4 ENVIRONMENTAL SETTING

This Chapter provides an overview of the existing environmental setting of the Eastern Newfoundland Offshore Area (also referred to interchangeably herein as the SEA Study Area), including the relevant components of its physical, biological and human environments.

The SEA Study Area covers a marine area of approximately 680,000 km^2 off the eastern portion of the Island of Newfoundland (see Figure 1.1). This Eastern Newfoundland SEA has included updating the previous (2003) SEA for the Orphan Basin region (LGL Limited 2003) and expanding its geographic coverage to the south and east.

As is typical at an SEA level of analysis, the objective of this section is to provide a relatively high-level overview of the existing environmental setting of the SEA Study Area, as a basis for identifying potential environmental issues and interactions and associated planning considerations and other mitigation, rather than a detailed and site-specific description of the existing environment.

4.1 Physical Environment

These sections give an overview description of relevant aspects of the physical environment of the SEA Study Area, including its geology, bathymetry, climatology, oceanography and ice conditions.

4.1.1 Geology

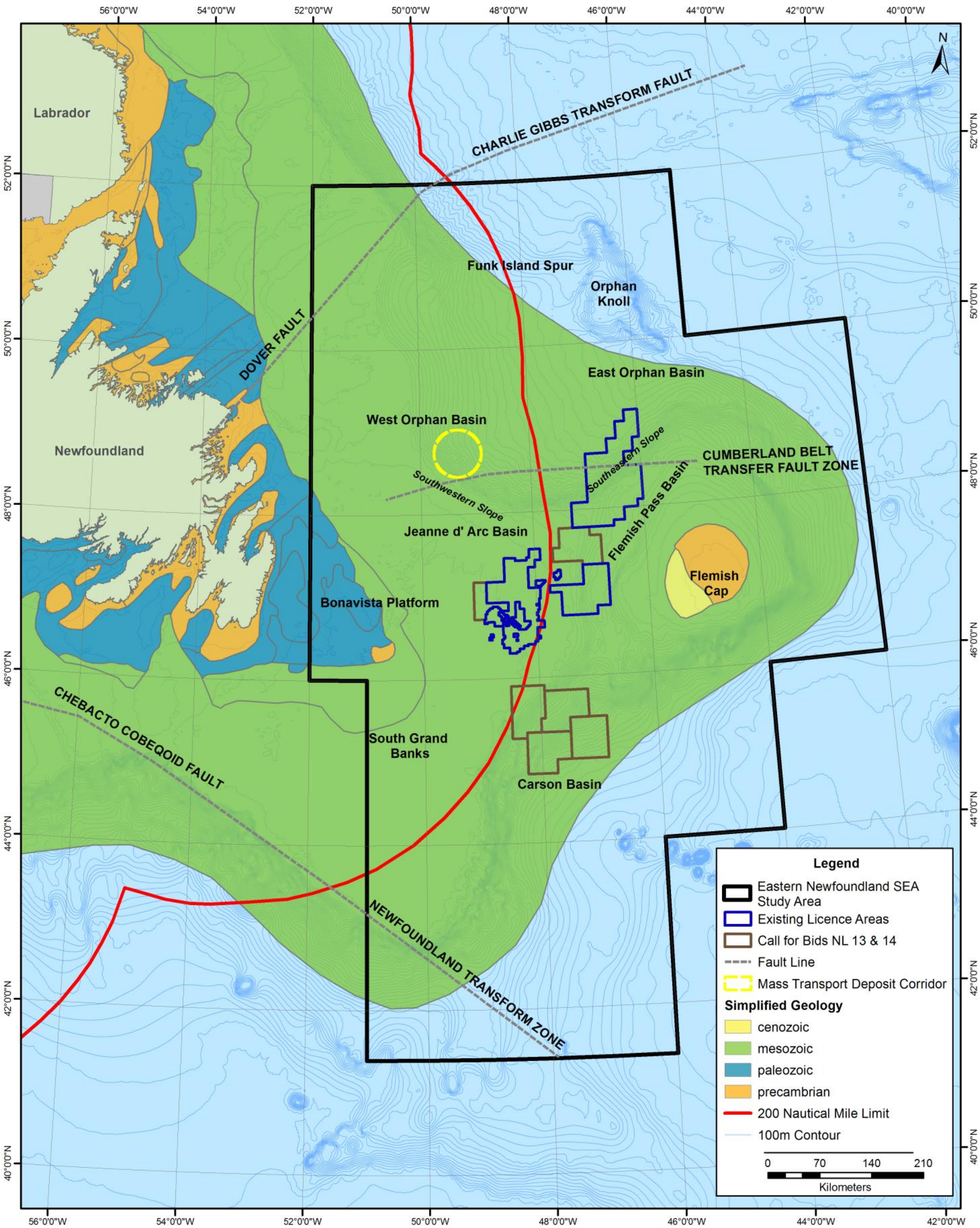
The geology of the Eastern Newfoundland Offshore Area is complex and dynamic, and the current bedrock and surficial characteristics of the SEA Study Area have been shaped by various natural and human factors and processes over time.

4.1.1.1 Bedrock Geology

The SEA Study Area is located within the offshore region of the Newfoundland continental margin and comprises primarily Mesozoic rocks, with the exception of a small area near the western boundary where there are Paleozoic formations. The area formed during the latest Wilson cycle which was initiated during the Late Triassic and involved tectonic activities resulting in the breakup of the supercontinent Pangea and opening of the Atlantic Ocean. These episodes of rifting and seafloor spreading heated the continental crust and lithosphere and then subsided to form a complex set of marginal Mesozoic basins, subbasins, troughs and sediment ridges. The extensional system is bounded in the north by the Dover Fault and Charlie Gibbs Transform Fault and in the south by the Newfoundland-Gibraltar Transform (Enachescu 2011). The resulting combination of stratigraphy, structure and timing has been conducive to hydrocarbon generation and entrapment (Bell and Campbell 1990).

The main sedimentary basins in the Study Area include the East and West Orphan, Flemish Pass, Jeanne D’Arc, Carson and South Grand Banks. A generalized overview of the bedrock geology of the SEA Study Area is presented in Figure 4.1 (after Fader et al 1989; Enachescu and Fagan 2005).

Figure 4.1 Geological Overview (Bedrock)



The primary reservoirs are located in the shallow marine and fluvial shale and sandstone deposited during the Late Jurassic and Early Cretaceous periods of the Mesozoic Era. The Late Jurassic Egret member of the Rankin Formation is a world-class source rock that is recognized as the primary source of the oil and gas discovered in the Jeanne d'Arc Basin, which is the only North American East Coast basin containing large producing oil fields. This rock type has also proven to be widespread in the Flemish Pass Basin (G&G 2003).

Notable topographic highs in the SEA Study Area are the Central Ridge, Flemish Cap and Orphan Knoll. The Central Ridge is a faulted intrabasinal high separating the Jeanne d'Arc and Flemish Pass basins (Enachescu 2012). The Flemish Cap is a large, isolated submarine knoll located approximately 600 km east of Newfoundland and represents the most easterly extension of North American continental crust (King and Fader 1985). It consists of a central core of Hadrynian rocks, including granodiorites, granites, dacites and an onlapping sequence of Mesozoic to Cenozoic aged sediments (King et al 1986). The Orphan Knoll is located approximately 550 km northeast of Newfoundland, and is comprised of Jurassic to Cretaceous sediments overlying mounds of Palaeozoic shallow water marine sediments.

