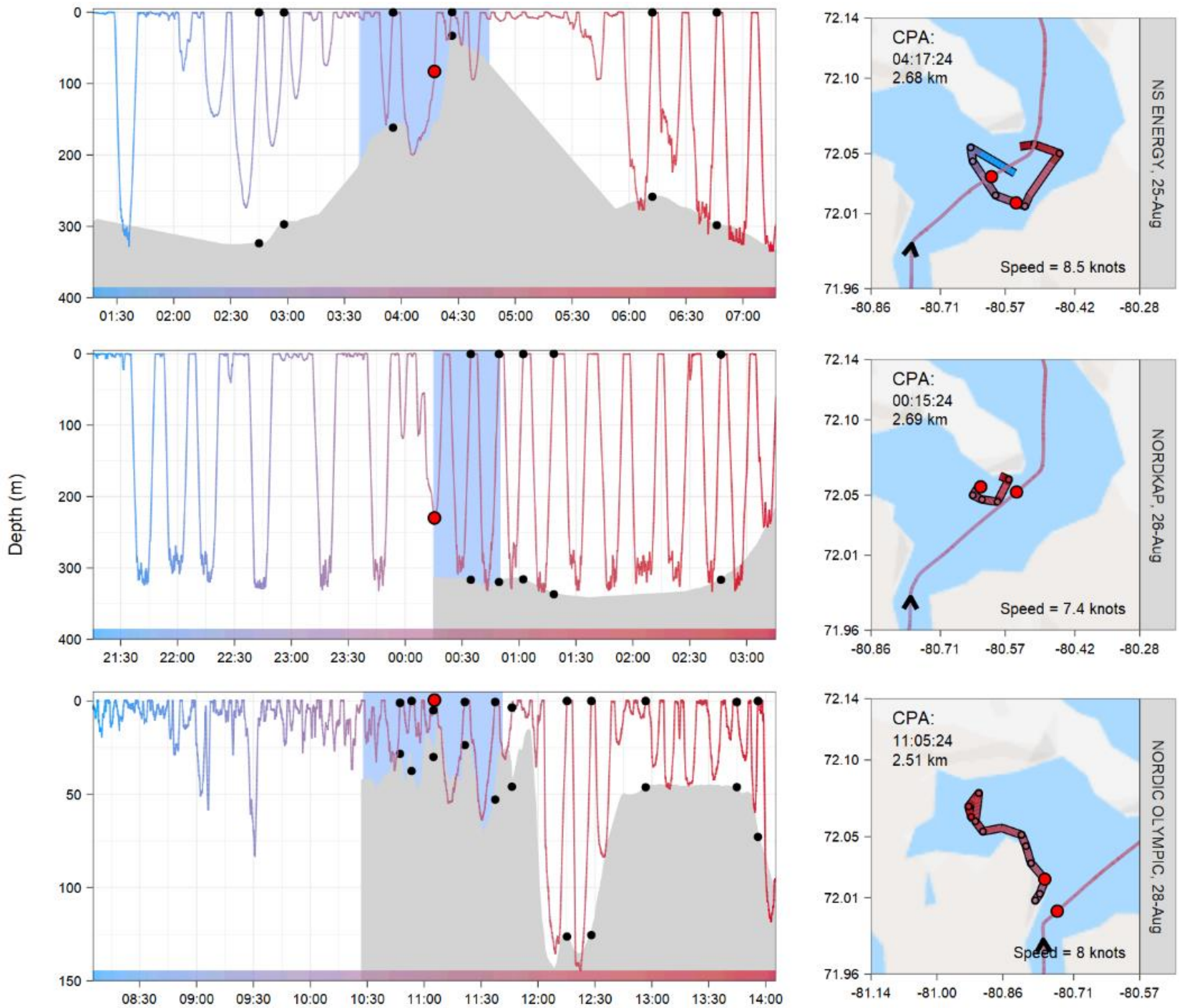

Figure 4-38: Movement and dive depths of NW22 relative to vessel transits 1-3. All vessels shown are Project-related

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 vessel.

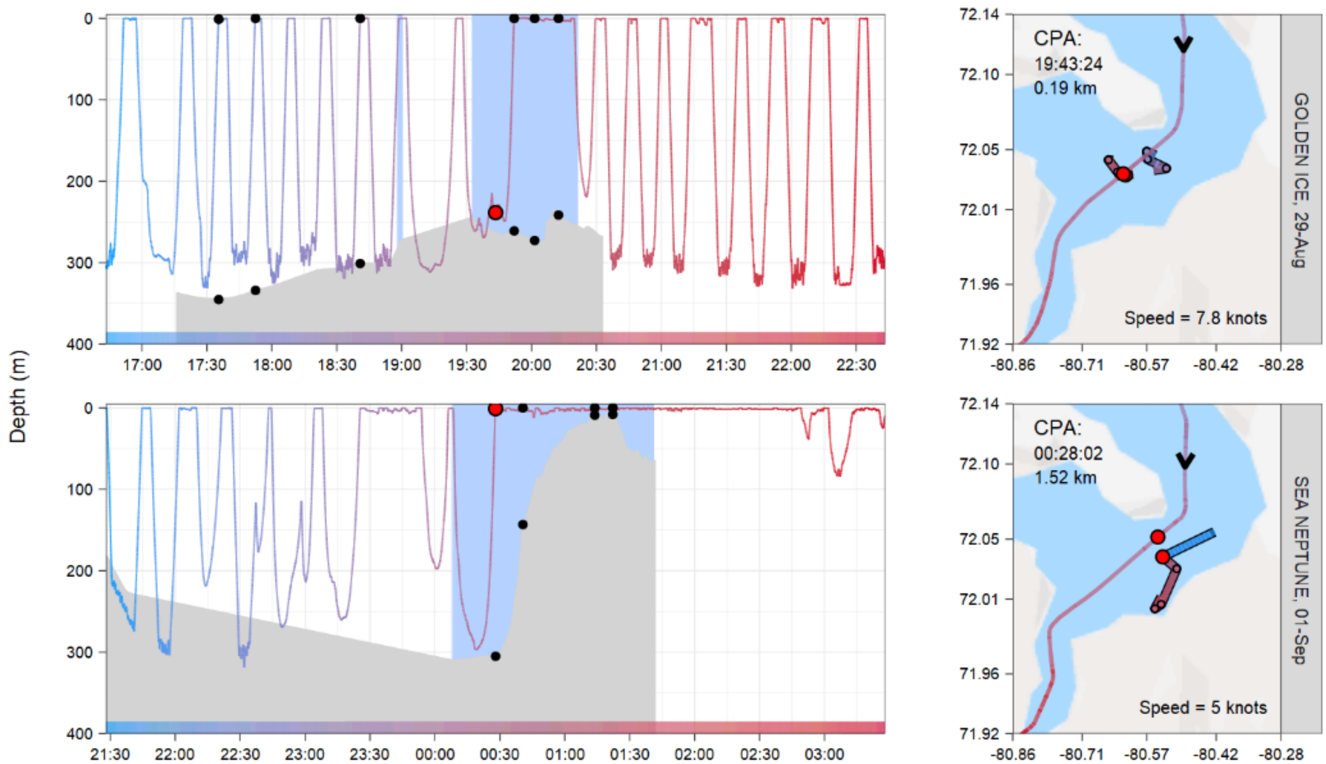

Figure 4-39: Movement and dive depths of NW22 relative to vessel transits 4-5. All vessels shown are Project-related

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 vessel.

4.2.2 Dive Behavior in Relation to Vessel Traffic

4.2.2.1 Surface Time

As mentioned previously, surface time was the only dive parameter in which additional tags were incorporated quantitatively into the analysis, beyond the six originally identified as meeting the specific criteria for inclusion. Of note, the surface time of 12 narwhal outfitted with MiniPAT and/or SPLASH10 tags was assessed. Of the 12 narwhal equipped with MiniPAT or SPLASH10 tags, no difference was observed in surface time between sexes, nor between MiniPAT and SPLASH10 tag types (Figure 4-40 and Table 4-6).

The proportion of time spent at the surface during exposure events was higher than during non-exposure events for most narwhal, but lower for NW01, NW13, and NW21. Exposure event data for NW05 and NW06 was not obtained as neither individual came within 10 km of a vessel during the time that they were tagged.

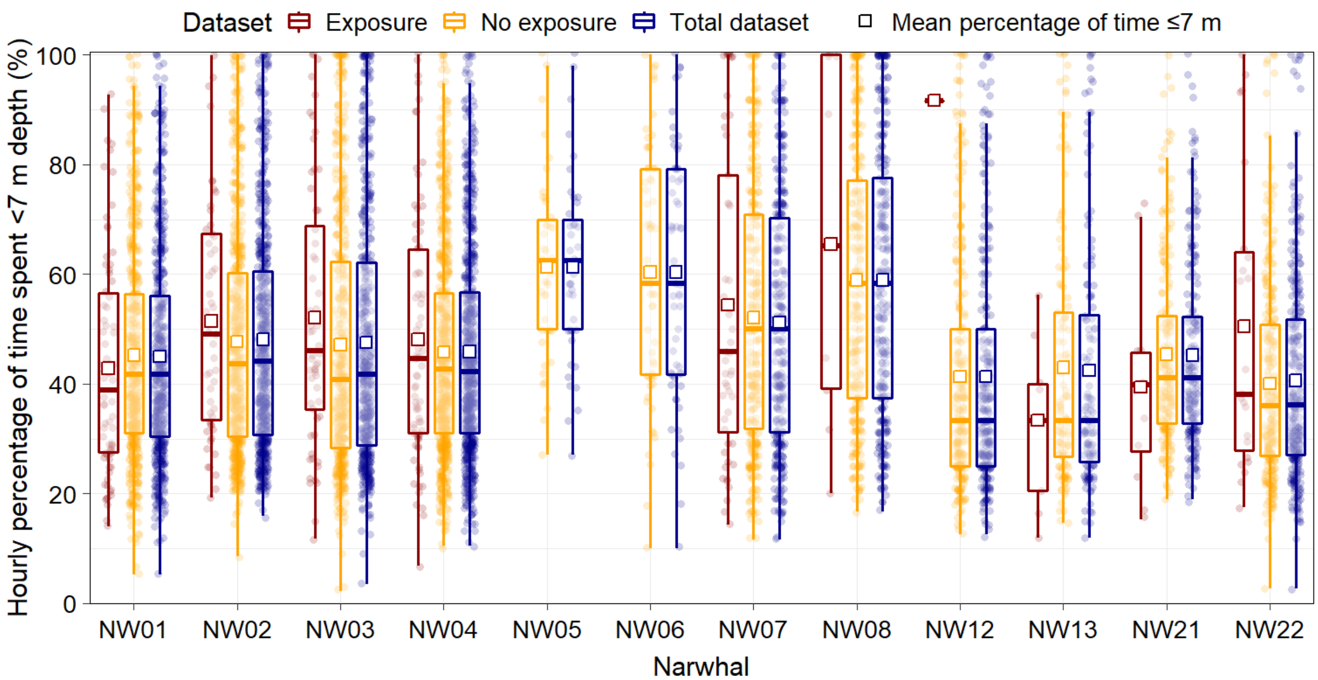

Figure 4-40: Observed proportion of time spent by narwhal at surface (0-7 m) under exposure, non-exposure, and in the total dataset.

Note: Summary statistics (minimum, maximum, and median) are provided in Table 4-6.

Table 4-6: Summary statistics of narwhal surface time (percent of time spent ≤7 m out of each hour)

Narwhal	Sex	Total dataset			Exposure Zone (≤10 km)			Non-exposure Zone (>10 km)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
NW01	M	5.29	41.7	100	13.9	38.9	92.7	5.29	41.8	100
NW02	F	15.9	44.1	100	19.2	49	100	8.6	43.7	100
NW03	F	3.42	41.7	100	11.8	46	100	2.28	40.7	100
NW04	M	10.4	42.2	100	6.77	44.6	100	10.4	42.7	100
NW05	M	27.1	62.5	100	n/a	n/a	n/a	27.1	62.5	100
NW06	M	10	58.3	100	n/a	n/a	n/a	10	58.3	100
NW07	M	11.6	50	100	14.3	45.8	100	11.6	50	100
NW08	F	16.7	58.3	100	20	65.2	100	16.7	58.3	100
NW12	F	12.5	33.3	100	91.7	91.7	91.7	12.5	33.3	100
NW13	M	12	33.3	100	12	33.3	56.2	14.6	33.3	100
NW21	F	18.9	41	99.9	15.3	39.7	72.8	18.9	41.1	99.9
NW22	F	2.74	36.1	100	17.6	38.1	100	2.74	36	100

The proportion of time that narwhal spent at the surface varied by individual and by location within the RSA (Figure 4-41). For example, both NW08 and NW12 spent time at Tremblay Sound, however NW08 spent more time than average at the surface, whereas NW12 was recorded diving, resulting in lower than average percent surface time. Surface time in Eclipse Sound was highly variable, with NW04 spending higher than average time at the surface, whereas NW01 and NW12 spent less than average time at the surface.

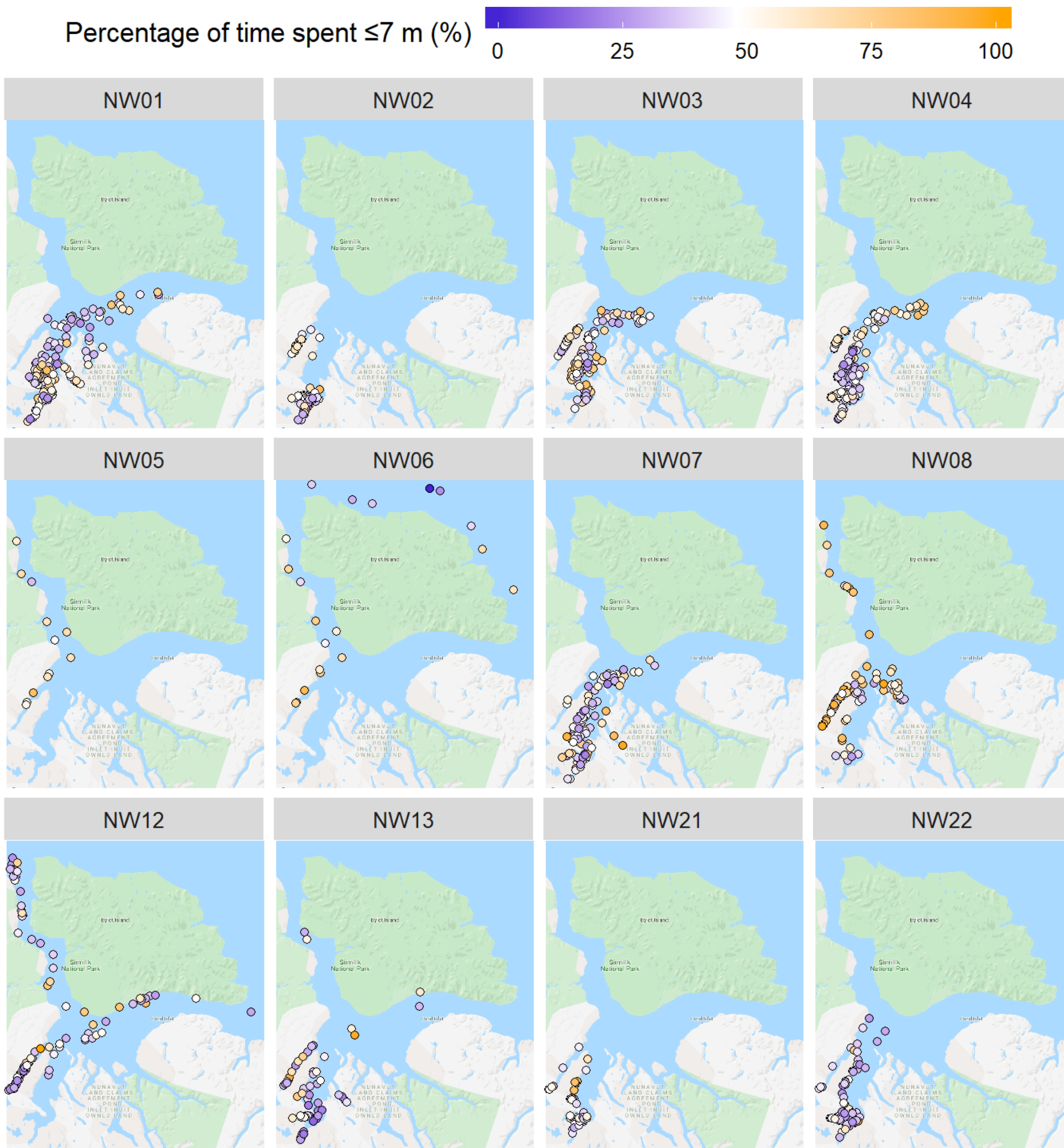

Figure 4-41: Percentage of time spent at 0-7 m depth, by tagged narwhal (averaged by 4 h time periods)

Note: Mean values across all animals shown in white.

Based on the smoothing trend curve (i.e., not accounting for any other pertinent variables), some directionality (i.e., difference in response to an approaching vessel and a vessel moving away) was noted when a narwhal was not previously at surface (Figure 4-42). On the other hand, the effect of vessel exposure with distance had no directionality when the narwhal was previously at surface. Overall, the relationship was subsequently modeled without directionality to maximize sample size in the near vicinity of vessels.

When no vessels were present within 10 km from the narwhal and the narwhal was previously deeper than 7 m, the smoothing trend curve suggested that mean percent time (averaged by narwhal tag) spent at surface ranged between 15% and 43% (Figure 4-42). When the narwhal was previously at surface, mean percent time during non-exposure ranged between 70% and 88%. Within the designated 10 km exposure zone, percent time spent at surface declined in close proximity to vessels, whether the vessel was approaching or moving away from the narwhal, however the response depended on whether the narwhal was previously at surface or deeper than 7 m.

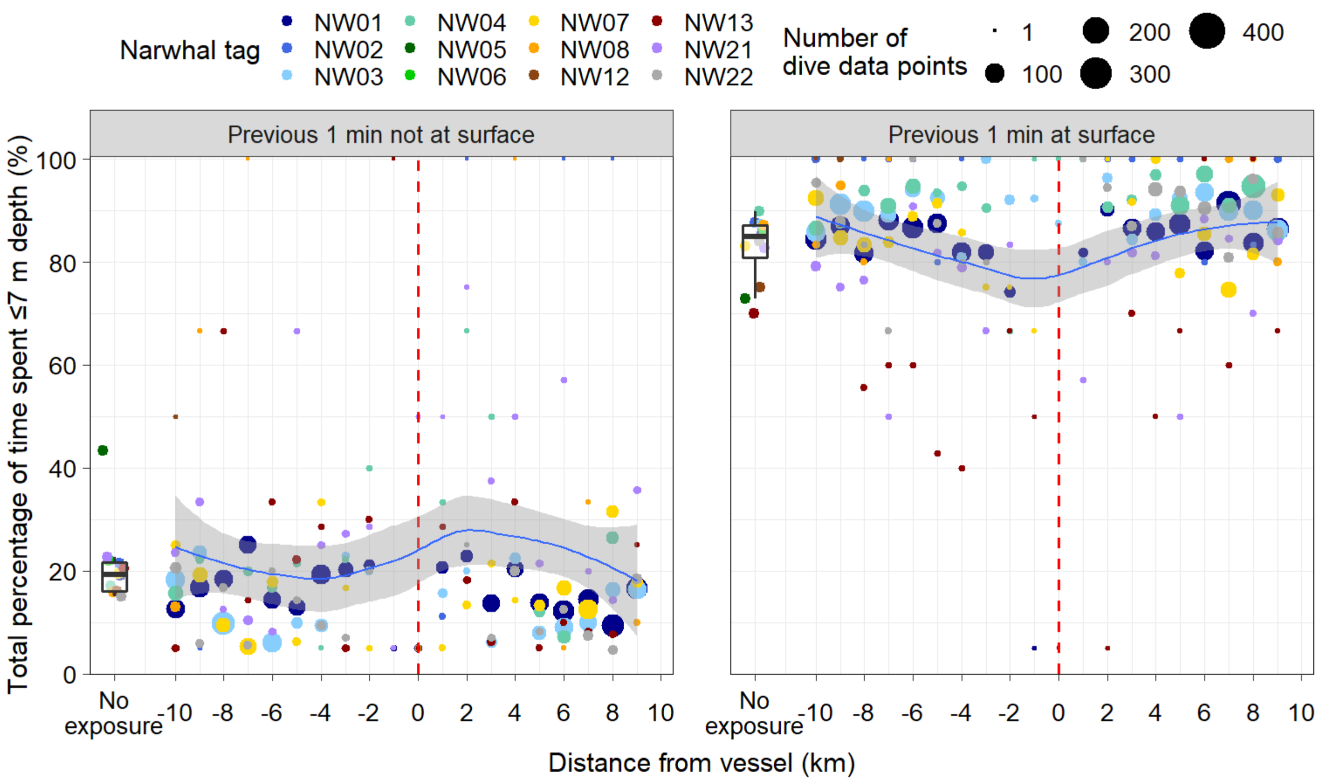

Figure 4-42: Percent time spent at surface (0-7 m depth) by tagged narwhal and as a function of distance from vessel (rounded to 1 km).

Note: Bubble size represents total amount of data available for each tag/distance combination (for exposure only). Boxplot is based on total percent time spent at 0-7 m by each narwhal when no vessels were present within 10 km from the narwhal. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

As stated in Section 3.5.2, the presence/absence of narwhal at surface (≤7 m) was analyzed using mixed effect 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 vessel), distance from vessel if present (3rd degree polynomial), whether the narwhal was at surface in the preceding 1 min period, the substratum, the tag type (MiniPAT or SPLASH10), and the period of time since the narwhal was last at surface (2nd degree polynomial). The random effect was a random intercept by narwhal tag.

The effect of substratum was statistically significant (*P*<0.001), as were the effects of whether the narwhal was at surface in the previous 1 min period (*P*<0.001) and the effect of cumulative period of time since last surfacing (*P*<0.001). The effect of tag type (SPLASH10 vs. MiniPAT) was not significant (*P*=0.3). The effect of distance from a vessel was statistically significant (*P*=0.021), while the overall effect of exposure was not (*P*=0.8). This result was due to the fact that the effect of exposure was only evident at close distances (<2 km; Figure 4-43), 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 0.453 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.457. That is, the model explained approximately 45% of the variability in surfacing probability, and the random effects did not account for much of the explained variability. Test statistics and coefficient estimates for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -13% or a +14% effect size in the test of the overall effect of distance from vessel (Appendix C).

The estimated population-level probability of narwhal presence at surface when no vessels were present within 10 km was 0.144 when the narwhal was not at the surface during the previous 1 min, and 0.850 when the narwhal was previously at the surface. These results were not significantly different from probabilities predicted when vessels were within 2-10 km from narwhal (*P*≥0.3 for all distances; Table 4-7). At a distance of 1 km, the population-level prediction of probability of narwhal presence at the surface decreased to 0.113 and 0.811 when the individual was previously deeper than 7 m and at the surface, respectively. These findings were marginally significantly different from predictions when no vessel was present within 10 km (*P*=0.059). At distance of 0 km, the population-level prediction of probability of narwhal presence at the surface decreased further to 0.083 and 0.752 when the individual was previously deeper than 7 m and at the surface, respectively. These findings were significantly different from predictions when no vessel was present within 10 km (*P*=0.020). The test had sufficient power (>0.8) to detect a distance-specific effect size of -40% or +35%; in comparison, the largest absolute magnitude of the observed effect was 46% (Appendix C).

The probability of being at the surface decreased with increasing time since last surfacing event, for periods up to 8 min since last surfacing event (Figure 4-43). The probability of being at the surface then increased, reaching close to 1.0 at 30 min since the last surfacing event. Surface time was significantly different between the substrata, regardless of vessel presence. Specifically, Koluktoo Bay and Tremblay Sound had significantly higher probabilities of narwhal being at the surface than Milne Inlet North or Milne Inlet South (Figure 4-43). Milne Inlet North had the lowest mean probability of narwhal being at the surface than any of the other substrata.

In summary, the 2017-2018 integrated dive data support rejection of the null hypothesis (**$H1_0$**) that surface time does not significantly change during vessel exposure events. The effect was only evident within 1 km from the vessels, where the probability of narwhal presence at surface decreased 5-22% at a vessel distance of 1 km and 12-42% at a distance of 0 km (depending on surface presence 1 min prior). **Considering the prediction that narwhal exposed to vessel traffic may respond by either increasing their time at the surface (i.e., freezing) or decreasing their time at the surface (i.e., avoidance), these results suggest that narwhal exhibit a potential avoidance response at close distances (<1 km) to a transiting vessel.**

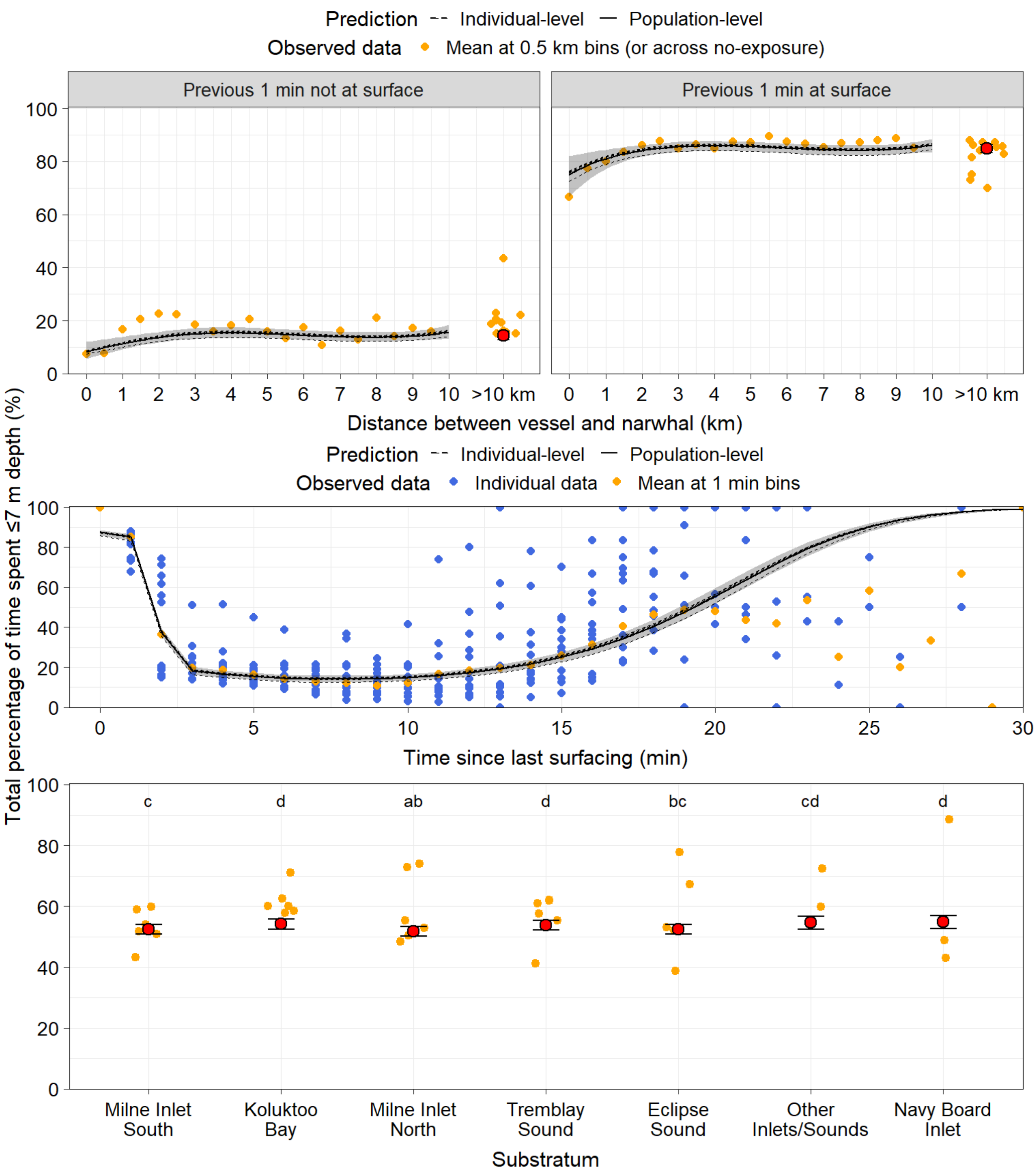

Figure 4-43: Percent surface time (time spent at depths ≤7 m) relative to distance from vessels in transit (based on whether narwhal was previously at surface or not), time since the last 1 min surfacing event, and substratum

Note: Black lines and red points represent population-level model predictions; error bars and ribbons represent the 95% confidence intervals associated with population-level predictions. Regions with different letters are significantly different from each other.

Table 4-7: Multiple comparisons of predictions of narwhal surfacing under non-exposure and incremental exposure distances from vessel (statistically significant values shown in bold)

Distance from Vessel (km)	Multiple Comparisons to Non-exposure – Least-squares Means with *P* values in Brackets	
	Preceding 1 min at Surface	Preceding 1 min not at Surface
0	**0.752 (0.020)**	**0.083 (0.020)**
1	0.811 (0.059)	0.113 (0.059)
2	0.841 (0.825)	0.136 (0.825)
3	0.855 (0.908)	0.15 (0.908)
4	0.859 (0.501)	0.153 (0.501)
5	0.856 (0.685)	0.150 (0.685)
6	0.850 (1.000)	0.145 (1.000)
7	0.844 (0.840)	0.139 (0.84)
8	0.842 (0.565)	0.137 (0.565)
9	0.847 (0.991)	0.142 (0.991)
10	0.862 (0.763)	0.157 (0.763)

4.2.2.2 Dive Rate

No clear difference in dive rate (number of dives per hour) was evident between male and female narwhal (Figure 4-44; Table 4-8). NW01, NW04, and NW21 generally had the highest median dive rates overall, while NW5 also had a high median dive rate during non-exposure only. Average dive rates observed during exposure events compared to non-exposure events were lower for some narwhal (NW02, NW07, NW08, NW13, NW21) and lower for others (NW01, NW03, NW04, NW22; Figure 4-45).

Narwhal equipped with SPLASH10 tags generally had lower dive rates than individuals equipped with MiniPAT tags, due to the DiveBomb algorithm missing dives in the lower-resolution SPLASH10 data, as detailed in Section 4.1.3. Results presented in Figure 4-45 must therefore be interpreted with caution as the six narwhal outfitted with MiniPAT tags (i.e., NW01, NW02, NW03, NW04, NW21, and NW22) show higher maximum dive rates compared to other individuals, which is likely the result of higher tag resolution than actual dive behavior.

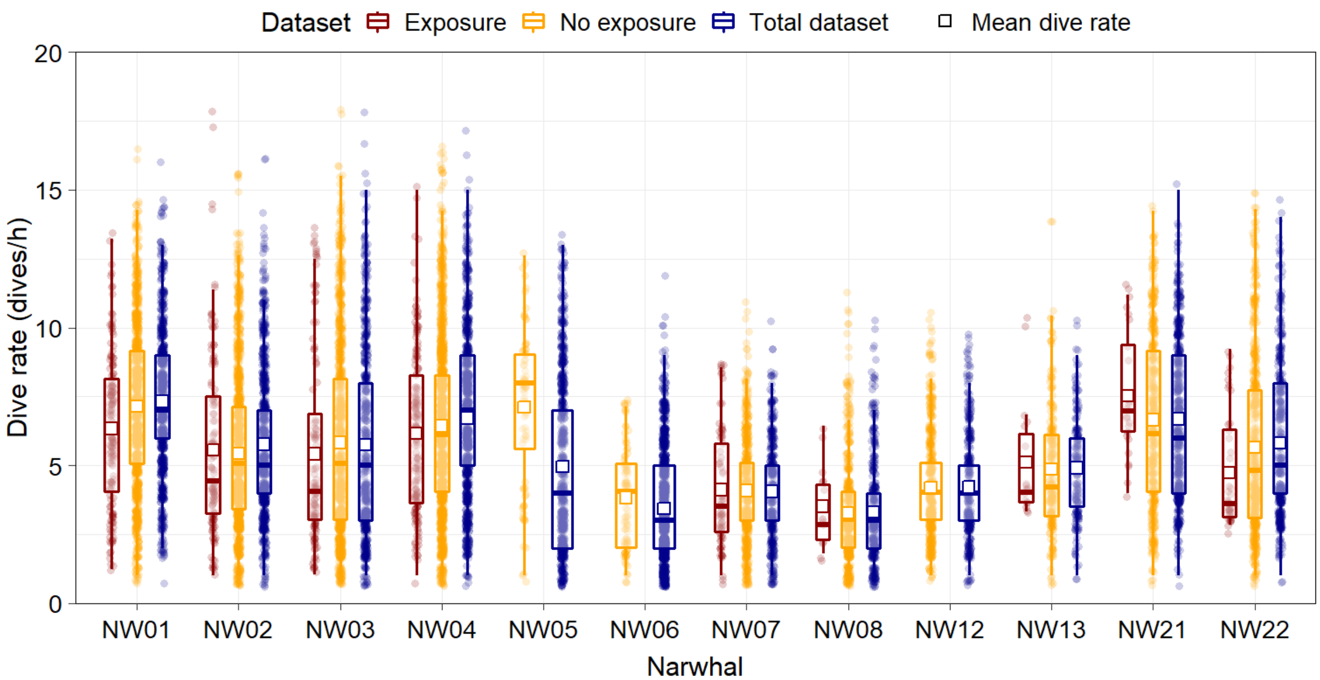

Figure 4-44: Observed hourly diving rate values (dives/h) by tagged narwhal under exposure, non-exposure, and for total dataset

Note: Summary statistics (minimum, maximum, and mean) are provided in Table 4-8.

Table 4-8: Summary statistics of narwhal dive rate (dives/h)

Narwhal	Sex	Total dataset			Exposure Zone (≤10 km)			Non-exposure Zone (>10 km)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
NW01	M	1.0	7.3	16.0	1.2	6.3	13.2	1.0	7.2	16.3
NW02	F	1.0	5.8	16.0	1.0	5.6	17.4	1.0	5.4	15.6
NW03	F	1.0	5.8	18.0	1.0	5.4	13.3	1.0	5.8	17.5
NW04	M	1.0	6.7	17.0	1.0	6.2	15.0	1.0	6.4	16.3
NW05	M	1.0	5.0	13.0	n/a	n/a	n/a	1.0	7.1	12.6
NW06	M	1.0	3.4	12.0	n/a	n/a	n/a	1.0	3.8	7.1
NW07	M	1.0	4.1	10.0	1.0	4.1	8.6	1.0	4.1	10.6
NW08	F	1.0	3.3	10.0	1.8	3.5	6.4	1.0	3.3	10.9
NW12	F	1.0	4.2	10.0	n/a	n/a	n/a	1.0	4.2	10.3
NW13	M	1.0	4.9	10.0	3.3	5.1	10.1	1.0	4.9	13.6
NW21	F	1.0	6.7	15.0	4.0	7.5	11.2	1.0	6.7	14.2
NW22	F	1.0	5.8	15.0	2.9	4.7	9.2	1.0	5.7	15.0

Notes:

a) 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., NW01).

b) Dive rates were calculated only for periods of 15 min or longer, resulting in removal of exposure data for NW12.

Maximum dive rate within a 4 h period was variable between individuals, strata, and study period (Figure 4-45). Overall, highest dive rate values were observed in Milne Inlet South and Milne Inlet North substrata, while dive rates in Eclipse Sound were low compared to other strata.

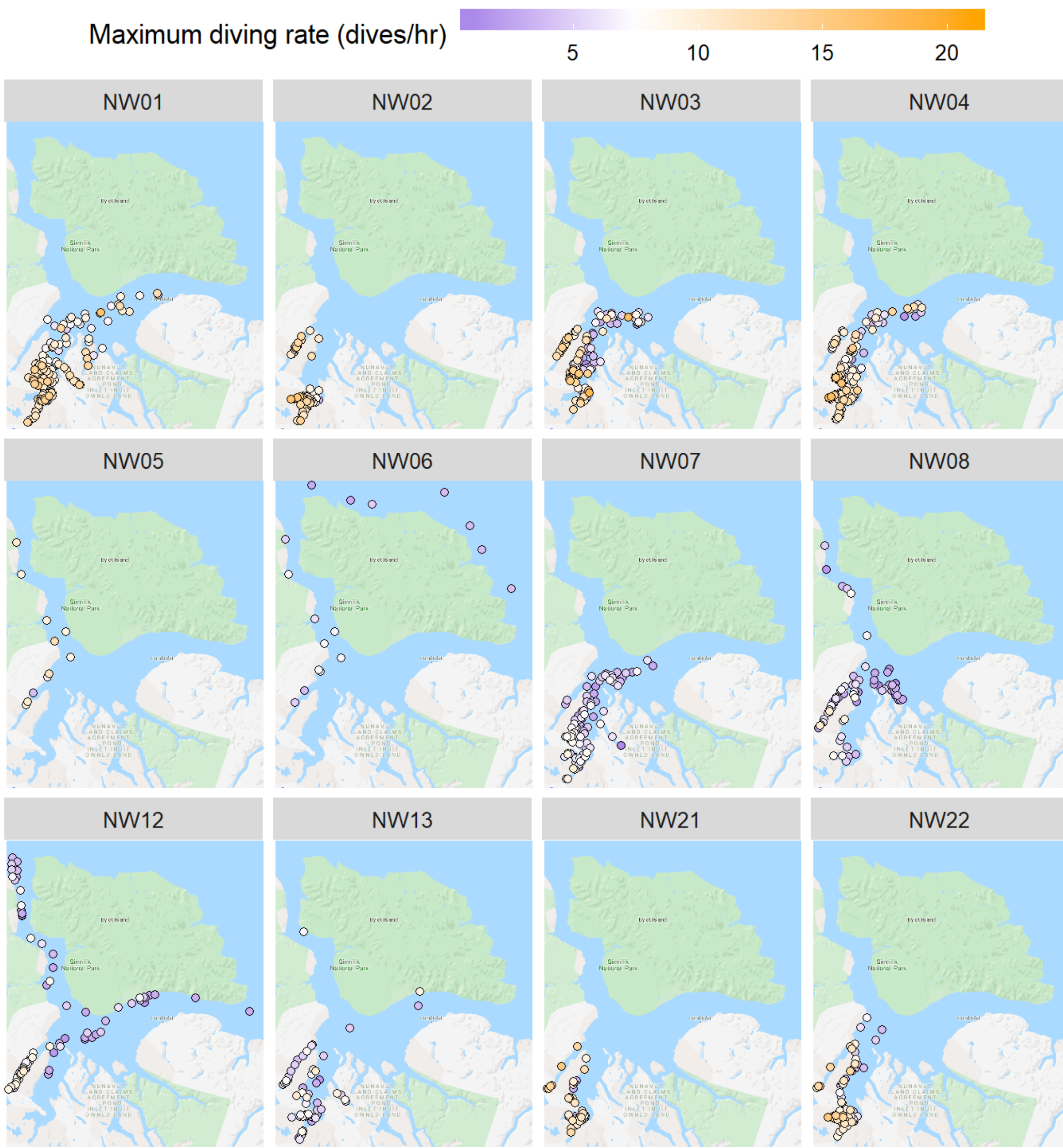

Figure 4-45: Maximum dive rate (dives/h) by tagged narwhal (averaged by 4 h time periods)

Note: Mean values across all animals shown in white.

In summary, considering the prediction that narwhal exposed to vessel traffic may respond by either increasing their dive rate (i.e., avoidance) or decreasing their dive rate (i.e., freezing), the qualitative assessment of dive data did not suggest a difference in dive rates between exposure and non-exposure events. Furthermore, no difference in dive rate was evident between male and female narwhal. Dive rates differed between tag types, and any future analysis using data from a combination of MiniPAT and SPLASH10 tags should account for tag type.

4.2.2.3 Performing Bottom Dives

Overall, tagged narwhal most commonly undertook shallow dives (<25% of the available bathymetry depth), followed by bottom dives (>75% of the available bathymetry depth; Figure 4-46). The proportional use of different dive depths varied between individuals, with shallow dives observed more frequently by NW01 (male) and NW03 (female) (62%-67% of all dives) than by NW02 (female), NW04 (male), and NW21 (female) (37%-43% of all dives). The lowest proportion of shallow dives was recorded for NW22 (female; 23% of all dives). Of the six narwhal included in this analysis, NW01 demonstrated the lowest proportion of bottom dives (17% of all dives) while NW22 demonstrated the highest proportion of bottom dives (50%). For all tagged narwhal, use of the mid-water column (25-49% and 50-74% depth intervals) was least common, ranging from 3% to 18% of total dives.

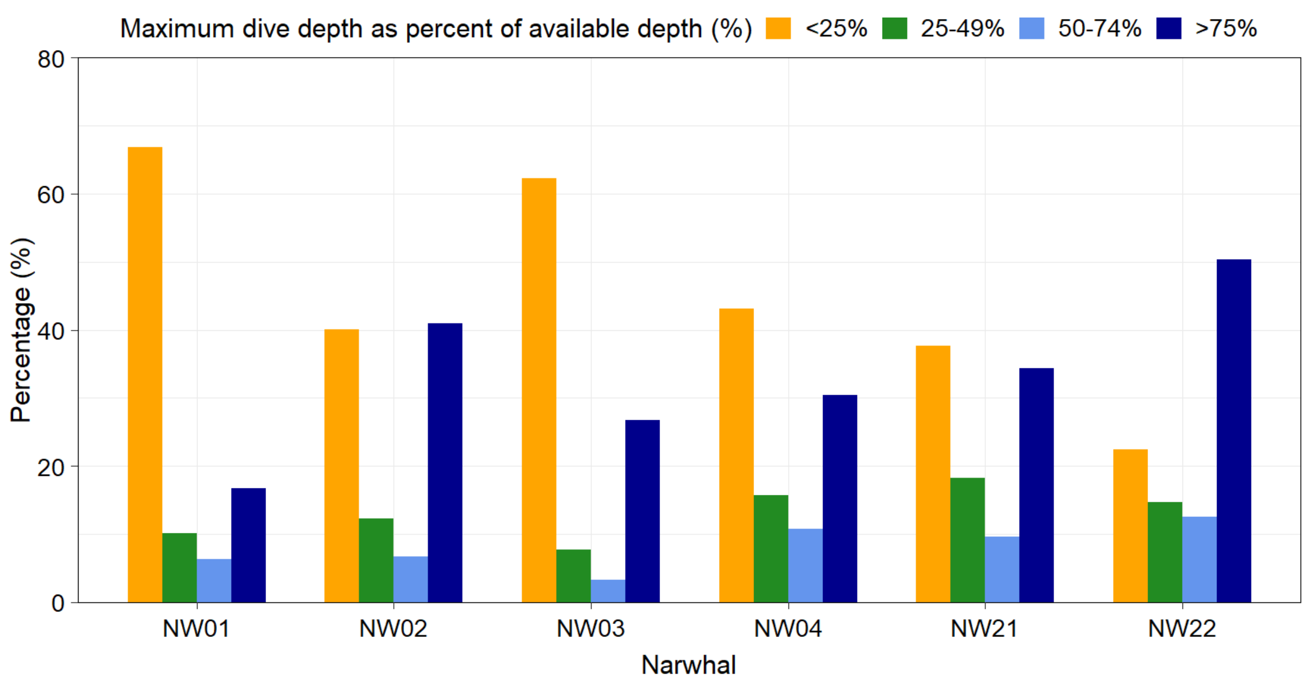

Figure 4-46: Observed maximum dive depth in proportion to available depth (%).

Of the six tagged individuals, NW02 (female) demonstrated the lowest maximum dive depth (334 m) throughout the study period, while the maximum depth for the other five narwhal ranged from 423.5 to 748 m (Table 4-9). 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 4-48), where available depths are generally shallower than in neighboring Eclipse Sound. In comparing narwhal dive depths between exposure and non-exposure events, median dive depths were slightly greater for all narwhal during non-exposure events than during exposure events, with the exception of NW04 and NW22 (Table 4-9). In assessing depth expressed as the proportion of available depth, however, median dive depth was greater for all individuals during non-exposure events, with the exception of NW03 (Figure 4-47).

Maximum dive depth relative to available depth (averaged over 4 h periods) indicated that narwhal conducted bottom dives throughout Milne Inlet, Tremblay Sound, Eclipse Sound, and neighboring water bodies, suggesting that deep water foraging occurs throughout the Eclipse Sound summering ground (Figure 4-48), consistent with findings by Watt et al. (2015, 2017). Bottom dives varied substantially among individuals both temporally and geographically. For example, NW01 was unique in that it did not conduct a single bottom dive during the first two weeks of it being tagged despite occupying most strata during this time. The individual then undertook bottom dives in all strata for the remainder of its deployment period. In contrast, NW04 performed bottom dives in all strata visited during the individual's first two weeks of deployment and 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 bottom dives. In 2018, NW21 performed bottom dives mostly near Bruce Head and in Tremblay Sound, whereas NW22 performed bottom dives throughout Milne Inlet South, Milne Inlet North, and Tremblay Sound, as well as in the west end of Eclipse Sound.

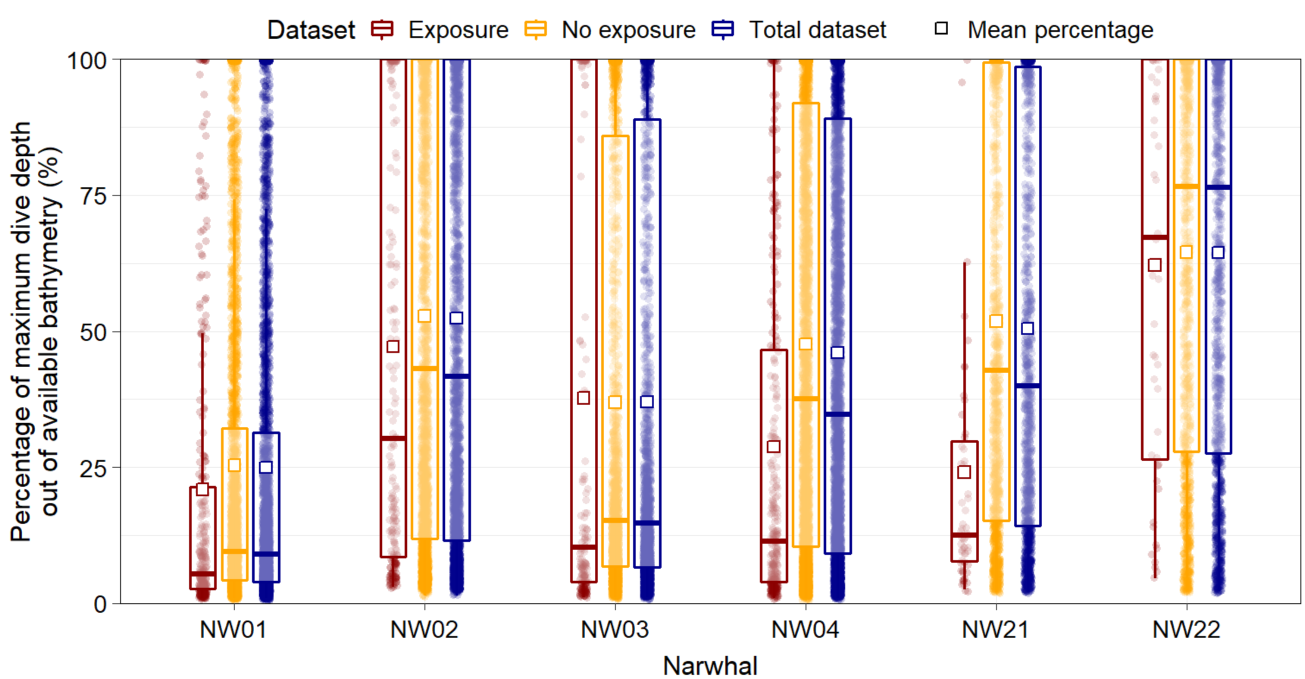

Figure 4-47: Observed maximum dive depth in proportion to available depth under exposure, non-exposure, and for total dataset

Note: Summary statistics (minimum, maximum, and median) are provided in Table 4-9.

Table 4-9: Summary statistics of maximum dive depth (m), where (%) identifies percentage of available depth.

Narwhal	Sex	Total dataset[a]			Exposure Zone (≤10 km)			Non-exposure Zone (>10 km)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
NW01	M	7 (1%)	16.5 (9%)	744 (100%)	7.5 (1%)	15 (5%)	728 (100%)	7 (1%)	17 (10%)	744 (100%)
NW02	F	7.5 (1%)	35 (42%)	334 (100%)	7.5 (3%)	33.2 (30%)	333.5 (100%)	7.5 (1%)	35 (43%)	334 (100%)
NW03	F	7.5 (1%)	20.5 (15%)	748 (100%)	7.5 (1%)	19 (10%)	746.5 (100%)	7.5 (1%)	20.5 (15%)	748 (100%)
NW04	M	7 (1%)	26 (35%)	745 (100%)	7.5 (1%)	27.2 (11%)	624.5 (100%)	7 (1%)	26 (38%)	745 (100%)
NW21	F	7.5 (2%)	22 (40%)	423.5 (100%)	7.5 (2%)	16 (12%)	332 (100%)	7.5 (2%)	22.5 (43%)	423.5 (100%)
NW22	F	7.5 (2%)	28.8 (76%)	675 (100%)	7.5 (5%)	35.2 (67%)	332.5 (100%)	7.5 (2%)	28.5 (77%)	675 (100%)

Note: [a] = only includes data with a known GPS position

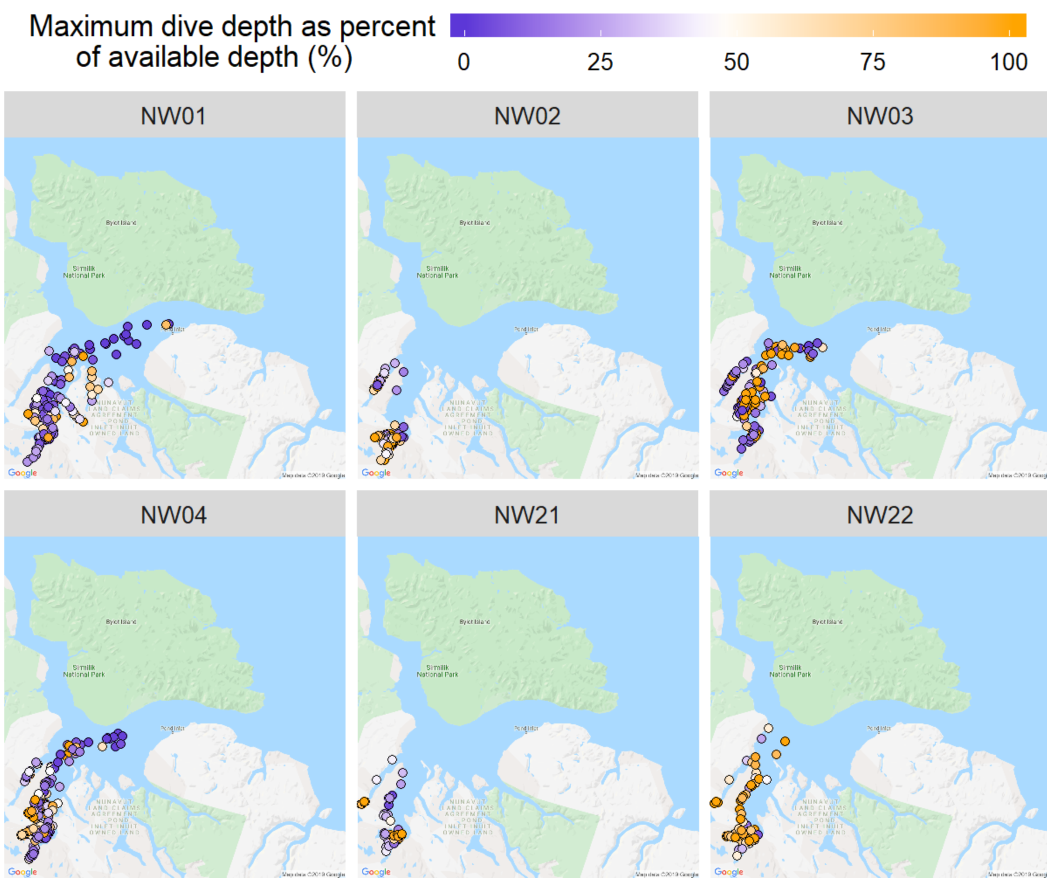

Figure 4-48: Maximum dive depth relative to available depth by tagged narwhal (averaged by 4 h time periods).

Note: Mean values across all animals shown in white.

Based on the smoothing trend curve (i.e., not accounting for any other pertinent variables), no directionality was evident in the relationship between the proportion of bottom dives and vessel distance (i.e., there was no difference in response to an approaching vessel and a vessel moving away; Figure 4-49). Therefore, directionality was not incorporated into the model in order to maximize sample size in the near vicinity of vessels.

When no vessels were present within 10 km from narwhal, the smoothing trend curve suggested that bottom dives accounted for 51-69% of all dives when the previous dive was also a bottom dive and 8-34% of all dives when the previous dive was not a bottom dive (Figure 4-49). When narwhal were within the 10 km exposure zone, however, the proportion of dives made to the bottom out of total dives undertaken was shown to change in response to distance from a vessel and in response to whether the preceding dive was also a bottom dive.

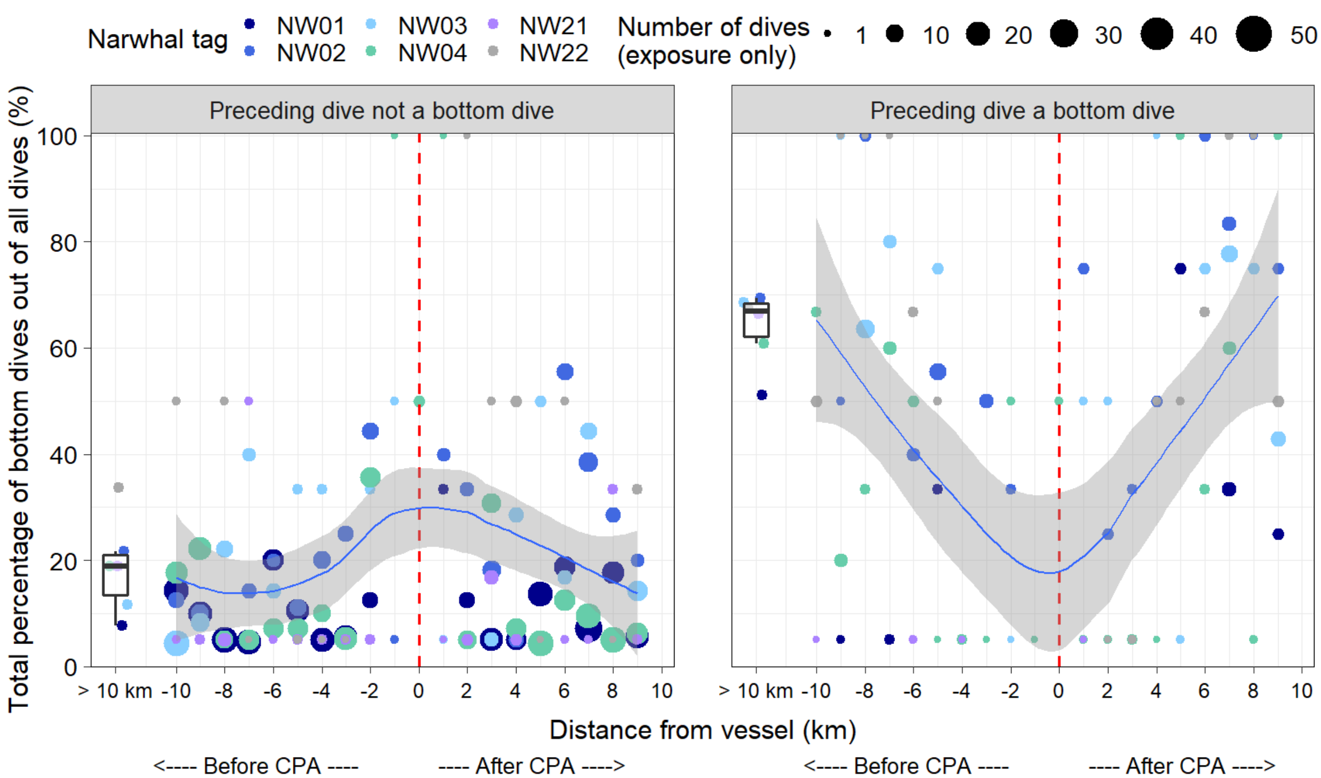

Figure 4-49: Percent of dives that were bottom dives (>75% of available bathymetry), by tagged narwhal and as a function of distance from vessel (rounded to 1 km)

Note: Bubble size in exposure events represents total amount of data available for each tag/distance combination. Boxplot summarizes total percent bottom dives by each narwhal when no vessels were present within 10 km from the narwhal. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

As stated in Section 3.5.2, maximum dive depth was analyzed using mixed effect logistic models with presence/absence of bottom dives as the response variable (i.e., whether the dive was deeper than 75% of the available bathymetry depth; Figure 4-50). In the analysis, fixed effects included in the model were whether the narwhal was within an exposure zone (≤10 km from a vessel), distance from a vessel if present (km; 2nd-degree polynomial), available bathymetry depth (m), whether the preceding dive was a bottom dive, substratum, time since the last bottom dive, an interaction between distance from a vessel and whether the preceding dive was a bottom dive, and interaction between whether the narwhal was in the exposure zone and whether the preceding dive was a bottom dive. The random effect was a random intercept by narwhal. As bottom 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 a bottom dive and the time elapsed since the last bottom dive allowed separating the data into two types of behavior – 1) repeated bottom dives (i.e., potentially feeding behavior) and 2) a bottom dive following a non-bottom dive (potentially escape behavior).

