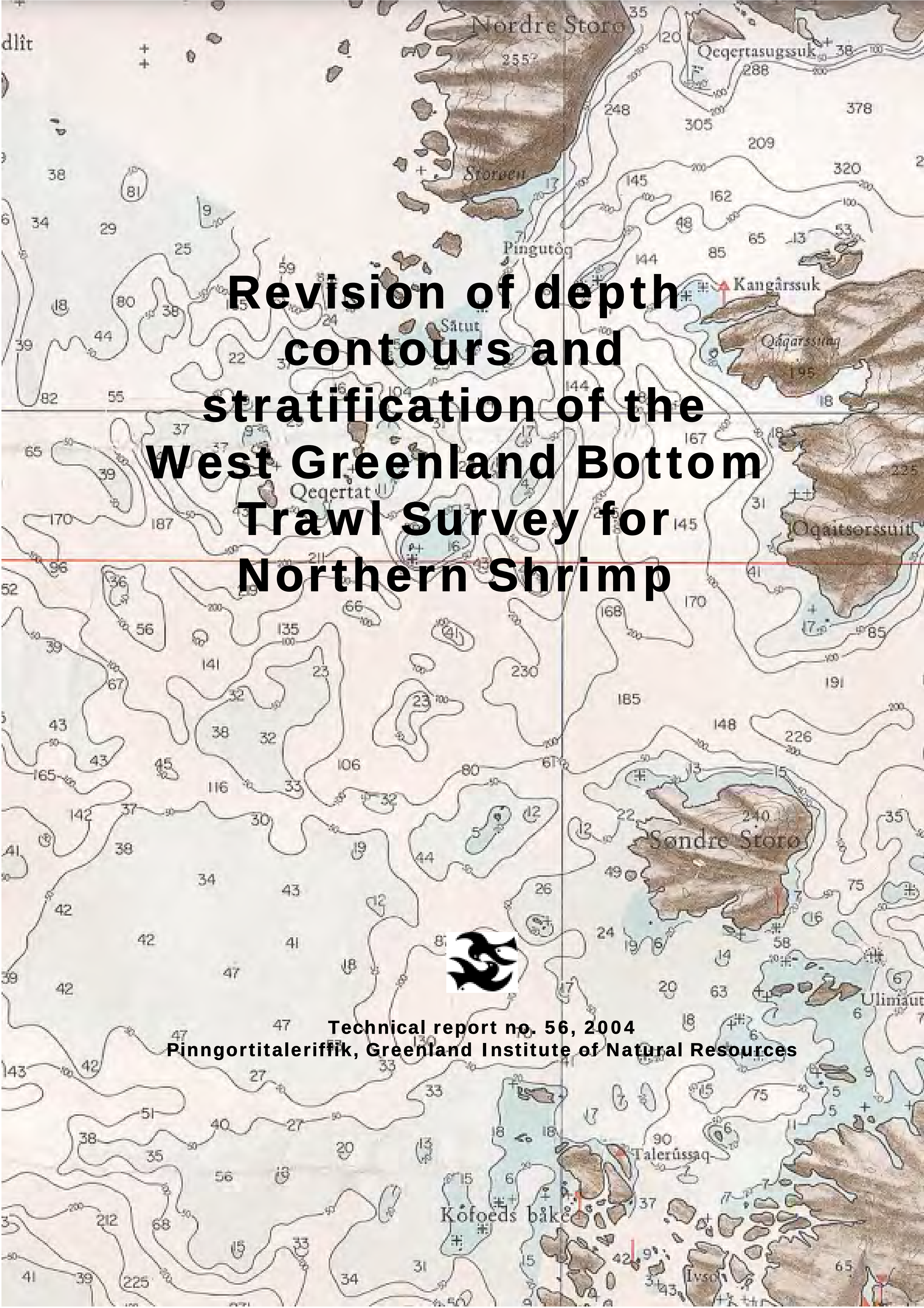


# Revision of depth contours and stratification of the West Greenland Bottom Trawl Survey for Northern Shrimp

Technical report no. 56, 2004
Pinngortitaleriffik, Greenland Institute of Natural Resources

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# Revision of depth contours and stratification of the West Greenland Bottom Trawl Survey for Northern Shrimp

by

Kai Wieland and Per Kanneworff

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# Contents

# Eqikkaaneq

Kitaata sineriaani rejenik aalisakkanillu ukiumoortumik Pinngortitaleriffiup misissuiffigisartagaata annersaani paasissutissat itisuumi uuttortaanermit pisut naammaginartumik tutsuiginassusillit suli pigineqanngillat. Taamaattumik paasissutissat itisuumi kilisannermit aammalu Paamiut misissuinerani angallavigineqartuni pissarsiat immikkut suliarineqaratik katiterneqarput. Nalilersuinermi uani paasissutissanut tunngavigineqartunut tapiliunneqarput qaammataasaq atorlugu itisuumi uuttortaanernit paasisat.

Kitaani kilisalluni Pinngortitaleriffiup misissuisarnerani tunngaviusup immap naqqata qaleriiaarneranut tunngasup nalileqqinnissaanut itissutsip isikkuata suliarinissaanut periuseq suut tigussaasut oqimaaqatigiinnerannik oqariartuutitalik atorneqarpoq. Sumiiffik misissuiffigineqartoq tassaavoq avannarpasissutsip 59-p 73-llu akornanniittoq aammalu Qeqertarsuup Tunuani / Vaigatimi sinerissap qanittua.

# Resumé

I hovedparten af det område langs Grønlands vestkyst, som Grønlands Naturinstitut dækker med årlige reje-fiskesurveys, har der ikke hidtil været tilgængelige bathymetriske oplysninger med tilstrækkelig pålidelighed. Dybdedata, opsamlet fra trawlstationer og fra sejlruterne under R/V Paamiuts surveys, er derfor kompileret. Til støtte for disse data er dybdedata fra satellithøjdemåling også medtaget i denne analyse. Geostatistike metoder er anvendt til konstruktion af dybdekonturer med henblik på revision af den stratifikation, der ligger til grund for udførelsen af institutionens trawlsurveys ved Vestgrønland. Det undersøgte område dækker de udenskærs områder mellem 59° og 73°N og indenskærsområdet Disko Bugt / Vaigat.

# Abstract

Reliable information on the bathymetry of the West Greenland shelf has been missing for a substantial part covered regularly by surveys conducted by the Greenland Institute of Natural Resources. Therefore, depth data recorded at trawls stations and along cruise tracks during surveys with RV Paamiut have been compiled. Additionally, depth information derived from satellite altimetry has been included in the analysis. Geostatistical tools were used to provide depth contours for a revision of the stratification applied in the West Greenland Bottom Trawl Survey for northern shrimp. The study area covered West Greenland offshore waters between 59 and 73°N and the inshore waters in the Disko Bay / Vaigat area.

# Introduction

The Greenland Institute of Natural Resources has conducted annual stratified-random bottom trawl surveys in the distribution area of northern shrimp (*Pandalus borealis*) at West Greenland since 1988. The area coverage of the survey was gradually extended in the early years, and since 1993 the entire West Greenland shelf from 59°15' to 72°30'N and the inshore waters in the Disko Bay and Vaigat area has been covered. The main target species is northern shrimp and the majority of the trawl stations are allocated to depths between 150 and 600 m according to the depth preference of this species. Depths shallower than 150 m are included in the survey area south of 68°50'N (northern limit of NAFO division 1B) to collect additional information on the distribution of demersal fish species.

The survey strata in areas deeper than 150 m correspond to major latitudinal divisions of the West Greenland shrimp fishing grounds (Carlsson et al. 2000). The offshore region south of 69°30'N and west of 48°15'W have been stratified applying four depth ranges: 150-200 m, 200-300 m, 300-400 m and 400-600 m. Available information did not allow a depth stratification in the remaining survey area, and the offshore region north of 69°30'N (west and northwest off Disko Island) and east of 48°15'W (Julianehåb Bay) as well as the inshore area (Disko Bay and Vaigat) were subdivided in a number of small geographical units instead (Fig. 1, Kanneworff & Wieland 2001).

The depth stratification of the offshore survey area south of 69°30'N and west of 48°15'W was based on depth contours derived from geological surveys. However, some substantial deviations between these depth contours and the information obtained from the echo sounder during the shrimp surveys were found. This made it regularly necessary to move trawl stations several nautical miles away from the planned position in order to maintain the original depth allocation.

In addition to information from trawl stations, continuous depth recordings along cruise tracks have become available from several surveys conducted by the Greenland Institute of Natural Resources with RV Paamiut since 2000. These data have been analyzed in the present study together with results from satellite altimetry in order to provide revised depth contours and to modify the stratification of the shrimp survey.

# Material and methods

## Data sources and selection

Depth at start and end of trawl operations were extracted from the institute's database. The data set contained shrimp surveys conducted in the years 1988 to 2003 covering depths from 25 to 600 m and surveys for Greenland halibut in the years 1997 to 2003, which covered mainly depths between 400 and 1500 m in the area between 62°30' and 72°45'N.

Position (GPS) and depth recordings along cruise tracks were made from RV Paamiut during the shrimp surveys in the years 2000 to 2003 and the Greenland halibut survey in

2003. However, depth data were not available for the entire survey periods because the echo sounder was switched off or the settings were not monitored properly during steaming in some cases. From the raw data, which were recorded in time intervals of 2 min, unreliable records were removed. False echo soundings were identified in particular belonging to two situations:

- constant values occurring over a longer period when the echo sounder was “locked” or the actual depth was out of the selected range;
- sudden jumps to a high value with more a less constant increments when the echo sounder lost bottom contact and returned close to the initial value within a short period.

The remaining data were filtered to a minimum spatial resolution of 0.1 nautical miles along the cruise tracks.

A depth grid with a resolution of about 2 km based on an interpolation of satellite altimetry data (see e.g. www. ngdc.noaa.gov/mgg/bathymetry for details on the method) was downloaded from the internet (http://topex.ucsd.edu/cgi-bin/get_data.cgi). This data set was compared with the survey observations and satellite altimetry data were removed in all areas in which they were in conflict with the echo sounder values.

In the Disko Bay and Vaigat area as well as in the area north of 72°N, which was not covered by the satellite altimetry data, additional geological information was used.

The study area was divided into nine overlapping parts (Fig. 1) for practical reasons and maps showing the corresponding data sets are given in the appendix 1.

The selected depth data were transferred from the original latitude/longitude coordinates to an UTM projection to allow a geostatistical analysis and area calculations in real distance units with Surfer® (Golden Software, Inc., www.goldensoftware.com).

## Geostatistical analysis

A geostatistical analysis usually involves two steps: a) the identification of the spatial structure, e.g. through the calculation and the fitting of a variogram, and b) the use of this structure, e.g. in the application of a linear method of spatial prediction such as kriging (Chilès & Delfiner 1999).

In the present study experimental variograms were computed from the sample points as an average over all directions (omnidirectional variogram) according to the classical formula:

$$\gamma^*(h) = 0.5\,\frac{1}{N(h)}\sum_{i=1}^{N(h)}\left(Z(x_i+h) - Z(x_i)\right)^2 \qquad (1)$$

where *N(h)* is the number of experimental pairs $Z(x_i + h) - Z(x_i)$ of data separated by the distance *h*. A distance lag width of 0.1 nautical miles was used and only the survey observations, i.e. depth from the trawl stations and the cruise tracks, were included in the calculation in all cases while the maximum distance considered varied in respect to the extension of the different domains.

