# Cruise Report: R/V *Dana*
# 21 August – 17 September 2020

The Arctic Observing Network: Renewing Observations at the Davis Strait Gateway

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## ABSTRACT

Oceanic freshwater and heat exchange between the Arctic and North Atlantic provide critical mechanisms through which the Arctic and global climate interact. Arctic fresh water, from riverine input and melting sea ice, flows southward through the Arctic Gateways to the west (Davis Strait) and east (Fram Strait) of Greenland into the regions of the subpolar North Atlantic where the waters that occupy the deep ocean interior are formed. At these sites, strong wintertime storms cool the upper ocean, making these waters dense enough to cause them to sink to depth, effectively communicating this atmospheric forcing into the ocean interior and driving the equator-to-pole transport of heat. Fresh, buoyant Arctic outflow reduces the density of surface waters in these deepwater formation regions, and thus has the potential to slow the sinking and modulate equator-to-pole heat transport. Changes in Arctic outflow also impact broad North Atlantic circulation patterns and circulation off the Labrador coast, with wide-ranging impacts to ecosystems. Conversely, the northward flow of relatively warm Atlantic waters can supply oceanic heat to melt Greenlandic glaciers where they encounter the ocean, thus accelerating the melting of Greenland ice cap. Uncertainty surrounding the role of oceanic heat in accelerating the melt of Greenland's glaciers is one of the largest sources of uncertainty in numerical predictions of future sea level rise. The critical role of Arctic-subpolar heat and freshwater exchange motivates renewed efforts to maintain sustained, persistent, measurements across Davis Strait, capturing exchange between the Arctic and subpolar North Atlantic (Labrador Sea) at a choke point at the southern end of Baffin Bay.

This project renews the integrated observational program at Davis Strait, delivering data to the community and matching ongoing collections at Bering Strait, Utqiagvik, Alaska, and Fram Strait to extend the time series of concurrent measurements across the major Arctic Gateways. The extended timeseries will document changes in freshwater and heat fluxes, and will be combined with numerical modeling to investigate the processes that control variability in the strait and the potential impacts. The backbone system relies on the tested combination of moorings instrumented with sensors to measure ice thickness and motion, ocean currents, temperature and salinity, and biennial ship-based sampling of chemical and biological properties that have successfully delivered core measurements for the past decade. Bottom pressure sensors augment the system to quantify sea surface height gradients, which will support investigations of the primary forcing mechanisms. Integrated marine ecosystem observing includes biogeochemical and marine mammal passive acoustic measurements augmented with tracking of key fish species, and zooplankton and phytoplankton observations. These observations will launch the Davis Strait/Baffin Bay Distributed Biological Observatory (DBO) in Davis Strait, complementing the developing Atlantic DBO that includes transect lines in Fram Strait and Barents Sea, and the existing Pacific DBO in the northern Bering, Chukchi, and Beaufort seas.

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## 1. SCIENCE BACKGROUND

The Arctic freshwater cycle is a longstanding framework for efforts to quantify and understand Arctic change due to its important role in modulating the Arctic energy balance and, further afield, global climate (e.g. *Prowse et al*., 2015; *Carmack et al*., 2016). Freshwater enters the Arctic upper ocean primarily through river discharge, Bering Strait inflow and net precipitation, with the majority exiting about equally though the Canadian Arctic Archipelago (CAA) and Fram Strait (*Serreze et al*., 2006; *Haine et al*., 2015). Because salinity controls Arctic Ocean stratification, this freshwater creates a cold, buoyant layer below the ice-ocean interface that insulates the surface from the warmer, more saline Atlantic waters below, thus modulating sea ice formation and melt and, through this, coupling between the upper ocean and local atmospheric forcing. Freshwater and heat exchange between the Arctic and North Atlantic provide critical mechanisms through which the Arctic and global climate interact. Arctic freshwater discharges through Davis and Fram straits near deepwater formation regions west and east of Greenland, where its buoyancy may act to modulate convective overturning and deepwater formation (e.g., *Karcher et al*., 2005; *Jahn and Holland*, 2013, *Yang et al*., 2016). Changes in Arctic freshwater outflow also modulate the extent and strength of the North Atlantic subpolar gyre, which can have profound impacts on fisheries (*Hatun et al*., 2009), nutrient flux (*Hatun et al*., 2017) and on carbon uptake and storage (*Schuster and Watson*, 2007) in this highly productive region. Additionally, northward penetration of warm Atlantic waters along the Greenland coast may accelerate the melting of marine terminating glaciers (e.g., *Holland et al*., 2008; *Straneo and Heimbach*, 2013; *Myers and Ribergaard*, 2013; *Gladish et al*., 2015), injecting additional fresh water into the system and contributing to sea level rise.

Davis Strait (**Fig. 1**) provides a single site for quantifying both CAA outflow and northward fluxes along the West Greenland slope and shelf that may impact land ice melt. The CAA component of Arctic outflow enters Baffin Bay though four distinct passages (Bellot Strait, Barrow Strait, Hell Gate/Cardigan Strait, and Nares Strait), undergoing numerous transformations along its transit to Davis Strait. By the time they reach Davis Strait, Arctic waters already embody most of the transformation they undergo prior to exerting their influence on the deepwater formation sites in the Labrador Sea. This makes the Strait an ideal site to quantify the variability and structure of the integrated CAA freshwater flux after it has undergone these complex transformations (*Azetsu-Scott et al*., 2012), and just prior to entering the Labrador Sea. Sustained observations at Davis Strait also provide early detection of corrosive Arctic outflow into the subpolar North Atlantic, where it may impact highly productive regions and important commercial fisheries; observations document changes in these chemical states and the marine ecosystem response to ocean acidification (*Azetsu-Scott et al*., 2010; *Hammill et al*., 2018).

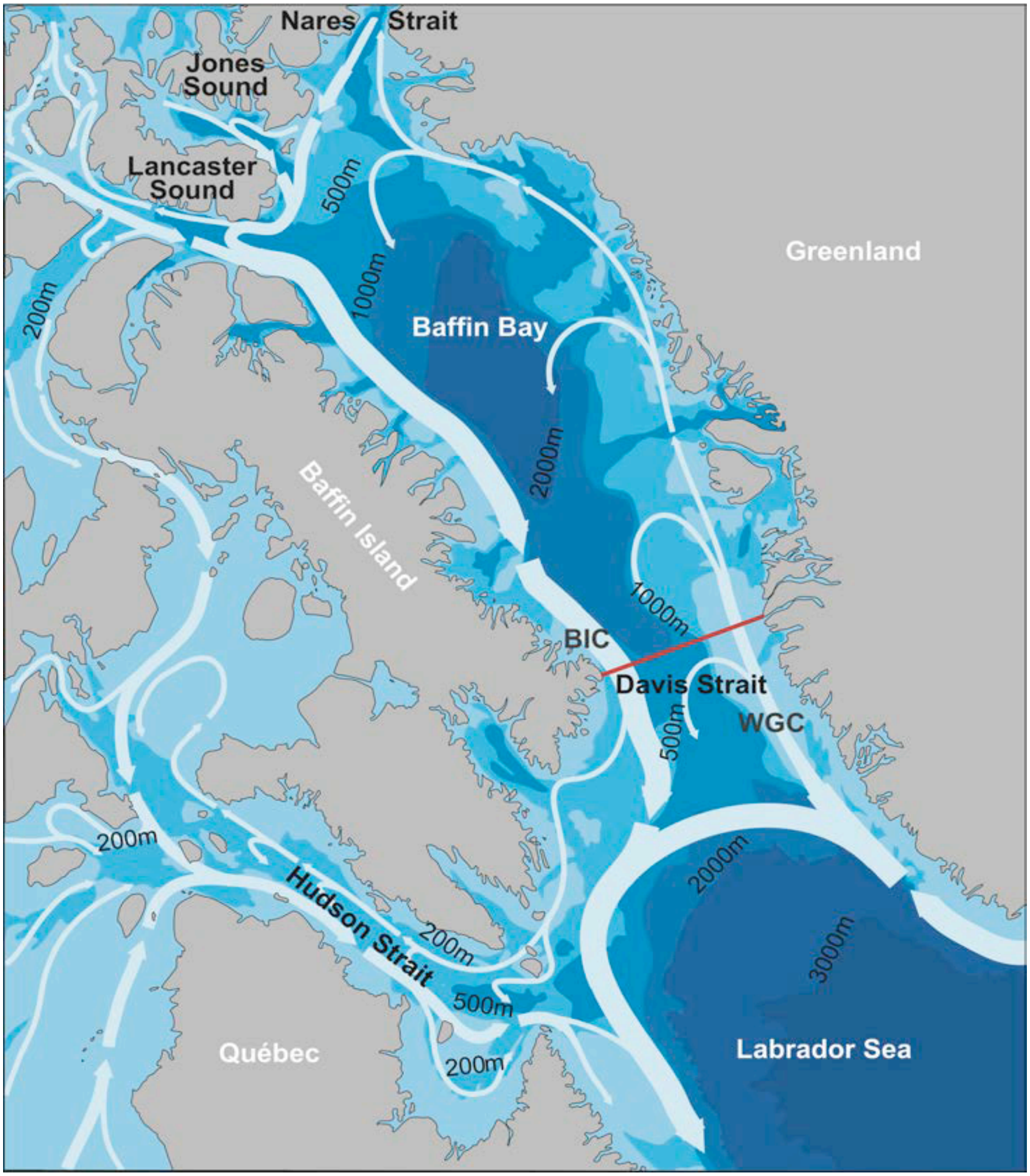


***Figure 1.*** *General circulation in Baffin Bay and Davis Strait (white arrows) and the location of the Davis Strait moored array (red line). AW, by way of the CAA, leaves Davis Strait as the broad, surface-intensified BIC. Northward flow on the eastern side of Davis Strait consists of the fresh WGC of Arctic origin on the shelf and warm, salty WGSC of North Atlantic origin on the slope. From Curry et al. (2014).*

## 2. DAVIS STRAIT ARCTIC GATEWAY OBSERVING SYSTEM

The Davis Strait observing system was established in 2004 to advance understanding of the role of Arctic – sub-Arctic interactions in the climate system by collecting sustained measurements of physical, chemical, and biological variability at one of the primary gateways that connect the Arctic and subpolar oceans. Efforts began as a collaboration between researchers at the University of Washington's Applied Physics Laboratory and Department of Fisheries and Oceans, Canada at Bedford Institute of Oceanography, but has grown to include researchers from the Greenland Institute of Natural Resources, Greenland Climate Institute, Technical University of Denmark, National Oceanography Centre, UK, the Swiss Federal Institute of Technology, Oregon State University, University of Alberta, and University of Colorado, Boulder. The project is a component of the NSF Arctic Observing and Atlantic Meridional Overturning Networks, and the international Arctic-Subarctic Ocean Flux (ASOF) program, Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP), Global Ocean Acidification Observing Network (GOA-ON), Synoptic Arctic Survey (SAS), Arctic Monitoring Assessment Programme (AMAP), and OceanSITES system.

The observing system employs an array of 12 moorings across Davis Strait, deployed at the locations occupied by the previous arrays (**Figs. 2** and **3**). The mooring array provides estimates of mass, heat, freshwater and ice transports, and marine mammal presence. Bottom pressure recorders deployed along the western and eastern flanks of Davis Strait and in northern Baffin Bay augment the mooring array by providing estimates of barotropic transport through the Strait, constraining interpretation of remotely sensed altimetry and gravity measurements and allowing an investigation of how sea surface height differences between the Arctic and Baffin Bay modulate exchange through Davis Strait. An extensive program of biennial chemical sampling in Davis Strait, northern Labrador Sea, and southern Baffin Bay (**Fig. 2**) quantifies changes in nutrient loads, carbon transport, and acidification, while also providing data for distinguishing freshwater constituents in the Davis outflow. These biogeochemical signals integrate changes in the large-scale circulation (e.g., the ratio of Pacific to Atlantic waters, carbon transport, and pH changes). The new system includes a significantly expanded suite of biological and biogeochemical measurements, including dissolved organic matter (DOM), particulate organic carbon (POC), chlorophyll, zooplankton biomass and community structure, phytoplankton productivity, fish larvae and census (from the Canadian Ocean Tracking Network), seabird observations, and marine mammal presence.

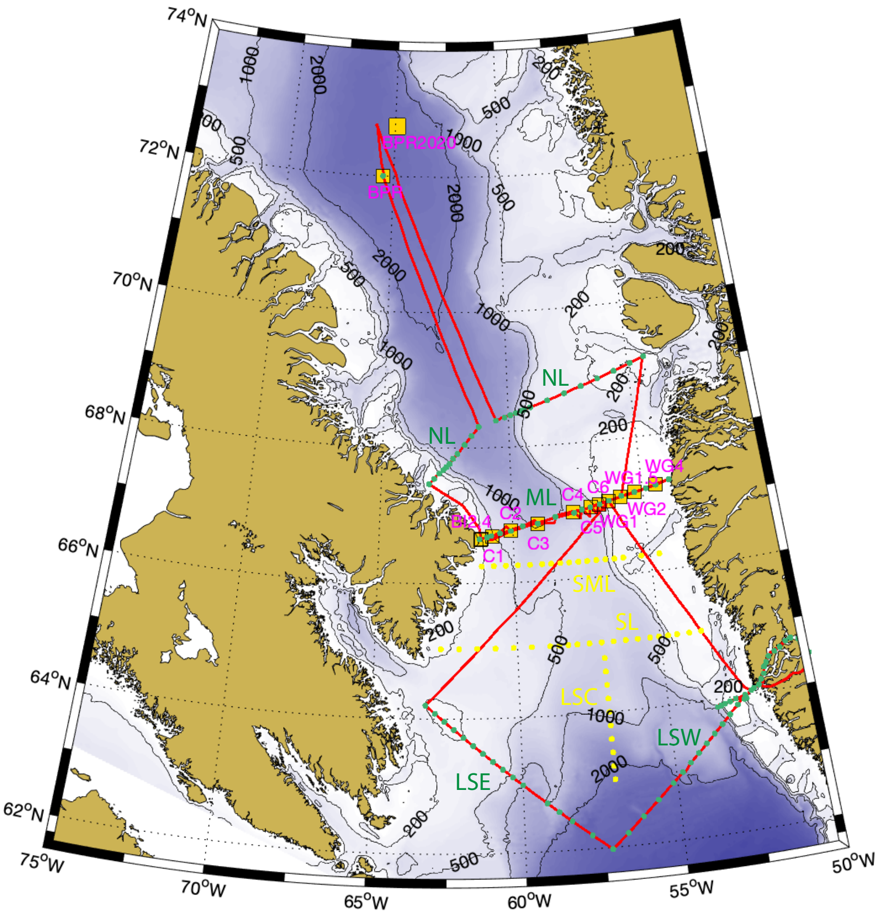


***Figure 2.*** *Davis Strait mooring sites (orange squares), and standard hydrographic sampling sections: Northern Line (NL), Mooring Line (ML), Labrador Sea West (LSW), Labrador Sea Central (LSC) and Labrador Sea East (LSE). Yellow and green dots mark CTD stations, with green dots indicating those sampled during the 2022 field program. Two previously sampled sections, the South Mooring Line (SML) and Southern Line (SL), are no longer regularly occupied.*

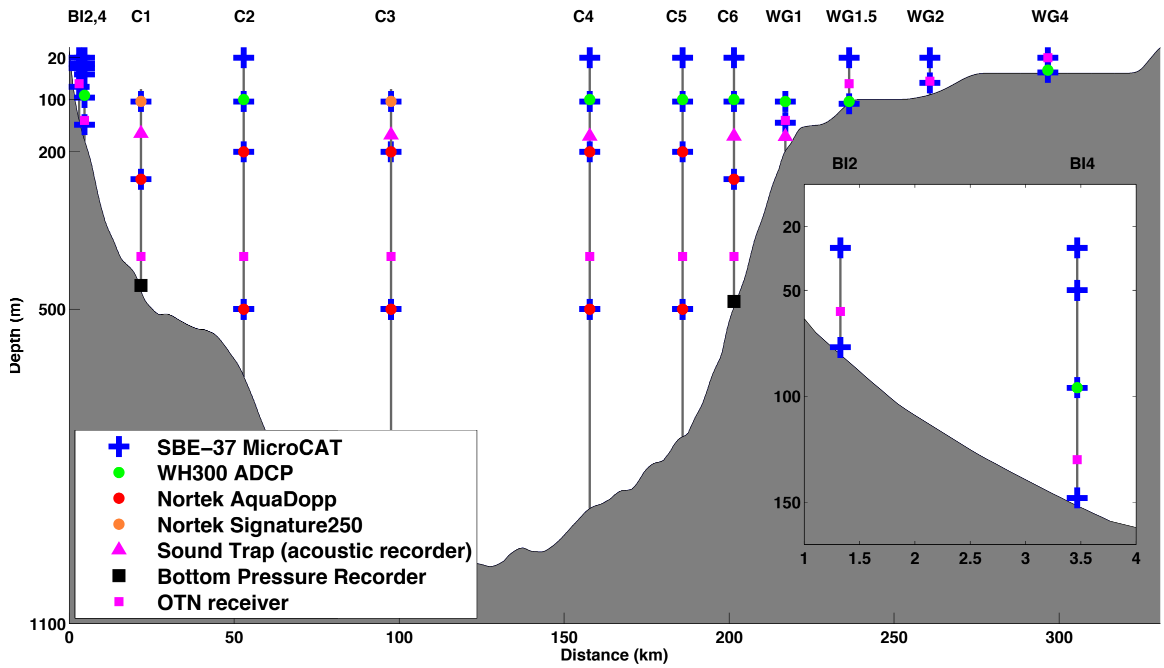


***Figure 3****. The Davis Strait mooring array. Nortek Signature 250-kHz 5-beam Doppler current profilers (water velocity profile, ice velocity, and ice draft) replace the WH300 ADCPs and IPS ice sonars previously deployed at C2 and C3. NORTEK AquaDopps replace the RCM11 current meters previously used for deeper current measurements.*

## 3. CRUISE NARRATIVE

Times in UTC unless otherwise noted.