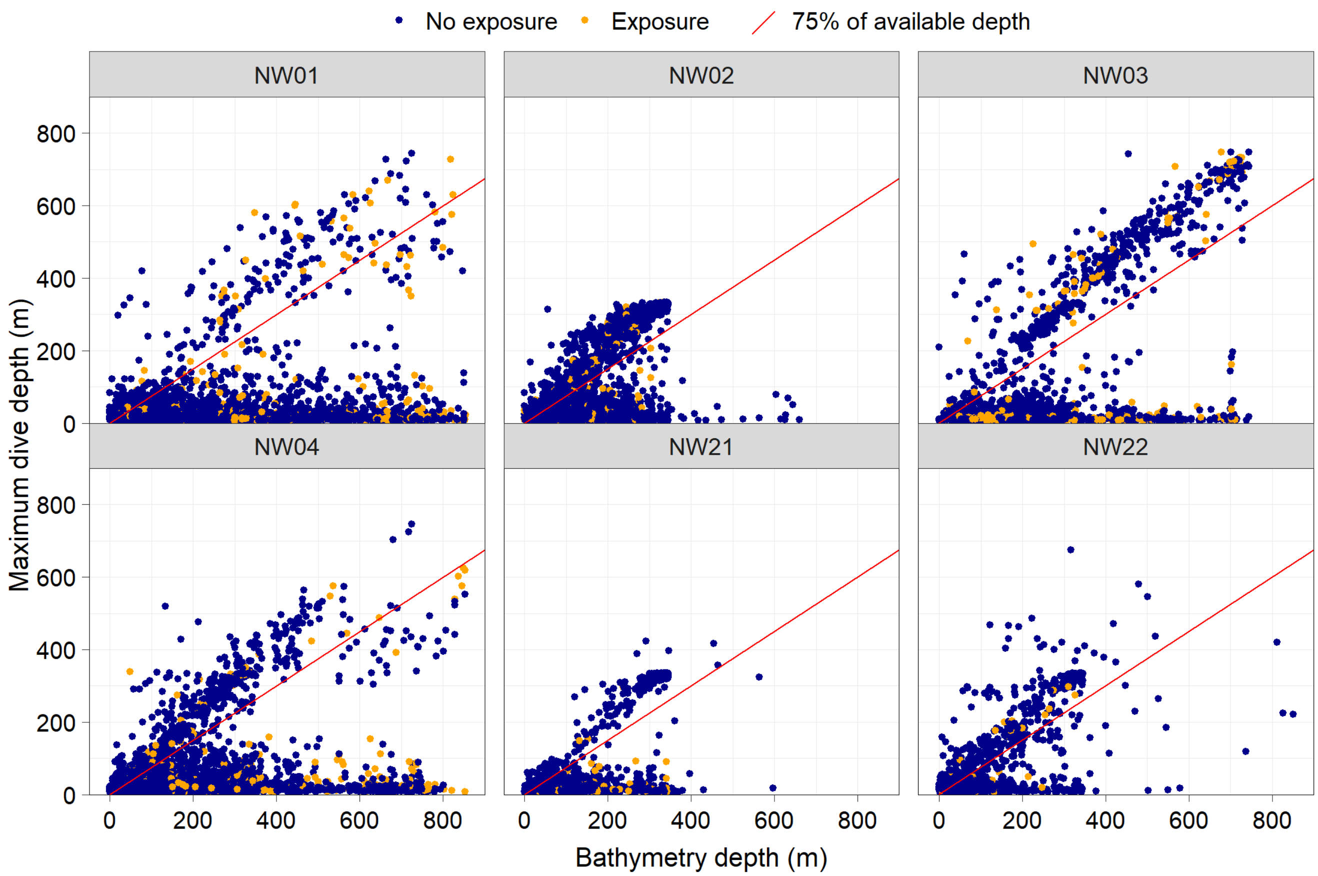

Figure 4-50: Maximum dive depth relative to available depth, with the cut-off for 75% of available depth.

The fixed-effect interaction between distance from a vessel and whether the preceding dive was a bottom dive was significant ($P<0.001$). The interaction between whether the narwhal was within the exposure zone and whether the preceding dive was a bottom dive was not significant ($P=0.9$), but the main effect of exposure was statistically significant ($P=0.002$). The effects of bathymetry, time elapsed since the last bottom dive, and substratum were also significant ($P\leq0.001$ for all). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.311 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.342. Test statistics and coefficient estimates for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -80% or a +150% effect size in the test of the overall effect of distance from vessel (Appendix C). In comparison, observed effect sizes ranged from -93% to +149%. That is, the test had sufficient power to detect an overall effect of distance from vessel at observed effect sizes.

When the preceding dive was a bottom dive (interpreted as narwhal potentially feeding), the probability of performing another bottom dive was low in close proximity of vessels but increased with an increasing distance between vessel and narwhal (Figure 4-51). For these potentially feeding animals, the probability of another bottom dive when no vessels were present within 10 km from the narwhal was 0.489. This was not significantly different from probabilities predicted when vessels were within 6-10 km from narwhal (P>0.2 for all distances; Table 4-10). At distance of 0-5 km from a vessel, however, the probability of a bottom dive following another bottom dive decreased to 0.034-0.303 (P≤0.009 for all cases compared to probability of 0.489 when no vessels present within 10 km). That is, feeding narwhal generally decreased the pattern of sequential bottom dives when a vessel was within 5 km from the narwhal. These results are consistent with the freeze response hypothesis (Figure 4-51).

When the preceding dive was not a bottom dive (interpreted as narwhal were not feeding), the probability of performing a bottom dive was higher when vessels were in close proximity (0-2 km) than when vessels were further away (Figure 4-51). When no vessels were present within 10 km from the narwhal, the probability of a bottom dive when the preceding dive was not a bottom dive was only 0.214. This was not significantly different from the probabilities of a bottom dive during exposure (0.150-0.359, depending on distance, P≥0.1 for all comparisons; Table 4-10). However, the multiple comparisons only had sufficient power (>0.8) to detect a distance-specific effect size of +200% when the previous dive was not a bottom dive; in comparison, the largest absolute magnitude of the observed effect when the previous dive was not a bottom dive was 149% (Appendix C). That is, the comparisons did not have sufficient statistical power to detect the observed effect sizes when the previous dive was not a bottom dive. The lack of significance of the multiple comparisons (and the low statistical power) are likely due to the high uncertainty associated with predictions in the vicinity of vessels, since an increase in the probability of performing a bottom dive in the vicinity of vessels was observed and predicted when the preceding dive was not a bottom dive (Figure 4-51). This response, while not statistically significant, is consistent with the avoidance response hypothesis.

The probability of performing a bottom dive decreased with an increasing time since the previous bottom dive, because bottom dives typically tended to be clustered. The probability of performing a bottom dive also decreased with increasing bathymetry values, however relatively sparse data was available in the deep portions of Eclipse Sound (Figure 4-48). The effect of substratum was statistically significant, suggesting that bottom diving differed between substrata regardless of vessel presence or absence. The estimated probability of performing bottom dives was shown to be highest in Eclipse Sound substratum (though this is likely due to the overall small amount of data available for the area) and significantly lower in Koluktoo Bay and Tremblay Sound (Figure 4-51). None of the remaining substrata were significantly different from each other or from Eclipse Sound, Koluktoo Bay, or Tremblay Sound.

Note that the model was based on limited data at close distances between narwhal and vessels, especially when preceding dives were bottom dives, resulting in highly variable mean response (e.g., individual-level probability values ranging between 0.2 to 0.6 at a distance of 0 km; dashed lines in top left panel of Figure 4-51). Much of the data informing the model at these close distances came from narwhal NW02 and NW04, with little information available from the other four tagged narwhal.

In summary, the 2017-2018 integrated dive data support the rejection of the null hypothesis (**$H3_0$**) that the occurrence of bottom dives (>75% of the available bathymetry depth) does not change significantly during vessel-exposure events. The results indicated a statistically significant effect of vessels, compared to non-exposure, when vessels were within 5 km (Table 4-10). When narwhal had previously been undertaking bottom dives (assumed to represent foraging), the model predicted a decrease in probability of bottom diving with decreasing distance from vessel from 0.303 at 5 km to 0.034 at 0 km. **Considering the prediction that narwhal engaged in**

foraging activity would spend a relatively greater amount of time performing bottom dives and that those exposed to vessel traffic may cease foraging activity in response to a perceived threat, these results suggest that narwhal potentially engaged in foraging may cease sequential bottom dives when within 5 km of a transiting vessel.

It is important to note that bottom dive data within the 10 km exposure zone were limited, resulting in high uncertainty when relating bottom dive behavior to distance from vessels. Further investigation is required to better characterize behavioral response and to confirm rejection of the null hypothesis.

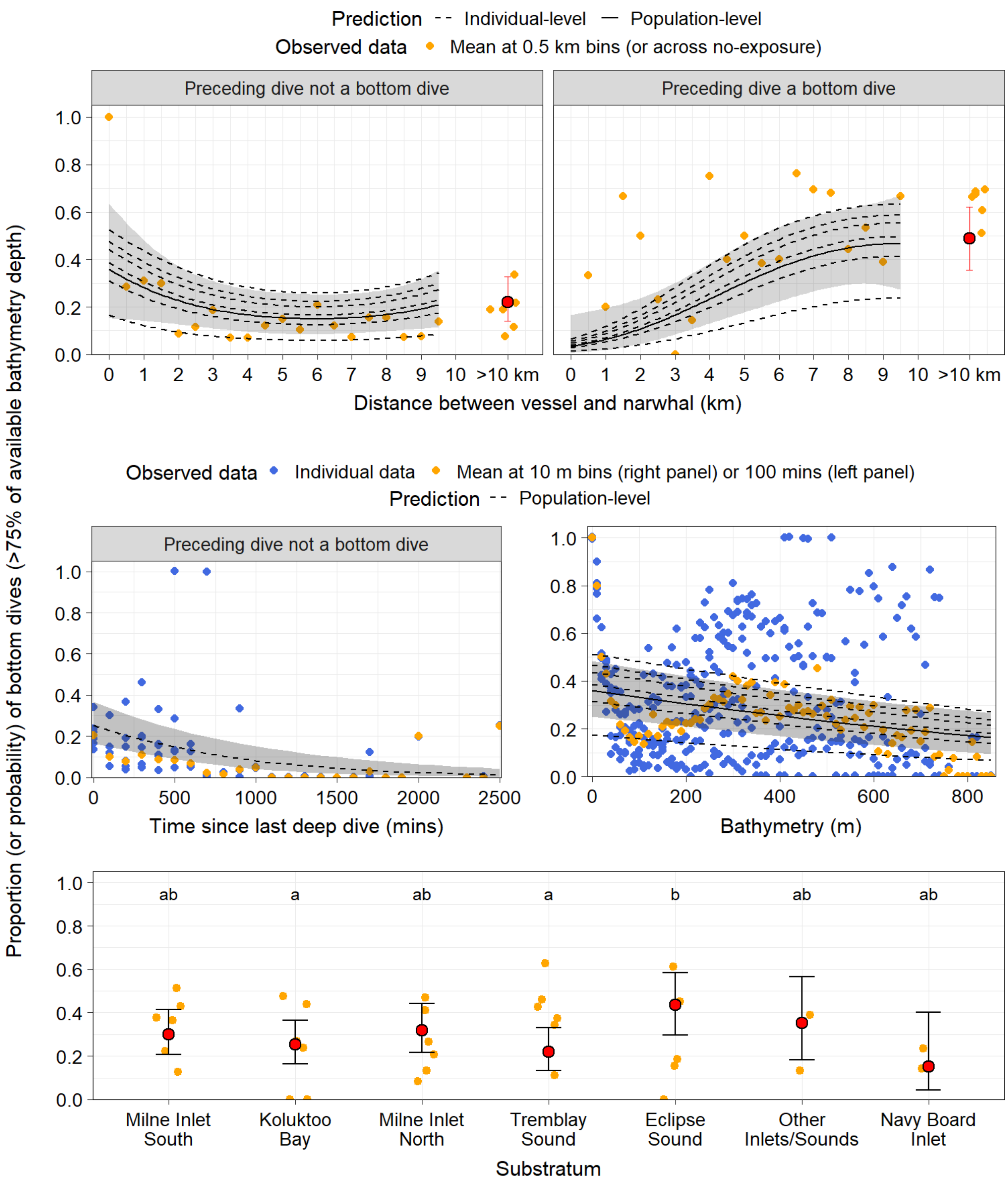

Figure 4-51: Proportion of observed bottom dives relative to distance from vessels in transit, time since the last bottom dive, bathymetry, and substratum.

Note: Black lines and red points represent population-level model predictions; error bars and ribbons represent the 95% confidence intervals associated with population-level predictions.

Table 4-10: Multiple comparisons of predictions of narwhal performing bottom dives under non-exposure and incremental exposure distances from vessel (statistically significant values shown in bold).

Distance from Vessel (km)	Multiple Comparisons to Non-exposure – Least-squares Means with *P* values in Brackets	
	Preceding non-Bottom Dive	Preceding Bottom Dive
0	0.359 (0.712)	**0.034 (0.001)**
1	0.282 (0.904)	**0.064 (<0.001)**
2	0.227 (1.000)	**0.108 (<0.001)**
3	0.190 (0.898)	**0.166 (<0.001)**
4	0.167 (0.392)	**0.234 (<0.001)**
5	0.154 (0.179)	**0.303 (0.009)**
6	0.150 (0.114)	0.366 (0.203)
7	0.154 (0.109)	0.416 (0.679)
8	0.168 (0.297)	0.449 (0.954)
9	0.192 (0.942)	0.465 (0.998)
10	0.230 (1.000)	0.462 (0.999)

4.2.2.4 Time at Depth

On average, tagged females (NW02, NW03, NW21, and NW22) spent longer periods within the deepest 20% of each dive than males (NW01 and NW04; Figure 4-52; Table 4-11), with median time ranging from 2.1 to 2.7 min for females, and from 1.8 to 2.0 min for males. Conversely, the maximum period spent within the deepest 20% of a dive was higher for males than females, with maximum time ranging from 15.0 to 17.1 min for males, and from 8.9 to 13.0 min for females (Table 4-11). In comparing narwhal time at depth between exposure and non-exposure events, mean time spent within the deepest 20% of each dive was not consistently different, while maximum time spent within the deepest 20% of each dive was higher during non-exposure events than exposure events for all six narwhal (Figure 4-52).

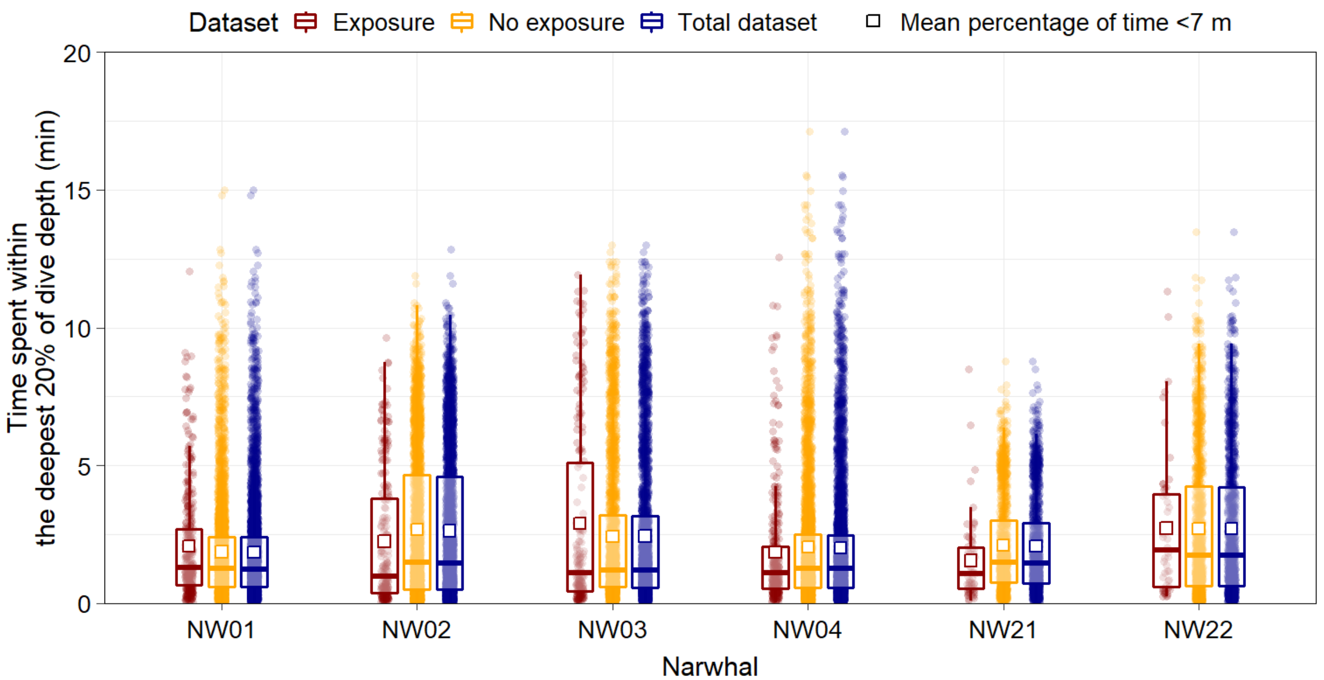

Figure 4-52: Observed time (min) spent within 20% of maximum dive depth, under exposure, non-exposure, and for the total dataset.

Note: Summary statistics (minimum, maximum, and mean) are provided in Table 4-11.

Table 4-11: **Summary statistics of time (min) spent within 20% of maximum dive depth.**

Narwhal	Sex	Total dataset			Exposure Zone (≤10 km)			Non-exposure Zone (>10 km)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
NW01	M	0.03	1.84	15.00	0.07	2.07	12.00	0.03	1.86	15.00
NW02	F	0.02	2.63	12.80	0.05	2.24	9.63	0.02	2.67	11.90
NW03	F	0.03	2.44	13.00	0.05	2.90	11.90	0.03	2.43	13.00
NW04	M	0.02	2.01	17.10	0.03	1.85	12.60	0.02	2.03	17.10
NW21	F	0.03	2.07	8.77	0.08	1.55	8.48	0.03	2.10	8.77
NW22	F	0.02	2.70	13.50	0.25	2.73	11.30	0.02	2.71	13.50

In general, narwhal close to Milne Port and throughout Tremblay Sound spent less time within the deepest 20% of each dive relative to when in other substrata (Figure 4-53). Dives made by narwhal near Koluktoo and Bruce Head often had longer time at depth (e.g., NW02 and NW04), and those made in the western portion of Eclipse Sound often (but not always) had longer time at depth (e.g., NW01 and NW03). For NW03, time at depth coincided with bottom dives, where maximum dive depth was 100% of the available bathymetry depth (Figure 4-48) and lower dive rate (Figure 4-45).

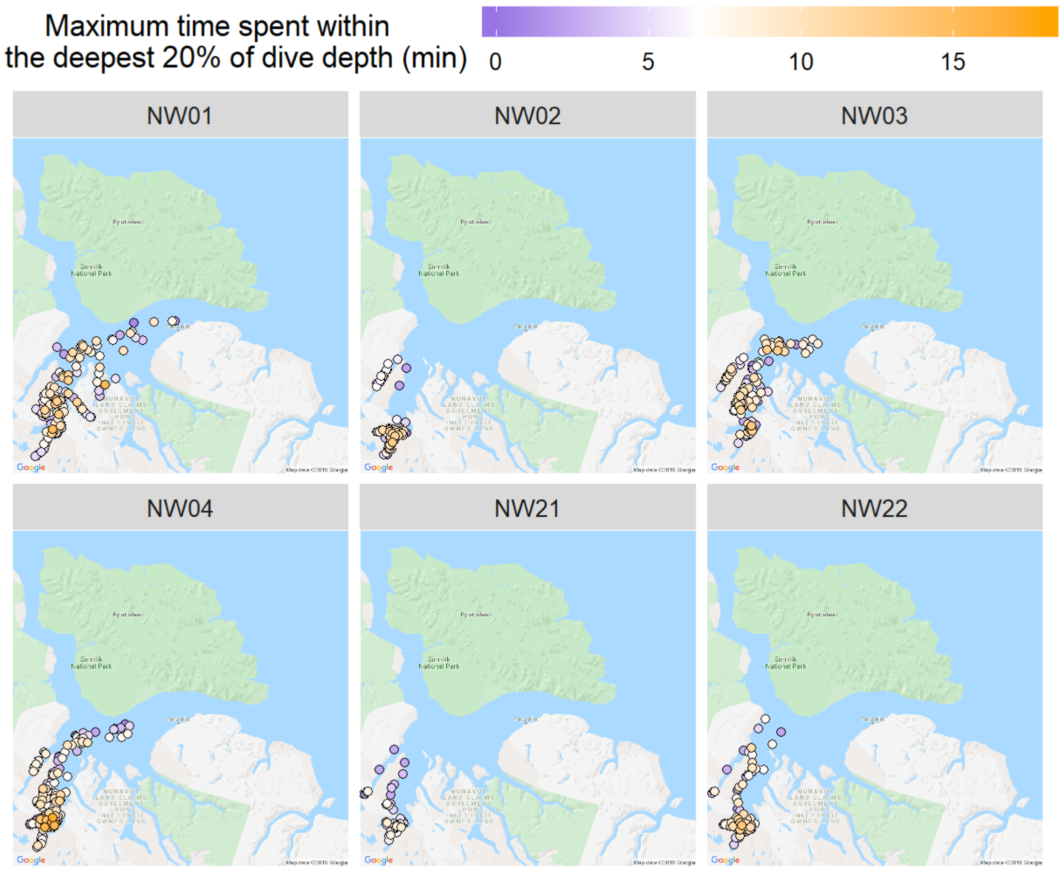

Figure 4-53: Maximum time (min) spent within 20% of maximum dive depth by tagged narwhal (averaged by 4 h time periods)

Note: Mean values across all animals shown in white.

Based on the smoothing trend curve (i.e., not accounting for any other pertinent variables), there was no directionality in the relationship between time spent within the deepest 20% of the dive and vessel distance (i.e., there was no difference in response to an approaching vessel and a vessel moving away) (Figure 4-54). Therefore, the relationship was subsequently modeled without directionality to maximize sample size in the near vicinity of vessels.

When no vessels were present within 10 km from the narwhal and the dive was a bottom dive, the smoothing trend curve suggested that time spent within the deepest 20% of the dive ranged between 3.4 min and 5.9 min Figure 4-54. When no vessels were present within 10 km and the dive was not a bottom dive, time spent within the deepest 20% of the dive ranged between 1.1 min and 1.6 min. Within the designated 10 km exposure zone, time spent within the deepest 20% of the dive was shown to change in response to distance from a vessel, but only if the dive was a bottom dive (>75% of the available bathymetry depth). Of note, when the dive was a bottom dive and a vessel was in close proximity (0-2 km) to the animal, time spent within the deepest 20% of the dive was shown to be shorter than when a vessel was further away (2-8 km).

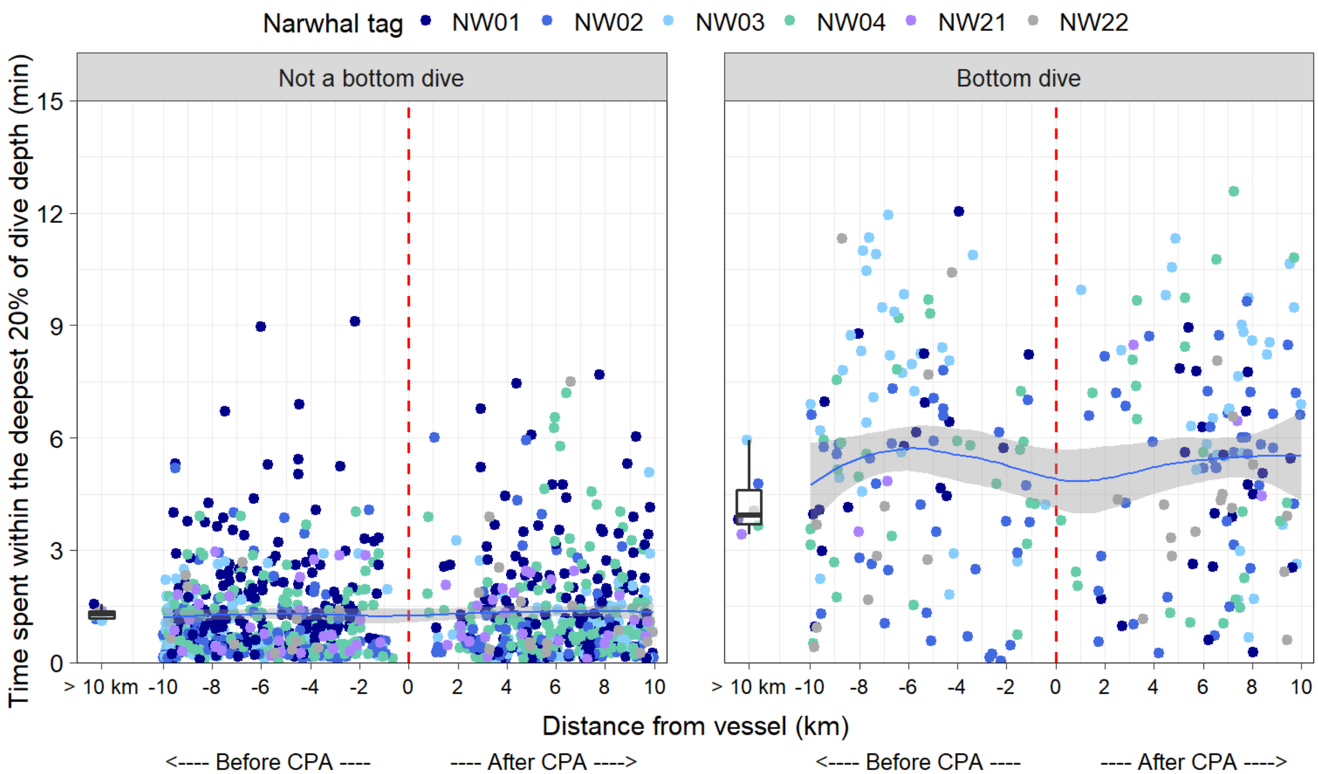

Figure 4-54: Time spent within the deepest 20% of the dive, by tagged narwhal, distance from vessel (rounded to 1 km), and whether the current dive was a bottom dive (>75% of available bathymetry).

Note: Boxplot summarizes narwhal-specific mean time at deepest 20% of the dive when no vessels were present within 10 km from the narwhal. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

As stated in Section 3.5.2, time spent within 20% of maximum dive depth was analyzed using mixed effect linear models. In the analysis, fixed effects included in the model were whether the narwhal was within the exposure zone (≤10 km from a vessel), distance from a vessel if present (km; 3rd-degree polynomial), maximum dive depth (m; second-degree polynomial), whether the dive was a bottom dive (>75% of the available bathymetry depth), whether the preceding dive was a bottom dive, and the substratum. In addition to the main effects, the model included an interaction between distance from vessel and whether the dive was a bottom dive, an interaction between whether there was a vessel present within 10 km and whether the dive was a bottom dive, an interaction between whether the dive was a bottom dive and maximum dive depth, and an interaction between whether the dive was a bottom dive and whether the preceding dive was a bottom dive. The random effects consisted of a random intercept by narwhal.

The main effects and the interactions involving distance from vessel and whether a vessel was within 10 km from narwhal were not statistically significant (P>0.1 for all). Therefore, no multiple comparisons were performed between time at depth under no exposure to vessels and time at depth with vessels at specific distances from narwhal. The interaction between whether the preceding dive was a bottom dive and whether the current dive was also a bottom dive was significant (P<0.001), as was the interaction between whether the current dive was a bottom dive and maximum dive depth (P=0.001). The main effect of substratum was also statistically significant (P<0.001).

The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.615 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.623. Test statistics and coefficient estimates for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -30% or a +25% effect size in the test of the overall effect of distance from vessel (Appendix C). In comparison, the absolute magnitude of the observed effect sizes was 21%. That is, the test did not have sufficient statistical power to detect the observed effect size, but it would have been able to detect a decrease of 30% or an increase of 25% in estimated time at depth (Appendix C).

Overall, the model indicated that time spent within the deepest 20% of the dive depended on the depth of the dive, the substratum, and whether the current and preceding dives were bottom dives. Predicted time spent at the deepest 20% of the dive increased with maximum depth until a peak at approximately 400-450 m (depending on whether the current dive was a bottom dive or not), followed by a decrease in estimated time spent at bottom (Figure 4-55). Multiple comparisons between substrata indicated that mean predicted time at depth was lowest at Eclipse Sound, which was significantly different from Milne Inlet South and Koluktoo Bay (which had the highest estimated time at depth; Figure 4-55). No significant differences were found between time at depth at Tremblay Sound, Navy Board Inlet, Milne Inlet North and the “other inlets/sounds” substratum.

The model estimated the highest values of time at depth for dives where both the current and the preceding dives were bottom dives and the lowest time at depth for dives where the current dive was not a bottom dive but the previous one was (Figure 4-55). All four combinations of whether the current dive was a bottom dive and whether the previous dive was a bottom dive were significantly different from each other.

In summary, the 2017-2018 integrated dive data do not support rejection of the null hypothesis (**$H4_0$**) that time at depth does not significantly change during vessel exposure events. **Considering the prediction that narwhal engaged in foraging activity would spend a relatively greater amount of time within the deepest 20% of a dive and that those exposed to vessel traffic may cease foraging activity in response to a perceived threat, potentially foraging narwhal may experience disturbance effects within 2 km from a vessel. However, the finding that narwhal spend less time at depth within 2 km from a vessel is based only on the smoothing trend curve and model-estimated effect sizes, which were not statistically significant due to insufficient power.**

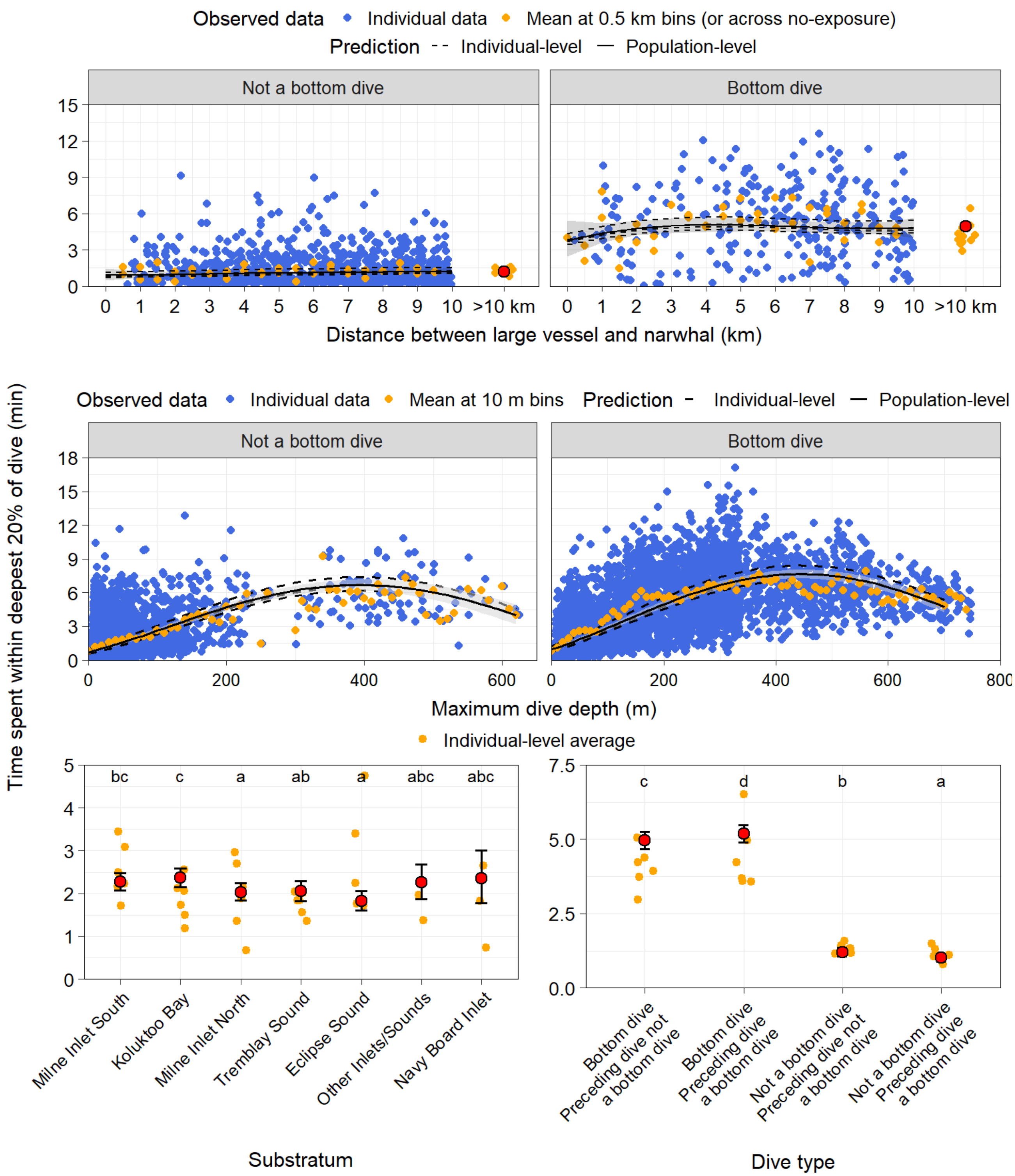

Figure 4-55: Time spent at the deepest 20% of the dive relative to distance from a vessel (top), maximum dive depth (middle), substratum (bottom left) and type of dive and preceding dive (bottom right).

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

4.2.2.5 Dive Duration

The dive duration (i.e., duration of individual dives; min) of three of the four tagged female narwhal (NW02, NW03, and NW22) was on average higher than that of the two tagged male narwhal (NW01 and NW04; Figure 4-56; Table 4-12). In comparing narwhal dive duration between exposure and non-exposure events, no differences in mean dive duration values were apparent based on summary statistics, although maximum dive duration values were higher during non-exposure events than during exposure events (Figure 4-56; Table 4-12).

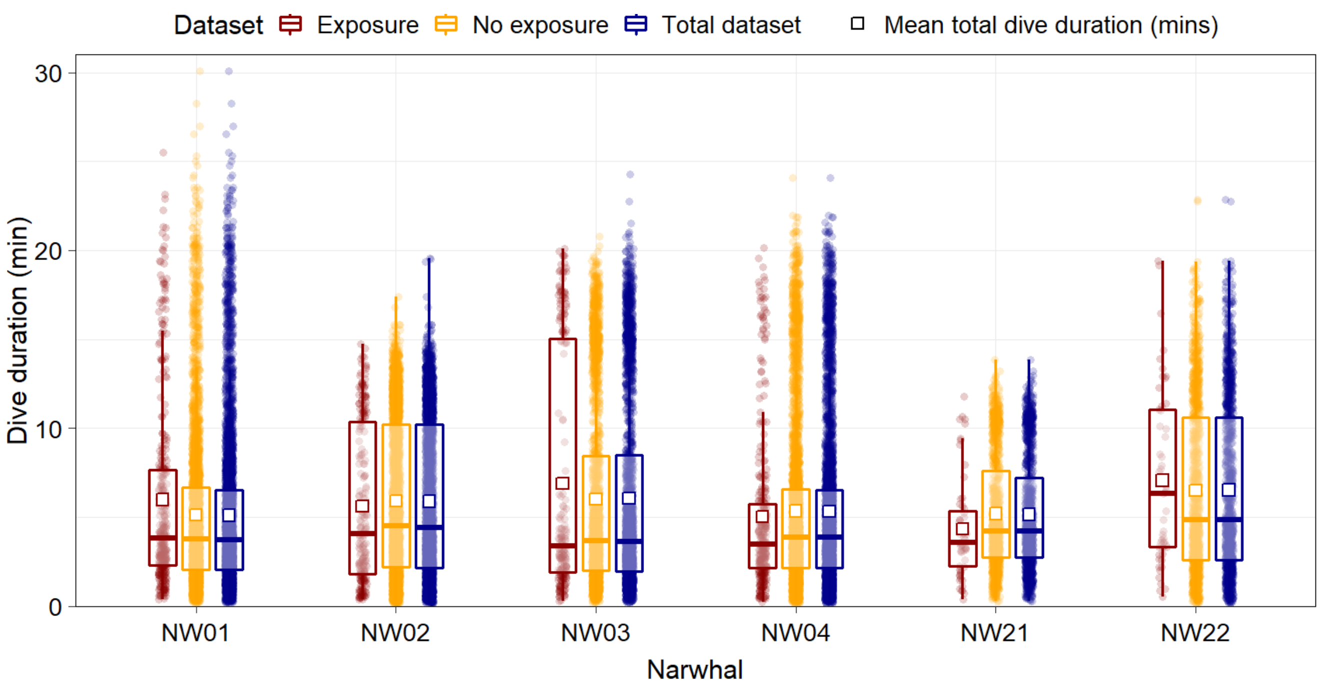

Figure 4-56: Dive duration (min) within each dive, by tagged narwhal under exposure, non-exposure, and for the total dataset

Note: Summary statistics (minimum, maximum, and mean) are provided in Table 4-12.

Table 4-12: Summary statistics of narwhal dive duration (min)

Narwhal	Sex	Total dataset			Exposure Zone (≤10 km)			Non-exposure Zone (>10 km)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
NW01	M	0.18	5.10	30.10	0.37	6.00	25.50	0.18	5.14	30.10
NW02	F	0.12	5.89	19.50	0.38	5.63	14.80	0.12	5.92	17.40
NW03	F	0.20	6.07	24.30	0.27	6.91	20.10	0.20	6.02	20.80
NW04	M	0.17	5.32	24.10	0.25	5.04	20.20	0.17	5.35	24.10
NW21	F	0.27	5.17	13.80	0.40	4.36	11.80	0.27	5.21	13.80
NW22	F	0.13	6.52	22.80	0.55	7.08	19.40	0.13	6.51	22.80

The dive duration values of narwhal (summarized over 4 h periods) differed by substrata and by tagged individual (Figure 4-57). For example, NW02 exhibited no dives longer than 20 min, unlike those that were recorded for other tagged narwhal, but exhibited a relatively high average dive duration overall (Figure 4-56), low to intermediate dive duration when in Tremblay Sound, and longer dive durations when in Koluktoo Bay substrata. NW03 exhibited relatively long dives when in Eclipse Sound (Figure 4-57), often to the full extent of the available bathymetry depth (Figure 4-48), leading to a low dive rate (Figure 4-45). NW21 exhibited a spatial distribution similar to NW02, where both used mostly Koluktoo Bay, Milne Inlet South, and Tremblay Sound. Despite the similar distribution, NW21 generally exhibited shorter dive durations than NW02.

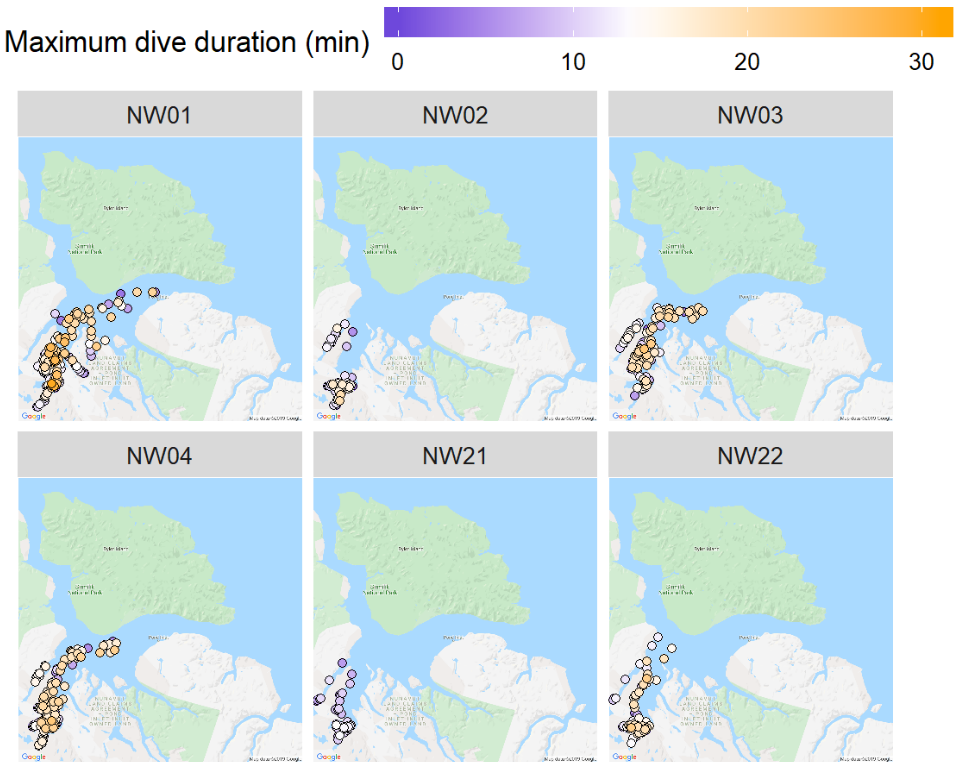

Figure 4-57: Maximum dive duration (min), by tagged narwhal (averaged by 4 h time periods).

Note: Mean values across all animals shown in white.

Based on the smoothing trend curve (i.e., not accounting for any other pertinent variables), there was no directionality in the relationship between total duration and vessel distance (i.e., there was no difference in response to an approaching vessel and a vessel moving away) (Figure 4-58). Therefore, the relationship was subsequently modeled without directionality to maximize sample size in the near vicinity of vessels.

When no vessels were present within 10 km from the narwhal and the dive was a bottom dive (>75% of the available bathymetry depth), the smoothing trend curve suggested that mean values of narwhal-specific dive durations ranged between 7.9 min and 13.6 min (Figure 4-58). When no vessels were present within 10 km and the dive was not a bottom dive, dive duration ranged between 3.2 min and 4.3 min. Within the designated 10 km exposure zone, dive duration changed in response to distance from a vessel, but only if the current dive was a bottom dive. When the dive was a bottom dive and a vessel was in close proximity (0-2 km), mean dive durations were generally shorter (approximately 11-13 min) than when a vessel was further away (2-8 km; approximately 13-14 min).

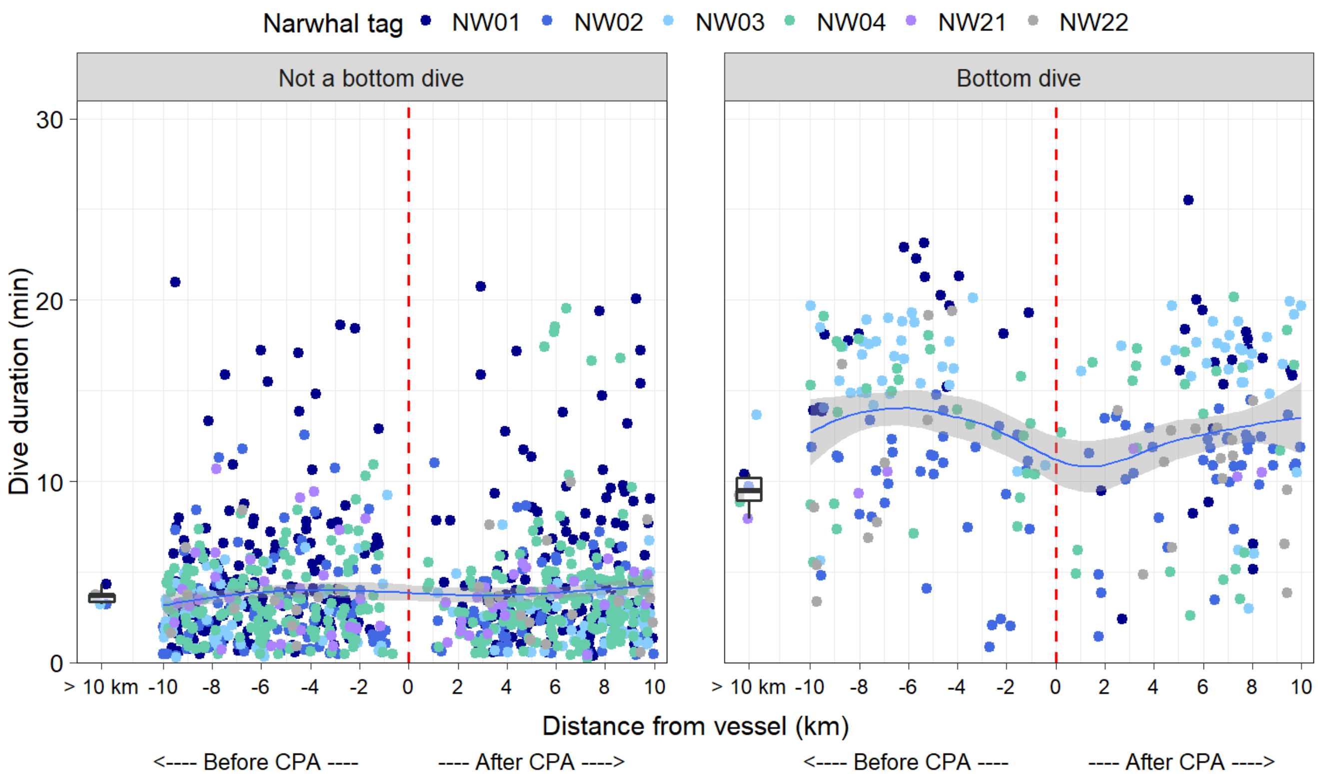

Figure 4-58: Dive duration, by tagged narwhal, distance from vessel (rounded to 1 km), and whether the current dive was a bottom dive (>75% of available bathymetry).

Note: Boxplot summarizes narwhal-specific dive duration when no vessels were present within 10 km from the narwhal. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

As stated in Section 3.5.2, dive duration (min) was analyzed using mixed effect linear models. In the analysis, the model's fixed effects included whether the narwhal was within the exposure zone (≤10 km from a vessel), distance from vessel if present (km; 3rd degree polynomial), maximum dive depth (m; 5th degree polynomial), whether the current dive was a bottom dive (>75% of the available bathymetry depth), whether the preceding dive was a bottom dive, duration of the preceding dive (min), substratum, an interaction between distance between narwhal and vessel and whether the current dive was a bottom dive, an interaction between whether there was a vessel within 10 km and whether the current dive was a bottom dive, as well as all two- and three-way interactions between the duration of the preceding dive, whether the preceding dive was a bottom dive, and whether the current dive was a bottom dive. The random effect was a random intercept by narwhal.

The interaction between distance from a vessel and whether the current dive was a bottom dive was statistically significant (P=0.035). The interaction between the effect of exposure and whether the current dive was a bottom dive was not significant (P=0.3), as was the main effect of exposure (P=1.0). The effects of maximum dive depth and substratum were statistically significant (P<0.001), as was the three-way interaction between the duration of the preceding dive, whether the preceding dive was a bottom dive, and whether the current dive was a bottom dive (P<0.001). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.793 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.805. Test statistics and coefficient estimates for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -17% or a +15% effect size in the test of the overall effect of distance from vessel (Appendix C). In comparison, the largest absolute magnitude of the observed effect sizes was 24%. That is, the test had sufficient statistical power to detect both the observed effect sizes and considerably smaller effect sizes.

The model predicted a slight decrease in dive duration in the immediate vicinity of vessels when the current dive was a bottom dive, where mean predicted dive duration decreased from 12.1 min when no vessels were within 10 km of the narwhal, to 11 min at 1 km from a vessel, and 8.9 min at 0 km from a vessel (26% reduction relative to non-exposure; Figure 4-59). However, dive duration values when no vessels were present within 10 km from the narwhal were only significantly different from dive duration when the vessel was 0 km from narwhal (P=0.026) and 4 km from narwhal (P=0.046), and not significantly different from dive durations when the vessel was at any other distances (Table 4-13). The test had sufficient power (>0.8) to detect a distance-specific effect size of -30% or +20% when the current dive was a bottom dive. The observed effects were all of reduction, rather than increase, in the response variable, and the strongest effect was -24% (Appendix C). That is, while statistical power at observed effect sizes was not sufficient (≤0.8), the multiple comparisons still detected a significant effect at 0 km distance.

When the current dive was not a bottom dive, the reduction was minimal, from 4.1 min when no vessels were present within 10 km to 3.6 min when a vessel was 0 km from the narwhal (12% reduction relative to non-exposure). When the current dive was not a bottom dive, only the multiple comparison at 2 km from the narwhal to when no vessels were present within 10 km was statistically significant (Table 4-13). The statistically significant comparisons at 2 km (for non-bottom dives) and 4 km (for bottom dives) are likely an artifact of the variability associated with the predictions, rather than an ecologically important effect. That is, the only statistically significant result that has a biologically plausible basis is for the comparison of dive durations under non-exposure to the duration of bottom dives when vessels are at 0 km. The test had sufficient power (>0.8) to detect a distance-specific effect size of -25% or +20% when the current dive was not a bottom dive. The observed effects were all of reduction, rather than increase, in the response variable, and were smaller than for bottom dives (Appendix C). That is, the statistical power at observed effect sizes was not sufficient (≤0.8) to detect the observed effects at close proximity to vessels.

Dive duration depended on maximum dive depth (Figure 4-59). Mean predicted dive durations increased from 1.2-3.2 min when dives were shallow (≤20 m) up to 13.7 min for dives at 300 m depth. Subsequent increases in dive depths resulted in a slight increase in mean predicted dive duration, up to 18.9 min for dives at 700 m depth. The shortest dives were estimated for Eclipse Sound and the longest dives were estimated for Milne Inlet.

In summary, the 2017-2018 dive data support rejection of the null hypothesis (**$H5_0$**) that dive duration does not change significantly during vessel exposure events. However, the effect of vessel exposure was only significant at close proximity (<1 km from vessel), and only when narwhal were undertaking a bottom dive. **Considering the prediction that narwhal engaged in foraging activity would exhibit dives that are relatively longer in duration and that those exposed to vessel traffic may cease foraging activity in response to a perceived threat, these results suggest that narwhal potentially engaged in foraging may experience disturbance effects when <1 km of a transiting vessel.**

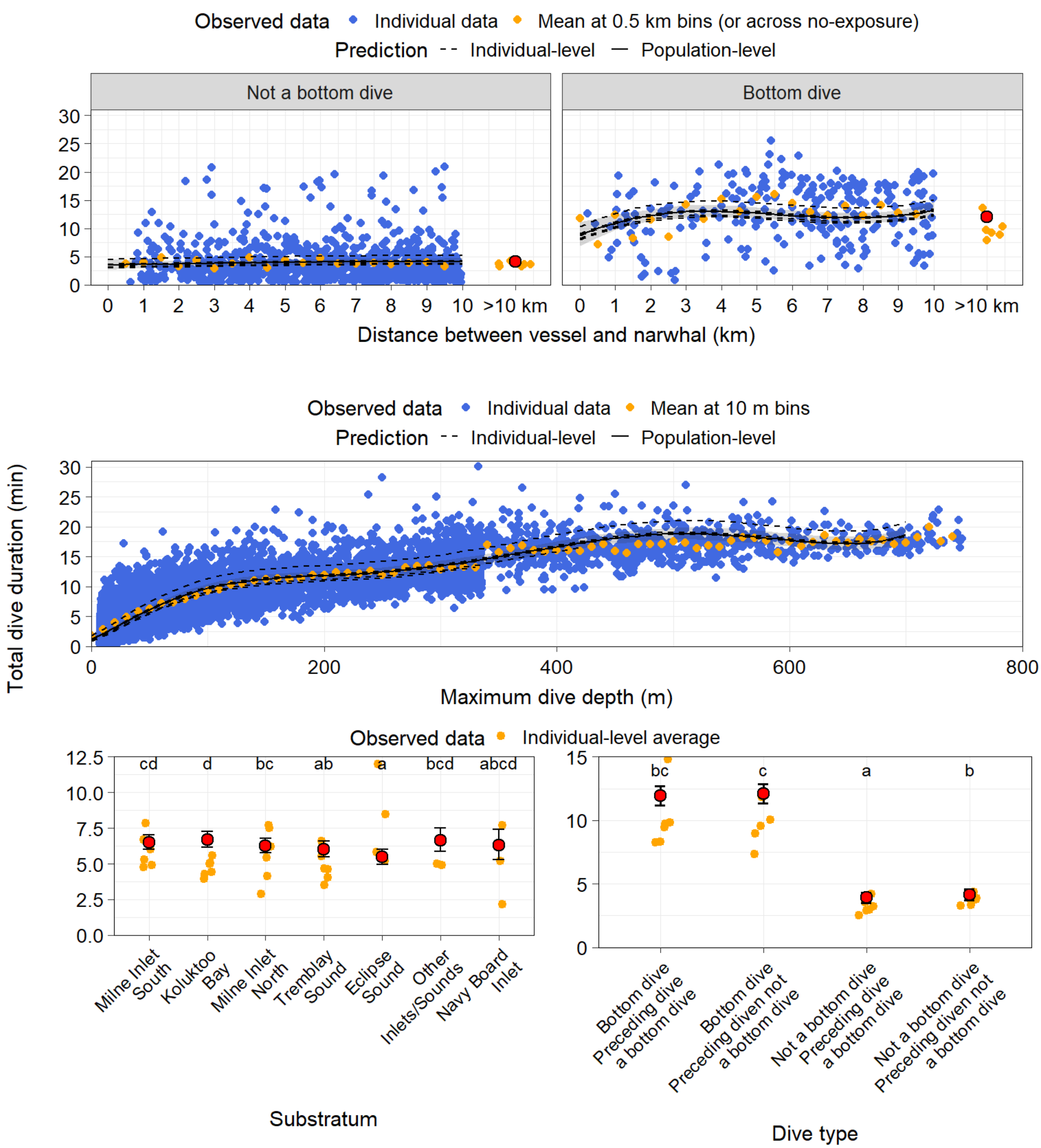

Figure 4-59: Dive duration (min) relative to distance between narwhal and vessel (km; top), maximum dive depth (m; middle), substratum (bottom left), and type of dive and preceding dive (bottom right).

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.

Table 4-13: Multiple comparisons of narwhal dive duration predictions between non-exposure and incremental exposure distances from vessel (statistically significant values shown in bold)

Distance from Vessel (km)	Multiple Comparisons to Non-exposure – Least-squares Means with *P* values in Brackets	
	Current Dive not a Bottom Dive	Current Dive a Bottom Dive
0	3.6 (0.671)	**8.9 (0.026)**
1	3.7 (0.247)	11.0 (0.259)
2	**3.8 (0.027)**	12.3 (0.916)
3	3.8 (0.054)	13.0 (0.110)
4	3.9 (0.263)	**13.0 (0.046)**
5	4.0 (0.624)	12.8 (0.119)
6	4.1 (0.948)	12.3 (0.787)
7	4.1 (1.000)	12.0 (0.982)
8	4.2 (0.986)	11.9 (0.896)
9	4.2 (0.968)	12.2 (0.959)

4.2.2.6 Descent Speed

The descent speed (m/s) of the four female narwhal was on average higher than that of the two male narwhal (Figure 4-60; Table 4-14). Individual differences were also apparent within sex, where NW02 had the highest and most variable descent speeds among the females, while NW21 had the lowest and least variable descent speeds among the females. No differences in mean descent speeds were apparent between exposure and non-exposure events, although maximum descent speeds were higher during non-exposure than during exposure events (Table 4-14).

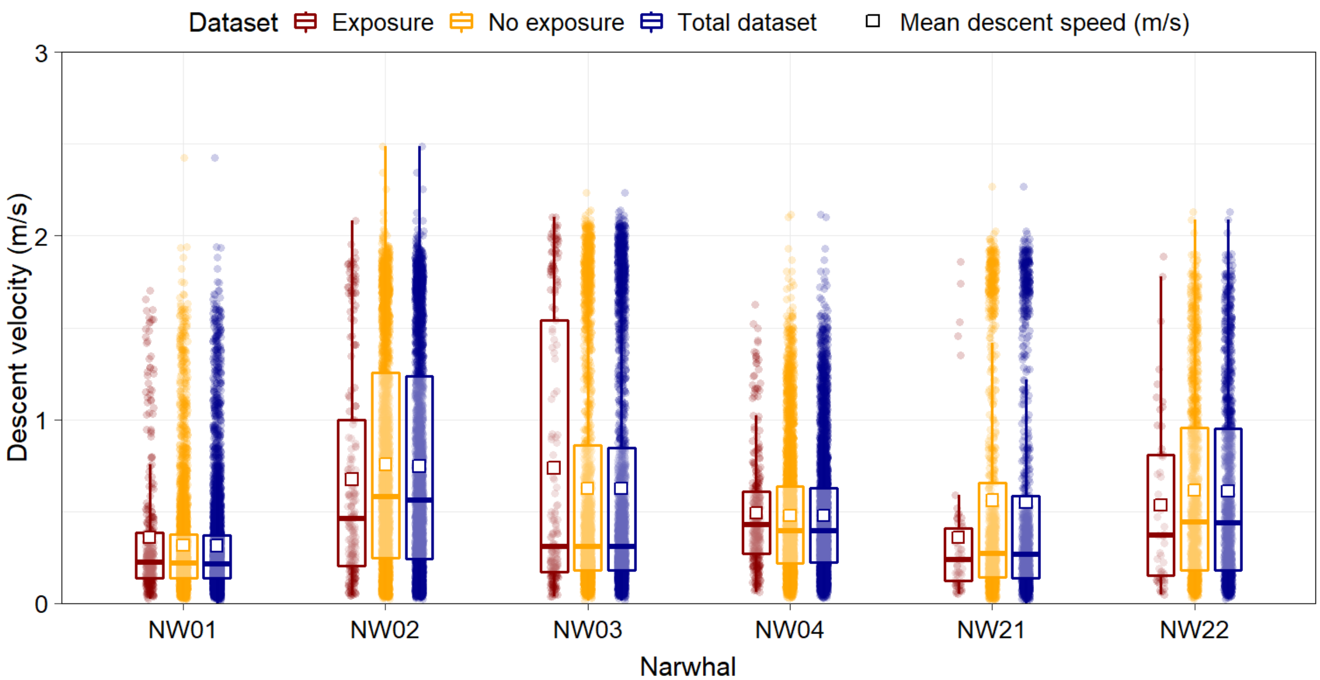

Figure 4-60: Descent speed (m/s) within each dive, by tagged narwhal under exposure, non-exposure, and in the total dataset

Note: Summary statistics (minimum, maximum, and mean) are provided in Table 4-14.

Table 4-14: Summary statistics of narwhal descent speed (m/s)

Narwhal	Sex	Total dataset			Exposure Zone (≤10 km)			Non-exposure Zone (>10 km)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
NW01	M	0.00	0.31	2.42	0.03	0.36	1.70	0.02	0.32	2.42
NW02	F	0.02	0.75	2.49	0.04	0.68	2.08	0.02	0.76	2.49
NW03	F	0.02	0.62	2.24	0.04	0.74	2.10	0.02	0.63	2.24
NW04	M	0.03	0.48	2.11	0.06	0.49	1.63	0.03	0.48	2.11
NW21	F	0.00	0.55	2.27	0.05	0.36	1.86	0.02	0.56	2.27
NW22	F	0.02	0.61	2.13	0.05	0.53	1.89	0.02	0.62	2.13

The descent speeds of narwhal (summarized over 4 h periods) tended to vary based on geographic location and tagged individual (Figure 4-61). For example, NW02 generally exhibited high descent speeds overall (Figure 4-60), particularly when diving south of the Bruce Head peninsula, but demonstrated low to intermediate descent speeds when in Tremblay Sound. NW03 exhibited relatively high descent speeds when in Eclipse Sound (Figure 4-61), with dives typically extending to the full extent of the available bathymetry depth (Figure 4-48), while NW01 typically exhibited lower descent speeds throughout the RSA.