4.1.1.2 Surficial Geology and Seabed Features

All of the Eastern Canadian continental shelf has been strongly influenced by Quaternary glaciation which resulted in an erosional morphology. Most of the glacial deposits on the shelf are recessional, with till sheets overlain by proglacial silts (Piper 1991). Five main seabed formations have been recognized within the SEA Study Area, which include the Grand Banks Drift, Downing Silt, Adolphus Sand, Grand Banks Sand and Gravel and Placentia Clay. Figure 4.2 shows the regional distribution of these formations, brief descriptions of which are provided below (from Sonnichsen and King 2005; Davidson and Simms 1997; Fader and Miller 1986).

The Grand Banks Drift is a glacial till comprised of poorly sorted, gravelly and sandy mud. This unit was formed directly beneath the grounded ice and conformably overlies the bedrock surface as a continuous thin till blanket and as long morainal ridges. It is typically confined to the deeper basins, channels and saddles between offshore banks. Overlying and interbedded with this formation is the Downing Silt, which occurs as lift-off moraine and till tongues similar to those on the Scotian Shelf. Also overlying the Grand Banks Drift is a patchy, silty sand veneer of Adolphus Sand. This formation was deposited as near-shore sands during the Late Wisconsinian low-stand of sea level. It generally comprises a compact to loose, olive-grey, fine to medium sand, often with silt, shells, and fine gravel and it rarely exceeds three metres in thickness. It typically occurs in the peripheral areas of the banks and in the adjacent saddles. The Placentia Clay formation is a thin, strongly to weakly laminated, sandy to silty mud derived from the reworking of glacial sediments during transgression of the shelf. The youngest of the formations is the Grand Banks Sand and Gravel, which is a basal transgressive deposit. It was formed by coastal and shallow water processes during the last shoreline transgression, and occurs typically at water depths shallower than 100 m. This formation is a clean, free-draining, well sorted material ranging from uniform fine sand to gravel sized components.

The main surficial geological features of the SEA Study Area are illustrated in Figure 4.3 (from Cameron and Best 1985). The area is characterized by a variety of seabed features such as iceberg scouring, sand ridges, sand waves, shell beds, pockmarks and seabed depressions of unknown origin. Seabed texture and gravel content are also illustrated, along with the interpreted late Wisconsinan low stand of sea level (at approximately 100 m water depth).

Figure 4.2 Geological Overview (Surficial)

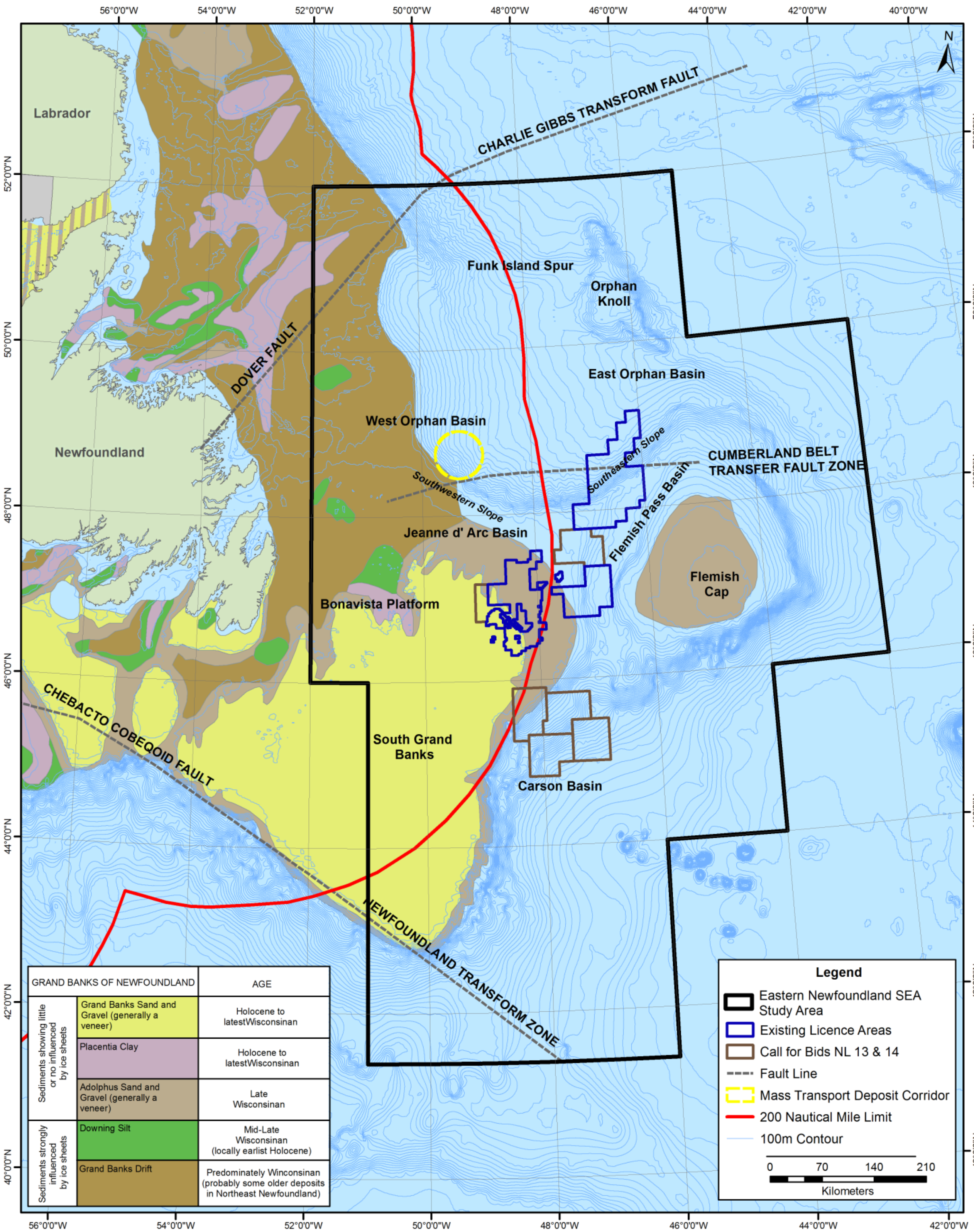
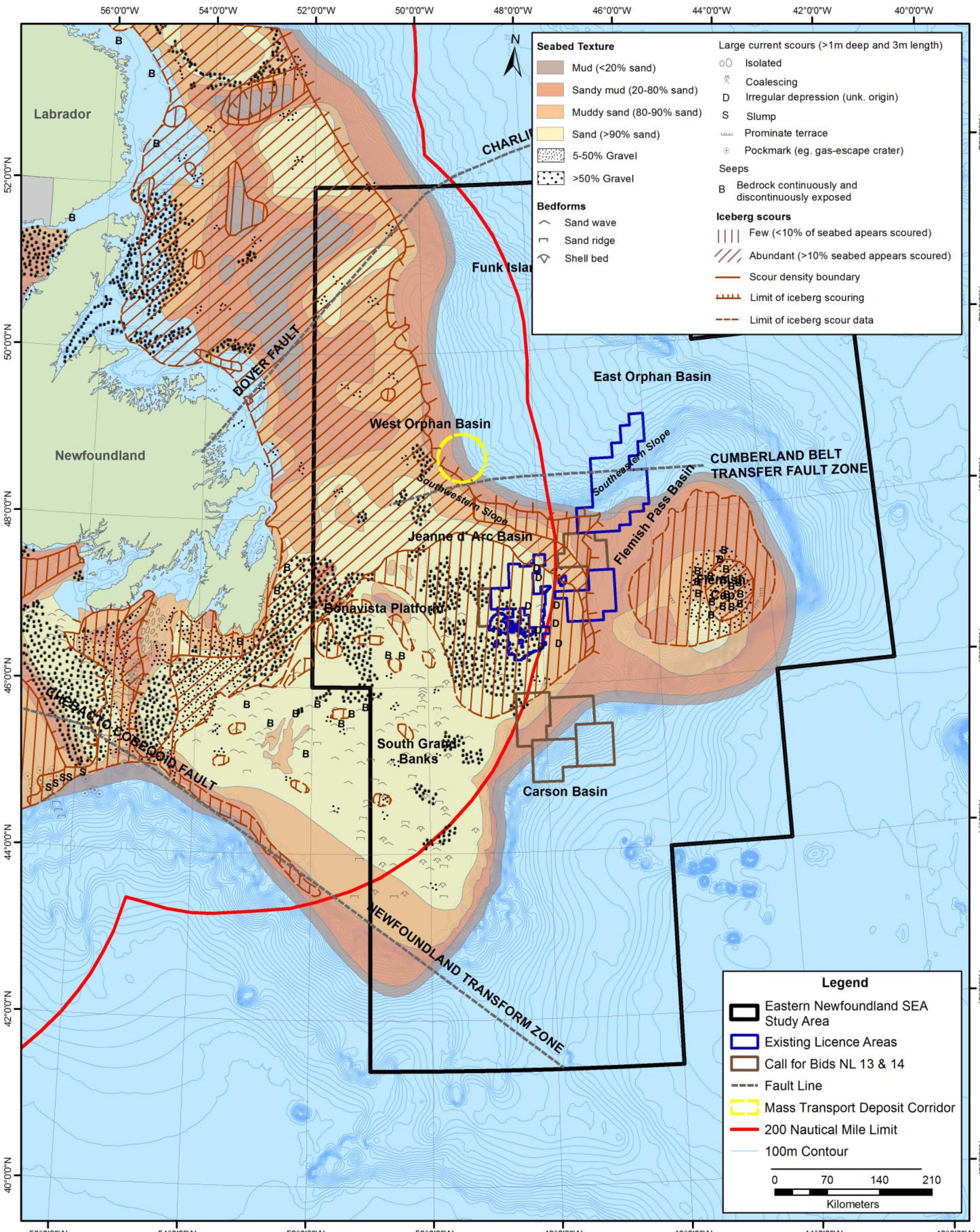