*18 August*

Begin loadout. Prepare instruments and set up lab.

*20 August*

DTU science team arrives. Loadout complete.

*21 August*

Depart Hirtshals, Denmark 15:00L. Windy with some rain, weather and seas build through the evening. Local time UTC+2.

*22 August*

30+ knot winds and 3-m seas make for a slow transit toward the North Sea. Calming by evening. Local time set to UTC+1.

*23 August*

Winds and seas continue to decrease. Forecast shows strong winds off the southern tip of Greenland to begin around Friday, as we pass through the area. In an attempt to avoid this, the Captain brings an extra engine online, increasing SOG from 11 kts to 14 kts. This should allow us to slip past Cape Farewell before the storm's arrival. Local time set to UTC.

*24 August*

Sunny and calm. Numerous whale sightings through the afternoon and evening. Local time set to UTC-1.

*25 August*

Sunny and calm. Local time set to UTC-2.

*26 August*

Sunny and calm.

*27 August*

Encounter German R/V *Maria S. Merian* after we pass Cape Farewell. German team is about to turn south (directly into the low pressure system) to occupy a CTD line.

*28 August*

Final day of transit to Nuuk. Test CTD cast to 2500 m provides a trial run for water sampling, allows for inspection of the damaged sections of cabl,e and enables respooling and level-winding under tension. Damage: 1250-m kink and broken strand of outer armor; 1420-m kink with some birds nesting that (mostly) closes under tension; 1470-m kink and broken strand of outer armor. Wrap area around broken strands in self vulcanizing tape to restraint the wires from continuing to unwind and making a mess.

*29 August*

Arrive outside of Nuuk fjord at 06:00L. Docked by 07:00L. Load Thomas, Caroline, and Else and back underway by 10:00L. Dockside testing of the 'angel wing' davit stressed the CTD termination to failure, forcing re-termination and reworking of strain relief. Large, long-period swell coming from the north makes transit a bit bumpy. Target is WG18 (the easternmost ML CTD station) for a 05:00 cast (tomorrow) to reduce backtracking for CTD work. Poor visibility overnight slows the transit.

*30 August*

Low winds and relatively calm seas, but foggy much of the day. Arrive at ML18 at ~05:45L and complete the cast prior to moving onward to deploy WG4. A combination of the ship's echosounder reading 4 m deep and a malfunctioning CTD altimeter results in the CTD striking the bottom, though fortunately at a slow descent speed. Eik is working to repair the altimeter before we begin this evening's CTD work.

Deploy moorings WG4, WG2, WG1.5, WG1, and C6, all from the port quarter. Mooring work goes smoothly, despite the tight work space and unconventional rigging.

Starting at C6 makes nighttime occupation of the eastern end of the ML line impractical, as round-trip transit time would consume most of the night. We instead choose to focus on the shelf break, aiming to occupy ML12 – ML15 overnight. We will occupy ML16–17 on the return from the BPR site and Northern Line.

We discover that a failed handoff within DTU resulted in the MSR clearance request for Canada not being filed. The Captain is working with DTU administration to expedite a new request, hoping that the Canadian government will be willing to act quickly to review and grant MSR clearance.

*31 August*

Deploy C5 and C4, ending at 15:30L. As C4 is the last mooring site in Greenlandic waters and we have not yet received Canadian clearance, we halt mooring operations and finish occupying ML11, ML10, and ML09.

*1 September*

No word on Canadian clearance after completing ML11, ML10, and ML09. To keep operations moving forward, we depart for the eastern end of the Northern CTD Line, where we can continue working the half of the sampling program planned for the Greenlandic EEZ.

Mid-afternoon (14:00L) we receive word that Canadian MSR clearance has been granted. At this point, we're six hours into our transit north. Turning around to resume mooring operations would result in over half a day of lost time, and we thus continue to NL25, the eastern end of the Northern Line.

Going forward the plan is: (i) complete Northern Line, (ii) BPR, (iii) finish mooring deployments, working east (C3) to west (BI1), (iii) ML16, ML17, (iv) Labradort Sea lines.

*2 September*

Learn that Canadian clearance has not been granted; yesterday's notification was premature.

Arrive at NL25 a bit after midnight and begin CTD operations. NL25 – NL23 overnight. Add nets to NL17 (the first NL station within the Canadian EEZ), but have not received clearance to enter the Canadian EEZ by the time we complete NL18. To make productive use of time, we repeat NL18 with full biological sampling as a stand-in for NL17, hoping for progress on the clearance request by the next morning.

*3 September*

Timeline for the clearance decision remains uncertain. Use the time to make the transit to the BPR site. Initially target the original site, which sits inside the Canadian EEZ, but switch to an alternative site in the Greenlandic EEZ (72° 45’ N, 64° 50’ W) when it becomes clear that clearance will not be granted in time.

*4 September*

Arrive at (relocated) BPR site at 09:00. Deploy BPR and survey anchor location. Conduct CTD cast with full chemical and biological sampling.

Work through the day with DTU and officials at the Danish embassy in Ottawa to secure MSR clearance for Canadian waters. Ultimately, we are offered clearance for work within the EEZ, but outside the 12 NM territorial limit, with the promise that they will continue to pursue permission to work further inshore. This precludes deploying the two Baffin moorings and occupying the westernmost CTD stations, but will allow us to complete the rest of our work. We receive official clearance in the evening, as we are finishing the final net tows at the BPR site.

The longer timeframe for permission to work within 12 NM of the coast is COVID-related, driven by concerns within the Nunavut government that a close approach might expose local communities to infection. The Nunavut government is part of the decision-making process for MSR clearances, and asked for time to review the request at their monthly meeting. We must thus wait until their regularly-scheduled meeting for them to take up our request.

To protect against the likelihood that we fail to secure permission for a close approach, we begin arranging for alternative paths for deployment.

*5 September*

Return to the Northern Line and resume sampling, working westward from NL17.

Lube from the CTD wire is sheeting off in clumps, some of which are landing on the CTD cage and on the bottles. No obvious contamination of bottle interiors, but will need to inspect carefully when time allows. Cable was lubed with copious amounts viscous, clumping, clingy goo during spooling. There is no practical way to strip this at sea.

*6 September*

Winds and sea picking up. Shift biological station from ML11 to ML12 to move it earlier in the day, before seas have a chance to build further.

Around 22:00L CTD communications fail. We trace this to a failed splice in the termination connecting cable, but also find birdcaging of wire just inboard of the strain relief. Two of the bolts that attach the yoke to the CTD frame have also failed, such that the entire frame has been suspended from the remaining two bolts and the deformed metal yoke. We replace the failed connecting cable, reterminate the CTD cable and rebuild the strain relief, bend the yoke back into shape and bolt it back to the frame.

*7 September*

CTD operations halted during early morning hours due to safety concerns driven by worsening sea state. Ship motion is amplified when working off the port quarter, and people are exposed when sampling the rosette, limiting the range of safe operating conditions.

Resume Northern Line CTD operations early morning. Growing concern over shedding of cable lube onto the CTD frame and bottle.

*8 September*

Finish Northern Line stations (with the exception of NL01, which is inside the 12-NM exclusion zone, and begin transit for ML17.

*9 September*

Finish the eastern end of the Mooring Line (ML17, ML16), followed by transit to C3 to resume mooring deployments. Reterminate CTD in transit due to damage incurred on deck.

Deploy C3 before shifting to CTD sampling for the night. CTD fails on first cast (ML03). Failure appears to be a short in the cable that persists after cutting off the 50 m closest to the CTD, suggesting issues in the damaged sections 1200-m in, or issues with the slip ring assembly. Troubleshooting will take significant time, so we switch to the small rosette (12 5-L bottles), which also has a bad termination. Generate a sampling schedule to ensure sufficient water collection, requiring three casts per station. Continue CTD work through the night, occupying ML03 and ML04.

*10 September*

Winds have eased and seas flattened.

Deploy C2 late morning, followed by C1 in early afternoon. Both deployments go smoothly.

Transit to ML08 while spooling CTD wire off the winch for the large rosette. This allows detailed check of cable and slip ring. Cable gives rapidly fluctuating readings that suggest a short, but are difficult to diagnose. Slip ring looks OK. Cable also shows damage in wraps closer to the drum, making it likely that we'd need to cut and discard a much larger span, likely leaving us with something significantly shorter than the 1800-m cable on the winch for the small rosette. Thus decide to spool the small-rosette cable onto the large rosette winch, reterminate and finish out the cruise with that cable and the large rosette. Going forward, we will be unable to use the small rosette again unless we take the time to localize the damaged section of the long cable, remove it and wind the remaining cable onto the small winch.

The CTD remains non-functional after transferring the shorter cable to the large rosette winch. Wire and terminations seem solid, but slip ring termination is suspect. Servicing this requires unspooling the cable, which is accomplished overnight.

*11 September*

CTD problem does not appear to be slip ring termination. Swap SBE9's between small and large rosette, which seems to make the large rosette work.

Respooling of the 1800-m shot onto the small winch goes poorly. Wire was spooled onto trawl winch with uneven tension, such that it is tangled on the drum. This complicates respooling and consumes significant time.

CTD still faults when plumbed to the 1800-m wire. Wire shows no shorts, and terminations appear good. Try replacing deck cable with a jury-rigged wire from winch to deck box. This appears to solve the problem, and allows both SBE9s to run.

In the process of rebuilding the frame, sensors are added one at a time. The PAR sensor causes the CTD to fault, and inspection reveals the bulkhead connector is loose. Disassembly reveals that the sensor head was also pushed in. Eik believes that this resulted from the sensor cap being accidentally left on for a cast. Unsure if this makes sense. Regardless, the faulty PAR sensor appears to be the root of the CTD issues, perhaps drawing enough power that the system exhibited heightened sensitivity to other, previously non-fatal, flaws in cabling.

Finish ML stations and transit to LSW01.

*12 September*

Forecast predicts a strong weather system coming up from the south, with seas building to 4-6 m and short period waves, by late Monday night/early Tuesday. Conditions in the Labrador Sea sampling regions are predicted to exceed R/V *Dana's* ability to conduct CTD operations. We thus plan a subsampled LSW line (every other shelf site, all sites on the slopes, every other central basin site), aiming to complete the line by Monday afternoon. This makes best use of our remaining good weather (more time sampling, less time steaming) and provides a decent occupation of the western region. The eastern half, especially the area off Nuuk, sees more routine sampling, and is thus lower priority. Begin occupation of LSW line.

*13 September*

Sampling along the LSW line. Conditions remain excellent through the afternoon, when a cold front moves through and winds begin to pick up. Winds reach 30 kts by midnight, intensifying earlier than predicted in the forecasts.

*14 September*

Complete LSW12 overnight but conditions continue to deteriorate. The night crew begins LSW14 early morning. Ship has significant pitch and roll in 30+ kt winds and 4-m seas, amplified because the CTD is being lowered from the port quarter. Conditions are marginal for CTD operations, and require careful timing to ensure that operations take place in between sets of waves. The deck crew aborts LSW14 as they deem conditions to be too difficult for safe overboarding. We have only a couple of days remaining in the cruise, and conditions are forecast to deteriorate. Without enough time to wait out the storm, we choose to begin the transit to Nuuk.

*15 September*

Arrive outside of Nuuk fjord at 06:00, holding offshore for a berth to clear. Tied up by 09:00.

## 4. MOORING OPERATIONS

The Davis Strait mooring array consists of thirteen sites (**Figs. 2** and **3**, **Table 1**). A twelve-element array (**Figs. 3** and **4a–l**) spans the Strait, situated north of the sill to avoid recirculation associated with local bathymetry (**Fig. 1**). Moorings are instrumented with acoustic Doppler current profilers (300-kHz Teledyne RDI Workhorse and 250-kHz Nortek Signature) and single point Nortek acoustic current meters to measure currents, sea ice draft, and velocity. Seabird Electronics SBE37 sensors measure conductivity (salinity), temperature, and depth (CTD) at specific points in the water column. Specialized IceCAT systems, designed and fabricated by the IOP group at the Applied Physics Laboratory, University of Washington, collect measurements in the hazardous region near the ice-ocean interface. Each IceCAT consists of a data logger, situated at a depth safe from the sea ice, connected to one or more SBE37 CTDs, at depths near the ice-ocean interface, through an inductive modem and a mechanical weak link. The weak link protects the mooring in the event that the shallow sensors are caught by sea ice, while the inductive link and data logger ensure data recovery regardless of sensor loss. Two moorings, one on each side of the strait (C1, **Fig. 4g** and C6, **Fig. 5l**), carry bottom pressure recorders (BPR) to quantify sea surface height. To investigate the processes that modulate exchange through Davis Strait, an additional BPR mooring (Baffin BPR, **Fig. 4m**) is sited further to the north, in central Baffin Bay (**Fig. 2**).

Eleven of the thirteen sites were successfully deployed (**Table 2**). Due to an oversight, R/V *Dana's* request for Canadian Marine Scientific Research (MSR) clearance was not submitted until after the vessel arrived in Baffin Bay. Operations early in the cruise were thus restricted to regions of Baffin Bay that sit outside the Canadian EEZ. An extraordinary effort by the Danish Embassy in Ottawa and their colleagues in the Canadian government secured last-minute permission for operations within the Canadian

EEZ, excluding the 12 NM Nunavut territorial waters where COVID concerns and the extraordinarily short timeframe complicated consideration of the request. To make efficient use of ship time within the constraints imposed by the delayed MSR clearance the Baffin BPR site was shifted northward, to a central basin location outside the Canadian EEZ. Ultimately, the inability to work within 12 NM of the Baffin Coast prevented deployment of the two Baffin Shelf moorings (BI2 and BI4).

Moorings were deployed off the port quarter using one of R/V *Dana's* large trawling winches, the port crane, and a series of snatch blocks. The work deck, sandwiched between the rail and the trawl ramp, was cramped, but worked well.

Hydrophone packages (Ocean Instruments ST500s) were deployed on five of the cross-strait moorings (WG1, C1, C3, C4, and C6). All the hydrophone packages except C3 were programmed to sample at 48 kHz for 6 min every hour while C3 was programmed to sample at 144 kHz for 3 min every 30 min. This was to obtain data on northern bottlenose whale acoustics because their echolocation is much higher frequency than 48 kHz.

