SCIENTIFIC COUNCIL MEETING – JUNE 2025

Telemetry insights for the assessment and management of Greenland halibut in NAFO SA2+Div. 3KLMNO (Newfoundland and Labrador)

by

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WHEELAND, L., BALES, B., DEVINE, B., MISIUK, B., NOVACZEK, E., & REGULAR, P. 2025. Telemetry insights for the assessment and management of Greenland halibut in NAFO SA2+Div. 3KLMNO (Newfoundland and Labrador). *NAFO Scientific Council Research Document*, SCR Doc. 25/029: 1-19.

Abstract

The Greenland halibut stock in NAFO SA 2+Div. 3KLMNO is widely distributed, and no single survey covers the whole stock area. Movement between survey areas and to depths poorly represented in survey indices have been identified as sources of uncertainty for the assessment of this stock. Telemetry data from both satellite tags and acoustic transmitters show deep-water use by large Greenland halibut and broad-scale movements within the stock area. Movement into other stock areas was not observed during this work, however, the ability to detect large-scale movements may be limited by tag deployment durations and the distribution of acoustic receivers. Recorded depth use indicates that the strata of the research vessel trawl surveys used to monitor this stock cover the depths used by Greenland halibut. However, tag data show substantial use of depths >750m, supporting the previous conclusion that surveys with incomplete deep strata coverage impair our ability to monitor older fish in this stock. Data were also reported from three Greenland sharks (*Somniosus microcephalus*) released with pop-off satellite archival tags (PSATs). As a bycatch concern in most Greenland halibut fisheries, understanding habitat overlap is important, and results indicate that PSATs can estimate overlap in habitat use between Greenland shark and Greenland halibut, and further work may help identify periods when Greenland shark are more susceptible to Greenland halibut fisheries.

Introduction

The Greenland halibut (*Reinhardtius hippoglossoides)* stock off Newfoundland and Labrador is wide ranging, with stock boundaries including the Newfoundland and Labrador Shelf (SA 2+ Div. 3K), Grand Bank (3LNO) and Flemish Cap (3M). Since 2017, TACs have been set based on a harvest control rule (HCR) and this Management Strategy was updated in 2024 (NAFO 2024).

The stock off Newfoundland and Labrador has been monitored by a series of disparate surveys conducted along NAFO SA 2+Div. 3KLMNO, none of which cover the entire stock area. Rather, portions of the stock area are sampled at different times of year, precluding the calculation of a combined index of stratified abundance or biomass for the whole stock. Partial indices are collected across seasons to inform on stock status and trends: CAN-Spring 3LNO (to 732 m), CAN-Fall 3LNO (to 1500 m in 3L, 732m in Div. 3NO), CAN-Fall 2J3K (to 1500 m), EU-Spain 3NO (to 1500 m), EU-Spain 3L (to 1500 m) and EU-Spain 3M (to 1400 m) (**Figure 1**). All of these indices, with the exception of Can-Spring 3LNO, are used to compute the HCR (SCS Doc. 24/16).

The depths sampled also differ between surveys and can vary year to year within a series. This is particularly prevalent in the CAN-Fall 2J3K index and in Div. 3L Fall where the survey allocation extends to 1500 m, but "deep" strata (defined as 750-1500 m) are often incomplete for the recent period. Given the small area and generally low survey catches in these deep strata, the surveys are still considered representative for Greenland halibut biomass trends when deep strata are incomplete (Rideout and Wheeland 2019; Rideout 2020), and therefore appropriate for use in the HCR. However, size- and age-based indices are problematic when deep strata are incomplete, as the absence of these data results in differences in calculated indices exceeding 10% for older Greenland halibut (ages 8+; Regular et al. 2020). Indices of Greenland halibut for age 8+ are therefore excluded from the age-structured operating models when deep strata were not covered (2018, 2019, 2021; Gullage et al. 2023).

Movement of Greenland halibut between survey areas and to depths poorly represented in survey indices have been identified as sources of uncertainty within the assessment of this stock. In 2022, Scientific Council recommended additional telemetry studies to help elucidate movements of this species (NAFO 2022). Here we report movement of Greenland halibut based on acoustic telemetry and pop-off satellite archival tags in Northeast Newfoundland and Labrador as it relates to current stock boundaries and survey coverage.

Additionally, in the management of Greenland halibut fisheries in the Northwest Atlantic Greenland shark (*Somniosus microcephalus)* are a bycatch concern (e.g. for Marine Stewardship Council certification assessments; e.g. Knapman et al. 2019). Data are reported here from three Greenland sharks tagged opportunistically during research programs by DFO-NL in 2022 and 2023, one of which was tagged and released alongside tagged Greenland halibut in an area of Div. 3K commonly used by the commercial fishery. Results are presented in the context of habitat use and its applicability to potential mitigation strategies to reduce bycatch.

Methods

Greenland halibut

Since 2021, Greenland halibut have been tagged with acoustic transmitters and pop-off satellite archival tags (PSATs) by DFO Newfoundland and Labrador Region in NAFO Divs. 2J3KL. Fish were caught at depths from 310 m to 943 m and released at site of capture. Tagging occurred offshore along the slope edge in Div. 2J3K and inshore in Div. 3L (Trinity Bay) (**Figure 1**).

PSATs (Wildlife Computers, Ltd., Redmond, Seattle, USA) were deployed on Greenland halibut caught via bottom-set longline and tagged during research trips in 2022 and 2023 aboard a chartered fishing vessel, the MV Patrick and William, offshore in Div. 3K and inshore in Trinity Bay (Div. 3L). Two PSAT types were used: miniPATs (N=20) and mrPATs (N=28). Tags were externally attached to the fish using titanium tag anchors. The miniPAT tags record depth and temperature used by each fish at up to 10-minute intervals for up to a year, while mrPAT tags record daily minimum and maximum temperature used for up to ~18 months. Each tag then releases from the fish and reports data collected via satellite uplink. The only positional information collected was the site of tagging and the location of tag when data are reported at tag pop-off. Geolocation light-loc data was disabled to maximize storage capacity for temperature and depth data given anticipated deep distribution of tagged animals beyond the photic zone. Only depth (miniPAT) and location (miniPAT and mrPAT) information are presented here. Tagging and tag pop-off days were excluded from data analyses in order to remove measurements as the fish descended through the water column following release, and those collected by the tag as it floated to the surface at pop-off.

Acoustic transmitters (VEMCO V13, V16) were surgically implanted in 305 Greenland halibut. These fish were captured via longline alongside the PSAT deployments, and with bottom otter trawl outfitted with a capture box specifically designed for the capture and release of flatfish (as in Albert and Vollen 2015). Acoustic transmitter releases have primarily occurred in Div. 3K (offshore) and inshore in Div. 3L (Trinity Bay), with minimal tagging occurring in Div. 2J (Table 1). Battery life for the acoustic transmitters used in this study range from ~5-10 years, and therefore results presented here are the start of the series for these fish and will be updated as more detection data are collected.

Movements of acoustically tagged Greenland halibut within the NL Region are recorded by moored acoustic receivers (**Figure 1**) set by DFO-NL and the Northern Cod Acoustic Telemetry (NCAT) project. Additional detections within NL and in adjacent areas can be recorded from partners within the Ocean Tracking Network (see https://members.oceantrack.org/). Receivers from these programs can record fish movements within the NL Region and can detect movements to adjacent areas where receivers are present. The DFO-NL and NCAT acoustic receivers offshore range from 200-538 m, while the receivers inshore in Trinity Bay targeting Greenland halibut are deployed at 200-585 m. Technical specifications limit the deployment of acoustic receivers in deeper waters, restricting the ability to detect deeper movements of these fish.