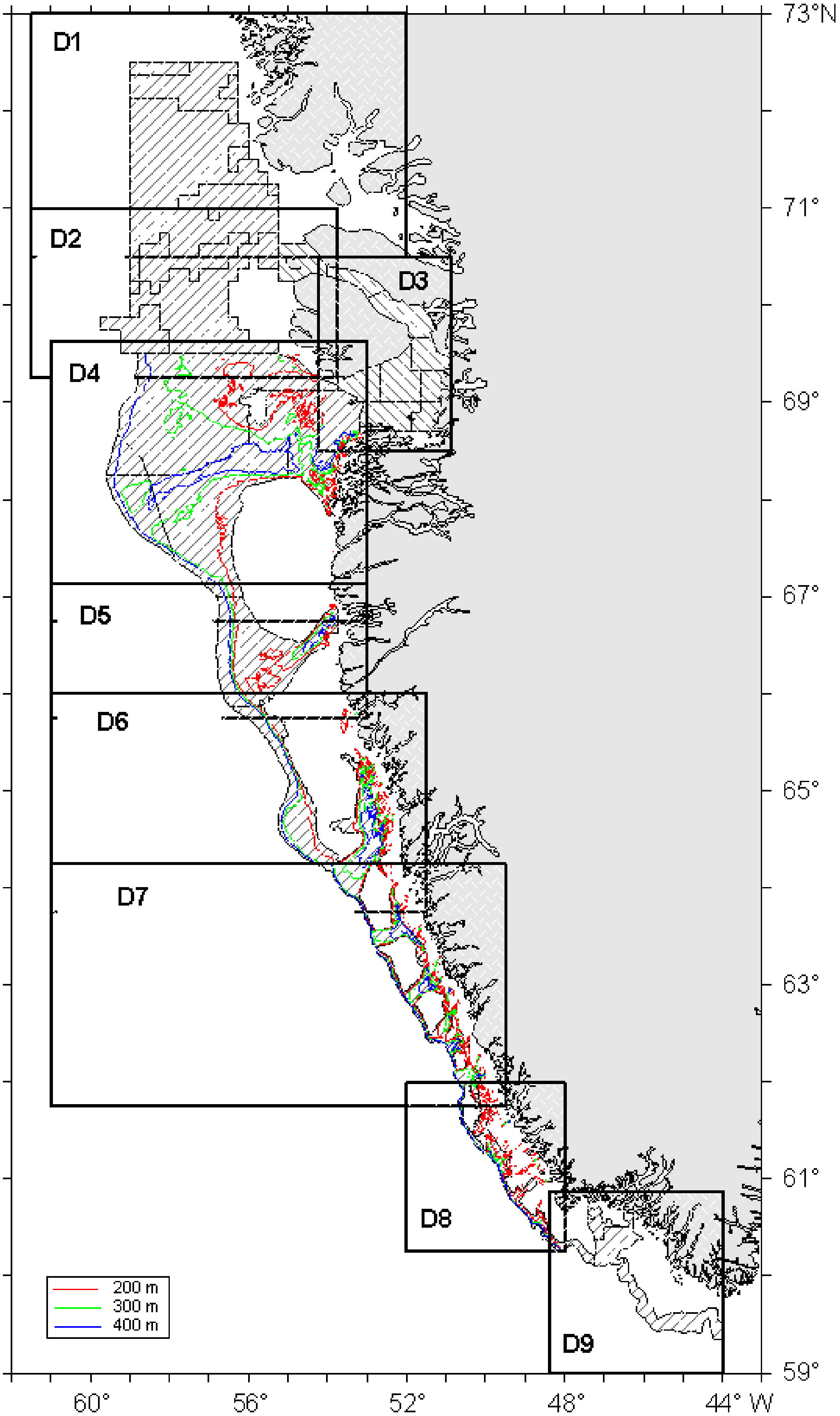


**Figure 1.** Division of the study area and survey stratification (shaded area) used in 2000 (total survey area: 118475 km²).

Variogram models were fitted using least squares applying a two-component structure, a nugget effect and a spherical component:

$$\gamma(h)=\begin{cases} 0, & h=0 \\ c_n + c_s\left(1.5\, h/r - 0.5\,(h/r)^3\right), & 0<h\le r \\ c_n + c_s, & h>r \end{cases} \qquad (2)$$

where $c_n$ is the nugget effect representing unresolved small-scale variation and observation error, $c_s$ the amplitude of the spherical component, $c_n + c_s$ the sill of the variogram that represents the maximum level of variability, and $r$ is the range beyond which the data are no longer autocorrelated.

Kriging is a linear estimator accounting for the spatial structure and the geometrical configuration. It is optimal in the sense that it is unbiased and it minimizes the variance of the estimation error. In ordinary kriging, the kriging weights $\lambda_i$, which are attributed to the data points when calculating the expected value at a grid node and which minimize the variance of the estimation error, are found by solving a system of linear equations:

$$\begin{cases} \sum_j \lambda_j\, \gamma(x_i - x_j) + \mu = \gamma(x_i - x_0) \quad \text{whatever } i \\ \sum_i \lambda_i = 1 \end{cases} \qquad (3)$$

where $\mu$ is a Lagrange parameter constraining the weights to satisfy the condition:

$$\sum \lambda_i = 100\% = 1 \qquad (4)$$

In the present study, depth grids with a resolution of 0.1 nautical miles were computed using ordinary point kriging based on the fitted variogram models and the entire input data sets, i.e. survey observation and satellite altimetry data, for the respective domains.

The depth grids were smoothed over a distance range of 0.5 nautical miles around each grid node with a Gaussian low pass filter and contours of 50, 100, 150, 200, 300, 400, 600 and 1000 m were extracted.

The 150 m and 600 m contours were used to redefine the outer limits covered by the shrimp survey and the areas of the strata were calculated corresponding to the four depth ranges used previously, i.e. 150-200 m, 200-300 m, 300-400 m and 400-600 m.

The depth contours from the nine different domains were finally transferred back to latitude/longitude coordinates and combined for the entire study area.

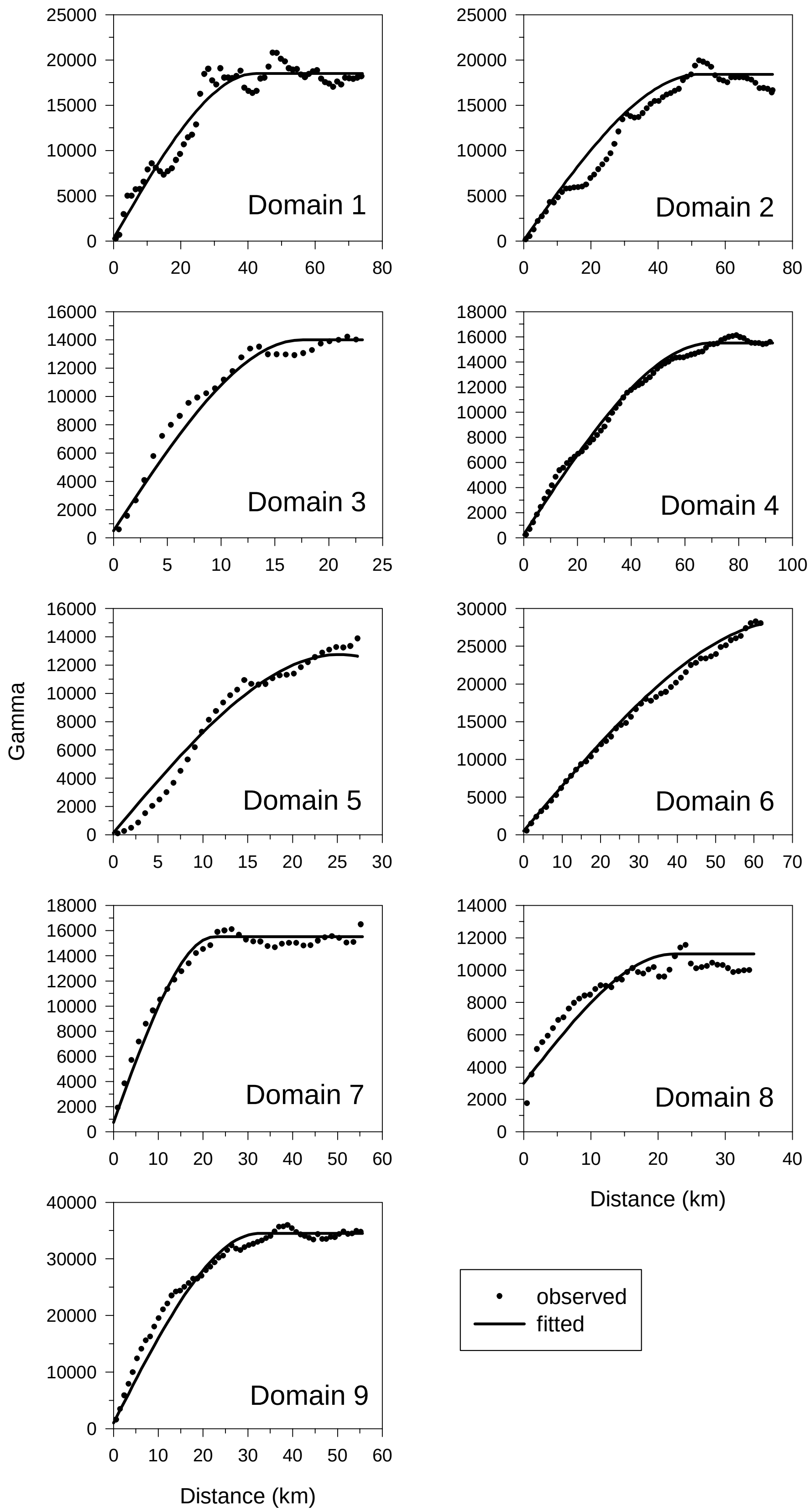


**Figure 2.** Experimental variograms and fitted variogram models.

# Results and Discussion

## Bathymetry

Satisfactory fits of the experimental variograms were obtained for all domains (Fig. 2) indicating spatial correlation within a distance range of 20 to 70 km. The maximum distance considered was always less than the half of the maximum distance over the domain, which was accepted be cause a good fit near the origin is most crucial for the interpolation with kriging. A comparatively low maximum distance was chosen for the Disko Bay / Vaigat area (Domain 3) to reduce the effect of cross-land computation.

The contours extracted from the depth grids (Fig. 3) matched the depths recorded at trawl positions closely with a very few exceptions only (see Appendix 1). Depths originated from satellite altimetry were rejected for several parts of the study area (see Appendix 1). This was in particular the case in the Disko Bay / Vaigat area, in the vicinity of the fishing banks south of 64°N and in the Julianehåb Bay. Steep gradients of the sea floor, ice coverage and the regular presence of large icebergs may be responsible for the poor agreement between the interpolated satellite data and the survey observations in these areas. Data coverage was sparse north of 72°N and, due to the exclusion of satellite data, also in some coastal areas, and the analysis should be repeated especially for these part of the study area when new information have become available, e.g. from future surveys.

## Survey stratification

The depth contours obtained from the geostatistical analysis were regarded as sufficient for a revision of the stratification of the shrimp survey (Fig. 4, Appendix 2) despite of some uncertainties and possible future changes in a part of the survey area.

Latitudinal divisions in the area south of 69°30'N were maintained and the outer boundaries as well as the limits between adjacent strata defined by depth contours were adjusted according to the new data. In addition to that, the previous two areas in the Canadian EEZ were combined to one (C0) considering its relative small size.

Major changes were made in those areas in which reliable information on depth had been missing:

- the original nine geographical strata in the region between 69°30' and 72°30'N were replaced by two offshore (U1 and U2) and one coastal area (U3) with stratification by depth in all of the three, and an extension towards the coast in U3 to include areas in which commercial fishing has taken place in recent years (Hvingel 2003),

- two depth-stratified areas, I1 and I2, replace the former nine geographical strata in the Disko Bay / Vaigat region, and

- two depth-stratified areas, W8 and W9, substitute the former geographical stratification in the Julianehåb Bay.

The total area covered by the shrimp survey strata amounts to 136812 km², which corresponds an increased by 13 % compared to the survey area covered in 2001 and is mainly due to the changes introduced in the region between 69°30' and 72°30'N.