Figure 4.3 Seabed Features

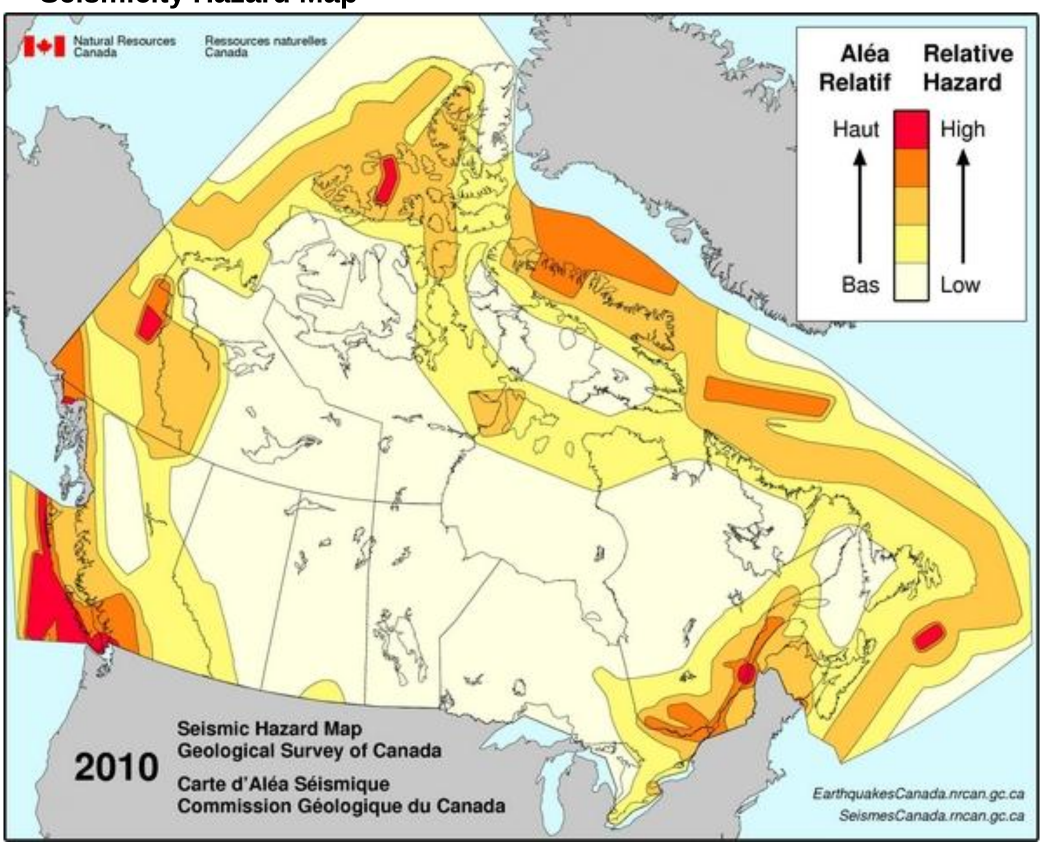


4.1.1.3 Seismicity

Eastern Canada is located within a relatively stable area of the North American Plate, where there has been a relatively low level of recorded seismic activity. Each year, approximately 450 earthquakes occur in Eastern Canada, with the majority having magnitudes between two and three. Along Canada's eastern continental margin, instrument-recorded earthquake epicenters are concentrated in a few areas of relatively intense seismic activity, such as the Laurentian Slope. The most recent edition of the Seismic Hazard Map prepared by Natural Resources Canada (Figure 4.4), which illustrates the probability of earthquake occurrences across Canada, indicates that the SEA Study Area has been classified as having a low to moderate seismic hazard.