Fish were only tagged if they were assessed to be in excellent physical condition and were large enough that tag weight in air was <2% of fish weight. When fish weight could not be measured at sea, established length:weight relationships were used to estimate fish weight and a conservative length-based cut-off was applied. PSATs were deployed on fish between 46 and 92 cm total length, while acoustic transmitters were implanted in fish 36 to 88 cm. Due to their relatively large size, miniPAT tags were only deployed on fish of total length 70 cm or greater.

Acoustic detections reported here cover data received to date for detections from date of tagging through October 6, 2024.

Greenland shark

Three Greenland sharks were captured and tagged opportunistically offshore in NAFO Div. 2H (N=2) and Div. 3K (N=1) (Figure 2). Sharks were each tagged with a single miniPAT tag set to record at 600 second intervals for up to 365 days. As with the Greenland halibut, geolocation light-loc data was disabled given anticipated deep distribution of tagged animals.

One female Greenland was caught at 583 m on a bottom longline baited with commercial squid (*Illex* sp.) during a DFO-NL Greenland halibut tagging trip in NAFO Div. 3K. Vessel window height from waterline precluded tagging near the dorsal fin, therefore the tag was inserted through a small incision in the upper lobe of the caudal fin using a domier umbrella dart. Total length was visually estimated to be ~3 m.

Two Greenland sharks were captured using a Campelen 1800 bottom trawl during the 2023 DFO-NL Fall Multispecies Trawl Survey aboard the CCGS *John Cabot*. Both sharks were caught in the same tow (standard

15-minute survey tow duration) spanning depths from 514 to 536 m (mean 522 m) and a bottom temperature of 4.3°C. Sharks were landed on vessel deck and health condition was assessed to ensure the animals were fit for tagging. Each Greenland shark was then measured for total length and sex was recorded. Tags were attached to each animal using a nylon domier umbrella dart inserted into the dorsal musculature near the first dorsal fin. Both sharks were released down the stern ramp.

Results

Greenland halibut

Acoustic transmitters:

Of the acoustic transmitters deployed, 17% have been detected to date, with most detections within the same Division they were tagged in (Table 2). All acoustic transmitter detections to date have been within the NL stock area. One fish tagged with an acoustic transmitter in Trinity Bay was detected offshore 3K, while to date all others tagged in Trinity Bay have only been detected within the bay. Detections show both year-round use of the NL shelf edge, and year-round use of Trinity Bay (inshore Div. 3L) (Figure 3). Most detections came from fish 55 to 74 cm in length (Figure 3).

PSAT tags:

Locations at tag pop-off were received from 27 of the PSAT tagged Greenland halibut (miniPAT and mrPATs) Tag deployment duration ranged from 12 to 475 days. All of these tags reported from within the NL stock area at pop-off, with locations reported in Div. 2H (N=1), 2J (N=1), 3K (N=12), and 3L (7 in Trinity Bay, 6 offshore). All PSATs deployed in Trinity Bay were within the bay at tag pop-off.

Depth information is available from eleven miniPAT tags. Data are reported here with a focus on fish tagged offshore (N=8) in order to be comparable to the coverage of the trawl surveys. The number of individual depth records per fish ranged from 240 to 26,832 based on the duration of the tag deployment and resolution of the transmitted data upon pop-off (data transmission differs based on remaining battery life at tag pop, cloud cover, etc.). Trinity Bay (N=3) is outside of the current survey area; these fish primarily occupied the deepest parts of the bay at ~600 m (**Figure 5**).

Three of the fish in the offshore recorded depths >1500 m, reaching a max depth of 1681 m (Figure 6). However, the proportion of depth reports >1500 m for each of these three ranged from 0.5 to 3% indicating only a small amount of time was spent beyond the range of the trawl survey coverage. All of the fish offshore spent time >750 m, with 68 to 100% of depth records by fish occurring >750m (Figure 7). There was no seasonal trend evident in the amount of time spent beyond 750 m (Figure 8).

Greenland sharks

Data was received from miniPAT tags for all three sharks, with tag deployments of 43 days and 51 days for the two sharks tagged during the DFO RV survey, and 544 days for the shark tagged during the longline trip. Daily depth and temperature profiles for all three sharks here indicate both benthic and pelagic behaviour.

Data transmission for Shark ID 241326 ("Concrete") (Figure 9) was minimal, with only 8 days of depth data and 7 days of temperature data received. An accurate pop-off location was not obtained; time-series data suggest the tag remained on the shark for only ~2 months before depth records indicate the tag at the surface (possibly due to poor retention of muscle-anchored tags in this species). An internal reset error likely occurred which prevented the tag from initiating surface detection data transmission, resulting in no pop-off location. Depth ranged from 108 to 849 m, at temperatures of 4.2 to 4.6°C. The depth and temperature data received all overlap with known habitat for Greenland halibut and conditions common to the slope edge area of the NL shelf.

Shark ID 241330 ("Barbie") (Figure 10) transmitted data collected from release in mid-September 2023 through mid-November 2023. This shark occupied depths from 158 to 1901 m, at temperatures from 2.9 to 4.7°C. Depth use reached just over 1000 m in late September, and in October were generally between 200-600 m, slowly deepening throughout the month. At the start of November this shark shifted to deeper waters, moving from ~500 to 1500 m over on Nov. 1st and then remaining below 1500 m for the rest of the tag deployment. Data indicate that this shark dove deeper than the limits of the tag specifications reporting a maximum depth of 1901 m triggering premature auto-release of the tag to prevent damage. This shark was tagged in NAFO Div. 2H and at tag pop-off this shark was still in this area.

Shark ID 213595 ("Cletus") (Figure 11) was tagged along the slope edge in NAFO Div. 3K in March 2022 and when the tag released from this fish in September 2023 it was near the mid-Atlantic ridge approximately 575 nautical miles (~1000 km) east of the edge of the Flemish Cap (Figure 7). Depth and temperature information collected with this tag suggest the shark was along the Newfoundland and Labrador shelf edge from tagging in March through the start of July, using a broad range of depths (93 to 1209 m) at temperatures ranging from 0.8 to 5.3°C. Following this, there was a marked change in depth and temperature occupied for the remainder of the tag duration, occupying depths primarily between 500 to 1000 m and warmer temperatures between 5 to 10°C, likely corresponding to departure from the NL Shelf eastward across the North Atlantic. Time-series data indicate a brief anomaly in depth-temperature occupied in early August when for approximately 1 hour the shark moved into epipelagic waters as shallow as 75 m and temperatures reached 17.3°C. The depth and temperature data combined with the tag pop-off location indicate this shark occupied areas of Greenland halibut distribution (and likely areas where commercial fishing occurs, given its tagging location) through spring and early summer before leaving the NL shelf and travelling eastward into open-ocean.

Discussion

Telemetry information presented here is consistent with known distribution and habitat use of Greenland halibut. Positional information from both acoustic and PSAT tags has fallen within the defined stock boundary, showing north-south movements offshore in Div. 2HJ3KL, and inshore-offshore connections. Year-round use of both offshore shelf slope areas and inshore bay habitat is evident.

There is clearly movement of individuals between survey areas (e.g. Fall 2J3K to Fall 3LNO). As there are no acoustic receivers deployed on the Flemish Cap or outside 200 nm on the Grand Bank we cannot detect movement between the Canadian survey areas and EU-Spain survey areas used to monitor this stock with the acoustic transmitters. No locations from PSATs were received from Div. 3M or Div. 3NO. Reported acoustic detections confirm presence, whereas an absence of detections does not necessarily indicate absence as fish may be outside the detection range of receivers. Notably, receivers are limited in depth to ~ 500 m which limits detectability, especially for larger Greenland halibut as individuals tend to move to deeper water as they grow. Acoustic detections are limited for largest tagged individuals (Figure 5), which likely spend their time deeper than array coverage. Detections are also limited for fish <54 cm; these smaller fish may be primarily using areas on top of the banks, shallower than the range of the current acoustic receiver array in that area.