**Table 1.** Planned Davis Strait mooring sites.

| | Lat (N) | Lon (W) | Bottom (m) | Notes |
|---|---|---|---|---|
| **BI2** | 66° 38.8' | 61° 13.4' | 79 m | |
| **BI4** | 66° 39.5' | 61° 10.2' | 152 m | |
| **WG1** | 67° 06.4' | 56° 19.7' | 144 m | |
| **WG1.5** | 67° 08.7' | 55° 52.7' | 111 m | |
| **WG2** | 67° 11.6' | 55° 18.6' | 73 m | |
| **WG4** | 67° 15.8' | 54° 28.5' | 65 m | |
| **C1** | 66° 38.5' | 60° 46.5' | 441 m | |
| **C2** | 66° 45.8' | 60° 04.7' | 656 m | |
| **C3** | 66° 51.2' | 59° 03.3' | 1032 m | |
| **C4** | 66° 58.8' | 57° 41.5' | 866 m | |
| **C5** | 67° 02.3' | 57° 02.2' | 685 m | |
| **C6** | 67° 04.2' | 56° 40.9' | 385 m | |
| **BPR** | 72° 00.0' | 65° 30.0' | 2000+ m | Alternate sites are: 70° N, 63° W and 69° N, 62° W. |

**Table 2.** Mooring deployment dates, surveyed locations, and depths at anchor drop location.

| Mooring | Date Deployed | Lat | Lon | Depth |
|---|---|---|---|---|
| **BI2** | Not deployed | | | |
| **BI4** | Not deployed | | | |
| **C1** | 10 Sep 2020 | 66° 38.478’ N | 60° 46.635’ W | 440 m |
| **C2** | 10 Sep 2020 | 66° 45.548’ N | 60° 04.230’ W | 662 m |
| **C3** | 9 Sep 2020 | 66° 51.091’ N | 59° 03.305’ W | 1039 m |
| **C4** | 31 Aug 2020 | 66° 58.511’ N | 57° 40.740’ W | 892 m |
| **C5** | 31 Aug 2020 | 67° 02.334’ N | 57° 02.558’ W | 704 m |
| **C6** | 30 Aug 2020 | 67° 04.180’ N | 56° 40.965’ W | 396 m |
| **WG1** | 30 Aug 2020 | 67° 06.401’ N | 56° 19.640’ W | 150 m |
| **WG1.5** | 30 Aug 2020 | 67° 08.719’ N | 55° 52.641’ W | 112 m |
| **WG2** | 30 Aug 2020 | 67° 11.497’ N | 55° 19.082’ W | 75 m |
| **WG4** | 30 Aug 2020 | 67° 15.703’ N | 54° 29.114’ W | 53 m |
| **BPR** | 4 Sep 2020 | 72° 44.822’ N | 64°55.575’ W | 2367 m |