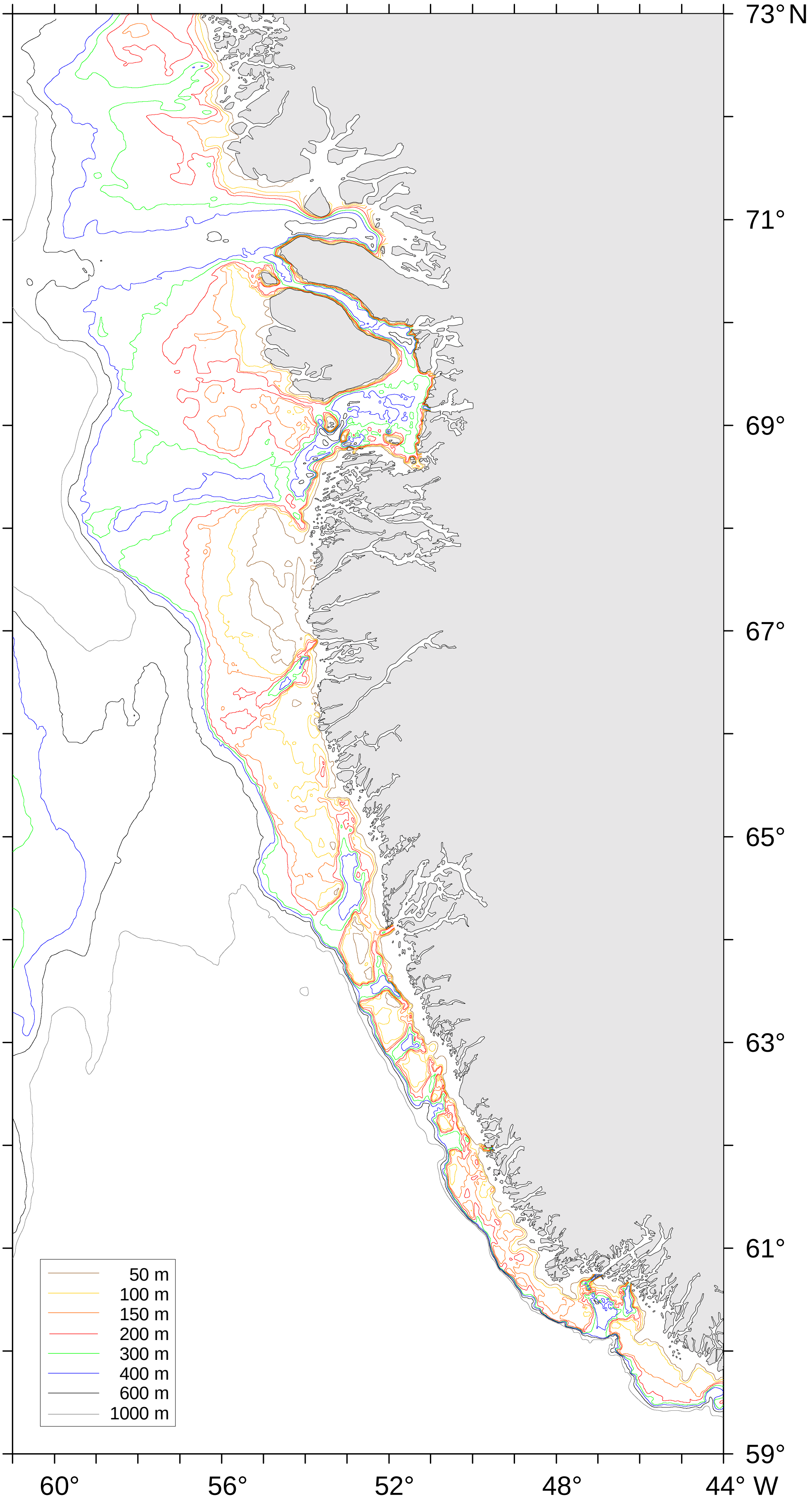


**Figure 3.** Depth contours.

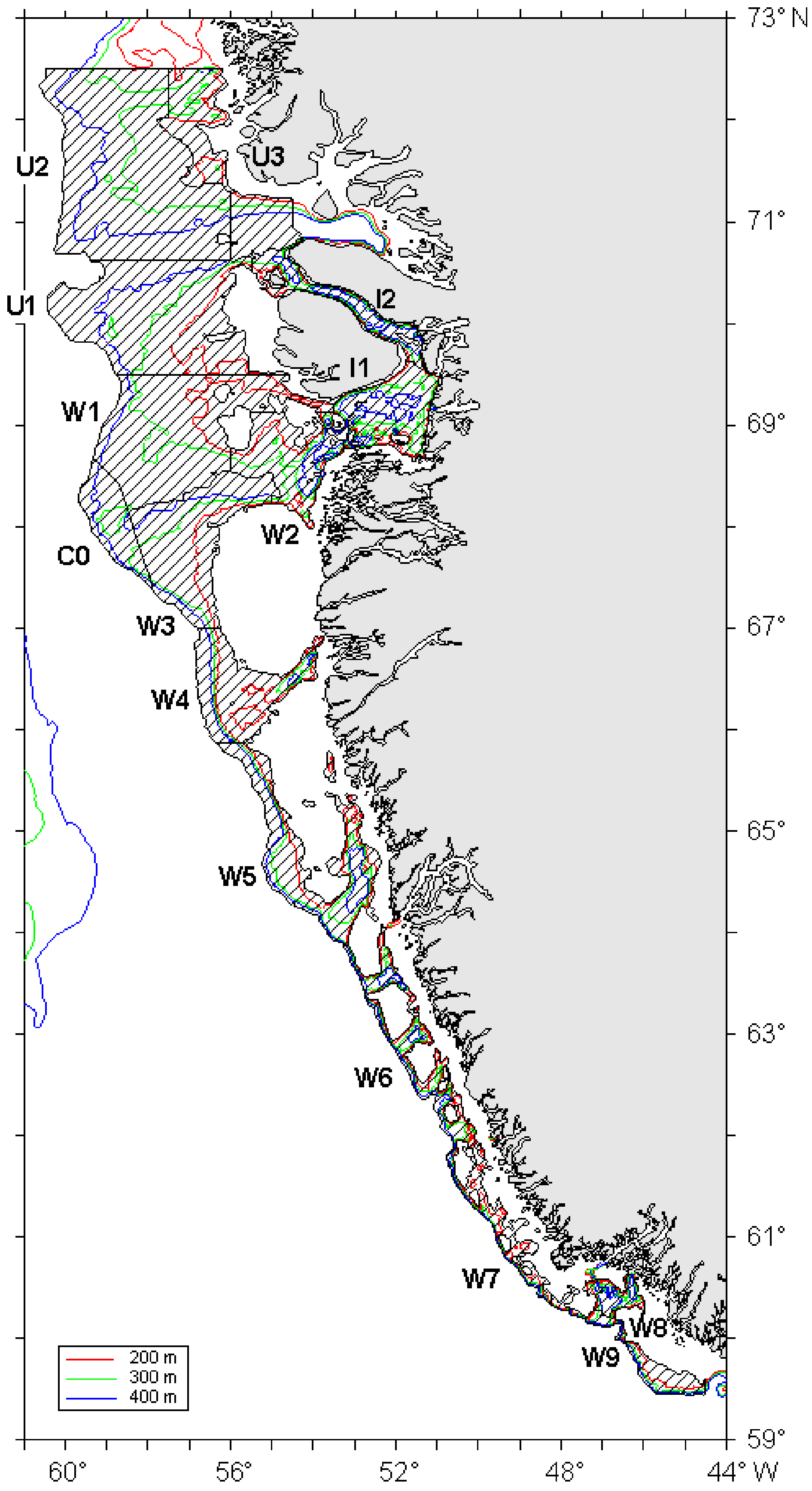


**Figure 4.** Shrimp survey area and stratification for 2004 (see appendix 2 for details on the stratum boundaries and the calculated areas, total survey area: 136812 km²).

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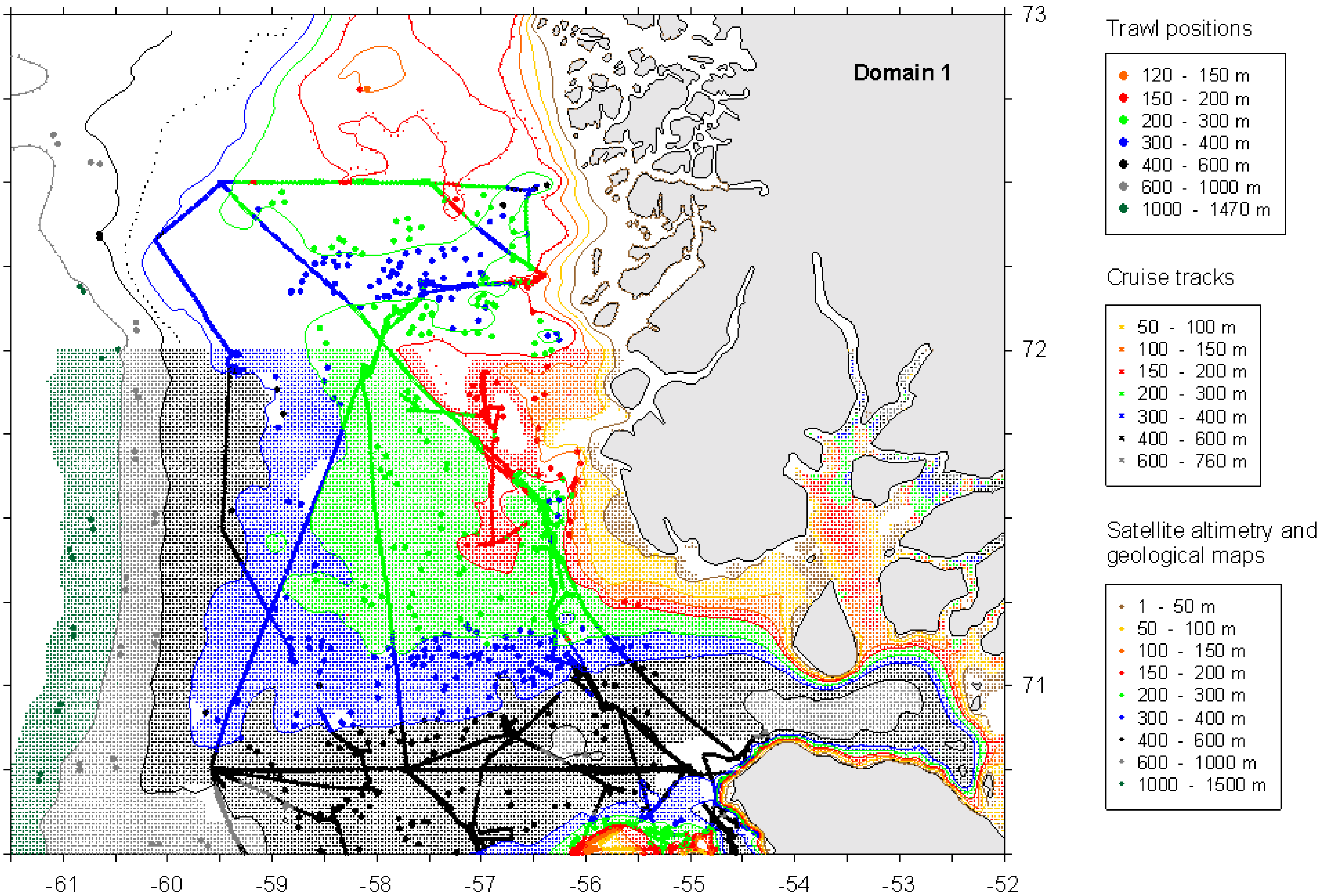
# Acknowledgements