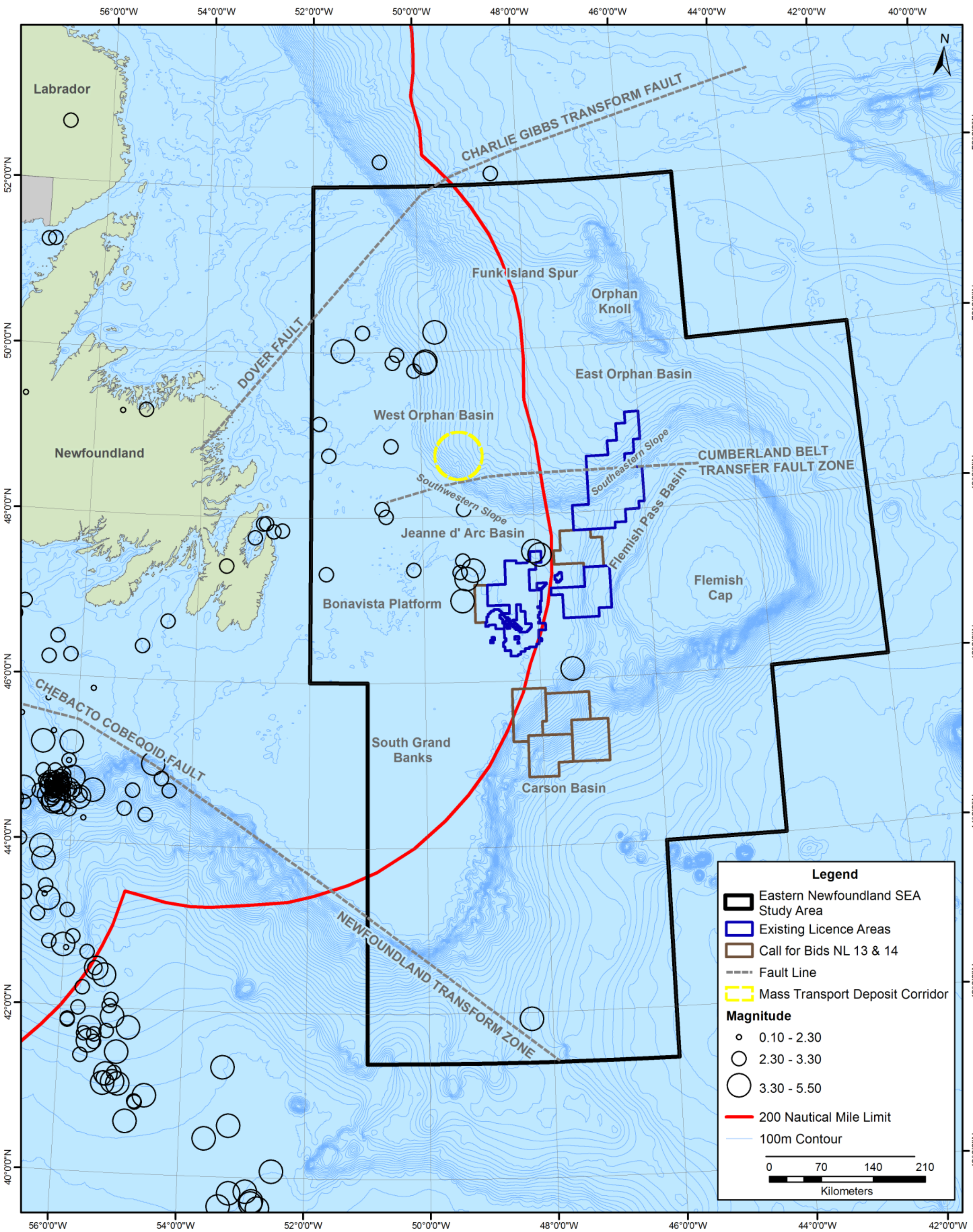
Earthquake information for the period 1985 – 2013 is available from the National Earthquake Database (Natural Resources Canada 2013) and is presented in Figure 4.5, which illustrates the approximate epicenter locations and magnitudes for earthquakes recorded during that timeframe within and adjacent to the SEA Study Area. Between January 1988 and August 2013 there were 25 such events recorded within the boundaries of the SEA Study Area. The magnitudes of these events have been relatively low, ranging from 2.6 to 4.7, with an average magnitude of 3.5 and a median of 3.3. The most recent such event occurred approximately 350 km east of St. John's on August 29, 2013 and had a recorded magnitude of 4.5. The majority of these recorded events have epicentres in the north-west portion of the SEA Study Area, and are likely related to the various tectonic lineaments in the area, most notably the Charlie Gibbs Transfer Fracture Zone and the Cumberland Belt Transfer Fault zone.

Figure 4.4 Seismicity Hazard Map



Source: Natural Resources Canada (2013)

Figure 4.5 Earthquake Epicentres (1985-2013) and Seismotechtonic Setting



4.1.1.4 Geohazards

Common offshore geohazards include slope instability, seismicity, sediment loading, venting of shallow gas, gas hydrates, seabed instabilities and ice scour. Sediment failure is essentially a consequence of gradient, magnitude of seismic acceleration and sediment strength. Most continental margin sediments, except on slopes of more than a few degrees, are relatively stable and would require seismic accelerations associated with a large earthquake (magnitudes of five or greater) to fail (Nadim et al 2005). Natural Resources Canada analysis indicates that in any given area offshore Eastern Canada, there is a risk of a major landslide every 20,000 years and a minor one every few thousand years. Most of the large failures on the seabed date back more than 10,000 years during periods of glaciations when large amounts of sediment were deposited directly onto the slope of the continental shelf (NRCan 2013).

Failure is typically more common on continental slopes where sedimentation rates from the adjacent continent are high, rather than on slopes of similar gradient that also receive muddy plume sedimentation far offshore such as the Orphan Knoll (Toews and Piper 2002). Key triggers for such failures can include high pore pressures, which may be induced by seismic accelerations or by melting of gas hydrates as a result of reduction in pressure due to falling sea level or increase in temperate due to warming of bottom waters (Piper and Campbell 2005). However, synchronous failures in multiple drainage systems suggest that most failures are earthquake triggered, with some seismicity induced by glacio-isostasy (Piper 2005). Mean recurrence interval of earthquakes with magnitudes of seven at any point on the margin is estimated at 30 thousand years from seismological models and 40 thousand years from the sediment failure record (Piper et al, in press). Within the Study Area, slope stability risk is higher on the south side of the Orphan Basin and in the northern Flemish Pass. In general, there is evidence of slope failures every 10,000 years or so. For an offshore production facility with a life of 20 years, for example, that means a one in 500 chance of a landslide (Cameron et al. 2014.). Currently, there have been no maps of slope failure risk produced but it is something that Natural Resources Canada hopes to achieve within the next couple of years (D. Piper, pers. comm.)

The Orphan Basin is a deep-water basin off the Northeast coast of Newfoundland that is bounded to the west, east and southeast by the Grand Banks, Orphan Knoll and Flemish Cap, respectively, and is currently an area of active hydrocarbon exploration. Evidence of past instability within the Orphan Basin includes thick, stacked mass-transport deposits on the basin floor and seabed failure scars on the continental slope (Campbell 2005). A geographically confined zone of repeated seabed failure, informally termed a mass-transport deposit corridor, has been recognized on the southwestern slope (Campbell 2005). Mass transport deposits may be unstable in areas based on the presence of diapiric features and can provide weak layers for the development of seabed creep (Campbell, 2005).The youngest widespread slope failure on the Orphan Basin occurred approximately seven thousand years ago which was recognized along a 250 km segment of the continental slope (Tripsanas et al 2008a in Piper et al, in press). Within the Orphan Basin, Piper et al (in press) suggest that slopes steeper than three degrees show widespread failure except where underlain by glacial till. Failures in the Orphan Basin represent earthquakes with magnitudes ranging from 5.6 to 7.6 (Piper et al, in press).

The slopes of the northern Orphan Basin (south of Funk Island Spur) appear to be less prone to landsliding based on very sparse data presented by Tripsanas et al (2007). North of Funk Island Spur, there is more evidence of landsliding on the slope but the frequency of landsliding is currently not well known. There is very little data around the southern Grand Banks but it is suspected that landslides are less common there than around Flemish Pass and southern Orphan Basin, although work remains to be done in that area (D. Piper, pers. comm.)

The Flemish Pass is a mid-slope basin bounded to the west by the Grand Banks of Newfoundland and to the east by the isolated Flemish Cap which has also been a site of active hydrocarbon exploration (Piper and Campbell 2005). In this area, large, complex landslides have been mapped along a 65 km length of the northeast flank of the Flemish Pass which extends about 20 km downslope. Failed sediments have run out as far as 20 km onto the floor of the Flemish Pass, forming mass transport deposits typically 50 m thick. These major sediment failures occurred 27 thousand and 20.5 thousand years ago and are believed to have been a result of earthquake triggers (Cameron et al 2014). Similarly, Piper and Campbell (2005) have presented brief regional geohazard assessment of the Flemish Pass area and also suggested that most large debris flow deposits in the area are the result of earthquake triggered slumps on both flanks of the Flemish Pass.