Acoustic transmitters should continue to report for years to come. This longer time-scale movement may increase insight into connectivity with adjacent areas as fish have more time to travel greater distances. These data may inform on changes of behavior with aging or associated with maturation and spawning. While tags will continue to operate, our ability to detect these fish relies on the long-term maintenance of receiver arrays.

Trinity Bay is located outside of the area covered by any of the current trawl surveys used to inform the assessment of this stock, though here we see year-round use of this area by relatively large Greenland halibut. Inshore strata that are no longer surveyed – including Trinity Bay – are now excluded from the stratified analyses in order to produce a more consistent index (Regular 2023). Though these strata were occupied by Greenland halibut, the area is relatively small and, as such, the exclusion of these data had a minor impact on the indices (<5% difference).

Depth use reported by tagged Greenland halibut in this study generally within the depths covered by the CAN-Fall survey and the EU-Spain surveys. Few fish moved deeper than 1500 m, and those that did had a negligible proportion of records at these depths (0.5 to 3%). However, large Greenland halibut offshore are spending the vast majority of their time at depths >750 m. As Greenland halibut are known to shift their distribution in response to changes in oceanographic conditions, with responses differing across size and age (Wheeland and Morgan 2020) the relative impact of missing the deep strata is also likely to change across time.

All surveys used in the operating models and in the harvest control rule demonstrate dome-shape catchability. While the fishery is capable of selecting Greenland halibut ages 6+, the catchability of these larger individuals in trawl surveys tend to decrease, reaching a minimum for ages 10+. Relatively poor catchability of older Greenland halibut aligns with observations from the results presented here as it provides further evidence that older Greenland halibut shift to waters deeper than covered by the spring survey. The dome-shape appears to be most pronounced for surveys that do not cover the deep strata. Finally, the effect would be exacerbated when deep strata are missed. Since ages 10+ are thought to constitute the mature, spawning, component of the population, it is critical that data from deep strata continue to be collected as absence of these data will add uncertainty to the trends in spawning stock biomass. However, we note that dome-shaped catchability is also evident in surveys covering the deep strata and this is likely influenced by the higher ability of large Greenland halibut to outswim the survey trawl given low trawl speed and short tow duration.

Tag data for Greenland shark indicate use of depths and temperatures consistent with those occupied by Greenland halibut in the RV survey. Cletus appeared to use these habitats for a small portion of the tag duration (approximately 4 months) prior to moving eastward to oceanic waters, as indicated by a change in depth-temperature profiles and pop-off location. This may be further supported by the depth-temperature anomaly occurring in August where the tag briefly recorded a temperature of 17.3°C extending to a depth of 200 m, a temperature profile consistent with warm-core mesoscale eddies in the region (Devine et al. 2021). Although deployment times were shorter for Concrete and Barbie (approximately 2 months), both sharks also used similar depths and temperatures common to Greenland halibut and likely overlapped with Greenland halibut fishing areas during this period. Prior to tag release, Barbie moved to significantly deeper waters – likely outside the range of the fishery in November. Although the exact tag pop-off location for Concrete is unknown, depth-temperature data recorded from the time preceding tag reporting are characteristic of NL shelf conditions. This suggests the shark was likely still in the region in November. While sample sizes are low here, these case studies suggest that additional tagging may be useful to explore seasonal patterns in habitat use and potential spatiotemporal overlap with Greenland halibut fishing areas.

There is currently insufficient information to inform on feasibility of potential seasonal fishing restrictions to mitigate Greenland shark bycatch. However, PSAT tags alone would be minimally informative for spatial overlap as depths used by this deepwater species limits geolocation data needed to examine detailed movements. Acoustic transmitters could be useful for undertaking fine-scale movement comparisons between Greenland shark and Greenland halibut, though there is currently inadequate acoustic receiver coverage across the range of habitats used by both species. Expansion of regional acoustic telemetry networks may establish large-scale movement patterns of value to inform mitigation strategies to reduce bycatch interactions, though technical limitations of deploying receivers at the deep range of either species' habitat use will be a challenge.

Conclusions

Greenland halibut are highly mobile within the SA 2+3KLMNO stock, using a wide range of depths and both inshore and offshore habitats. Individuals move between survey areas used for the various indices that inform the assessment and HCR for this stock. Results are consistent with survey observations of deep-water use by large Greenland halibut, and previous mark-recapture tagging that shows movement within the stock area. None of our observations here show movement into other stock areas, though Greenland halibut are known to make broad-scale movements across management boundaries (Vihtakari et al. 2022). The ability to detect these large-scale movements may be limited here by duration of tag deployments and/or acoustic receiver distribution.

The strata of the research vessel trawl surveys used to monitor this stock well cover the depths used by Greenland halibut with very few records occurring deeper than 1500 m. However, results here support the previous conclusions that surveys with incomplete deep strata (>750 m) impair our ability to monitor older fish in this Greenland halibut stock. It is critical that data from deep strata continue to be collected as absence of these data will add uncertainty to the trends in spawning stock biomass.

Due to limited sample size, there is currently insufficient information to inform on feasibility of potential fishing restrictions to mitigate Greenland shark bycatch. PSAT tags can effectively measure overlap in habitat use between a commercial species and a species of conservation concern, and further work may be useful to inform on times when these sharks are likely to be in areas of Greenland halibut habitat and likely to be exposed to fishing effort.

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Table 1. Number of Greenland halibut tagged with each kind of tag (Pop-off archival satellite tag "PSAT", acoustic transmitter) from 2021 through 2024.

	PSAT		Acoustic Transmitter	
Year	MINIPAT	MR PAT	V13	V16
2021	.	.	76	4
2022	17	24	13	38
2023	3	4	75	26
2024	9	.	.	73

Table 2. Summary of detected movements by NAFO Division. All Greenland halibut tagged in Trinity Bay (inshore 3L) have only been detected in Trinity Bay with the exception of one that was detected offshore in Div. 3K. Five fish tagged in Div. 3K have been detected both in 3K and another NAFO Division (2J, 3L), while others have been detected only in Div. 3K or only offshore in Div. 3L.

Tagged in:	Detected in:	Number of Greenland halibut:
Trinity Bay	Trinity Bay	17
Trinity Bay	Div. 3K	1
Div. 3K	Div. 3K	10
Div. 3K	Div. 2J & 3K	1
Div. 3K	Div. 3K & 3L	4
Div. 3K	Div. 3L	2