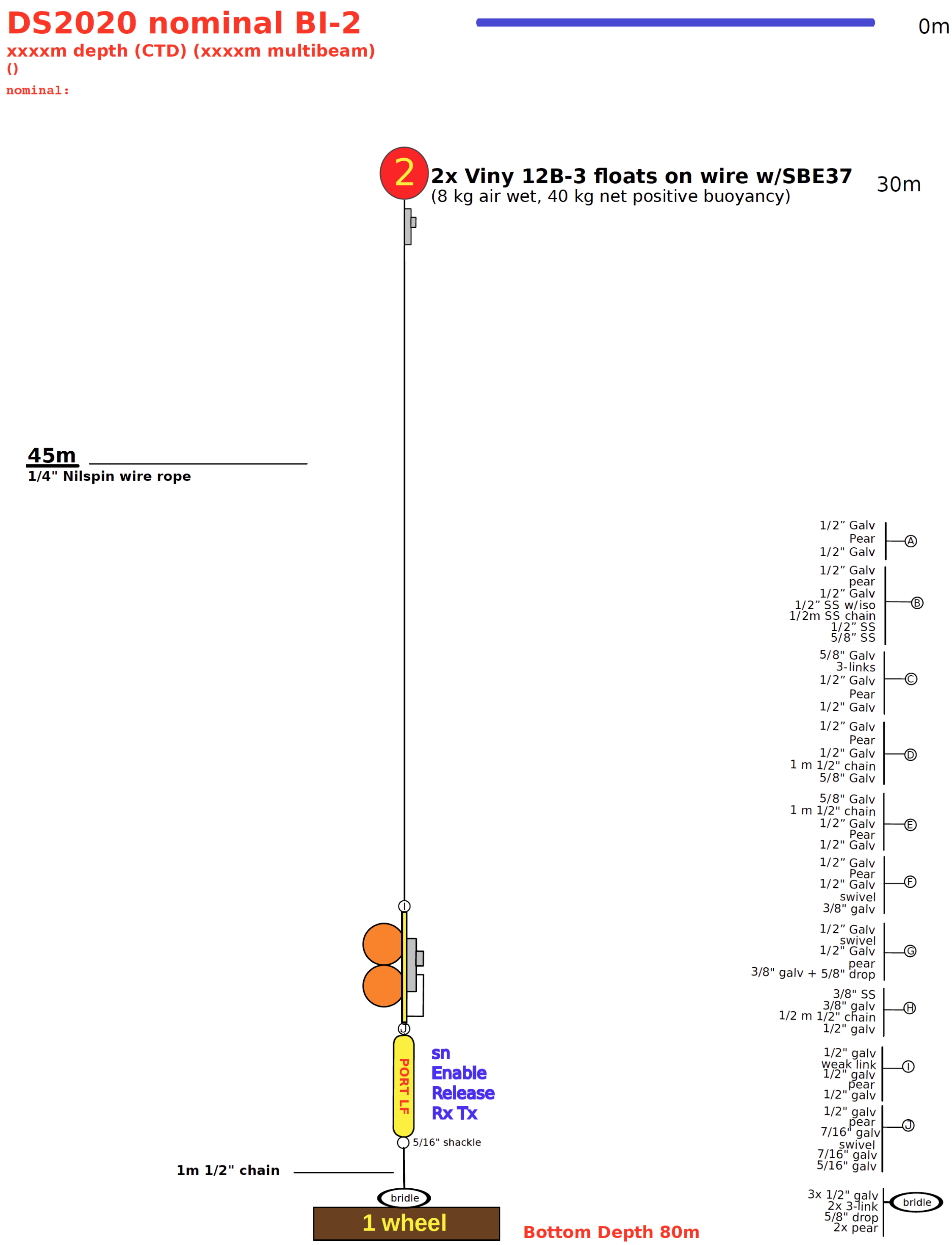


***Figure 4a.*** *BI2 Mooring diagram (Baffin Shelf).*

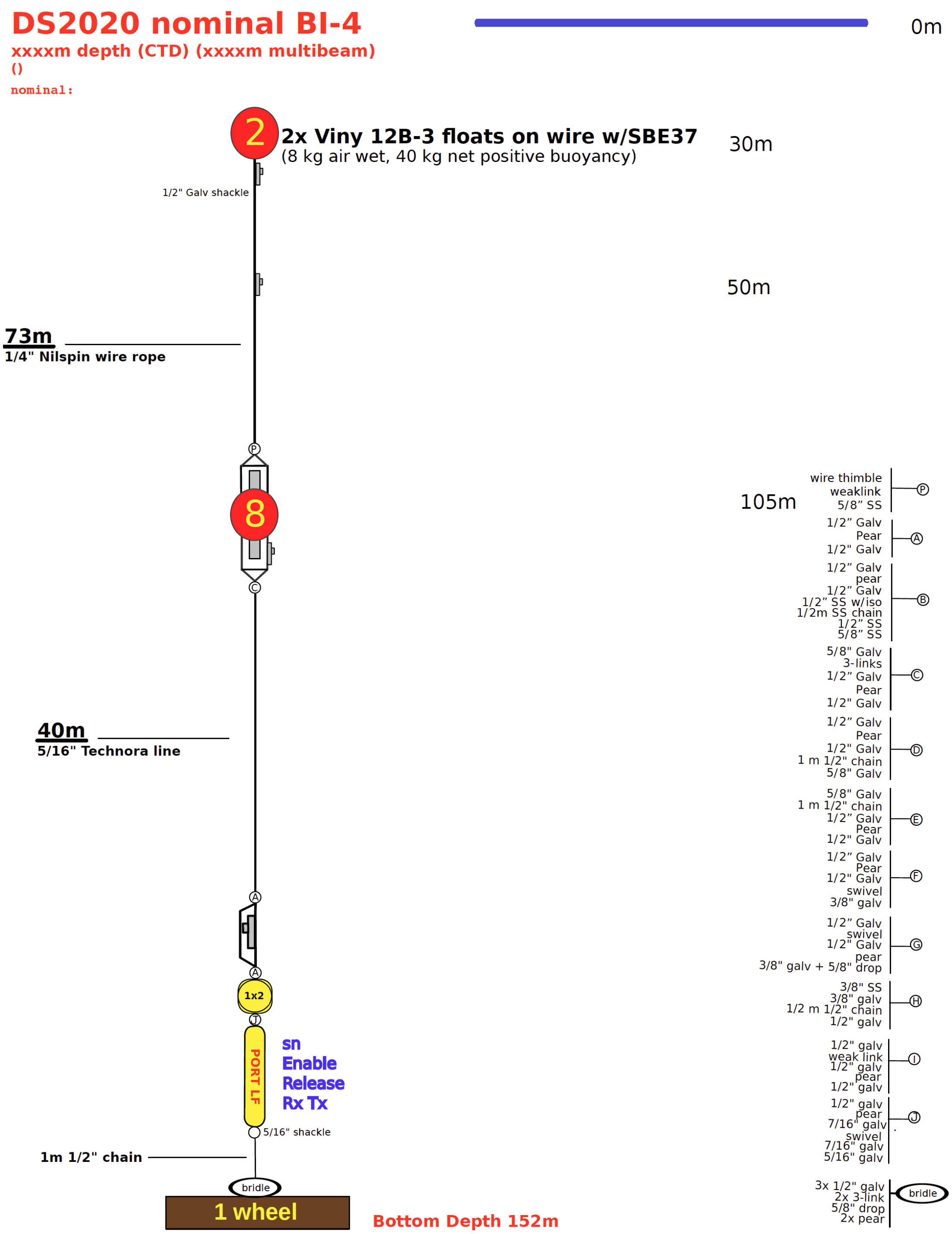


***Figure 4b.*** *BI4 Mooring diagram (Baffin Shelf).*

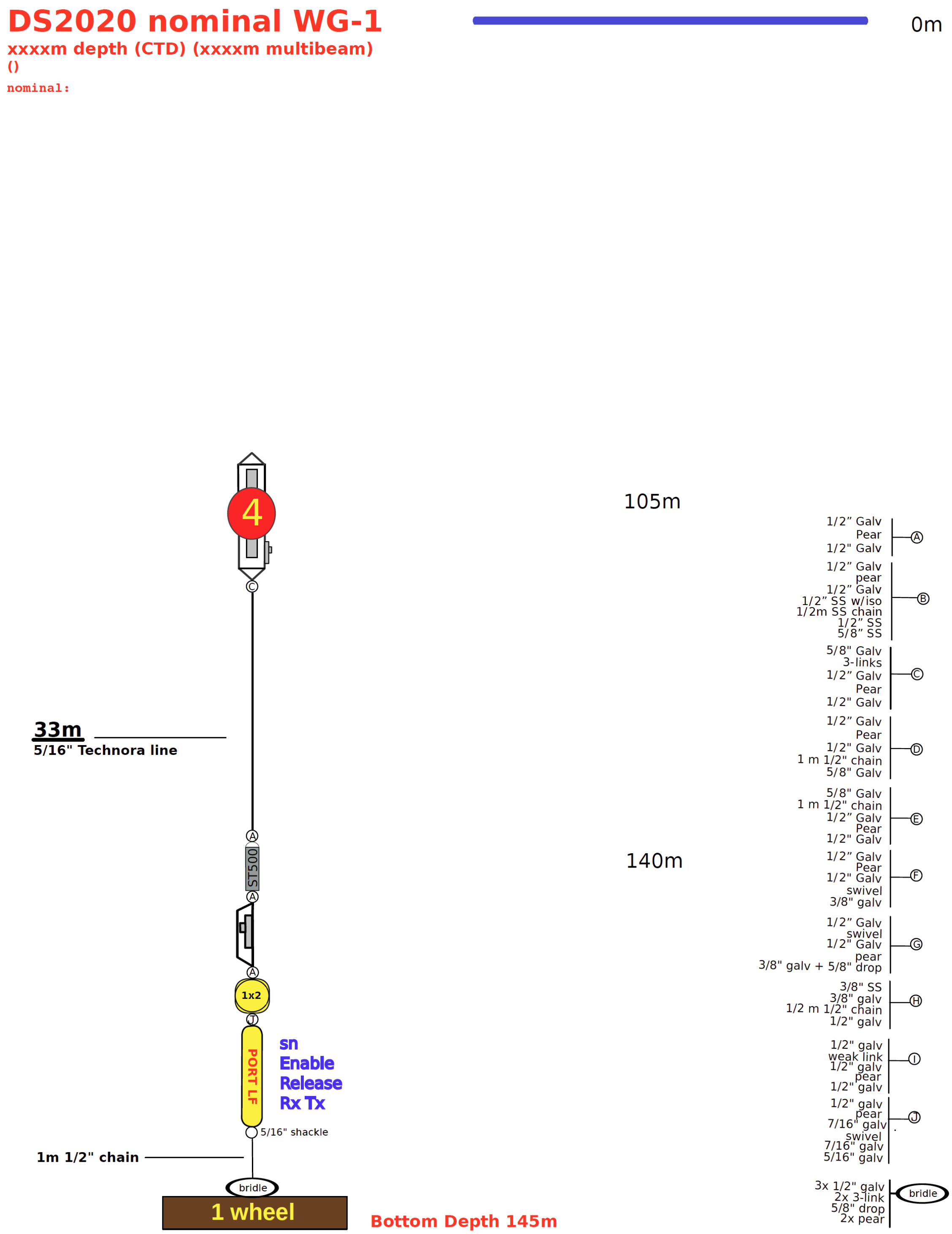


***Figure 4c.*** *WG1 Mooring diagram (West Greenland Shelf).*

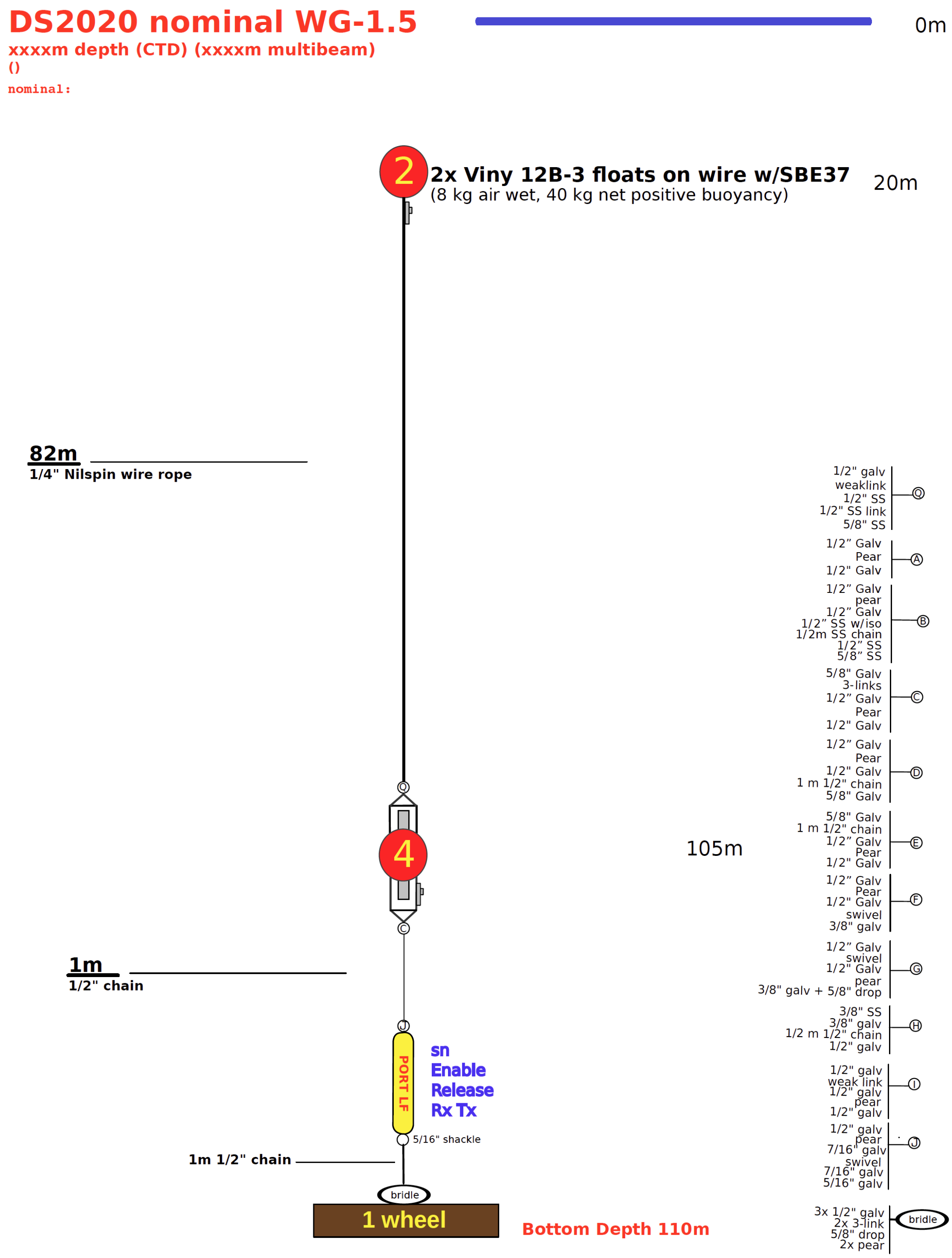


***Figure 4d.*** *WG1.5 Mooring diagram (West Greenland Shelf).*

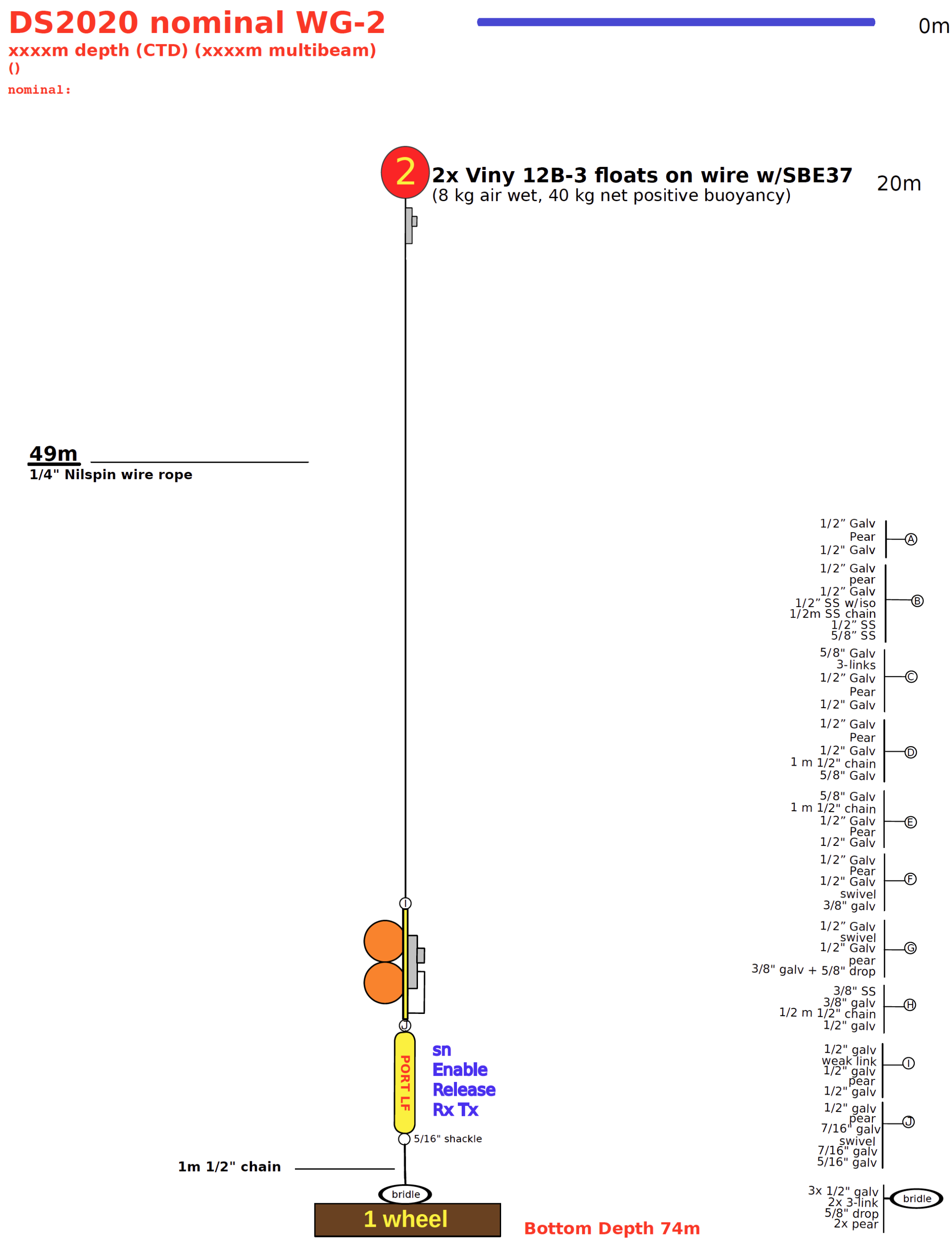