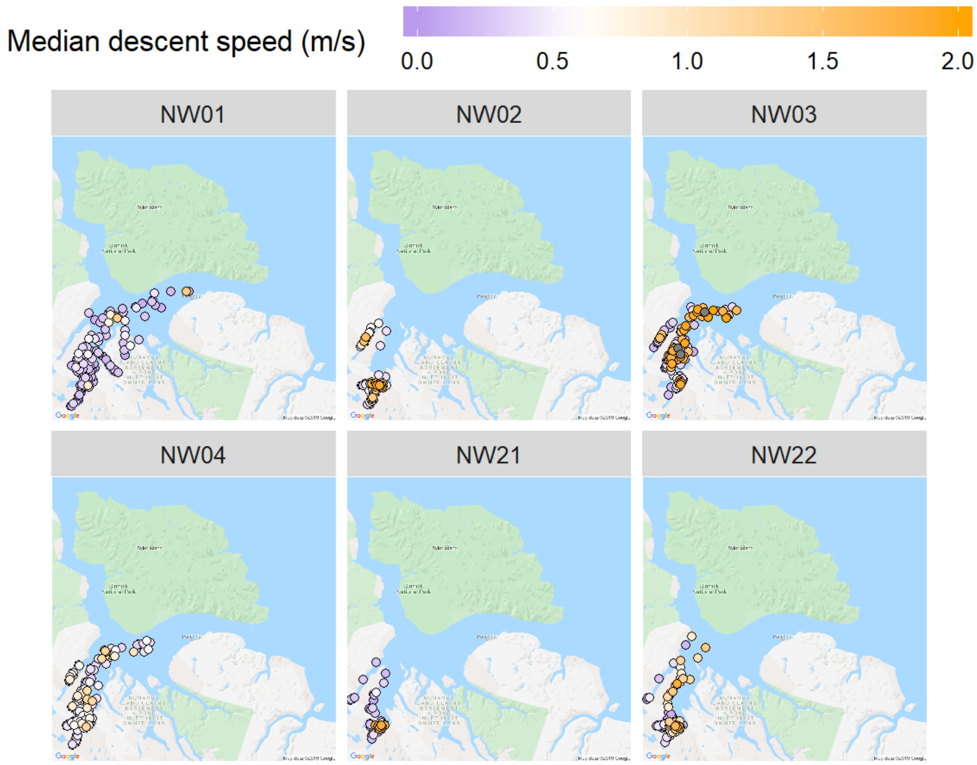

Figure 4-61: Median descent speed (m/s) by tagged narwhal (averaged by 4 h time periods)

Note: Mean values across all animals shown in white.

Based on the smoothing trend curve (i.e., not accounting for any other pertinent variables), there was no directionality in the relationship between descent speed and vessel distance (i.e., there was no difference in response to an approaching vessel and a vessel moving away; Figure 4-62). Therefore, the relationship was subsequently modeled without directionality to maximize sample size in the near vicinity of vessels.

When no vessels were present within 10 km from the narwhal and the dive was a bottom dive (>75% of the available bathymetry depth), the smoothing trend curve suggested that descent speed ranged between 0.6 m/s and 1.5 m/s (Figure 4-62). When no vessels were present within 10 km and the dive was not a bottom dive, descent speed ranged between 0.2 m/s and 0.4 m/s. Within the designated 10 km exposure zone, descent speed was shown to change in response to distance from a vessel, with the change being greatest when the dive was a bottom dive. Of note, when narwhal undertook a bottom dive and a vessel was in close proximity (0-4 km), descent speed was shown to be lower than when a vessel was further away (4-10 km).

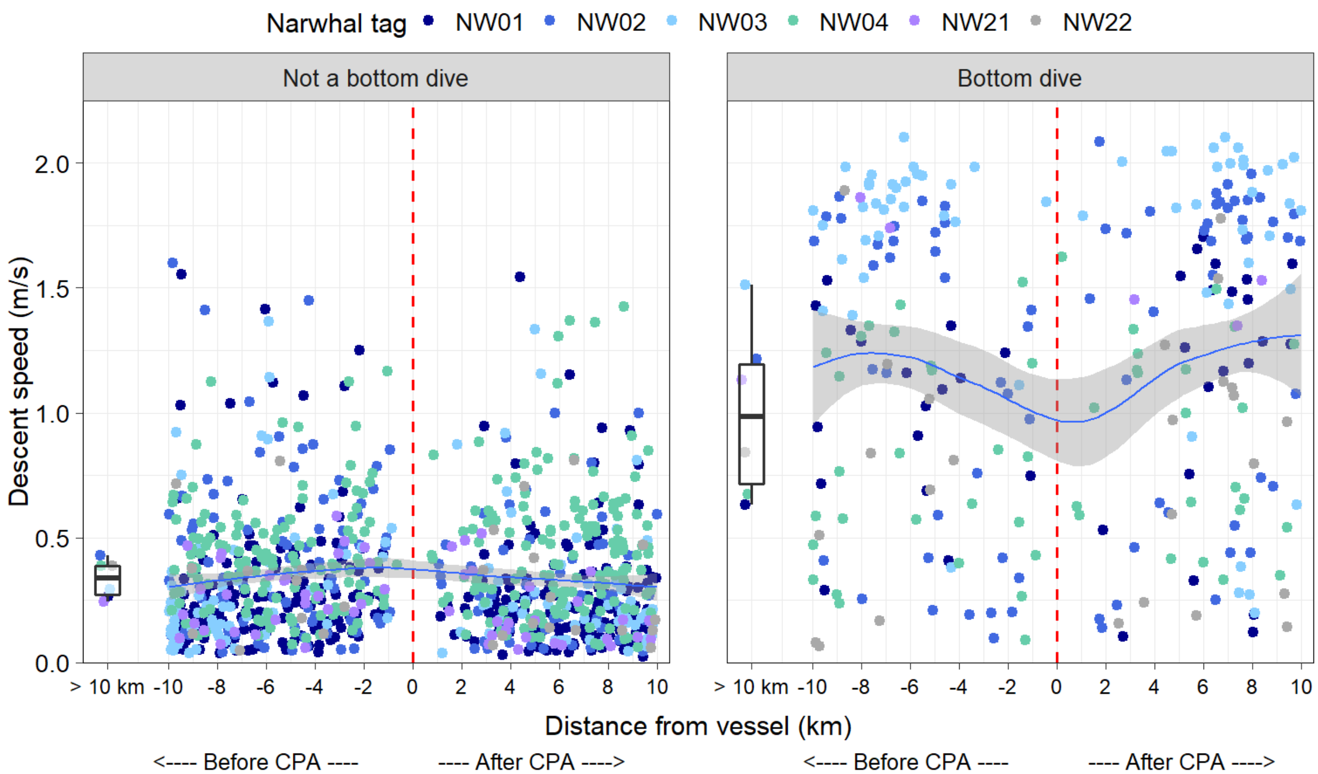

Figure 4-62: Descent speed, by tagged narwhal, distance from vessels (rounded to 1 km), and whether the current dive was a bottom dive (>75% of available bathymetry).

Note: Boxplot summarizes narwhal-specific descent speed when no vessels were present within 10 km from the narwhal. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

As stated in Section 3.5.2, descent speed (m/s) was analyzed using mixed effect linear models. In the analysis, the model's fixed effects included whether the narwhal was within an exposure zone (≤10 km from a vessel), distance from vessel if present (km; 2nd degree polynomial), maximum dive depth (m; 3rd degree polynomial), whether the current dive was a bottom dive (>75% of the available bathymetry depth), whether the preceding dive was a bottom dive, descent speed of the preceding dive (m/s), substratum, an interaction between distance between narwhal and vessel and whether the current dive was a bottom dive, an interaction between whether there is a vessel within 10 km and whether the current dive was a bottom dive, as well as all two- and three-way interactions between the descent speed of the preceding dive, whether the preceding dive was a bottom dive, and whether the current dive was a bottom dive. The random effect was a random intercept by narwhal.

The main effects and the interactions involving distance from vessel and whether a vessel was within 10 km from narwhal were not statistically significant (*P*>0.4 for all). The three-way interaction between descent speed of the preceding dive, whether the preceding dive was a bottom dive, and whether the current dive was a bottom dive was significant (*P*<0.001), as were the main effects of maximum dive depth (*P*<0.001) and substratum (*P*=0.04). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.671 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.682. Test statistics and coefficient estimate for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -22% or a +20% effect size in the test of the overall effect of distance from vessel (Appendix C). In comparison, the largest absolute magnitude of the observed effect sizes was 11%.

That is, the test had sufficient statistical power to detect a reasonable effect size, however the observed effect sizes were smaller, resulting in lack of statistical significance.

When narwhal were undertaking bottom dives, the model predicted a slight decrease in descent speed in the immediate vicinity of vessels, where mean descent speed decreased from 1.01 m/s when no vessels were within 10 km from the narwhal, to 0.94 m/s at 1 km from a vessel, and 0.91 m/s at 0 km from a vessel (Figure 4-63). When narwhal were not undertaking bottom dives, the model predicted a slight increase in descent speed in the immediate vicinity of vessels, where mean descent speed increased from 0.32 m/s when no vessels were within 10 km from the narwhal, to 0.34 m/s at 0 km from a vessel (Figure 4-63). However, the relationship overall between descent speed and distance from vessel was not significant, and no multiple comparisons were performed.

Descent speed depended on dive depth (Figure 4-63). Mean predicted speeds increased from 0.30 m/s when dives were very shallow (20 m) to 0.63 m/s for dives at 100 m depth and 0.98 m/s for dives at 200 m. Subsequent increases in dive depths resulted in a slower increase in mean predicted descent speed, up to 1.42 m/s for dives at 700 m depth. There was no significant difference between descent speeds within the different substrata. The lowest descent speeds were estimated when both current and preceding dives were not bottom dives (Figure 4-63), which was significantly different from the remaining combinations of whether the current or preceding dives were bottom dives, although estimated speeds when the current dive was a bottom dive were higher. This result is expected, since a narwhal may be diving faster when exhibiting foraging behavior.

In summary, the 2017-2018 dive data do not support rejection of the null hypothesis (**$H6_0$**) that descent speed does not significantly change during vessel exposure events. **Considering the prediction that an increase in descent speed by narwhal exposed to vessel traffic would indicate a potential avoidance response to a perceived threat, neither the smoothing trend curve nor the modeling results suggest that narwhal increase their descent speed in the presence of transiting vessels.**

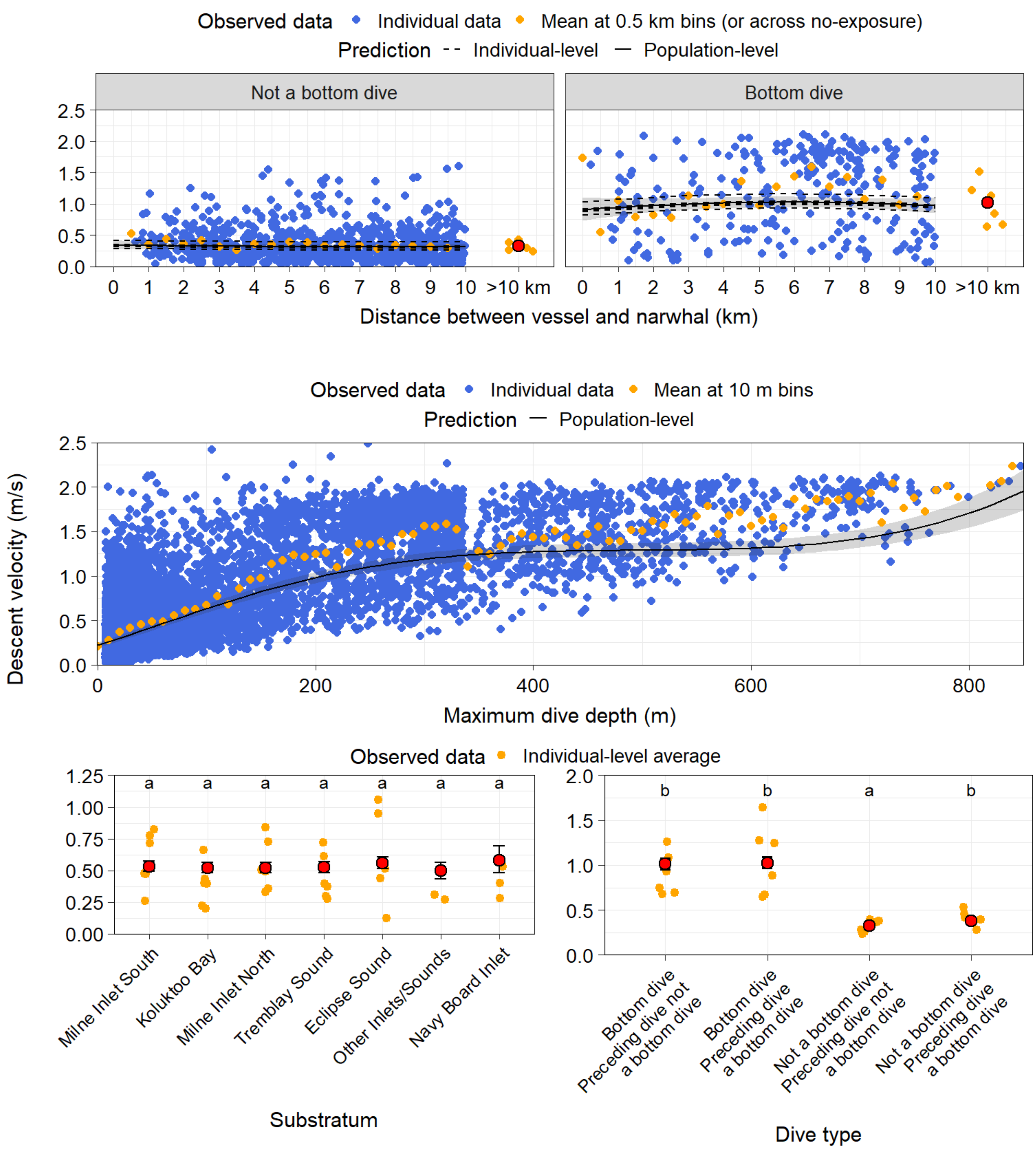

Figure 4-63: Descent speed (m/s) relative to distance between narwhal and vessel (km), maximum dive depth (m), substratum, and whether the current and preceding dives were bottom dives.

Note: Means with different letters are significantly different from each other. 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.

4.2.3 Surface Behavior in Relation to Vessel Traffic

4.2.3.1 Turning Angle

A total of 14 narwhal tagged during the 2017 and 2018 field seasons had sufficient GPS point data to estimate turning angles. Unlike the following section (Section 4.2.3.2) that assesses narwhal orientation relative to vessels, the analysis of turning angle does not assess whether narwhal turn toward or away from a given vessel but only that their turning angle changes, and whether that change is related to distance from a vessel. That is, a small turning angle by a narwhal may indicate a linear travel mode, whereas a large turning angle may indicate avoidance (e.g., turning back on their own track) or simply nondirectional travel.

It was predicted that the effect of vessel exposure would increase with decreasing distance. Visual data exploration prior to analysis supported this hypothesis (Figure 4-64), with higher average turning angles closer to the vessels, either before or after the CPA. Narwhal turning angles were shown to decrease, on average, with an increase in distance from vessels, approaching the median of non-exposure values approximately 4-8 km from the vessel.

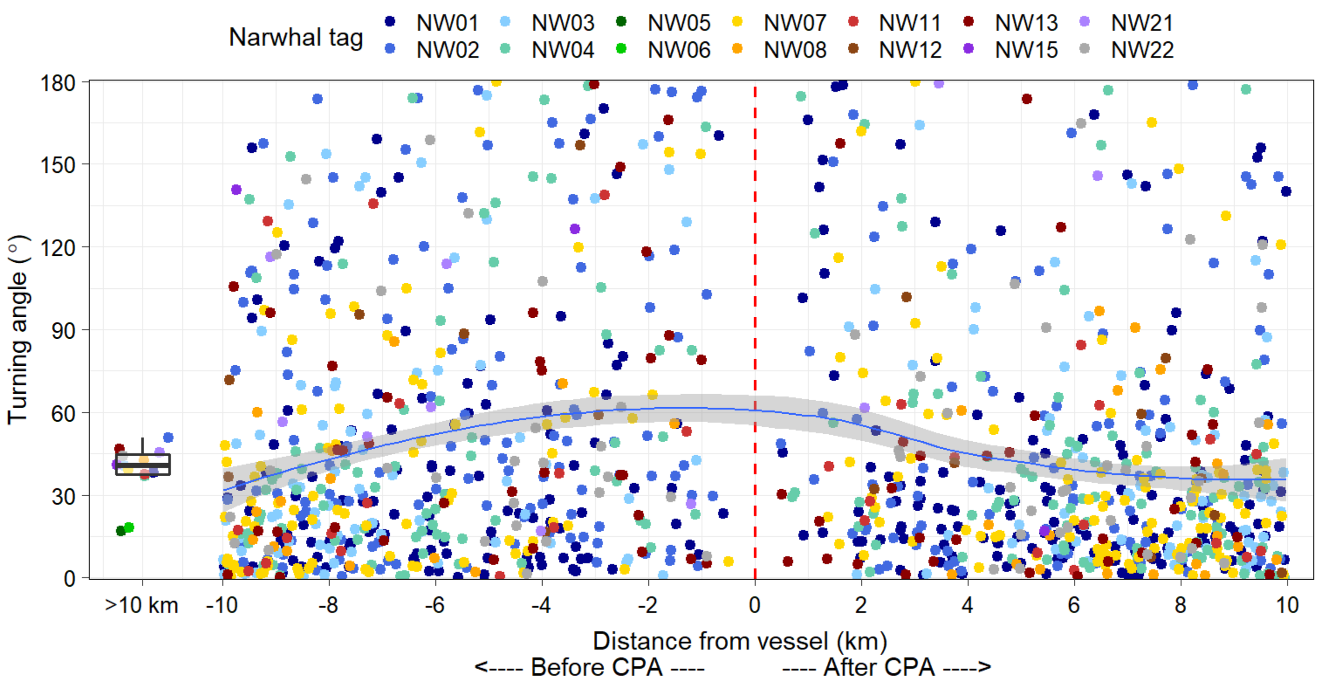

Figure 4-64: Observed turning angles relative to directional distance from vessel during exposure and non-exposure events

Note: Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

The turning angle data were analyzed using a model that included non-directional distance as a predictor (i.e., did not incorporate an effect of whether the distance represented data collected before or after CPA), because of the sparse data available at close proximity to vessels and the lack of strong directionality in response (Figure 4-64). There were significant effects of distance from vessel on turning angle (*P*=0.002), substratum (*P*<0.001), and the effect of turning angle at the previous GPS point (*P*<0.001). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.044 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.059. Test statistics and coefficient estimates for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -39% or a +41% effect size in the test of the overall effect of distance from vessel (Appendix C). In comparison, the largest absolute magnitude of the observed effect sizes was 42%. That is, the test had sufficient statistical power to detect the observed effect size.

The model predicted increasing turning angles when distance between narwhal and vessel decreased (Figure 4-65). The prediction that the effect of vessel exposure would increase with decreasing distance was therefore supported based on the results of the turning angle model. Alternatively, if vessel distance had no effect on narwhal turning angle, the slope of the relationship would have been flat, with a large *P* value.

To assess the distance at which vessel transit affects narwhal turning angle, multiple comparisons were performed on model predictions. When no vessels were present within 10 km from narwhal, mean predicted turning angle was 38°. The predicted turning angle increased in the vicinity of vessels to 51° at a distance of 1 km (34% increase) and 54° at a distance of 0 km (42% increase). The results of multiple comparisons indicated that narwhal turning angles were significantly ($P<0.05$) higher when vessels were within 1-4 km from the individual relative to when no vessels were within 10 km (see Table 4-15 for detailed value). The adjusted *P* value at 0 km from a vessel relative to non-exposure estimates was not significant ($P=0.1$), likely due to the increased uncertainty in prediction at distances ≤1 km due to low sample sizes (Figure 4-65). Overall, turning angles were higher when a vessel was within 4 km from narwhal relative to non-exposure estimates. The test had sufficient power (>0.8) to detect a distance-specific effect size of -40% or +50%; in comparison, the largest observed effect size was +42% (Appendix C). That is, the multiple comparisons detected significant differences despite not having sufficient statistical power at the observed effect sizes.

Contrary to results presented in Golder (2019), where distance from shore was found to have a significant effect on turning angles (P<0.001), distance from shore was not a significant variable in the current analysis (P=0.3), due to the inclusion of substratum as an independent variable in the model.

During exposure to vessel traffic, narwhal were generally close to shore (Figure 4-13). 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 indicates that animals tended to have greater surface time at intermediate distances from a vessel, the higher densities of GPS locations present has the potential to skew results in this component of the analysis.

In summary, the analysis of narwhal turning angle supports rejection of the null hypothesis (**$H7_0$**) that narwhal turning angles do not significantly change during vessel exposure events. Statistically significant effects of vessel exposure on narwhal turning angle was evident within 1-4 km of the vessel. **Considering the prediction that a small turning angle by narwhal is indicative of a linear travel mode, whereas a large turning angle may indicate avoidance (e.g., turning back on their own track) or simply nondirectional travel, these results suggest that narwhal turn back on their own track, potentially demonstrating avoidance, when within 1-4 km of a transiting vessel.**

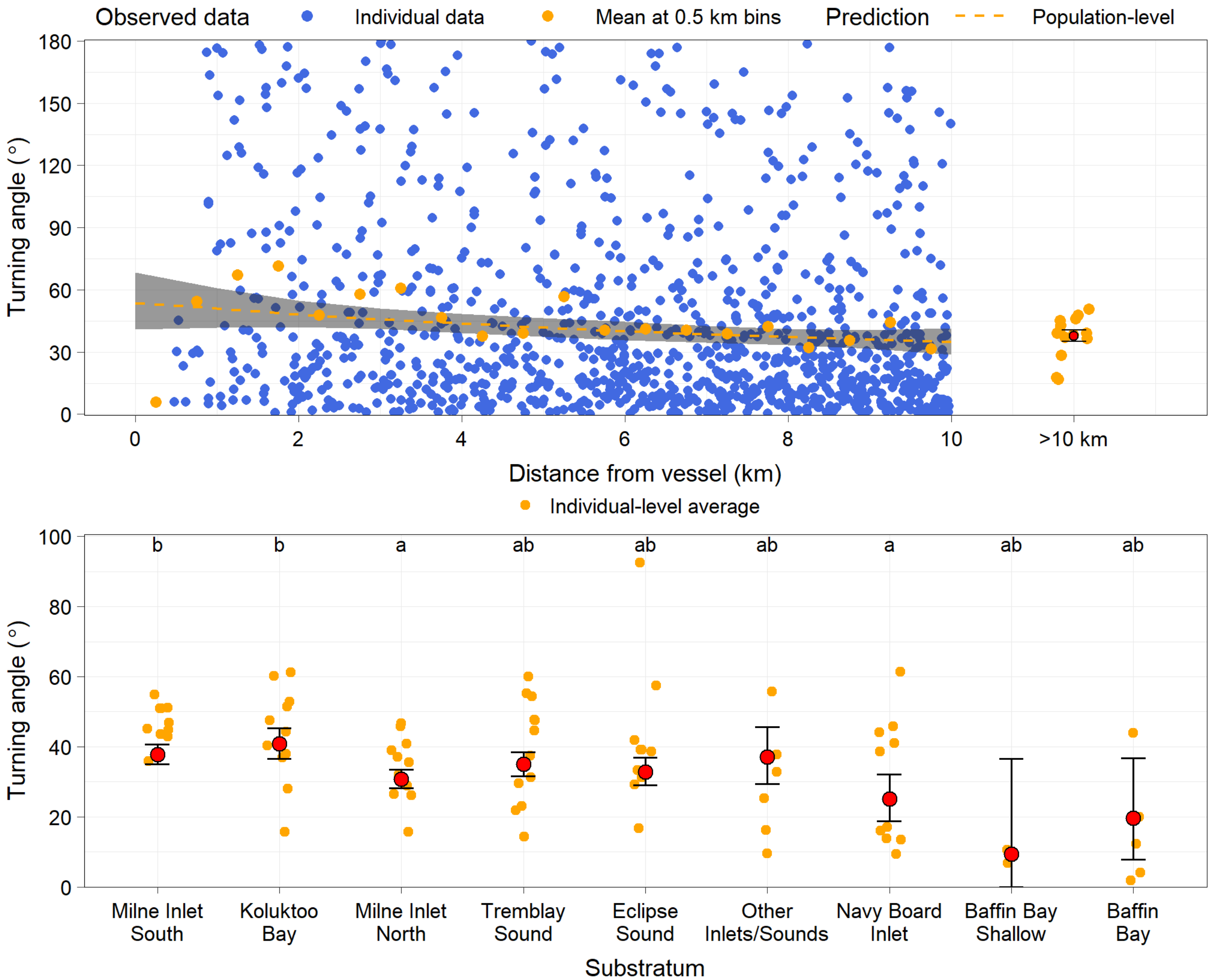

Figure 4-65: Observed and predicted narwhal turning angles by relative to distance from vessel during exposure and non-exposure events, and by substratum.

Note: Blue points depict raw data; orange points depict means of raw data, by distance or by narwhal (in top panel, >10 km from vessel). Lines and ribbons (and error bar in top panel) show predicted mean and 95% confidence intervals.

Table 4-15: Multiple comparisons of turning angles between non-exposure predictions and predictions at specific distances between narwhal and vessels; statistically significant values are shown in bold.

Distance from Vessel (km)	Multiple Comparisons to Non-exposure – Least-squares Means with *P* values in Brackets
0	53.7 (0.112)
1	**50.9 (0.029)**
2	**48.2 (0.005)**
3	**45.9 (0.003)**
4	**43.7 (0.029)**
5	41.8 (0.313)
6	40.0 (0.829)
7	38.5 (0.998)
8	37.1 (0.994)
9	35.9 (0.898)
10	34.9 (0.897)

4.2.3.2 Travel Orientation Relative to Vessels

A total of 11 narwhal tagged during the 2017 and 2018 field seasons were recorded within 10 km of a vessel and had sufficient GPS data to analyze narwhal travel orientation relative to vessel location (i.e., the angle between narwhal travel direction and the vessel position). Tags NW05, NW06, and NW15 were either not recorded within 10 km from a vessel, or data recorded were not sufficient to calculate orientation (e.g., only two consecutive GPS points within 10 km from a vessel, whereas three points are required to calculate both relative angle and the relative angle at the previous position). Since the dataset focused on the orientation between narwhal and vessels, the dataset available for modeling was restricted to cases where a vessel was present, and data from narwhal locations with no vessel exposure were not modeled.

Narwhal travel orientation relative to vessels was modeled as a function of distance from the vessel. Mean values less than 90° were expected if distance from a vessel had no effect on narwhal travel orientation as an angle less than 90° would indicate narwhal heading toward a vessel (regardless of the orientation of the vessel itself). An angle larger than 90° would indicate a narwhal heading away from a vessel and would be expected under avoidance behavior. It was predicted that the effect of vessel exposure would increase with decreasing distance. Visual data exploration prior to analysis supported this hypothesis (Figure 4-66), with relative angles between narwhal and vessels greater than 90° when narwhal were closer to the vessels, either before or after the CPA.

Unlike the analysis of narwhal turning angles (Section 4.2.3.1), where narwhal response was similar before and after the CPA, the travel orientation of narwhal relative to vessels had a strong directionality. Travel orientation of narwhal relative to vessels increased steadily before CPA, peaked at approximately 2 km after CPA, and decreased slightly with increasing distance after CPA (Figure 4-66).

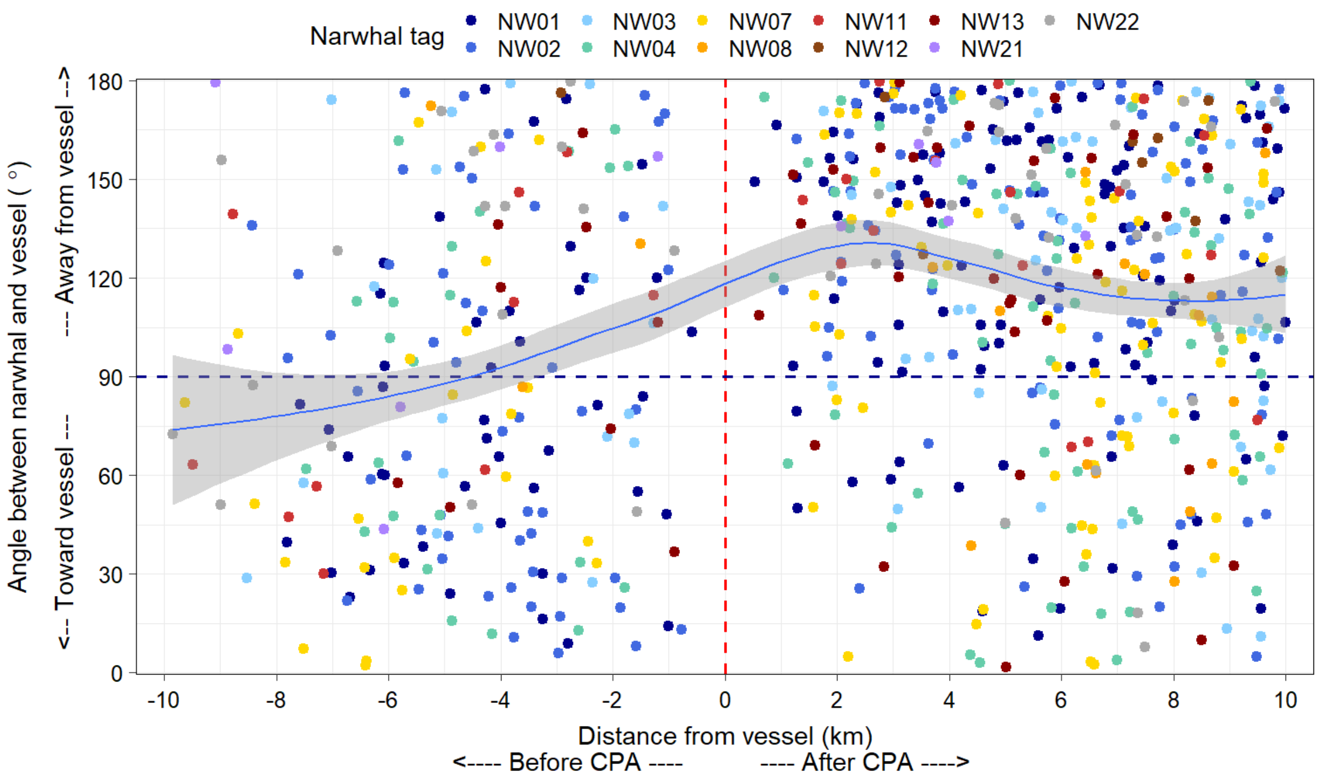

Figure 4-66: Observed and predicted orientation of narwhal relative to directional distance from vessels during exposure events.

Note: Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

Due to the pronounced directionality of response, the model included an effect of distance from a vessel, an effect of whether the data point was before or after the CPA, and the interaction between the two variables. In addition, the effect of substratum was included in the model, to account for possible differences in narwhal travel and shipping track location relative to the shoreline.

Both the effect of distance and the effect of Before/After CPA were significant ($P<0.001$), whereas the interaction between the two variables was not significant ($P=0.5$). This indicates that while relative orientation differed between before and after CPA, the rate of change in orientation (i.e., the slope of the relationship) was similar between the two periods. The effect of substratum was not significant ($P=0.9$). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.188 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.188. Test statistics and coefficient estimates for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -17% or a +13% effect size in the test of the overall effect of distance from vessel (Appendix C). In comparison, the largest absolute magnitude of the observed effect sizes was 40%. That is, the test had sufficient statistical power to detect both the observed effect sizes and considerably smaller effect sizes.

The prediction that the effect of vessel exposure would increase with decreasing distance was therefore supported based on the results of relative angle model (Figure 4-66). Alternatively, if vessel distance had no effect on the relative angle between narwhal and vessels, the slope of the relationship would have been flat, with a large *P* value. Contrary to the results presented in Golder (2019), where the effect of distance on relative angle was not significant (*P*=0.2) and where the model did not take into account the directionality of the effect relative to the CPA, the model presented here estimated a significant effect of vessel transit on relative angle, with a strong effect of Before/After CPA. Before CPA, relative angle increased from 73.0° when a vessel was 10 km from the narwhal to 101.0° at a distance of 0.5 km (38% increase). After CPA, relative angle decreased from 130.8 when the vessel was 0.5 km from the narwhal to 110.1° when the vessel was at a distance of 10 km (16% decrease). The predicted relative angle between narwhal and vessel decreased by 3.0° and 2.0° with every 1 km increase in distance between narwhal and vessel before and after CPA, respectively, and the effect was statistically significant. The difference between before and after CPA (where narwhal after CPA generally had relative angles approximately 30° higher than narwhal before CPA) indicates that after CPA, narwhal oriented themselves away from the vessel more often than before CPA.

Overall, vessel distance during transit had a significant effect ($P<0.001$) on the relative angle between narwhal and vessel, and the effect was different before and after CPA. Mean model predictions crossed the 90° value (representing expected mean under a random distribution of relative angles) between 4 km and 5 km from the vessel prior to the CPA and remained higher than 90° for the entire 10 km extent post CPA. That is, narwhal turned away from vessels when within 4-5 km of a vessel prior to the CPA and for the full extent of the 10 km exposure zone following the CPA.

In summary, analysis of narwhal travel orientation relative to vessels supports rejection of the null hypothesis (**$H8_0$**) that narwhal travel orientation does not significantly change during vessel exposure events. In addition to the overall significant effect of distance from vessel, the effect was higher post-CPA than prior to CPA. **Considering the prediction that narwhal travel orientation relative to vessels would be less than 90° if distance from a vessel had no effect on narwhal orientation (i.e., an angle less than 90° would be indicative of narwhal heading toward a vessel), results suggest that narwhal orient themselves away from transiting vessels, potentially demonstrating avoidance, within 4-5 km of a transiting vessel prior to the CPA, but for the full extent of 10 km post CPA.**

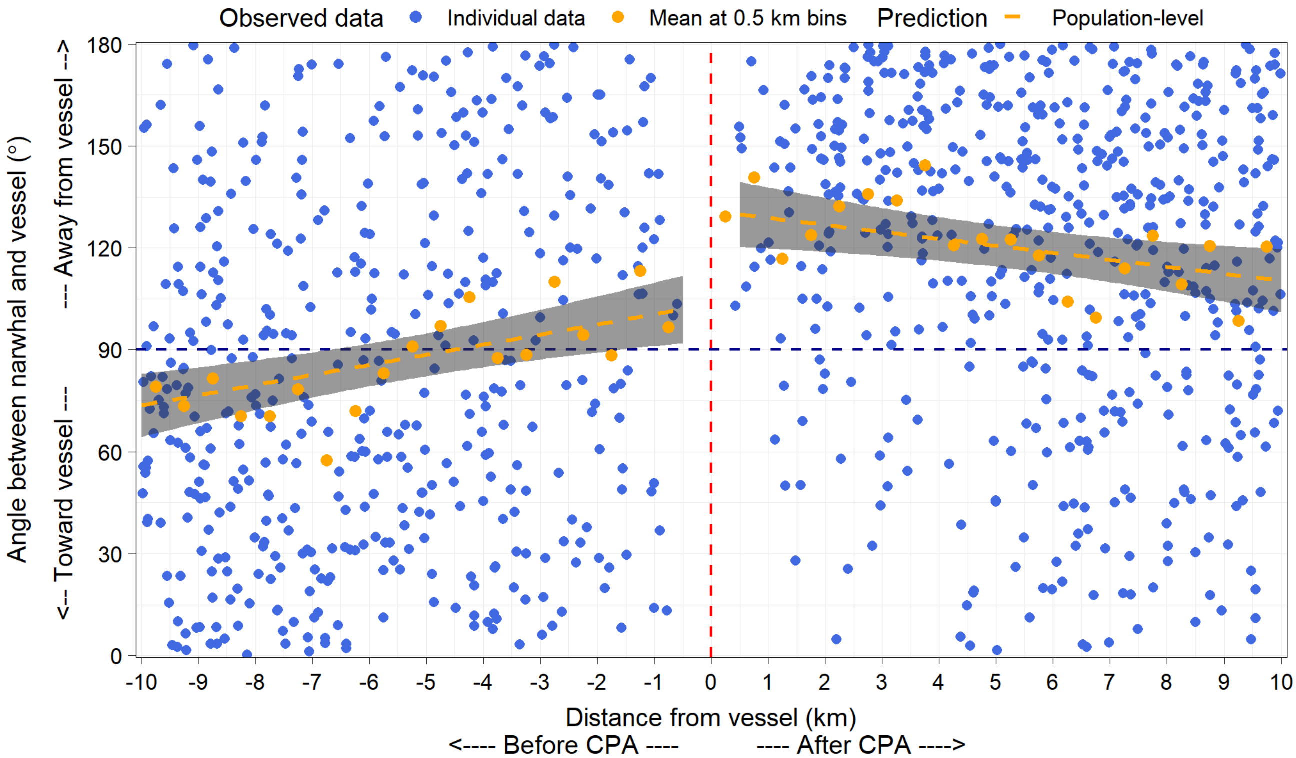

Figure 4-67: Observed and predicted angles between narwhal and vessels during exposure events.

Note: Blue points depict raw data; orange points depict means of raw data by distance. Lines and ribbons show predicted mean and 95% confidence intervals.

4.2.3.3 Horizontal Displacement

A total of 12 narwhal tagged during the 2017 and 2018 field seasons were recorded within 10 km of a vessel and had sufficient GPS point data to estimate horizontal displacement (Figure 4-68 and Figure 4-69). These points represent snapshots in time of narwhal locations relative to the vessel heading, but not relative to 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 a result of the 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, and 1 km of the vessel bow and stern (Figure 4-69). This gap in distribution in close proximity to vessels may indicate movement away from the vessel by narwhal (i.e., horizontal or vertical avoidance) but may also be a function of the low-resolution GPS location data available.

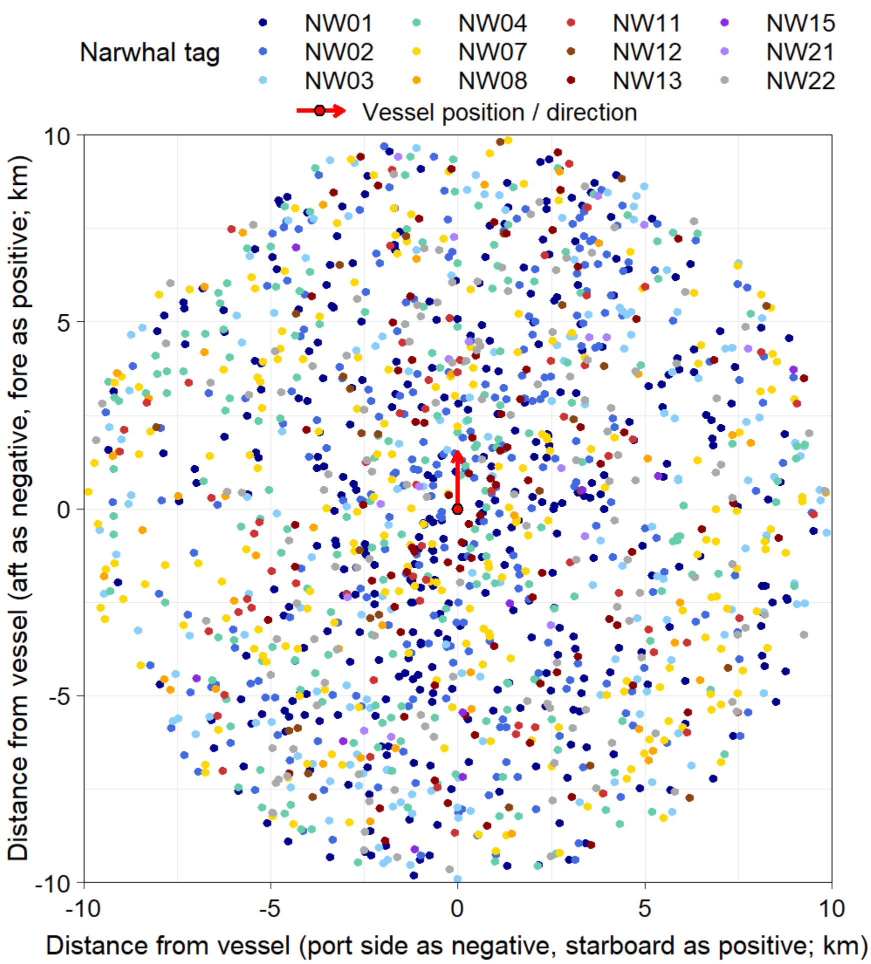

Figure 4-68: Relative distance between vessels and narwhal (limited to 10 km) during August, September, and October 2017-2018.

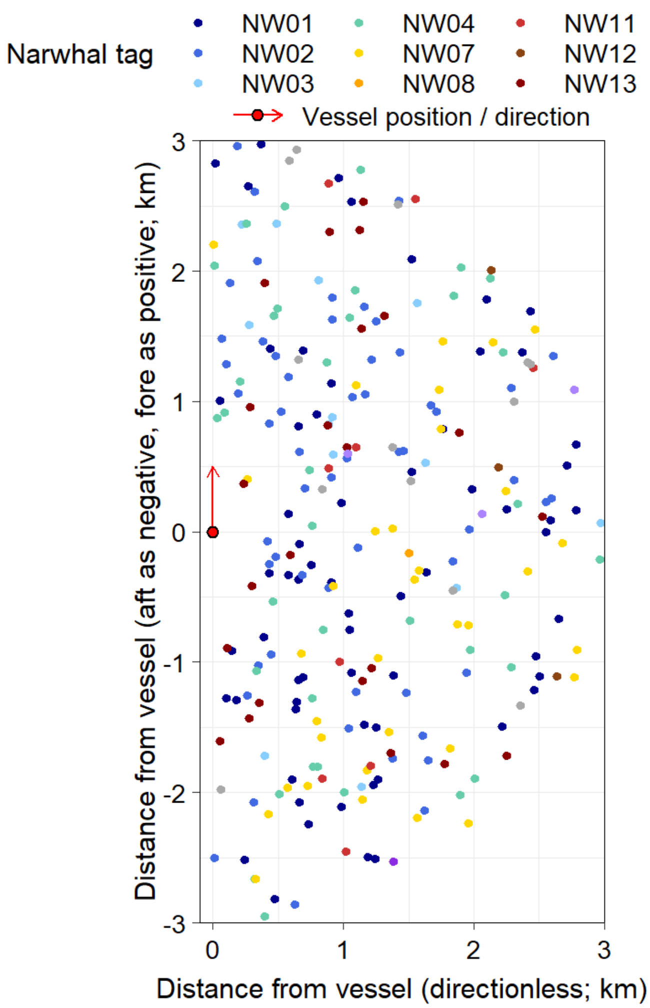

Figure 4-69: Distance between vessels and narwhal (limited to 3 km) during August, September, and October 2017-2018

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 4-70). 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 4-70), in accordance with the gap of recorded positions (Figure 4-69). 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=0.8), 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=0.3), despite the observed difference in narwhal density astern/forward relative to port/starboard at the immediate vicinity of the vessels.

In summary, analysis of narwhal horizontal displacement from vessels supports rejection of the null hypothesis (**H9$_0$**) that narwhal horizontal displacement does not significantly change during vessel exposure events. **Considering the prediction that narwhal would actively avoid transiting vessels at some distance from the vessel given the ability of toothed whales to perceive their environment via echolocation, the gap in narwhal GPS locations in close proximity to transiting vessels suggests avoidance behavior. However, this gap in distribution may also be a function of the low-resolution GPS location data available.**

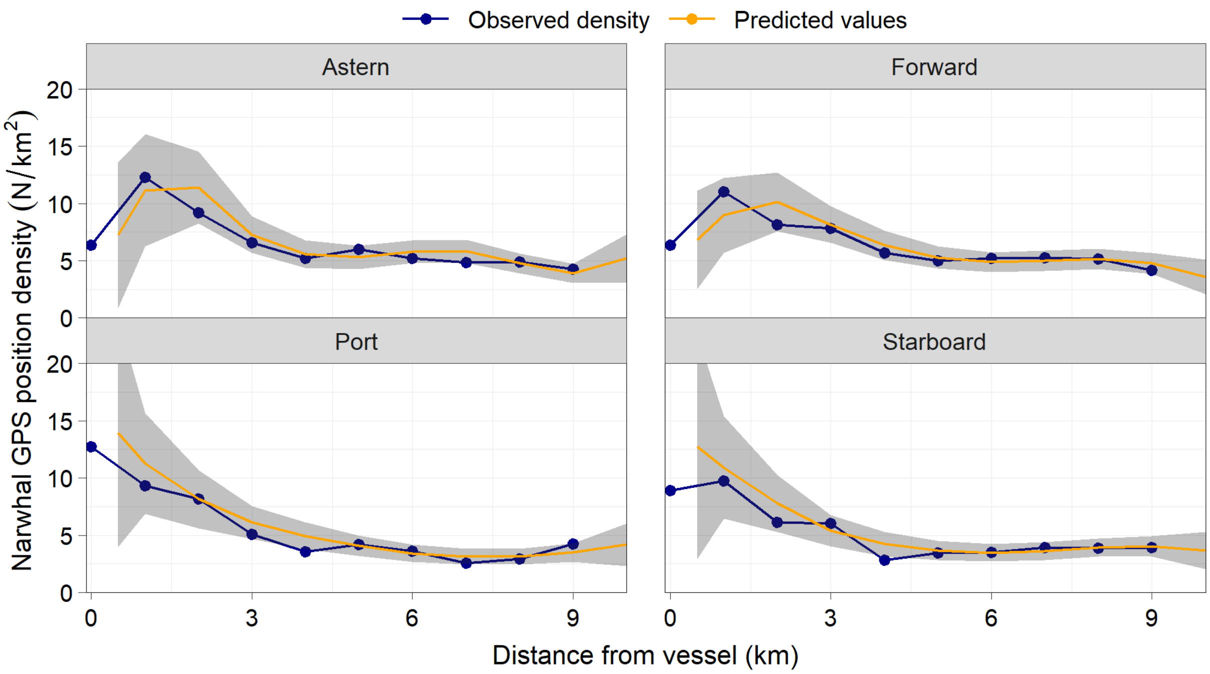

Figure 4-70: Observed (blue points) and predicted (orange lines) narwhal density at distance and position relative to the vessel.

Note: Data shown in Figure 4-68.

4.2.3.4 Effect of Repeated Exposure on Horizontal Displacement

As an assessment of narwhal habituation to vessel traffic, temporal changes to the time series of CPA distances between narwhal and vessels were modeled (Figure 4-71). The model included an effect of day/time and an effect of year (2017 vs 2018). Neither effect was statistically significant (P=0.1 and P=0.6, respectively). The model did not support random slopes (P value = 0.6), suggesting no strong individual variability in the change of distance from vessels. While in Golder (2019) a similar model indicated a significant effect of time, with a daily reduction of 39 m/day in the distance between narwhal and vessel, the current model did not find a significant effect of time, and only estimated reductions of 12-15 m/day. Test statistics and coefficient estimates for the model are provided in Appendix A. The test had sufficient power (>0.8) to detect a -43% or a +45% effect size in the test of the effect of time on CPA distance (Appendix C). In comparison, the observed effect size was -22%. That is, the test did not have sufficient statistical power to detect the observed effect size, likely due to the high variability in data.

In summary, the integrated 2017-2018 narwhal location data suggested that distance at CPA decreased over time, however the analysis did not have sufficient statistical power to detect a significant effect. Therefore, the analysis does not support rejection of the null hypothesis (**$H10_0$**) that CPA distance between narwhal and vessels does not significantly change throughout the shipping season, despite the 22% effect size. **Considering the prediction that a seasonal decrease in the CPA between narwhal and transiting vessels would indicate potential habituation to shipping activities along the Northern Shipping Route while an increase would indicate potential longer term avoidance or displacement, results indicating a marginal decrease in the CPA suggest potential habituation of narwhal to vessel traffic, though the findings were not statistically significant. Results also suggest no long-term avoidance of the Northern Shipping Route by narwhal nor displacement from the RSA by narwhal as a result of vessel traffic.**

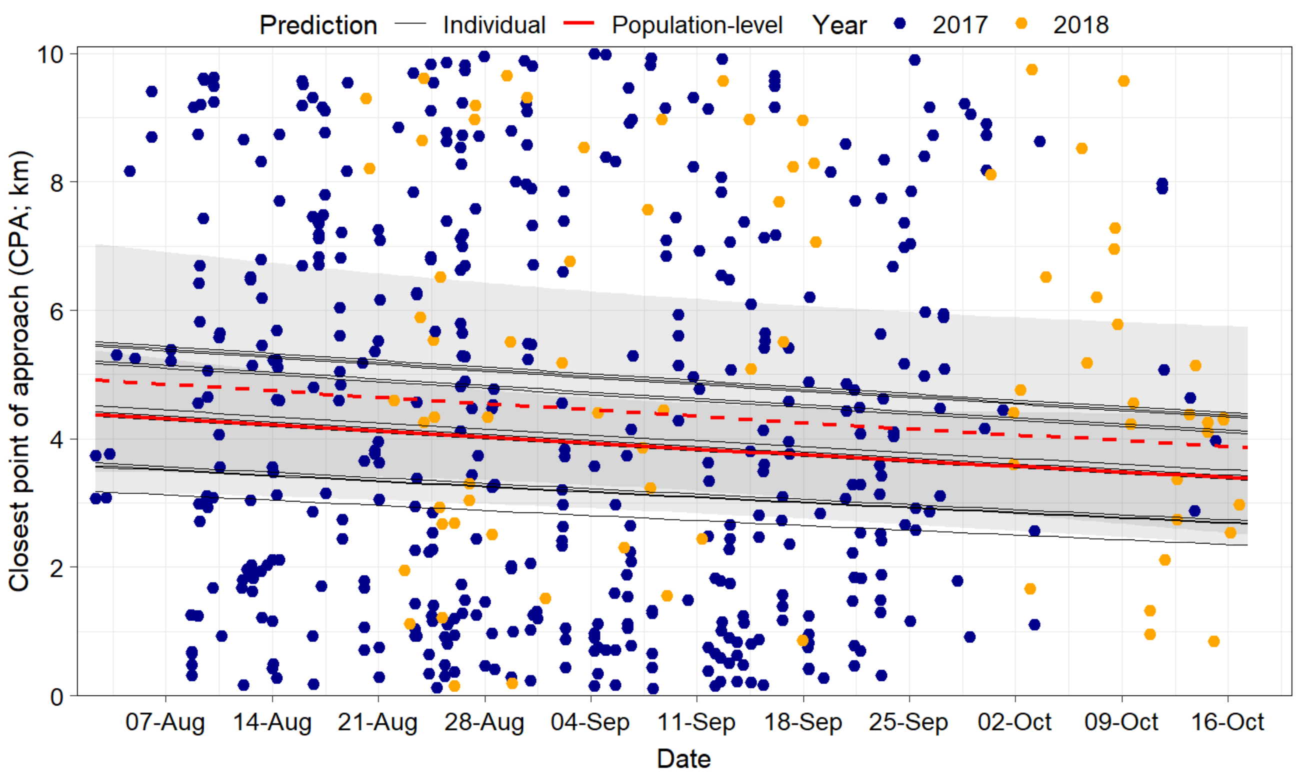

Figure 4-71: Distance between narwhal and vessel (km) over time (2017 and 2018).

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 mid-October at 7-8.5 km from vessels were removed to avoid extending the x-axis.

4.2.3.5 *Habitat Re-Occupation*

Instances in which narwhal crossed the track of vessels, as indicated by GPS locations either to the bow or to the stern of a vessel, are presented in Figure 4-72. For narwhal crossing events at the bow of the vessel, the realized (future) vessel track was used.

Narwhal made regular crossings to the bow and stern of vessels during the 2017 and 2018 shipping seasons, with crossing events before and after vessel passage essentially being a 'mirror image' of the other (Figure 4-72). Although narwhal crossing vessel tracks are only a subset of the total interactions with vessels, this analysis informs the extent to which narwhal were physically displaced by the passage of a vessel. The extent of the temporal lag between vessel passage and the individual'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 min), suggesting no prolonged avoidance of the shipping route due to vessel passage.

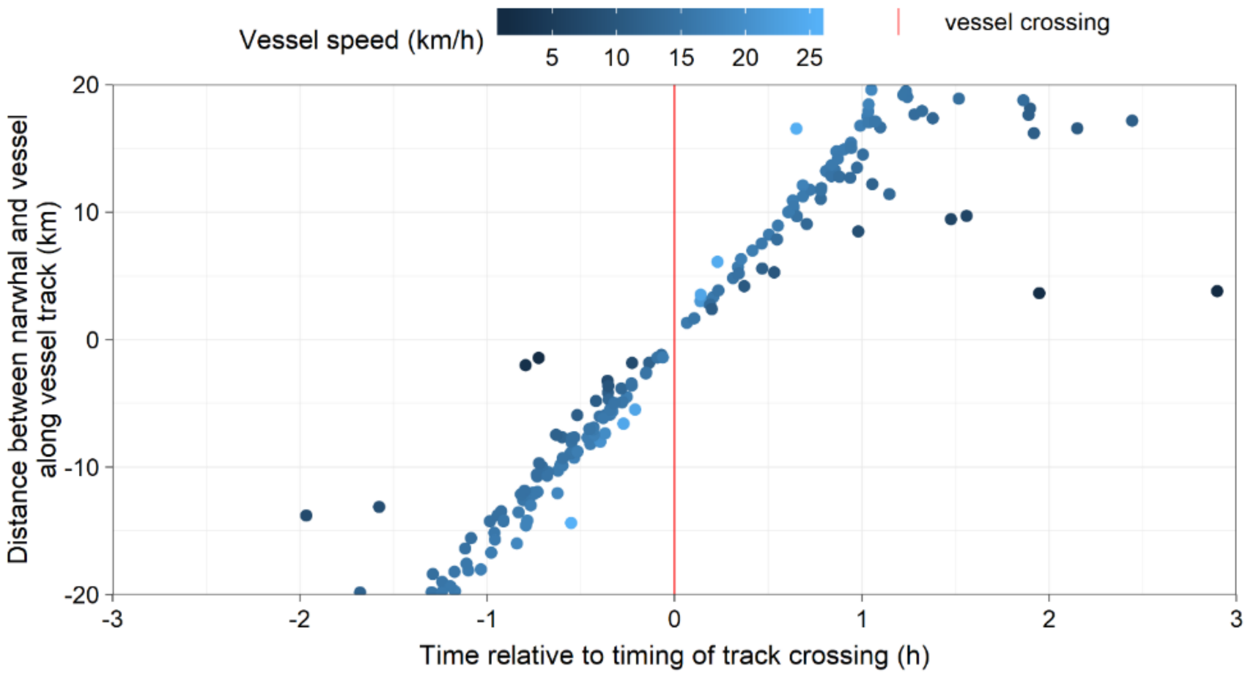

Figure 4-72: Time elapsed and distance travelled by vessels before narwhal cross vessel track; points colour-coded by vessel speed.

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

The time series of time and distance relative to track crossing (Figure 4-73) were analyzed as mixed models. For the analysis, only values obtained from narwhal crossing at the stern of the vessel (rather than both at the bow and the stern) were used. This dataset provided insight into whether habitat re-occupation post vessel passage changed over time. The two models (where the response variables were distance and time relative to track crossing) included an effect of date (as a standardized numeric value of day of year), a main effect of year (2017 vs 2018), and an interaction between the two.

For both models, none of the effects were significant ($P>0.4$ for all). There were no significant temporal effects on narwhal habitat re-occupation in terms of time since vessel passage and narwhal crossing of the vessel track or distance to the stern of the vessel at which narwhal crossed the vessel track. While not statistically significant, the model of time elapsed between vessel passage and narwhal crossing the vessel track estimated a decrease of 19% (from 0.97 h to 0.79 h) in the time between vessel and narwhal crossing between 2 August and 28 September 2017, and a decrease of 4% (from 1.07 h to 1.03 h) in the time between vessel and narwhal crossing between

24 August and 16 September 2018. The model of distance between vessel passage and narwhal crossing estimated a 21% decrease in distance (from 12.6 km to 10.0 km) between 2 August and 28 September 2017, but an increase of 19% in distance (from 11.8 km to 14.0 km) between 24 August and 16 September 2018. The 2018 dataset was, however, limited and model estimates for 2017 should therefore be considered the more reliable source of information. That is, narwhal may have exhibited a seasonal habituation to vessel passage, although the findings were not statistically significant due to data variability. Test statistics and coefficient estimates for the model are provided in Appendix A.