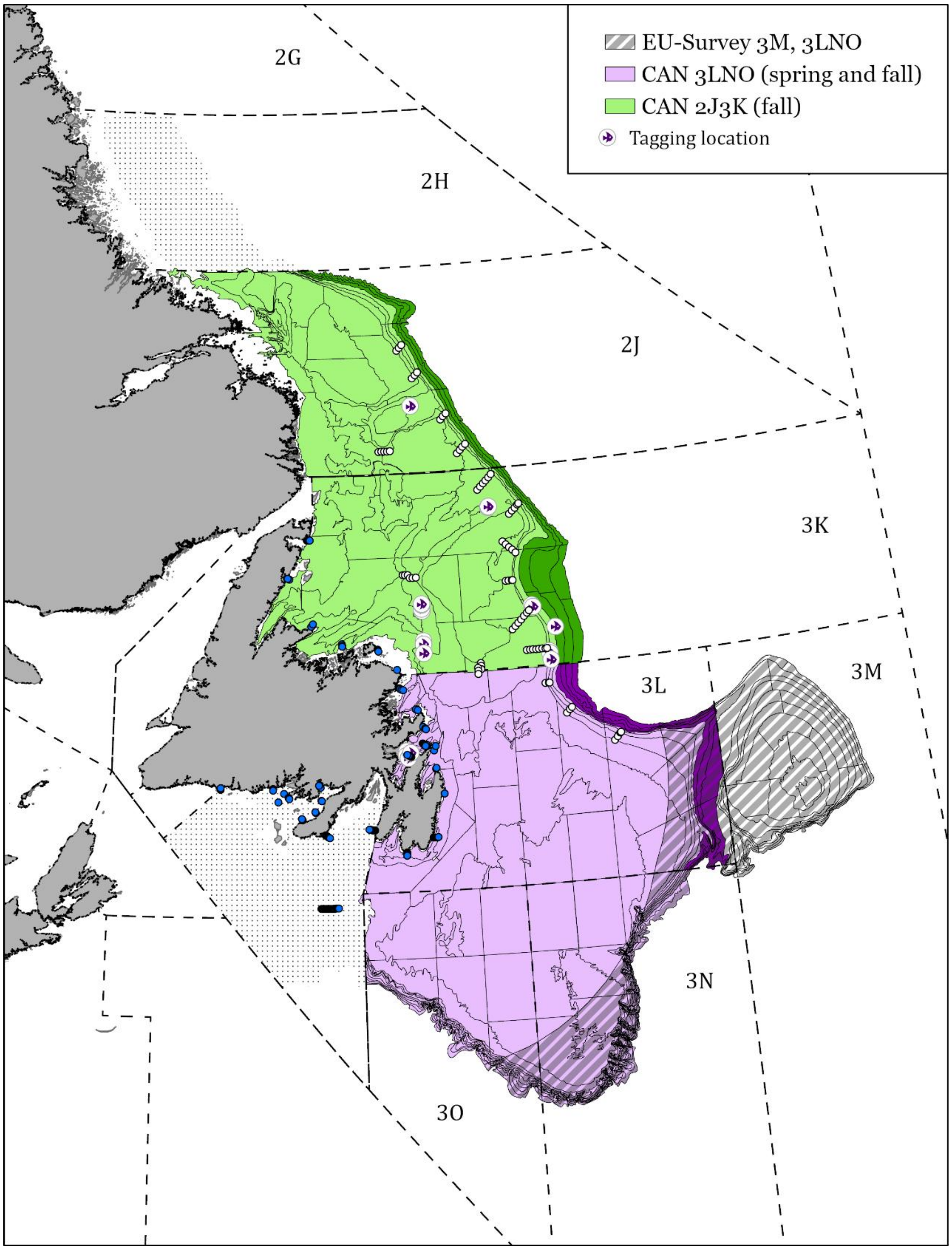

Figure 1. Survey areas used for indices of Greenland halibut in NAFO SA2+Div. 3KLMNO. Darker areas within the CAN surveys mark the "deep" strata >750 m. Dotted areas in Div. 2H and 3P show area within the CAN-NL fall and spring surveys, respectively, that are not used in the Greenland halibut assessment. Tagging locations (acoustic transmitters, PSATs) are shown with fish icons. Points show locations of acoustic receivers deployed by DFO-NL Groundfish (blue) and the collaborative Northern Cod Acoustic Telemetry (NCAT) project (white) from 2021-2024.

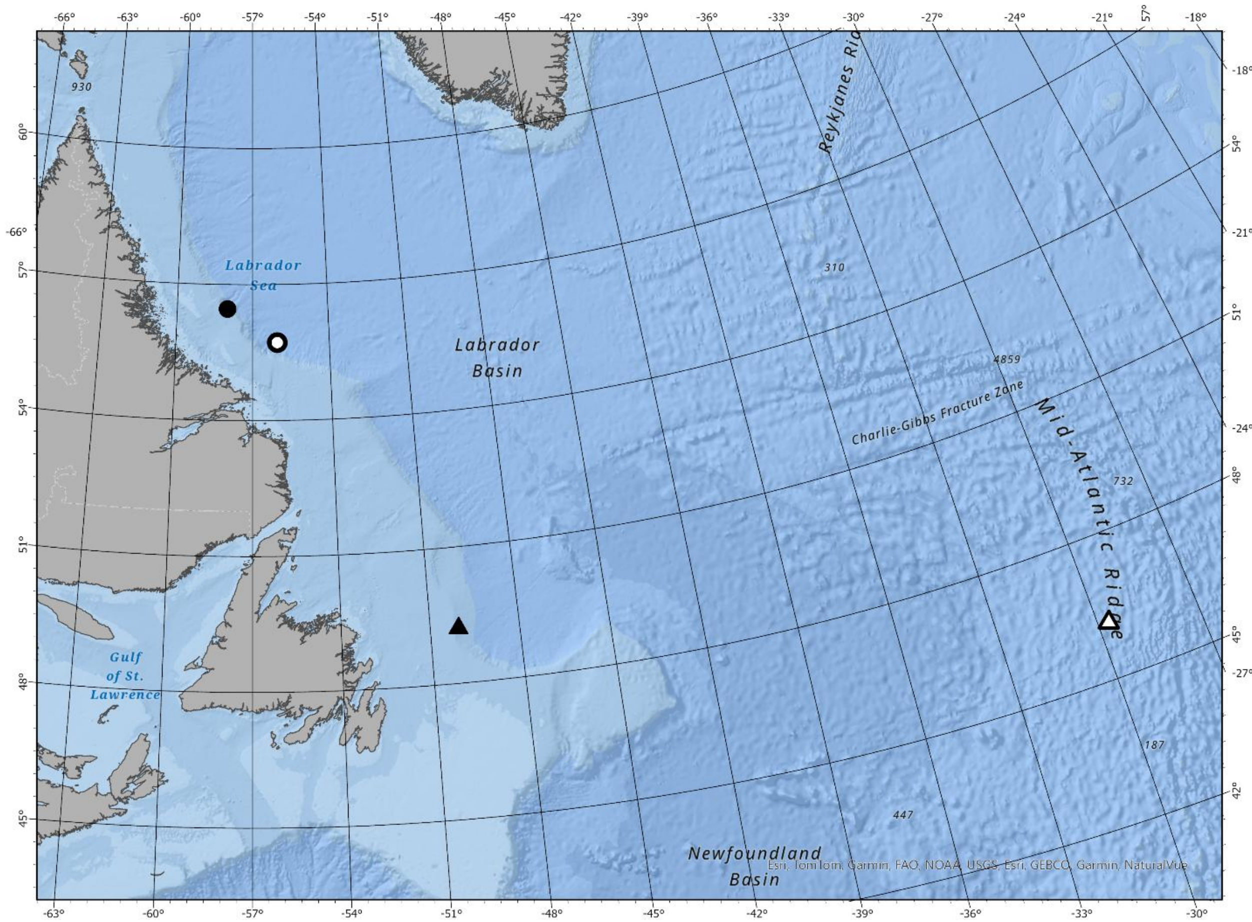

Figure 2. Tagging (black) and tag pop-off (white) locations for two Greenland sharks (Barbie = circle, Cletus = triangle). Note: Concrete was tagged at same location as Barbie (black circle) but pop-off location could not be determined.