***Figure 4e.*** *WG2 Mooring diagram (West Greenland Shelf).*

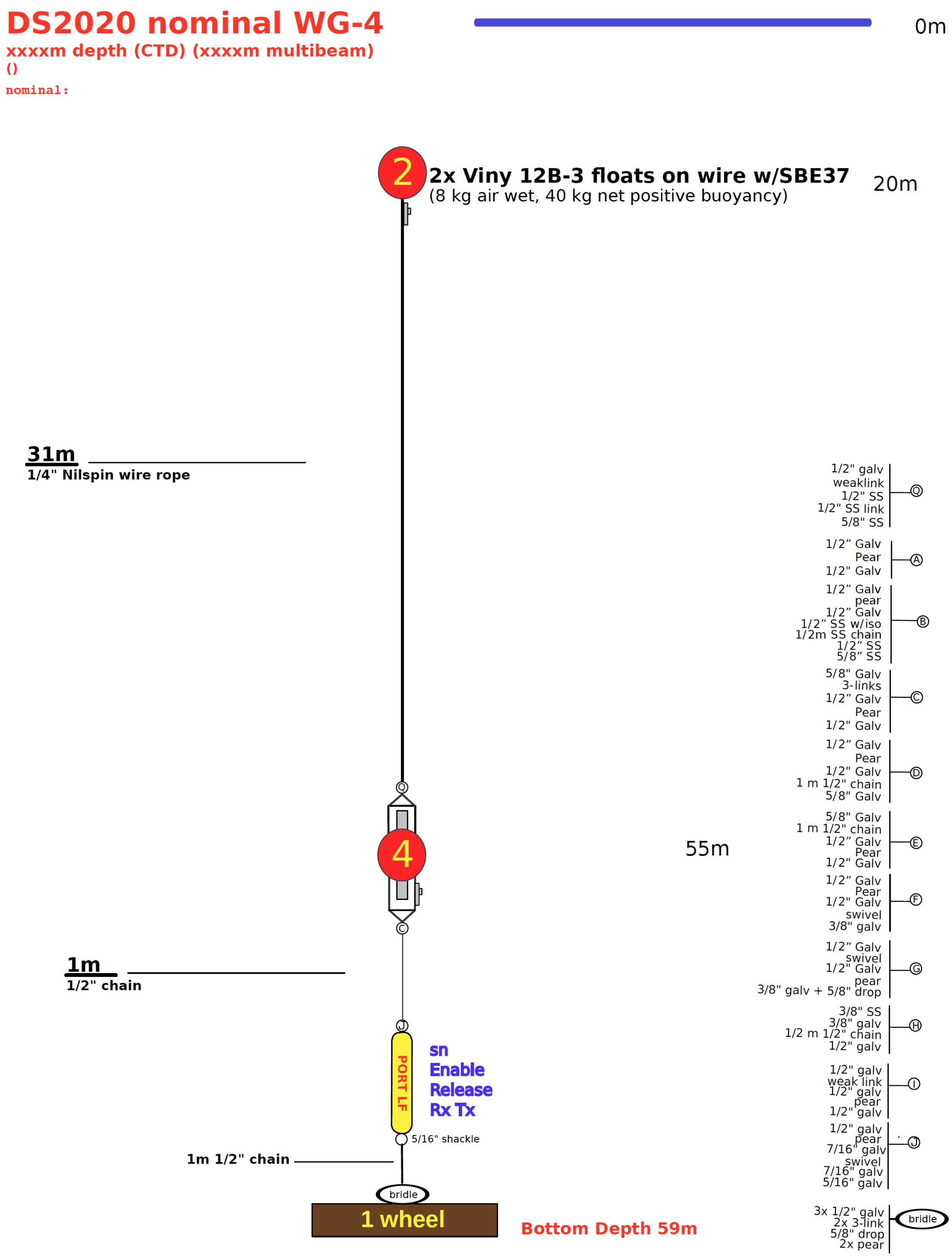


*Figure 4f.* *WG4 Mooring diagram (West Greenland Shelf).*

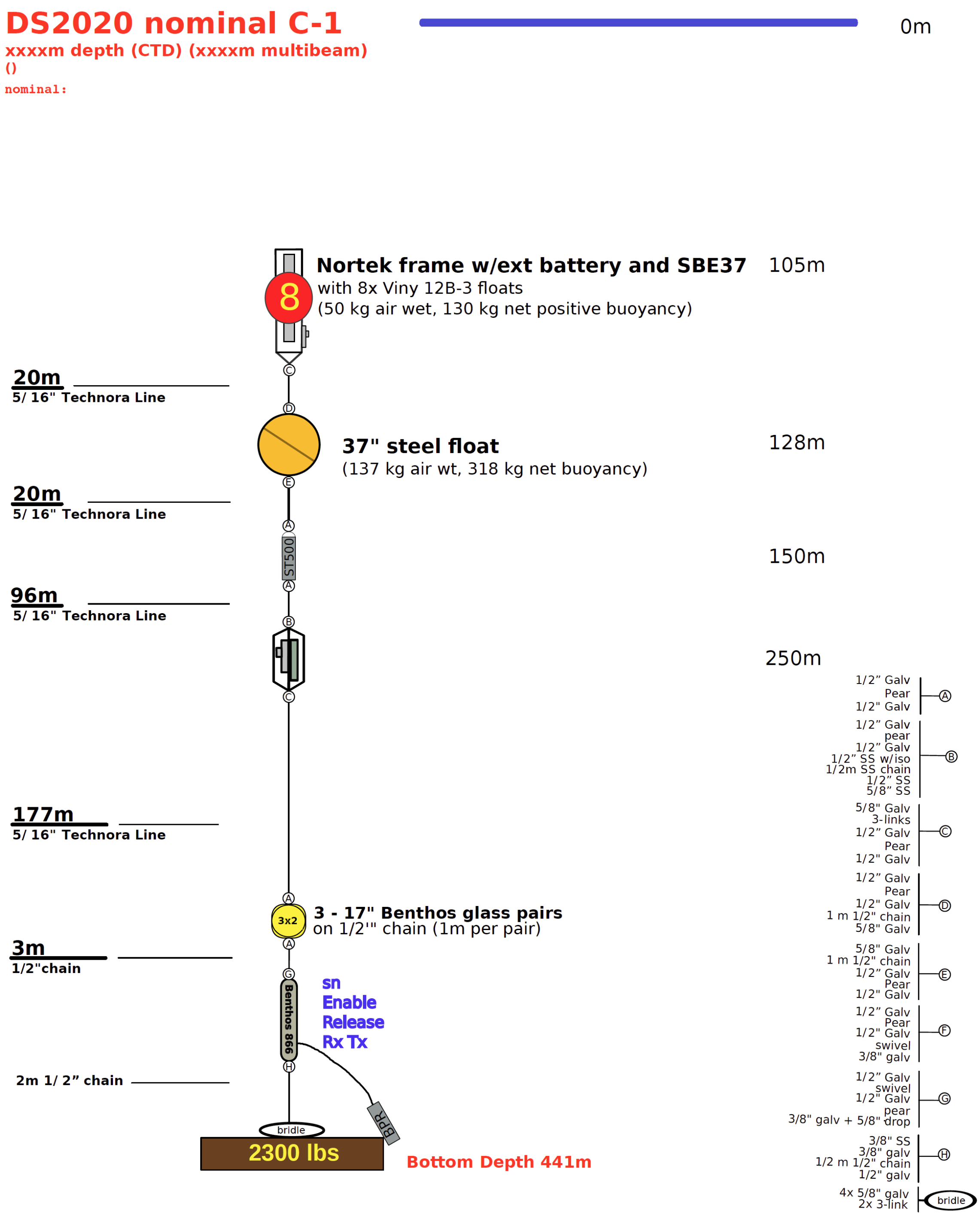


*Figure 4g.* *C1 Mooring diagram (central strait).*

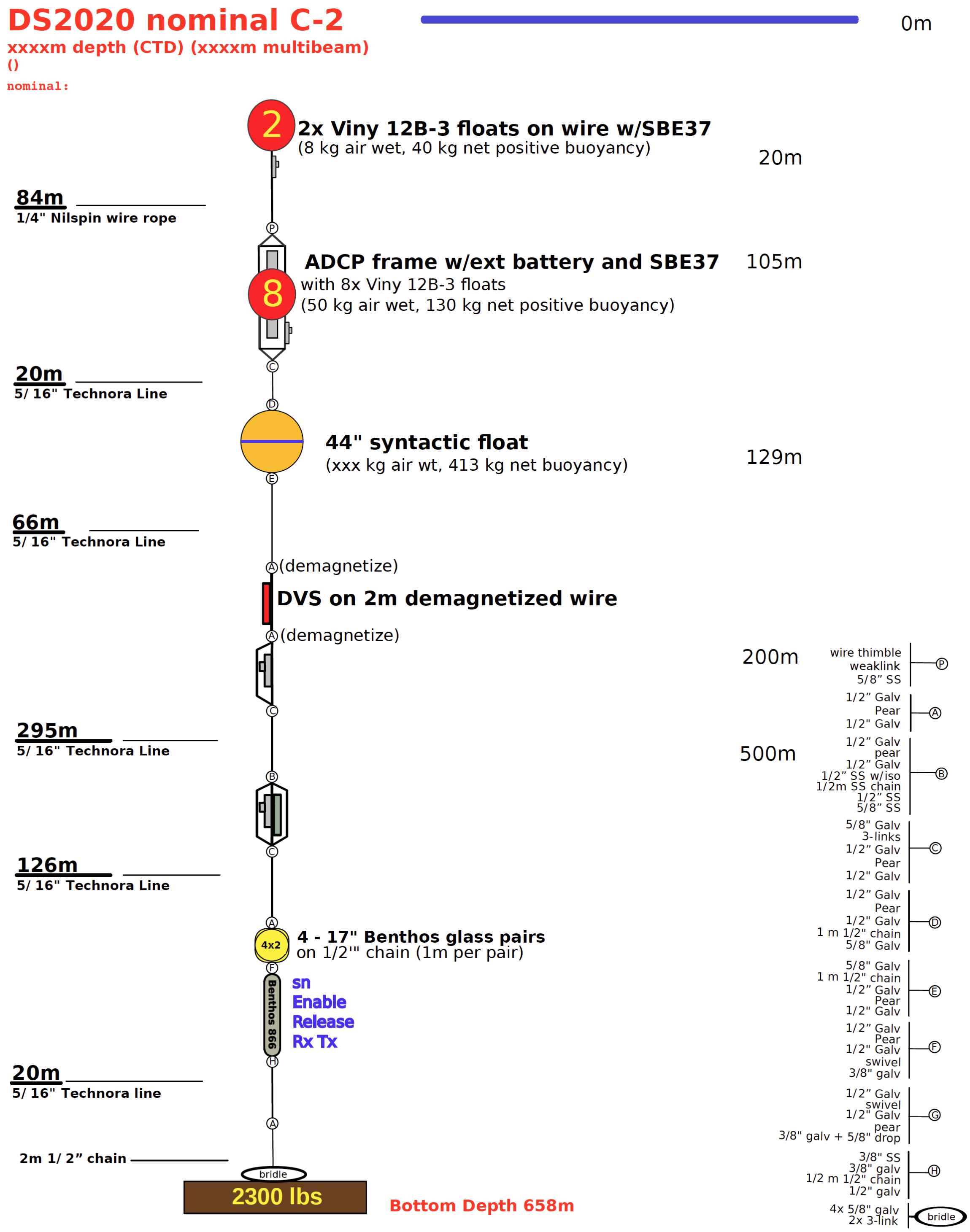


***Figure 4h.*** *C2 Mooring diagram (central strait).*

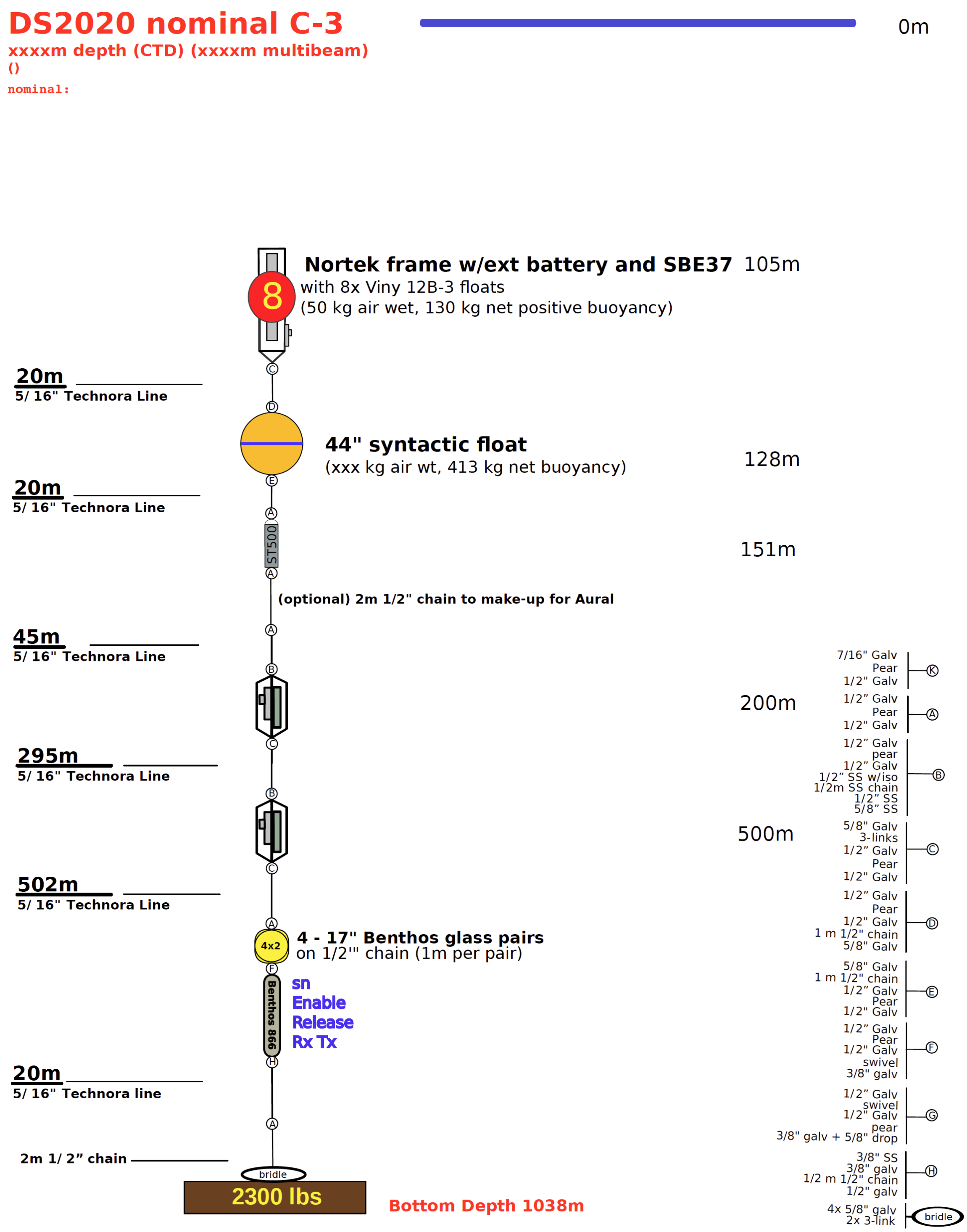


*Figure 4i.* C3 Mooring diagram (central strait).