Piper and Campbell (2005) indicate that gas hydrates may also act as a trigger for failure in the Flemish Pass as observed by a pattern of younger debris-flow deposits in the central region of the area. Bottom water temperature in Flemish Pass is buffered by the supply of cold arctic water through the Labrador Current, so that times of gas hydrate melting are likely restricted to periods of falling sea level between interglacial and glacial maximum conditions. Falling sea level results in less hydrostatic pressure in seabed sediments and consequently a melting of gas hydrate. The natural risk of large slope failure appears very low with a recurrence interval of 100 thousand years. It is likely preconditioned by high pore pressure and triggered by earthquakes. In northern Flemish Pass and southern Orphan Basin, the steep slopes, abundant shallow gas, and possibly greater seismicity make large landslides more frequent, with a recurrence interval of 10 thousand years (Cameron et al 2014)

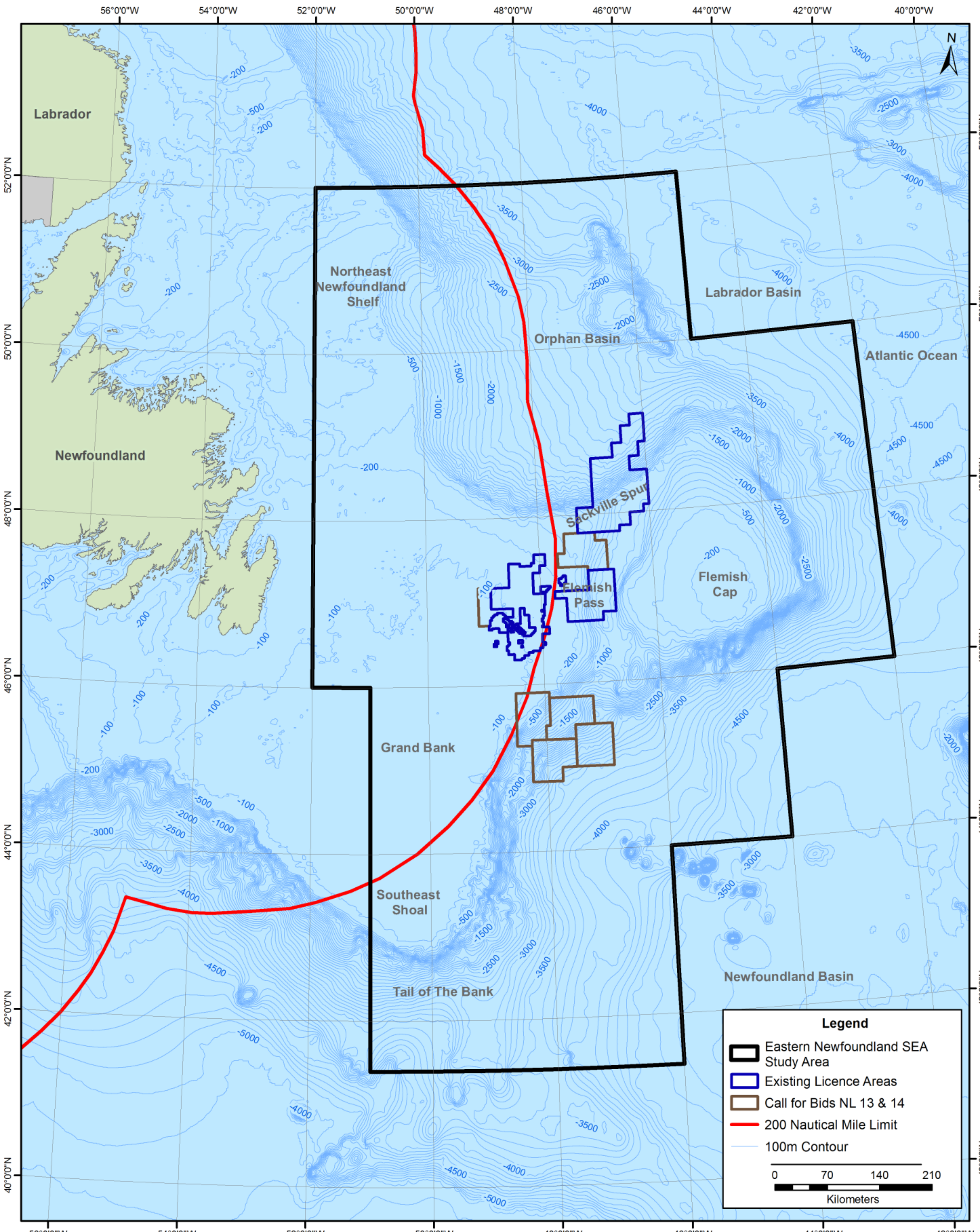
4.1.2 Bathymetry

The Eastern Newfoundland Offshore Area covers a large expanse of the Northwest Atlantic Ocean, and the bathymetry of this region is generally well known (Figure 4.6).

The west-central portion of the SEA Study Area contains the Grand Banks, a region with average depths of about 75 m. The Grand Banks extend from the western boundary of the Study Area east about 350 km to the 200 m depth contour, and then a further 25 to 50 km to the 1,000 m depth contour and the Flemish Pass with depths of almost 1300 m. On the eastern side, depths rise again to the Flemish Cap, a large bathymetric feature of about 50,000 km^2 with depths rising back up to about 130 m. The banks extend also to the north and south. To the south, the Tail of the Banks is located about 330 km from the southeast corner boundary of the SEA Study Area. Numerous canyons in this region run down off the continental slope into the Newfoundland Basin, with deep ocean depths of between approximately 2,000 m to 4,000 m. The Southeast Shoal, with depths of about 40 to 50 m, lies about 75 to 125 km to the north of the tail.

The Sackville Spur extends the nose of the Grand Banks at depths of up to 1,000 m at about 450 km east-northeast from the western boundary of the SEA Study Area. The Grand Banks extend north to the Northeast Newfoundland Shelf with depths of approximately 200 to 300 m. Northeast of the shelf lies the Orphan Basin occupying about one fifth of the SEA Study Area. Depths in the Orphan Basin increase from about 1,200 m at the edge of the continental shelf to as deep as 3,500 m. The Labrador Basin and deep ocean lie farther offshore to the north and east of the Orphan Basin and Flemish Cap, with depths of 3,000 to over 4,000 m.

Figure 4.6 General Bathymetry



4.1.3 Climatology

The following sections provide an overview of the key climatological conditions and characteristics of the Eastern Newfoundland SEA Study Area, including wind, air temperature, precipitation, fog and visibility, and tropical systems.

4.1.3.1 Wind Conditions

The wind climatology is characterized using statistics derived from the latest MSC50 wind and wave hindcast dataset, spanning the period from 1954 to 2011 inclusive (MSC 2012).

There are numerous hindcast data nodes located within the SEA Study Area. Recognizing this, and the large marine area covered by the SEA Study Area, four MSC50 grid point locations were selected to be generally representative of this region. The locations are noted below and illustrated in Figure 4.7.

- 6017801 (51°N, 49°W) for the Orphan Basin;
- 6013451 (48°N, 44°W) for the Flemish Cap;
- 6011595 (47°N, 50°W) for the Grand Bank; and
- 6003889 (43°N, 50°W) for the Tail of the Grand Banks.

This is in keeping with the approach for, and the type and level of information that has been included in, other SEAs in the NL Offshore Area. It should be reiterated, however, that the intent here is to provide a regional overview for general illustration, rather than detailed and site-specific climatological information for design and operational purposes.

The MSC50 dataset includes hourly wind and wave parameters of the North Atlantic Ocean and includes consideration of iced-over periods (Swail et al 2006). The hindcast data were produced through the kinematic reanalysis of all significant tropical and extra-tropical storms in the North Atlantic for the continuous period 1954-2011.