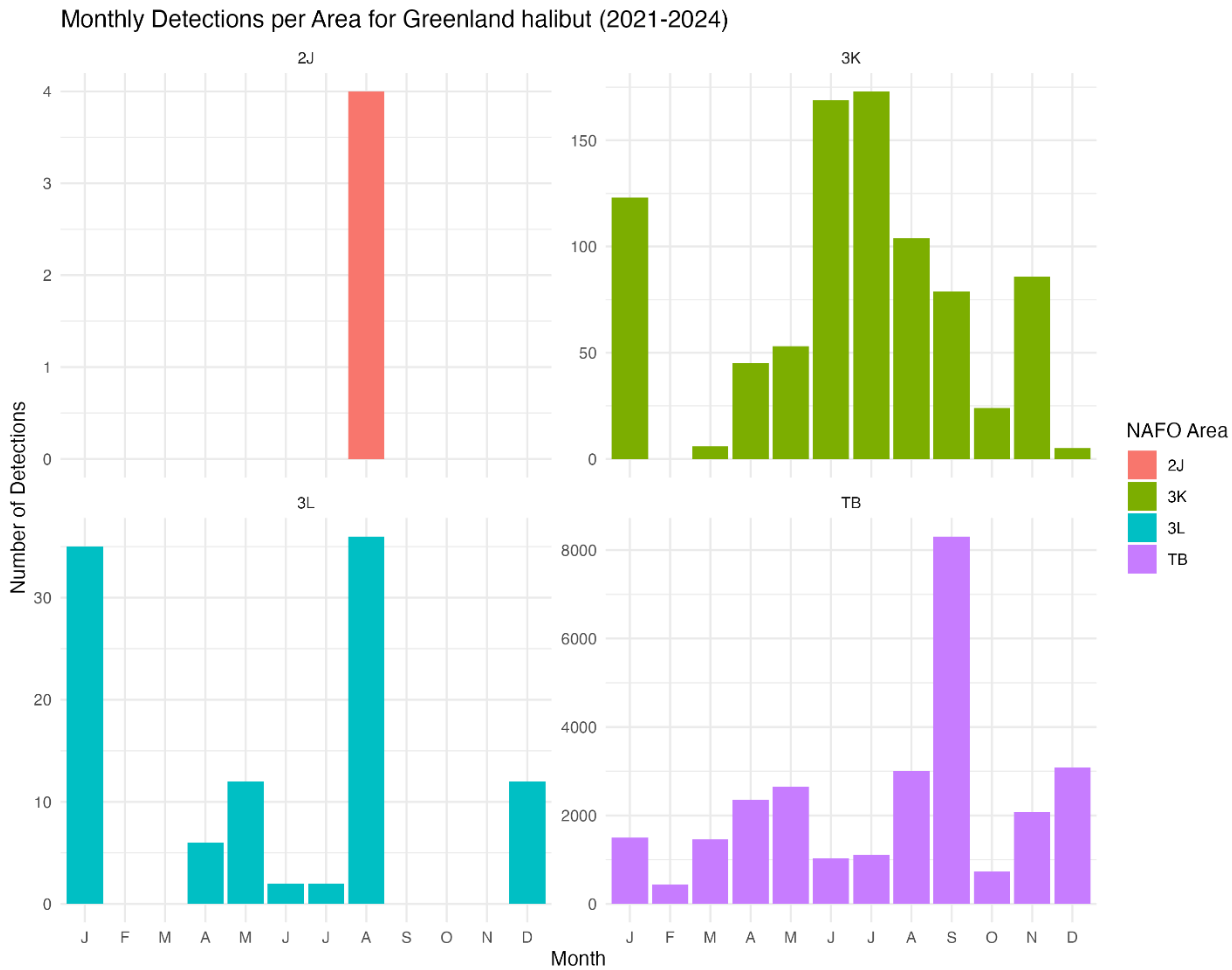

Figure 3. Number of detections at acoustic receivers on the Newfoundland and Labrador Shelf by NAFO Division and in Trinity Bay (TB).

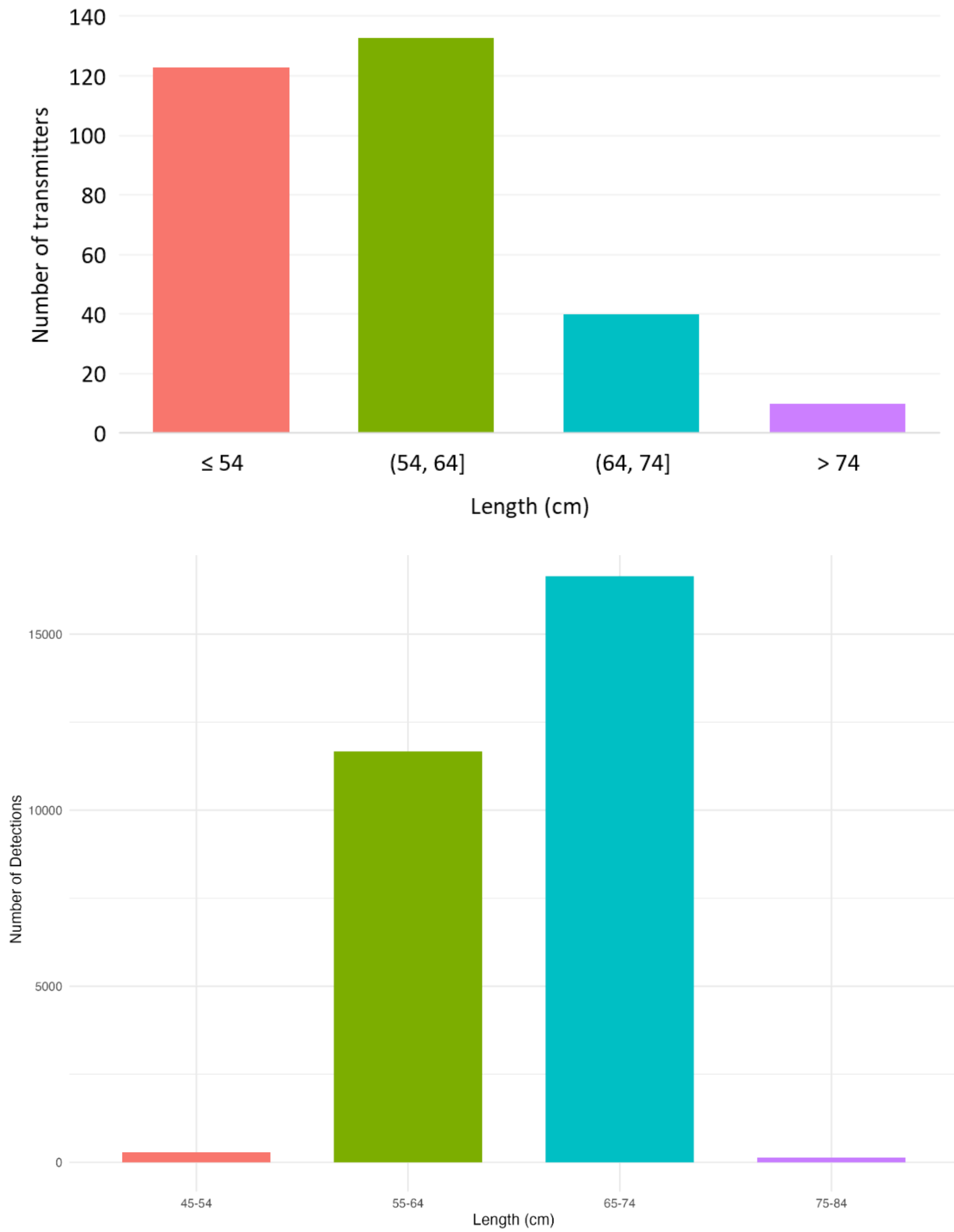

Figure 4. Number of transmitters deployed (top) and number of acoustic detections (bottom) by length.