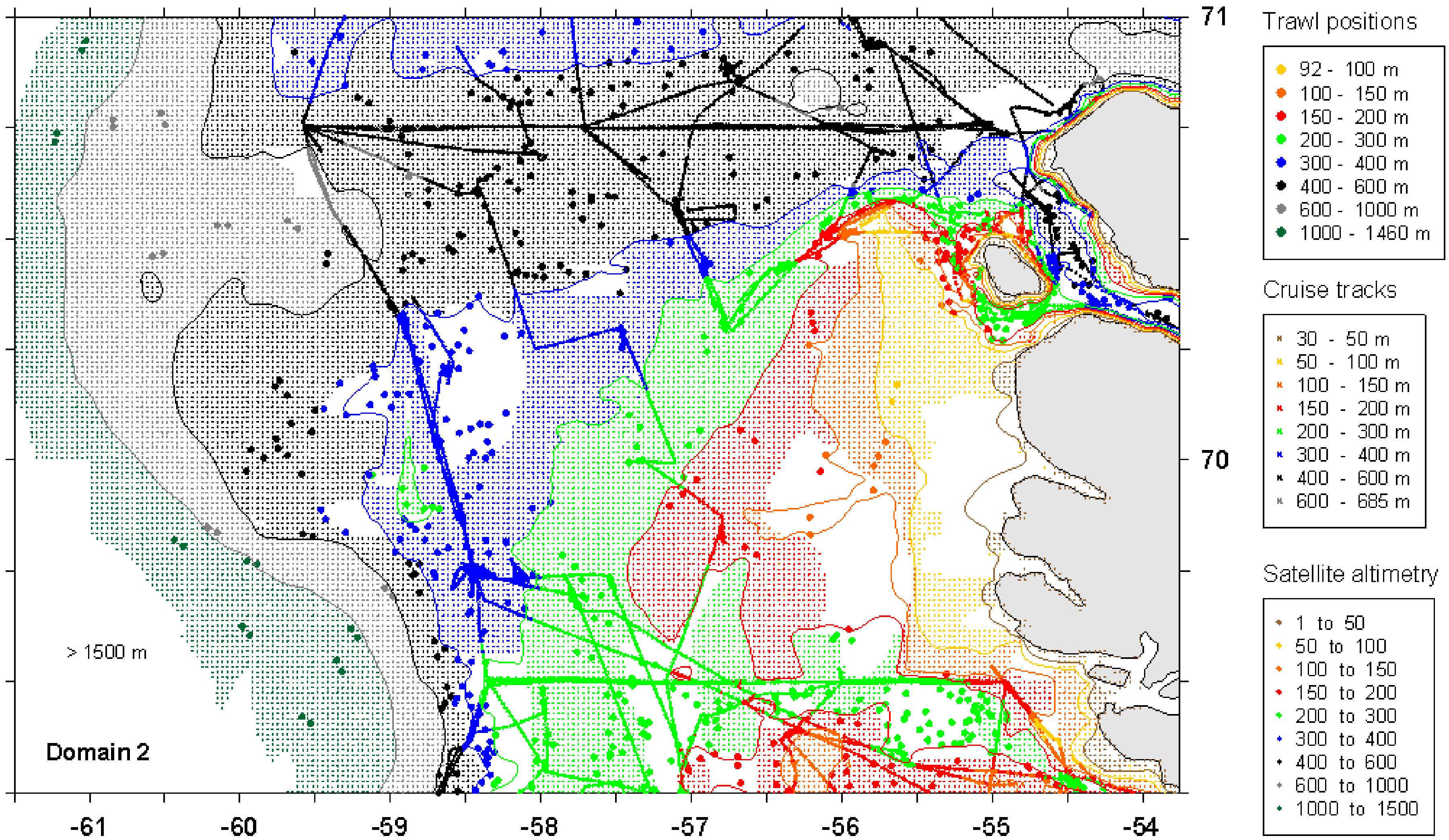
The cooperation with the crew of RV Paamiut is gratefully acknowledged. Thanks also to Claus Simonsen (Greenland Institute of Natural Resources) who downloaded the satellite altimetry depth grid and to Ole Jørgensen (Danish Institute for Fisheries Research) for providing depth data at trawl stations from the Greenland halibut surveys.

# Appendix 1

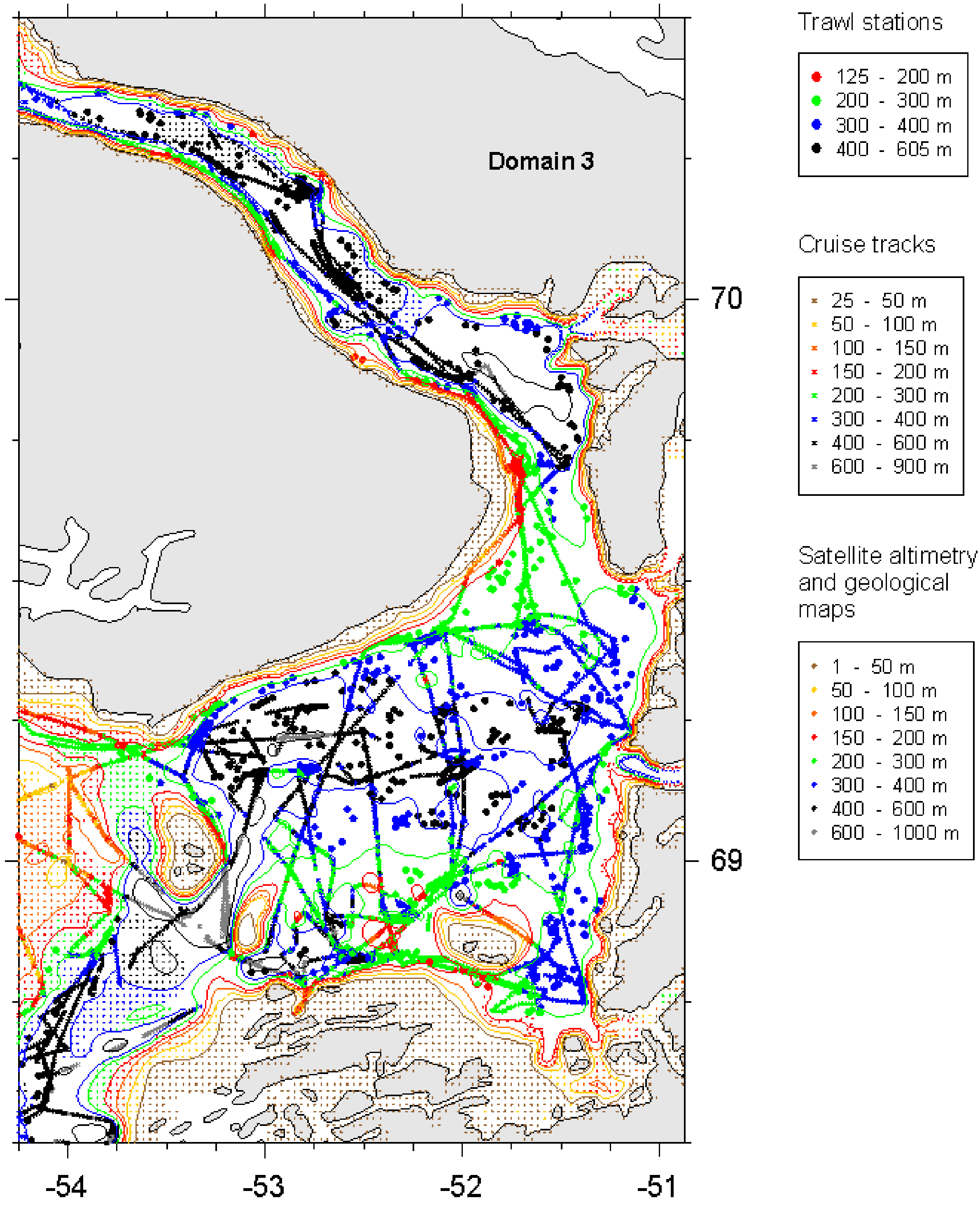
Selected input data and computed depth contours



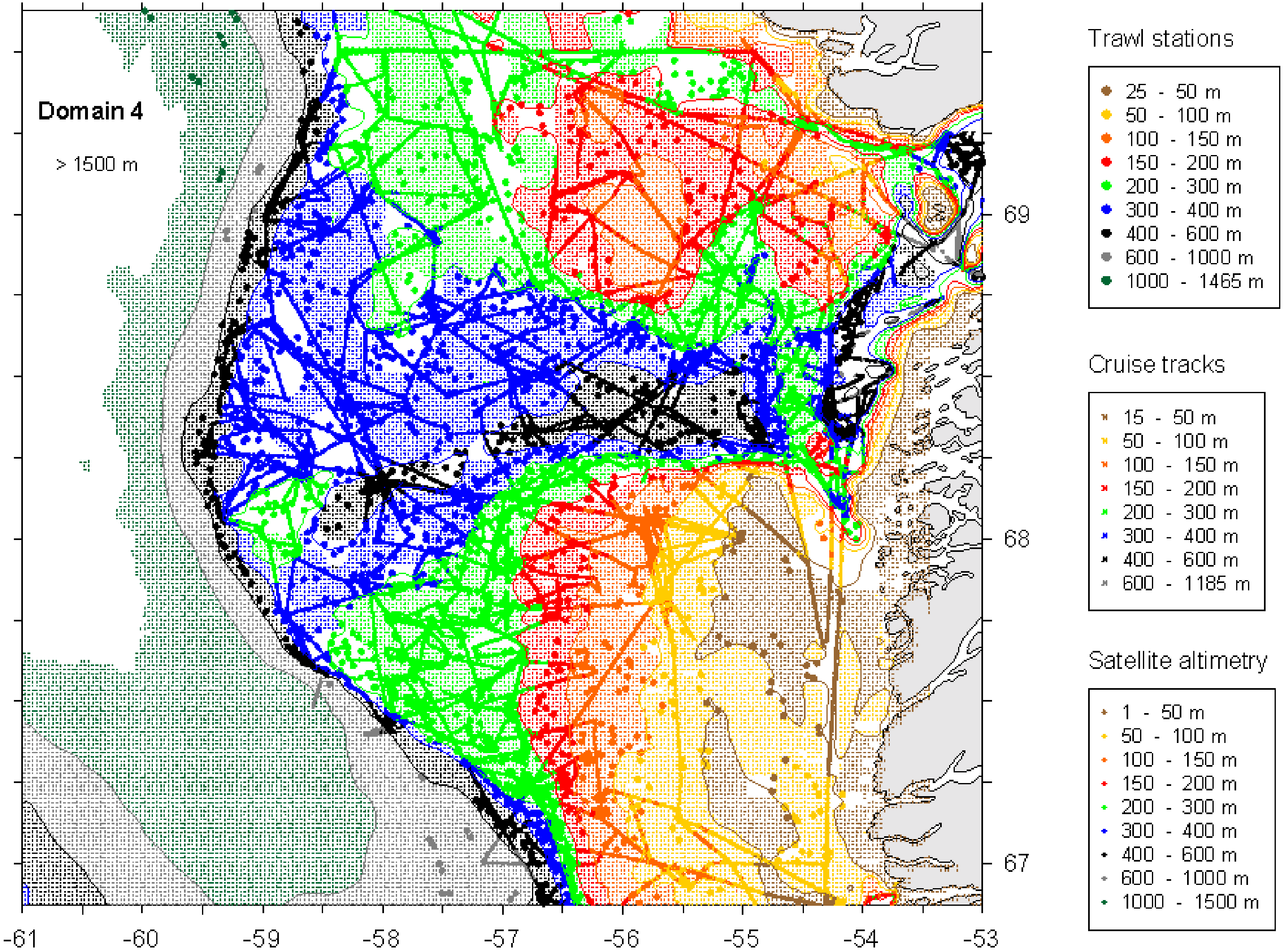
Domain 1
73
72
71
-61
-60
-59
-58
-57
-56
-55
-54
-53
-52
Trawl positions
120 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1470 m
Cruise tracks
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 760 m
Satellite altimetry and geological maps
1 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1500 m