In summary, the integrated 2017-2018 narwhal location data does not support rejection of the null hypothesis (**H11$_0$**) that narwhal do not exhibit significant seasonal habituation to vessel passage. **Considering the prediction that re-occupation of vessel tracks by narwhal would indicate potential habituation to shipping activities along the Northern Shipping Route, results indicate that narwhal may have exhibited marginal seasonal habituation to vessel passage, although neither the effect of day/time or the effect of year were statistically significant. Furthermore, narwhal crossed the vessel tracks both shortly before and shortly after vessel passage (minimum value of 4 min), suggesting no long-term avoidance of the Northern Shipping Route by narwhal nor displacement from the RSA by narwhal as a result of vessel traffic.**

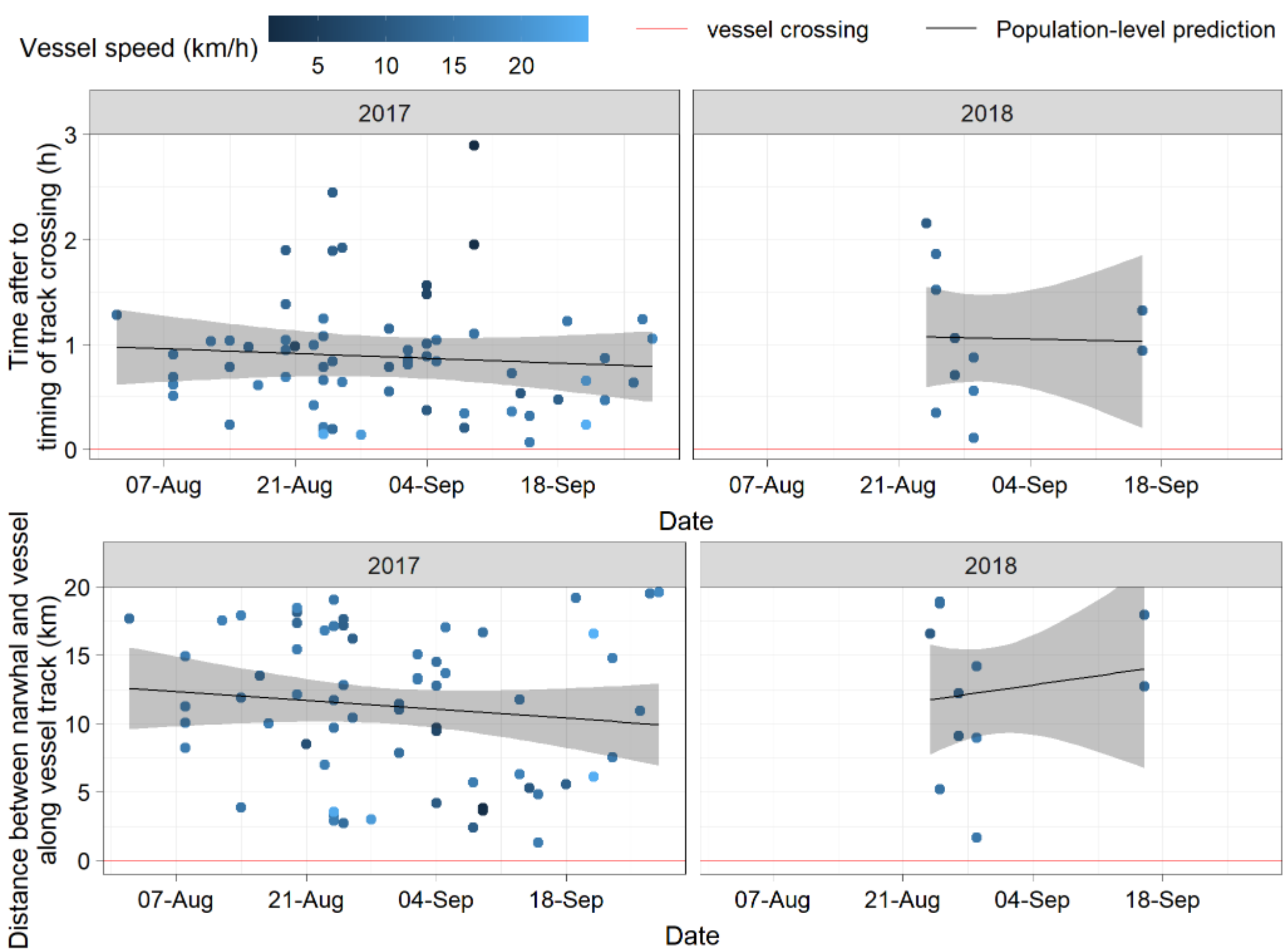

Figure 4-73: Time series of time elapsed and distance travelled by vessels before narwhal cross vessel track behind the vessel; points colour-coded by vessel speed.

4.2.3.6 Travel Speed

Mean narwhal travel speeds ranged between 0.8 m/s (NW03) and 1.6 m/s (NW05 and NW06; Table 4-16), which is consistent with the range of narwhal swimming speeds reported in the literature (0.64 m/s to 2.36 m/s; Dietz and Heide-Jørgensen 1995, Heide-Jørgensen and Dietz 1995, Laidre et al. 2002, Laidre et al. 2003, Williams and Noren 2011). Mean travel speeds were similar between exposure and non-exposure events, whereas maximum travel speeds were generally higher during non-exposure than during exposure events. No differences were apparent in narwhal travel speeds between sexes or between tag types (Figure 4-74; Table 4-16). Narwhal engaged in both slow and fast movements throughout the spatial extent of the RSA (Figure 4-75).

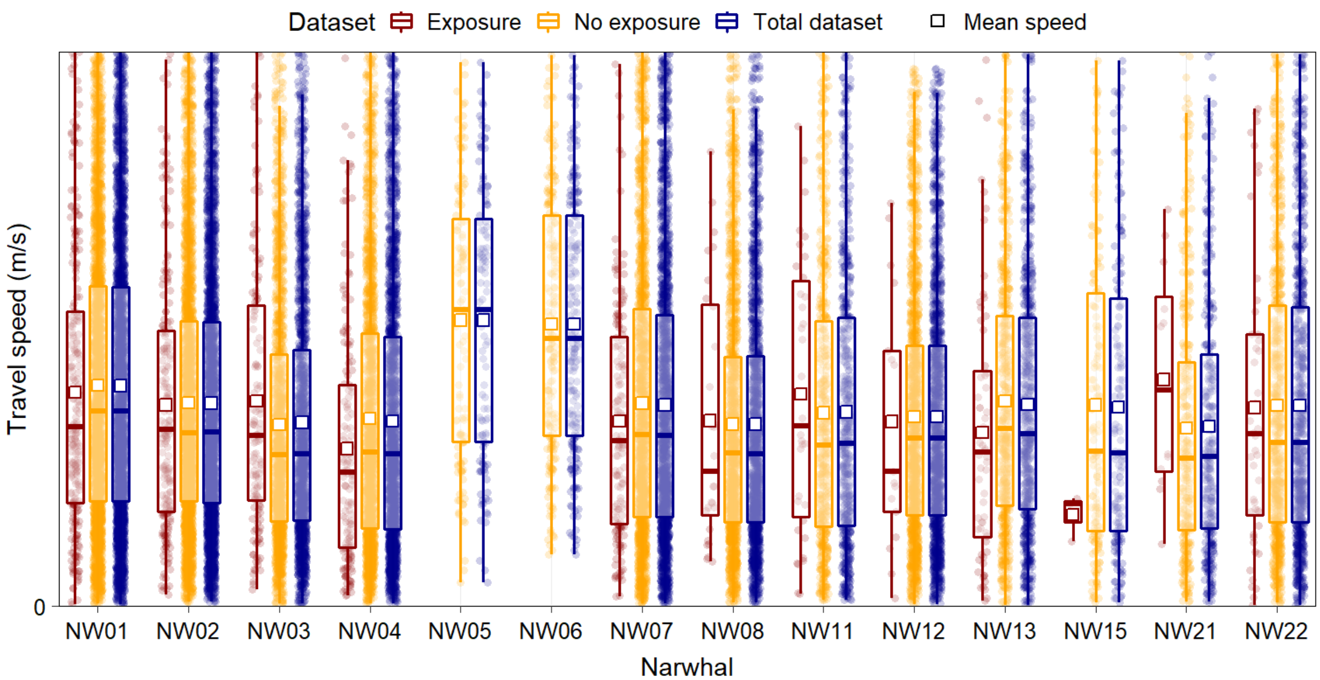

Figure 4-74: Travel speed (m/s) within each dive, by tagged narwhal under exposure, non-exposure, and for the total dataset

Note: Summary statistics (minimum, maximum, and mean) are provided in Table 4-16.

Table 4-16: Summary statistics of narwhal travel speed (m/s)

Narwhal	Sex	Full dataset			Exposure Zone (≤10 km)			Non-exposure Zone (> 10 km)		
		Min	Average	Max	Min	Average	Max	Min	Average	Max
NW01	M	0.0	1.1	2.5	0.0	1.1	2.4	0.0	1.1	2.5
NW02	F	0.0	1.0	2.5	0.0	0.9	2.2	0.0	1.0	2.5
NW03	F	0.0	0.8	2.5	0.1	0.9	2.5	0.0	0.8	2.4
NW04	M	0.0	0.9	2.4	0.0	0.8	2.2	0.0	0.9	2.4
NW05	M	0.2	1.6	2.3	n/a	n/a	n/a	0.2	1.6	2.3
NW06	M	0.2	1.6	2.4	n/a	n/a	n/a	0.2	1.6	2.4
NW07	M	0.0	1.0	2.5	0.1	1.0	2.5	0.0	1.0	2.5
NW08	F	0.0	0.9	2.4	0.2	1.1	2.0	0.0	0.9	2.4

Narwhal	Sex	Full dataset			Exposure Zone (≤10 km)			Non-exposure Zone (> 10 km)		
		Min	Average	Max	Min	Average	Max	Min	Average	Max
NW11	F	0.0	0.9	2.4	0.1	0.9	1.6	0.0	0.9	2.4
NW12	F	0.0	0.9	2.5	0.0	0.8	1.9	0.0	0.9	2.5
NW13	M	0.0	1.0	2.4	0.0	0.8	1.9	0.0	1.0	2.4
NW15	M	0.0	0.9	2.5	0.1	0.9	1.2	0.0	0.9	2.5
NW21	F	0.0	0.9	2.1	0.2	1.0	2.1	0.0	0.9	2.0
NW22	F	0.0	0.9	2.4	0.0	0.9	2.1	0.0	1.0	2.4

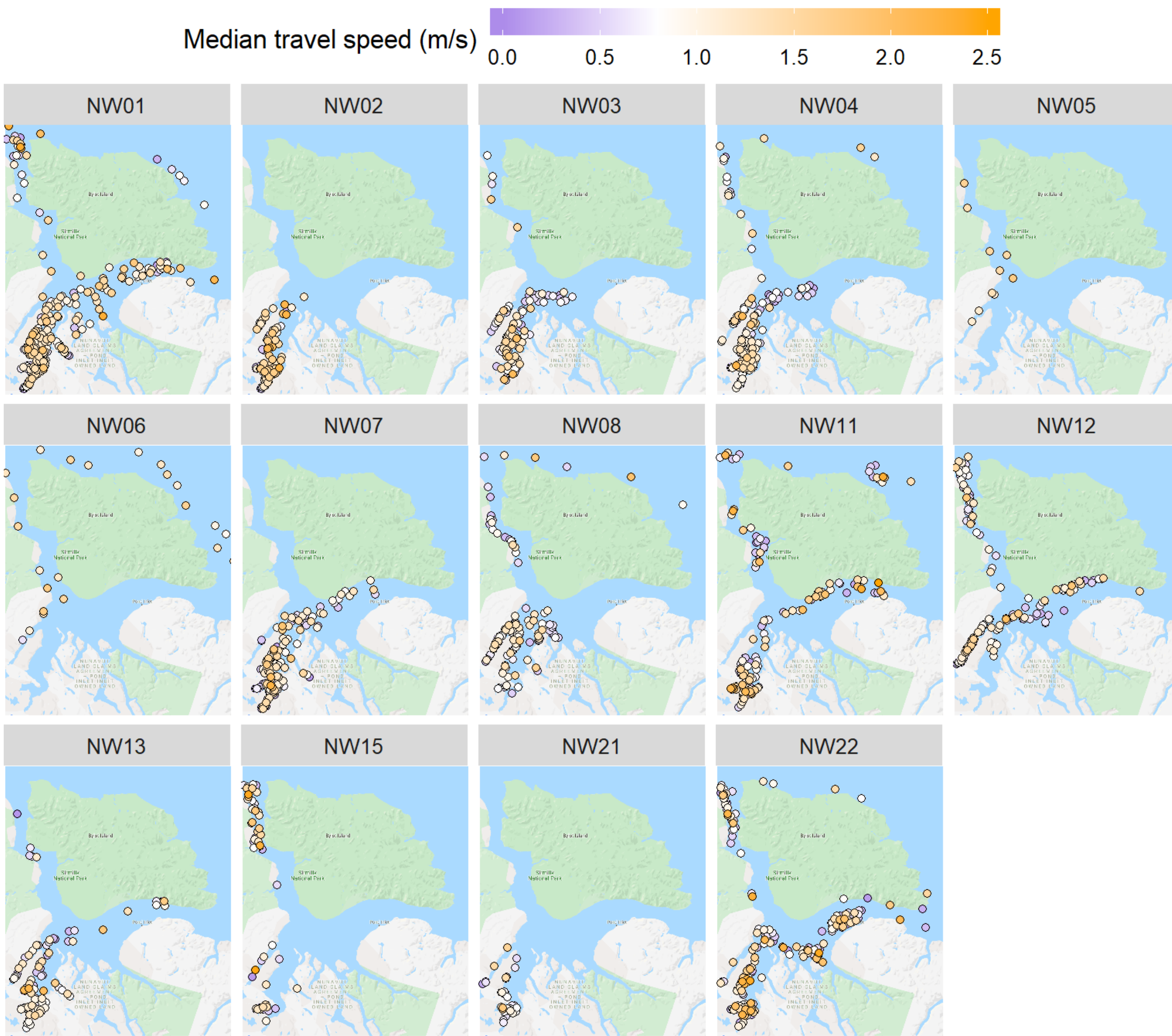

Figure 4-75: Narwhal travel speed (m/s), by tagged narwhal (averaged by 4 h time periods).

Note: Mean values across all animals shown in white.

It was predicted that the effect of vessel exposure on narwhal travel speed would increase with decreasing distance. Low travel speed may be indicative of a freeze response or of diving behavior (as horizontal distance covered between surfacing events would be shorter than if narwhal moved at the same speed but did not dive), while high travel speed may be indicative of an avoidance response. Visual data exploration prior to analysis suggested that travel speed decreased slightly in close proximity to vessels, both before and after CPA, though without strong directionality (Figure 4-76).

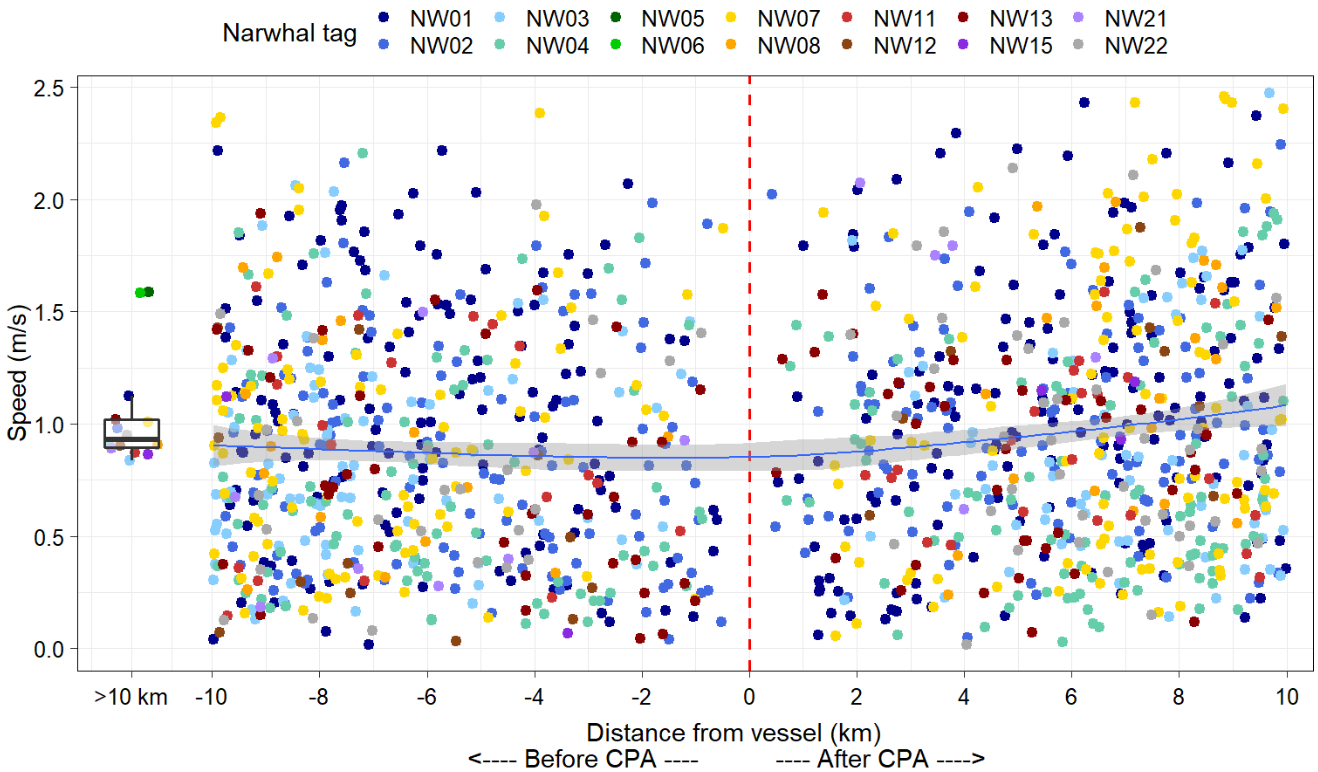

Figure 4-76: Observed travel speeds relative to directional distance from vessels during exposure and non-exposure events

Note: Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

As stated in Section 3.5.3, the data were analyzed using a model of directional distance (i.e., distance that takes into account whether the data were collected before or after the CPA), to best accommodate slight difference in slope near distance of 0 km. The model included an effect of distance from a vessel, an effect of whether the data point was before or after the CPA, and the interaction between the two variables. In addition, the effect of distance from shore and the substratum occupied were included in the model, to account for possible differences in narwhal travel and vessel track location relative to the shoreline. The effect of speed at the previous GPS position was included in the model to address autocorrelation of travel speed data.

There was a significant effect of exposure (where “exposure” was a categorical variable with the following three values: before CPA, after CPA, or “non-exposure”; P=0.04). The effect of distance from a vessel on travel speed was not statistically significant (P=0.2). The test had sufficient power (>0.8) to detect a -13% or a +13% effect size in the test of the overall effect of distance from vessel (Appendix C). In comparison, the largest absolute magnitude of the observed effect sizes was 15%. That is, the test did not detect an effect of distance despite having sufficient statistical power. The effect of distance from vessel had a very small effect. For example, a 1 km increase in distance between a narwhal and a vessel after a CPA resulted in only 0.01 m/s increase in travel speed. Since it is predicted that the effect of vessel exposure would increase with decreasing distance, the lack of significance of the slope of the distance effect 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. Since the effect of distance was not significant, multiple comparisons were not performed.

The effects of substratum, distance from shore, and travel speed at previous GPS point were all statistically significant (P<0.001 for all). Travel speeds were estimated to be highest at Baffin Bay Shallow, Baffin Bay, and Milne Inlet North substrata, and lowest at Koluktoo Bay and the Other Inlets/Sounds substrata (Figure 4-77). Travel speed was generally high near the shoreline, declined within a short distance from the shore, and increased at distances of >15 km from shoreline. That said, only limited data were available for locations that were >15 km from shoreline. The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.012 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.056. Test statistics and coefficient estimates for the model are provided in Appendix A.

In summary, the integrated 2017-2018 narwhal location data do not support rejection of the null hypothesis (**$H12_0$**) that travel speed does not significantly change during vessel exposure events. **Considering the prediction that a decrease in travel speed by narwhal exposed to vessel traffic would indicate a potential freeze response to a perceived threat (as observed in the presence of killer whales; Laidre et al. 2006), and an increase in travel speed would indicate a potential avoidance response, results did not suggest that narwhal either increased or decreased their travel speed in the presence of transiting vessels.**

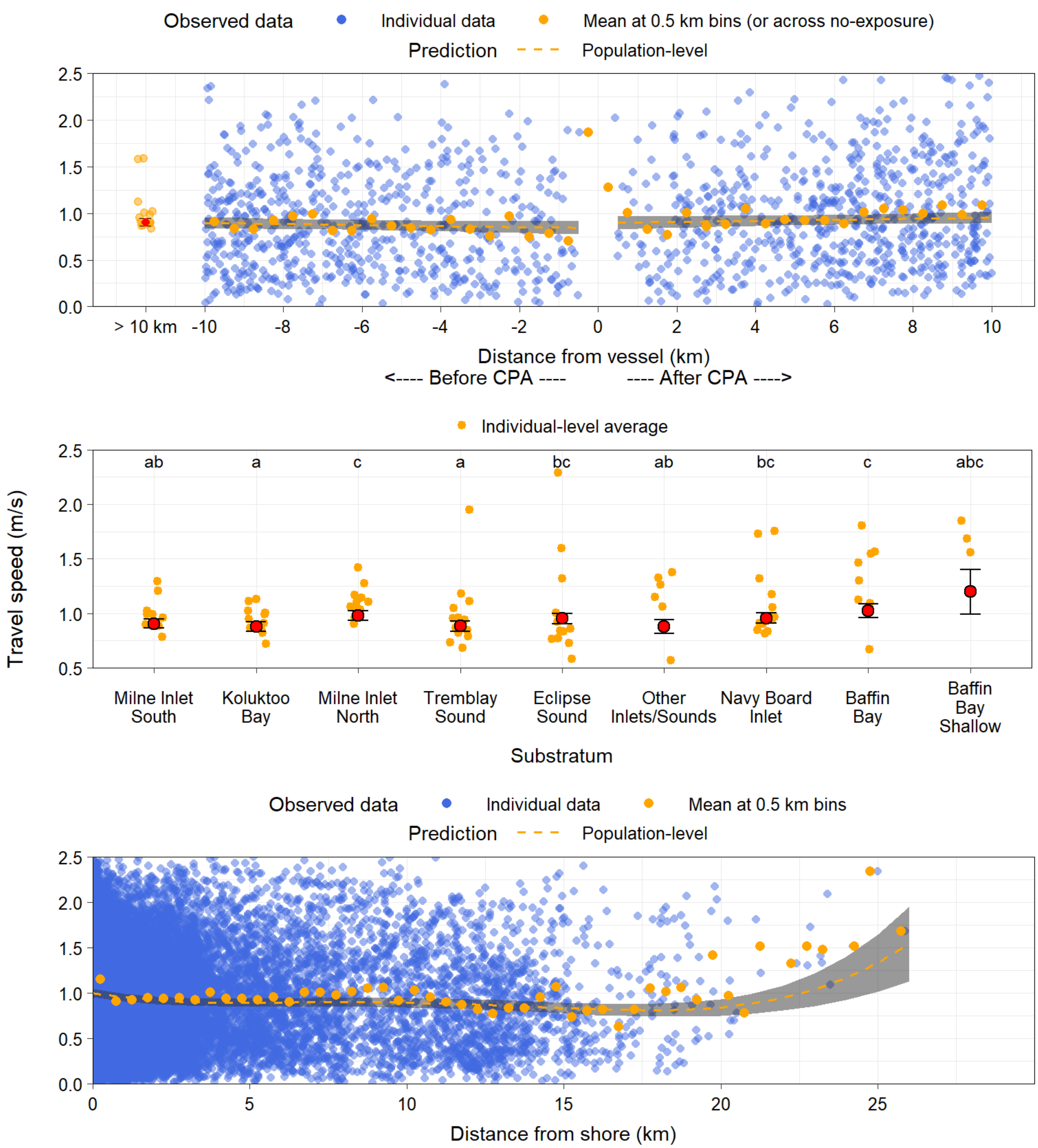

Figure 4-77: Observed and predicted narwhal travel speed relative to distance from vessels (top), substratum (middle), and distance from shore (bottom).

Note: Blue points (top panel) depict raw data; orange points depict means of raw data, by distance or by narwhal (in top panel, >10 km from vessel). In bottom panel, orange points depict mean speed by narwhal within each substratum; means with different letters are significantly different from each other. Lines and red points, and ribbons and error bars show predicted mean and 95% confidence intervals, respectively.

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4.2.4 Dive and Surface Behavior During Exposure to Multiple Vessels

4.2.4.1 Surface Time

Surface time was strongly affected by whether narwhal were at the surface during the previous 1 min period of time (Figure 4-78). In comparing to events when narwhal were exposed to only a single vessel within the 10 km exposure zone, there were no apparent differences in the relationship between surface time and distance from the nearest vessel when two or more vessels were present. Data available for distances <0.5 km between narwhal and a transiting vessel was limited, although there were cases with both a single vessel and multiple vessels (Figure 4-78).

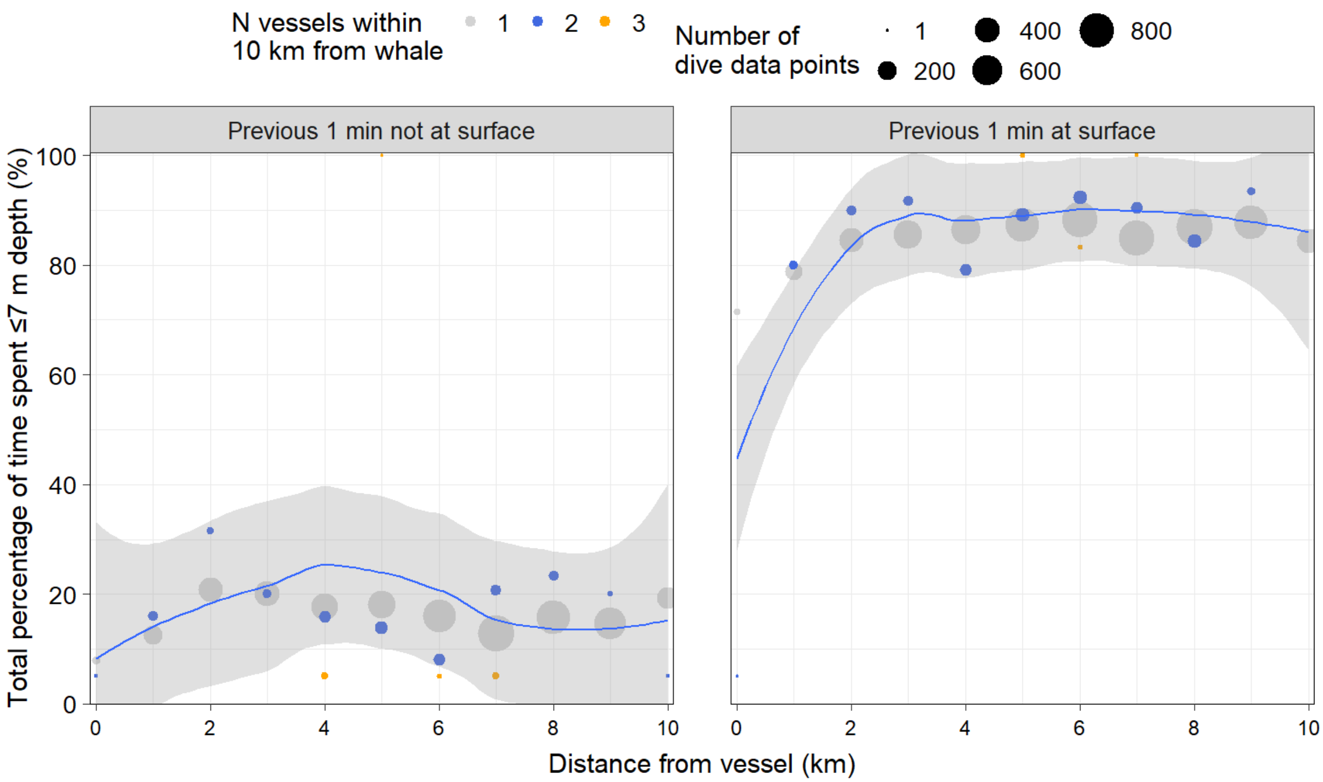

Figure 4-78: Percent time spent at ≤7 m depth, by number of vessels present within exposure zone and distance from vessels (rounded to 1 km).

Note: Bubble size represents total amount of data available for each data point. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

In the analysis of the effect of multiple vessels on surface time, the effect of tag type, which was included in the original analysis that only accounted for a single vessel, had to be removed to achieve convergence. Tag type was not statistically significant in the original analysis (*P*=0.3).

The presence/absence of narwhal at surface (≤7 m) in relation to multiple vessels was analyzed using a mixed effect generalized linear model. In the analysis, fixed effects included in the model were distance from the nearest vessel (3rd degree polynomial), number of vessels present (categorical variable – one or more than one vessel), whether the narwhal was at surface in the preceding 1 min period, the substratum, and the period of time since the narwhal was last at surface (2nd degree polynomial). The random effect was a random intercept by narwhal tag.

The effect of substratum was statistically significant (*P*=0.009), as were the effects of whether the narwhal was at surface in the previous 1 min period (*P*<0.001) and the effect of cumulative period of time since last surfacing (*P*<0.001). The effect of distance from the nearest vessel was statistically significant (*P*=0.002), with lower probabilities of surface time at close proximity of vessels (Figure 4-79). The effect of the number of vessels present within the exposure zone was not significant (*P*=0.9), and the effect size associated with a change from a single vessel to multiple vessels was very small, a reduction of 1% in the odds of narwhal being at surface when multiple vessels are present compared to when a single vessel is present. The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.492 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.495. Test statistics and coefficient estimates for the model are provided in Appendix B. The test had sufficient power (>0.8) to detect a -16% or a +14% effect size in the test of the effect of multiple vessel presence (Appendix C). In comparison, the observed effect size was only -1%. That is, the test had sufficient power to detect small effect sizes in response to presence of multiple vessels.

The estimated population-level probability of narwhal presence at surface was lowest when distance from the nearest vessel was small and increased with an increase in distance (Figure 4-79). When a single vessel was present at 0 km (where the strongest effect is expected), the probability of presence at surface was 0.054 when the narwhal was not at surface in the previous 1 min period, and 0.732 when the narwhal was previously at surface. When two or more vessels were present, the predicted values decreased to 0.053 and 0.730, respectively. That is, the model predicted slightly lower probabilities of surfacing when multiple vessels were present within 10 km from narwhal, however the effect was not significant, and the effect size was very small.

In summary, the 2017-2018 dive data do not support rejection of the null hypothesis (**H13$_0$**) that the probability of narwhal surface time does not significantly change during multiple-vessel passage in comparison to a single-vessel passage. However, since the effect of single vessel passage on surface time was only evident within 1 km from narwhal (Section 4.2.2.1), it is likely that the definition of multiple vessel passage as the number of vessels within the overall 10 km exposure zone is not sufficiently focused. Further restriction of the definition of multiple vessel passage may be possible in the future, should additional narwhal tagging data be collected in close proximity to vessels.

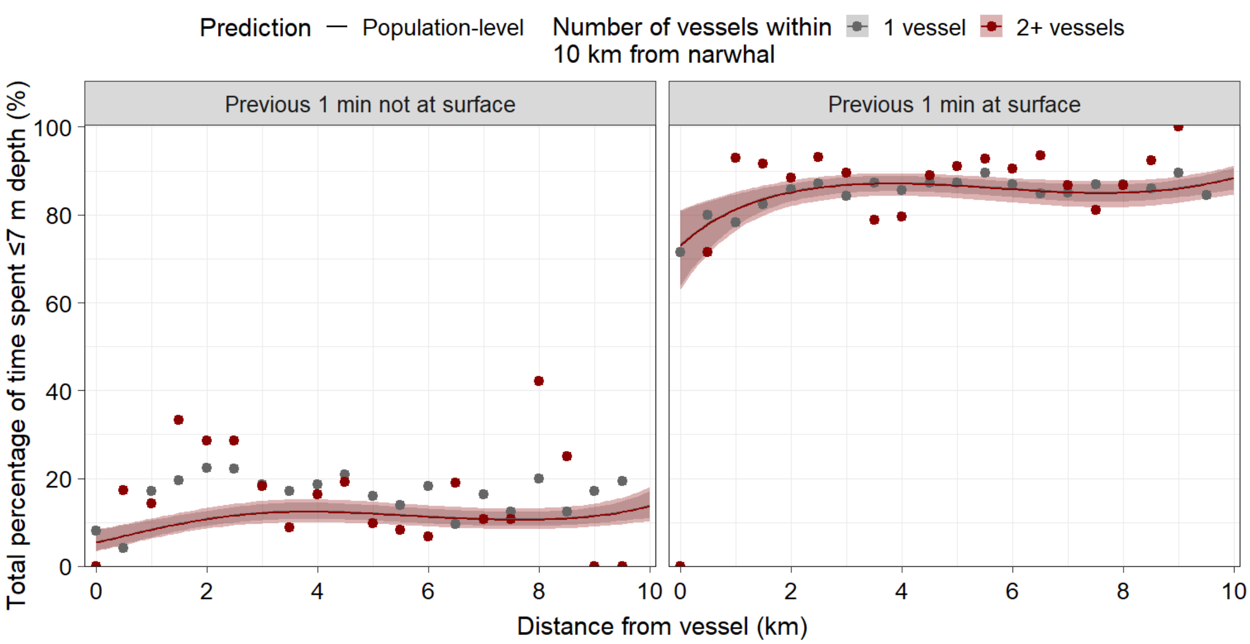

Figure 4-79: Proportion of narwhal depths at surface (0-7 m) relative to number of vessels present in exposure zone and distance from vessels.

Note: Lines and ribbons represent population-level model predictions and the 95% confidence intervals associated with them.

4.2.4.2 Performing Bottom Dives

Bottom dive depth (i.e., whether the dive was deeper than 75% of the available bathymetry) was strongly affected by whether the preceding dive was a bottom dive or not (Figure 4-80). There were no immediately apparent differences in the relationship between the percentage of bottom dives performed at various distances from the nearest vessel and the number of vessels present within the exposure zone.

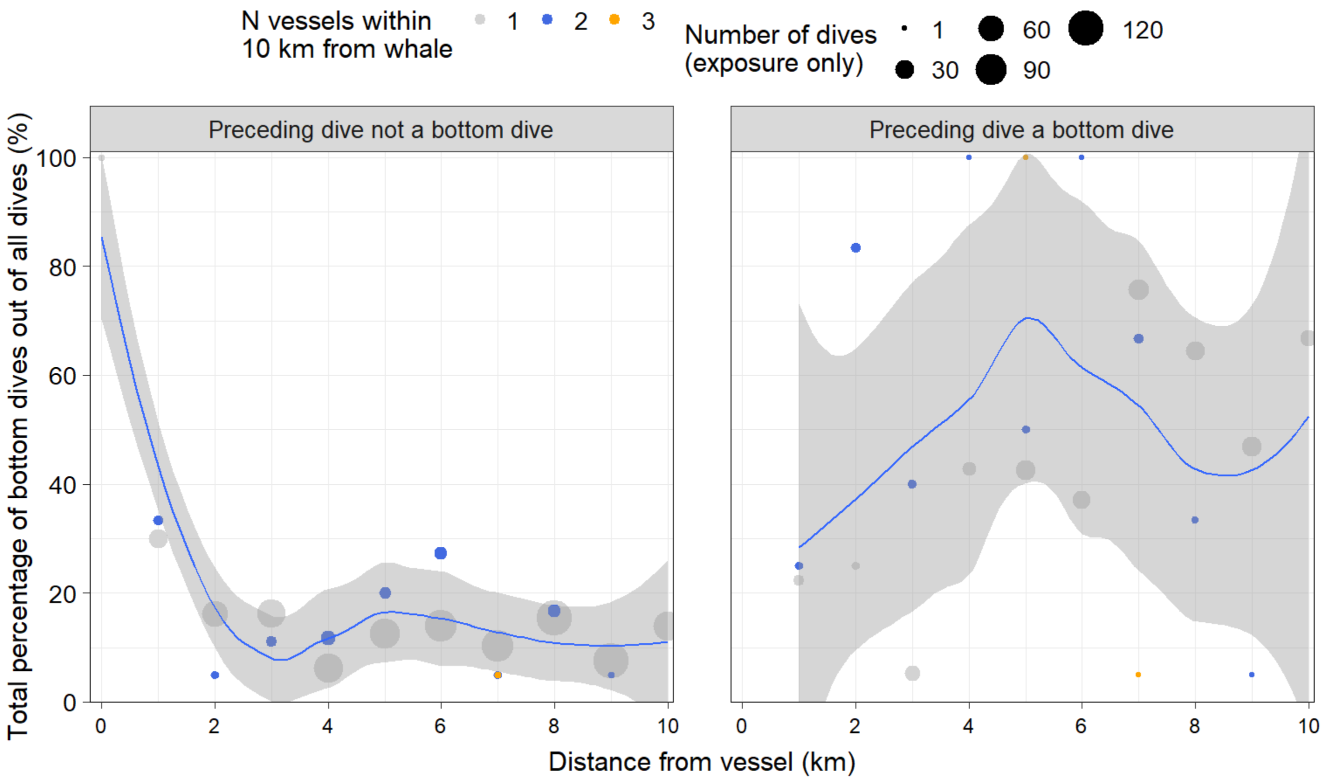

Figure 4-80: Percentage of bottom dives, by number of vessels present within exposure zone and distance from vessels (rounded to 1 km).

Note: Bubble size represents total amount of data available for each data point. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

Maximum dive depth was analyzed using a mixed effect logistic model as a presence/absence of bottom dives (i.e., whether the dive was deeper than 75% of the available bathymetry depth). In the analysis, fixed effects included in the model were distance from the nearest vessel (km; 2nd degree polynomial), number of vessels present (categorical variable – one or more than one vessel), available bathymetry depth (m), whether the preceding dive was a bottom dive, substratum, time since the last bottom dive, and an interaction between distance from vessel and whether the preceding dive was a bottom dive. The random effect was a random intercept by narwhal.

The fixed-effect interaction between distance from the nearest vessel and whether the preceding dive was a bottom dive was significant (P<0.001). The effect of whether there was a single vessel within the exposure zone or two or more vessels was not significant (P=0.3), with a log odds of 0.317, which translates to an odds ratio of 1.373, or a 37% increase to the odds of a bottom dive when multiple vessels were present. The effects of bathymetry and substratum were not significant (P>0.7 for both). The effect of time elapsed since the last bottom dive was significant, as was the main effect of whether the preceding dive was a bottom dive (*P*<0.001 for both). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.275 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.324. Test statistics and coefficient estimates for the model are provided in Appendix B. The test had sufficient power (>0.8) to detect a -110% or a +55% effect size in the test of the effect of multiple vessel presence (Appendix C). In comparison, the observed effect size was only +41%. That is, the test did not have sufficient power to detect the observed effect size in response to presence of multiple vessels.

The estimated population-level probability of a bottom dive when the preceding dive was also a bottom dive was lowest when distance from the nearest vessel was small and increased with distance (Figure 4-81). In comparison, when the preceding dive was not a bottom dive, the probability of performing a bottom dive was highest at close proximity to vessels. When the preceding dive was not a bottom dive, the probability of performing a bottom dive when the nearest vessel was at 0 km (where the strongest effect is expected) was 0.302 when a single vessel was present in the exposure zone, but increased to 0.372 when two or more vessels were present. When the preceding dive was a bottom dive, the probability of performing another bottom dive when the nearest vessel was at 0 km was very low for both a single vessel and a multiple vessel scenario (0.035 and 0.048, respectively). Overall, the model predicted a 37% increase to the odds of performing a bottom dive when multiple vessels were present in comparison to a single vessel (regardless of whether the preceding dive was also a bottom dive), however the effect was not significant, likely due to small sample size and high variability.

In summary, presence of two vessels resulted in higher probability of narwhal performing bottom dives relative to when a single vessel was present (effect size of 37%), however the results were not statistically significant, due to small sample size and high variability, and the null hypothesis (**$H14_0$**) could not be rejected. More data are required to adequately assess the effect of multiple vessel presence on bottom diving.

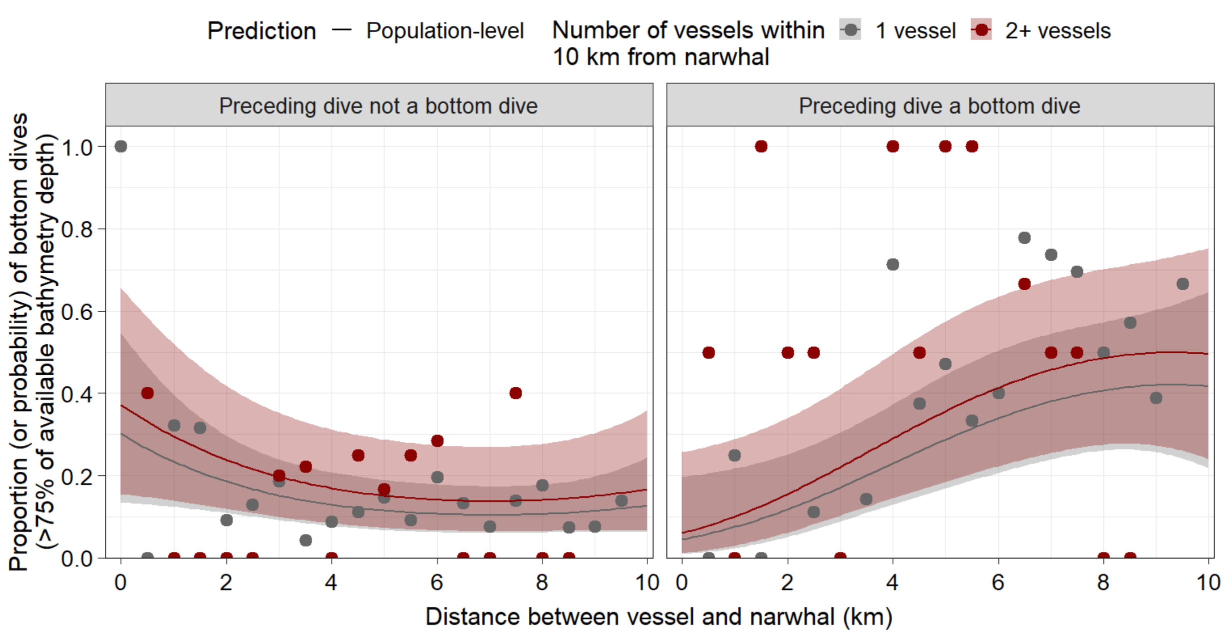

Figure 4-81: Observed mean proportions and predicted mean probabilities of performing bottom dives relative to number of vessels present in exposure zone and distance from vessels.

Note: Lines and ribbons represent population-level model predictions and the 95% confidence intervals associated with them.

4.2.4.3 Dive Duration

Dive duration was strongly affected by whether the dive was a bottom dive (>75% of available bathymetry) or not (Figure 4-82). There were no immediately apparent differences in the relationship between mean dive durations at various distances from the nearest vessel and the number of vessels present within the exposure zone.

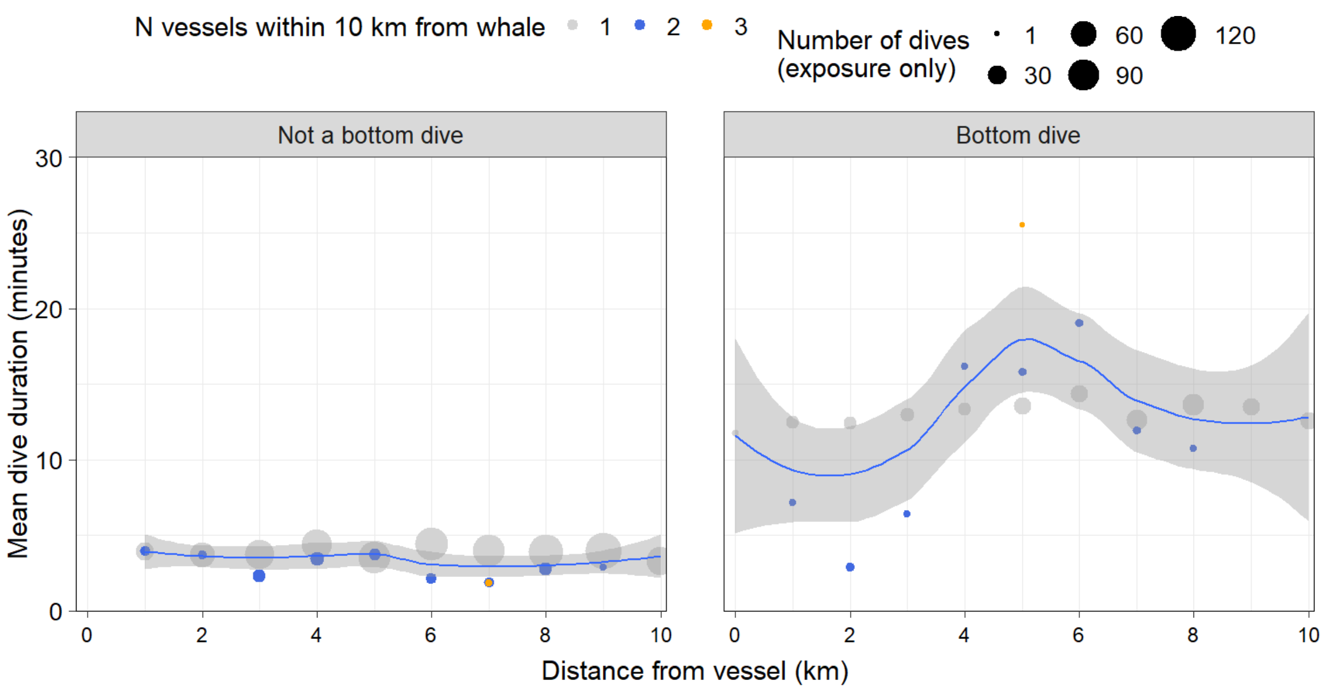

Figure 4-82: Dive duration, by number of vessels present within exposure zone and distance from vessels (rounded to 1 km).

Note: Bubble size represents total amount of data available for each data point. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

As stated in Section 3.5.2, dive duration (min) was analyzed using mixed effect linear models. In the analysis, the model's fixed effects included distance from the nearest vessel (km; 3rd degree polynomial), number of vessels within exposure zone (categorical variable), maximum dive depth (m; 5th degree polynomial), whether the current dive was a bottom dive (>75% of the available bathymetry), whether the preceding dive was a bottom dive, duration of the preceding dive (min), substratum, an interaction between distance between narwhal and vessel and whether the current dive was a bottom dive, as well as all two- and three-way interactions between the duration of the preceding dive, whether the preceding dive was a bottom dive, and whether the current dive was a bottom dive. The random effect was a random intercept by narwhal.

The interaction between the distance from the nearest vessel and whether the current dive was a bottom dive was statistically significant (*P*=0.03). The effect of the number of vessels within the exposure zone was not significant (*P*=0.07). The effects of maximum dive depth and substratum were statistically significant (*P*<0.001 for both). The main effect of duration of previous dive was significant (*P*=0.016), whereas all of the interactions with that variable were not significant (*P*>0.06 for all). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.862 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.879. Test statistics and coefficients estimate for the model are provided in Appendix B. The test had sufficient power (>0.8) to detect a -12% or a +11% effect size in the test of the effect of multiple vessel presence (Appendix C). Considering that the observed effect size was just on the boundary of sufficient statistical power and that the effect of multiple vessels was concluded to not be significant due to a *P* value of 0.07, the test was slightly underpowered to detect the observed effect size. However, the observed effect size was relatively small (11% decrease in dive duration).

The estimated population-level dive duration was smallest when distance from the nearest vessel was small and generally increased with distance, for both bottom dives and non-bottom dives, however predicted dive duration was larger for bottom dives (Figure 4-83). Predicted dive duration was also lower when multiple vessels were present within the exposure zone (regardless of whether dives were bottom dives or not). When the dive was not a bottom dive, mean predicted dive duration when the nearest vessel was at 0 km (where the strongest effect is expected) was 4.3 min when a single vessel was present in the exposure zone, but decreased to 4.0 min when two or more vessels were present. When the dive was a bottom dive, predicted dive duration when the nearest vessel was at 0 km was 10.9 min and 10.3 min for a single vessel and a multiple vessel scenario, respectively. Overall, at 0 km from the nearest vessel, the model predicted a reduction of 8.5% in dive duration of non-bottom dives and a reduction of 5.4% in dive duration of bottom dives in the presence of multiple vessels in comparison to a single vessel, however the effect was not significant, likely due to small sample size and high variability.

In summary, the analysis of 2017-2018 dive data did not detect a statistically significant effect of multiple vessels on dive duration, due to a relatively small effect size (11% decrease) and data variability. Overall, the analysis does not support rejection the null hypothesis (**H15$_0$**) that dive duration does not significantly change during multiple-vessel passage in comparison to a single-vessel passage. However, since the effect of a single vessel passage on dive duration was only evident within <1 km from the narwhal (Section 4.2.2.5), it is likely that the sample size is not sufficient and that definition of multiple vessel passage as the number of vessels within the overall 10 km exposure zone is not sufficiently focused.

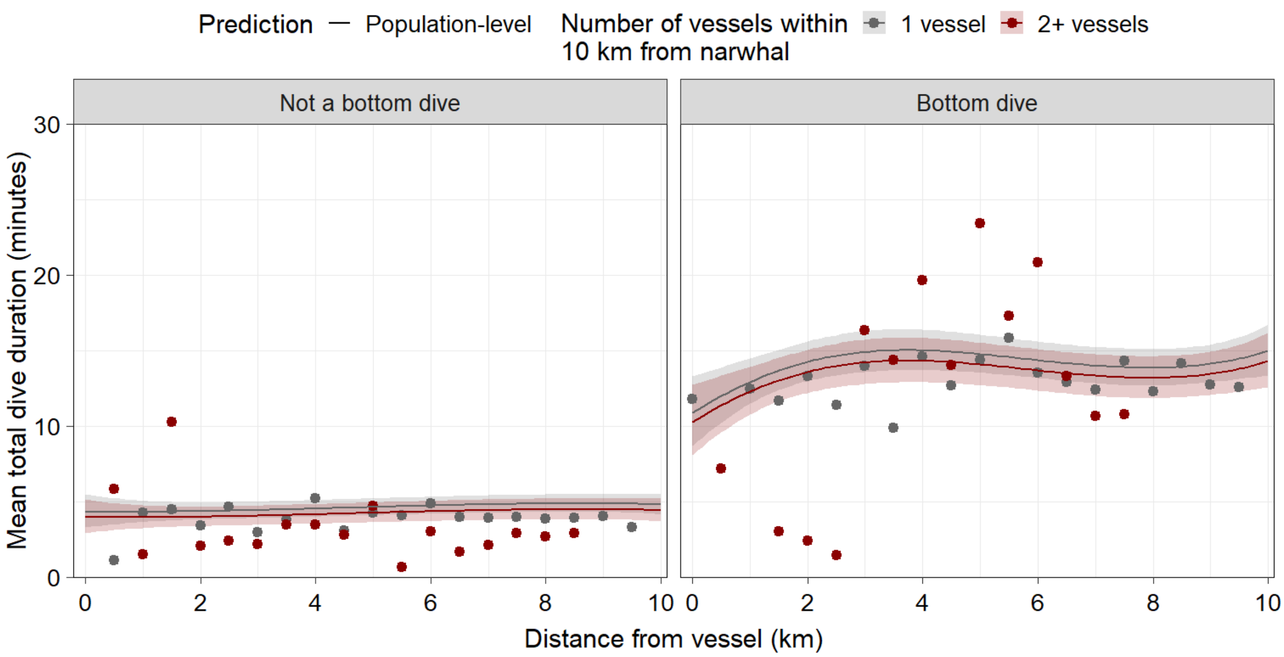

Figure 4-83: Mean observed and predicted dive durations relative to number of vessels in exposure zone and distance from vessels.

Note: Lines and ribbons represent population-level model predictions and the 95% confidence intervals associated with them.

4.2.4.4 Turning Angle

As discussed in Section 4.2.3.1, a smaller turning angle (0°) indicates linear travel by narwhal, while a higher turning angle indicates a sudden change to its movement trajectory (180°), regardless of orientation to vessel. According to an initial review of data, narwhal turning angle was shown to be highest at close-to-intermediate distances (1-4 km) from the nearest vessel and decreased when the nearest vessel was further away (Figure 4-84). At very close distances (<0.5 km), data were relatively limited, leading to the LOESS smoother declining from approximately 55° turning angles at 1 km from a vessel to approximately 15° turning angles at 0 km. Turning angles when two or more vessels were present appeared on average higher in comparison to turning angles in the presence of a single vessel in the exposure zone.

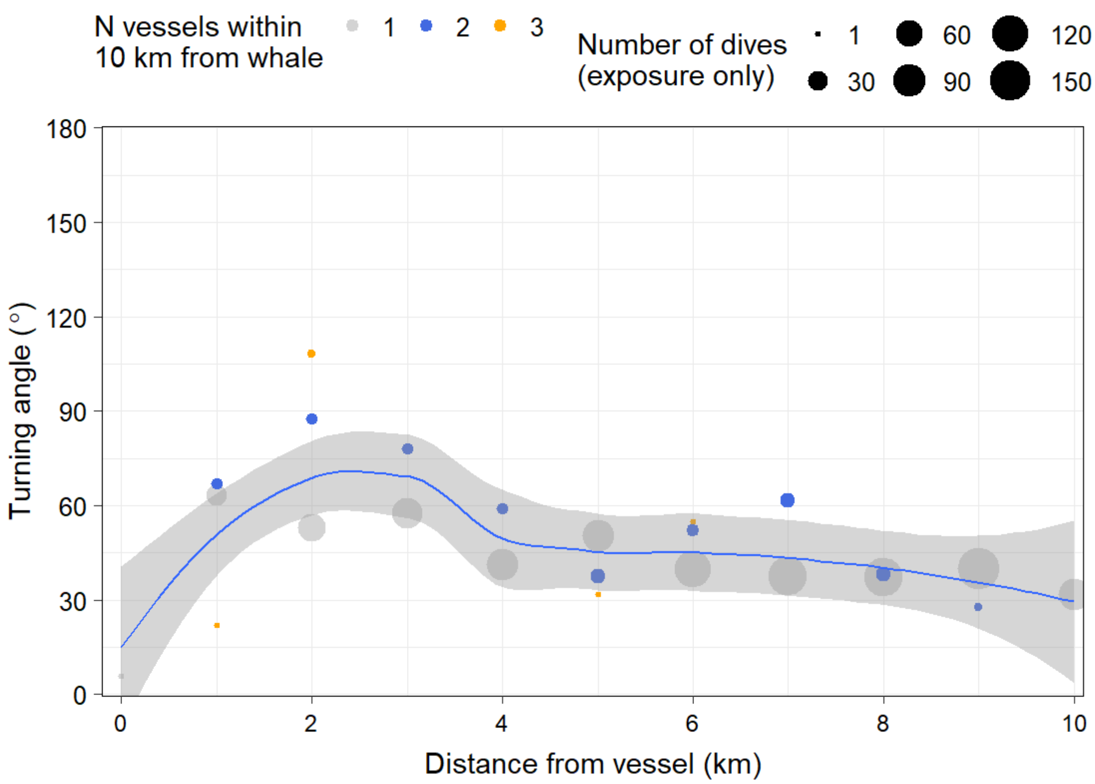

Figure 4-84: Turning angle, by number of vessels present within exposure zone and distance from vessels (rounded to 1 km).

Note: Bubble size represents total amount of data available for each data point. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

Narwhal turning angles (°) were analyzed using a linear mixed effects model. In the analysis, the model's fixed effects included distance from the nearest vessel (km; 2nd degree polynomial), distance from shore, the effect of turning angle at the preceding GPS point, and the number of vessels within exposure zone (categorical variable). The random effect was a random intercept by narwhal

The effects of distance from nearest vessel, number of vessels present in the exposure zone, and the turning angle at the preceding GPS point were all statistically significant (*P*<0.001, *P*=0.004, *P*=0.008, respectively).

The effects of distance from shore and substratum were not significant (*P*>0.2 for both). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.072 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.103. Test statistics and coefficient estimates for the model are provided in Appendix B. The test had sufficient power (>0.8) to detect a -27% or a +35% effect size in the test of the effect of multiple vessel presence (Appendix C). In comparison, the observed effect size was +28%, however it was still found to be significant.

The estimated population-level turning angle was largest when distance from the nearest vessel was small and decreased with distance (Figure 4-85). Predicted turning angles were higher when multiple vessels were present within the exposure zone. Mean predicted turning angle when the nearest vessel was at 0 km (where the strongest effect is expected) was 57° when a single vessel was present in the exposure zone, but increased to 73° when two or more vessels were present (Table 4-17). At a distance of 10 km to the nearest vessel (i.e., where the weakest effect is expected), predicted turning angles were 34° and 47° under single and multiple vessel scenarios, respectively. The increase in turning angles between a single vessel and multiple vessels within the exposure zone had an overall significance level of *P*=0.004. Overall, at 0 km from the nearest vessel, the model predicted a 28% increase in the turning angle in the presence of multiple vessels in comparison to a single vessel.

In summary, the analysis of 2017-2018 GPS data supports rejection of the null hypothesis (**$H16_0$**) that turning angles do not significantly change during multiple-vessel passage in comparison to a single-vessel passage. This was based on statistically significant effects of number of vessels and the distance from vessel, which suggested that changes in narwhal turning angles were greater at closer proximity and with a greater number of vessels.

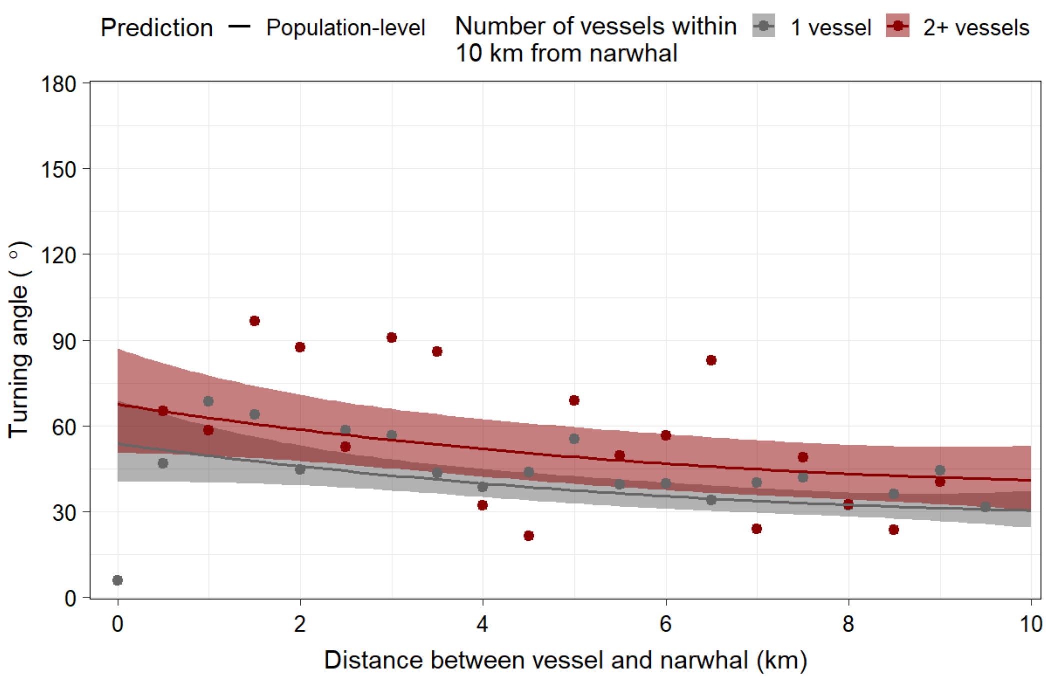

Figure 4-85: Mean observed and predicted turning angles relative to number of vessels present within exposure zone and distance from vessels.

Note: Lines and ribbons represent population-level model predictions and the 95% confidence intervals associated with them.