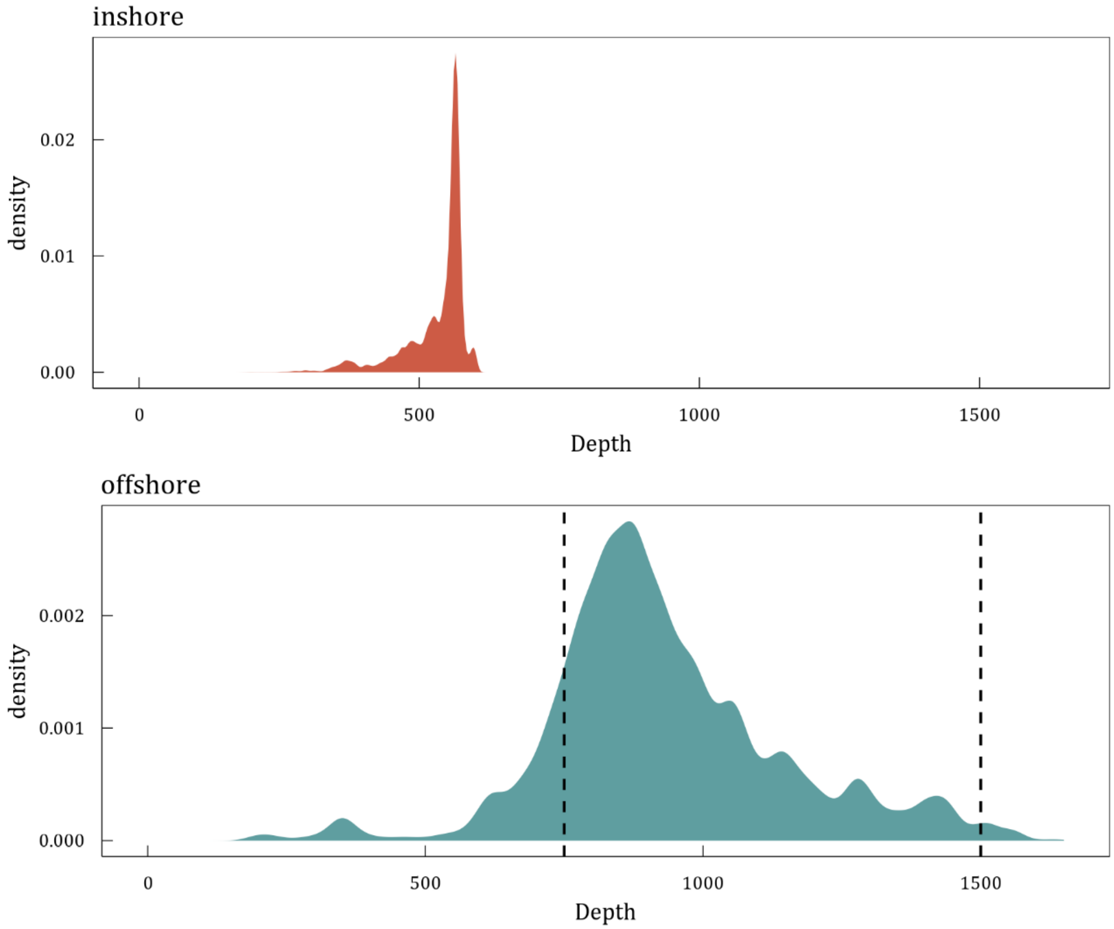

Figure 5. Density of depth records from miniPAT tags on Greenland halibut tagged inshore (Trinity Bay) and offshore (Div. 3K). Inshore fish reached a maximum depth of 602 m, at or near the maximum depth available in Trinity Bay. Vertical dashed lines are located at 750 m and 1500 m in the offshore panel demarking depth boundaries for the “deep strata” in the CAN trawl surveys.

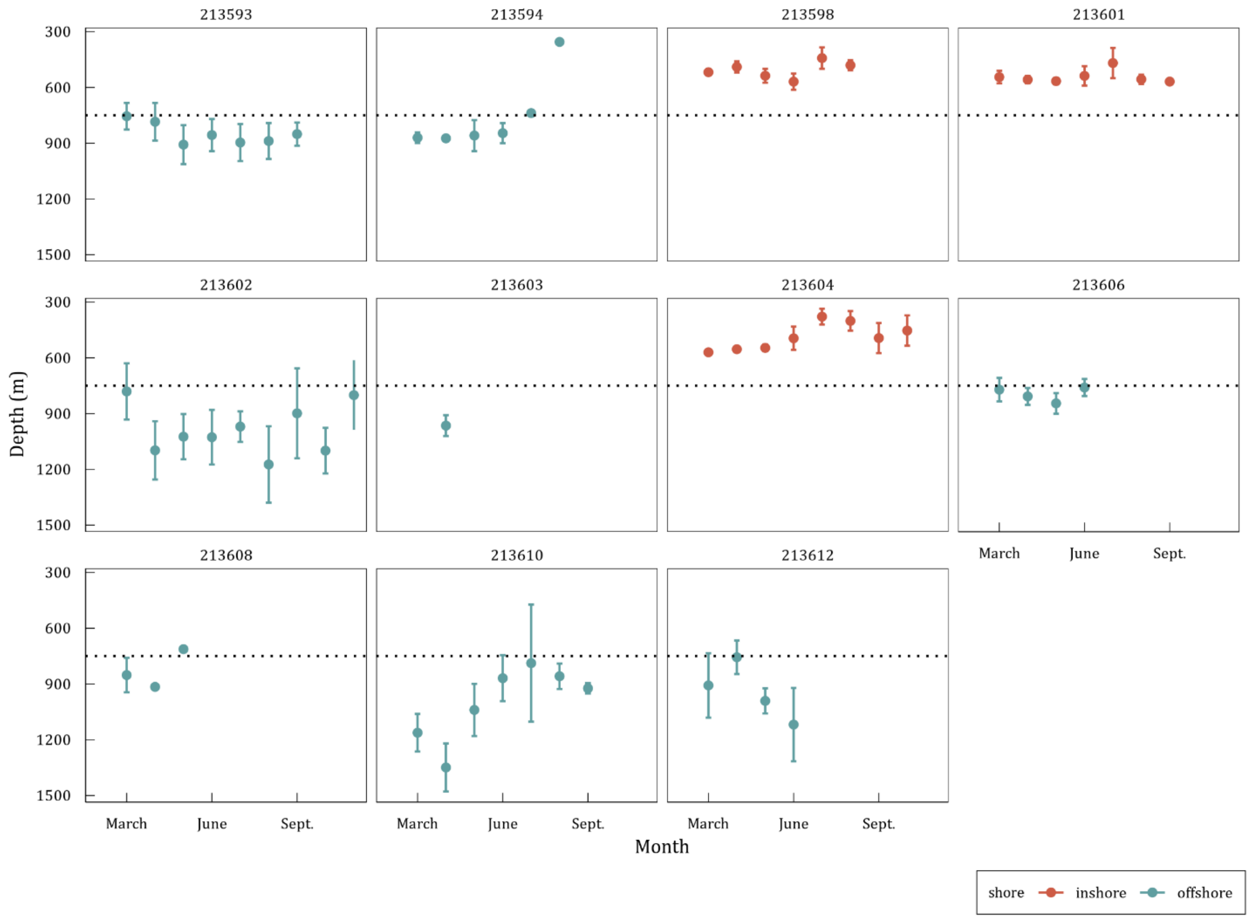

Figure 6. Mean (+/- SD) depth reported by each tagged Greenland halibut by month. Fish IDs 213598, 213601, 213604 were inshore in Trinity Bay and are not considered for proportion of time >750 m.

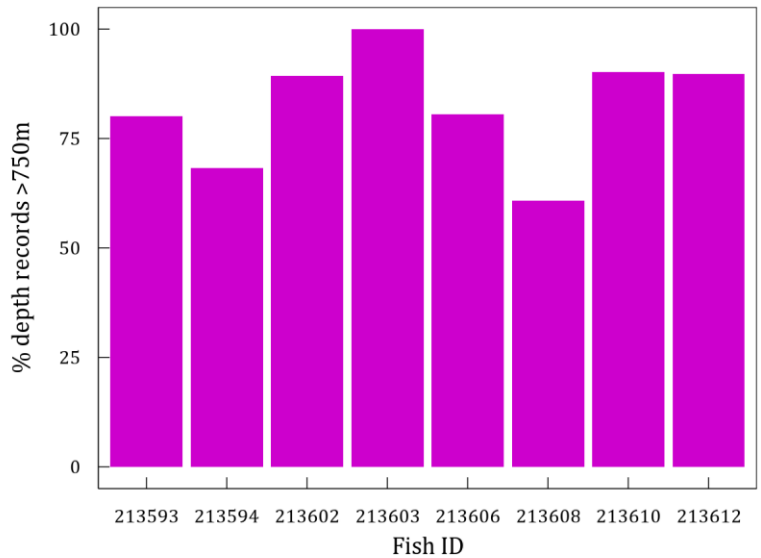

Figure 7. Proportion of depth records >750 m over the course of the deployment (bottom) for each miniPAT tag reported from offshore NL. Each panel shows a different Greenland halibut, with number indicating the tag ID.