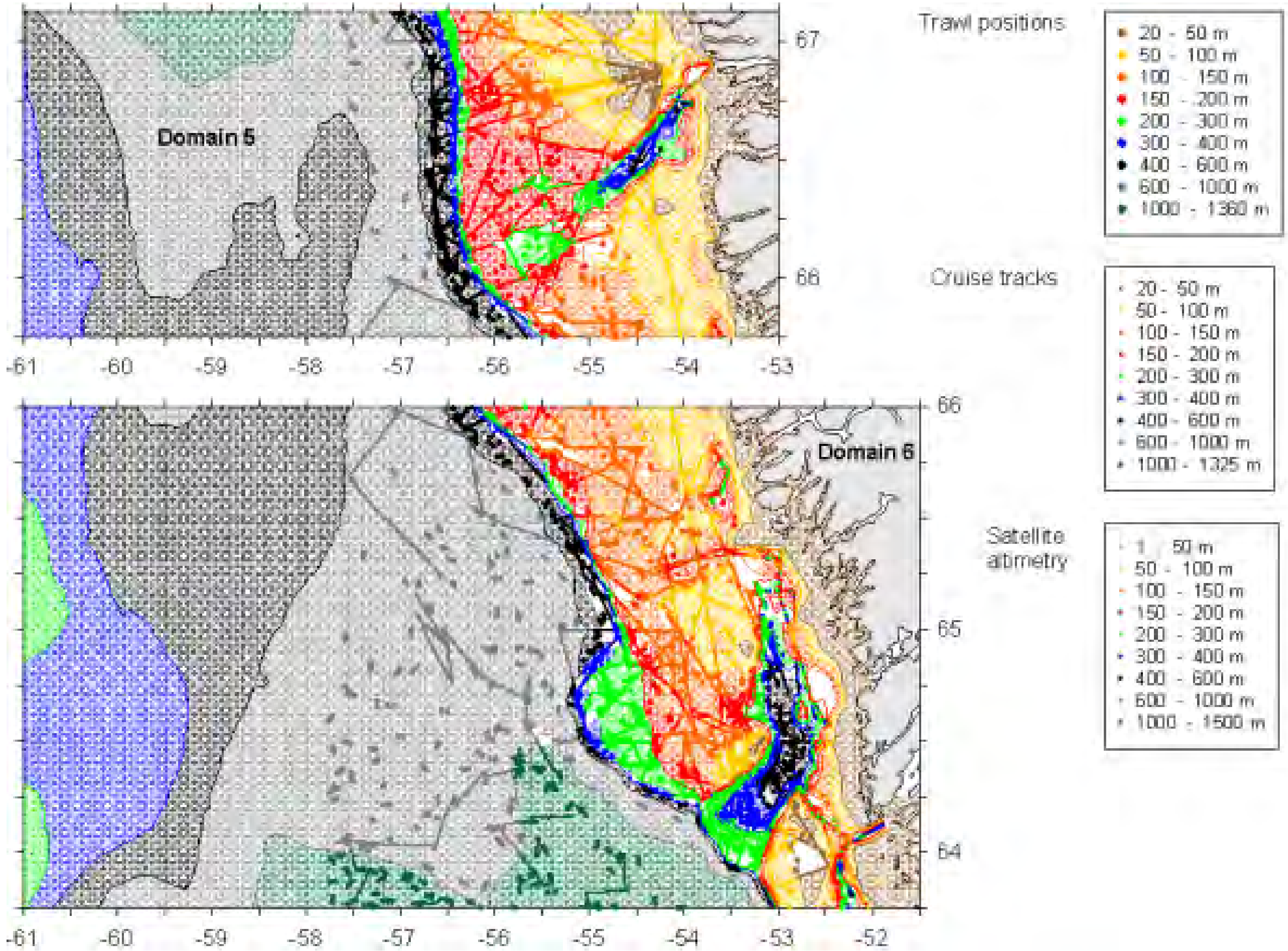


71
70
-61
-60
-59
-58
-57
-56
-55
-54
> 1500 m
Domain 2
Trawl positions
92 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1460 m
Cruise tracks
30 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 685 m
Satellite altimetry
1 to 50
50 to 100
100 to 150
150 to 200
200 to 300
300 to 400
400 to 600
600 to 1000
1000 to 1500



Domain 3
70
69
-54
-53
-52
-51
Trawl stations
125 - 200 m
200 - 300 m
300 - 400 m
400 - 605 m
Cruise tracks
25 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 900 m
Satellite altimetry and geological maps
1 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m


Domain 4
> 1500 m
69
68
67
-61
-60
-59
-58
-57
-56
-55
-54
-53
Trawl stations
25 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1465 m
Cruise tracks
15 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1185 m
Satellite altimetry
1 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1500 m



Domain 5
Domain 6
67
66
65
64
-61
-60
-59
-58
-57
-56
-55
-54
-53
-52
Trawl positions
20 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1360 m
Cruise tracks
20 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1325 m
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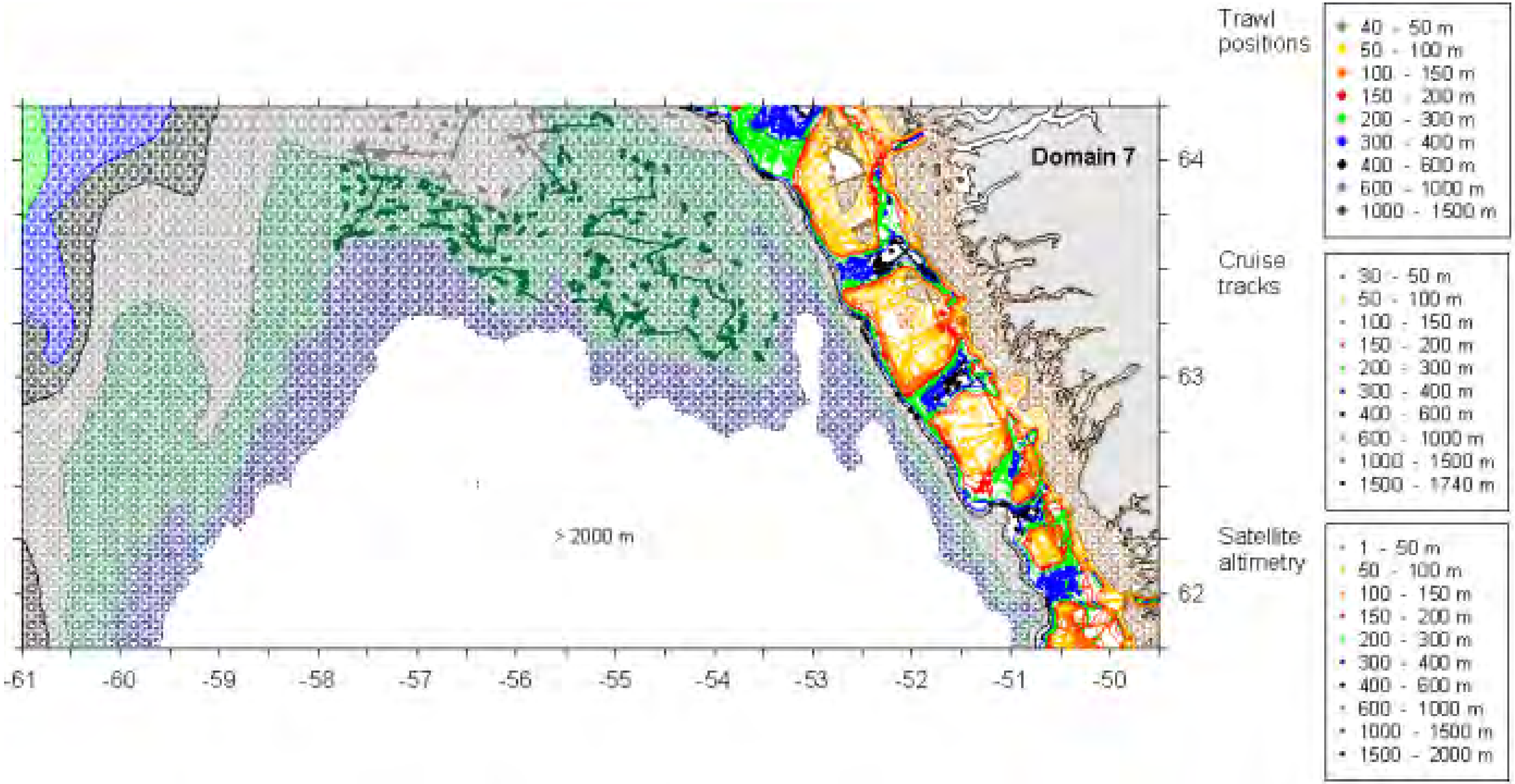
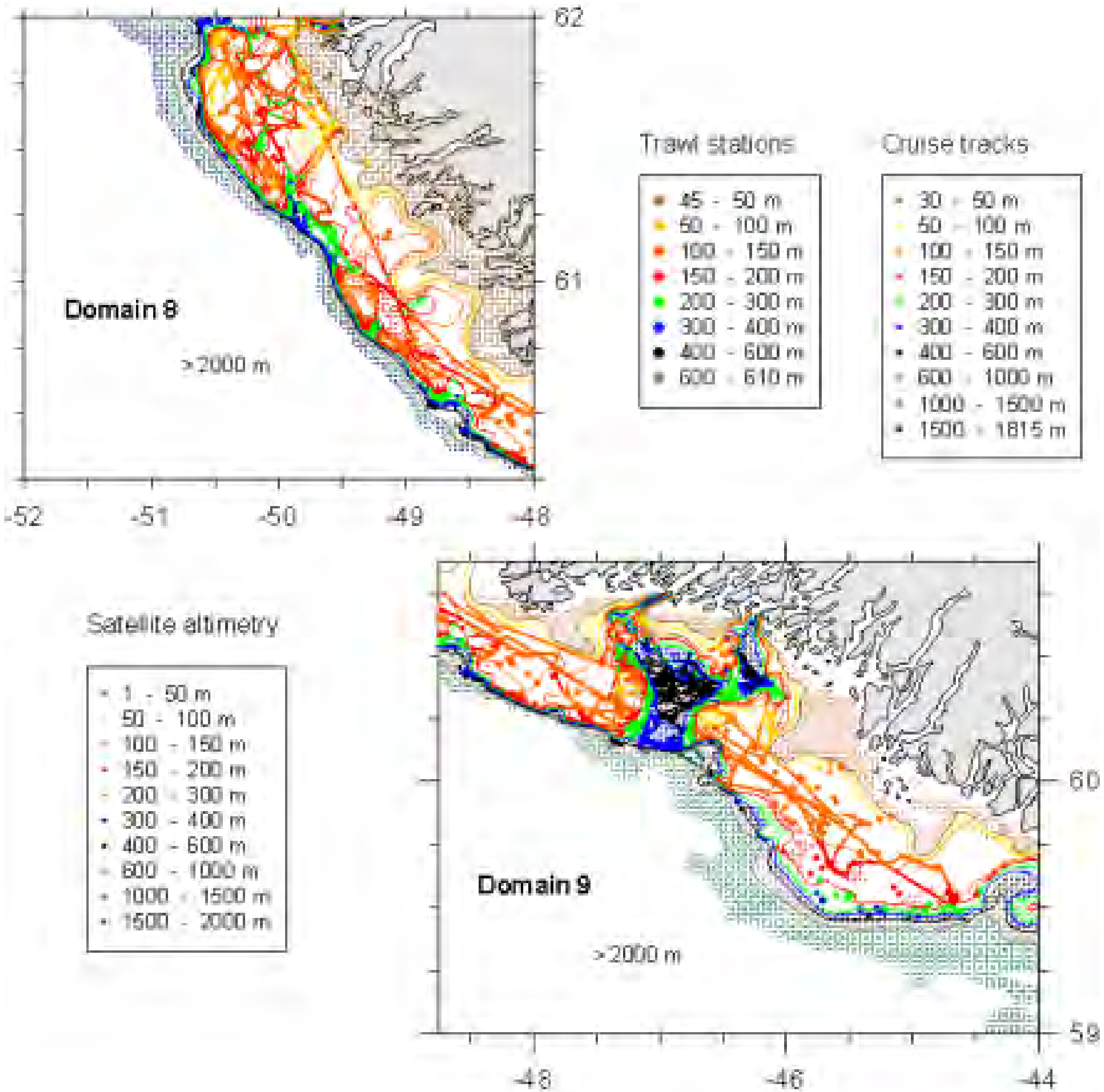
600 - 1000 m
1000 - 1500 m