Table 4-17: Least squares means of turning angles under single and multiple vessel scenarios at specific distances between narwhal and vessels

Distance from Vessel (km)	Least-squares Means		
	One Vessel	Two or More Vessels	*P* Value (Effect of Multiple Vessels)
0	53.7	67.5	**0.004**
1	49.5	62.8	
2	45.9	58.7	
3	42.7	55.1	
4	39.9	51.9	
5	37.5	49.1	
6	35.4	46.8	
7	33.7	44.8	
8	32.4	43.2	
9	31.3	42.0	
10	30.5	41.0	

4.2.4.5 Travel Orientation relative to Vessels

As stated in Section 4.2.3.2, mean relative angles less than 90° are indicative of narwhal heading toward a vessel (regardless of the orientation of the vessel itself), while angles larger than 90° indicate a narwhal heading away from a vessel and are expected under avoidance behavior. According to an initial review of the data, narwhal angles relative to vessels were highest at close-to-intermediate distances (0-4 km) from the nearest vessel and decreased when the nearest vessel was further away (Figure 4-86). Relative angles of narwhal when two or more vessels were present in the exposure zone appeared on average higher in comparison to when only a single vessel was present.

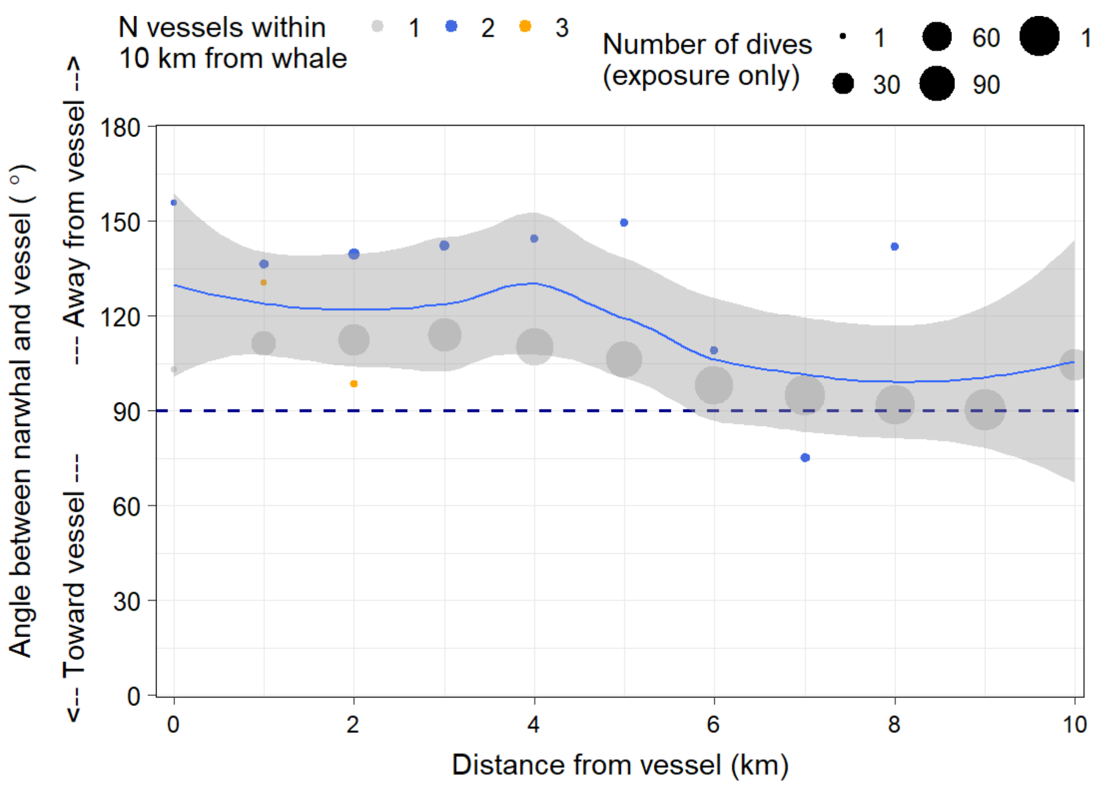

Figure 4-86: Travel orientation relative to vessels, by number of vessels present within exposure zone and distance from vessels (rounded to 1 km).

Note: Bubble size represents total amount of data available for each data point. Curve and confidence band represent a LOESS (locally estimated scatterplot smoothing) trend curve.

Narwhal angles relative to the nearest vessel (°) were analyzed using a linear mixed effects model. In the analysis, the model's fixed effects included distance from the nearest vessel (km), the number of vessels within exposure zone (categorical variable), and substratum. The random effect was a random intercept by narwhal.

The effects of distance from the nearest vessel and number of vessels present in the exposure zone were statistically significant (P<0.001 and P=0.014, respectively), whereas the effect of substratum was not (P=0.8). The model had a marginal (i.e., fixed-effects only) pseudo-R^2 of 0.032 and a conditional (i.e., full mixed effects) pseudo-R^2 of 0.122. Test statistics and coefficient estimates for the model are provided in Appendix B. The test had sufficient power (>0.8) to detect a -20% or a +25% effect size in the test of the effect of multiple vessel presence (Appendix C). In comparison, the observed effect size was +20%, however it was still found to be significant.

The estimated population-level relative angle was largest when distance from the nearest vessel was small and decreased with an increase in distance (Figure 4-87). Predicted relative angles were higher when multiple vessels were present within the exposure zone. Mean predicted relative angle when the nearest vessel was at 0 km (where the strongest effect is expected) was 117° when a single vessel was present in the exposure zone, but increased to 141° when two or more vessels were present (Table 4-18). At a distance of 10 km to the nearest vessel (i.e., where the weakest effect is expected), predicted turning angles were 91° and 114° under single and multiple vessel scenarios, respectively. Overall, the model predicted a 20-26% increase in the relative angle between a narwhal and a vessel in the presence of multiple vessels in comparison to a single vessel.

In summary, the 2017-2018 GPS data analysis supports rejection of the null hypothesis (**$H17_0$**) that orientation relative to vessels does not significantly change during multiple-vessel passage in comparison to a single-vessel passage. This was based on statistically significant effects of number of vessels and the distance from the nearest vessel, which suggested narwhal changed their travel orientation away from vessels, with a greater effect at closer proximity and with a greater number of vessels.

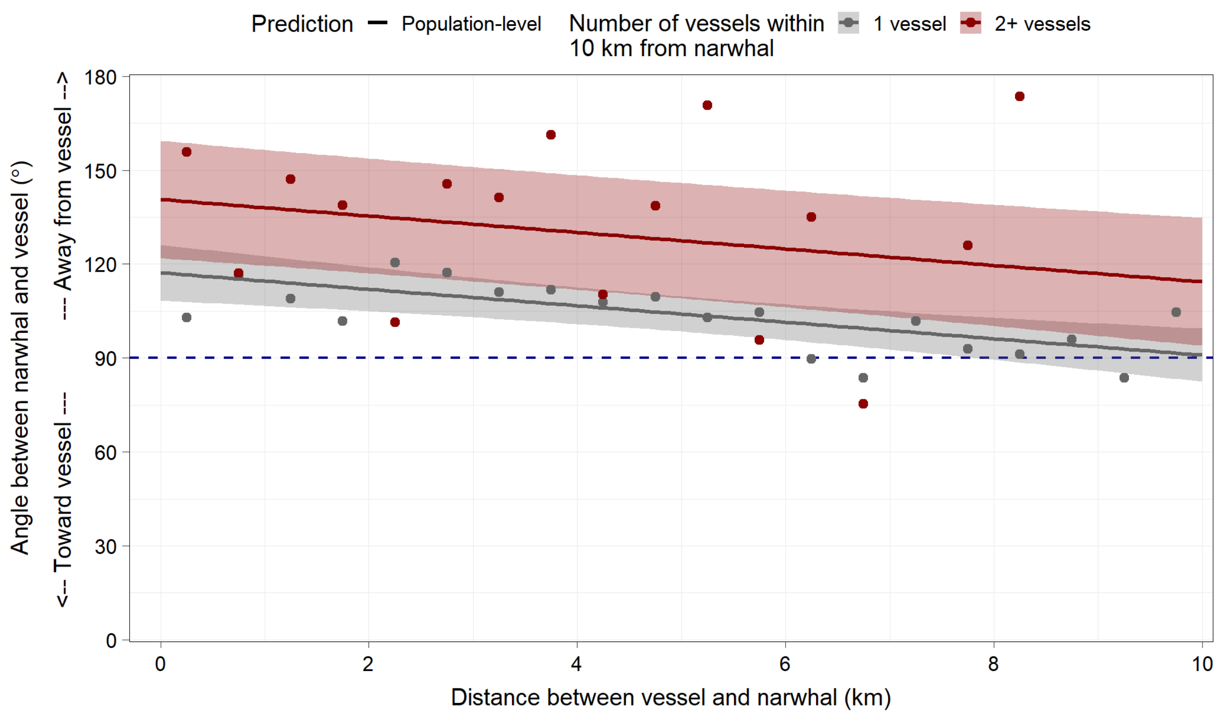

Figure 4-87: Mean observed and predicted travel orientation relative to number of vessels present within exposure zone and distance from vessels.

Note: Lines and ribbons represent population-level model predictions and the 95% confidence intervals associated with them.

Table 4-18: Least squares means of travel orientation relative to vessels under single and multiple vessel scenarios at specific distances between narwhal and vessels

Distance from Vessel (km)	Least-squares Means		
	One Vessel	Two or More Vessels	*P* Value (Effect of Multiple Vessels)
0	117.2	140.7	**0.014**
1	114.6	138.0	
2	112.0	135.4	
3	109.3	132.8	
4	106.7	130.1	
5	104.1	127.5	
6	101.5	124.9	
7	98.8	122.2	
8	96.2	119.6	
9	93.6	117.0	
10	90.9	114.3	

5.0 DISCUSSION

The integrated 2017-2018 narwhal tagging data suggest that most changes in narwhal dive and surface behavior are elicited at relatively close distances (<1 km) to a transiting vessel, although several behavioral responses are observed at intermediate distances (up to 5-10 km). Of note, narwhal responded to vessel traffic by decreasing their time at the surface and potentially being horizontally displaced when in very close proximity to vessels (0-1 km), but were more likely to orient themselves away, or potentially avoid, vessels at intermediate distances (within 5 km of an approaching vessel and within 10 km of a departing vessel).

In assessing the dive response of narwhal that were potentially foraging, individuals that were previously engaged in a bottom dive (i.e., >75% of the available bathymetry depth) were less likely to continue performing bottom dives when within 5 km of a vessel ($P \leq 0.009$) and potentially spent less time within the deepest 20% of their dive when within 2 km of a vessel (although the latter finding was not significant; $P > 0.1$). Total dive duration of potentially foraging narwhal also significantly decreased when <1 km of a vessel ($P = 0.026$). Contrary to what would be expected during a potential avoidance response, descent speed (m/s) of potentially foraging narwhal was shown to decrease when within 4 km of a vessel, however this finding was not significant ($P > 0.4$). For narwhal that were not predicted to be foraging (i.e., not previously engaged in a bottom dive), individuals may have initiated bottom dives when within 2 km of a vessel, however this finding was also not significant ($P \geq 0.1$). No significant change was observed in the time that non-foraging narwhal spent diving overall or within the deepest 20% of their dive when exposed to vessel traffic. Finally, no significant change was observed in descent speed for non-foraging narwhal exposed to vessel traffic.

Observed behavioral responses of narwhal to vessel traffic and associated 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'. The fact that no tagged narwhal occurred within 0.5 km of a vessel's port and starboard side, or within 1 km of its bow and stern suggests that narwhal actively avoid close encounters with vessels and could 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 at close distances to vessels, also supports the avoidance response theory and contradicts the freeze response theory, suggesting a decreased risk of vessel strikes on narwhal. 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 are unlikely to lead to large-scale displacement effects or abandonment of the summering grounds in the RSA. Rather, tagged narwhal remained within the RSA throughout the majority of the shipping season, regularly crossed the vessel tracks both shortly before and shortly after vessel passages (minimum time of 4 min), and may have exhibited marginal seasonal habituation to vessel traffic over time, with an estimated reduction in CPA distance of 12-15 m/day, though neither the effect of day/time nor the effect of year were shown to be statistically significant.

Distances at which behavioral responses were observed in the 2017-2018 Integrated Narwhal Tagging Study were 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. Based on measured sound levels obtained in 2018 and 2019 via passive acoustic monitoring (Frouin-Mouy et al. 2019; 2020), it was confirmed that model estimates were overly conservative in predicting the distances to which the disturbance threshold would propagate from a vessel. The discrepancy between modeled disturbance distances and disturbance distances measured in the present study are likely due to one or more of the following factors: site-specific noise propagation limitations, overly conservative model assumptions, animal habituation to vessel noise, 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 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.

Narwhal tagging results are not directly comparable to narwhal behavioral patterns observed as part of the Bruce Head Shore-based Monitoring Program (Golder 2018; 2019; 2020) 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 (specific to the Bruce Head study area) and applied several different analytical parameters such as vessel travel direction. However, *ad lib* observations recorded by observers at Bruce Head were in close agreement with behavioral responses observed in the current study, where the response of narwhal to vessel traffic was shown to be variable, ranging from ‘no obvious response’ (animals remained in close proximity to vessels as they transited through the RSA), to temporary and localized displacement and related changes in behavior (Golder 2018; 2019; 2020). 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 over an extended uninterrupted time series. 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 behavior.

It is important to note that the dive behavior models were based on a limited amount of near-field distance data, and therefore results should be interpreted with caution. In addition, dive and surface behavior analyses were based on movement data collected from only six to 12 tagged narwhal (depending on the response variable assessed) collected over the 2017 and 2018 shipping seasons. Therefore, sample size was relatively small. Should more data become available during future tagging efforts, the relationship between vessel distance and narwhal surface and dive behavior would benefit from further evaluation.

6.0 SUMMARY OF KEY FINDINGS

The following is a summary of key findings pertaining to narwhal behavioral responses to vessel traffic based on a comparison of animal-borne tag data with AIS vessel-tracking data during the 2017 and 2018 shipping seasons.

Dive Behavior

- Surface time: It was predicted that narwhal exposed to vessel traffic may either increase or decrease their time at the surface, depending on whether their response to a perceived threat consisted of a ‘freeze’ behavior or was expressed through active avoidance, respectively. The estimated population-level probability of narwhal presence at the surface when not exposed to vessels (vessels > 10 km away) was 0.144 and 0.850 for individuals not at the surface (i.e., deeper than 7 m) and at the surface (≤7 m) during the 1 minute prior, respectively. At a distance of 1 km from a vessel, the probability of narwhal presence at the surface decreased to 0.113 and 0.811 for individuals previously deeper than 7 m and at the surface, respectively. These findings were marginally significantly different from model predictions when no vessels were present within 10 km (*P*=0.059). At distance of 0 km, the probability of narwhal presence at surface decreased further to 0.083 and 0.752 for individuals previously deeper than 7 m and at the surface, respectively. These findings were significantly different from predictions when no vessels were present within 10 km (*P*=0.020). That is, the effect of distance from a vessel on narwhal surface time was statistically significant at close distances only, with the probability of an individual being at the surface decreasing by 5-22% when at a distance of 1 km from a vessel, and by 12-42% when at a distance of 0 km from a vessel, depending on whether the individual was at the surface during the 1 min prior. **This result suggests that narwhal decreased their surface time at distances up to 1 km of a transiting vessel (moderate-level avoidance response). This would be equivalent to a total exposure period of 7 min per vessel transit (based on a 9 knot travel speed), with animals returning to their pre-response behavior following the exposure period (temporary effect). Given that vessels were within 1 km of a tagged narwhal for <1% of the GPS datapoints collected in the RSA during 2017 and 2018, the frequency of occurrence of this effect was considered intermittent.**

  Furthermore, narwhal surface time was significantly different between substrata, with Koluktoo Bay and Tremblay Sound substrata having higher probabilities of narwhal being at the surface than Milne Inlet North or Milne Inlet South substrata. These findings are consistent with anecdotal observations made through the Bruce Head Shore-based Monitoring Program in which narwhal were often observed resting or milling at the surface near the entrance of Koluktoo Bay (Golder 2018), suggesting that animals use the different water bodies within the RSA for different purposes. Milne Inlet North had the lowest mean probability of narwhal being at the surface than any of the other substrata.

  The effect of exposure to multiple vessels did not result in significantly different surface time for narwhal than when exposed to a single vessel. Not only was this effect not significant, but the effect size was small.

- Dive rate: It was predicted that narwhal exposed to vessel traffic may either increase or decrease their dive rate, depending on whether their response to a perceived threat consisted of a ‘freeze’ behavior or was expressed through active avoidance, respectively. As the distance between a given narwhal and a vessel changed substantially over the period necessary to yield reliable results (i.e., one hour), dive rate (number of dives per hour) was not analyzed in relation to distance from vessel. Therefore, only a qualitative assessment of dive rate during exposure and non-exposure periods was conducted and suggested no difference between the two periods or between male and female narwhal.

- Performing bottom dives: It was assumed that narwhal engaged in foraging would spend a relatively greater amount of time at or near the bottom (>75% of the available bathymetry depth) and that actively foraging narwhal exposed to vessel noise may cease foraging activity in response to a perceived threat such as shipping. The effect of distance from a vessel on narwhal performing bottom dives was statistically significant when individuals were within 5 km from a vessel ($P \leq 0.009$), only if the individual was previously engaged in a bottom dive (assumed to represent feeding). Of note, when no vessels were present within 10 km, the probability of a narwhal performing a bottom dive was 0.489 when the preceding dive was also a bottom dive and decreased to 0.303 when 5 km from a vessel and to 0.034 when 0 km from a vessel ($P \leq 0.009$ for all distances between 0 and 5 km). When no vessels were present within 10 km and narwhal were not previously engaged in a bottom dive (not assumed to be feeding), the probability of an individual performing a bottom dive was 0.214 and increased when in close proximity (0-2 km) to a vessel, however this finding was not significant ($P \geq 0.1$). **This result suggests that narwhal that are actively engaged in foraging (i.e., bottom dives) at the time of vessel exposure may reduce the number of subsequent dives they make to the bottom when they are within 5 km of a transiting vessel (moderate-level disturbance response). This would be equivalent to a total exposure period of 36 min per vessel transit (based on a 9 knot travel speed), with animals returning to their pre-response behavior following the exposure period (temporary effect). Given that vessels were within 5 km of a tagged narwhal for <2% of the GPS datapoints collected in the RSA during 2017 and 2018, the frequency of occurrence of this effect was considered intermittent.**

  The effect of exposure to multiple vessels on narwhal performing bottom dives was moderate (37% increase in odds), however it was not significant relative to when only a single vessel was present (P=0.3). This was likely due to small sample size and variable data, and more data are required to adequately assess this relationship.

- Time at depth: It was predicted that narwhal engaged in foraging activity would spend a relatively greater amount of time within the deepest 20% of a dive and that those exposed to vessel traffic may cease foraging activity in response to a perceived threat. When narwhal were not exposed to vessel traffic (i.e., no vessels were present within 10 km), time spent within the deepest 20% of the dive ranged between 3.4 min and 5.9 min for narwhal undertaking bottom dives and between 1.1 min and 1.6 min for narwhal not undertaking bottom dives. Although the effect of 'distance from vessel' on 'time at depth' was not statistically significant (P>0.1), the smoothing trend curve suggested that time spent within the deepest 20% of the dive was shorter when in close proximity (0-2 km) to a vessel than when a vessel was further away (2-8 km), but only for bottom dives.

  Time at depth was lowest in Eclipse Sound substratum, which was significantly different from Milne Inlet South and Koluktoo Bay (which had the highest estimated time at depth).

- Dive duration: It was predicted that narwhal engaged in foraging activity would exhibit dives that are relatively longer in duration overall and that those exposed to vessel traffic may cease foraging activity in response to a perceived threat. When narwhal were not exposed to vessel traffic (i.e., no vessels were present within 10 km), mean dive duration was 12.1 min for narwhal undertaking bottom dives and 4.1 min for narwhal not undertaking bottom dives. The effect of distance from vessel on narwhal dive duration was significant at close distances only, with dive duration decreasing when <1 km from a vessel, and only when narwhal were undertaking a bottom dive (P=0.026). **This result suggested that narwhal decreased their dive duration (moderate-level disturbance response) at distances up to 1 km of a transiting vessel.**

This would be equivalent to a total exposure period of 7 min per vessel transit (based on a 9 knot travel speed), with animals returning to their pre-response behavior following the exposure period (temporary effect). Given that vessels were within 1 km of a tagged narwhal for <1% of the GPS datapoints collected in the RSA during 2017 and 2018, the frequency of occurrence of this effect was considered intermittent.

An 11% reduction in narwhal dive duration was estimated in the presence of multiple vessels in comparison to a single vessel, however the effect was not significant (*P*=0.07), due to the relatively small effect size and due to data variability. More data would be required to adequately assess this relationship.

- Descent speed: It was predicted that an increase in descent speed by narwhal exposed to vessel traffic would indicate a potential avoidance response to a perceived threat. When narwhal were not exposed to vessel traffic (i.e., no vessels were present within 10 km), mean descent speed was 1.01 m/s for narwhal undertaking bottom dives and 0.32 m/s for narwhal not undertaking bottom dives. Although the effect of distance from vessel on descent speed was not statistically significant (*P*>0.4), the smoothing trend curve suggested that, for narwhal undertaking bottom dives, descent speed was marginally lower when in close proximity to a vessel (0-4 km) than when a vessel was further away.

Surface Behavior

- Turning angle: It was predicted that a small turning angle by narwhal was indicative of a linear travel mode, whereas a large turning angle may indicate avoidance (e.g., turning back on their own track) or simply nondirectional travel. Narwhal turning angles were significantly (*P*<0.05) higher when within 1-4 km of vessels relative to when no vessels were within 10 km. The adjusted *P* value at 0 km from a vessel relative to non-exposure estimates was not significant (*P*=0.1), likely due to the increased uncertainty in prediction at distances ≤1 km due to low sample sizes (Figure 4-65). That is, turning angles were highest when narwhal were within 1-4 km from a transiting vessel. **This result suggested that narwhal turned back on their own track (low-level avoidance response) at distances up to 4 km of a transiting vessel. This would be equivalent to a total exposure period of 29 min per vessel transit (based on a 9 knot travel speed), with animals returning to their pre-response behavior following the exposure period (temporary effect). Given that vessels were within 10 km of a tagged narwhal for <2% of the GPS datapoints collected in the RSA during 2017 and 2018, the frequency of occurrence of this effect was considered intermittent.**

  Within the 10 km exposure zone, narwhal significantly increased their turning angle (i.e., turned back on their own track) when exposed to multiple vessels, compared to when exposed to only a single vessel (*P*=0.004), with a 28%-38% difference between the two scenarios, depending on distance from nearest vessel.

- Travel orientation relative to vessels: It was predicted that narwhal travel orientation relative to vessels would be less than 90° if distance from a vessel had no effect on narwhal orientation (regardless of the orientation of the vessel itself). That is, an angle less than 90° would be indicative of narwhal heading toward a vessel while an angle larger than 90° would be indicative of a narwhal heading away from, or potentially avoiding, a vessel. Both the effect of distance and the effect of Before/After CPA were significant (*P*<0.001). The orientation of narwhal relative to transiting vessels was predicted to be higher than 90° when narwhal were within 5 km of a vessel prior to CPA, suggesting that narwhal tended to orient themselves away from vessels within this distance. Following CPA, mean model predictions remained above the 90° value for the entire 10 km extent. **These results suggest that narwhal demonstrate a change in travel orientation relative**

to the vessel (low-level avoidance response) at distances up to 5 km of an approaching vessel, and up to 10 km of a departing vessel (localized effect). This would be equivalent to a total exposure period of 54 min per vessel transit (based on a 9 knot travel speed), with animals returning to their pre-response behavior following the exposure period (temporary effect). Given that vessels were within 10 km of a tagged narwhal for less than 7% of the GPS datapoints collected in the RSA during 2017 and 2018, the frequency of occurrence of this effect was considered intermittent.

The effect of exposure to multiple vessels had a significant effect on narwhal travel orientation relative to presence of a single vessel (P=0.014). On average, narwhal tended to orient themselves away from vessels more readily when multiple vessels were present (increase of 23.5°).

- Horizontal displacement: It was predicted that narwhal would actively avoid transiting vessels at some distance from the vessel given the ability of toothed whales to perceive their environment via echolocation. 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 a vessel's port and starboard, and within 1 km of a vessel's bow and stern. Observed and model-predicted densities increased close to the vessel in all four directions relative to densities at distance. However, densities observed in both port and starboard directions continued increasing up to <1 km from the vessel, whereas densities observed in both forward and astern directions peaked at 1 km and decreased <1 km, in accordance with the gap of recorded positions. **This gap in narwhal distribution in close proximity to transiting 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.**

  Effect of repeated exposure on horizontal displacement: It was assumed that a seasonal decrease in the CPA (distance between narwhal and a transiting vessel) would suggest habituation to shipping activities along the Northern Shipping Route and a seasonal increase would suggest longer-term avoidance and/or displacement effects. In assessing narwhal habituation to vessel traffic over the 2017 and 2018 shipping seasons, temporal changes to the time series of CPA distances were modeled. Unlike the seasonal decrease in CPA of 39 m/day reported in Golder (2019), the current model (2017 and 2018 data combined) estimated a seasonal decrease in the CPA of 12-15 m/day (minimum CPA = 0.1 km), though the effect of day/time and the effect of year were determined to be not significant (P=0.1 and P=0.6, respectively).

- Habitat re-occupation: It was predicted that re-occupation of vessel tracks by narwhal would indicate potential habituation to shipping activities along the Northern Shipping Route. Overall, narwhal crossed the vessel track both shortly before and shortly after vessel passage (minimum value of 4 min), suggesting no long-term avoidance of shipping activities along the Northern Shipping Route. Narwhal may have exhibited marginal seasonal habituation to vessel passage (i.e., decrease in re-occupation time over season), although neither the effect of day/time or the effect of year were shown to be statistically significant (P>0.4).

- Travel speed: It was predicted that an increase in travel speed by narwhal exposed to vessel traffic would indicate a potential avoidance response to a perceived threat while a decrease in travel speed may indicate a potential freeze response. The effect of distance from a vessel on narwhal travel speed was not statistically significant (P=0.2) and had a small effect size. However, the effect of substratum was statistically significant (P<0.001), with travel speeds being highest at Baffin Bay Shallow, Baffin Bay, and Milne Inlet North substrata, and lowest in Koluktoo Bay and the Other Inlets/Sounds substrata. This finding suggested that while narwhal did not alter their travel speed in the presence of transiting vessels, animals traveled at different speeds in specific areas of the RSA, regardless of exposure to vessel traffic.

In summary, narwhal positional data from 2017 and 2018 demonstrated that tagged narwhal occurred in all strata during the summer period, but were more common in certain areas of the RSA, namely Milne Inlet South, Koluktoo Bay, Milne Inlet North and Tremblay Sound. High use areas in the RSA included the central portion of Tremblay Sound, the western shore of Milne Inlet North, and most of Koluktoo Bay and Milne Inlet South, particularly in areas south of Bruce Head (i.e., entrance to Koluktoo Bay) and in Assomption Harbour (i.e., Milne Port site). These results were consistent with areas of high narwhal concentrations identified during baseline aerial surveys conducted in the RSA during 2007, 2008, 2013 and 2014 (Elliott et al. 2015; Thomas et al. 2015) prior to the commencement of iron ore shipping along the Northern Shipping Route. With respect to interactions between tagged narwhal and existing shipping in the RSA, the majority of the GPS data collected during 2017 and 2018 occurred when narwhal were >10 km from medium- and large-sized vessels (Project and non-Project related). Vessel exposure events (<10 km) occurred throughout the RSA but were more common in the Milne Inlet South and Koluktoo Bay strata due to the confined nature of the channel along this part of the Northern Shipping Route. Satellite tag data from 2017 indicated that several of the tagged narwhal moved between Eclipse Sound and Admiralty Inlet during their deployment period. These results support the notion that some degree of mixing occurs between the Eclipse Sound and Admiralty Inlet stocks during the shipping season.

Narwhal dive behavioral responses that were shown to be significantly influenced by vessel-generated noise and/or close vessel encounters included surface time, dive duration, and bottom dives; the latter only during periods when narwhal were engaged in bottom diving at the initial time of vessel exposure. No significant effects were observed for dive rate, time at depth, descent speed, or bottom dives (during periods when narwhal were not actively diving to the bottom at the initial time of exposure). The distance at which significant changes were observed in dive behavior ranged from 1 to 5 km dependent on the response variable. This corresponded with an exposure period ranging from 7 to 36 min per vessel transit (based on a 9-knot travel speed), with animals returning to their pre-response behavior following the exposure period (temporary effect). The frequency of this effect was considered intermittent given that vessels were within 5 km of a tagged narwhal for <1% of the GPS datapoints collected in the RSA during 2017 and 2018.

Narwhal surface movement responses that were shown to be significantly influenced by vessel-generated noise included turning angle and orientation relative to vessel (low level severity responses). No significant effects were observed for travel speed, horizontal displacement or habitat re-occupation. The distance at which significant changes were observed in surface movement behavior ranged from 4 to 10 km dependent on the response variable. This corresponded with an exposure period ranging from 29 to 54 min per vessel transit (based on a 9-knot travel speed), with animals returning to their pre-response behavior following the exposure period (temporary effect). The frequency of this effect was considered intermittent given that vessels were within 10 km of a tagged narwhal for <7% of the GPS datapoints collected in the RSA during 2017 and 2018. Although no significant effect was observed for horizontal displacement, a clear spatial gap in narwhal positional data was evident in the immediate proximity of the vessel (within 0.5 km of the vessel's port and starboard beam and within 1 km of its bow and stern). This gap may reflect close-range avoidance behavior but may also be a function of the low-resolution GPS location data available.

Overall, results from the 2017 and 2018 narwhal tagging study support predictions made in the Final Environmental Impact Statement (FEIS) for the Early Revenue Phase (ERP), in that vessel-generated noise effects on narwhal will be limited to temporary, short-term avoidance behavior, consistent with low[11] to moderate[12] severity responses as defined in Section 2.6.3 of this report. No evidence was observed of large-scale avoidance behavior, displacement effects, or abandonment of the summering grounds (high severity responses), which might in turn result in a population or stock-level consequence (consistent with the definition of a non-significant effect used in the FEIS).

7.0 RECOMMENDATIONS FOR FUTURE STUDIES

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 was coarse and somewhat irregular which could lead to less precise estimates of narwhal-vessel distances and subsequently introduce noise when attempting to link distance effects with narwhal behaviors. Additionally, the sparse temporal resolution of the GPS data impeded the ability to detect fine scale geographic movements of the animal to a vessel passage. For future tagging efforts, Golder recommends 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 behavior (e.g., Golder 2018). Despite many of the tagged narwhal likely encountering hunting activities at some point during the tag deployment period, hunting effects were not accounted for in the present analysis as shooting events could not be documented within the full extent of the RSA in real time. As narwhal responses specific to hunting activities are likely to contribute noise to the dataset and potentially obscure vessel-specific effects (or non-effects), ongoing monitoring efforts at Bruce Head should attempt to better document hunting activities in this region. This information could potentially be used as a covariate in future analyses of narwhal tagging data.
- Unfortunately, none of the narwhal fitted with acoustic recording tags (Acousonde 3B; Greeneridge Sciences) were recorded entering Milne Inlet or Eclipse Sound during the period that tags remained on the animal. For this reason, the acoustic behavior of narwhal in relation to 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 should explore whether the frequency, intensity, and duration of different narwhal call types changes in the presence of vessel traffic. This is particularly relevant to assessing changes (if any) in mother-calf contact calls as a result of vessel traffic and associated noise. By analyzing the data from acoustic recording tags deployed on narwhal during the 2018 shipping season, potential thresholds above which received sound levels correspond to a change in narwhal

[11] Low severity responses are within an animal's range of typical (baseline) behaviors and are unlikely to disrupt an individual to a point where natural behavior patterns are significantly altered or abandoned (Southall et al. 2007; Finneran et al. 2012; 2017). Low severity responses are consistent with minor/brief responses (Severity Score 0-3) described by Southall et al. (2007) that are unlikely to affect vital rates.

[12] Moderate severity responses would include avoidance of sound source or changes in migratory movement, locomotion (speed, heading), dive profiles, nursing, breeding, feeding/foraging, resting and vocal behavior. Moderate severity responses are not considered significant behavioral responses if they last for a short duration and the animal immediately returns to their pre-response behavior (Southall et al. 2007; Finneran et al. 2012; 2017).

vocalizations and/or locomotive behavior may be explored. This analysis is currently in process through a collaborative study between Golder, JASCO, the University of New Brunswick and Baffinland.

- It was proposed in Golder (2019) that analyses of the 2017-2018 integrated narwhal tagging data would attempt to include variables that may assist in identification of adaptive management measures, including consideration of multiple vessel interactions in the statistical model. The effects of multiple vessels on narwhal dive and surface behavior were examined herein in a separate set of models. For these, only response variables that had a significant effect of distance from vessel were carried forward (e.g., surface time, performing bottom dives, dive duration, turning angle, and travel orientation relative to vessels). Number of vessels was expressed as a categorical variable (1 vessel or 2+ vessels) and was used as an independent variable. The significance of the variable and its effect size were evaluated for each response variable examined. In assessing narwhal interactions with multiple vessels, sample sizes were small for most response variables, data variability was high, and it is likely that the definition of multiple vessel passage (i.e., the number of vessels within the overall 10 km exposure zone) was not sufficiently focused. Therefore, it is recommended that the definition of multiple vessel passage be further restricted in the future to adequately assess the effect of exposure to multiple vessels on the various response variables, should additional data be collected in close proximity to vessels.
- It was proposed in Golder (2019) that analyses of the 2017-2018 integrated narwhal tagging data would include consideration of vessel direction relative to narwhal (i.e., testing for potential differences in narwhal response to approaching vs. departing vessels). Prior to the formal analysis, each response variable was plotted against distance from vessel, where directionality of vessel distance was included as a negative value before CPA and a positive value following CPA. These plots were accompanied by smoother trends, which informed the evaluation of whether narwhal responded differently to vessels prior to CPA or following the CPA. Where the effect of directionality was evident, it was carried forward into the formal models. The scatter plots with smoother trends were included in this report for transparency. It is recommended that this approach continue to be utilized for future analyses.

8.0 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

Model Test Statistics and Coefficient Summaries – Analysis in Relation to a Single Vessel

Dive Behavior in Relation to Vessel Traffic

Surface Time

Table A-1: Test statistics of logistic model of presence/absence of narwhal at surface (type II *P* values)

Parameter	Chi squared	Df	*P* value
Effect of distance from vessel (3rd degree polynomial)	9.752	3	0.021
Effect of exposure	0.076	1	0.783
Effect of narwhal presence at surface in the preceding 1 min interval	16915.360	1	<0.001
Effect of substratum	114.485	7	<0.001
Effect of tag type	1.276	1	0.259
Effect of time since last 1 min surface period (2nd degree polynomial)	1269.280	2	<0.001

Table A-2: Coefficient estimates for fixed effects in a mixed logistic model of presence/absence of narwhal at surface (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, narwhal not at surface in the preceding 1 min interval, MiniPAT tag)	-1.724	0.131	-13.150	<0.001
Distance from vessel[1]	1.474	2.739	0.540	0.590
Distance from vessel squared[1]	-2.481	3.846	-0.650	0.519
Distance from vessel cubed[1]	8.113	2.861	2.840	0.005
Exposure	-0.010	0.035	-0.280	0.783
Narwhal at surface in the preceding 1 min interval	2.927	0.023	130.060	<0.001
Substratum – Eclipse Sound	0.364	0.115	3.160	0.002
Substratum – Koluktoo Bay	0.500	0.116	4.310	<0.001
Substratum – Milne Inlet North	0.308	0.115	2.670	0.007
Substratum – Milne Inlet South	0.366	0.115	3.190	0.001
Substratum – Navy Board Inlet	0.551	0.107	5.150	<0.001
Substratum – Other Inlets / Sounds	0.535	0.128	4.190	<0.001
Substratum – Tremblay Sound	0.465	0.114	4.100	<0.001
TagType – SPLASH10	-0.105	0.093	-1.130	0.259
Time since last surfacing[1]	-34.925	4.337	-8.050	<0.001
Time since last surfacing squared[1]	109.465	3.360	32.580	<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.

Performing Bottom Dives

Table A-3: Test statistics of logistic model of presence/absence of bottom dives (type II *P* values)

Parameter	Chi squared	Df	*P* value
Distance from vessel (2nd degree polynomial)	3.200	2	0.202
Effect of exposure	9.208	1	0.002
Effect of whether the preceding dive was a bottom dive	430.534	1	<0.001
Effect of bathymetry	20.810	1	<0.001
Effect of time elapsed since previous bottom dive	27.257	1	<0.001
Effect of substratum	22.226	6	0.001
Interaction between distance from vessel and whether the preceding dive was a bottom dive	18.530	2	<0.001
Interaction between exposure and whether the preceding dive was a bottom dive	0.005	1	0.942

Table A-4: Coefficient estimates for fixed effects in a mixed logistic model of presence/absence of bottom dives (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, mean bathymetry and time from previous bottom dive, preceding dive not bottom dive, Eclipse Sound)	-0.624	0.332	-1.883	0.060
Distance from vessel [1]	-1.385	3.893	-0.356	0.722
Distance from vessel squared [1]	9.649	5.363	1.799	0.072
Exposure	-0.468	0.191	-2.455	0.014
Preceding dive was a bottom dive	1.187	0.061	19.503	<0.001
Effect of bathymetry [2]	-0.232	0.051	-4.562	<0.001
Effect of time since last bottom dive [2]	-0.355	0.068	-5.221	<0.001
Substratum – Koluktoo Bay	-0.891	0.242	-3.680	<0.001
Substratum – Milne Inlet North	-0.539	0.210	-2.567	0.010
Substratum – Milne Inlet South	-0.626	0.217	-2.882	0.004
Substratum – Navy Board Inlet	-1.554	0.695	-2.235	0.025
Substratum – Other Inlets / Sounds	-0.378	0.423	-0.894	0.371
Substratum – Tremblay Sound	-1.093	0.269	-4.060	<0.001
Interaction between distance from vessel [1] and whether the preceding dive was a bottom dive	24.525	6.671	3.676	<0.001
Interaction between distance from vessel squared [1] and whether the preceding dive was a bottom dive	-20.509	9.032	-2.271	0.023
Interaction between exposure and whether the preceding dive was a bottom dive	-0.020	0.276	-0.073	0.942

[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 A-5: Test statistics of model of time spent at bottom 20% of each dive (type II *P* values)

Parameter	Chi squared	Df	*P* value
Distance from vessel (3rd degree polynomial)	5.0792	3	0.166
Effect of exposure	0.7446	1	0.388
Effect of whether the current dive was a bottom dive	250.0597	1	<0.001
Effect of maximum dive depth (2nd degree polynomial)	818.0307	2	<0.001
Effect of substratum	88.9655	6	<0.001
Effect of whether the preceding dive was a bottom dive	17.3304	1	<0.001
Interaction between distance from vessel and whether the current dive was a bottom dive	2.0392	3	0.564
Interaction between exposure and whether the current dive was a bottom dive	2.1281	1	0.145
Interaction between maximum dive depth and whether the current dive was a bottom dive	13.977	2	0.001
Interaction between whether the preceding dive was a bottom dive and whether the current dive was a bottom dive	89.398	1	<0.001

Table A-6: Coefficient estimates for fixed effects in a mixed model of time spent at bottom 20% of each dive (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive, current dive not bottom dive, Eclipse Sound)	1.167	0.035	33.020	<0.001
Distance from vessel [1]	1.109	0.518	2.140	0.032
Distance from vessel squared [1]	-0.551	0.747	-0.740	0.461
Distance from vessel cubed [1]	-0.222	0.540	-0.410	0.681
Exposure	-0.034	0.024	-1.440	0.150
Effect of whether the current dive is a bottom dive	0.120	0.015	8.090	<0.001
Effect of maximum dive depth [1]	56.651	1.723	32.880	<0.001
Effect of maximum dive depth squared [1]	-31.125	1.503	-20.710	<0.001
Substratum – Koluktoo Bay	0.180	0.024	7.440	<0.001
Substratum – Milne Inlet North	0.052	0.022	2.410	0.016
Substratum – Milne Inlet South	0.135	0.021	6.410	<0.001
Substratum – Navy Board Inlet	0.127	0.082	1.550	0.122
Substratum – Other Inlets / Sounds	0.058	0.039	1.480	0.139
Substratum – Tremblay Sound	0.083	0.028	2.910	0.004
Preceding dive was a bottom dive	-0.111	0.012	-9.320	<0.001
Interaction between distance from vessel [1] and whether the current dive is a bottom dive	-1.297	1.103	-1.180	0.240
Interaction between distance from vessel squared [1] and whether the current dive is a bottom dive	-0.815	1.450	-0.560	0.574
Interaction between distance from vessel cubed [1] and whether the current dive is a bottom dive	0.739	1.040	0.710	0.477
Interaction between effect of exposure and whether current dive is a bottom dive	0.067	0.046	1.460	0.145
Interaction between maximum dive depth [1] and whether the current dive is a bottom dive	1.928	1.863	1.030	0.301
Interaction between maximum dive depth squared [1] and whether the current dive is a bottom dive	5.931	1.589	3.730	<0.001
Interaction between whether the current dive is a bottom dive and whether the preceding dive was a bottom dive	0.170	0.018	9.450	<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.

Dive Duration

Table A-7: Test statistics of model of dive duration (type II *P* values)

Parameter	Chi squared	Df	*P* value
Distance from vessel (3rd degree polynomial)	8.507	3	0.037
Effect of exposure	0.002	1	0.964
Effect of whether the current dive was a bottom dive	49.273	1	<0.001
Effect of substratum	64.412	6	<0.001
Effect of maximum dive depth (5^{th} degree polynomial)	2582.065	5	<0.001
Effect of duration of previous dive	25.285	1	<0.001
Effect of whether the preceding dive was a bottom dive	33.221	1	<0.001
Interaction between distance from vessel and whether the current dive was a bottom dive	8.583	3	0.035
Interaction between exposure and whether the current dive was a bottom dive	1.074	1	0.300
Interaction between duration of previous dive and whether the preceding dive was a bottom dive	10.237	1	0.001
Interaction between duration of previous dive and whether the current dive was a bottom dive	31.854	1	<0.001
Interaction between whether the preceding dive was a bottom dive and whether the current dive was a bottom dive	3.006	1	0.083
Interaction between duration of previous dive, whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive	34.159	1	<0.001

Table A-8: Coefficient estimates for fixed effects in a mixed model of dive duration (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive, current dive not bottom dive, average dive depth, average duration of preceding dive, Eclipse Sound)	1.976	0.059	33.370	<0.001
Distance from vessel [1]	1.257	0.487	2.580	0.010
Distance from vessel squared [1]	-0.532	0.684	-0.780	0.437
Distance from vessel cubed [1]	-0.063	0.494	-0.130	0.899
Effect of exposure	-0.012	0.024	-0.510	0.613
Effect of whether the current dive is a bottom dive	0.047	0.016	2.970	0.003
Substratum – Koluktoo Bay	0.257	0.036	7.190	<0.001
Substratum – Milne Inlet North	0.168	0.032	5.270	<0.001
Substratum – Milne Inlet South	0.220	0.032	6.820	<0.001
Substratum – Navy Board Inlet	0.179	0.100	1.790	0.074
Substratum – Other Inlets / Sounds	0.248	0.068	3.680	<0.001
Substratum – Tremblay Sound	0.118	0.041	2.870	0.004
Effect of maximum dive depth [1]	95.496	0.791	120.680	<0.001
Effect of maximum dive depth squared [1]	-36.352	0.551	-65.940	<0.001
Effect of maximum dive depth cubed [1]	23.515	0.469	50.160	<0.001
Effect of maximum dive depth to power of 4 [1]	-17.828	0.457	-38.980	<0.001
Effect of maximum dive depth to power of 5 [1]	10.384	0.439	23.630	<0.001
Effect of duration of preceding dive [2]	-0.013	0.007	-1.780	0.076
Effect of whether preceding dive was a bottom dive	-0.056	0.015	-3.830	<0.001
Interaction between distance from vessel and whether the current dive is a bottom dive	-1.478	0.995	-1.490	0.137
Interaction between distance from vessel squared [1] and whether the current dive is a bottom dive	0.516	1.307	0.390	0.693
Interaction between distance from vessel cubed [1] and whether the current dive is a bottom dive	2.576	0.938	2.750	0.006
Interaction between effect of exposure and whether current dive is a bottom dive	0.044	0.043	1.040	0.300
Interaction between duration of preceding dive [2] and whether the preceding dive was a bottom dive	-0.068	0.012	-5.810	<0.001
Interaction between duration of preceding dive [2] and whether the current dive was a bottom dive	-0.024	0.017	-1.420	0.157
Interaction between whether the current dive is a bottom dive and whether the preceding dive was a bottom dive	0.034	0.021	1.600	0.110
Interaction between duration of preceding dive [2], whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive	0.124	0.021	5.840	<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. [2] = Variable was standardized prior to modeling

Descent Speed

Table A-9: Test statistics of model of descent speed (type II *P* values)

Parameter	Chi squared	Df	*P* value
Distance from vessel (2nd degree polynomial)	0.388	2	0.824
Effect of exposure	0.134	1	0.714
Effect of whether the current dive was a bottom dive	25.965	1	<0.001
Effect of whether the preceding dive was a bottom dive	34.457	1	<0.001
Effect of substratum	12.946	6	0.044
Effect of maximum dive depth (3rd degree polynomial)	6502.957	3	<0.001
Effect of descent speed at preceding dive	203.058	1	<0.001
Interaction between distance from vessel and whether the current dive was a bottom dive	1.599	2	0.450
Interaction between exposure and whether the current dive was a bottom dive	0.422	1	0.516
Interaction between descent speed at preceding dive ^{2} and whether the preceding dive was a bottom dive	4.169	1	0.041
Interaction between descent speed at preceding dive ^{2} and whether the current dive was a bottom dive	34.119	1	<0.001
Interaction between whether the current dive is a bottom dive and whether the preceding dive was a bottom dive	20.617	1	<0.001
Interaction between descent speed at preceding dive ^{2}, whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive	82.903	1	<0.001

Table A-10: Coefficient estimates for fixed effects in a mixed model of descent speed (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive, current dive not bottom dive, Eclipse Sound)	0.664	0.016	40.400	<0.001
Distance from vessel [1]	-0.165	0.205	-0.800	0.421
Distance from vessel squared [1]	0.099	0.293	0.340	0.736
Exposure	-0.006	0.009	-0.630	0.531
Effect of whether the current dive is a bottom dive	0.032	0.006	4.920	<0.001
Effect of whether preceding dive was a bottom dive	0.048	0.006	8.340	<0.001
Substratum – Koluktoo Bay	-0.027	0.011	-2.510	0.012
Substratum – Milne Inlet North	-0.027	0.009	-2.900	0.004
Substratum – Milne Inlet South	-0.020	0.009	-2.130	0.033
Substratum – Navy Board Inlet	0.015	0.035	0.420	0.674
Substratum – Other Inlets / Sounds	-0.046	0.021	-2.210	0.027
Substratum – Tremblay Sound	-0.026	0.012	-2.200	0.028
Effect of maximum dive depth [1]	24.120	0.318	75.840	<0.001
Effect of maximum dive depth squared [1]	-8.686	0.220	-39.400	<0.001
Effect of maximum dive depth cubed [1]	3.350	0.192	17.410	<0.001
Interaction between distance from vessel [1] and whether the current dive was a bottom dive	0.044	0.004	10.530	<0.001
Interaction between distance from vessel squared [1] and whether the current dive was a bottom dive	0.229	0.424	0.540	0.589
Interaction between exposure and whether the current dive was a bottom dive	-0.609	0.559	-1.090	0.276

[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 Behavior in Relation to Vessel Traffic

Turning Angle

Table A-11: Test statistics of mixed model of square-root transformed turning angles (type II *P* values)

Parameter	Chi squared	Df	*P* value
Effect of exposure	1.059	1	0.304
Effect of distance from shore[2]	1.254	1	0.263
Effect of distance from vessel (2nd degree polynomial) [1]	12.373	2	0.002
Effect of turning angle at previous GPS point (2nd degree polynomial) [1]	95.567	2	<0.001
Effect of substratum	35.702	8	<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. [2] = Variable was standardized prior to modeling

Table A-12: Coefficient estimates for fixed effects in a mixed model of turning rates (type I *P* values)

Parameter	Coefficient	SE	z value	*P* value
Intercept (no exposure, Baffin Bay)	4.130	0.831	4.967	<0.001
Effect of exposure	0.158	0.154	1.026	0.305
Effect of narwhal distance from shore [2]	-0.089	0.078	-1.139	0.255
Effect of distance from vessel [1]	-11.274	3.237	-3.483	<0.001
Effect of distance from vessel squared [1]	1.785	4.430	0.403	0.687
Effect of angle at previous GPS point[1]	28.429	4.251	6.687	<0.001
Effect of angle at previous GPS point squared [1]	-26.716	3.256	-8.205	<0.001
Effect of substratum (Baffin Bay Shallow)	-1.332	1.699	-0.784	0.433
Effect of substratum (Eclipse Sound)	1.303	0.821	1.587	0.113
Effect of substratum (Koluktoo Bay)	1.996	0.856	2.332	0.020
Effect of substratum (Milne Inlet North)	1.109	0.841	1.318	0.187
Effect of substratum (Milne Inlet South)	1.732	0.847	2.046	0.041
Effect of substratum (Navy Board Inlet)	0.573	0.899	0.637	0.524
Effect of substratum (Other Inlets/Sounds)	1.603	0.901	1.779	0.075
Effect of substratum (Tremblay Sound)	1.508	0.852	1.771	0.077

[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 A-13: Test statistics of mixed model of travel orientation relative to vessels (type II *P* values)

Parameter	Chi squared	Df	*P* value
Effect of distance from vessel[1]	17.443	1	<0.001
Before or after CPA	118.567	1	<0.001
Substratum	1.685	5	0.891
Interaction between distance and before/after CPA	0.504	1	0.478

[1] = Variable was standardized prior to modeling

Table A-14: Coefficient estimates for fixed effects in a mixed model of travel orientation relative to vessels (type I *P* values)

Parameter	Coefficient	SE	z value	*P* value
Intercept (mean distance, Eclipse Sound, Before CPA)	86.554	4.069	21.271	<0.001
Effect of distance from vessel[1]	-7.622	2.146	-3.551	<0.001
Effect of After CPA	33.951	3.118	10.889	<0.001
Effect of substratum (Koluktoo Bay)	-7.342	6.591	-1.114	0.265
Effect of substratum (Milne Inlet North)	-4.023	5.230	-0.769	0.442
Effect of substratum (Milne Inlet South)	-1.450	4.632	-0.313	0.754
Effect of substratum (Navy Board Inlet)	4.733	24.209	0.195	0.845
Effect of substratum (Tremblay Sound)	-5.857	20.291	-0.289	0.773
Interaction between distance and the effect of After CPA	86.554	4.069	21.271	<0.001

[1] = Variable was standardized prior to modeling

Seasonal Change and Horizontal Displacement

Table A-15: Test statistics of mixed model of habituation (square root-transformed closest point of approach [CPA] over time; type II *P* values)

Parameter	Chi squared	Df	*P* value
Day-time of study (where 1 is Aug 2 at 08:00) [1]	2.180	1	0.140
Year (as categorical covariate)	0.318	1	0.573

[1] = Variable was standardized prior to modeling

Table A-16: Coefficient estimates for fixed effects in a mixed model of habituation (type I *P* values)

Parameter	Coefficient	SE	t value	*P* value
Intercept (average day-time of study, year 2017)	1.984	0.088	22.652	<0.001
Day-time of study (where 1 is Aug 2 at 08:00) [1]	-0.058	0.040	-1.476	0.140
Year (2018)	0.125	0.222	0.564	0.585

[1] = Variable was standardized prior to modeling

Habitat Re-Occupation

Table A-16: Test statistics of mixed model of time after track crossing (type II *P* values)

Parameter	Chi squared	Df	*P* value
Day of study (where 1 is Aug 2) [1]	0.401	1	0.526
Year (as categorical covariate)	0.564	1	0.453
Interaction between day of study[1] and year	0.004	1	0.948

[1] = Variable was standardized prior to modeling.

Table A-17: Coefficient estimates for fixed effects in a mixed model of time after track crossing (type I *P* values)

Parameter	Coefficient	SE	z value	*P* value
Intercept (average day of study, year 2017)	11.194	0.666	16.805	<0.001
Effect of day of study (where 1 is Aug 2) [1]	-0.793	0.815	-0.972	0.331
Year (2018)	1.379	1.781	0.774	0.439
Interaction between day of study [1] and year (2018)	2.443	3.491	0.700	0.484

[1] = Variable was standardized prior to modeling.

Table A-18: Test statistics of mixed model of distance after track crossing (type II *P* values).

Parameter	Chi squared	Df	*P* value
Day of study (where 1 is Aug 2) [1]	0.692	1	0.406
Year (as categorical covariate)	0.404	1	0.525
Interaction between day of study and year	0.490	1	0.484

[1] = Variable was standardized prior to modeling.

Table A-19: Coefficient estimates for fixed effects in a mixed model of distance relative to track crossing (type I *P* values)

Parameter	Coefficient	SE	z value	*P* value
Intercept (average day of study, year 2017)	11.194	0.666	16.805	<0.001
Effect of day of study (where 1 is Aug 2) [1]	-0.793	0.815	-0.972	0.331
Year (2018)	1.379	1.781	0.774	0.439
Interaction between day of study [1] and year (2018)	2.443	3.491	0.700	0.484

[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.

Travel Speed

Table A-20: Test statistics of mixed model of travel speed (type II *P* values)

Parameter	Chi squared	Df	*P* value
Effect of exposure (as Before/After CPA)	6.494	2	0.039
Effect of distance from vessel[2]	1.759	1	0.185
Distance from shore (4th degree polynomial) [1]	90.080	4	<0.001
Substratum	100.895	8	<0.001
Speed at previous GPS point (2nd degree polynomial) [1]	9570.217	2	<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. [2] = Variable was standardized prior to modeling.

Table A-21: Coefficient estimates for fixed effects in a mixed model of travel speed (type I *P* values)

Parameter	Coefficient	SE	z value	*P* value
Intercept (no vessels within 10 km, Baffin Bay, mean distance from shore)	1.097	0.031	35.950	<0.001
Effect of Before CPA	-0.030	0.017	-1.750	0.080
Effect of After CPA	0.026	0.016	1.600	0.111
Distance from shore[2]	0.015	0.011	1.330	0.185
Distance from shore squared[1]	-4.174	0.715	-5.840	<0.001
Distance from shore cubed[1]	2.147	0.458	4.690	<0.001
Distance from shore to power of 4[1]	-1.070	0.442	-2.420	0.016
Substratum - Baffin Bay Shallow	0.174	0.105	1.660	0.097
Substratum - Eclipse Sound	-0.070	0.026	-2.730	0.006
Substratum - Koluktoo Bay	-0.144	0.028	-5.140	<0.001
Substratum - Milne Inlet North	-0.043	0.026	-1.640	0.101
Substratum - Milne Inlet South	-0.117	0.027	-4.380	<0.001
Substratum - Navy Board Inlet	-0.068	0.027	-2.550	0.011
Substratum - Other Inlets/Sounds	-0.145	0.035	-4.110	<0.001
Substratum - Tremblay Sound	-0.140	0.028	-4.970	<0.001
Effect of speed at previous GPS point[1]	44.795	0.460	97.320	<0.001
Effect of speed at previous GPS point squared[1]	6.483	0.403	16.080	<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. [2] = Variable was standardized prior to modeling.

APPENDIX B

Model Test Statistics and Coefficient Summaries – Analysis in Relation to Multiple Vessels

Dive and Surface Behavior in Relation to Multiple Vessel Exposure

Surface Time in Relation to Multiple Vessel Exposure

Table B-1: Test statistics of logistic model of presence/absence of narwhal at surface (type II *P* values)

Parameter	Chi squared	Df	*P* value
Effect of distance from vessel (3rd degree polynomial)	15.300	3	0.002
Effect of number of vessels (categorical variable)	0.011	1	0.917
Effect of narwhal presence at surface in the preceding 1 min interval	1115.823	1	<0.001
Effect of substratum	13.593	4	0.009
Effect of time since last 1 min surface period (2nd degree polynomial)	126.080	2	<0.001

Table B-2: Coefficient estimates for fixed effects in a mixed logistic model of presence/absence of narwhal at surface (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (One vessel, narwhal not at surface in the preceding 1 min interval, Eclipse Sound)	-1.183	0.085	-13.930	<0.001
Distance from vessel[1]	2.260	3.038	0.740	0.457
Distance from vessel squared[1]	-3.213	2.899	-1.110	0.268
Distance from vessel cubed[1]	10.634	2.875	3.700	<0.001
More than one vessel within 10 km from narwhal	-0.010	0.092	-0.100	0.917
Narwhal at surface in the preceding 1 min interval	2.859	0.086	33.400	<0.001
Substratum – Koluktoo Bay	-0.146	0.117	-1.250	0.212
Substratum – Milne Inlet North	-0.250	0.071	-3.500	<0.001
Substratum – Milne Inlet South	-0.182	0.076	-2.410	0.016
Substratum – Tremblay Sound	-0.564	0.722	-0.780	0.435
Time since last surfacing[1]	-26.226	4.379	-5.990	<0.001
Time since last surfacing squared[1]	38.181	3.409	11.200	<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 in Relation to Multiple Vessel Exposure

Table B-3: Test statistics of logistic model of performing bottom dives (type II *P* values)

Parameter	Chi squared	Df	*P* value
Distance from vessel (2nd degree polynomial)	1.005	2	0.605
Effect of number of vessels (categorical variable)	31.907	1	<0.001
Effect of whether the preceding dive was a bottom dive	1.083	1	0.298
Effect of bathymetry	0.040	1	0.842
Effect of time elapsed since previous bottom dive	14.935	1	<0.001
Effect of substratum	1.769	4	0.778
Interaction between distance from vessel and whether the preceding dive was a bottom dive	20.710	2	<0.001

Table B-4: Coefficient estimates for fixed effects in a mixed logistic model of performing bottom dives (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, mean bathymetry and time from previous bottom dive, preceding dive not bottom dive, Eclipse Sound)	-1.876	0.356	-5.275	<0.001
Distance from vessel [1]	-6.090	3.689	-1.651	0.099
Distance from vessel squared [1]	5.552	3.488	1.592	0.111
Preceding dive was a bottom dive	1.103	0.211	5.225	<0.001
More than one vessel within 10 km from narwhal	0.317	0.304	1.041	0.298
Effect of bathymetry [2]	-0.029	0.144	-0.199	0.842
Effect of time since last bottom dive [2]	-0.862	0.223	-3.865	<0.001
Substratum – Koluktoo Bay	0.129	0.445	0.290	0.772
Substratum – Milne Inlet North	-0.292	0.320	-0.913	0.361
Substratum – Milne Inlet South	-0.082	0.358	-0.229	0.819
Substratum – Tremblay Sound	-0.803	1.484	-0.541	0.588
Interaction between distance from vessel [1] and whether the preceding dive was a bottom dive	25.867	6.253	4.137	<0.001
Interaction between distance from vessel squared [1] and whether the preceding dive was a bottom dive	-12.212	5.925	-2.061	0.039

[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.