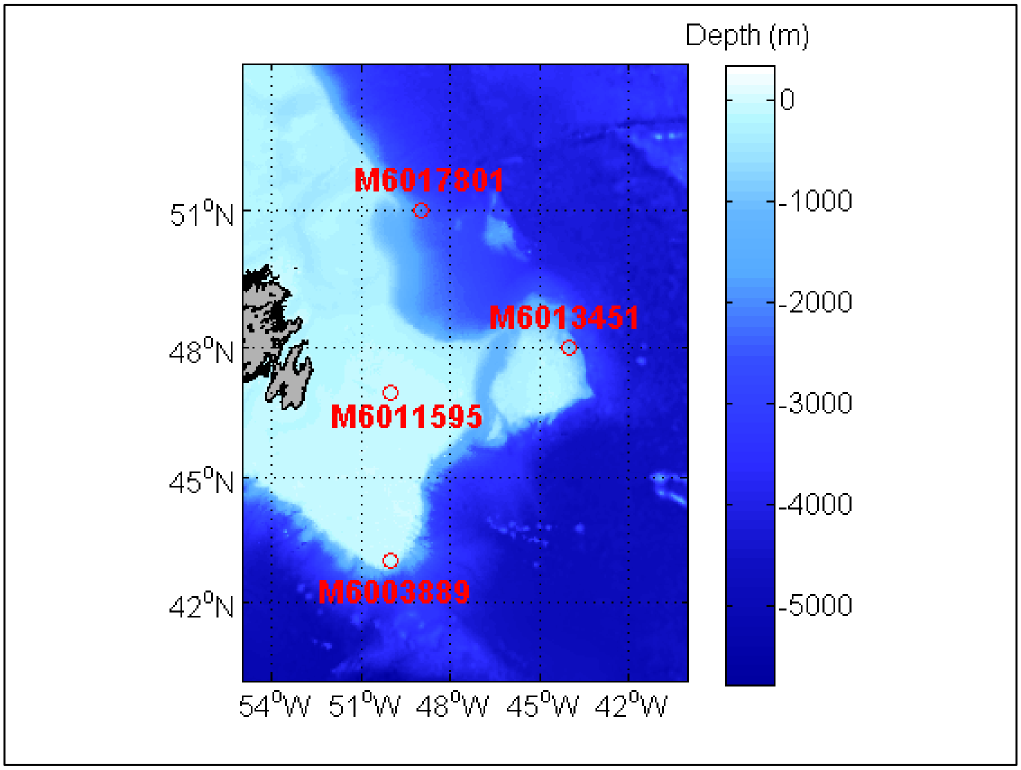
The MSC50 wind speeds are 1-hour average wind speeds for a height of 10 m above sea level. Wind speed measurements are frequently averaged over shorter durations, e.g., 10 minutes for marine reports and two minutes for aviation, and a one minute average is used for the categorization of tropical cyclones. Wind gusts are typically for 1, 2 or 5 second durations. Several formulas, e.g., ISO/DIS 19901-1 (2005), can be used to scale winds to averaging times less than 1 h and for different reference elevations (e.g., between 10 m and rig anemometer heights or vice versa), and are frequently applied in design criteria studies applying measured and hindcast data sets. The wind climatology information presented here is for strategic EA purposes, not for design.

The hourly wind speed and direction data have been used to derive annual) and monthly wind rose plots of wind speed and wind direction distributions for each sub-region. Summary descriptions of these distributions have also been tabulated and are provided in the associated Tables.

In an attempt to facilitate an assessment of tropical storm winds, the 1-hour average maximum winds have been correspondingly scaled to a 1-min average, following the At-Sea class gust factor of 1.11 reported in WMO (2012), and are also reported in the wind speed and direction descriptive statistics Tables. The 1-min average is selected to align with the HURDAT winds reported in Section 4.1.3.5.

Note that application of comparable (10 m elevation and 1-min average) scaling with the ISO/DIS 19901-1 (2005) yields a factor of 1.25.

Figure 4.7 Location of the MSC50 Nodes Selected to Describe Wind and Wave Conditions (1954-2011)



Regional Wind Summary

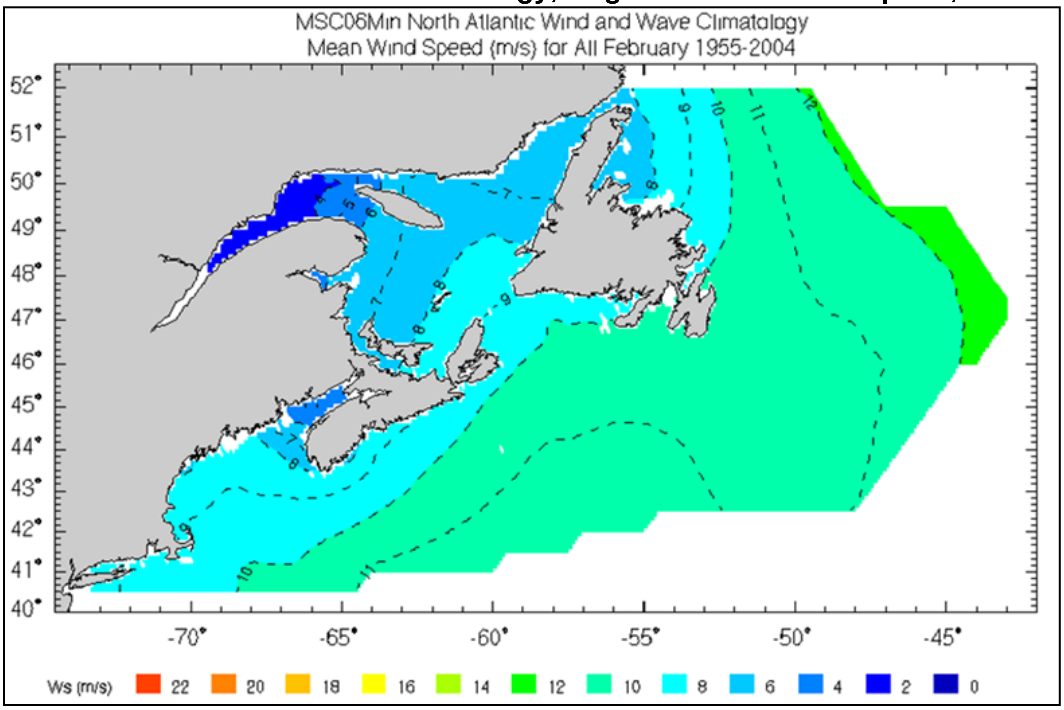
It is recognized that there are limitations in using a single point to be representative of a large area. For the wind and wave climatology the SEA Study Area has been characterized using four points. A review of regional wind conditions as reported in the MSC50 hindcast climatology (Oceanweather 2011) does not indicate a large variation in the climate, and the four points as selected above are considered to provide reasonable coverage. A similar review of regional wave conditions is presented in Section 4.1.4.1.

Maps of the mean and 99th percentile wind speeds for February, as an indication of winter time when conditions are generally least favourable, are presented in Figures 4.8 and 4.9). These particular analyses cover the period 1955 to 2004 (compared with the statistics and roses below for the selected SEA Study Area four grid points which report more recent data for 1954 through 2011).

Mean wind speeds in February range from about 10 m/s in the northwest portion of the SEA Study Area (latitude 52°N, longitude 52°W) to 11 m/s to the south (latitude 43°N) and as large as 12 to 13 m/s to the far east of the Flemish Cap region (Figure 4.8). Inspection of the corresponding August map, as an indication of summer time conditions, shows corresponding mean wind speeds of 6 to 7 m/s across the entire SEA Study Area.