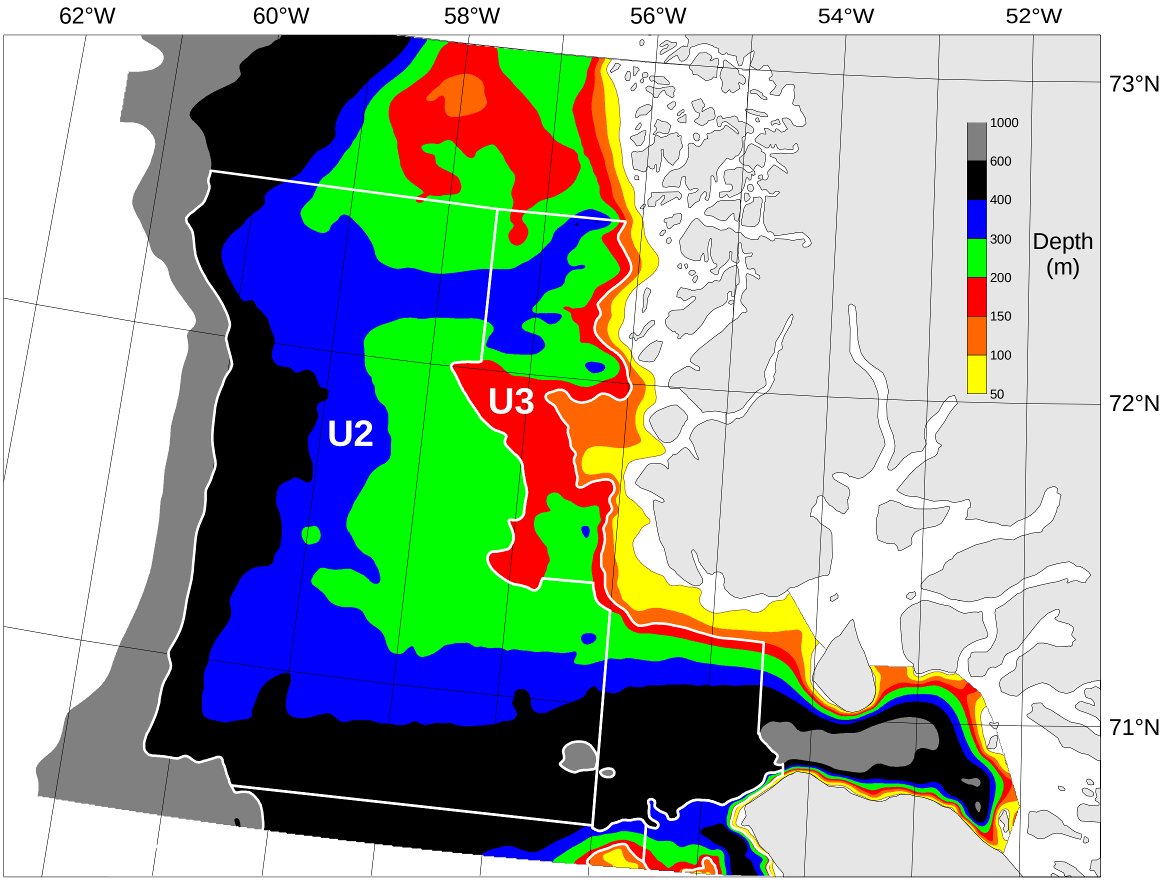


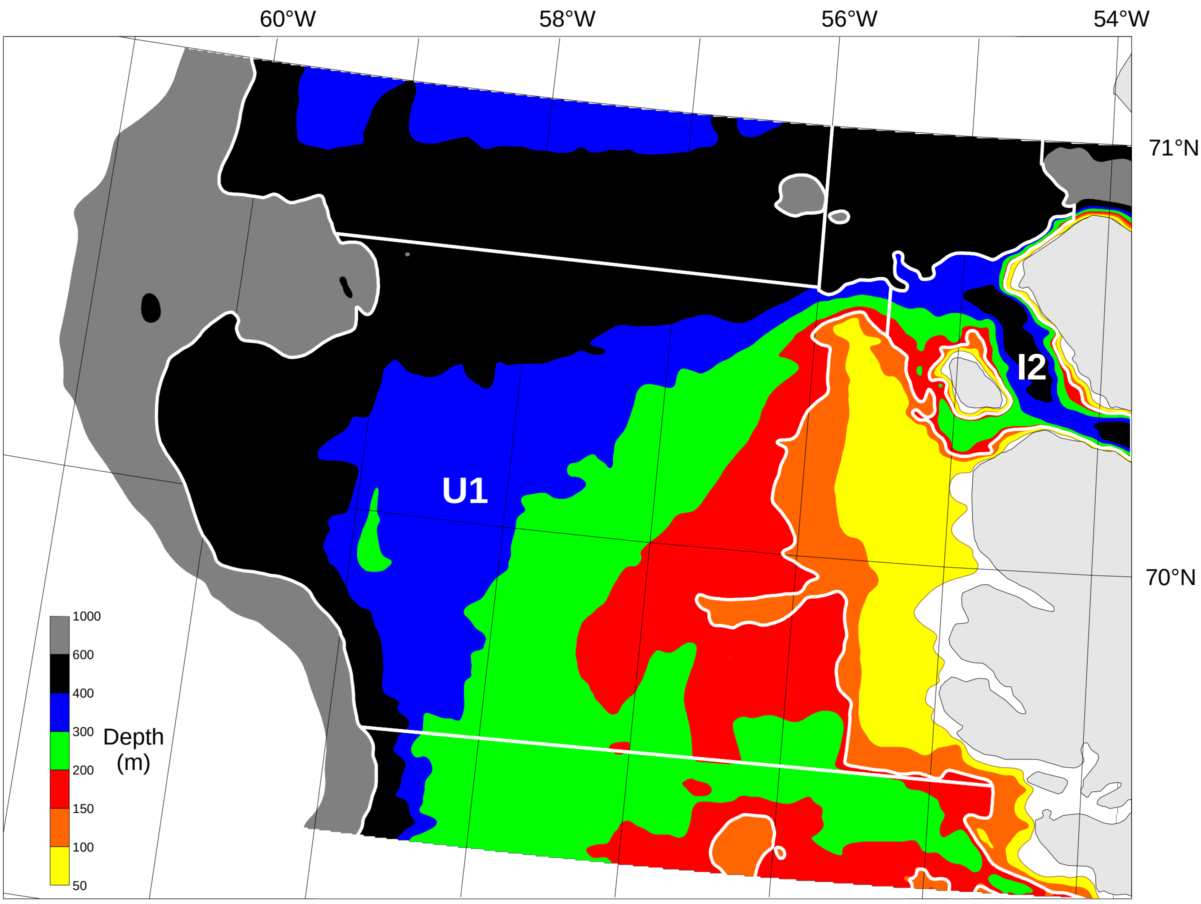
Domain 7
64
63
62
> 2000 m
-61
-60
-59
-58
-57
-56
-55
-54
-53
-52
-51
-50
Trawl positions
40 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1500 m
Cruise tracks
30 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1500 m
1500 - 1740 m
Satellite altimetry
1 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1500 m
1500 - 2000 m

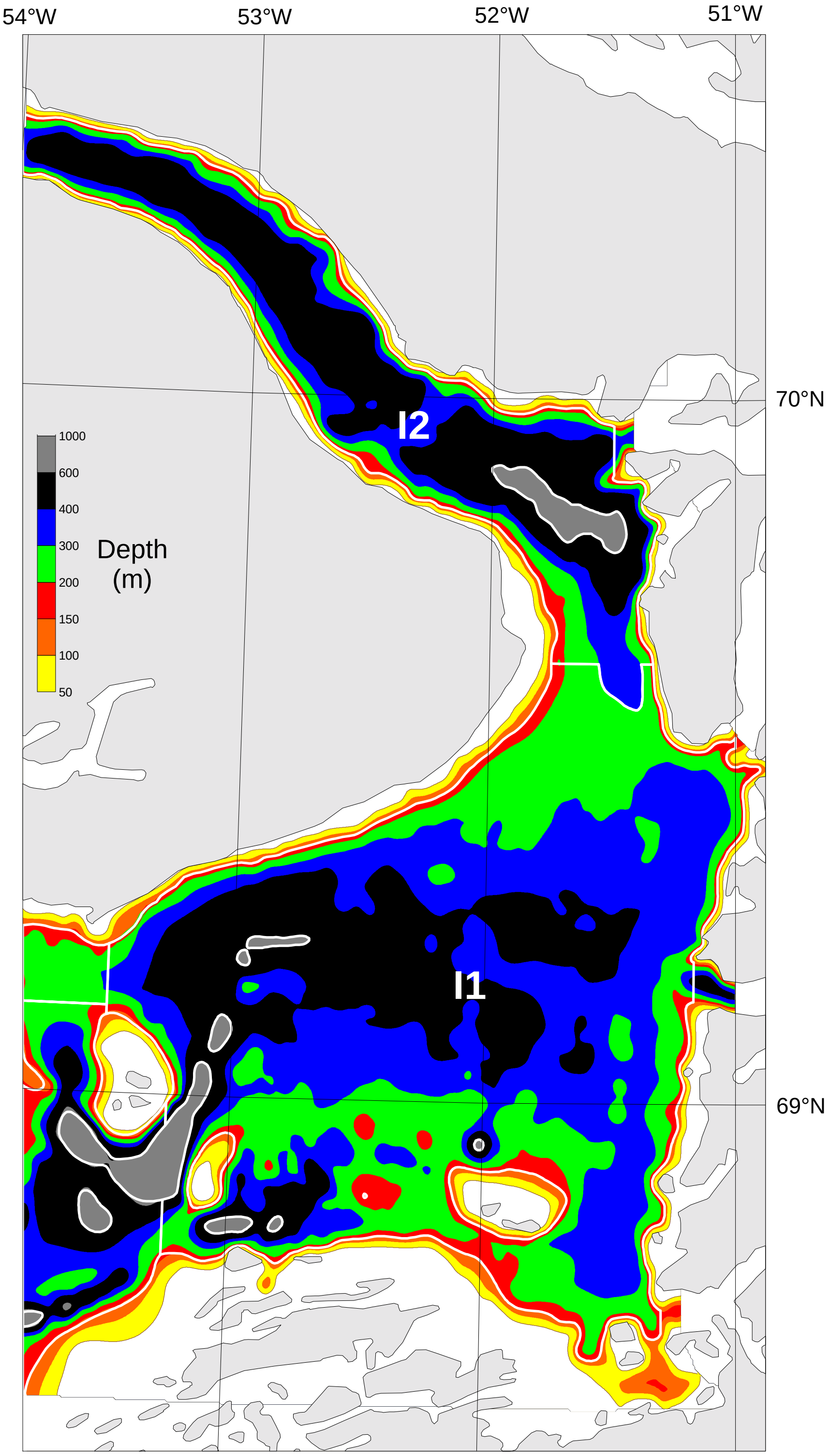

62
61
Domain 8
> 2000 m
-52
-51
-50
-49
-48
Trawl stations
45 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 610 m
Cruise tracks
30 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1500 m
1500 - 1815 m
Satellite altimetry
1 - 50 m
50 - 100 m
100 - 150 m
150 - 200 m
200 - 300 m
300 - 400 m
400 - 600 m
600 - 1000 m
1000 - 1500 m
1500 - 2000 m
60
Domain 9
> 2000 m
59
-48
-46
-44