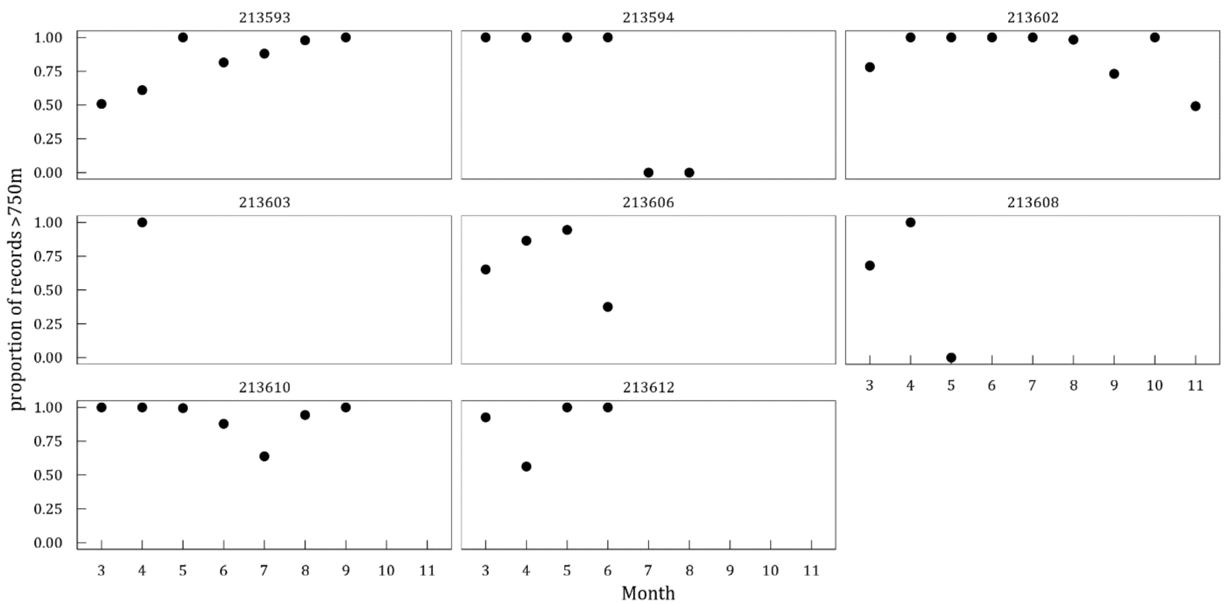

Figure 8. Proportion of depth records >750 m by month for each miniPAT tag reported from offshore NL. Each panel shows a different Greenland halibut, with number indicating the tag ID.

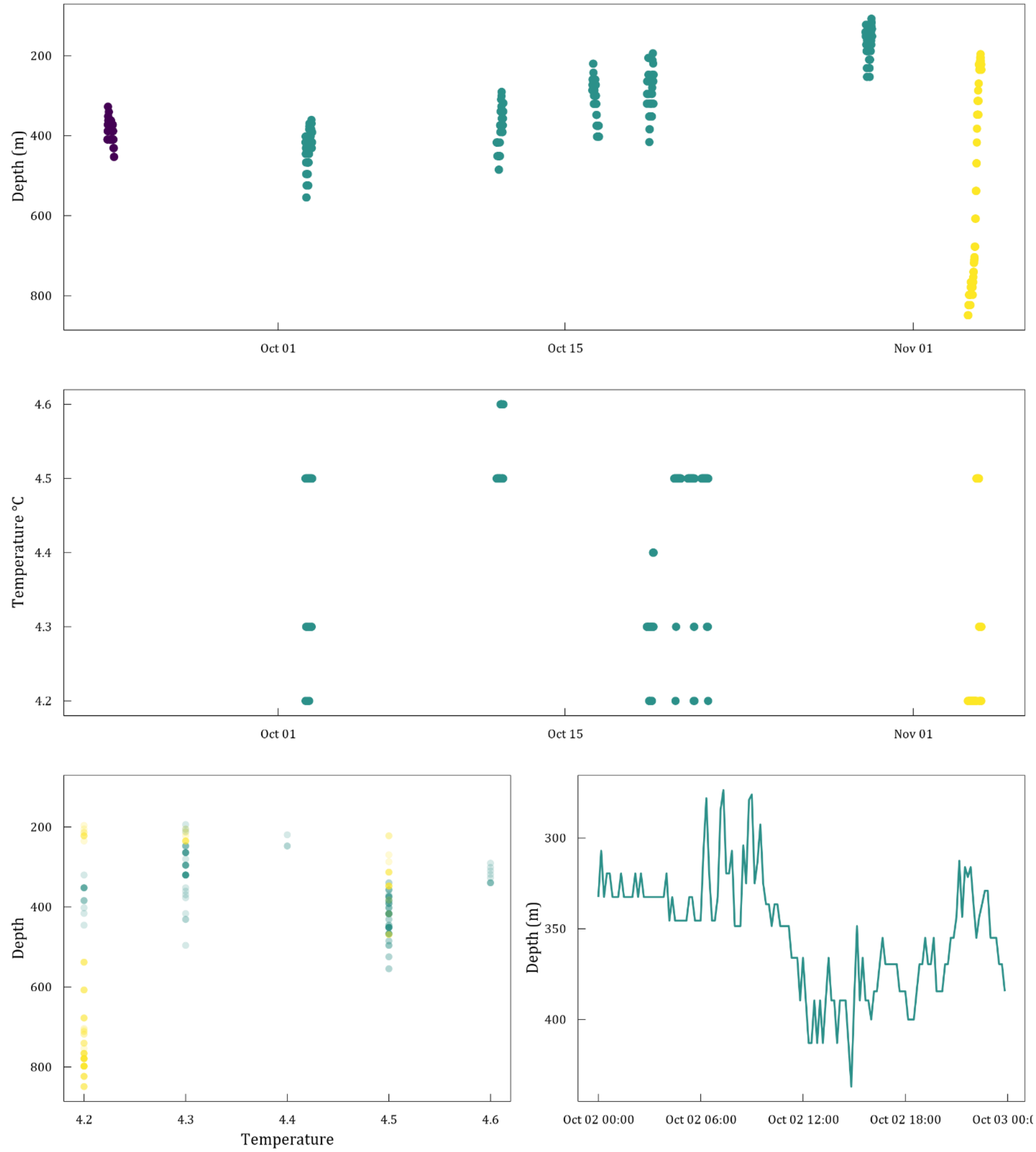

Figure 9. Depth (top) and Temperature (middle) timeseries collected by Shark ID 241326 "Concrete" along with plots of temperature at depth (bottom left) and a single day depth track (bottom right) as an example of daily movement patterns. Times are in UTC. Colours show months from purple (September) through yellow (November).