Dive Duration in Relation to Multiple Vessel Exposure

Table B-5: Test statistics of model of dive duration (type II *P* values)

Parameter	Chi squared	Df	*P* value
Distance from vessel (3rd degree polynomial)	8.739	3	0.033
Effect of whether the current dive was a bottom dive	12.397	1	<0.001
Effect of number of vessels (categorical variable)	3.306	1	0.069
Effect of substratum	23.948	4	<0.001
Effect of maximum dive depth (5^{th} degree polynomial)	254.939	5	<0.001
Effect of duration of previous dive	5.789	1	0.016
Effect of whether the preceding dive was a bottom dive	0.967	1	0.325
Interaction between distance from vessel and whether the current dive was a bottom dive	8.937	3	0.030
Interaction between duration of previous dive and whether the preceding dive was a bottom dive	1.630	1	0.202
Interaction between duration of previous dive and whether the current dive was a bottom dive	3.492	1	0.062
Interaction between whether the preceding dive was a bottom dive and whether the current dive was a bottom dive	0.119	1	0.730
Interaction between duration of previous dive, whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive	2.275	1	0.131

Table B-6: Coefficient estimates for fixed effects in a mixed model of dive duration (type I *P* values)

Parameter	Coefficient	SE	*z* value	*P* value
Intercept (No exposure, preceding dive not bottom dive, current dive not bottom dive, average dive depth, average duration of preceding dive, Eclipse Sound)	1.967	0.074	26.710	<0.001
Distance from vessel [1]	1.415	0.495	2.860	0.004
Distance from vessel squared [1]	-0.321	0.467	-0.690	0.491
Distance from vessel cubed [1]	-0.257	0.467	-0.550	0.582
Effect of whether the current dive is a bottom dive	0.174	0.059	2.970	0.003
More than one vessel within 10 km from narwhal	-0.090	0.050	-1.820	0.069
Substratum – Koluktoo Bay	0.282	0.072	3.920	0.000
Substratum – Milne Inlet North	0.157	0.056	2.820	0.005
Substratum – Milne Inlet South	0.261	0.055	4.770	<0.001
Substratum – Tremblay Sound	0.095	0.268	0.350	0.723
Effect of maximum dive depth [1]	27.303	0.732	37.290	<0.001
Effect of maximum dive depth squared [1]	10.825	0.496	-21.850	<0.001
Effect of maximum dive depth cubed [1]	6.753	0.427	15.830	<0.001
Effect of maximum dive depth to power of 4 [1]	-4.929	0.431	-11.430	<0.001
Effect of maximum dive depth to power of 5 [1]	2.838	0.413	6.880	<0.001
Effect of duration of preceding dive [2]	-0.032	0.024	-1.350	0.177
Effect of whether preceding dive was a bottom dive	0.024	0.062	0.380	0.701
Interaction between distance from vessel and whether the current dive is a bottom dive	-1.727	0.987	-1.750	0.080
Interaction between distance from vessel squared [1] and whether the current dive is a bottom dive	-0.329	0.874	-0.380	0.706
Interaction between distance from vessel cubed [1] and whether the current dive is a bottom dive	2.368	0.884	2.680	0.007
Interaction between duration of preceding dive [2] and whether the preceding dive was a bottom dive	-0.079	0.042	-1.870	0.062
Interaction between duration of preceding dive [2] and whether the current dive was a bottom dive	0.009	0.059	0.150	0.880
Interaction between whether the current dive is a bottom dive and whether the preceding dive was a bottom dive	-0.085	0.097	-0.870	0.385
Interaction between duration of preceding dive [2], whether the current dive was a bottom dive, and whether the preceding dive was a bottom dive	0.124	0.082	1.510	0.131

[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

Surface Behavior in Relation to Multiple Vessel Exposure

Turning Angle in Relation to Multiple Vessel Exposure

Table B-7: Test statistics of mixed model of square-root transformed turning angles (type II *P* values)

Parameter	Chi squared	Df	*P* value
Effect of distance from shore[2]	1.082	1	0.298
Effect of distance from vessel (2nd degree polynomial) [1]	15.561	2	<0.001
Effect of turning angle at previous GPS point (2nd degree polynomial) [1]	9.683	2	0.008
Effect of number of vessels (categorical variable)	8.300	1	0.004
Effect of substratum	7.116	5	0.212

[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-8: Coefficient estimates for fixed effects in a mixed model of turning angles (type I *P* values)

Parameter	Coefficient	SE	z value	*P* value
Intercept (one vessel within 10 km from narwhal, mean distance from shore and from vessel, mean previous angle, Eclipse Sound)	5.169	0.341	15.172	<0.001
Effect of narwhal distance from shore [2]	0.194	0.187	1.040	0.298
Effect of distance from vessel [1]	-13.007	3.344	-3.890	<0.001
Effect of distance from vessel squared [1]	2.392	3.118	0.767	0.443
Effect of angle at previous GPS point[1]	10.317	4.037	2.555	0.011
Effect of angle at previous GPS point squared [1]	-7.349	3.213	-2.287	0.022
More than one vessel within 10 km from narwhal	0.991	0.344	2.881	0.004
Effect of substratum (Koluktoo Bay)	1.256	0.535	2.347	0.019
Effect of substratum (Milne Inlet North)	0.499	0.410	1.217	0.224
Effect of substratum (Milne Inlet South)	0.932	0.469	1.986	0.047
Effect of substratum (Navy Board Inlet)	3.377	3.053	1.106	0.269
Effect of substratum (Tremblay Sound)	0.326	1.392	0.234	0.815

[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-9: Test statistics of mixed model of travel orientation relative to vessels (type II *P* values)

Parameter	Chi squared	Df	*P* value
Effect of distance from vessel[1]	15.017	1	<0.001
Effect of number of vessels (categorical variable)	6.070	1	0.014
Substratum	2.313	5	0.804

[1] = Variable was standardized prior to modeling

Table B-10: Coefficient estimates for fixed effects in a mixed model of travel orientation relative to vessels (type I *P* values)

Parameter	Coefficient	SE	z value	*P* value
Intercept (mean distance from vessel, Eclipse Sound, one vessel within 10 km from narwhal)	105.478	3.712	28.414	<0.001
Effect of distance from vessel[1]	-6.805	1.756	-3.875	<0.001
More than one vessel within 10 km from narwhal	23.420	9.506	2.464	0.014
Effect of substratum (Koluktoo Bay)	-7.685	6.760	-1.137	0.256
Effect of substratum (Milne Inlet North)	-5.836	5.307	-1.100	0.272
Effect of substratum (Milne Inlet South)	-3.740	4.697	-0.796	0.426
Effect of substratum (Tremblay Sound)	13.355	27.367	0.488	0.626

[1] = Variable was standardized prior to modeling

APPENDIX C

Power Analysis

POWER ANALYSIS - METHODS

A Type I error is concluding there is a significant effect when none exists (i.e., a false positive). Alpha (α) is the probability of committing a Type I error. A Type II error is the probability of concluding there is no significant effect when there is a real effect of some specified magnitude (i.e., a false negative). Beta (β) is the probability of committing a Type II error. Effect sizes are the magnitude of the change or difference in the response variables, which in this report were the metrics of diving behaviour of narwhal. The power of a statistical test (1 - β) is the probability of detecting a real effect. The power of a statistical test depends on the alpha level, the effect size, the sample size, and the variability in the data. In this analysis, the Type I error-rate (α), also referred to as the significance level, was set to 0.05. The desired minimum statistical power was 80%, which corresponds to a Type II error-rate of 0.2.

Power analyses were conducted to assess the power of statistical tests of the effect of vessel traffic on each of the analyzed response variables for surface movement and diving behaviour across a range of effect sizes, assuming the same sample size and variability as the observed data. For each model, a range of effect sizes were created, based on preliminary power analyses, so that power >80% was achieved at the largest absolute values of effect sizes. The power of detecting either a freeze or a flight response was assessed by using both negative and positive effect sizes. The results show the range of effect sizes (e.g., -50% to +50% change, depending on the response variable variable) that are required for the study to detect statistically significant effects of vessel traffic.

Data Simulation following Effect Size Application

The power to detect statistically significant effects was estimated using residual bootstrapping in R v. 3.6.1 (R 2019), following the approach of Fox and Weisberg (2018). The general approach was to simulate data based on the model selected for interpretation, the observed sample size, and the residuals, and re-run the models that were used for the original analysis using the simulated data. The data simulation and analysis were repeated 1,000 times, and the proportion of repetitions where the *P*-values of interest were significant ($P<0.05$) was interpreted as the statistical power of the test.

To produce simulated data, the original model was used to predict values of the response variable, and the raw residuals (i.e., the difference between the predicted and observed value for each observation) from the original model were calculated and retained. The predicted values were then adjusted according to the effect size, depending on the analysis (see below for details). The simulated data were then analyzed using the same model structure as the original analysis. Effect sizes and statistical tests were applied differently to different models and datasets, as detailed below.

Effects of a Single Vessel

In the analysis of single-vessel data, where the question of interest was the effect of a vessel on the behavioural response variable, the effect size was calculated as percent reduction or increase relative to data when no vessels were present within 10 km of the narwhal. Since the majority of statistically significant results in the original analyses were obtained within 5 km of a vessel, the effect was only applied up to 5 km, and narwhal at >5 km from a vessel were simulated to have no effect (while still modelled as being within the exposure zone, for consistency with the original models). Overall, an increasing effect size resulted in a steeper trend, whereas a decreasing effect size resulted in a flatter trend, and an effect size of zero resulted in a flat line (Figure 1).

The simulated data were analyzed using the same model as the original analysis described in the main report, and the *P*-values for the effects of distance on the response variable were retained, which included both the main effect of distance from vessel and any interactions with distance from a vessel. If any of these *P*-values were less than 0.05, it was considered a significant overall effect of distance from a vessel. The proportion of repetitions with at least one *P*-value less than 0.05 was interpreted as the statistical power of the overall regression for that effect size. Following tests of the overall effect of distance from a vessel, multiple comparisons were performed, comparing the predicted values of the response variable between several distances from a vessel (1 to 5 km, at 1 km increments) to the predicted values when no vessels were present within 10 km. The multiple comparisons were performed using the package emmeans (Lenth 2019) and used the Dunn–Šidák adjustment for control of familywise error rate. The *P*-values of each comparison were retained. For each effect size, the proportion of repetitions with *P*-values below 0.05 at each distance was interpreted as the statistical power of the multiple comparisons.

Effect Sizes and Data Simulation in Models with a Numeric Response Variable

For models with a numeric response variable (e.g., duration of dive, measured in minutes), for each iteration of the simulation, the raw residuals were sampled with replacement, and an effect size was applied to the predicted values. The re-sampled residuals and effect size-adjusted predicted values were summed to produce a set of simulated data. Adding the residuals to the effect size-adjusted predictions was done to create a level of variability in the simulated data that was similar to the observed data. For cases within the dataset that did not have an effect size applied to them (i.e., cases with no vessels within 10 km and cases where vessels were present within 10 km, but farther than 5 km from the narwhal), predictions were still summed with resampled residuals, resulting in simulated data that differed from the originally collected data.

To produce simulated data, the original dataset was duplicated, and in the duplicate dataset, all data were assigned to a reference (i.e., no vessels within 10 km from narwhal). The original model was used to predict response values for this duplicate dataset, creating a “reference” dataset of predictor values and predicted responses. The raw residuals from the original model were calculated and retained. The effect size was then applied to the predicted “reference” values. For all data cases that were “impact” cases in the original data, the predicted “reference” response was multiplying by the effect size, to produce a range of responses as the various effect sizes.

The simulated data were then analyzed using the same model structure as the original analysis.

Effect Sizes and Data Simulation in Logistic Models

For models with a binary response variable (e.g., occurrence of bottom dives), the effect size was applied to the odds ratio, i.e., to the exponentiated difference in predicted values between a case where a vessel was within 5 km from narwhal and a “reference” case (where no vessel was present within 10 km from narwhal) on logit-scale, rather than to the predicted values themselves. Overall, an increasing effect size resulted in a steeper trend, whereas a decreasing effect size resulted in a flatter trend, and an effect size of zero resulted in a flat line. However, due to the nonlinearity of probabilities, a negative and a positive effect size of the same magnitude may result in asymmetrical magnitudes of change on the probability scale (Figure 2). For each iteration of the simulation, the predictions on the logit scale were used to calculate the probability of the outcome. Then, a binomial distribution was used to generate a random value using the probability of the outcome calculated above. The generation of a random probability was done to create random variability in the simulated data.

For cases within the dataset that did not have an effect size applied to them (i.e., cases with no vessels within 10 km and cases where vessels were present within 10 km, but farther than 5 km from the narwhal), predictions were still used to generate a random value, resulting in simulated data that differed from the originally collected data.

To produce simulated data for logistic models, the original dataset was duplicated, and in the duplicate dataset, all data were treated as reference (i.e., no vessels within 10 km from narwhal). The original model was used to predict response values for this duplicate dataset, creating a "reference" dataset of predictor values and predicted responses. The effect size was then applied to the predicted "reference" values. For all data cases that were "impact" cases in the original data, the predicted "reference" response was multiplied by the effect size, to produce a range of responses as the various effect sizes. For logistic models, the effect size was applied to the odds ratio – that is, the exponentiated difference between the logit-scale predictions of "reference" and "impact" cases.

Effect Sizes and Data Simulation in Linear Models

For models with a linear relationship between distance from vessel and the response variable, the effect size was to the full 10 km distance from vessel, so that the simulation did not create a nonlinearity in the effect. In cases where the data contained cases with both vessels present and absent within 10 km from narwhal, multiple comparisons were performed as detailed above, comparing the effects of vessels at various distances from narwhal to cases when no vessels were presence. In models were the dataset only contained cases with vessels present within 10 km from narwhal (these included travel orientation relative to vessels and habituation to vessel traffic), no multiple comparisons were possible, and only the statistical power to detect an overall effect of distance was presented.

Effects of Multiple Vessels

In the analysis of multiple vessels, where the question of interest was whether the effect of presence of multiple vessels within 10 km from narwhal is different from the effect of presence of a single vessel, the effect size was calculated as percent reduction or increase relative to data when only a single vessel was present within 10 km from narwhal. For these power analyses, the dataset was reduced to only cases where vessels were present within 10 km from narwhal, as was done for the original analysis.

For analyses of multiple vessel effects, the *P*-values associated with the effect of multiple vessel presence were retained. The simulations were repeated 1,000 times for each effect size, and the proportion of repetitions with $P<0.05$ for the effects of models was interpreted as the power to detect an effect of multiple vessel presence.

Effect Sizes and Data Simulation in Models with a Numeric Response Variable of Multiple Vessel Effects

To produce simulated data, the original dataset was duplicated, and in the duplicate dataset, all data were treated as reference (i.e., only a single vessel within 10 km from narwhal). The original model was used to predict response values for this duplicate dataset (on link or transformed scale, as applicable), creating a "reference" dataset of predictor values and predicted responses. The raw residuals from the original model were calculated and retained. The effect size was then applied – for all data cases that were "impact" cases in the original data, the predicted “reference” response (on the transformed scale) was multiplied by the effect size, to produce a range of response values at the different effect sizes.

For each iteration of the simulation, the residuals from the original analysis were sampled with replacement, and then summed with effect size-adjusted model predictions, to produce a set of simulated data. Adding the residuals to the effect size-adjusted predictions was done to create random variability in the simulated data. For cases within the dataset that did not have an effect size applied to them (i.e., cases with only a single vessel), predictions were still summed with resampled residuals to generate a simulated dataset that differed from the originally collected data.

Effect Sizes and Data Simulation in Logistic Models of Multiple Vessel Effects

To produce simulated data, the original dataset was duplicated, and in the duplicate dataset, all data were treated as reference (i.e., only a single vessel within 10 km from narwhal). The original model was used to predict response values for this duplicate dataset on the logit scale, creating a “reference” dataset of predictor values and predicted responses. The effect size was then applied to the “reference” dataset. For logistic models, the effect size was applied to the odds ratio – that is, the exponentiated difference between the logit-scale predictions of “reference” and “impact” cases. After the application of effect sizes, the predicted values were used to calculate the probability of the outcome (e.g., the probability of performing a bottom dive) for each case in the dataset. Then, a binomial distribution was used to generate a random value using the probability of the outcome calculated above. The generation of a random value was done to create random variability in the simulated data. For cases within the dataset that did not have an effect size applied to them (i.e., cases with only a single vessel), predictions were still used to generate a random value, resulting in simulated data that differed from the originally collected data.

Power Analysis – Reporting of Results

To summarize the results of the power analyses, power curves were produced. Power curves show statistical power, which is the probability of detecting a significant effect, as a function of effect size, which is shown as a percentage change of the response variable. Separate curves were produced for overall effects and for multiple comparisons (for single vessel effects only). Horizontal lines were added to visualize statistical power values of 0.8 (hereafter sufficient power) and 0.9 (hereafter high power). A vertical line was added to visualize the magnitude of difference that was observed in the original data.

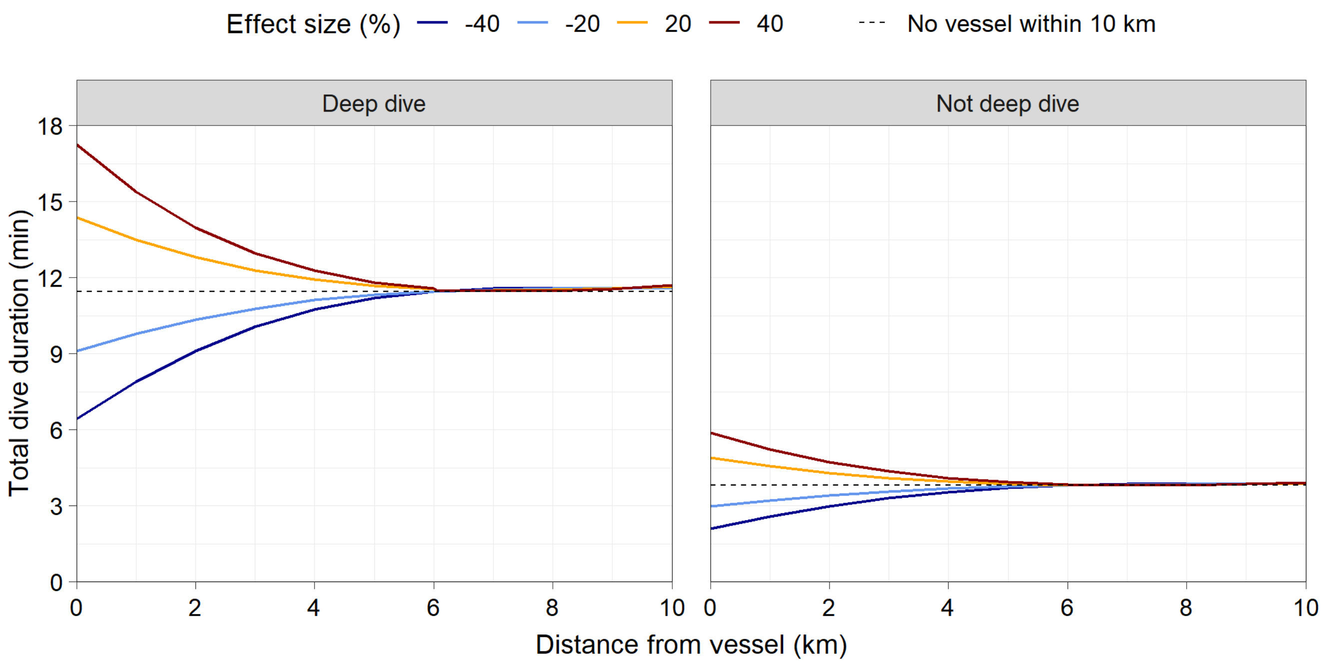

Figure 1. Application of effect sizes to a model with a numeric response variable (total dive duration).

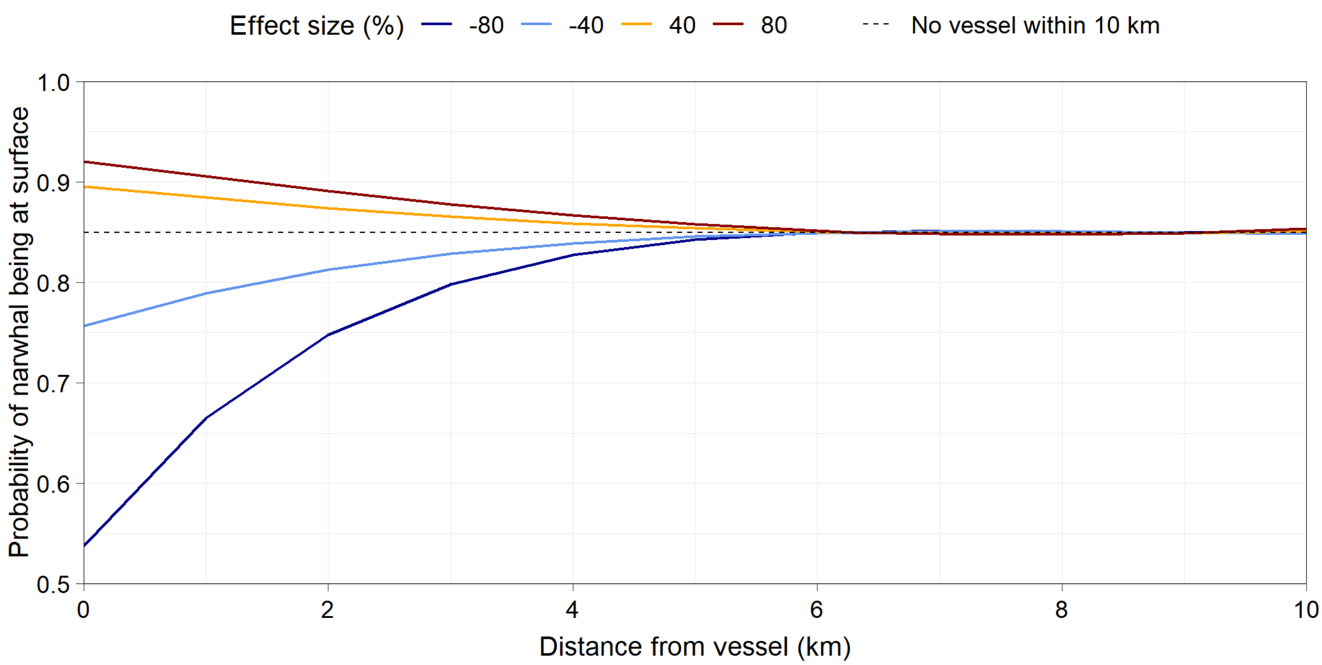

Figure 2. Application of effect sizes to a model with a binary response variable (surface behaviour)

POWER ANALYSIS – RESULTS

1.1 Effects of Distance from a Single Vessel

1.1.1 Surface Time

The power analysis indicated that there was sufficient power (>0.8) to detect an effect of distance from vessel on surface time at effect sizes of +13% or -13%, relative to no vessel exposure (Figure 3). High power (>0.9) was attained at effect sizes of +20% or -20%. These effect sizes for the binary response variable, surface time, were on the odds ratio scale, meaning that there was 80% power to detect a 13% increase in the odds of a narwhal being at the surface during a one-minute interval. These results indicate strong power to detect the effect of distance from a single vessel at relatively small differences in surface time, compared to the observed effect size, which was 47% decrease in the odds ratio for narwhal to be at the surface. The high power to detect relatively small effect sizes for this analysis is likely due to the large amount of data available for each narwhal, since data were available at one minute intervals. These power analysis results are consistent with the finding of a significant effect of distance from vessel in the original analysis of surface time (Section 4.2.2.1 of the main report).

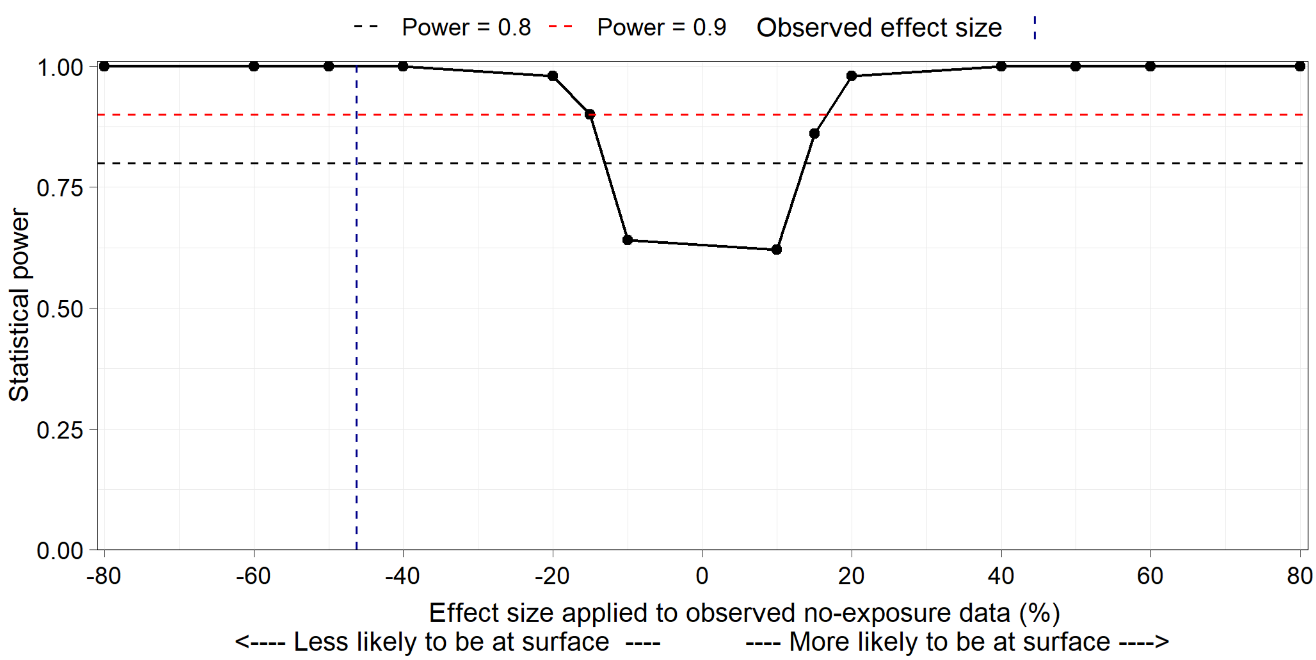

Figure 3. Statistical power of the overall model of surface time to detect a significant effect of distance from vessel or a significant difference in distance effects between bottom and non-bottom dives.

Statistical power was lower for multiple comparisons between specific distances (0 to 5 km) and no vessel, than for the overall effect of distance relative to no vessel. For comparisons between distances of 0 to 3 km and no vessel, the effect size needed to achieve sufficient power (>0.8) ranged from 35% to 50%. At 4 km, decrease of 80% or greater would be required for sufficient power. Statistical power was very low (<0.25) at all simulated effect sizes for the comparison between 5 km and no vessel, suggesting that it would be unlikely to detect a significant effect at this vessel distance. At the observed effect sizes, the analysis suggested insufficient power (estimates between 0 and 0.35) of multiple comparisons between distances of 1 to 5 km and no vessel at the observed effect sizes (Figure 4). Power was close to 0.8 at the observed effect size for the comparison between a vessel at 0 km and no vessel. This was reflected by the original analysis, which found a significant different in surface time between 0 km and no vessel, but not for any of the other multiple comparisons (Table 4-7 in Section 4.2.2.1 in main report).

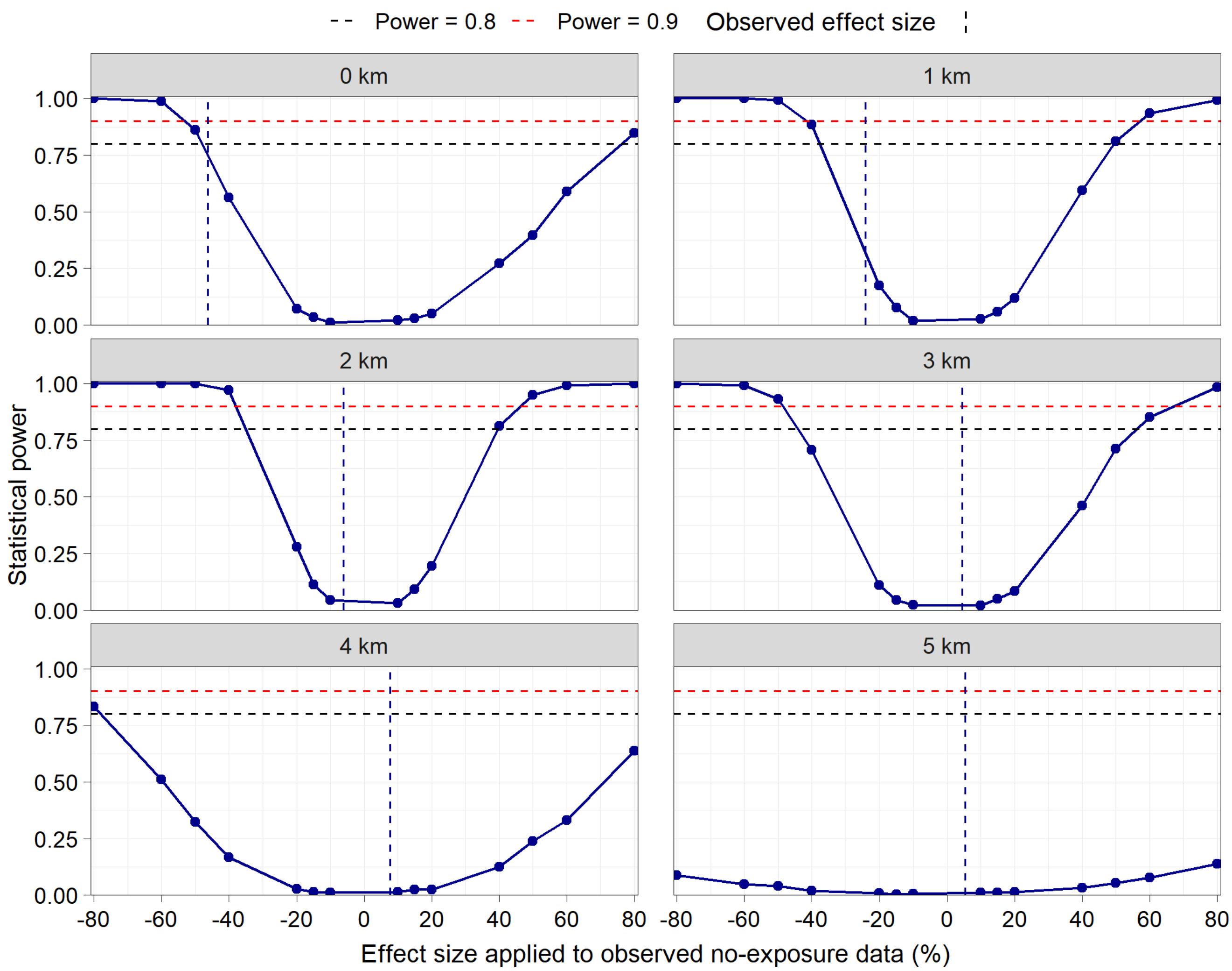

Figure 4. Statistical power of multiple comparisons between surface time at various distances from vessels relative to when no vessels were present within 10 km from narwhal. Each panel shows a separate comparison, with the distances compared displayed at the top of the panel.

1.1.2 Performing Bottom Dives

There was sufficient power (>0.8) to detect an effect of distance from vessel on the probability of a bottom dive at effect sizes of +150% or -80% (Figure 9). As the response variable was binomial, the +150% effect size corresponded to a 150% increase in the odds of a dive being greater than 75% of the bathymetry depth. When the previous dive was not a bottom dive, the observed effect size was +98% and the estimated power was approximately 0.55. When the previous dive was a bottom dive, the observed effect size was -86% and the estimated power was 0.85. Therefore, at the observed effect sizes the analysis suggested there was sufficient power to detect the effect of distance from vessel, but only if the preceding dive was a bottom dive.

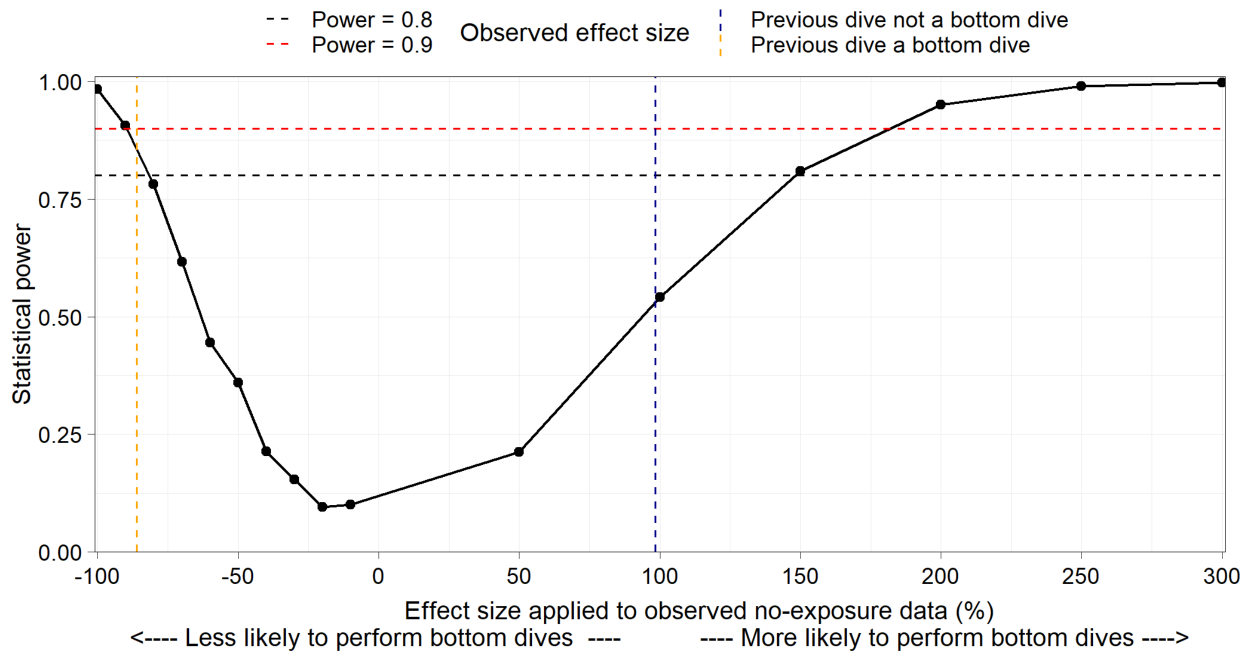

Figure 5. Statistical power of the overall model of performing bottom dives to detect a significant effect of distance from vessel or a significant difference in distance effects between bottom and non-bottom dives.

Multiple comparisons of the probability of a bottom dive at various distances from vessel relative to when no vessels were present suggested low power (<0.5) at all distances and for all simulated effect sizes when the preceding dive was not a bottom dive (Figure 6). When the preceding dive was a bottom dive, sufficient power (>0.8) was achieved at effect sizes ranging from 160% to 210% for distances of 0 to 3 km. At distances of 4 to 5 km compared to no vessel exposure, estimated power was insufficient (<0.8) at all simulated effect sizes (up to 300%), suggesting that detecting an effect at these distances would be unlikely. The observed effect sizes, when the preceding dive was a bottom dive, were all negative, with values between -50% and -100%, which corresponded to estimated power values ranging from 0.12 to 0.40, at distances of 0 to 3 km, but power less than 0.1 at 4-5 km distance from the vessel. Despite these relatively low values of estimated power, the original analysis found significant differences in probability of a bottom dive in all of the multiple comparisons between no vessel exposure and distances from 0 to 5 km from a vessel (Table 4-10 in Section 4.2.2.3 in main report).

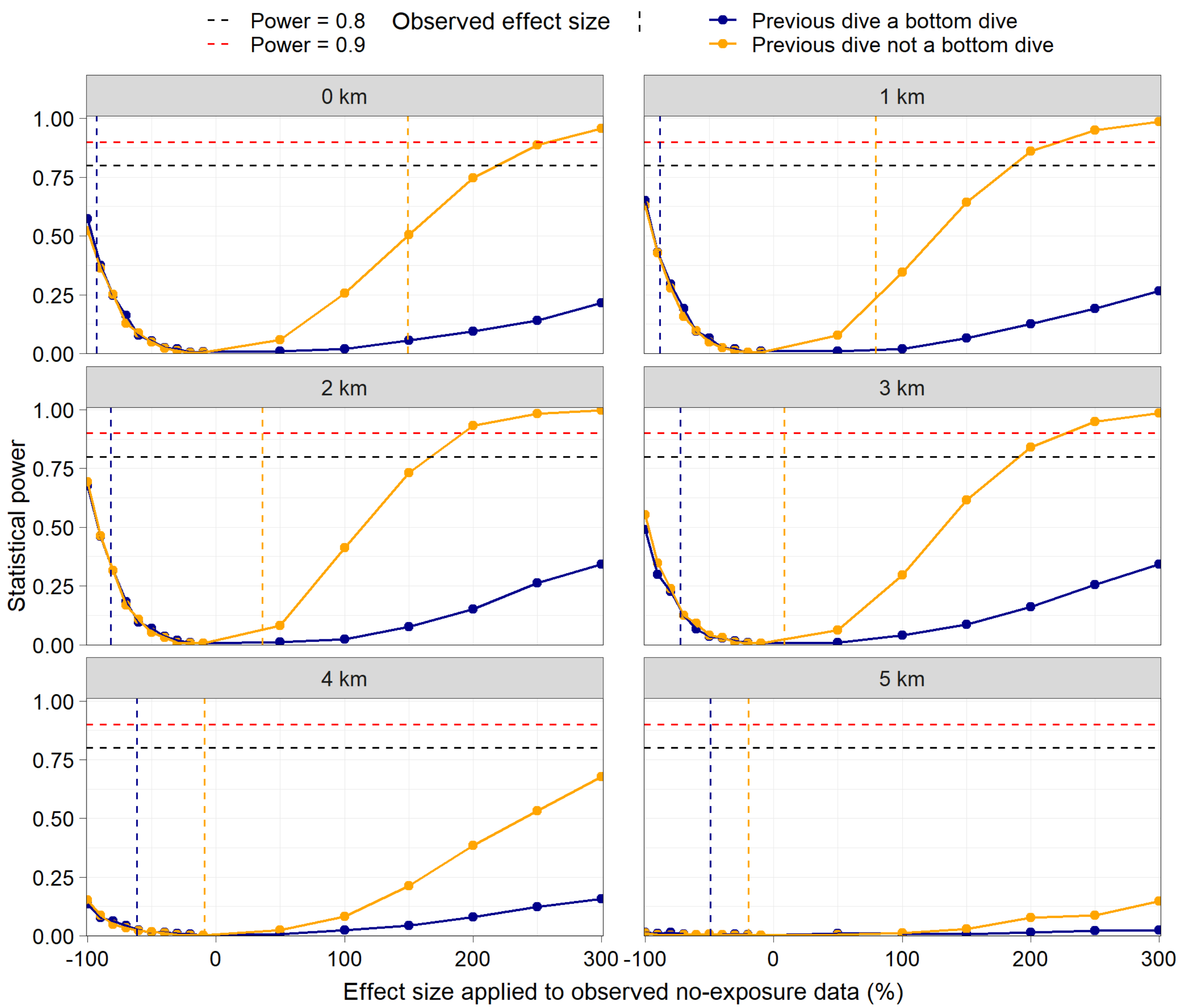

Figure 6. Statistical power of multiple comparisons between bottom dive performance at various distances from vessels relative to when no vessels were present within 10 km from narwhal. Each panel shows a separate comparison, with the distances compared displayed at the top of the panel.

1.1.3 Time within Deepest 20% of a Dive

The power analysis indicated that the analysis of time spent within the deepest 20% of a dive had sufficient power (>0.8) to detect an overall effect of distance when effect sizes were -30% or +25% relative to no-vessel scenarios (Figure 7). The largest magnitude of the observed effect sizes (indicated by vertical lines in Figure 7) was only -21%; therefore, low statistical power (approximately 0.5) at the observed effect size may explain the lack of a significant difference in the original analysis (Section 4.2.2.4 in the main report).

In multiple comparisons between the predicted response at various distances from vessel (1 to 5 km) relative to when no vessels were present within 10 km from narwhal, the power analysis indicated that there was sufficient power to detect significant differences if effect sizes were at least -40% or +35% at distances of 1 or 2 km (Figure 8). At distances of 0 or 3 km, a decrease or an increase of 50% or greater in the response variable were needed to achieve sufficient power. For comparisons between 4 or 5 km and no vessel, estimated power was low (<0.25) at all simulated effect sizes. The observed effect sizes were considerably smaller than the effect size needed for sufficient power at all distances. Overall, the analysis of time spent at bottom 20% of the dive had sufficient power to detect a 40% reduction or a 35% increase in time spent at bottom of the dive at a minimum of one of the assessed distances (1-5 km) relative to when no vessels were present within 10 km. As observed differences were much lower, the original model did not find a significant effect of distance from vessel in the original analysis (Section 4.2.2.4 in the main report).

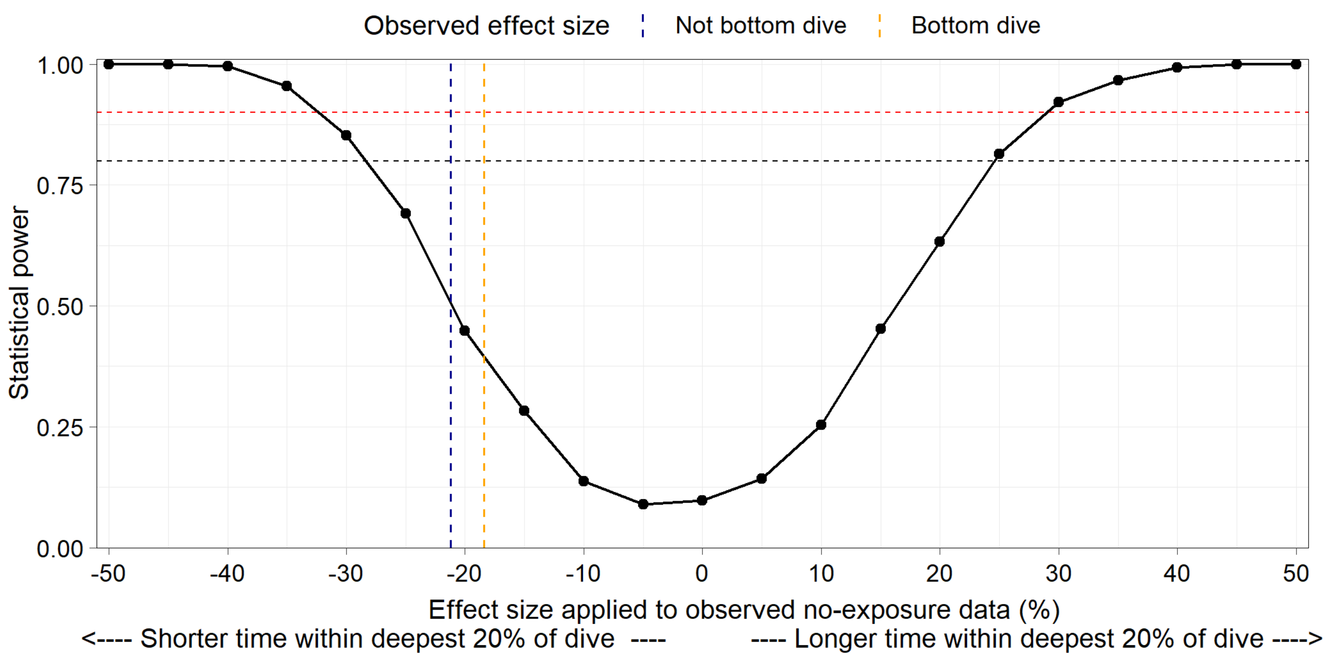

Figure 7. Statistical power of the overall model of time spent within deepest 20% of a dive to detect a significant effect of distance from vessel or a significant difference in distance effects between bottom and non-bottom dives.

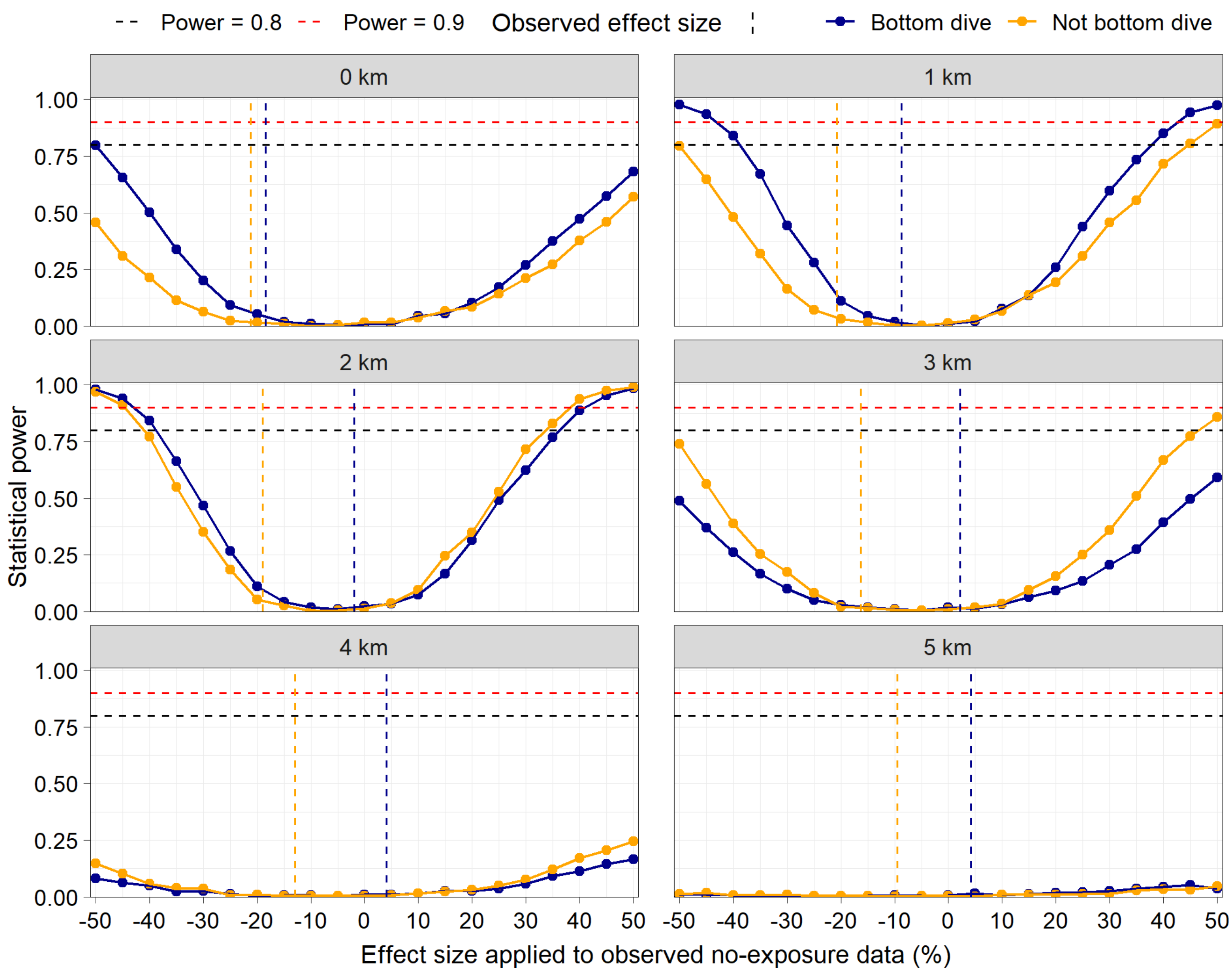

Figure 8. Statistical power of multiple comparisons between time spent within deepest 20% of a dive at various distances from vessels relative to when no vessels were present within 10 km from narwhal. Each panel shows a separate comparison, with the distances compared displayed at the top of the panel.

1.1.4 Dive Duration

There was sufficient power (>0.8) to detect an effect of distance from vessel on dive duration at effect sizes of +15% or -17% (Figure 9). Estimated power at the observed effect size was 0.62 for non-bottom dives and greater than 0.90 for bottom dives. These results suggest strong statistical power to detect the effect of vessel distance at relatively small percentage changes in dive duration.

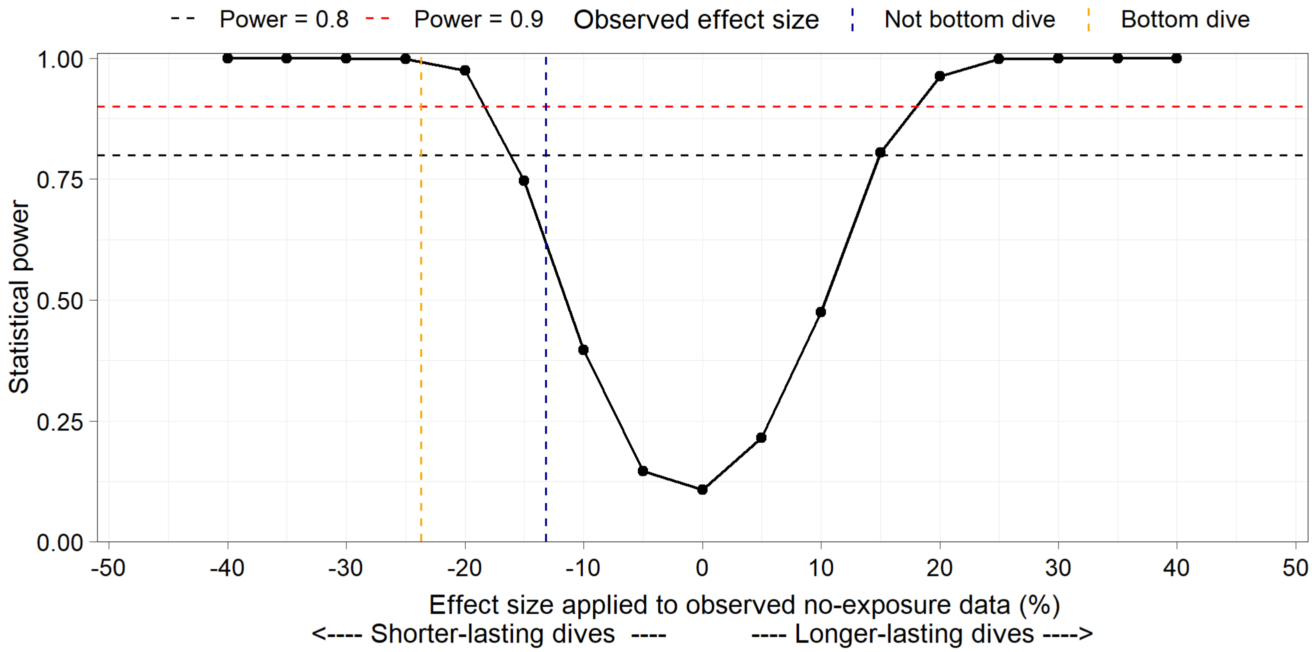

Figure 9. Statistical power of the overall model of total dive duration to detect a significant effect of distance from vessel or a significant difference in distance effects between bottom and non-bottom dives.

In multiple comparisons of dive duration at various distances from vessel relative to when no vessels were present within 10 km from narwhal, sufficient power (>0.8) was achieved at effect sizes of -25% or +20% for distances of 0 to 3 km (Figure 10). Estimated power was insufficient (<0.8) for the comparison between when a vessel was at a distance of 4 km and when no vessel was present, and very low (<0.15) for the comparison between when a vessel was at a distance of 5 km and when no vessel was present at all simulated effect sizes. At the observed effect sizes, estimated power was less than 0.8 for all comparisons between no vessel and when a vessel was present at distances between 0 and 5 km. The largest observed effect sizes were -13% for non-bottom dives and -24% for bottom dives at a vessel distance of 0 km, but less than 15% for at all other distances (1 to 5 km). Despite the low estimated power, the original analysis found significant differences in 3 of 20 of the multiple comparisons (Table 4-13 in Section 4.2.2.5 in main report).

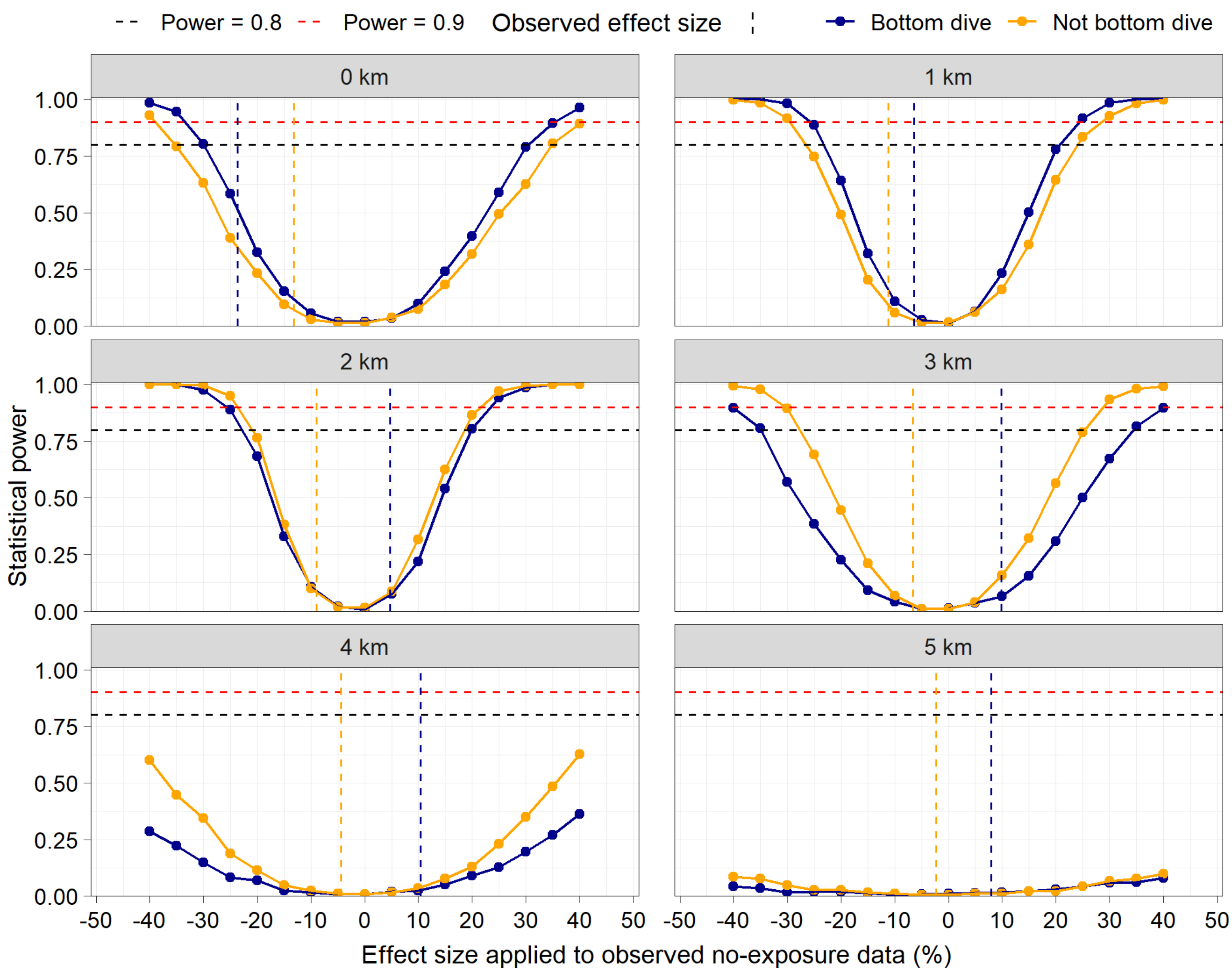

Figure 10. Statistical power of multiple comparisons between total dive duration at various distances from vessels relative to when no vessels were present within 10 km from narwhal. Each panel shows a separate comparison, with the distances compared displayed at the top of the panel.

1.1.5 Descent Speed

There was sufficient power (>0.8) to detect an effect of distance from vessel on descent speed at effect sizes of +20% or -22% (Figure 9). Estimated power was ~0.2 at the observed effect size of +7% for non-bottom dives, and ~0.3 at the observed effect size of -11% for bottom dives. These results suggest that observed effect sizes would need to be approximately doubled (assuming the same direction of effect) to detect a statistically significant effect 80% of the time. This is reflected in the lack of significance of overall effects in the original analysis (*P*>0.4 for all effects; Section 4.2.2.6 in main report).

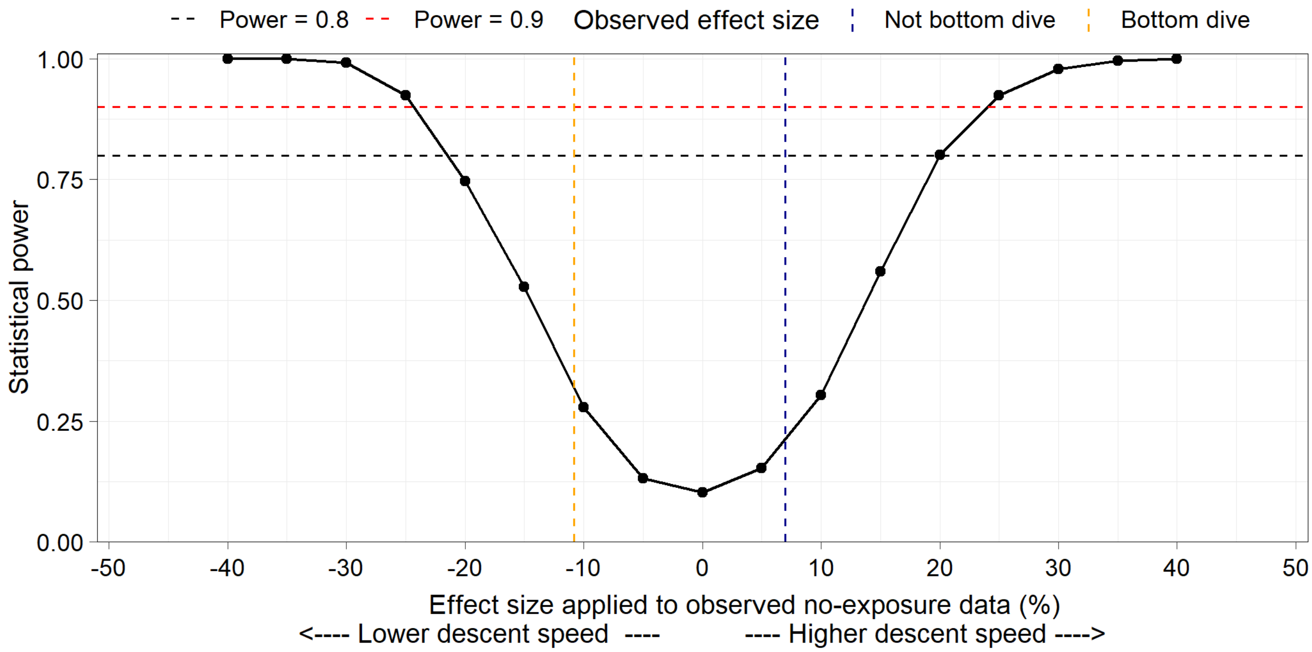

Figure 11. Statistical power of the overall model of descent speed to detect a significant effect of distance from vessel or a significant difference in distance effects between bottom and non-bottom dives.