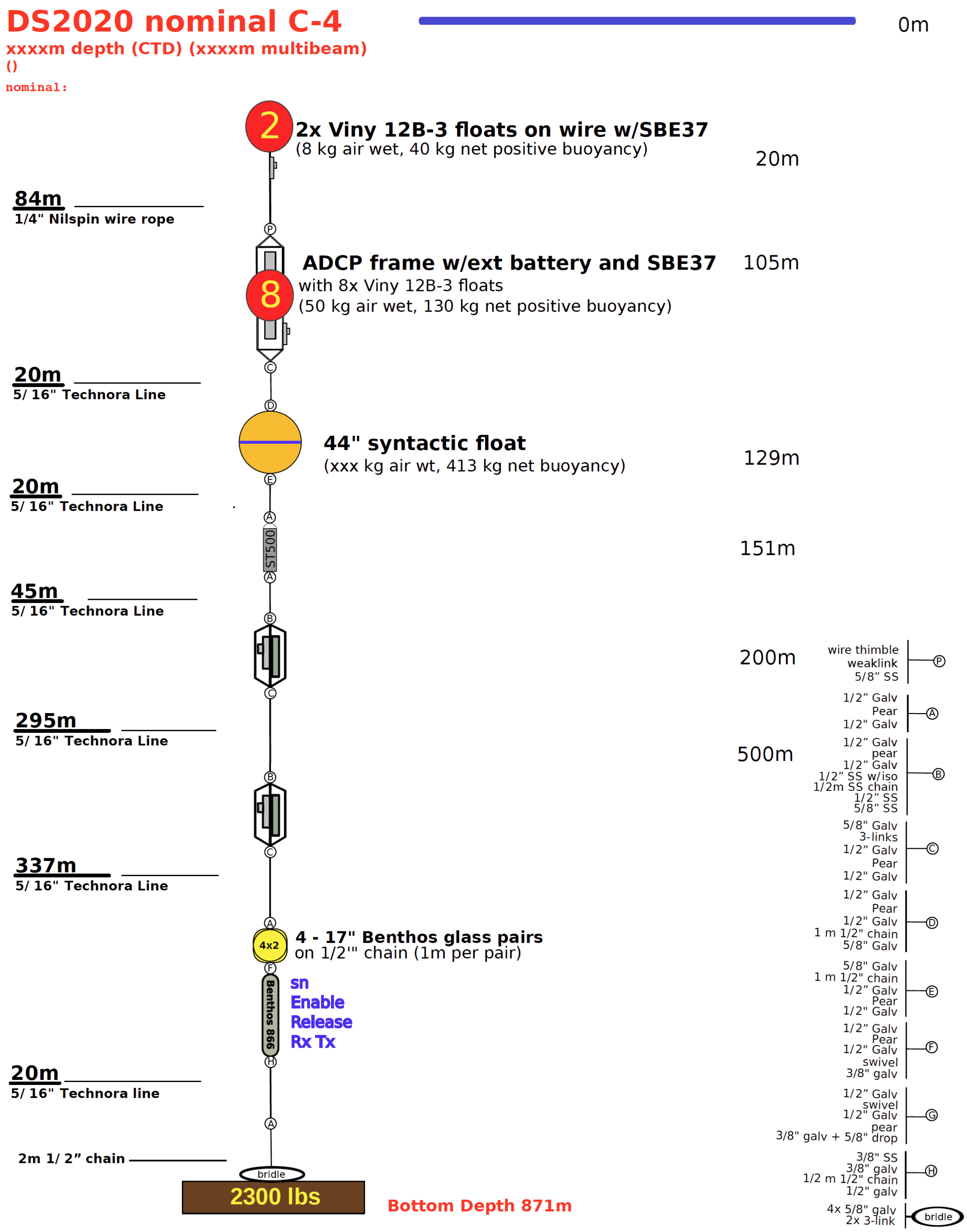


*Figure 4j.* *C4 Mooring diagram (central strait).*

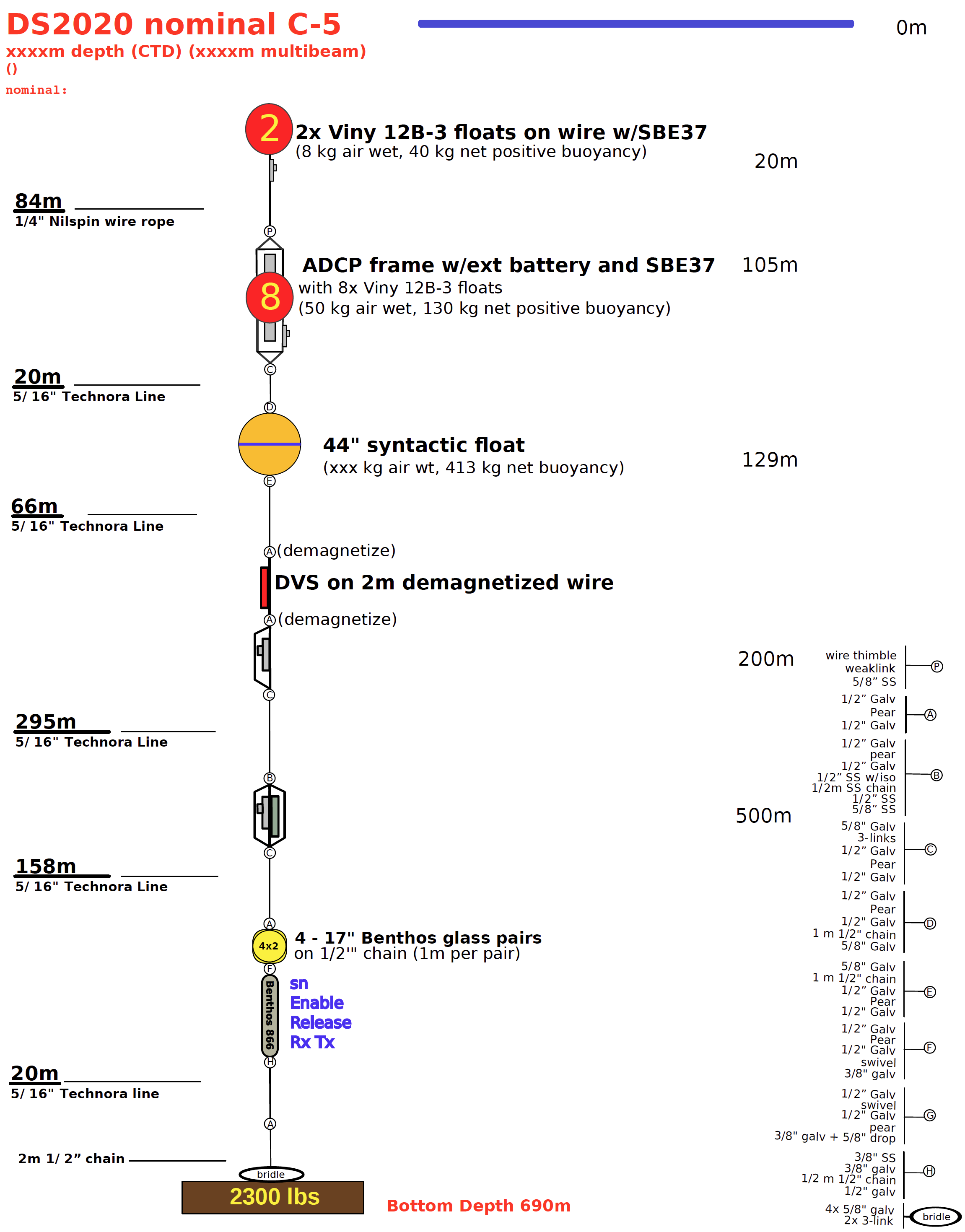


*Figure 4k.* *C5 Mooring diagram (central strait).*

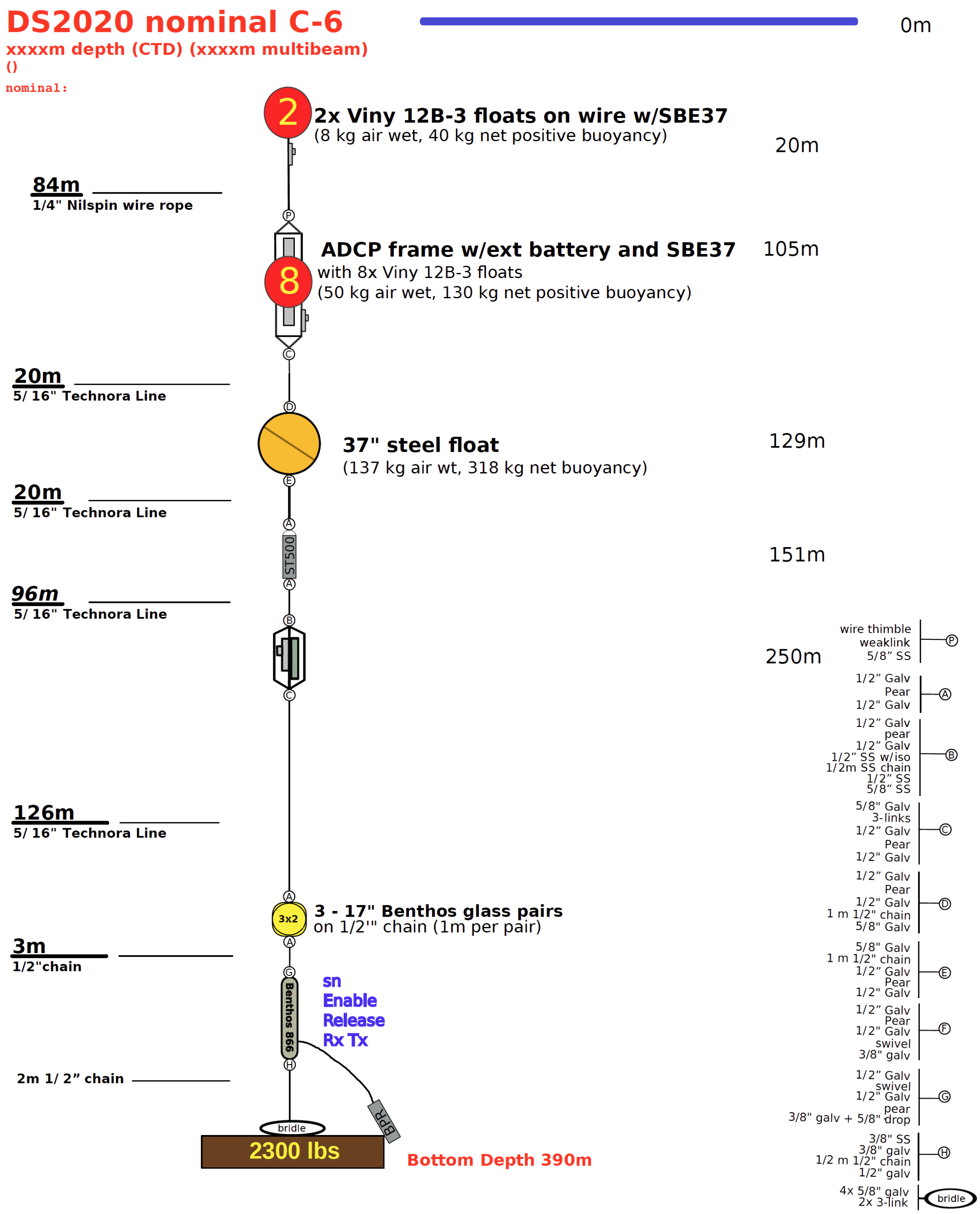


***Figure 4l.*** *C6 mooring diagram (central strait).*

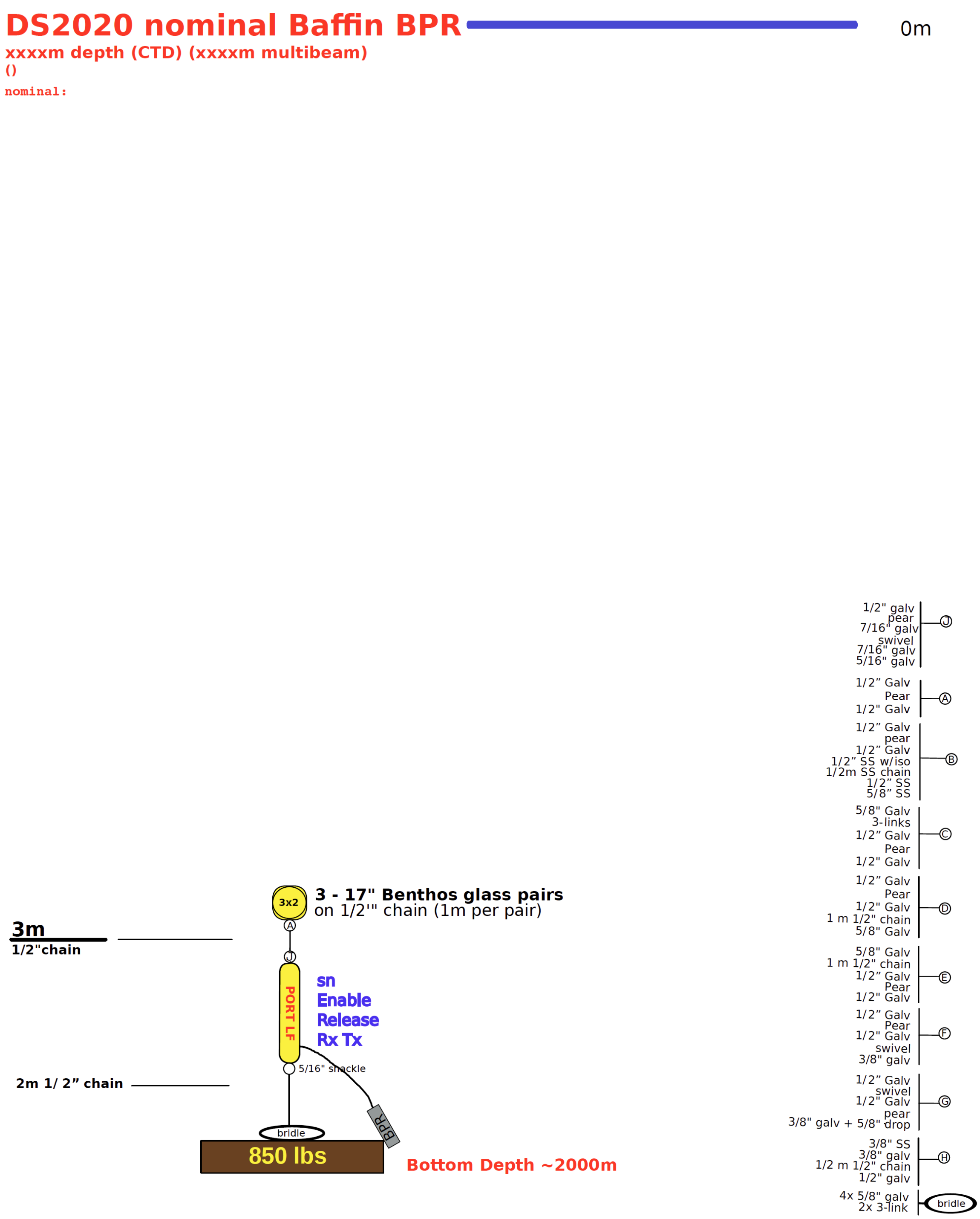


*Figure 4m. BPR Mooring diagram (central Baffin Bay).*

## 5. HYDROGRAPHIC SAMPLING

Biennial hydrographic sampling focuses on the northern Labrador Sea, Davis Strait, and southern Baffin Bay, continuing the occupation of sampling lines established during the first phase (2004–2015) of the program (**Fig. 2**). Time constraints limited the 2020 effort to the Mooring and Northern and Labrador Sea West lines, while MSR clearance constraints excluded sampling at stations located within 12 NM of the Nunavut coast (**Table 3**).

Hydrographic sampling employed a Seabird Electronics 911+ CTD system paired with a 24-place, 10 L rosette. Chemical parameters collected included total inorganic carbon (TIC), total alkalinity (TA), dissolved organic matter (DOM), DO, $^{18}O$, nutrients, underway $pCO_2$ and salinity.

### Total Inorganic Carbon (TIC) and Total Alkalinity (TA)

To understand the temporal and spatial variability of carbon fluxes and ocean acidification, a total of 309 samples were collected from the following stations:

- Mooring Line: All stations except ML01
- Northern Line: All stations except NL01, NL02
- Lab Sea West: LSW stations 01, 03, 05, 07, 09, 10, 11, 12, 13
- BPR mooring (one cast)

Samples were collected in 500 mL borosilicate glass bottles and preserved with mercuric chloride following SOP 1 (*Dickson et al*., 2007). Some of the TIC bottle lids were stuck, probably due to the lack of grease. We were therefore unable to use them for sampling and they were shipped back as empties. Most of the TIC/TA sampling was carried out smoothly, with exceptions regarding a few Niskin bottles that did not fire, and noted down on the deck sheets.

The samples were transported back to the Bedford Institute of Oceanography for analysis. The lack of Certified Reference Materials (CRMs) due to the halted production at Scripps Institute of Oceanography due to COVID-19, is delaying the TIC and TA analyses. When CRMs are available, TIC will be determined using gas extraction and coulometric titration with photometric endpoint detection (*Johnson et al*., 1985). Total alkalinity is measured by open-cell potentiometric titration with full curve Gran Point determination using a Titrando dosimat with Tiamo software in conjunction with a sample delivery system built in-house. The CRMs (supplied by Professor Andrew Dickson, Scripps Institution of Oceanography, San Diego, USA) will be analyzed in duplicate at intervals to evaluate accuracy.

**Table 3.** Sampling stations, their positions, sampling date, and approximate time and the gear deployed at each station. (MULTI) Multinet Midi (Hydrobios), (DSN) *Dana* Special Net, designed for the collection of fish larvae.

| Station | Date and time | Position | | Gear |
|---|---|---|---|---|
| | | Latitude | Longitude | |
| **ML18** | 30.8. 8:00 | 67° 19.052’ N | 053° 57.463’ W | CTD |
| **ML15** | 30.8. 23:00 | 67° 11.370’ N | 055° 18.756’ W | CTD |
| **ML14** | 31.8. 01:40 | 67° 09.112’ N | 055° 49.043’ W | CTD |
| **ML13** | 31.8. 03:40-07:00 | 67° 06.028’ N | 056° 18.177’ W | CTD, WP2 x 2, MULTI |
| **ML12** | 31.8. 21:30 – 1.9. 00:40 | 67° 04.010’ N | 056° 41.112’ W | CTD, DSN, WP2 x 2, MULTI |
| **ML11** | 1.9. 02:40-06:00 | 67° 02.155’ N | 057° 02.469’ W | CTD, DSN, WP2 x 2, MULTI |
| **ML10** | 1.9. 8:00 | 67° 00.835’ N | 057° 21.169’ W | CTD |
| **ML09** | 1.9. 10:30 | 66° 58.646’ N | 057° 41.211’ W | CTD |
| **NL25** | 2.9. 02:45 | 69° 09.863’ N | 054° 19.927’ W | CTD |
| **NL24** | 2.9. 04:40 | 69° 05.554’ N | 054° 53.496’ W | CTD |
| **NL23** | 2.9. 07:00-09:00 | 69° 00.279’ N | 055° 35.329’ W | CTD, DSN, WP2 x 2, MULTI |
| **NL22** | 2.9. 11:20 | 68° 55.084’ N | 056° 16.562’ W | CTD |
| **NL21** | 2.9. 13:30 | 68° 50.049’ N | 056° 59.123’ W | CTD |
| **NL20** | 2.9. 16:00 | 68° 44.642’ N | 057° 42.060’ W | CTD |
| **NL19** | 2.9. 18:00 | 68° 39.367’ N | 058° 23.495’ W | CTD |
| **NL18** | 2.9. 20:30- 3.9. 01:30 | 68° 34.124’ N | 059° 05.688’ W | CTD, DSN, WP2 x 2, MULTI |
| **BPRCTD** | 4.9.14:00 – 18:40 | 72° 45.017’ N | 064° 51.263’ W | CTD, DSN, WP2 x 2, MULTI |
| **NL17** | 5.9. 23:00 | 68° 32.276’ N | 059° 19.916’ W | CTD |
| **NL16** | 6.9. 02:20 | 68° 31.590’ N | 059° 27.767’ W | CTD |
| **NL15** | 6.9. 03:20 | 68° 29.230’ N | 059° 41.432’ W | CTD |
| **NL14** | 6.9. 06:20 | 68° 28.122’ N | 059° 55.051’ W | CTD |
| **NL13** | 6.9. 09:00 | 68° 26.295’ N | 060° 09.399’ W | CTD |
| **NL12** | 6.9. 12:00 – 17:00 | 68° 23.625’ N | 060° 29.152’ W | DSN, CTD, WP2 x 2 |
| **NL11** | 6.9. 19:00 | 68° 18.428’ N | 061° 11.950’ W | CTD |

| | | | | |
|---|---|---|---|---|
| **NL10** | 7.9. 03:00 | 68° 10.938’ N | 061° 29.247’ W | CTD |
| **NL09** | 7.9. 11:20- 15:00 | 68° 02.907’ N | 061° 46.324’ W | CTD, MULTI |
| **NL08** | 7.9. 18:30 | 67° 55.039’ N | 062° 03.526’ W | CTD |
| **NL07** | 7.9. 21:00 | 67° 50.647’ N | 062° 13.469’ W | CTD |
| **NL06** | 7.9. 23:40 + 8.9. 01:30 | 67° 46.213’ N | 062° 21.617’ W | CTD x 2 |
| **NL04** | 9.8. 03:40 | 67° 40.431’ N | 062° 36.957’ W | SEA |
| **NL03** | 9.8. 05:00 – 07:45 | 67° 37.678’ N | 062° 45.066’ W | CTD, DSN, WP2 x 2, MULTI |
| **NL02** | 9.8. 09:00 | 67° 33.431’ N | 062° 55.491’ W | CTD |
| **ML17** | 9.9. 03:10 – 04:40 | 67° 15.421’ N | 054° 29.673’ W | CTD, DSN, WP2 x 2, MULTI |
| **ML16** | 9.9. 06:00 | 67° 13.677’ N | 054° 51.926’ W | CTD |
| **ML03** | 10.9. 00:00 – 05:00 | 66° 41.673’ N | 060° 46.102’ W | WP2 x 2, DSN, CTD x 3 |
| **ML04** | 10.9. 07:00 – 08:30 | 66° 43.969’ N | 060° 28.838’ W | CTD x 3 |
| **ML08** | 11.9. 17:00-21:30 | 66° 56.040’ N | 058° 23.106’ W | MULTI, DSN, WP2 x 2, CTD |
| **ML07** | 12.9. 01:00 | 66° 50.665’ N | 059° 03.698’ W | CTD |
| **ML06** | 12.9. 04:00 | 66° 49.140’ N | 059° 37.523’ W | CTD |
| **ML05** | 12.9. 07:00 – 10:30 | 66° 45.605’ N | 060° 04.020’ W | CTD, WP2 x 2, MULTI, DSN |
| **LSW01** | 13.9. 02:00 | 64° 11.992’ N | 063° 11.883’ W | CTD |
| **LSW03** | 13.9. 04:30 – 06:20 | 63° 57.508’ N | 062° 33.602’ W | CTD, 2 x WP2, MULTI, DSN |
| **LSW05** | 13.9. 09:00 | 63° 43.273’ N | 061° 55.303’ W | CTD |
| **LSW07** | 13.9. 11:30 | 63° 28.761’ N | 061° 16.789’ W | CTD |
| **LSW09** | 13.9. 14:00 | 63° 14.301’ N | 060° 38.136’ W | CTD |
| **LSW10** | 13.9. 17:00 – 22:00 | 63° 07.105’ N | 060° 19.358’ W | CTD, 2 x WP2, MULTI, DSN |
| **LSW11** | 13.9. 22:00 | 62° 59.905’ N | 060° 00.111’ W | CTD |
| **LSW12** | 14.9. 02:00 | 62° 42.878’ N | 059° 14.565’ W | CTD |

**Dissolved Oxygen (DO)**

A total of 119 water samples were collected for analysis of dissolved oxygen concentration to calibrate CTD oxygen sensors. Samples were taken at three depths (bottom, 10 m, and chlorophyll *a* max.) at every water sampling station. A few samples for dissolved oxygen analysis were not taken as some Niskin bottles were eventually not fired. Samples were analyzed on board employing the Winkler method for oxygen determination with assistance of an automated titration set up. Six samples out of the total 119 could not be measured due to operational problems such as presence of air bubbles in the system, problems with the titration system, etc.

**Discrete p$CO_2$/$CH_4$**

No samples were collected, as an incorrectly sized crimper made it impossible to properly seal the sample bottles. Multiple ad hoc approaches were tried, but none were deemed reliable enough to ensure proper sample collection.

**Underway Surface Water p$CO_2$ and Atmospheric $CO_2$**

A Pro-Oceanus Pro Atmosphere p$CO_2$ sensor was installed next to the water pump inlet located in the wet chemistry lab during the transit to Greenland following the protocols provided with the instrument. The flow rate of the water inlet was assessed before connecting the tubing to make sure that it would fit with the limitation of the Pro-Oceanus sensor. Data from the p$CO_2$ sensor were acquired continuously throughout the cruise on a PC running Teraterm terminal software and daily backups of the log file were saved. Samples for calibration (TIC/TA) were collected from the sensor outflow at around noon each day and temperature, salinity, time, and position coordinates were recorded on a log sheet.

Calibration samples were not taken before arriving in Nuuk, since the $HgCl_2$ for the poisoning was to be delivered from the scientific team boarding the ship there. After departing from Nuuk the sampling team forgot to collect underway calibration samples for the first couple of days. When the sampling for underway calibration was finally started, the sensor stopped working properly. At that point, it was discovered that seawater was leaking out of the air inlet of the Pro-Oceanus p$CO_2$ sensor and it was decided to stop the measurements. The sensor was programmed to make a series of air measurements at 6-h intervals. For this purpose, air from the foredeck was pumped continuously to the sensor through flexible tubing.

**Oxygen Isotope Composition ($\delta^{18}O$–$H_2O$)**

Samples for $\delta^{18}O$–$H_2O$ analysis were collected to investigate the freshwater composition (sea ice meltwater and meteoric water) in 60-mL Boston Round bottles according to the SOP, from all the same aforementioned stations noted in the TIC section. Samples were missed only due to bottles that failed to fire. Samples for each station were noted on the deck sheets.

**Nutrients (Silicate, Phosphate, and Nitrate/Nitrite)**

Nutrient samples were collected according to the SOP to estimate nutrient distribution and fluxes, at each of the aforementioned stations noted in the TIC section. They were immediately frozen at upright position and placed in bags the next day. Some nutrient samples were placed in a –70°C freezer after upright freezing at –18°C due to limited storage space in the –18°C freezer. Samples were kept frozen with dry ice until returning to Bedford Institute of Oceanography for analyses. Nutrient samples in one station were contaminated with Nitrile gloves (mentioned in the deck sheet). Due to Niskin bottles not firing, some depths could be missing from individual stations.

**Salinity**

Salinity samples were collected to calibrate CTD sensors, typically 3–4 samples per station according to the SOP from all the same aforementioned stations noted in the TIC section above. Due to Niskin bottles not firing, some depths were not sampled at some stations. Whenever this occurred, it was noted in the deck sheet.

**Dissolved Organic Matter (DOM)**

The goals of the dissolved organic matter (DOM) sampling were to investigate the use of the optical properties of DOM (absorption and fluorescence) as a tracer of Arctic freshwater and organic carbon. The aim was to build on the finding of *Gonçalves-Araujo et al*. (2016) and complement the physical and biological sampling and measurement program.

**Sampling and Sample Processing**

A total of 265 samples were collected for the analysis of dissolved organic matter (DOM). DOM analyses encompass three methods that focus on distinct fractions of DOM: dissolved organic carbon (DOC), colored dissolved organic matter (CDOM), and fluorescent dissolved organic matter (FDOM).

Samples for DOM analyses were collected at all water sampling stations (7–18 samples depending on the local depth) in the following sites: Mooring Line, BPR site, and Labrador Sea West Line. Samples were immediately filtered through 0.2-$\mu$m cartridge filters directly from the Niskin bottles into pre-combusted acid-washed glass amber 50-mL vials and transferred to the lab. For each sampling depth, two vials were sampled: one for both CDOM and FDOM analyses and another for DOC analysis.

**Analyses of CDOM and FDOM**

Analyses of CDOM and FDOM were conducted on board after bringing the samples to room temperature immediately after sampling (and stored in the dark). CDOM absorption spectra (240–700 nm) were acquired with a Shimadzu Spectrophotometer at 1-nm interval. FDOM analysis was performed with a Horiba Aqualog Fluorescence

Spectrophotometer. Excitation spectra were acquired at 240–450 nm while emission spectra were collected at 300–600 nm.