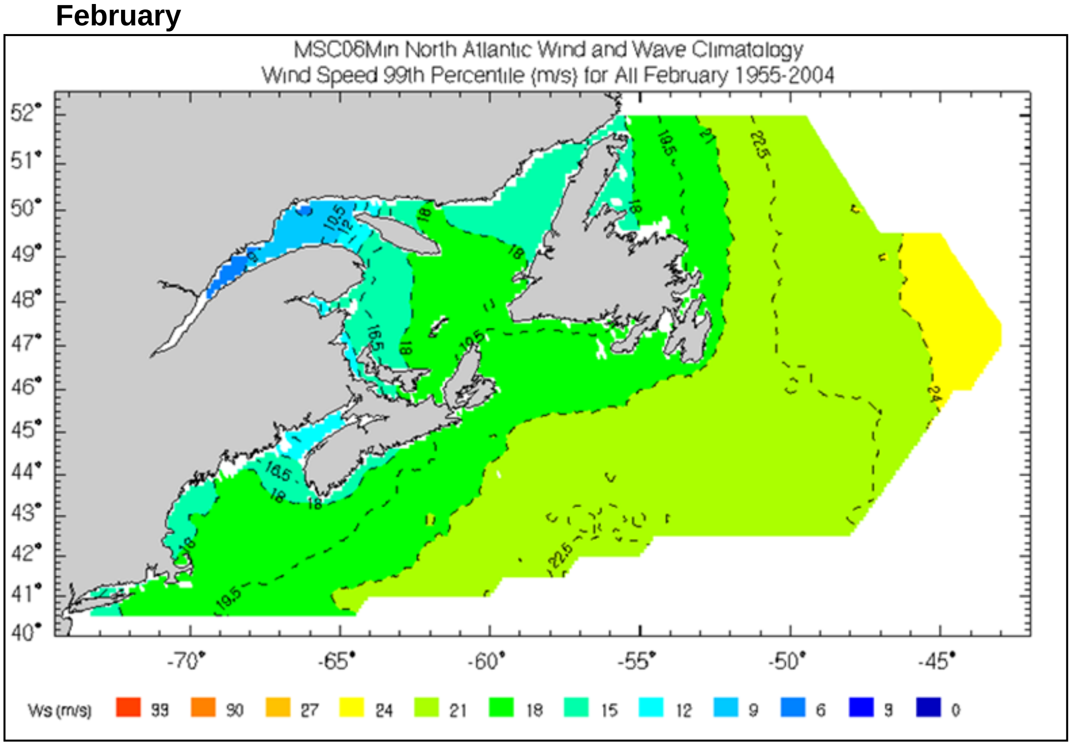
Figure 4.9 reports the 99th percentile wind speed values for February. Values range from about 21 m/s in the northwest to 22 to 23 m/s in the south and slightly greater than 24 m/s to the east. Inspection of the corresponding August map shows corresponding 99th percentile wind speed values of about 13.5 to 15.5 m/s uniformly across the SEA Study Area.

Figure 4.8 MSC50 Wind and Wave Climatology, Regional Mean Wind Speed, February



Source: Oceanweather (2011)

Figure 4.9 MSC50 Wind and Wave Climatology, Regional 99th Percentile Wind Speed, February



Source: Oceanweather (2011)

Orphan Basin

The prevailing winds annually are southwesterly (20.3 percent), westerly (20.1 percent) or northwesterly (16.4 percent) direction, depending on the time of the year (Figure 4.10). The monthly plots reveal that westerly and northwesterly winds are dominant during the period from October to March, while southwesterly and southerly winds are more frequent during the warmer months from May to September (Figure 4.11). Mean hourly wind speeds range from 6.6 m/s (July) to 12.4 m/s (January), while the strongest winds of 32.0 m/s occur in September (from the southeast) and December (from the northwest) and January and February (from the west). The maximum hourly wind speeds (Table 4.1) indicate that gale force winds, in the range from 17.5 to 24.2 m/s, occur throughout the year, while storm force winds, in the range from 24.7 to 32.4 m/s, are expected to occur in all months except July. Sustained hurricane force winds (stronger than 32.9 m/s) occur in the Orphan Basin sub-region in February where the maximum wind speed is 33.5 m/s.

Figure 4.10 Annual Directional Distribution of Wind Speed for the Orphan Basin, MSC #17801 (1954-2011)

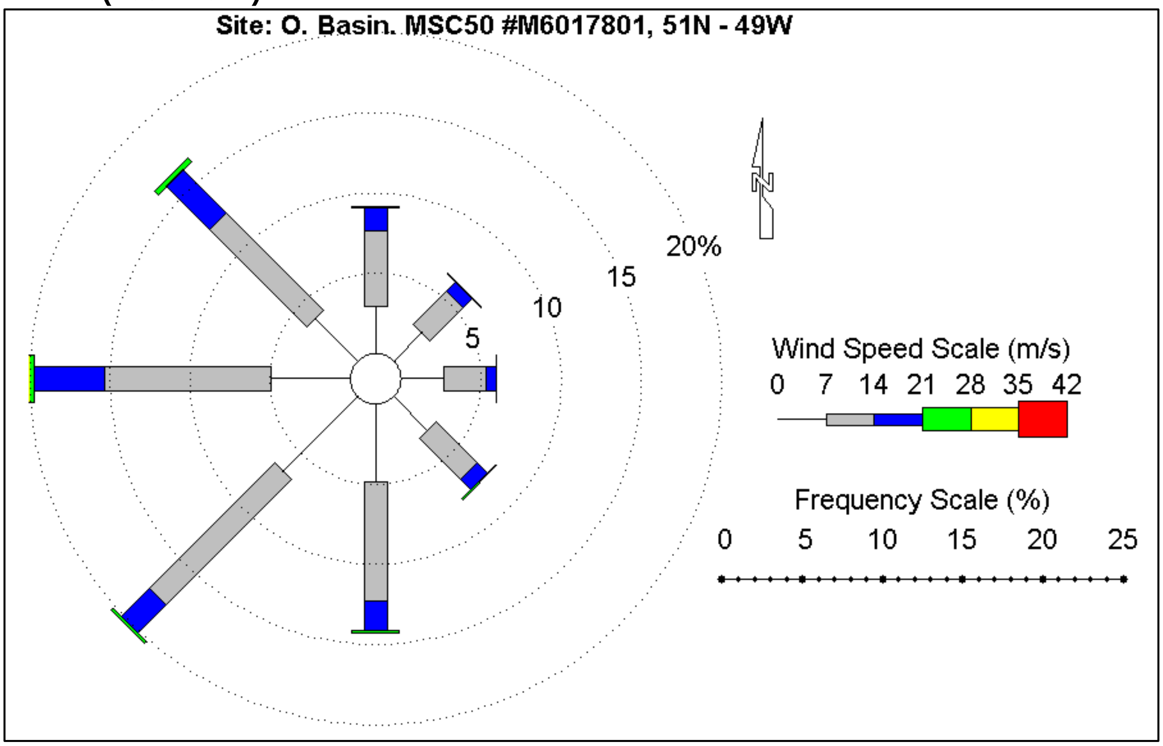


Figure 4.11 Monthly Directional Distributions of Wind Speed for the Orphan Basin, MSC #17801 (1954 – 2011)