In multiple comparisons of descent speed at various distances from vessel relative to when no vessels were present within 10 km from narwhal, sufficient power (>0.8) was achieved at effect sizes ranging from approximately +25% to +30% for distances of 0 to 3 km (Figure 10). Estimated power was insufficient (<0.8) for the comparison between a vessel at a distance of 4 km and no vessel, and very low (<0.15) for the comparison between a vessel at a distance of 5 km and no vessel at all simulated effect sizes. At observed effect sizes of -11% to +7% for 0 km, and -7% to +5% for 1 km, estimated power was low (<0.1). The very small observed effect sizes at vessel distances of 2 to 5 km (-4.5% to +3% effect sizes) reflect very small differences in descent speed for these comparisons. Overall, the lack of statistical differences in the analysis of descent speed was likely due to small effect sizes and not low statistical power.

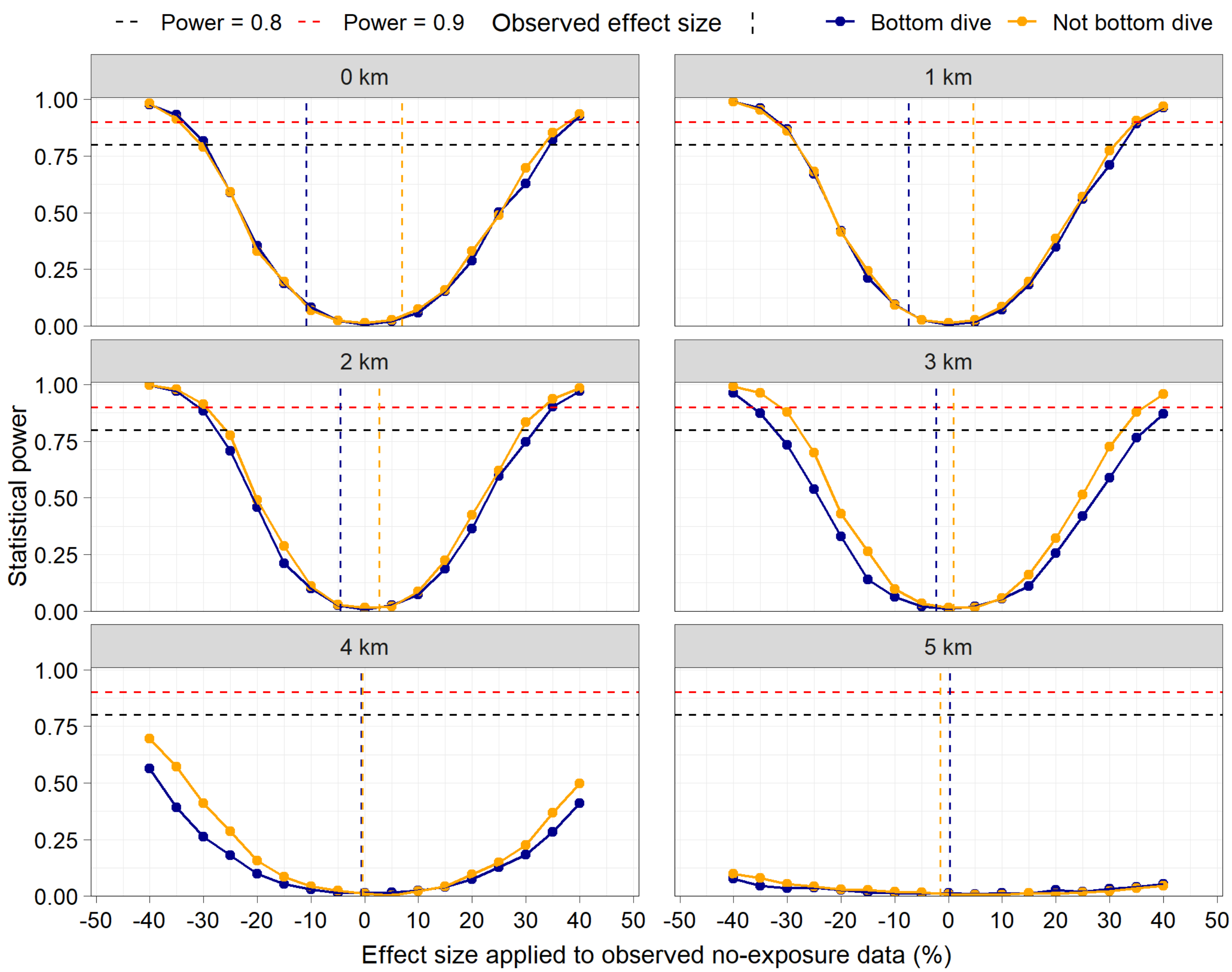

Figure 12. Statistical power of multiple comparisons between descent speed at various distances from vessels relative to when no vessels were present within 10 km from narwhal. Each panel shows a separate comparison, with the distances compared displayed at the top of the panel.

1.1.1 Turning Angle

There was sufficient power (>0.8) to detect an effect of distance from vessel on descent speed at effect sizes of +41% or -39% (Figure 13). Estimated power was >0.8 at the observed effect size of +42% (i.e., the observed effect size was sufficient to detect a statistically significant effect 80% of the time).

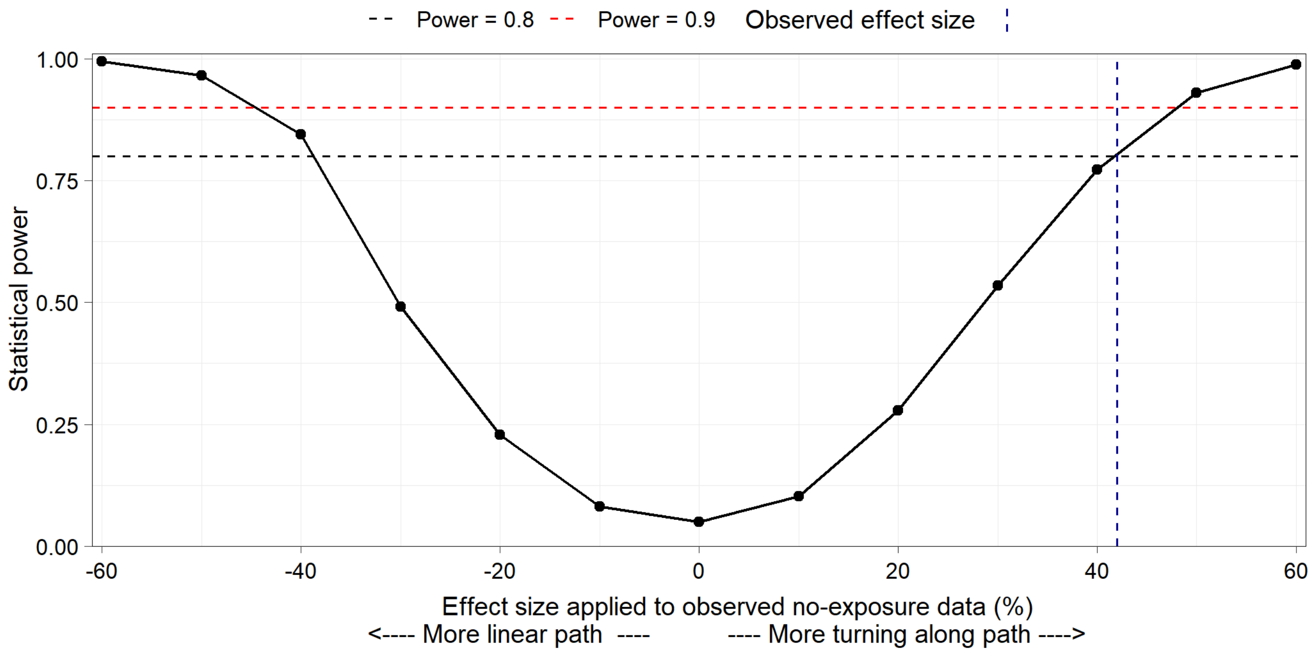

Figure 13. Statistical power of the overall model of turning angle to detect a significant effect of distance from vessel.

In multiple comparisons of turning angles at various distances from vessel relative to when no vessels were present within 10 km from narwhal, sufficient power (>0.8) was achieved at effect sizes of -40% or a greater decrease for distances of 0 to 3 km (Figure 14). Estimated power was insufficient (<0.8) for the comparison between a vessel at a distance of 4 km and no vessel, and very low (<0.15) for the comparison between a vessel at a distance of 5 km and no vessel at all simulated effect sizes. At observed effect sizes of +42% for 0 km and +34% for 1 km, estimated power was insufficient (~0.65 and ~0.45, respectively). Despite the insufficient power, the original analysis found significant differences between the presence of a vessel at 1 km to 4 km and when no vessels were present within 10 km (Section 4.3.2.1 in the main report).

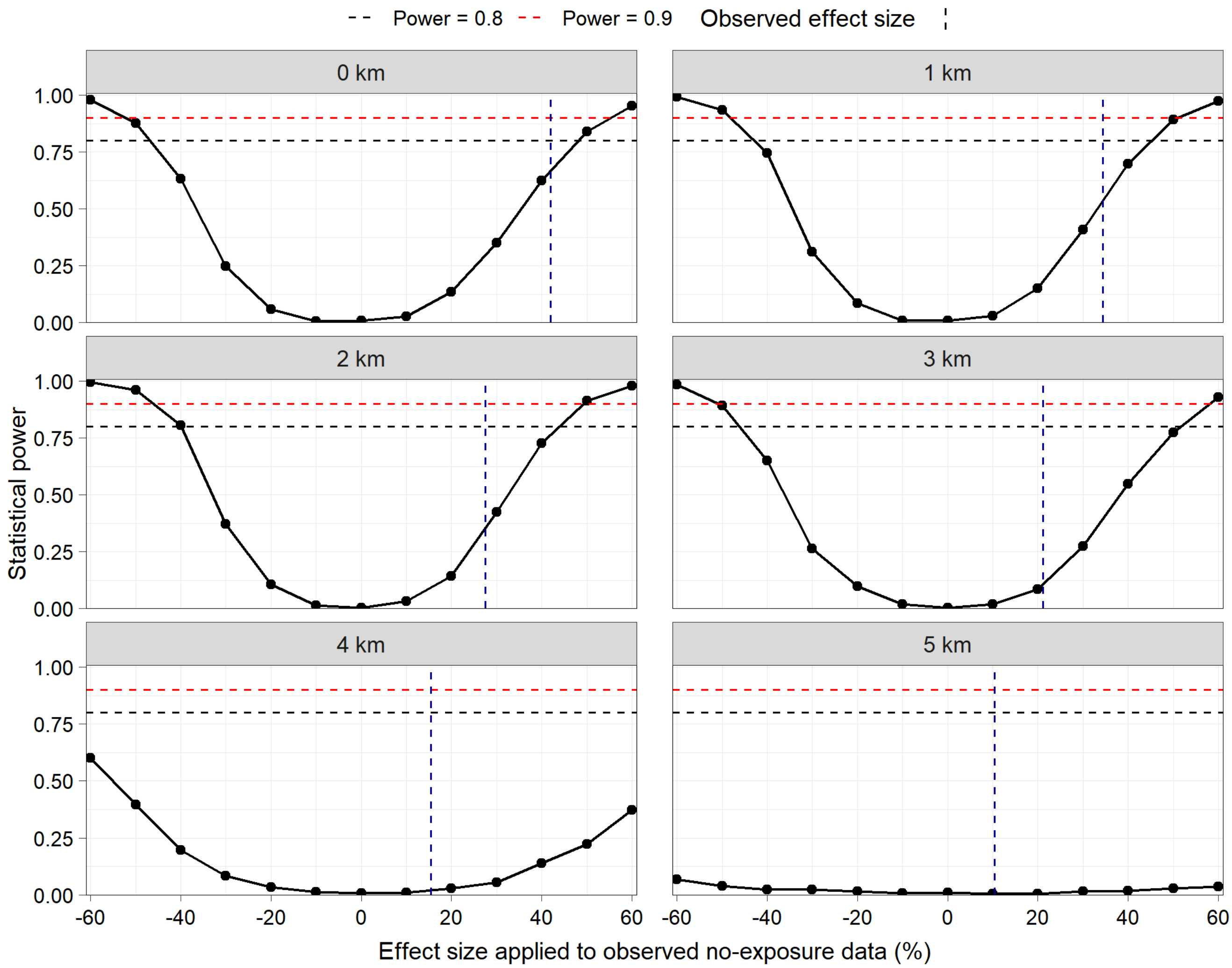

Figure 14. Statistical power of multiple comparisons between turning angles at various distances from vessels relative to when no vessels were present within 10 km from narwhal. Each panel shows a separate comparison, with the distances compared displayed at the top of the panel.

1.1.2 Travel Orientation relative to Vessels

There was sufficient power (>0.8) to detect an overall effect of a vessel on relative angle between narwhal and vessel when effect sizes were -17% or +13%, relative to travel orientation when the vessel was 10 km from narwhal (Figure 15). At the observed effect sizes of +20% (after CPA) and +40% (before CPA), the estimated power was 0.99. The high power at the observed effect size was reflected in the significant finding of the effect of vessels on travel orientation relative to vessels (*P*=0.001; Section 4.2.3.2 in main report). Overall, the analysis had sufficient power to detect effect sizes <20% (in either increasing or decreasing direction). Since the effect of the distance from vessel was modelled as a simple linear relationship with travel orientation, and since the overall power tests the significance of this relationship, multiple comparisons were not required.

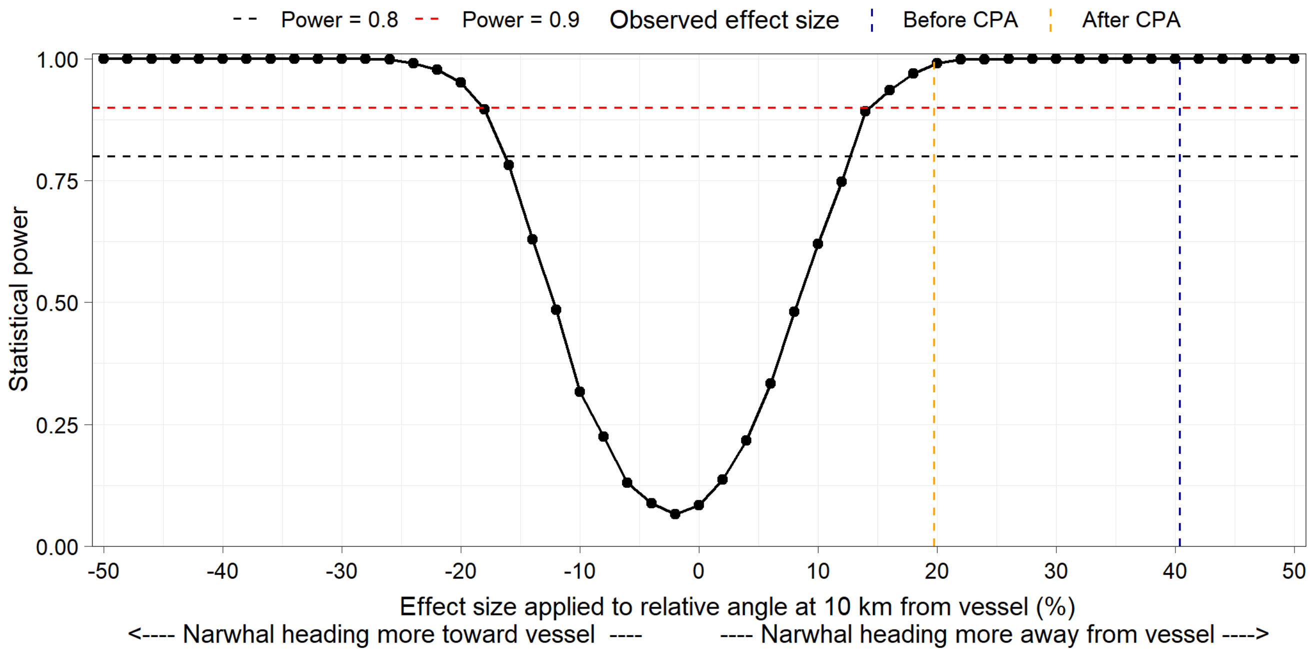

Figure 15. Statistical power of the overall model of travel orientation relative to vessels to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

1.1.3 Travel Speed

There was sufficient power (>0.8) to detect an effect of distance from vessel on travel speed, relative to no vessel exposure, at effect sizes of +13% or -13% (Figure 16). Estimated power at the observed effect size was approximately 0.6 for travel speeds after the Closest Point of Approach (CPA; effect size = -10%) and 0.9 for travel speeds before the CPA (effect size = -15%). This suggests that the lack of a significant effect of distance in the original analysis (Section 4.2.3.6 in the main report) was not necessarily due to low statistical power.

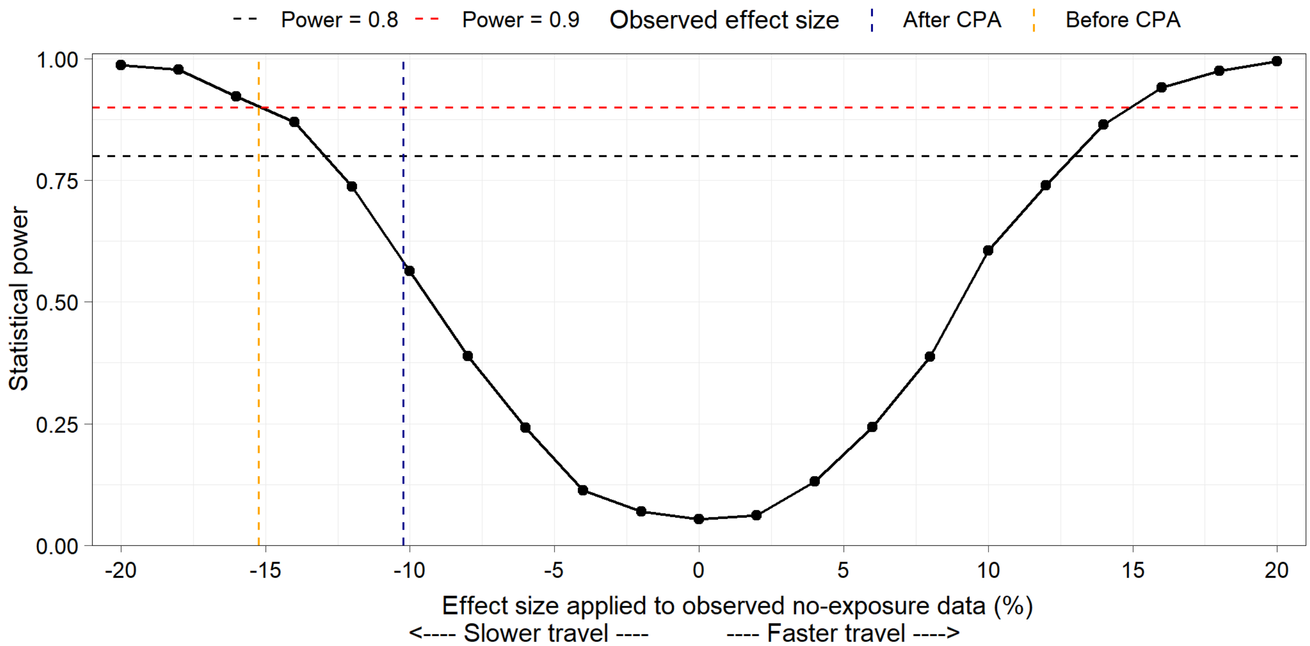

Figure 16. Statistical power of the overall model of travel speed to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

In multiple comparisons of travel speed at various distances from vessel relative to when no vessels were present within 10 km from narwhal, sufficient power (>0.8) was achieved at effect sizes of -13% or +12% for at least one comparison at distances of 0 to 5 km (Figure 17). At the observed effect sizes, estimated power was sufficient for at least one comparison at distances between 0 and 4 km, but not at distance of 5 km. The largest observed effect sizes were -10% after CPA and -16% before CPA at a vessel distance of 0 km, but only -7% and -12%, respectively, at a distance of 5 km. Despite the sufficient power, since the original model did not find a significant main effect of distance from vessel on travel speed, no multiple comparisons were performed in the original analysis (Section 4.2.3.6 in main report). Overall, the analysis had sufficient power to detect relatively small effect sizes (an increase or decrease of 13% in travel speed).

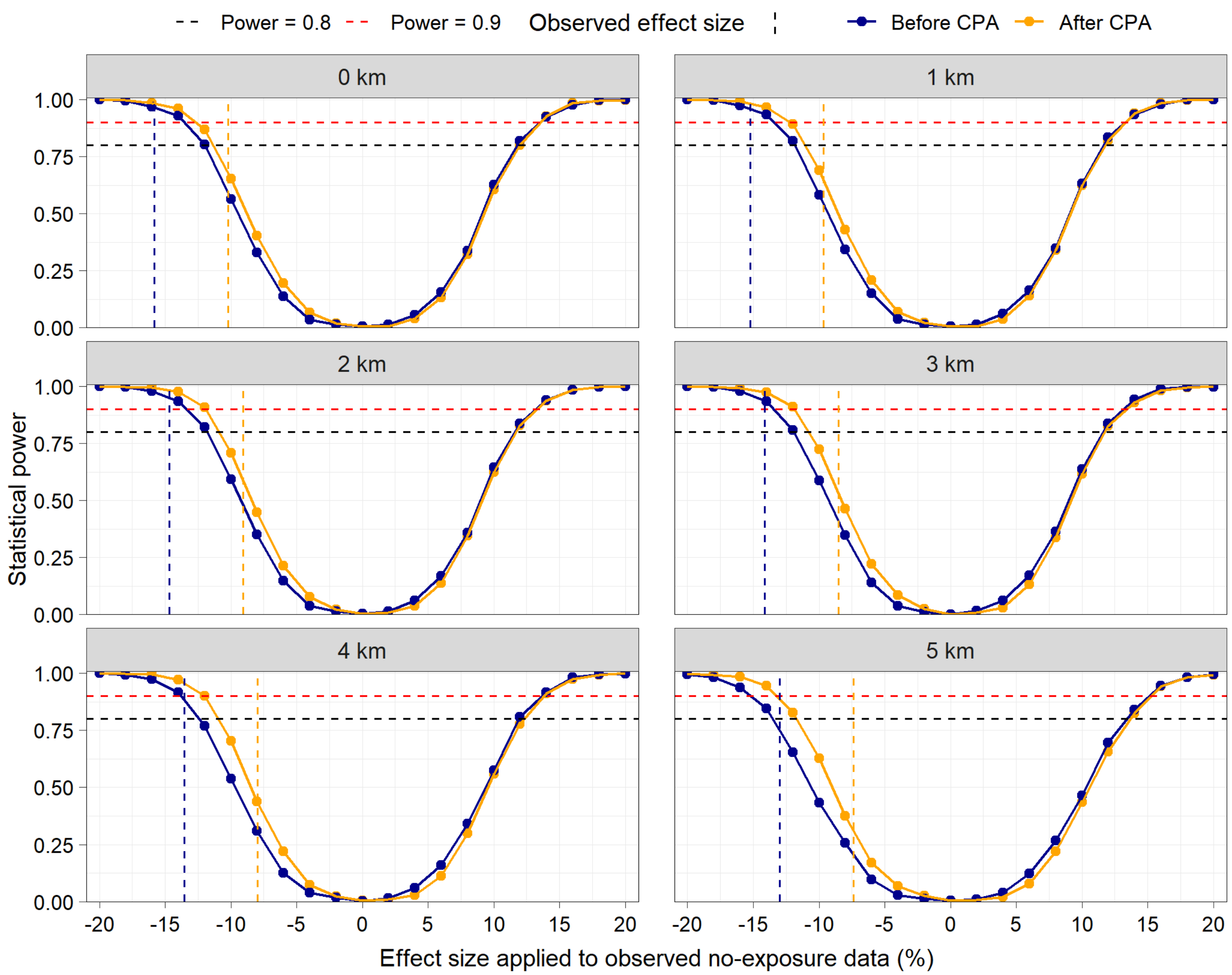

Figure 17. Statistical power of multiple comparisons between travel speed at various distances from vessels relative to when no vessels were present within 10 km from narwhal. Each panel shows a separate comparison, with the distances compared displayed at the top of the panel.

1.2 Effects of Multiple Vessels Present within 10 km from Narwhal

1.2.1 Surface Time

There was sufficient power (>0.8) to detect an overall effect of multiple vessels on surface time when effect sizes were -16% or +14%, relative to single vessel presence (Figure 18). The observed effect size was small (-1%), which resulted in a low estimate of statistical power (<0.15), and a non-significant effect of multiple vessels in the original analysis (Section 4.2.4.1 of main report). The results suggest that the model had sufficient power to detect a relatively small effect size. Since the observed effect size was so small, much larger differences in surface time than those in the dataset would be needed to detect a significant effect of multiple versus single vessel exposure.

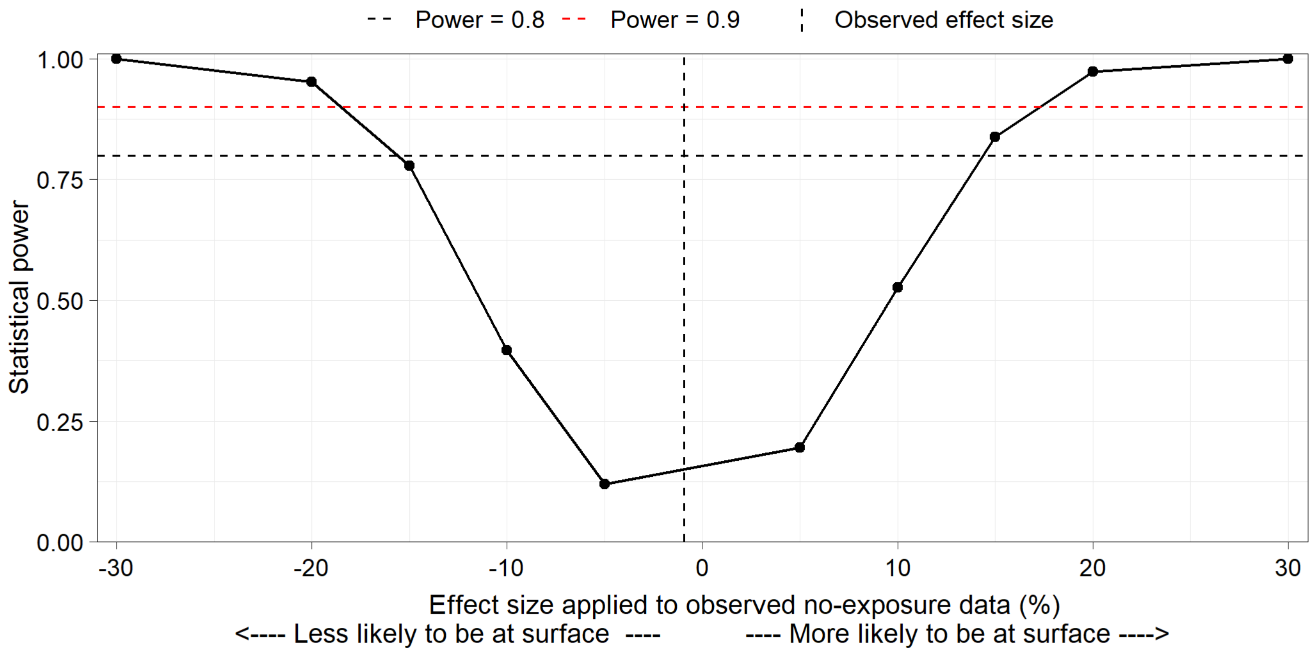

Figure 18. Statistical power of the overall model of surface time to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

1.2.2 Performing Bottom Dives

There was sufficient power (>0.8) to detect an overall effect of multiple vessels on the probability of a bottom dive when effect sizes were -110% or +60%, relative to single vessel presence (Figure 18). As the response variable was binomial, the +60% effect size corresponded to a 60% increase in the odds of a dive being greater than 75% of the total depth. At the observed effect size of +41%, the estimated power was ~0.5. These power analysis results were consistent with the original analysis in the main report (Section 4.2.4.2), which did not find a significant effect the number of vessels (multiple vs. single vessel).

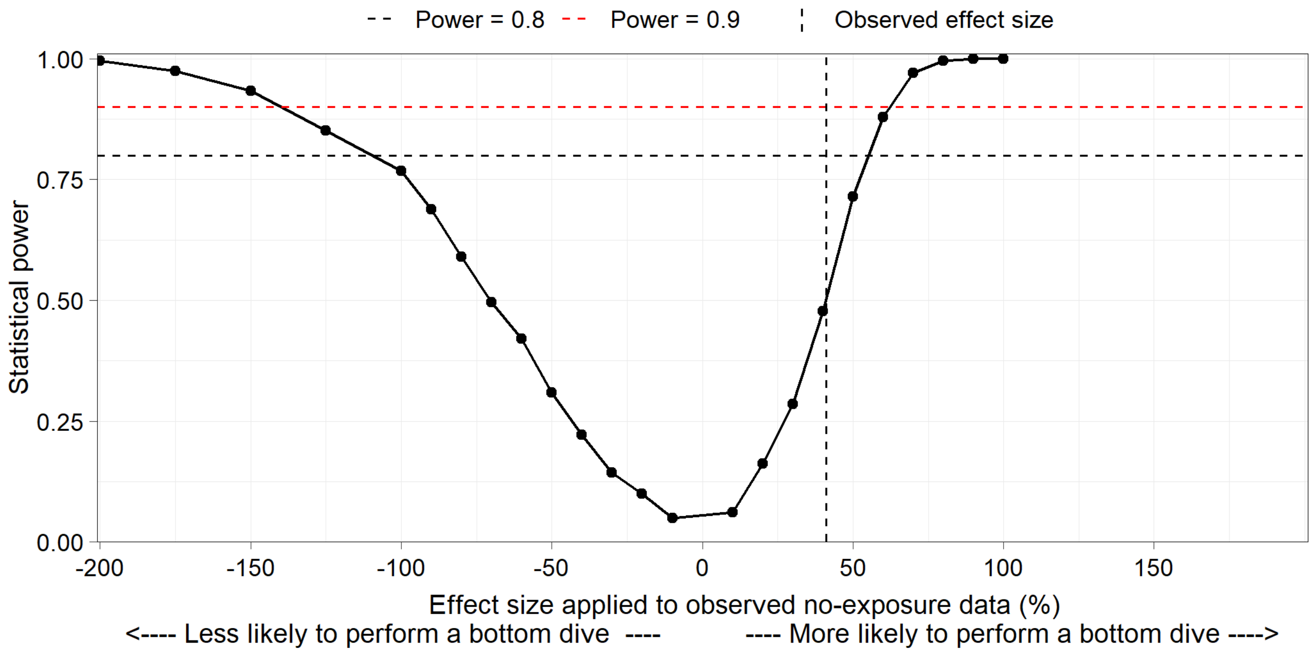

Figure 19. Statistical power of the overall model of performance of bottom dives to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

1.2.3 Dive Duration

The power analysis indicated that the analysis of dive duration had sufficient power (>0.8) to detect an overall effect of multiple vessels within 10 km when effect sizes were -12% or +11% relative to a single vessel presence (Figure 20). The largest magnitude of the observed effect sizes (indicated by vertical lines in Figure 20) was -11%, which had an estimated power of ~0.77. This result was consistent with the finding of no significant effect of multiple vessel presence (P = 0.07) in the original analysis of dive duration (Section 4.2.4.3 in the main report). That said, the P value of the original analysis could be considered marginally significant, and a slightly larger effect size (i.e., -12% instead of the observed -11%) would likely have resulted in a statistically significant result at a significance level of 0.05.

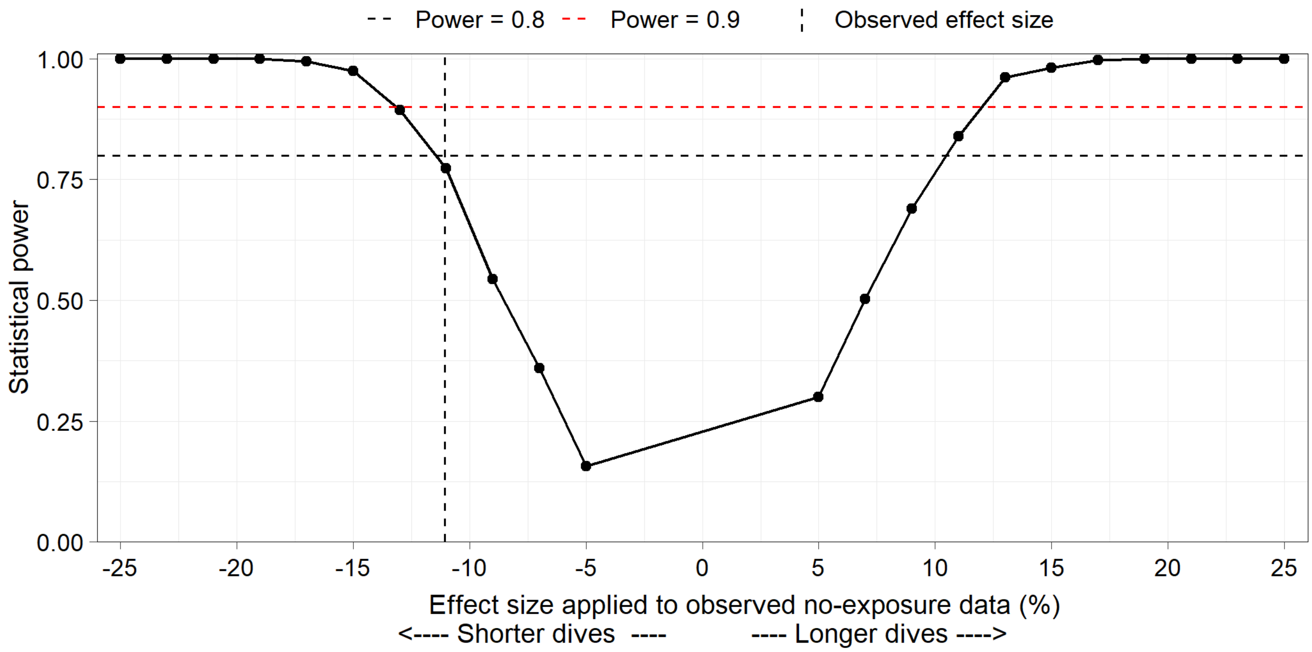

Figure 20. Statistical power of the overall model of dive duration to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

1.2.4 Turning Angle

There was sufficient power (>0.8) to detect an overall effect of multiple vessels on turning angle when effect sizes were -27% or +35%, relative to single vessel presence (Figure 18). At the observed effect size of +28%, the estimated power was 0.6. Although the estimated power was lower than the desired value of 0.8, the original analysis indicated a statistically significant effect of multiple vessels at the observed effect size (*P*=0.004; Section 4.2.4.4 in main report).

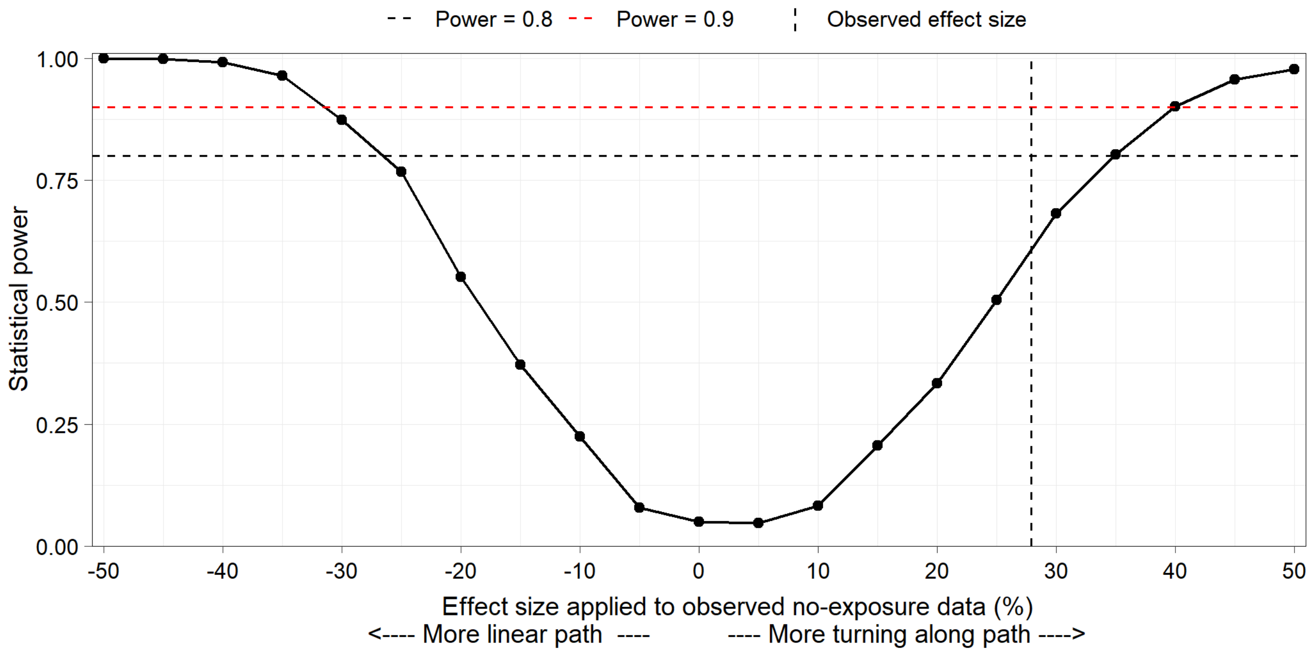

Figure 21. Statistical power of the overall model of turning angle to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

1.2.5 Travel Orientation Relative to Vessels

There was sufficient power (>0.8) to detect an overall effect of multiple vessels on travel orientation relative to vessels when effect sizes were -20% or +25%, relative to single vessel presence (Figure 22). At the observed effect size of +20%, the estimated power was 0.6. Although the estimated power was lower than the desired value of 0.8, the original analysis indicated a statistically significant effect of multiple vessels at the observed effect size (P=0.014; Section 4.2.4.5 in main report)

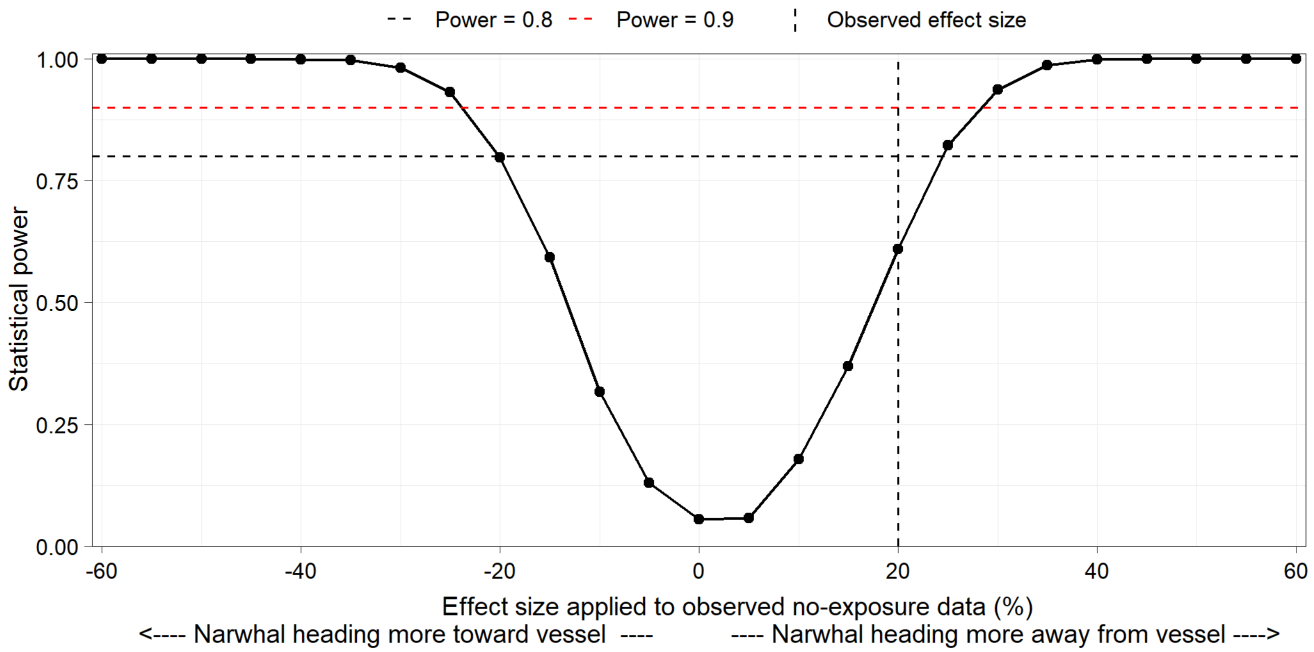

Figure 22. Statistical power of the overall model of travel orientation relative to vessels to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

1.3 Seasonal Change and Horizontal Displacement

There was sufficient power (>0.8) to detect an effect of time on the distance at CPA, at effect sizes of +45% or -43% (Figure 23). Estimated power at the observed effect size (-22%) was approximately 0.2. This suggests that the lack of a significant effect of time on seasonal habituation in the original analysis (Section 4.2.3.4 in the main report) was due to low statistical power, likely because of the high variability in the observed data.

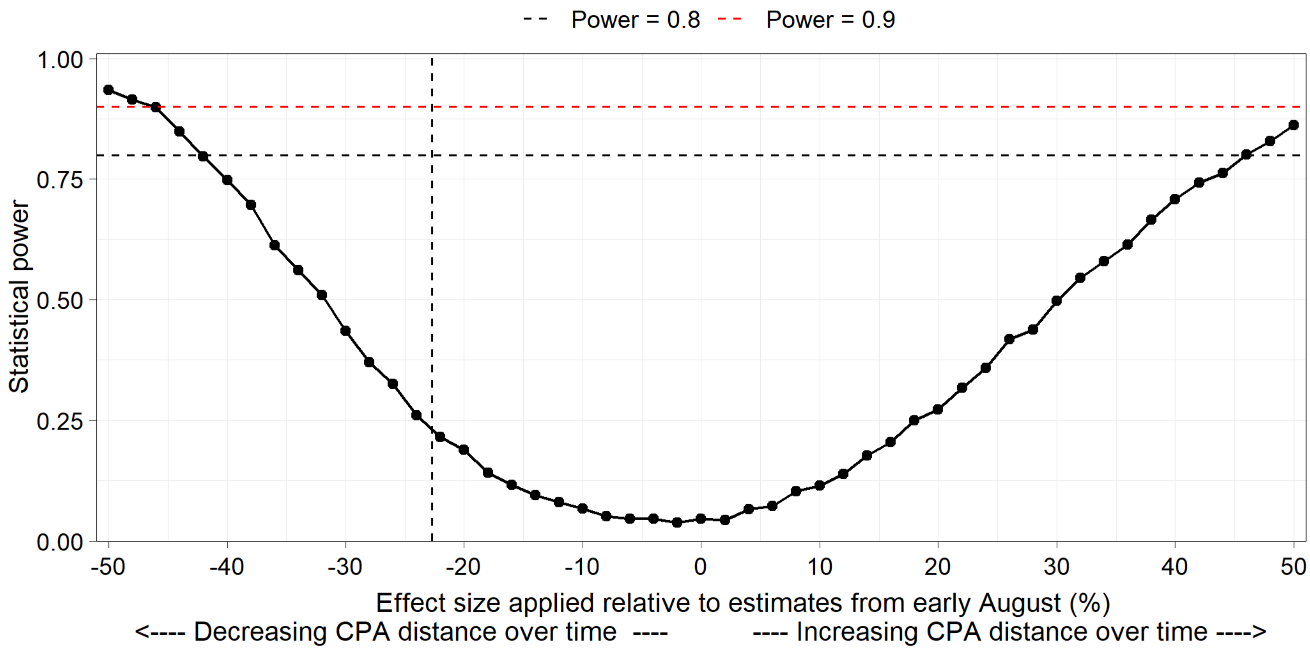

Figure 23. Statistical power of the overall model of seasonal habituation to detect a significant effect of presence of multiple vessels within 10 km from narwhal.

1.4 Summary

Eight of the 14 assessed analyses had sufficient power to detect an effect of 25% increase or decrease, with one more (time within deepest 20% of a dive) having sufficient power to detect an effect of 25% increase, but only a 30% decrease (Tables 1, 2). All but two (performing bottom dives for both single and multiple vessels) had sufficient power to detect an effect size of 50% increase or decrease.

For models where multiple comparisons were made between the effects of vessel at various distances and when no vessel was present within 10 km from narwhal (seven analyses), effect sizes required were larger than those needed to detect an overall effect (Table 1). For example, in the analysis of surface time, sufficient power to detect an overall effect was achieved at an effect size of -13% or +14%, however an effect size of -40% or +35% was required to detect a difference between a vessel at a specific distance and when no vessel was present. Hence, only one of the seven analyses (travel speed) had sufficient power to detect a significant multiple comparison with an effect size of ±25%. However, six out of seven had sufficient power to detect a significant multiple comparison with an effect size of ±50%.

In summary, the majority of analyses had sufficient power to detect a reasonable effect size (increase or reduction of 25%), and all but one had sufficient power to detect a relatively large effect size (increase or reduction of 50%). Hence, when the original analyses indicated lack of statistical significance, most cases were due to small effect sizes rather than insufficient power, with the exception of the analysis of seasonal habituation and the analysis of performing bottom dives (for multiple vessel effects).

Table 1: Power to detect effects of distance from a single vessel.

Variable	Overall effect			Multiple comparison effects		
	Effect size for power ≥0.8 (%)	Largest magnitude of observed effect size (%)	Effect detected in original analysis?	Minimum effect size for power ≥0.8 (%)	Largest magnitude of observed effect size (%)	Effect detected in original analysis?
Surface time	-13% or +14%	-46%	Y	-40% or +35%	-46%	Y
Performing bottom dives	-80% or +150%	-93% or +149%	Y	+200%	-93% or +149%	Y
Time within deepest 20% of a dive	-30% or +25%	-21%	N	-40% or +35%	-21%	N/A
Dive duration	-17% or +15%	-24%	Y	-30% or +20%	-24%	Y
Descent speed	-22% or +20%	-11%	N	-30% or +35%	-11%	N/A
Turning angle	-39% or +41%	+42%	Y	-40% of +50%	42%	Y
Travel orientation relative to vessels	-17% or +13%	40%	Y	N/A	40%	N/A
Travel speed	-13% or +13%	-15%	N	-13% or +13%	-15%	N/A

Table 2: Power to detect effect of presence of multiple vessels within 10 km from narwhal.

Variable	Overall effect		
	Effect size for power ≥0.8 (%)	Observed effect size (%)	Effect detected in original analysis?
Surface time	-16% or +14%	-1%	N
Performing bottom dives	-110% or +55%	+41%	N
Dive duration	-12% or +11%	-11%	N
Turning angle	-27% or +35%	+28%	Y
Travel orientation relative to vessels	-20% or +25%	+20%	Y

APPENDIX D

Comments

Baffinland

Name: Marianne Marcoux, Jacquie Bastick, Chantal Vis

Agency / Organization: DFO/PCA

Date of Comment Submission: June 8th, 2020

#	Document Name	Section Reference	Comment	Baffinland Response
1	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	Executive Summary - English	This study only evaluates the behaviour of narwhals that came in contact within 10 km of vessels. It is possible that narwhal actively avoided ships and stayed at distances greater than 10 km. Therefore, these analyses are not designed to answer the question of narwhal avoidance of vessels.	The reviewer has misunderstood the information presented in the report. 10 km was merely defined as the exposure zone (see justification in response to comment #3). The movements of tagged narwhal occurring within the full extent of the RSA were included in this analysis.
2	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	Executive Summary - English	BIM states: "Overall, results from the 2017 and 2018 narwhal tagging study support predictions made in the Final Environmental Impact Statement (FEIS) for the ERP, in that ship noise effects on narwhal will be limited to temporary, short-term avoidance behaviour, consistent with low to moderate severity responses as defined in Section 2.6.3 of this report. No evidence was observed of large-scale avoidance behaviour, displacement effects, or abandonment of the summering grounds (high severity responses), which might in turn result in a population or stock-level consequence (consistent with the definition of a non-significant effect used in the FEIS)." This study was not designed to test for large-scale avoidance behaviour, displacement effects,	The comment provided is suggesting that large-scale avoidance or displacement effects would only ever be exhibited by narwhal upon their first exposure to ship noise at the start of the shipping season. While we do not disagree that this type of response is possible, it is not the only way narwhal may exhibit large-scale avoidance or displacement effects from shipping. For example, narwhal may select to avoid ships at any point during the shipping season following repeated exposure to ship noise (a response for which the tagging study was designed to capture). If shipping noise was preventing animals from foraging efficiently or communicating effectively, it stands to reason that the animal would eventually decide to move to a different area where it was less

#	Document Name	Section Reference	Comment	Baffinland Response
			or abandonment of the summering grounds. Narwhals that were tagged as part of this study were tagged in the RSA while shipping was occurring. Therefore, they already made the choice to come to the area with the presence of ships. This study was designed to test for the small scale effect of interactions between ship and narwhals. It was also designed to measure levels of noise by narwhal. In order to test for large-scale avoidance, methods for monitoring abundance are required.	impacted. However, this does not mean this necessarily would occur immediately upon the animal's first encounter with the ship. Arguably, it would take some period of time (and multiple exposures) before the animal, or group of animals, would make this decision. Furthermore, large-scale avoidance and displacement responses are not necessarily limited to animals avoiding the RSA as a whole. There are areas within the RSA where ship noise is virtually absent or greatly reduced, such as Navy Board Inlet and Tremblay Sound (where animals were initially captured and tagged). If ship noise was impacting narwhal to the point of impeding their critical life functions, it would stand to reason that animals would move into, or remain in these areas of reduced noise (and show active avoidance of high traffic areas). Again, this would be an example of large-scale avoidance or displacement within the RSA, and could be initiated at any point during the season, for reasons aforementioned. This is also a type of response the tagging study was designed to capture (in addition to localized avoidance and displacement responses). Other examples of large-scale avoidance or displacement would be a change in animal distribution that would extend well beyond the ship detection period. For example, if narwhal were actively foraging or milling in the shipping channel near Bruce Head when no ships were present, and then were to travel

#	Document Name	Section Reference	Comment	Baffinland Response
				into Koluktoo Bay during ship exposure events, and remain there for several hours following the acoustic exposure event, this again would be an example of large-scale avoidance or displacement. This is also a type of response the tagging study was designed to capture. Based on tagging results to date, it is evident that narwhal have not demonstrated any of the above examples of large-scale avoidance or displacement effects throughout the shipping season after being exposed to ship noise. Tagged animals were shown to come in relatively close contact with vessels repeatedly throughout the duration of the tag deployments. For reasons above, we disagree with DFO's statement that the present study is unable to test for large-scale avoidance or displacement effects. Where we do agree with DFO is that the tagging study is unable to investigate to what degree animals choose not to enter the RSA in early summer due to shipping noise. This question is currently addressed through the aerial survey program by looking at potential changes in stock abundance and distribution in the RSA over time. Although this question could also theoretically be studied at the individual level using a tagging approach, this would necessitate tagging the animals during the spring near the floe edge prior to the start of the shipping season. Golder has

#	Document Name	Section Reference	Comment	Baffinland Response
				previously attempted to address this specific research objective by requesting to collaborate with DFO on their floe edge narwhal tagging program to collect this information, but this was not approved. Should the floe edge tagging program resume in the future, we would welcome the opportunity to collaborate with DFO on investigating this potential type of initial response to shipping. Finally, it is acknowledged that one of the initial objectives of the tagging study was to monitor changes in narwhal vocal behavior in relation to vessel traffic. Unfortunately, none of the animals outfitted with the Acousonde acoustic tags entered the shipping channel area during the short duration that the tags remained attached to the animals. Therefore, the study objective of linking behavioral responses with received ship noise levels was not possible. However, Golder in collaboration with JASCO, Is presently exploring an acoustic modelling approach to link behavioural responses with received ship noise levels.
3	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	3.5.1 Identification of Narwhal Encounters with Vessels	Vessel encounter was defined based on the presence of vessel within 10 km of narwhals. It is stated that 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 knots through Milne Inlet.” Given that the 120 dB threshold might be up to 20 km, and given	The distance used to delineate exposure vs. non-exposure zones (i.e. 10 km) is supported by acoustic modeling conducted by JASCO in which the majority of the disturbance noise field falls within 10 km of the source. Of note, the R95% values indicated a disturbance zone of between 5.93 and 11.20 km. Monitoring results collected to date as part of JASCO’s Passive Acoustic Monitoring (PAM)

#	Document Name	Section Reference	Comment	Baffinland Response
			that not disturbance threshold have been developed for narwhals, did BIM consider a different distance threshold for the analysis?	program suggest that modelling estimates are conservative (i.e., the 120 dB disturbance zone is likely well under 10 km). The present study considers distance as a continuous variable for anything under 10 km, so yes BIM considered multiple distance threshold possibilities in the analysis, although these were all under 10 km. This is further supported through conservatism already built into the 120 dB disturbance threshold, in that this value is not weighted to account for the frequency range in which marine mammals are sensitive to hearing. As 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), accounting for species-specific hearing sensitivity would decrease the 10 km distance associated with the disturbance zone rather than increase it. Therefore, as stated in the report and further supported by passive acoustic monitoring undertaken in 2018 and 2019, 10 km is likely an overestimate of the disturbance zone for narwhal and determined to be the most appropriate distance threshold for the present analysis. The 10 km cut-off distance is further supported by other available marine mammal research including a review of sonar and seismic survey marine mammal monitoring literature, in which no

#	Document Name	Section Reference	Comment	Baffinland Response
				significant behavioural reactions by toothed whales (excluding beaked whales and harbour porpoise) have been observed beyond several kilometers (Stone and Tasker 2006; Weir 2008; Southall et al 2014; Finneran et al. 2017). Based on this body of research, The US Navy uses a 10 km cutoff distance for limiting assessment of significant behavioural reactions for sonar emissions on toothed whales (Finneran et al 2017). As sonar and seismic noise sources are considerably louder than vessel noise, marine mammals are considerably more responsive to these types of sound sources than they are to vessel noise. If toothed whale responses to sonar or seismic are deemed to be insignificant beyond 10 km, it is reasonable to assume the same would apply for toothed whale responses to vessel noise (10 km would actually be quite conservative in this sense). The body of knowledge collected through this study, in combination with other studies, will eventually lead to the development of revised disturbance thresholds specific to narwhal, that would serve to replace the existing 120 dB disturbance threshold (generic to all marine mammals). Ideally this work would be led by DFO and other relevant regulatory agencies, to be applied to the current Project as well as to other industrial projects. However, given that research and regulatory guidance in this area is limited, Baffinland is presently evaluating these

Baffinland

#	Document Name	Section Reference	Comment	Baffinland Response
				thresholds based on Proponent-led monitoring and research initiatives. In the interim, we default to existing disturbance thresholds based on best available science (NOAA 2013). This approach is consistent with all other comparable projects in Canada and abroad.
4	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	3.5.2 Narwhal Dive Behaviour	For the null hypotheses, what alpha level was considered significant? Given the small sample sizes, could an alpha level of 0.1 be considered?	The alpha level used was 0.05. An increase of alpha to 0.1 would generally only have a small effect – for example, in surface time analysis, it would increase the distance of effect from <1 km from vessel to <2 km from vessel, and would have no effect on the results for bottom dives, time at depth, or descent speed.
5	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events)	From the information in this paragraph, it seems that 6 narwhals were within 10 km of vessels. Is it correct that the other 14 narwhals did not get within 10 km of vessels? Could you provide some summary about how many tagged narwhals came in close contact to vessels?	That is not correct. Only six individual narwhal were outfitted with high-resolution MiniPAT tags capable of collecting detailed dive behavior (as discussed in section 4.2.1). Figure 4-13 in Section 4.2 summarizes all exposure events, color-coded by narwhal, and Figure 4-66 in Section 4.2.2.1 identifies which whales were recorded within 10 km from vessels (i.e. 12 of 14 whales included in the analysis). The two whales that did not come within the exposure zone (NW05 and NW06) were the pair of whales that travelled immediately to Admiralty Inlet (outside the RSA) after being released following capture at the Tremblay Sound tagging camp.

#	Document Name	Section Reference	Comment	Baffinland Response
6	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	5.0 Discussion	This study illustrated the great variation between narwhals in their behaviour. According to a meta-analysis of mega fauna tagging studies (Sequeira et al 2019), sample sizes of around 100 individuals are required to investigate the impact of human disturbance on wild animals. While the tagging report documents the reaction of 6 to 12 narwhals to close contact with vessels, the sample size is not big enough to come up with any significant conclusion. Sequeira, A.M.M., Heupel, M.R., Lea, M. -A., Eguíluz, V.M., Duarte, C.M., Meekan, M.G., Thums, M., Calich, H.J., Carmichael, R.H., Costa, D.P., Ferreira, L.C., Fernandéz-Gracia, J., Harcourt, R., Harrison, A. -L., Jonsen, I., McMahon, C.R., Sims, D.W., Wilson, R.P., and Hays, G.C. 2019. The importance of sample size in marine megafauna tagging studies. Ecol Appl 29(6). doi:10.1002/eap.1947.	We disagree with the comment that no significant conclusion can be drawn from the data included herein. Of the 12 narwhal that were included in this study, statistically significant changes in behaviour were identified that inform responses at the individual level. Increased sample size would, however, be beneficial to better define response patterns at the stock level. The number of narwhal tagged to date represents two years' worth of data collection. In 2017, the maximum allowable number of narwhal were tagged as per permit allowance (20 animals). In 2019, the program was suspended. Should the collaborative tagging program resume in the future, this would increase the sample size of narwhal that may be incorporated into this analysis.
7	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	4.2.3.3 Horizontal Displacement	BIM noted: A gap without narwhal GPS locations was evident within approximately 0.5 km of vessel port and starboard, and 1 km of the vessel bow and stern (Figure 4-69). 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. It should be noted that the tags do not transmit when narwhals are underwater. Therefore, the horizontal movement of narwhals underwater can only be extrapolated from transmission at the surface. Thus, it	This is correct. Text in section 4.2.3.3 has been updated to reflect that avoidance may be horizontal or vertical.