### Samples for DOC Analysis

The samples for DOC analysis were acidified to pH 2–3 by adding orthophosphoric acid right after sampling. Those samples were stored in dark and cold (4°C) and will be analyzed at DTU-Aqua, where the DOC concentration will be quantified using a Shimadzu TOC-VCPH analyzer.

## 6. PHYTOPLANKTON AND PARTICULATE CARBON

The study area covers the Greenlandic and Canadian shelf, shelf-break and deeper areas of the Southern Baffin Bay, Davis Strait, and northern Labrador Sea. The marine ecosystems in this region are considered highly productive, sustaining economically important offshore fisheries.

Pelagic primary production is the principal source of organic material sustaining the pelagic and benthic communities in most offshore regions. High primary productivity in certain areas can therefore have a cascading effect up through the pelagic food web to higher trophic levels. Primary produced organic material diverted through the pelagic food web is partially ingested and degraded and/or completely remineralized. Intact algal cells and excreted material from the pelagic heterotrophic organisms, combined with advected material, often coagulate and form sinking aggregates. During descent the organic material continues to be degraded, often resulting in an attenuation in particulate carbon with depth.

Chlorophyll *a* concentration constitutes a widely used proxy for phytoplankton biomass. Size-fractionated (0.7 $\mu$m and 10 $\mu$m) chlorophyll *a* concentrations were measured on water samples collected at multiple depths (**Tables 3** and **4**). Data on chlorophyll *a* concentrations complement fluorescence profiles obtained from the CTD profiler and can be used to convert fluorescence values from the CTD profiler.

Water samples collected at 5 m and at the depth of chlorophyll *a* maximum were incubated onboard, using P-I curve incubations, to estimate the particulate primary production of the sampled phytoplankton community. Data obtained from the P-I curve incubations will be used to estimate *in situ*, maximum, and biomass specific productivity of the phytoplankton communities at each station. These data will subsequently be used to study phytoplankton productivity in relation to hydrographical and nutrient conditions in the study area.

Phytoplankton species composition and abundance from water collected at 5 m and at the depth of the chlorophyll *a* maximum from selected stations will be determined using a microscopic analysis method (**Table 4**). These data will elaborate on the phytoplankton community structure and provide information on the seasonal species diversity across the region.

Concentrations of particulate organic carbon (POC) will be determined from water collected at chosen depths from the surface to near-bottom at selected stations (**Table 4**). The depth profile of POC concentrations can be used to estimate the attenuation, i.e., degradation, of sinking particulate organic material.

The collected data sets will provide information on the biological productivity of the study area in relation to the bathymetry, oceanographic conditions, nutrient concentrations, and seasonal light regime. The data will also detail the attenuation of surface produced particulate organic material during the vertical descent towards the seafloor.

**Table 4.** Number of depths sampled for concentrations of chlorophyll *a* (0.7 μm and 10 μm) and particulate organic carbon (POC), phytoplankton species composition and abundance, and primary production.

| | Chlorophyll *a* | | | | |
|---|---|---|---|---|---|
| Station ID | 0.7 μm | 10 μm | Prim. Prod. | Phytoplankton | POC |
| BPR | 9 | 9 | 2 | 2 | 8 |
| LSW01 | 9 | 0 | 0 | 0 | 5 |
| LSW03 | 9 | 9 | 2 | 2 | 5 |
| LSW05 | 9 | 0 | 0 | 0 | 5 |
| LSW07 | 9 | 0 | 0 | 0 | 6 |
| LSW09 | 9 | 0 | 0 | 0 | 6 |
| LSW10 | 8 | 0 | 2 | 2 | 7 |
| LSW11 | 9 | 0 | 0 | 0 | 8 |
| LSW12 | 9 | 0 | 0 | 0 | 8 |
| ML03 | 7 | 7 | 2 | 2 | 5 |
| ML04 | 8 | 0 | 0 | 0 | 7 |
| ML05 | 8 | 6 | 2 | 2 | 7 |
| ML06 | 8 | 0 | 0 | 0 | 7 |

| | | | | | |
|---|---|---|---|---|---|
| ML07 | 8 | 0 | 0 | 0 | 7 |
| ML08 | 9 | 9 | 2 | 2 | 7 |
| ML09 | 9 | 0 | 2 | 2 | 7 |
| ML10 | 9 | 0 | 0 | 0 | 7 |
| ML11 | 9 | 9 | 2 | 0 | 7 |
| ML12 | 9 | 9 | 2 | 0 | 5 |
| ML13 | 9 | 0 | 2 | 0 | 5 |
| ML14 | 9 | 0 | 0 | 0 | 4 |
| ML15 | 8 | 0 | 0 | 0 | 4 |
| ML16 | 8 | 0 | 0 | 0 | 4 |
| ML17 | 8 | 8 | 2 | 2 | 3 |
| ML18 | 6 | 0 | 0 | 0 | 3 |
| NL03 | 9 | 9 | 2 | 2 | 5 |
| NL05 | 9 | 0 | 0 | 0 | 7 |
| NL07 | 8 | 0 | 0 | 0 | 8 |
| NL09 | 9 | 0 | 0 | 0 | 7 |
| NL10 | 8 | 0 | 0 | 0 | 0 |
| NL11 | 7 | 0 | 0 | 0 | 6 |
| NL12 | 9 | 9 | 2 | 2 | 8 |
| NL13 | 9 | 0 | 0 | 0 | 8 |
| NL15 | 9 | 0 | 0 | 0 | 7 |
| NL17 | 9 | 0 | 0 | 0 | 6 |
| NL18 | 9 | 9 | 2 | 2 | 5 |
| NL19 | 9 | 0 | 0 | 0 | 5 |
| NL20 | 0 | 0 | 2 | 0 | 0 |
| NL21 | 7 | 0 | 0 | 0 | 6 |
| NL23 | 9 | 9 | 2 | 2 | 5 |
| NL25 | 9 | 0 | 0 | 0 | 5 |
| Total | 341 | 102 | 32 | 24 | 235 |

## 7. ZOOPLANKTON

The purpose of the zooplankton work was to investigate 1) the link between the hydrography, phytoplankton biomass and size distribution, and zooplankton species composition, and 2) the potential effect of the zooplankton species composition on the trophic transfer efficiency and the effectivity of the biological carbon pump. Also, the zooplankton abundance, biomass, and species composition can be compared to the previous studies from the area that were conducted in the early 1980s (*Huntley et al.*, 1983). Emphasis was placed on small (< 1 mm) zooplankton species, which are typically undersampled by the standard WP2 nets that have a mesh size of 200 $\mu$m, and which have been suggested to dominate the zooplankton community in late summer and autumn. These species include *Oncaea* and *Microsetella*, which are known to feed on the sinking particles (*Green and Dagg*, 1997), and therefore to influence the effectivity of the biological carbon flux (*Koski et al.*, 2020).

Zooplankton studies included:

- Vertical distribution of zooplankton biomass and species composition: Sampling in five depth layers from bottom to the surface, using a Multinet with 50-$\mu$m nets
- Collection of live zooplankton: Sampling using a WP2 net with 100-$\mu$m mesh size towed from 100 m to the surface
- Individual carbon budget of dominant species: Incubation experiments to measure the egg production, fecal pellet production and respiration of dominant species (*Calanus* spp., *Pseudocalanus* sp., *Oncaea* spp.)

The multinet samples were taken at all biological sampling stations (**Table 3**), with the exception of NL12 and ML03 where multinet samples could not be taken due to the problems with the wire. Incubations to measure the zooplankton pellet production were conducted at selected stations with late copepodite stages of *Calanus* sp. and *Pseudocalanus* sp. These species were present and dominant at most stations, which made it possible to compare the link between hydrography, primary production and feeding of mesozooplankton between the stations, using the pellet production as an indication for feeding. Incubations to measure zooplankton respiration were conducted with the dominant species from each station, mainly *Calanus* sp. copepodites, *Pseudocalanus* sp. copepodites and *Oncaea* spp. females, using a microrespirometer system. Egg production rate of dominant copepods will be obtained from preserved multinet samples. This is possible since the dominant species with abundant adult stages were egg-carrying copepods, where numbers of egg-sacs and eggs can be estimated from preserved samples. Together, the vertical distribution of zooplankton biomass and the estimates of individual egg production, respiration, and fecal pellet production will allow for an estimate of the carbon flow in different zooplankton communities.

The zooplankton community appeared to differ between the coastal and open ocean stations, between the south and north stations, and between the Greenlandic and Canadian sides of the strait. These qualitative differences observed based on the live zooplankton catches included the abundance / dominance of late copepodite stages of *Calanus* spp., presence/absence of the arctic species *Calanus hyperboreus*, abundance of *Pseudocalanus* sp., and the abundance of small copepods *Oncaea* spp., *Oithona* spp. and *Microsetella norvegica*. Similarly, the pellet production differed between the stations, with the highest pellet production of up to 53 pellets ind.$^{-1}$ d$^{-1}$ at the stations ML03 and ML05, intermediate production (20–40 pellets ind.$^{-1}$ d$^{-1}$) along the Northern Line (NL03, NL23, and NL17) and low pellet production of < 16 pellets ind.$^{-1}$ d$^{-1}$ at the remaining stations (ML8, ML13, and ML17). The next steps in zooplankton work will include analysis of the multinet samples that will be conducted during the spring, including abundance and biomass of species.

## 8. FISH

Sampling focused on age-0 fish, mesozooplankton, and hydroacoustics (**Table 3**).

A double square net (DSN, **Fig. 5**), consisting of a rectangular frame carrying two 6-m long, 1-m$^2$ mouth aperture, square-conical nets (one 335-$\mu$m mesh, one 750-$\mu$m mesh), one 10-cm diameter cylindrical net (50 $\mu$m), two KC Denmark® flowmeters, a Scanmar® depth sensor, and two 20-kg V-fin depressors, was deployed at station ML13 on August 31, and lost during recovery due to human error (see near miss report, Annex A, in Danish). Thankfully the crew welded a 1-m$^2$ frame, repaired the DSN wires, and a Single Square Net (SSN) was assembled using a 6-m long, 500-$\mu$m mesh net, a Hydrobios® V-fin depressor, a Hydrobios® flowmeter, and a Scanmar® depth sensor (**Fig. 6**).

***Figure 5.*** *Example of a double square net (DSN) used to sample age-0 fish and mesozooplankton (not the actual DSN lost during the cruise).*

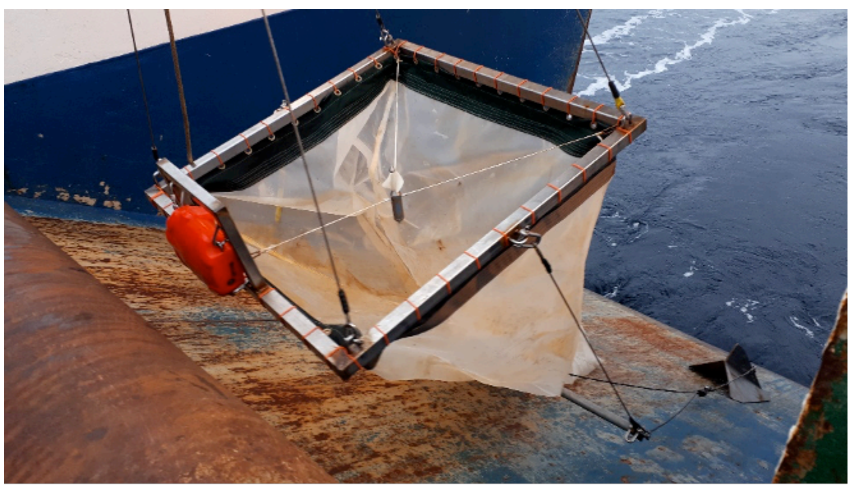

***Figure 6.*** *Single square net (SSN) used to sample age-0 fish and mesozooplankton during the cruise after the loss of the DSN.*

Thereafter, age-0 fish and mesozooplankton were sampled successfully at 13 stations using the SSN. Age-0 fish were sorted out from the zooplankton samples, measured fresh on board, photographed (**Fig. 7**), identified to the lowest taxonomical level possible, and preserved individually in 95% ethanol. Zooplankton samples were preserved in 4% buffered formaldehyde seawater solution.

The ship's hull-mounted split-beam echosounder Simrad EK60®, operating at frequencies of 18, 38, and 120 kHz, recorded continuously during the cruise, to 1000 m depth. Hydroacoustics data, CTD data and age-0 fish catch data will be used to estimate the densities of mesozooplankton, age-0 fish (mostly polar cod *Boreogadus saida*) and pelagic fish along the cruise track.

A total of 135 age-0 fish belonging to 6 families and 7 species were collected during the cruise (**Table 5**). The vast majority (90%) were polar cod.

**Table 5.** Summary of age-0 fish collected during the cruise.

| Family | Scientific Name | Common Name (FAO) | Number collected | Standard length range (mm) |
|---|---|---|---|---|
| Ammodytidae | *Ammodytes* spp. | Sand lance | 2 | 60-63 |
| Bathylagidae | *Bathylagus euryops* | Goiter blacksmelt | 1 | 26 |
| Cottidae | *Triglops' Nybelini* | Bigeye sculpin | 1 | 40 |
| Gadidae | *Boreogadus saida* | Polar cod | 122 | 17-39 |
| Liparidae | *Liparis gibbus* | Variegated snailfish | 2 | 37-39 |
| Liparidae | *Liparis fabricii* | Gelatinous snailfish | 2 | 29-35 |
| Pleuronectidae | *Hippoglossoides platessoides* | American plaice | 5 | 27-40 |


***Figure 7.*** *Examples of age-0 fish collected: Boreogadus saida (top left), Triglops nybelini (top right), Liparis gibbus (bottom left), Hippoglossoides platessoides (bottom right).*

## 9. SEABIRDS

### Background

The North Atlantic Ocean and Arctic waters support millions of breeding marine birds as well as migrants from the South-ern Hemisphere. In 2005, the Canadian Wildlife Service (CWS) of Environment and Climate Change Canada (ECCC) initiated the Eastern Canada Seabirds at Sea (ECSAS) program with the goal of identifying and minimizing the impacts of human activities on birds in the marine environment. Since that time, a scientifically rigorous protocol for collecting data at sea and a geodatabase have been developed, relationships with industry, academia, and other government departments to support offshore seabird surveys have been established, and over 150,000 km of ocean track have been surveyed by CWS-trained observers. These data are now being used to identify and address threats to birds at sea, and to investigate the role birds play as predators in marine ecosystems. CWS is taking part in the Davis Strait research program to help document changes in top-predator communities.

**Methods**

Seabird surveys were conducted from the port side of the bridge from Hirsthals, Denmark to Nuuk, Greenland between 28 August and 14 September 2020. Surveys were conducted while the ship was moving at speeds greater than 4 knots, looking forward and scanning a 90° arc to one side of the ship. All birds observed on the water within a 300-m-wide transect were recorded, and we used the snapshot approach for flying birds (intermittent sampling based on the speed of the ship) to avoid overestimating abundance of birds flying in and out of transect. Distance sampling methods were incorporated to address the variation in bird detectability. Marine mammal and other marine wildlife observations were also recorded, although surveys were not specifically designed to detect marine mammals. Details of the methods used can be found in the CWS standardized protocol for pelagic seabird surveys from moving platforms.

**Seabird Sightings**

We surveyed 3238 km of ocean from 28 August to 14 September 2020, of which 1992 km of survey effort occurred within Baffin Bay and Davis Strait. Results presented herein focus only on sightings within this region, west of Greenland (**Fig. 8**).

A total of 2586 birds were observed in transect from five families (**Table 6**). Bird densities averaged 4.3 birds ± SD 11.6 km$^{2}$ (range 0 – 149.7 birds km$^{2}$). The highest densities of birds (> 50 birds km$^{2}$) were observed in the deep water of central Baffin Bay (primarily dovekie *Alle alle* and northern fulmar *Fulmarus glacialis*), central Davis Strait (dovekie, northern fulmar, and black-legged kittiwake *Rissa tridactyla*), along the southeastern coast of the Cumberland Peninsula (dovekie) and off the southwestern coast of Greenland (dovekie and great shearwater *Ardenna gravis*) (**Fig. 8**).