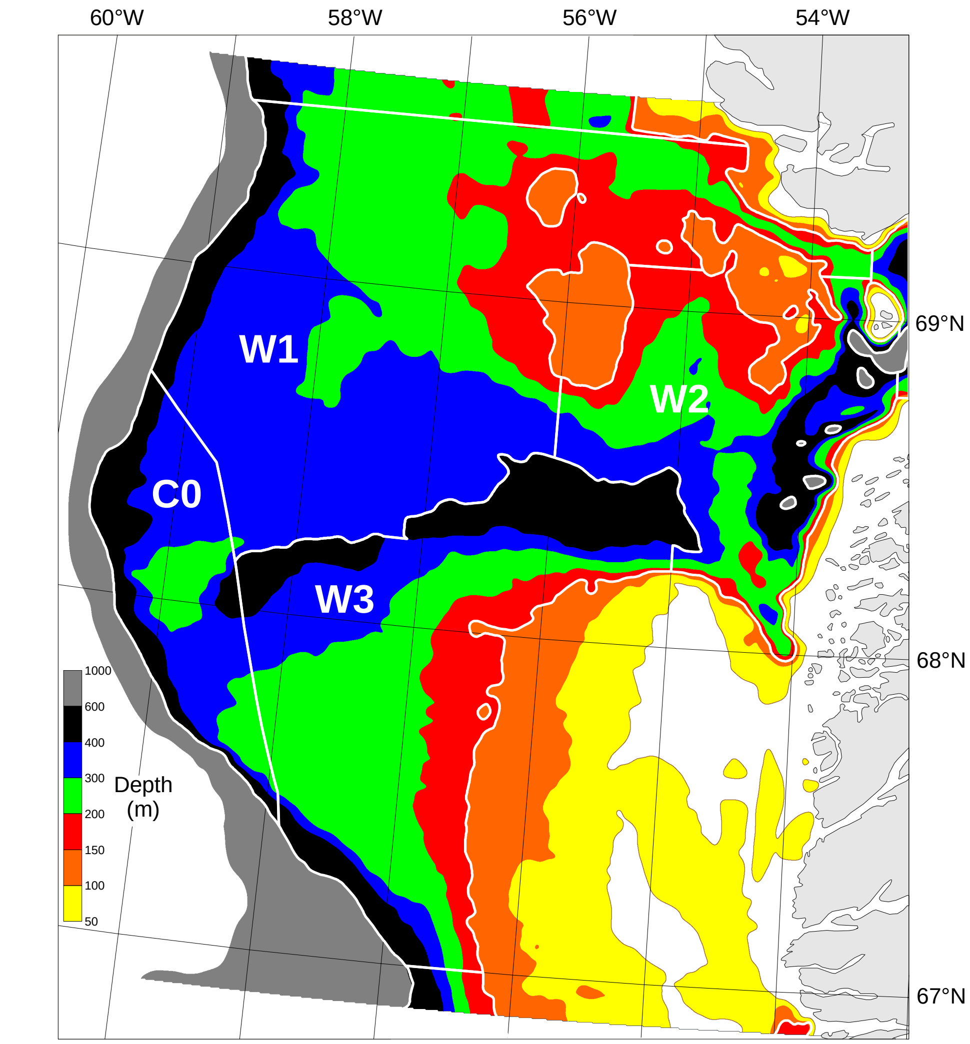
# Appendix 2

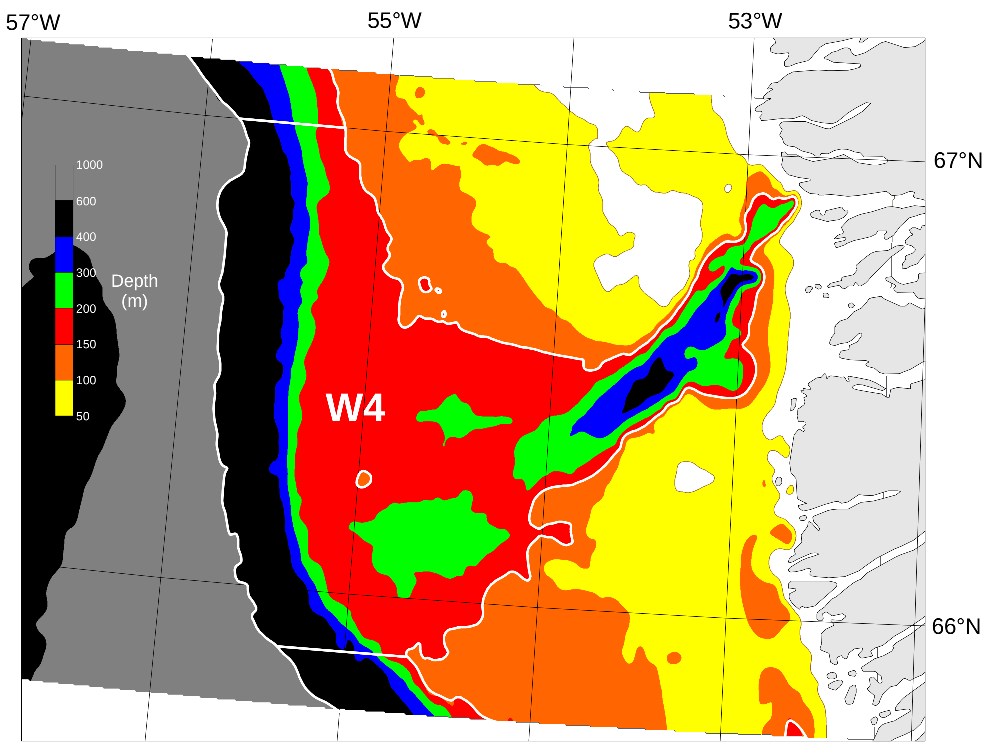
Stratum limits, depth stratification and areas for the shrimp survey in 2004**.**

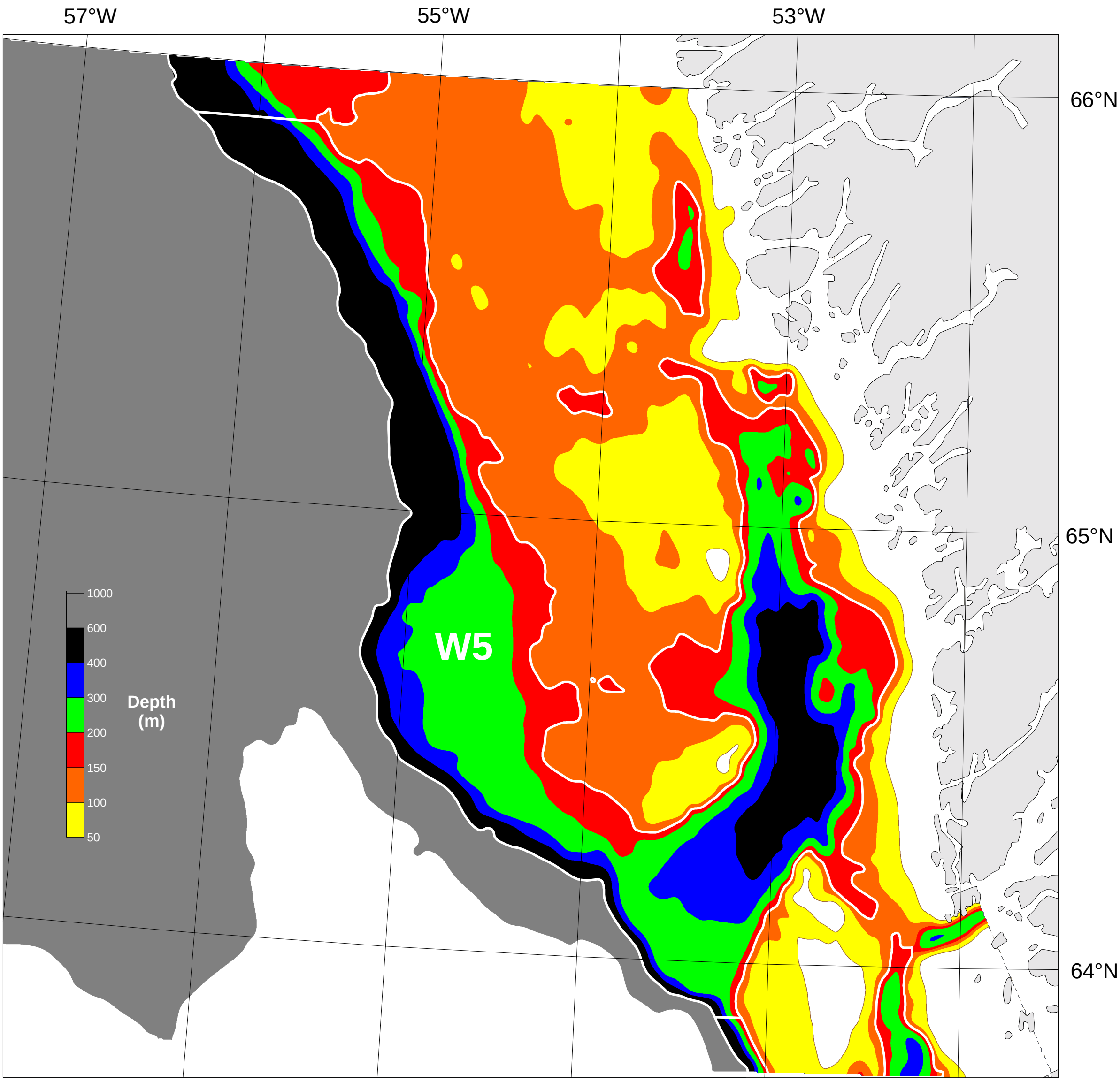

62°W
60°W
58°W
56°W
54°W
52°W
73°N
72°N
71°N
1000
600
400
300
200
150
100
50
Depth (m)
U2
U3