#	Document Name	Section Reference	Comment	Baffinland Response
			is possible that narwhals went underwater in proximity of vessels.	
8	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	5.0 Discussion	The interpretation of bottom dive result should be considered more carefully. Some of the results should be interpreted in the light of Williams et al (2017) finding that narwhals performed deep dives as a response to a stressor. Therefore, deep dives in narwhal are not always indicative of feeding and in some cases, it might be a stress response. Williams, T.M., Blackwell, S.B., Richter, B., Sinding, M.-H.S., and Heide-Jørgensen, M.P. 2017. Paradoxical escape responses by narwhals (Monodon monoceros). Science 358(6368): 1328–1331. doi:10.1126/science.aao2740.	The paper by Williams et al. (2017) focuses on the paradoxical response of narwhal to exhibit extreme down regulation in heart rate while simultaneously increasing their stroke frequency. The paper does not focus on bottom diving behavior of narwhal specifically but briefly discusses dive depth in relation to five narwhal, of which none dive beyond a depth of 500m (no relation to bottom time). There is no mention in this paper of time at depth or dive depth in relation to available bathymetry and it is therefore not possible to comment on bottom diving behavior of narwhal based on this study alone. Based on the extensive research conducted on bottom diving behavior of cetaceans (referenced in section 2.5.1), we stand by the interpretation of consecutive bottom dives likely representing foraging dives.
9	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report	APPENDIX C Power Analysis	Could you specify which R package was used for the Bootstrapping? Were you able to incorporate the random effect of individuals in the Bootstrapping?	The bootstrapping was performed using custom-written functions, as opposed to a specific package. The simulation algorithm was detailed in the power analysis appendix. Following the data simulation, the original model structure was used, which included a random effect of individuals. The random variation of individuals was also taken into account during the data simulation process, since the simulation values were based on the conditional predictions of the models (i.e., individual-based, rather than population-based values).

Baffinland

Name: Amanda Joynt

Agency / Organization: Oceans North

Date of Comment Submission: June 8, 2020

These comments refer to an independent analysis with the title of: Underwater Radiated Noise from Ships in Eclipse Sound:2018-2019 (Jones, 2020). Applicable figures and tables from this analysis are provided with these comments. A full copy of the analysis will be provided to Baffinland and the MEWG when it is in its final version.

#	Document Name	Section Reference	Comment	Baffinland Response
1	Draft 2017-2018 Integrated Narwhal Tagging Study	Pg. 125, Paragraph 3. "Results suggest that narwhal orient themselves away from transiting vessels, potentially demonstrating avoidance, within 4-5km of a transiting vessel prior to the CPA, but for the full extent of 10km post CPA."	In Jones (2020), the 10km distance radius around the ship is assessed to have a broadband received sound pressure level (SPL) of 110 dB or less for bulk carriers, the most common project-related ship type (e.g. Jones, 2020; Table 3, Figs 7,8,9). As the full extent of reported avoidance post-CPA is 10km, it is important to include information on these lower levels of noise in impact assessments and monitoring programs. The 10km range limit for evaluating disturbance may not be appropriate. Observed radii to behavioral disturbance in tagged narwhal (1-10 km) suggest that a range of received ship noise levels may provoke a behavioral response. Depending on ship type, ranges to 120 dB broadband SPL may be greater than 10 km, as predicted and observed for project icebreakers and tanker vessels. Also, ranges to ships when behavioral disturbance is observed in tagged animals may correspond to lower received SPL than 120 dB. Received levels at	Of the response variables considered in this study, significant responses of narwhal were not observed beyond 5 km from a vessel, with the exception of narwhal travel orientation relative to vessels, specifically post-CPA, in which responses were observed for the full extent of the 10km exposure zone. The usefulness of how this particular response variable is able to inform behavioral change, however, is currently being examined given that different types of interactions between a narwhal-vessel can result in mixed interpretations of this response. Baffinland acknowledges that the range from ships at which narwhal exhibit a response may correspond to lower received levels than 120 dB (or it may alternatively correspond to higher received levels). This is presently unknown. Without having acoustic tags attached to the animals collecting data on received sound levels in concert with behavioral data, it was necessary that the spatial extent of the exposure zone be informed by other data sources

			actual ranges to behavioral disturbance should be evaluated by comparing these ranges with received levels measured in separate/concurrent acoustic studies undertaken by BIMC. Previous visual observation study reports from Bruce Head included response to radii of up to 15 km. Is there a difference in the way the data is being analyzed for tag data that no longer include these longer distances?	available. The distance used to delineate exposure vs. non-exposure zones (i.e. 10 km) is supported by acoustic modeling conducted by JASCO in which the majority of the disturbance noise field falls within 10 km of the source. Of note, the R95% values indicated a disturbance zone of between 5.93 and 11.20 km. Furthermore, the behavioral threshold commonly referred to in the literature is not weighted to account for the frequency range in which marine mammals are sensitive to hearing. As 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), accounting for species-specific hearing sensitivity would decrease the 10 km distance associated with the disturbance zone rather than increase it. Therefore, as stated in the report and further supported by passive acoustic monitoring undertaken in 2018, 10 km is likely an overestimate of the disturbance zone for narwhal and received sound levels are likely much lower than 120 dB within this range. Response radii considered in the Bruce Head reports were restricted to 10 km in 2019, based on the rationale stated previously and on results from previous years indicating that behavioral responses to ships were typically evident at ranges closer than 10 km.

#	Document Name	Section Reference	Comment	Baffinland Response
2	Draft 2017-2018 Integrated Narwhal Tagging Study	Document reference number Baffinland Mary River Project Phase 2 Proposal, Appendix N, Attachments related to the Marine Environment. Attachment 2, Technical Memorandum - Analysis of 2018 Narwhal Tagging Data during Fall Shoulder Season. 1663724-162-TM-Rev0-12000, Oct. 15, 2019. Section 3.2 Page 7-9.	There are no results from the icebreaking shoulder season for the narwhal tagging results included in this referenced report. Please clarify why these data not included in the Integrated report.	Refer to response to comment #3. Icebreaking vessels transiting through the RSA during the 2018 fall shoulder season are included in the analysis of 2017-2018 tagging data. A separate analysis of narwhal interactions with icebreaking vessels is presented in a Technical Memorandum on shoulder season shipping, dated 15 October 2019. A reference to the Technical Memorandum has been added in section 3.5.4. of the report.

#	Document Name	Section Reference	Comment	Baffinland Response
3	Draft 2017-2018 Integrated Narwhal Tagging Study	There are no sections to reference as the comments center on what is not included in the report.	In Jones (2020), there are 19 and 35 ship transit events of the icebreaker Botnica passing the Pond Inlet and Milne Inlet reference locations, respectively, from Sept 28, 2018 to Sept 22, 2019 (Jones, 2020; Table 1). This period includes one late and one early shoulder shipping season during which concurrent acoustic measurements of received noise levels from ships were made by and are reported in Jones 2020. Why are these icebreaking ship events in proximity to tagged narwhal not included or analyzed in the Integrated Report? It would be helpful to see tagged narwhal behavioral response ranges and data analysis for the 2018 fall shoulder season for comparison with acoustic results. Icebreaking is the largest sound source associated with the project and occurs during the quietest time of the shipping year (i.e. July). Icebreaker ship transits are highest both in measured received sound pressure levels relevant to behavioral disturbance and with respect to listening space reduction (LSR). It is important to analyze these data in relation to the radius from the ship at the time of observed behavioural responses as much as possible.	Narwhal responses to ships during the 2018 Fall shoulder season are presented in a technical memorandum dated 15 October 2019. A reference to the Technical Memorandum has been added in section 3.5.4. of the report. Only two animals were outfitted with satellite tags during this time, of which one provided relatively low-resolution GPS data. Dive and acoustic data collected for both animals did not extend into the 2018 Fall shoulder season. Therefore, the memorandum focuses on narwhal positional data collected between 29 September and 17 October 2018, coincident with the period that the MSV Botnica was conducting Project-related icebreaking operations along the Northern Shipping Route. A total of 26 events took place in which a tagged narwhal came within the acoustic disturbance zone of an icebreaking vessel (i.e. 54.4 km, as determined by acoustic modelling conducted by Jasco Applied Sciences). No narwhal were tagged in 2019, during either the shoulder or open water seasons.

#	Document Name	Section Reference	Comment	Baffinland Response
4	Draft 2017-2018 Integrated Narwhal Tagging Study	Section 6.0 Pg. 154-155	Please clarify how the Southall (2007; Table 4) severity scale is applied to the post-CPA behaviour, and how it was determined when behavior had returned to pre-response behaviour to then assess the disturbance at the level of moderate. What estimated severity scores are assigned to each of the types of behavioral disturbance significantly related to ship proximity in this study?	Narwhal surface movement behavioural responses (i.e., changes in orientation and turning angle) that were shown to be significantly influenced by vessel noise or close vessel encounters corresponded with severity scores ranging from 1 to 3. Narwhal dive behavioural responses (i.e., changes in surface time, dive duration and bottom dives) that were shown to be significantly influenced by vessel noise or close vessel encounters corresponded with severity scores ranging from 3 to 4. Severity Score 4 is defined as 'moderate changes in locomotion speed, direction and/or dive profile…' (Southall et al. 2007). No prolonged changes in dive behaviour were evident in the tagging data which would correspond with severity scores of 5 or higher. Changes were considered prolonged (or long-term) if they persisted beyond the vessel exposure period (consistent with the time period an animal would occur within the 120 dB exposure zone of a passing ship).

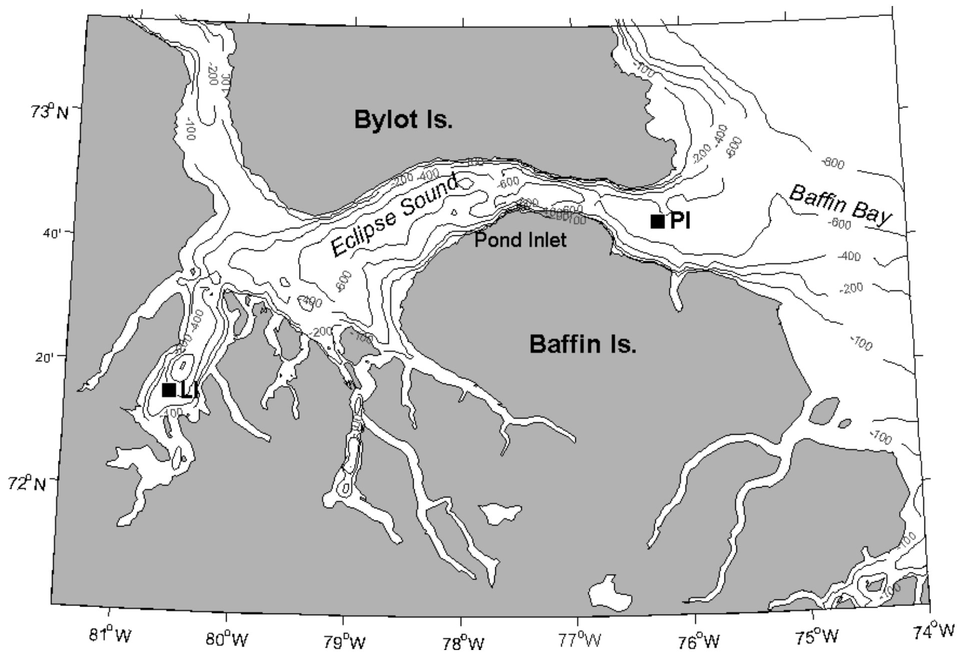

Figure 1. Long-term acoustic recording sites in Eclipse Sound, N. Baffin Island, Nunavut Territory, Canada. High-frequency Acoustic Recording Packages (HARPs) were deployed at Pond Inlet (PI) from May 2016 through September, 2019 and at Milne Inlet (MI) from Sept 2018 through Aug 2019

Bulk carriers

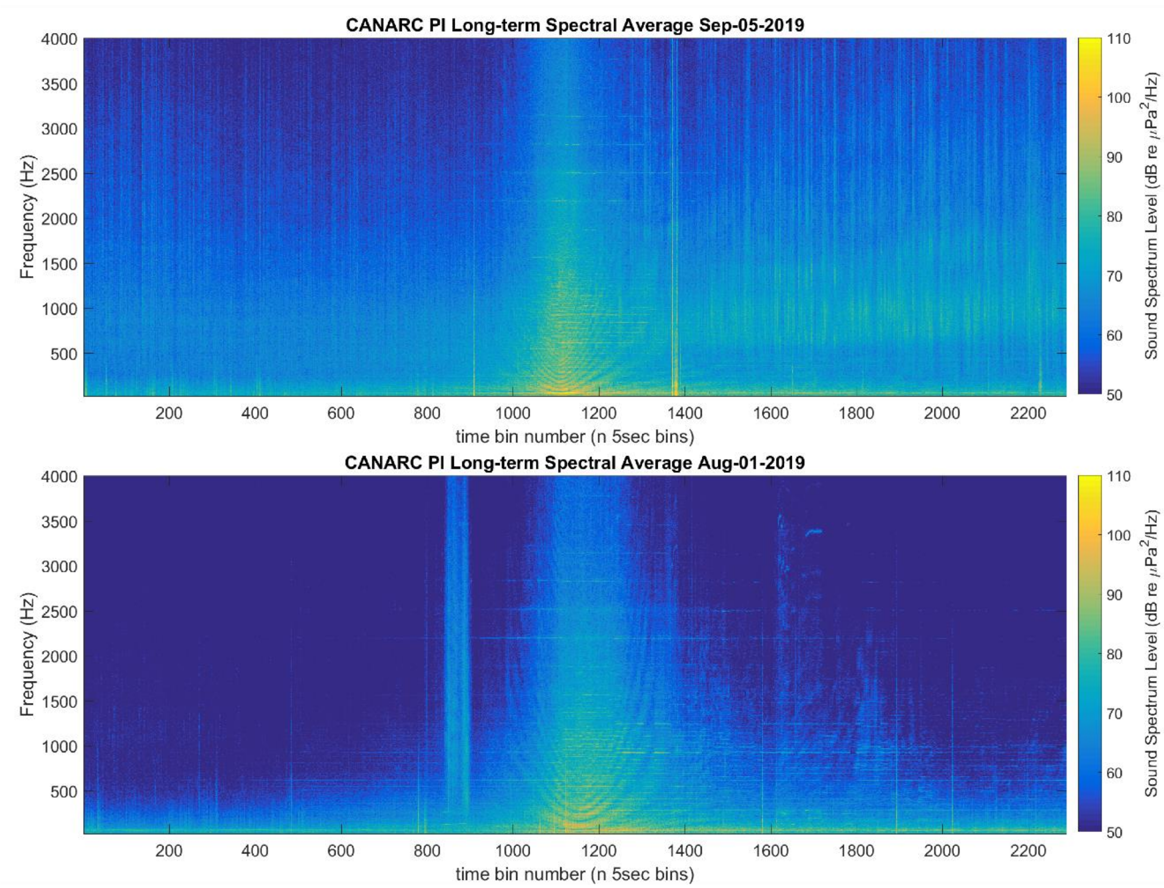

Figure 7. Long-term spectral average (LTSA) of the 6-hour window about the closest point of approach (CPA) of 225 m bulk carrier Nordic Orion (IMO ##) during two transits past the recording location. Wind-generated noise below 4 kHz is evident in the Sep 5, 2019 transit (top panel; CPA range 2 km). A transit of the same vessel Aug 1, 2019 (bottom panel; CPA range 2.4 km) occurs during lower background noise at the start of the ice-free season.

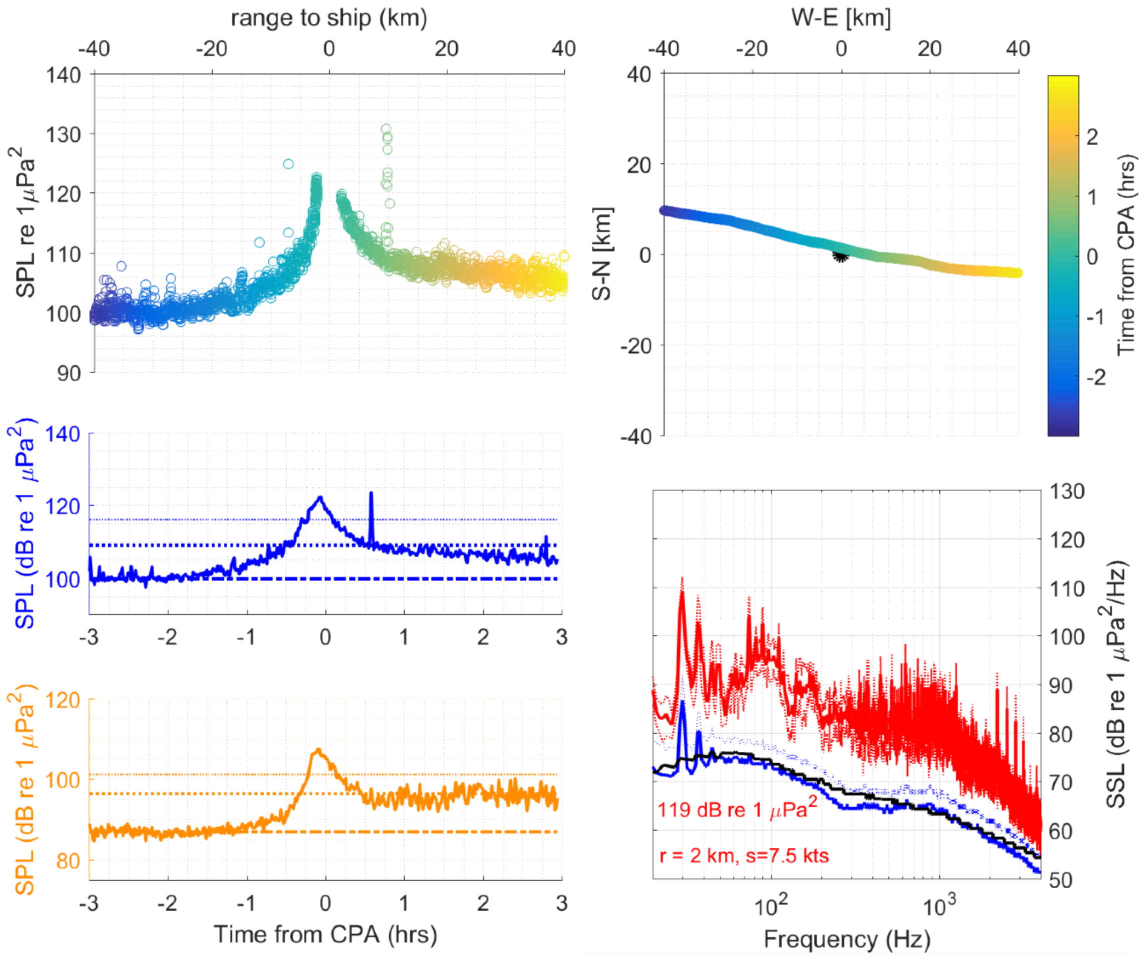

Figure 8. Ship transit analysis for bulk carrier Nordic Orion Sep 05, 2019. Broadband sound pressure level (SPL_{BB} 20-4000 Hz; top left open circles) averaged every 5s increases gradually beginning apx. 2 h prior to the closest point of approach (CPA), increasing more rapidly within 30 min of the closest point recorded (CPR) at a range of 2 km and max. SPL_{BB} 119 dB re 1 μPa^2. Colors in SPL scatter plot and map showing ship track (top right) represent time from CPA (5s bins). Middle left) received SPL for the 20-4000 Hz band (blue) and the 1 kHz 1/3rd octave band (bottom left; orange) during ship transit plotted with 50th (dash-dot line), 90th (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Bottom right) Sound spectrum level (SSL) of CPR period (red) with median SSL of the 1st 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

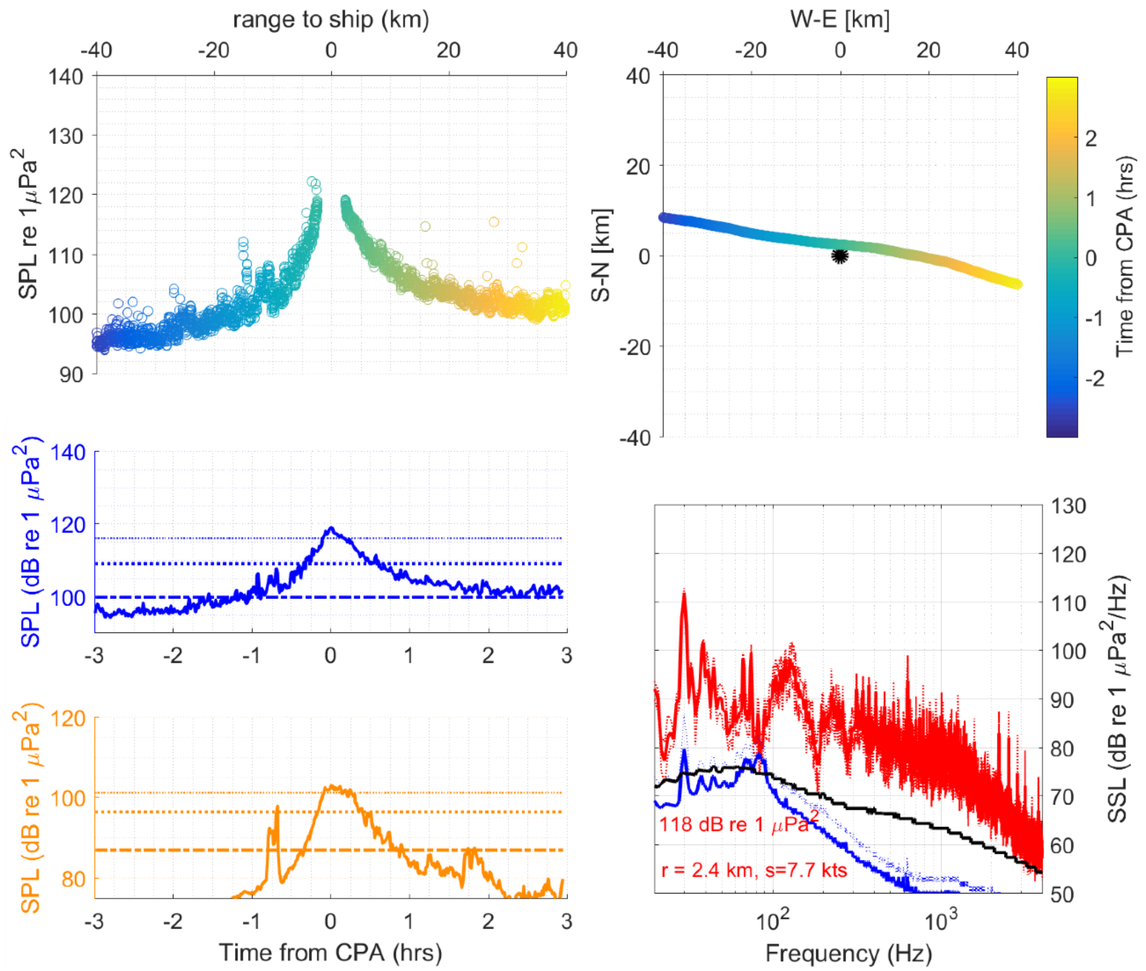

Figure 9. Ship transit analysis for bulk carrier Nordic Orion Aug 01, 2019. Broadband sound pressure level (SPL_{BB} 20-4000 Hz; top left open circles) averaged every 5s increases gradually beginning apx. 2 h prior to the closest point of approach (CPA), increasing more rapidly within 30 min of the closest point recorded (CPR) at a range of 2.4 km and max. SPL_{BB} 118 dB re 1 μPa^2. Colors in SPL scatter plot and map showing ship track (top right) represent time from CPA (5s bins). Middle left) received SPL for the 20-4000 Hz band (blue) and the 1 kHz $1/3^{rd}$ octave band (bottom left; orange) during ship transit plotted with 50^{th} (dash-dot line), 90^{th} (dotted line), and 99th (upper dotted line) percentile levels without ships (background levels). Bottom right) Sound spectrum level (SSL) of CPR period (red) with median SSL of the 1^{st} 30 min of transit plot (blue) and shipping season median background sound levels during periods without ships (black).

Table 1. Summary of AIS vessel transits, passing within 15 km of the Pond Inlet (PI) and Milne Inlet (MI) acoustic recording locations between Sep 28, 2018 and Sep 21, 2019.

Ship type	Pond Inlet		Milne Inlet	
	Number of transits	Percent of transits	Number of transits	Percent of transits
Bulk Carriers	150	57%	150	63%
General Cargo	25	9%	21	9%
Passenger Ships	20	8%	0	0%
Icebreakers	19	7%	39	16%
Oli and Chemical Tanker	15	6%	10	4%
Pleasure Craft	7	3%	1	0%
Sailing	6	2%	0	0%
Tug	6	2%	9	4%
Military	6	2%	2	1%
Other Cargo	5	2%	6	3%
CCGS-SAR	5	2%	0	0%
Total	264		238	

Table 3. Acoustic characteristics of ship transits

Design characteristics and acoustic measurements of a representative set of ships of seven common types transiting Eclipse Sound. Ranges and 20-4000 Hz broadband received sound pressure levels (in dB re 1 μPa^2) at closest point of approach (CPA) are given for each example ship transit along with observed ranges to the ship when received levels were measured at 110 and 120 dB. Where values for bow and stern aspect 110 and 120 dB RL range differ substantially, both are given (i.e. bow range (km), stern range (km)).

	Ship information						Acoustic measurements				
Ship type	MMSI number	Ship name	Ship length (m)	Year built	Gross tonnage (10^3)	Deadweight tonnage (10^3)	Ship speed (kts)	Range at CPR (km)	Received level at CPR*	Range to 110 dB (km)	Range to 120 dB (km)
Bulk Carriers	356364000	NORDIC ODIN	225	2015	41071	76180	8.7	0.9	121	4,7	0.9
	356364000	NORDIC ODIN	225	2015	41071	76180	8.6	0.6	123	4,7	0.9
	373437000	NORDIC ORION	225	2011	40142	75603	7.5	2	119	5,7	2
	373437000	NORDIC ORION	225	2011	40142	75603	7.7	2.4	118	5,7	-
	374322000	NORDIC ODYSSEY	225	2010	40142	75603	8.4	1	127	10	3
	538008053	GOLDEN PEARL	225	2013	41718	74300	7.3	1.8	114	4	1.8
	538008053	GOLDEN PEARL	225	2013	41718	74300	8.6	0.3	125	5,7	1
	636015651	NS YAKUTIA	225	2013	40972	74559	8.1	1	115	2,3	-
	636015650	NS ENERGY	225	2012	40972	74518	7	3.1	116	4,6	-
	636092901	KAI OLDENDORFF	229	2019	44029	81243	8	1.9	120	4,7	1.9
	255805765	GISELA OLDENDORFF	229	2013	44218	80839	8.8	1	119	3,7	1
	538004978	AM QUEBEC	230	2013	43987	81792	7	1.1	130	10,20	4,5
General Cargo	316015133	ZELADA DESGAGNES	139	2009	9611	12692	8	1.9	130	-	8
	316011358	ROSAIRE A. DESGAGNES	138	2007	9611	12776	8.2	0.6	127	10,15	3
	246770000	MOLENGRACHT	143	2012	9524	11744	8.9	0.2	135	13,15	4,7
	316003010	CLAUDE A. DESGAGNES	138	2011	9627	12671	8	2.2	126	20	8,10
Oil and Chemical Tankers	316012308	SARAH DESGAGNES	147	2007	11711	17998	9	2	133	10,35	4,16
	316012308	SARAH DESGAGNES	147	2007	11711	17998	8.2	2.6	133	10,20	10,20
	316095000	DARA DESGAGNES	124	1992	6262	10511	8.5	0.3	130	7,20	2,4
	316095000	DARA DESGAGNES	124	1992	6262	10511	7.2	0.6	133	20,25	4,5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	3.1	123	10,25	5
	316037373	KITIKMEOT W	150	2010	13097	19983	13	0.1	135	10,-	3,5
Passenger Ships	311000419	OCEAN ENDEAVOUR	137	1982	12907	1762	11	2	122	8,13	3,4
Pleasure Craft	319030600	ARCADIA	36	8	308						
	304977000	HANSE EXPLORER	48	2006	885	198	11	2.7	119	5,6	3,4
	304977000	HANSE EXPLORER	48	2006	885	198	9.8	2.6	111	4,5	-
Icebreaker	276805000	BOTNICA	97	1998	6370	2850	8.9	0.3	134	(14-28) (17-40)	(4-10) (4-16)
	276805000	BOTNICA	97	1998	6370	2850	8	2.7	133	18,30	7,16
	265182000	ODEN	108	1989	9605	4906	8	3.4	118	10	4
CCGS-SAR	316050000	CCGS AMUNDSEN	98	1979	5910	2865	13	1.9	122	9,10	3
	316050000	CCGS AMUNDSEN	98	1979	5910	2865	10	7	119	15,22	8,12
	316122000	TERRY FOX	88	1983	4233	2113	14	0.7	136	20,25	6

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Name: Jeff W. Higdon

Agency / Organization: Qikiqtani Inuit Association

Date of Comment Submission: 08 June 2020

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1	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	General (also see comment below re: DISCUSSION)	It would be useful to see results integrated with those from other programs (if not here, then in a different report [I also note that we are still reviewing other materials and such an integrated summary may exist elsewhere already]). For example, how do the responses of tagged narwhals compare with received sound levels from the PAM data? How do observations of tagged whale distances to vessels (e.g., gap directly around vessels) compare to observations from Bruce Head? Or with CPA and behavioural data from the SBO program?	Comment noted. The various programs undertaken by Baffinland are designed to obtain a comprehensive understanding of narwhal response to vessel traffic. A Technical Memorandum entitled "Summary of Results for the 2019 Marine Mammal Monitoring Programs" was submitted to the MEWG in May 2020 and incorporated an integrated summary of the results of all the marine mammal monitoring programs. Furthermore, Baffinland will be preparing a standalone technical report that will correlate visual and acoustic data collected on narwhal during the 2019 field season. This report will be available in Q1 of 2021 and will also use data collected from the various studies (i.e. Tagging Study, Bruce Head Shore-based monitoring, PAM) to inform the overall study design and interpret the results.

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2	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	General	How are results from the tagging study being reported back to the impacted communities? For example, what types of written and graphical materials are being prepared? What opportunities do community members have to learn about results and contribute feedback?	In years when the tagging program is scheduled to occur, the overall scope of the program is presented to members of the MHTO and QIA in Pond Inlet for their review and approval. Results from the annual tagging program are presented in person to members of the MHTO and QIA – generally this occurs in Pond Inlet. The materials are presented in a customized slide deck (Power Point presentation) in a non-technical format translated in Inuktitut. The presentations are followed by a discussion with the community representatives that attend the meeting using a live interpreter. Digital and printed versions of the presentations are provided to the MHTO and QIA at the meetings. The results of the tagging study are also shared with representatives of the MHTO and QIA at bi-annual in-person and teleconference-based MEWG meetings. Digital and printed copies of the marine monitoring reports are provided to the MHTO. Digital copies of the monitoring reports are provided to QIA. These reports include a translated version of the Executive Summary in Inuktitut. We do not directly follow-up with the MHTO or the QIA as to the method(s) that their participating representatives use to further share the information provided (digital and printed versions of PowerPoint presentations and monitoring

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				reports) and inform other members of impacted communities. Fisheries and Oceans Canada (DFO) also meets separately with the MHTO to receive approval for the Tremblay tagging study. Community members are hired by DFO as Inuit researchers on the tagging program. Baffinland is unaware of how DFO and the hired Inuit researchers report back to other community members at the end each field program, or when and how DFO results from the tagging study are made available to the members of impacted communities.
3	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	General	Re: the various models, were any diagnostics used to look for collinearity among variables?	Yes, variance inflation factors (VIFs) were calculated for each model, where VIFs > 3 indicated collinearity (Zuur et al., 2010). For all models, all VIF values were <3. Zuur A.F., Ieno E.N, and Elphic C.S. 2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution 1:3–14
4	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	1.0 INTRODUCTION, p. 1	Newer sources on narwhal status and threats, such as NAMMCO's 2019 comprehensive review, could be incorporated into the Introduction.	The global narwhal abundance estimate (85,000-100,000) reported in NAMMCO (2017) has been included in section 2.1

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5	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	1.1 Overview of Narwhal tagging Program, p. 3	What is considered a "sufficient period to determine the extent to which habituation may occur"? What literature, IQ, etc. supports this estimate?	This language comes directly from PC Condition No. 109. Baffinland and Golder are not aware of the literature used by NIRB to inform development of this PC Condition. ■ 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 <u>shall continue over a sufficiently lengthy period to determine the extent to which habituation occurs</u> for narwhal, beluga, bowhead and walrus".
6	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	1.1 Overview of Narwhal tagging Program, p. 3	Re: PCC 111, how does the program contribute to the development of "clear thresholds for determining if negative impacts as a result of vessel noise are occurring?" What thresholds are being considered?	The body of knowledge collected through this study, in combination with other studies, will eventually lead to the development of revised disturbance thresholds specific to narwhal, that would replace the existing 120 db disturbance threshold (generic to all marine mammals). Ideally this work would be led by DFO and other relevant regulatory agencies, to be applied for this Project and others. However, given that research and regulatory guidance in this area is limited, Baffinland is presently evaluating these thresholds based on Proponent-led monitoring and research initiatives. In the interim,

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				we default to existing disturbance thresholds based on best available science (NOAA 2013). This approach is consistent with all other comparable projects in Canada and abroad.
7	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	2.1 Population Status and Abundance, p. 6	DFO's (and Golder's) estimates from the 2016 ES aerial survey should be added here, in addition to the 2013 estimates.	Comment noted. Content has been added to report.
8	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	2.2 Geographic and Seasonal Distribution, p. 6-7	"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". Source? Is it JPCS 2017?	Correct. JPCS 2017 citation added to report.
9	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	2.5.1 Subsurface Movements (Dive Behaviour), p. 9	"... no obvious pattern between surface time and... presence/absence of calves was observed on a study conducted by Heide-Jørgensen et al. (2001)." Sample size for females and calves was very small in this study, only 2 of 25 instrumented whales. The Heide-Jørgensen and Dietz (1995) study also used data from one of these whales (i.e., n = 1 for females with calves). Have females with dependent calves been instrumented in more recent studies, and is	Golder acknowledges that the sample size from these studies was small. Females with dependent calves were selectively not outfitted with satellite tags during the 2017/2018 tagging programs given the unknown consequences of disrupting a calves' ability to maintain an echelon position with its mother. To our knowledge, no additional literature is available on mothers tagged with dependent calves.

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			additional relevant information available in the literature?	
10	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	2.5.2 Surface Movements, p. 10	"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." How are data on these confounding effects being collected in Baffinland's monitoring programs and being incorporated into the various analyses of effects?	We acknowledge the importance of considering confounding effects such as the presence of killer whales when assessing movement patterns of tagged narwhal. However, incorporating these confounding effects into the analyses would require obtaining GPS positions of killer whales in the area during the same period that narwhal were tagged, as was done by Breed et al. (2017). This is logistically prohibitive as it is not possible to tag all predators (i.e. killer whales) whose presence within the entire spatial extent of the RSA could have influenced the movement patterns of tagged narwhal.
11	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	2.5.2 Surface Movements, p. 10	"Normal (pre-exposure) behaviour was said to resume shortly (< 1 hour) after the killer whales departed the area (Laidre et al. 2006). This observation is supported by Breed et al. (2017)…" In Breed et al. (2017), we showed that behavioural effects extended beyond predation events and persisted steadily for the entire 10 day period that the killer whales were present.	We acknowledge this and note that the remainder of the paragraph captures this point appropriately: "…who suggested that behavioral 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)."

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12	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	2.6.3 Narwhals and Vessel Noise, p. 11-12	"... however, limited information is available for cetaceans inhabiting Arctic waters and for narwhal specifically". What about relevant beluga whale literature, as the species most closely-related to narwhal?	It is acknowledged that beluga are the most closely-related species to narwhal. The sentence was included for the purpose of providing context as to the relatively limited information that exists for narwhal response to vessel traffic and associated noise. Although information on this topic is sparse, it is not non-existent, and what is known has been provided.
13	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	2.6.3 Narwhals and Vessel Noise, p. 12	"... a response would be considered 'long-duration' if it lasted up to several hours, or enough time to significantly disrupt an animal's daily routine." How long a disturbance is required to significantly disrupt a narwhal's daily routine, particularly if important behaviours such as foraging or nursing are disturbed?	The statement referenced is excerpted directly from the literature (Southall et al. 2007; Finneran et al. 2019). No distinction is provided in the literature for what would constitute a significant disruption to a daily routine, for narwhal or any species (as this is presently unknown for most species). For the purpose of developing Early Warning Indicators and action thresholds for the project, 'Long duration' is considered a response that lasts for the full duration of acoustic exposure (zone of audibility) or longer, regardless of how long that may have been. This does not necessarily represent the period at which a narwhal's daily routine would be significantly disrupted, as this is unknown for narwhal or for any marine mammal, as aforementioned.

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14	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.4.1 Narwhal GPS Data, p. 20	"In order to evaluate the spatial distribution of narwhal in the RSA, a custom R function developed by Binder et al. (2018) was used to divide the RSA into a grid of 500 x 500 m cells. For each 500 x 500 m cell, two values were then calculated..." How was land area considered in the cells that included it (i.e., coastline areas)?	Land area could not be incorporated into the function at this time. However, the function (and its outputs) does not consider density, but rather the counts of animals (or GPS positions).
15	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.4.4 AIS Data, p. 21	"To prioritize the high-resolution shore-based AIS data, satellite AIS points recorded within three minutes of a shore-based AIS data point were removed. The cut-off 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 or vice versa)…" It would be helpful to see a figure of these visual examinations as an example.	For clarity, the sentence was rewritten as follows: "Due to the higher resolution of the shore-based AIS data, the AIS data included in the analyses were primarily shore-based, with satellite data points included only where gaps in the shore-based AIS coverage were evident."
16	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.5.1 Identification of Narwhal Encounters with Vessels, p. 21-22	Event = "the 6 h time period (3 h before CPA, 3 h after CPA) associated with each narwhal-vessel encounter where the CPA <+ 3 km". Why 3 hours before/after? How sensitive are model results to different time period definitions?	The time period of 3 h was selected for visualization purposes of narwhal dive and surface movements only. The full extent of narwhal movements were incorporated into the model and were not restricted by this time period.
17	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study	3.5.1 Identification of Narwhal Encounters with Vessels, p. 22	"Ten kilometers was selected as an appropriate distance to delineate exposure vs non-exposure zones as the 120 dB re: 1 µPa (SPL_{rms}) disturbance threshold was predicted to propagate 9.82 km < R_{max} < 19.24 km from a Post-Panamax	The distance used to delineate exposure vs. non-exposure zones (i.e. 10 km) is supported by acoustic modeling conducted by JASCO (TSD #24) in which the majority of the disturbance noise field falls within 10 km of the source. Of note, the

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	DRAFT FOR MEWG.pdf")		vessel... according to acoustic modeling results…". How sensitive are the models to different definitions of exposure? For example, 15 km, which is the approximate midpoint of the range in the acoustic model results.	R95% values indicated a disturbance zone of between 5.93 and 11.20 km. Furthermore, the behavioral threshold commonly referred to in the literature is not weighted to account for the frequency range in which marine mammals are sensitive to hearing. As 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), accounting for species-specific hearing sensitivity would decrease the 10 km distance associated with the disturbance zone rather than increase it. Therefore, as stated in the report and further supported by passive acoustic monitoring undertaken in 2018, 10 km is likely an overestimate of the disturbance zone for narwhal. To assess sensitivity to different definitions, models would have to be rerun using different cut-off values, and results would have to be compared across the various cut-offs. However, as the vast majority of models indicated that effects were evident in a much shorter spatial extent than 10 km (in some cases, within only 1 km from a vessel), Golder does not agree that this analysis is needed at this time.

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18	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.5.1 Identification of Narwhal Encounters with Vessels, p. 22	Could data analyses be done using continuous distance data, i.e., narwhal behaviour as a function of vessel distance? This would let the data show when "exposure" occurred, instead of defining it a priori.	Distance was indeed modeled as a continuous variable. For each response variable, the extent of exposure was quantified. For most variables, the exposure was shown to occur at distances of ≤5 km.
19	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.5.2 Narwhal Dive Behaviour, p. 23	Re: 'time at depth', is there literature to support using the bottom 20% of the dive depth? How sensitive are results to differing definitions, e.g., 15 or 25%?	The DiveBomb algorithm, which was used to characterize individual dives, only outputs information on time at the bottom 20% of the dive depth. For the purpose of assessing foraging behaviour, Golder assumed that an extended dive, in which narwhal spent a prolonged period of time at the bottom of the dive, was a potential foraging dive. The 20% depth cut-off was deemed adequate to separate U-shaped dives (i.e. potential foraging dives in which narwhal remained at depth for an extended period) from V-shaped dives (i.e. potential avoidance dives in which narwhal spent a brief period of time at the bottom of the dive).
20	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.5.2 Narwhal Dive Behaviour, p. 24	"A 4 h window was selected as an appropriate resolution to provide sufficient data for visualization while not compromising the comparison of spatial distribution with dive behaviour." This isn't clear to me. How would a longer or shorter window compromise comparison? A 6-hour window was used for other data.	The 4 h window was used for data visualization plots only, where all data within the 4 h period were averaged, to produce a single point on the map, which reduced plot congestion. The 6 h window refers to the plots presented in Section 4.2.1, showing raw dive and both interpolated and raw GPS data for a 6 h period - 3 h before and 3 h after CPA. The two time windows and plot types are not comparable and were used for different purposes.

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21	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	3.5.2 Narwhal Dive Behaviour, p. 25	“In cases where narwhal were exposed to more than one vessel at a time, only the event involving the closer vessel was retained... Analysis of exposure to multiple vessels was performed separately…”. How might including these events in the single-vessel analysis bias the analysis and results, given that two or more vessels were actually present?	These events were not omitted from analysis, rather only the distance to the closer vessel was used. The bias would have resulted from including 2 data points for each time stamp – one for distance to the closer vessel and one for distance to the farther vessel. Since the narwhal are more likely to respond to the closer vessel, the inclusion of the data point for the farther vessel could result in a mismatch between behavioural response and vessel distance. For example, if one vessel is in close proximity (1 km) and another vessel is far (9.5 km), the response of the whale would be attributed to both, whereas it is more likely that only the closer vessel elicited the response. This would result in a false positive response estimate.
22	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	3.5.2.2 Dive Rate, p. 27	“... dive rate was calculated only for exposure and non-exposure periods.” How do diving parameters including dive rate vary with time of day, season, tidal cycle, sea state, etc?	We agree that inclusion of environmental data in the models would be a reasonable way to account for some of the remaining variability. However, the spatial extent of this study precludes the use of environmental data from a single point of collection, since environmental conditions at Bruce Head would be entirely different from those near Pond Inlet, for example. For inclusion of tidal data, tidal conditions at each narwhal GPS location would have to be estimated, extrapolated from a single-point measuring station. At this time, it is not considered practical to include either type of variable.

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23	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	3.5.2.3 Performing Bottom Dives, p. 28-29	How does the 75% of depth cutoff compare to the analysis by Watt et al? Consistent definitions would allow direct comparison of results and identification of potential shifts in foraging areas. The models don’t include tide data, which could be an important factor is diving behaviour. How can results be interpreted in regards to environmental effects on behaviour?	Watt et al. (2017) also used a 75%-100% of total depth cut-off to designate bottom dives. Therefore, the definition used in the report is in full agreement within the analysis presented in Watt et al. (2017). For comment regarding tide data, see response to comment #22.
24	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	3.5.3 Narwhal Surface Behaviour, p. 35	“In cases where narwhal were exposed to more than one vessel at a time, only the event with the nearest vessel was retained and the event with the vessels further away were omitted from the dataset.” Multiple vessel transits were analyzed separately, but excluding them from these analyses might obscure effects that would otherwise be detected. This comment is relevant to all the models.	See response to comment #21.
25	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	3.5.3.4 Seasonal Change and Horizontal Displacement, p. 38	“... potential habituation or seasonal changes…” Why not include a date/time component in all models?	Date/time was considered as a variable for all models, however following visual examination of response variables vs this potential predictor, the variable was not included in the models. Not only was there no evidence of a long-term relationship, but the scatterplots indicated highly variable spikes and drops in the relationship over time, which would be difficult to capture in the model, and which are not informative of long-term changes.

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26	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.5.4 Dive and Surface Behaviour During Exposure to Multiple Vessels, p. 40-42	"... subset of the dive and surface behaviour analyses detailed above were selected and repeated with an additional predictor variable of number of vessels present within the 10 km exposure zone. The analyses selected were those where the effect of distance to vessel was statistically significant." Restricting the analyses this way potentially misses situations where an effect of multiple vessels was significant. A non-significant effect from single-vessel transits could be significant with 2 or more vessels.	We disagree with this comment. The main analyses included all data from all exposure events, but only included the distance to the closer vessel when more than one vessel was present within 10 km. It is not likely that narwhal response would not be captured due to removal of only the farther vessel data.
27	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	3.5.4 Dive and Surface Behaviour During Exposure to Multiple Vessels, p. 40-42	"The effect of multiple vessel presence on narwhal dive and surface behaviour was modelled by including the following two predictor values - 1) the number of vessels present within 10 km from the narwhal (as a categorical variable), and 2) distance from the nearest vessel." Why not just include that categorical variable in all the models?	The main question of interest was the overall effect of shipping on narwhal behaviour. The main analysis therefore focused on the effect of distance from the nearest vessel. The question of the effect of multiple vessels was secondary, and was examined in a separate set of analyses. The number of cases with multiple vessels was very small relative to the size of the full dataset, and it was deemed that the effect of multiple vessels would be better understood if exposure-only data were analyzed for that component.
28	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.1.2 Narwhal GPS Location Data, Figures 4-2 to 4-5	It would be useful to have sample sizes labeled for each 2-week map.	Figures have been amended to display number of narwhal in each panel.

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29	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.1.4 Vessel Traffic, p. 55	Other vessel types (passenger vessels, CCG, fishing vessels) were recorded on 39 and 45 days. Were there many fishing vessels in the RSA?	There was a total of two fishing vessels recorded in the RSA: INUKSUK 1 and SIVULLIQ – both medium-sized fishing vessel, recorded in 2017.
30	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2 Narwhal Interactions with Vessel Traffic, p. 59	Figure 4.3 shows exposure events in Navy Board Inlet, are these sealift vessels or tankers?	Neither – these were events associated with two non-Project vessels – a passenger vessel (OCEAN ENDEAVOUR) and a government icebreaker (TERRY FOX).
31	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events), p. 60	"Paired vessel transits were not included in the main analyses. Instead, effects of paired vessel transits on narwhal behaviour are assessed in Section 4.2.4." As previously noted, the exclusion of the other vessels from the primary analyses could obscure response effects.	See response to comment #21.
32	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events), Figures 4-14 to 4-39	In these figures (Figures 4-14 to 4-39), it would be useful to note which vessels are non-Project vessels, particularly in cases where vessel speed limitations are being exceeded (see following comments).	Text was added to each figure caption to detail whether the vessel was Project-related or not.

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33	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events), Figures 4-14 to 4-39	Is the BBC VOLGA (General Cargo) a Project-vessel? There are multiple instances of this vessel being non-compliant with the required speed limits (Figure 4-14 - 13.9 knots, Figure 4-19 - 12 knots, Figure 4-20 - 13.7 knots, Figure 4-35 - 12.7 knots).	Yes, the BBC Volga is a Project-related vessel. For clarity, once fuel or freight vessel discharge their cargo at Milne Port, they are no longer under contract to Baffinland, and therefore no longer required to comply with Baffinland imposed speed restrictions. No federally regulated speed restrictions exist within these waters that the vessels would otherwise be required to follow. In light of this, the only non-compliance event for the BBC Volga shown in this report is on Figure 4-19. Figure 4-14 shows the BBC Volga travelling at 13.9 knots, Northbound through Milne Inlet – i.e. no longer under contract to Baffinland. Figure 4-20 shows the BBC Volga travelling at 13.7 knots, Northbound through Milne Inlet – i.e. no longer under contract to Baffinland. Figure 4-35 shows the BBC Volga travelling at 12.7 knots, Northbound through Milne Inlet – i.e. no longer under contract to Baffinland.
34	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events), Figures 4-14 to 4-39	These figures show that vessels from the Desgagnés group are consistently non-compliant with vessel speed limits (e.g., Figure 4-18, Figure 4-23, Figure 4-34). There appears to be a company-specific issue with non-compliance. What is Baffinland doing to address this?	For clarity, once fuel or freight vessel discharge their cargo at Milne Port, they are no longer under contract to Baffinland, and therefore no longer required to comply with Baffinland imposed speed restrictions. However, Baffinland acknowledges that non-compliance events with respect to the Desgagnés group of vessels did occur in some instances

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				while the vessels were Southbound (i.e. heading to Milne Port). No federally regulated speed restrictions exist within these waters that the vessels would otherwise be required to follow. As has been previously communicated to the MEWG, Baffinland being the only operator in the area to impose this, did result in a 'learning curve' for vessels under contract to Baffinland that frequently travel in the RSA, as past voyages (i.e. for other customers) did not require speed restrictions to be applied. To address this, Baffinland has been working consistently with the vessel owners and operators to communicate requirements. In light of these efforts, in 2019, fuel tankers were compliant with the 9 knot speed restriction 98.2% of the time and under 10 knots for 99.4% of the time. Baffinland expects the rate of compliance to continue to improve in future years.
35	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events), Figures 4-14 to 4-39	Is the CG MAPLE Buoy-Laying Vessel employed by Baffinland? It was also non-compliant with speed limits (e.g., Figure 4-31, speed at CPA = 12.1 knots).	Yes, The CG MAPLE was contracted by Baffinland.

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36	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	4.2.1 Close Encounters with Large and Medium Sized Vessels (CPA Events), Figures 4-14 to 4-39	Why are bathymetric data missing from some plots? There should be data available for southern Milne and Koluktoo Bay?	Bathymetric data are missing from the plots when no GPS data were available for >20 minutes from the last raw GPS point, as detailed in the footnotes for the plots – “Left panels depict dive depths (colour-coded as function of time) and bathymetry within 20 min from GPS position.”
37	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	4.2.2.1 Surface Time, p. 90	“... the model explained approximately 45% of the variability in surfacing probability, and the random effects did not account for much of the explained variability.” It could be useful to include more environmental data (tides, wind/sea state) as available (tide data, wind speed from Bruce Head weather station, etc.).	See Comment #22
38	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	4.2.2.3 Performing Bottom Dives, p. 96	“... narwhal conducted bottom dives throughout Milne Inlet, Tremblay Sound, Eclipse Sound, and neighboring water bodies, suggested that deep water foraging occurs throughout the Eclipse Sound summering ground (Figure 4-48).” How do these finding compare with Watt’s work on foraging areas based on diving data?	Our findings are consistent with those reported by Watt et al. (2015, 2017), in that they both confirm that deep water foraging by narwhal occurs throughout Eclipse Sound. Text in section 4.2.2.3 of the report has been updated to reflect this.
39	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	4.2.2.3 Performing Bottom Dives, p. 96	“The effect of substratum was statistically significant, suggesting that bottom diving differed between substrata regardless of vessel presence or absence.” These findings could be integrated with other data available on oceanography, fisheries, etc.	See response to comment #22.

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40	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.2.3 Performing Bottom Dives, p. 101	"... these results suggest that narwhal potentially engaged in foraging may cease sequential bottom dives when within 5 km of a transiting vessel." It is important to link these findings to other monitoring programs (e.g., PAM data), and discuss with respect to fitness consequences.	Due to the intermittent nature of vessel exposure and the relatively short duration associated with individuals being within 5 km of a vessel (i.e. 36 min per vessel transit), no potential consequences to narwhal fitness are expected as a result of a reduced bottom diving activity.
41	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.2.3 Performing Bottom Dives, p. 101	"It is important to note that bottom dive data within the 10 km exposure zone were limited, resulting in high uncertainty when relating bottom dive behaviour to distance from vessels. Further investigation is required to better characterize behavioural response and confirm rejection of the null hypothesis." What does Baffinland propose for further investigation?	To obtain additional data within the exposure zone, more narwhal would have to be tagged. However, in 2019, the tagging program was suspended. Should the collaborative tagging program with DFO resume in the future, Baffinland hopes to continue tagging efforts with one of the primary objectives being to increase the sample size of narwhal that may be incorporated into this analysis.
42	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.2.4 Time at Depth, p. 107	"However, the finding that narwhal spend less time at depth within 2 km from a vessel is based only on the smoothing trend curve and model-estimated effect size, which were not statistically significant due to insufficient power." Effects that are not statistically significant can still be biologically significant. What are the potential fitness consequences of a reduction in time at depth?	It is acknowledged that effects can still be biologically significant even if not statistically significant. It is also possible for statistically significant effects to be biologically negligible. These are fundamentals of biostatistics, and have been considered in the study design. Based on the intermittent nature of vessel exposure and the relatively short duration associated with individuals being within 2 km of a vessel (i.e. 14 min per vessel transit), no potential consequences to narwhal fitness are expected as a result of a reduced time at depth.

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43	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.2.5 Dive Duration, p. 112	"Results suggest that narwhal potentially engaged in foraging may experience disturbance effects within < 1 km of a transiting vessel." As noted above, what are the potential fitness consequences of these disturbances?	Due to the intermittent nature of vessel exposure and the relatively short duration associated with individuals being within 1 km of a vessel (i.e. 7 min per vessel transit), no potential consequences to narwhal fitness are expected as a result of a reduced dive duration.
44	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.3.2 Travel Orientation Relative to Vessels, p. 123	"... results suggest that narwhal orient themselves away from transiting vessels, potentially demonstrating avoidance, within 4-5 km of a transiting vessel prior to the CPA, but for the full extent of 10 km post CPA." What potential explanations are there for this difference? For example, does it vary depending on whether a vessel is in-bound or out-bound?	Once a narwhal turns away from a vessel, it may be expected that the narwhal will maintain its direction. That is, the narwhal may move away from the vessel, and maintain their direction (as shown in Section 4.2.3.1), which would result in a longer time series of narwhal heading away from the vessel.
45	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.3.5 Habitat Re-Occupation, p. 132	"... may have exhibited marginal seasonal habituation to shipping activities..." How does Baffinland propose to continue monitoring habituation throughout the RSA in the future, given that no tagging work is being done at present and this was a key prediction in the FEIS?	Baffinland is hopeful that the narwhal tagging program will resume in the future given it offers the most reliable data for evaluating narwhal behavioral responses to shipping. In the interim, Baffinland's other ongoing marine mammal monitoring programs will assist in future evaluation of potential narwhal habitation to shipping noise. In addition, Baffinland will continue to work with the MEWG in developing and enhancing our monitoring programs to address this monitoring objective.

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46	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.3.6 Travel Speed, p. 133-136	How does the mean and range of travel speeds here compare with results from the literature?	Narwhal swimming speeds reported in the literature range from 0.64 m/s to 2.36 m/s (Dietz and Heide Jorgensen 1995, Heide Jorgensen and Dietz 1995, Laidre et al. 2002, Laidre et al. 2003, Williams and Noren 2011). Text in section 4.2.3.6 of report has been updated to reflect this.
47	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.4.1 Surface Time, p. 139 (also 4.2.4.3 Dive Duration)	"However, since the effect of single vessel passage on surface time was only evident within 1 km from narwhal (Section 4.2.2.1), it is likely that the definition of multiple vessel passages as the number of vessels within the overall 10 km exposure zone is not sufficiently focused. Further restriction of the definition of multiple vessel passage may be possible in the future, should additional narwhal tagging data be collected in close proximity to vessels." How can this be improved in the future? What information from other monitoring programs, and from IQ, can contribute?	As stated in the quoted sentence, future analyses should further restrict the spatial extent of a multiple-vessel exposure. At present, if a vessel is present at 0.5 km and another at 9.9 km, the data point is considered to have multiple vessels. This results in high variability, since the effect from the farther vessel is likely completely obscured by the very-near vessel. Narwhal behaviour in this case would be very different from when two vessels are at 1 km distance, for example. A restriction of the distance to the farther vessel would help focus the dataset and clarify patterns.
48	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.4.2 Performing Bottom Dives, p. 140	"The effect of whether there was a single vessel within the exposure zone of two or more vessels was not significant…" How could there be a single vessel in the exposure zone of two or more vessels? By definition wouldn't there be more than a single vessel?	This is a typo as "of" should have read "or": "The effect of whether there was a single vessel within the exposure zone or two or more vessels was not significant…" Text in section 4.2.4.2. has been updated accordingly.

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49	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	4.2.4.3 Dive Duration, p. 143 (and other sections as relevant, e.g. 4.2.4.5)	What are the potential biological consequences of reduced dive duration, increased changes to orientation, etc. for narwhals? How will these biological effects be monitored and mitigated if necessary? What role can these monitoring results play in the development of Early Warning Indicators?	One of the primary objectives in assessing narwhal dive behavior in relation to vessel traffic was to inform whether foraging activity may be interrupted in the presence of transiting vessels. Should critical life functions such as foraging be interrupted as a result of vessel exposure, there is potential that narwhal may experience long term consequences such as reduced fitness. However, due to the intermittent nature of vessel exposure and the relatively short duration associated with individuals being within the zone predicted to cause disturbance (i.e. < 5 km), narwhal are not expected to be significantly affected by vessel exposure. See also response to Comment No. 43. Ongoing monitoring of narwhal response to vessel traffic will continue through Baffinland's Bruce Head Shore-based monitoring program and through the aerial survey program.
50	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file "2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf")	5.0 DISCUSSION, p. 149-150	As noted above, it would be useful to see additional comparisons with and discussions of other monitoring programs, and a greater integration of monitoring results. All the different programs are complimentary and should be considered as a whole with respect to results and how they can feed into adaptive management and mitigation.	See response to comment #1.

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51	2017-2018 Integrated Narwhal Tagging Study - Technical Data Report (PDF file “2017_2018 Integrated Narwhal Tagging Study DRAFT FOR MEWG.pdf”)	6.0 SUMMARY OF KEY FINDINGS, p. 150-155	A summary table would help.	Based on the context required to discuss each response variable, Golder determined the current format (i.e. bullet points summarizing each key finding) to be most appropriate.

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