Dovekie was the species most commonly observed, accounting for 61% of the sightings (**Table 6**). Dovekie breed in dense colonies (i.e., millions of individuals) along the northwestern coast of Greenland and are considered the most abundant seabird species in the eastern Arctic and north Atlantic at this time of year when they are leaving the breeding grounds to winter off the east coast of Canada (Newfoundland and Labrador, Nova Scotia). Dovekie are planktivorous and considered a good indicator of highly productive waters. The surface-feeding piscivore, black-legged kittiwake, is another common high-Arctic breeding species, which accounted for 21% of the sightings, observed in high densities across Davis Strait and along the southern coast of Greenland. Northern fulmar (another surface-feeding piscivore) was sighted throughout the survey area, accounting for 5% of the sightings. Thick-billed murre *Uria lomvia* were observed in relatively high numbers (4% of the sightings) as they moved from their Arctic breeding colonies to wintering grounds further south. Murres are deep-diving predators, regularly diving to depths of 100 m in pursuit of fish and squid. Great Shearwater (3% of the sightings) breed in the southern hemisphere but occur in Atlantic and sub-Arctic waters from April through November. Although not observed in Davis Strait or Baffin Bay, their densities were relatively high along the southern coast of Greenland. Future work will use these data combined with the physical, chemical, and biological data collected along the same sections to examine linkages between seabirds and their marine habitat.

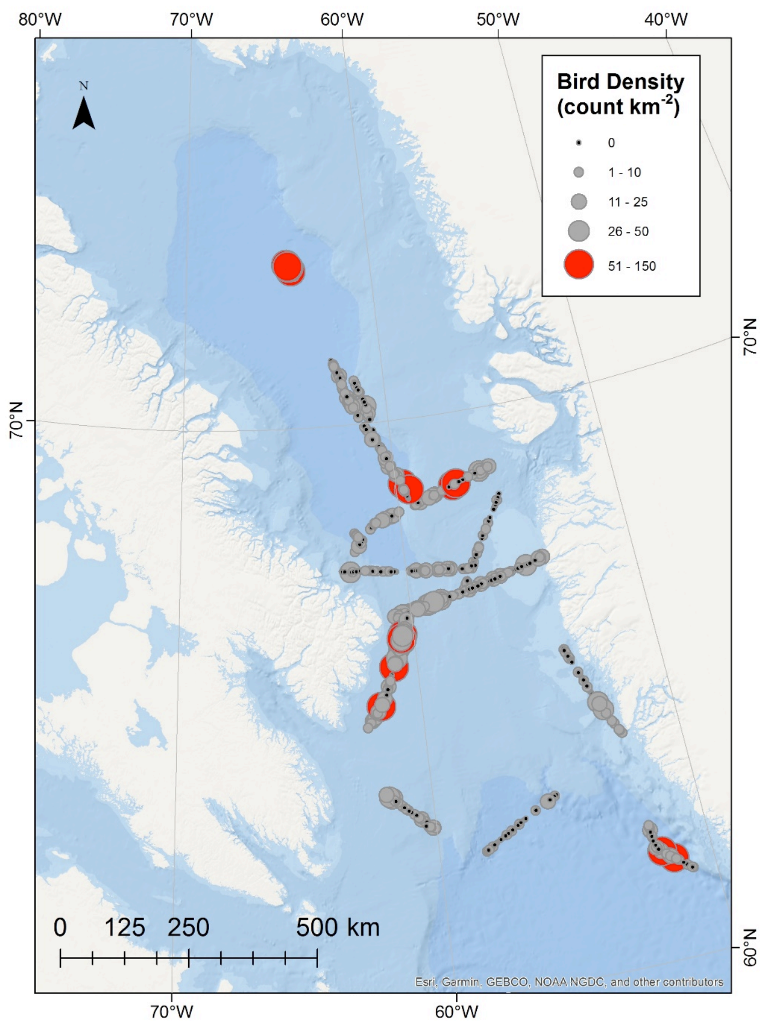


***Figure 8.*** *Density of birds observed in transect during surveys in Baffin Bay and Davis Strait region 28 August – 14 September 2020.*

**Table 6.** List of bird species observed in transect during surveys in Baffin Bay and Davis Strait 28 August –14 September 2020.

| Family | Species | Common Name | Number observed in transect |
|---|---|---|---|
| Procellariidae | *Fulmarus glacialis* | Northern Fulmar | 118 |
| | *Ardenna gravis* | Great Shearwater | 71 |
| | *Ardenna griseus* | Sooty Shearwater | 1 |
| Anatidae | *Somateria mollissima* | Common Eider | 12 |
| Scolopacidae | *Phalaropus fulicaria* | Red Phalarope | 29 |
| Lardae | *Rissa tridactyla* | Black-legged Kittiwake | 553 |
| | *Larus hyperboreus* | Glaucous Gull | 67 |
| | *Larus marinus* | Great Black-backed Gull | 4 |
| | *Larus glaucoides* | Iceland Gull | 1 |
| | *Sterna paradisaea* | Arctic Tern | 12 |
| | *Stercorarius pomarinus* | Pomarine Jaeger | 18 |
| | *Stercorarius parasiticus* | Parasitic Jaeger | 2 |
| Alcidae | *Alle alle* | Dovekie | 1580 |
| | *Uria lomvia* | Thick-billed Murre | 105 |
| | *Uria aalge* | Common Murre | 2 |
| | *Cepphus grylle* | Black Guillemot | 2 |
| | *Fratercula arctica* | Atlantic Puffin | 8 |
| | Alcidae | Unidentified alcids | 1 |
| Total | | | 2586 |

## 10. MARINE MAMMALS

During the transit from Hirtshals to Nuuk, a marine mammal watch was conducted during daylight hours from mid bridge. Surveys were conducted while the ship was moving at speeds greater than 5 knots, with visibility better than 1 km and sea states of Beaufort 5 or less looking forward and scanning 45° to starboard and port. Watches were also undertaken during transits between mooring locations. When on station, marine mammal observations were recorded as “off-effort.”

Northern bottlenose whales were the most abundant species sighted in Davis Strait. Species sighted during the crossing of the Atlantic included blue and fin whales, Atlantic whitesided, white beaked and Risso's dolphins. Also seen were pilot whales, sperm whales and killer whales. Humpback whales were seen near the coast of Greenland.

## 11. SCIENCE TEAM

| Name | Institution | Role |
|---|---|---|
| Craig Lee | Applied Physics Laboratory, Univ. of Washington | Chief Scientist |
| Kate Stafford | Applied Physics Laboratory, Univ. of Washington | PI |
| Eric Boget | Applied Physics Laboratory, Univ. of Washington | Engineer |
| Chris Archer | Applied Physics Laboratory, Univ. of Washington | Engineer |
| Holly Hogan | Canada Wildlife Service (seabird observer) | Scientist |
| Marja Koski | Danish Technical University | Scientist |
| Rafael Goncalves-Araujo | Danish Technical University | Postdoc |
| Anders Jensen | Danish Technical University | Grad Student |
| Maria Papadimitraki | Danish Technical University | Grad Student |
| Thomas Juul Pedersen | Greenland Institute of Natural Resources | Scientist |
| Caroline Bouchard | Greenland Institute of Natural Resources | Scientist |
| Else Ostermann | Greenland Institute of Natural Resources | Lab Technician |

Kumiko Azetsu-Scott and Diana Cardoso (BIO) were unable to secure a waiver to Canadian government travel restrictions, and thus could not participate as planned. DTU graduate students Andres Jensen and Maria Papadimitraki graciously volunteered, with little notice, to join the cruise and assist with biogeochemical sampling.

## 12. COVID MITIGATION

The 2020 Davis Strait cruise was undertaken during the COVID-19 pandemic that severely impacted nearly all aspects of life. Cruise execution required navigating travel restrictions, undertaking PCR testing and quarantine, and following measures designed to prevent introduction and spread of the virus onboard the ship.

Travel and mobilization posed significant challenges. To minimize the chance of bringing infection to Greenland, we elected to stage from Denmark. Travel from the U.S. to Europe was restricted at the time of the cruise, and U.S. citizens were required to provide documentation to gain an exception to the travel ban. Science team members traveling from the U.S. carried letters from the U.S. National Science Foundation and the Danish Technical University detailing the reason for travel and the quarantine measures that the travelers would follow, and documentation identifying them as on-signing members for R/V *Dana's* crew, and thus eligible for a seafarer's travel exemption. Ironically, although science team members traveling from Canada were not subject to European restrictions, Canadian travel restrictions prevented two government scientists from joining the cruise.

Prior to embarking on R/V *Dana*, the science team followed the 'gold standard' protocol defined in the UNOLS 'Coronavirus (COVID-19) Considerations for Making Decisions Regarding Conducting Science Onboard U.S. Academic Research Fleet Vessels' guidelines (v1.8, revised 1 June 2020). These guidelines have concurrence from the National Science Foundation and the Office of Naval Research and represent best practice for seagoing science operations. Personnel originating from outside Denmark and Greenland (U.S. and Canada) underwent 14 days of self-isolation near the port of embarkation (Hirtshals), housed in apartments in Grønhøj, Denmark. All personnel onboarding from abroad undertook RT-PCR testing immediately prior to travel, along with tests at day 7 and day 14 of the self-isolation period. All personnel were required to complete a health questionnaire and pass a temperature check immediately prior to boarding.

The Danish Technical University implemented additional measures designed to mitigate other pathways for infection, including restricting shipboard access to crew and essential maintenance personnel, heightened control and disinfection measures and 72-h quarantine of cargo brought aboard the vessel. All personnel (crew and science) aboard R/V *Dana* were accommodated in single staterooms, each with a private bathroom. DTU's COVID mitigation protocol prohibited people from entering staterooms other than their own, and occupants were required to clean their own staterooms and bathrooms. Individuals self-monitored their health, with instructions to report COVID symptoms. Meals were eaten in shifts designed to allow 2-m separation while waiting in line and while dining. Food was plated (rather than served buffet-style), and access to the galley and mess were restricted. Break rooms, gym, laundry, and bridge had limited occupancy. R/V *Dana* also implemented a program of frequent cleaning and disinfection, with contact points and high-traffic areas disinfected multiple times per day.

The mitigation measures added significant time on the front end of the cruise with participants quarantining for 14 days prior to embarkation and an additional 8 days of transit from Denmark to Greenland. These efforts were successful as the cruise participants remained COVID-free from embarkation in Hirtshals to disembarkation in Nuuk, Greenland.

The most significant operational impacts stemming from COVID included:

- COVID-related delays in preceding cruises restricted scientist participation, making it impossible to measure some parameters including CFCs, SF6, underway $pCO_2$.
- National and institutional variations in COVID policy made it difficult to ensure participation of all science teams and ultimately resulted in the chemistry team from the Bedford Institute of Oceanography being unable to participate in the cruise.
- Closure of Greenland to air travel and uncertainties surrounding travel to Iceland forced the cruise to start in Denmark, adding eight days of transit to the sailing schedule.
- Large added costs associated with two weeks of quarantine in Denmark, eight days of additional sea time (ship costs and science team salary), extensive COVID testing, and added transportation expenses.

## 13. REFERENCES

Azetsu-Scott, K., A. Clarke, K. Falkner, J. Hamilton, E. P. Jones, C. Lee, B. Petrie, S. Prinsenberg, M. Starr, and P. Yeats (2010). Calcium carbonate saturation states in the waters of the Canadian Arctic Archipelago and the Labrador Sea. *J. Geophys. Res.* 115, C11021, doi:10.1029/2009JC005917.

Azetsu-Scott, K., B. Petrie, P. Yeats and C. Lee (2012), Composition and fluxes of freshwater through Davis Strait using multiple chemical tracers. *J. Geophys. Res.* 117, C12011, 10.1029/2012/JC008172.

Dickson, A.G., and F.J. Millero (1987). A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. *Deep Sea Res.* 34, 1733–1743. (Corrigenda, Deep Sea Res., 36, 983).

Dickson, A.G., Sabine, C.L. and Christian, J.R., Eds. (2007). *Guide to Best Practices for Ocean CO2 Measurements*. PICES Special Publication 3, 191 pp.

Gladish, C., D. Holland and C. Lee (2015). Ocean Boundary Conditions for Jakobshavn Glacier: Part II. Provenance and Sources of Variability of Disko Bay and Ilulissat Icefjord Waters, 1990-2011. *J. Phys. Ocean.* 45, 33-63, doi:10.1175/JPO-D-14-0045.1.

Gonçalves-Araujo, R., et al. (2016). Using fluorescent dissolved organic matter to trace and distinguish the origin of Arctic surface waters. *Sci. Rep.* 6, 33978; doi:10.1038/srep33978.

Green, E.P., and Dagg, M.J. (1997). Mesozooplankton associations with medium to large marine snow aggregates in the northern Gulf of Mexico. *J. Plankton Res.* 19: 435-447.

Haine, T.W.M., B. Curry, R. Gerdes, E. Hansen, M, Karcher, C. Lee, B. Rudels, G. Spreen, L. deSteur, K.D. Stewart and R. Woodgate (2015). Arctic freshwater export: Status, mechanisms and prospects. *Global Planetary Change*, 125, 13-35, doi:10.1016/j.gloplacha.2014.11.013.

Hátún, H., Payne, M.R., Beaugrand, G., Reid, P.C., Sando, A.B., Drange, H., Hansen, B., Jacobsen, J.A., Bloch, D. (2009). Large bio-geographical shifts in the north-eastern Atlantic Ocean: From the subpolar gyre, via plankton, to blue whiting and pilot whales. *Prog. Oceanogr.* 80, 149-162.

Hátún, H., Azetsu-Scott, K., Somavilla, R. et al. (2017). The subpolar gyre regulates silicate concentrations in the North Atlantic. *Sci. Rep.* 7, 14576, doi:10.1038/s41598-017-14837-4

Holland, D.M., Thomas, R.H., de Young, B., Ribergaard, M.H., and Lyberth, B. (2008). Acceleration of Jakobshavn Isbrae triggered by warm subsurface ocean waters. *Nat. Geosci*. 1, 659–664.

Huntley, M., Strong, K., and Debgler, A. (1983). Dynamics and community structure of aooplankton in the Davis Strait and Northern Labrador Sea. *Arctic* 36: 121–225.

Jahn, A., and M.M. Holland (2013). Implications of Arctic sea ice chances for North Atlantic deep convection and the meridional overturning circulation in CCSM5-CMIP5 simulations, *Geophys. Res. Lett*. 40, 1206-1211, doi:10.1002/grl50183.

Johnson, K.M., A.E. King, and M.Mc Sieburth (1985). Coulometric $TCO_2$ analyses for marine studies: An introduction, *Mar. Chem*. 16, 61–82.

Karcher, M., Gerdes, R., Kauker, f., Kaberle, C. and Yashayaev, I. (2005). Arctic Ocean change heralds North Atlantic freshening. *Geophys. Res. Lett*. L21606, doi:10.1029/2005GL023861.

Koski, M., Valencia, B., Newstead, R., Thiele, C. (2020). The missing piece of the upper mesopelagic carbon budget? Biomass, vertical distribution and feeding of aggregate-associated copepods at the PAP site, *Prog. Oceanogr*. 181, 102243.

Myers, P.G., and Ribergaard, M.H. (2013). Warming of the polar water layer in Disko Bay and potential impact on Jakobshavn Isbrae, *J. Phys. Oceanogr*. 43(12), 2629-2640.

Prowse, T., A. Bring, J. Mård, and E. Carmack (2015). Arctic Freshwater Synthesis: Introduction, *J. Geophys. Res. Biogeosci*. 120, 2121-2131, doi:10.1002/2015JG003127.

Schuster, U., and A.J. Watson (2007). A variable and decreasing sink for atmospheric $CO_2$ in the North Atlantic, *J. Geophys. Res*. 112, C11006, doi:10.1029/2006JC003941.

Serreze, M.C., Barrett, A.P., Slater, A.G., Woodgate, R.A., Aagard, K., Lammers, R., Steele, M., Moritz, R., Meredith, M., Lee, C.M. (2006). The large-scale freshwater cycle of the Arctic, *J. Geophys. Res*. 111, C11010, doi:10.1029/2005JC003424.

Straneo, F., and P. Heimbach (2013). North Atlantic warming and the retreat of Greenland's outlet glaciers, *Nature* 504, 36–43.

Yang, Q., Dixon, T., Myers, P. et al. (2016). Recent increases in Arctic freshwater flux affects Labrador Sea convection and Atlantic overturning circulation. *Nat. Commun*. 7, 10525.