60°W
58°W
56°W
54°W
71°N
70°N
1000
600
400
300
200
150
100
50
Depth (m)
U1
I2

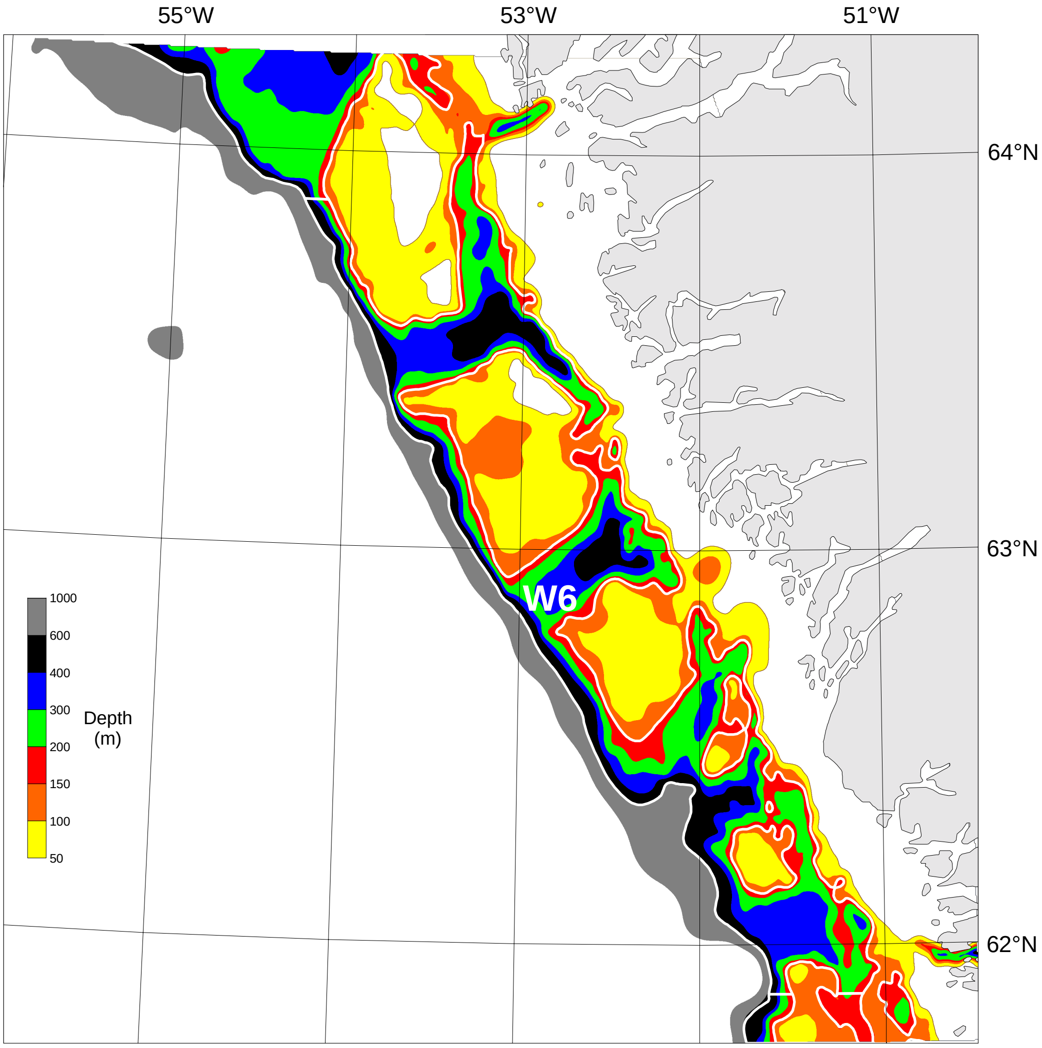

54°W
53°W
52°W
51°W
70°N
69°N
1000
600
400
300
200
150
100
50
Depth
(m)
I2
I1

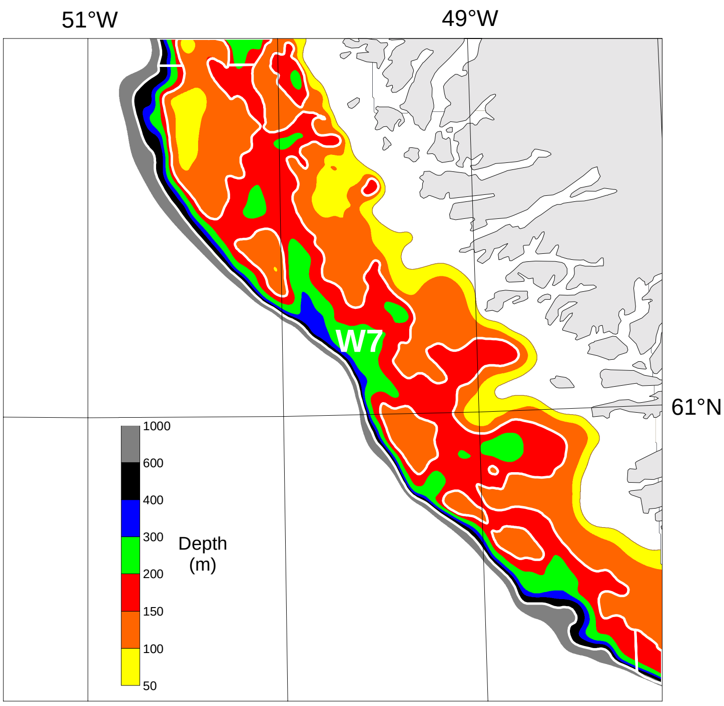

60°W
58°W
56°W
54°W
69°N
68°N
67°N
W1
W2
C0
W3
1000
600
400
300
200
150
100
50
Depth
(m)

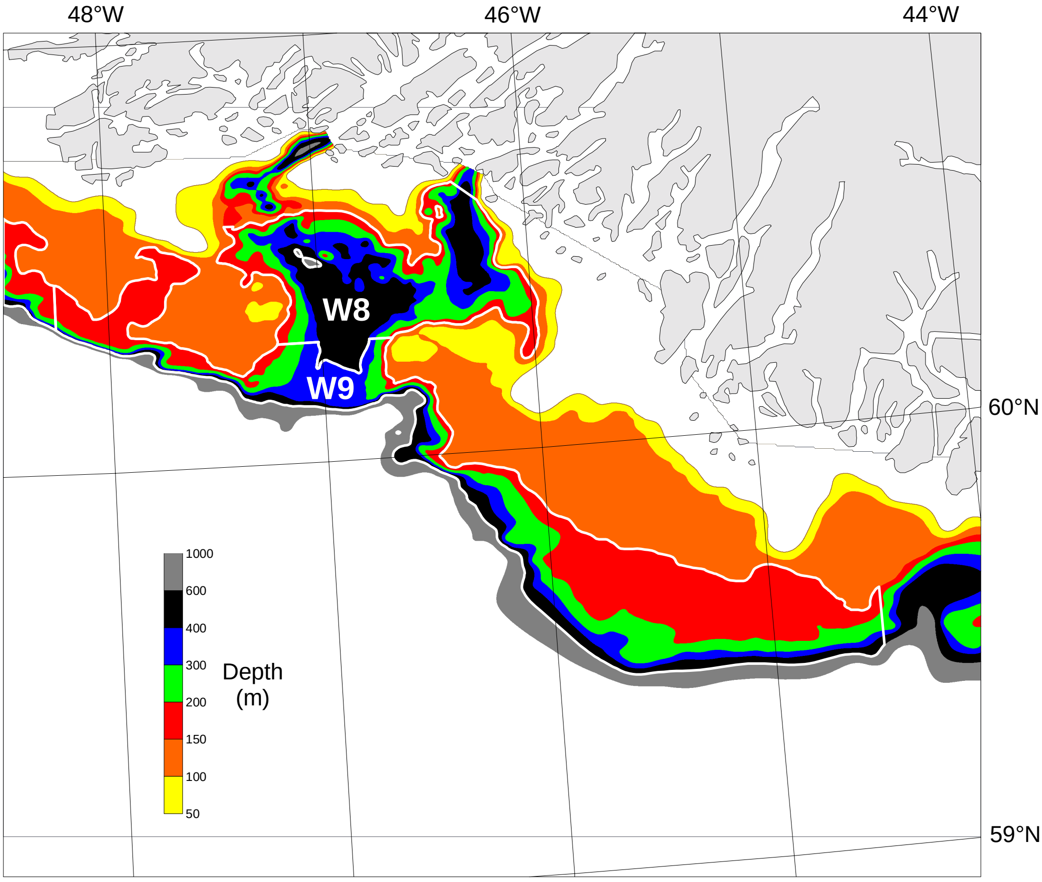

57°W
55°W
53°W
67°N
66°N
W4
1000
600
400
300
200
150
100
50
Depth
(m)



57°W
55°W
53°W
66°N
65°N
64°N
W5
1000
600
400
300
200
150
100
50
Depth
(m)


55°W
53°W
51°W
64°N
63°N
62°N
W6
1000
600
400
300
200
150
100
50
Depth
(m)


51°W
49°W
61°N
W7
1000
600
400
300
200
150
100
50
Depth
(m)


48°W
46°W
44°W
60°N
59°N
W8
W9
1000
600
400
300
200
150
100
50
Depth
(m)

| Stratum | | Depth (m) | Area (km²) |
|---|---|---|---|
| W1 | -1 | 150-200 | 2967.5 |
| | -2 | 200-300 | 6035.1 |
| | -3 | 300-400 | 7514.6 |
| | -4 | 400-600 | 876.9 |
| | total | | 17394.0 |
| W2 | -1 | 150-200 | 1698.5 |
| | -2 | 200-300 | 2616.4 |
| | -3 | 300-400 | 1768.0 |
| | -4 | 400-600 | 965.2 |
| | total | | 7048.1 |
| W3 | -1 | 150-200 | 2160.1 |
| | -2 | 200-300 | 4698.2 |
| | -3 | 300-400 | 2119.0 |
| | -4 | 400-600 | 2921.3 |
| | total | | 11898.7 |
| W4 | -1 | 150-200 | 4254.5 |
| | -2 | 200-300 | 1695.2 |
| | -3 | 300-400 | 777.0 |
| | -4 | 400-600 | 1873.1 |
| | total | | 8599.7 |
| W5 | -1 | 150-200 | 3001.1 |
| | -2 | 200-300 | 3647.6 |
| | -3 | 300-400 | 1950.3 |
| | -4 | 400-600 | 3021.3 |
| | total | | 11620.4 |
| W6 | -1 | 150-200 | 1205.5 |
| | -2 | 200-300 | 2005.8 |
| | -3 | 300-400 | 1585.1 |
| | -4 | 400-600 | 1234.3 |
| | total | | 6030.8 |
| W7 | -1 | 150-200 | 2442.4 |
| | -2 | 200-300 | 891.4 |
| | -3 | 300-400 | 264.5 |
| | -4 | 400-600 | 316.9 |
| | total | | 3915.1 |
| W8 | -1 | 150-200 | 349.2 |
| | -2 | 200-300 | 533.5 |
| | -3 | 300-400 | 469.5 |
| | -4 | 400-600 | 745.3 |
| | total | | 2097.5 |
| W9 | -1 | 150-200 | 1886.0 |
| | -2 | 200-300 | 805.5 |
| | -3 | 300-400 | 567.5 |
| | -4 | 400-600 | 457.2 |
| | total | | 3716.3 |
| W | total | | 72320.7 |

| Stratum | | Depth (m) | Area (km²) |
|---|---|---|---|
| U1 | -1 | 150-200 | 3324.8 |
| | -2 | 200-300 | 4516.5 |
| | -3 | 300-400 | 4671.4 |
| | -4 | 400-600 | 5378.9 |
| | total | | 17891.6 |
| U2 | -1 | 150-200 | na |
| | -2 | 200-300 | 7168.2 |
| | -3 | 300-400 | 8918.9 |
| | -4 | 400-600 | 8290.3 |
| | total | | 24377.4 |
| U3 | -1 | 150-200 | 2215.2 |
| | -2 | 200-300 | 2316.9 |
| | -3 | 300-400 | 1304.3 |
| | -4 | 400-600 | 2414.9 |
| | total | | 8251.2 |
| U | total | | 50520.3 |

| Stratum | | Depth (m) | Area (km²) |
|---|---|---|---|
| I1 | -1 | 150-200 | 345.9 |
| | -2 | 200-300 | 1853.1 |
| | -3 | 300-400 | 2469.6 |
| | -4 | 400-600 | 1557.1 |
| | total | | 6225.7 |
| I2 | -1 | 150-200 | 393.5 |
| | -2 | 200-300 | 769.4 |
| | -3 | 300-400 | 1025.3 |
| | -4 | 400-600 | 1321.3 |
| | total | | 3509.4 |
| I | total | | 9735.2 |

| Stratum | | Depth (m) | Area (km²) |
|---|---|---|---|
| C0 | -1 | 150-200 | na |
| | -2 | 200-300 | 897.3 |
| | -3 | 300-400 | 2125.9 |
| | -4 | 400-600 | 1212.6 |
| | total | | 4235.8 |