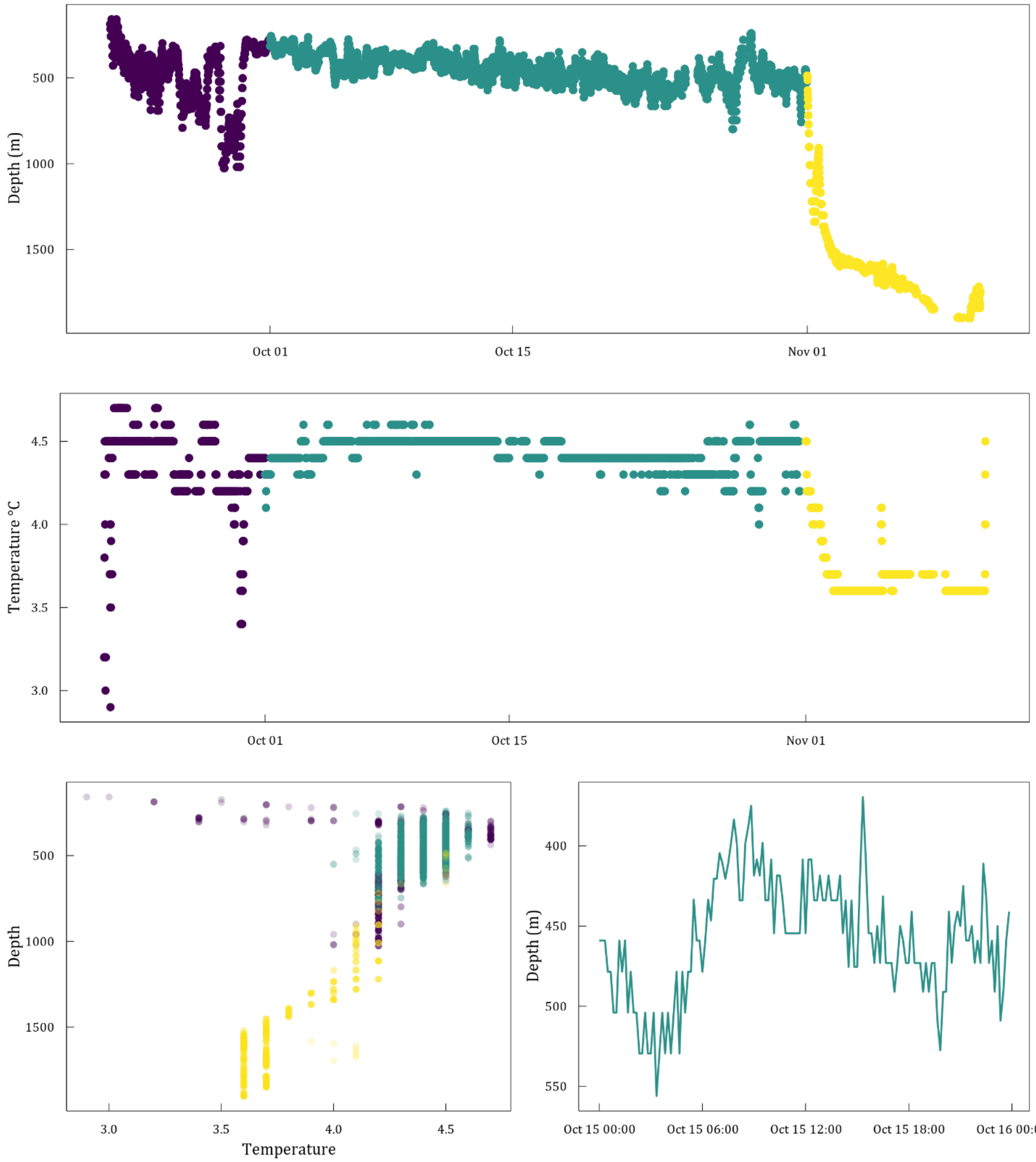

Figure 10. Depth (top) and Temperature (middle) timeseries collected by Shark ID 241330 "Barbie" along with plots of temperature at depth (bottom left) and a single day depth track (bottom right) as an example of daily movement patterns. Times are in UTC. Colours show months from purple (September) through yellow (November).

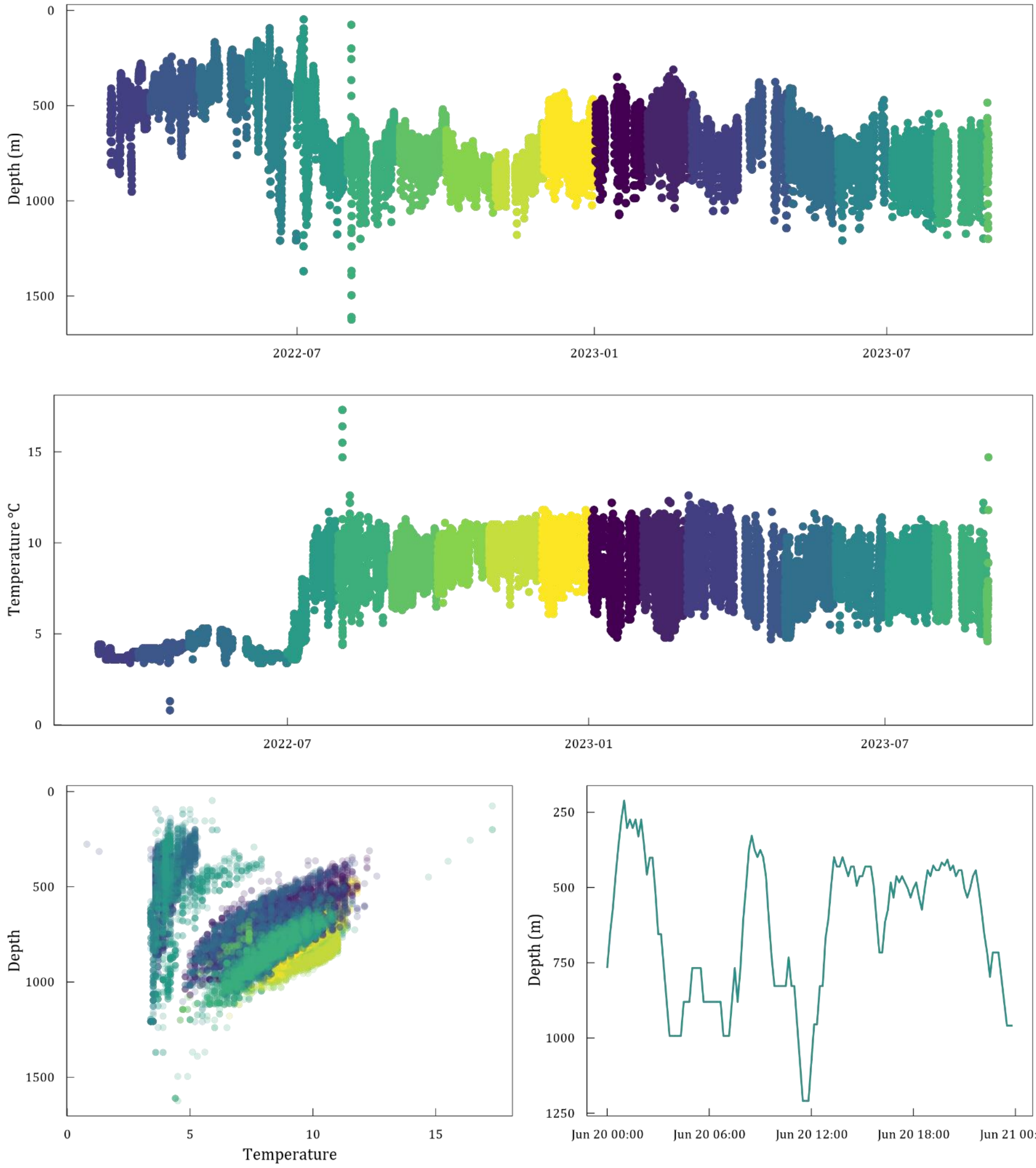

Figure 11. Depth (top) and Temperature (middle) time series collected by Shark ID 213595 "Cletus" along with plots of temperature at depth (bottom left) and a single day depth track (bottom right) as an example of daily movement patterns. Times are in UTC. Colours show months of the year from Purple (January) through yellow (December).