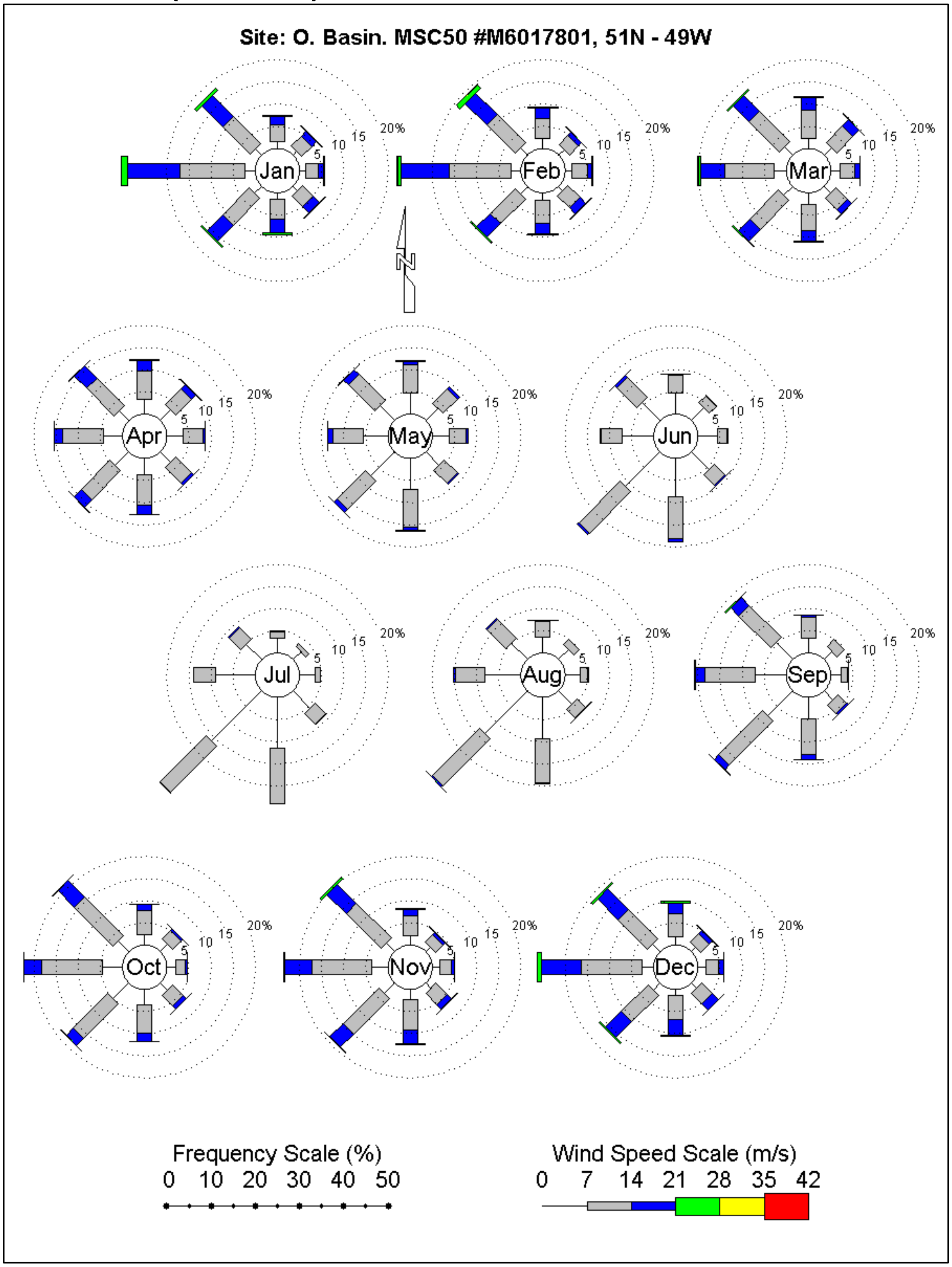


Table 4.1 Wind Speed and Direction Descriptive Statistics, MSC50 Data for the Orphan Basin (1954 – 2011)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean hourly speed (m/s)	12.4	12.0	11.0	9.6	8.1	7.1	6.6	7.0	8.6	10.0	11.1	12.0	9.6
Most frequent direction (from)	W	W	W	SW	SW	SW	SW	SW	SW	W	W	W	SW
Maximum hourly speed (m/s)	32.3	33.5	30.2	24.5	25.3	24.6	19.0	28.2	32.2	28.4	28.7	32.0	33.5
Maximum 1-min speed (m/s)	35.9	37.2	33.5	27.2	28.1	27.3	21.1	31.3	35.7	31.5	31.9	35.5	37.2
Direction of max. hourly speed (from)	W	W	NW	NW	NW	NW	NW	S	SE	S	W	NW	W

Flemish Cap

In this sub-region, the prevailing winds through most of the year have a westerly (24.2 percent of the time annually) or southwesterly (20.8 percent of the time annually) direction (Figure 4.12). The monthly plots reveal that westerly and northwesterly winds are generally most frequent during the period from October to April, while southwesterly and westerly winds are most frequent during the warmer months from May to September (Figure 4.13). Mean hourly wind speeds range from about 6.7 m/s (July) to 12.5 m/s (January), while the strongest winds in excess of 32 m/s are most likely to occur in December (from the northwest), January (from the west) and March (from the west). The maximum hourly wind speeds (Table 4.2) indicate that gale force winds, in the range from 17.5 to 24.2 m/s (MSC 2012), occur throughout the year, while storm force winds, in the range from 24.7 to 32.4 m/s, occur in all months except June and July. Sustained hurricane force winds (stronger than 32.9 m/s) occur in December when the maximum wind speed is 35.8 m/s.

Figure 4.12 Annual Directional Distribution of Wind Speed for the Flemish Cap, MSC #13451 (1954-2011)

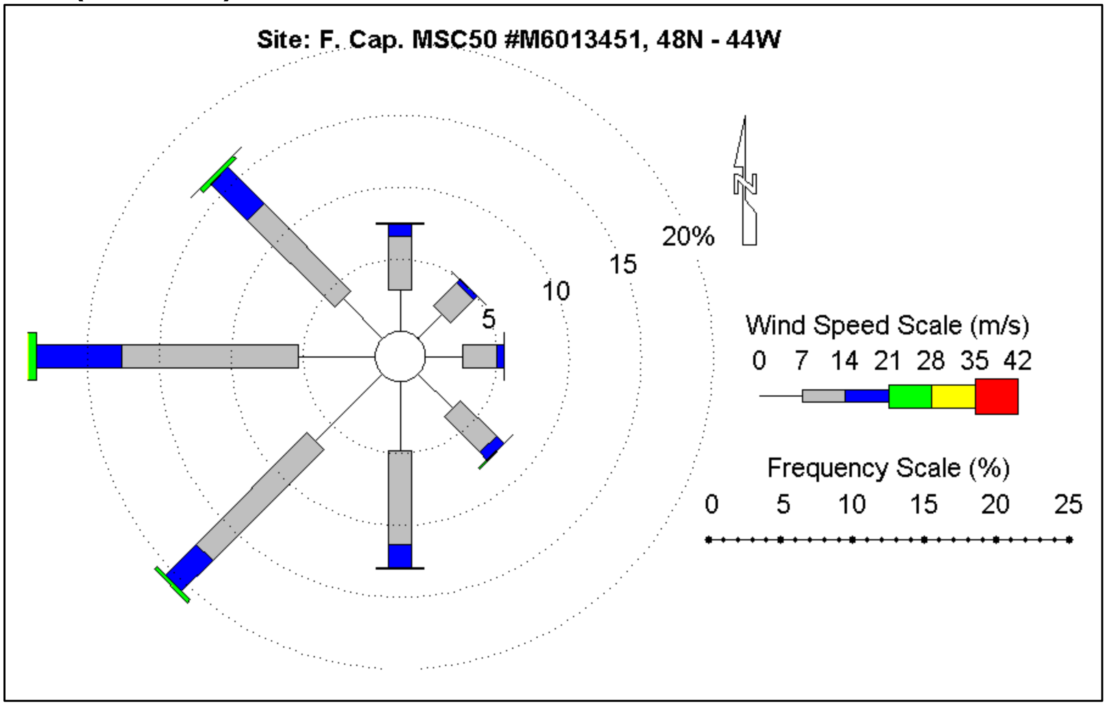


Figure 4.13 Monthly Directional Distributions of Wind Speed for the Flemish Cap, MSC #13451 (1954 – 2011)

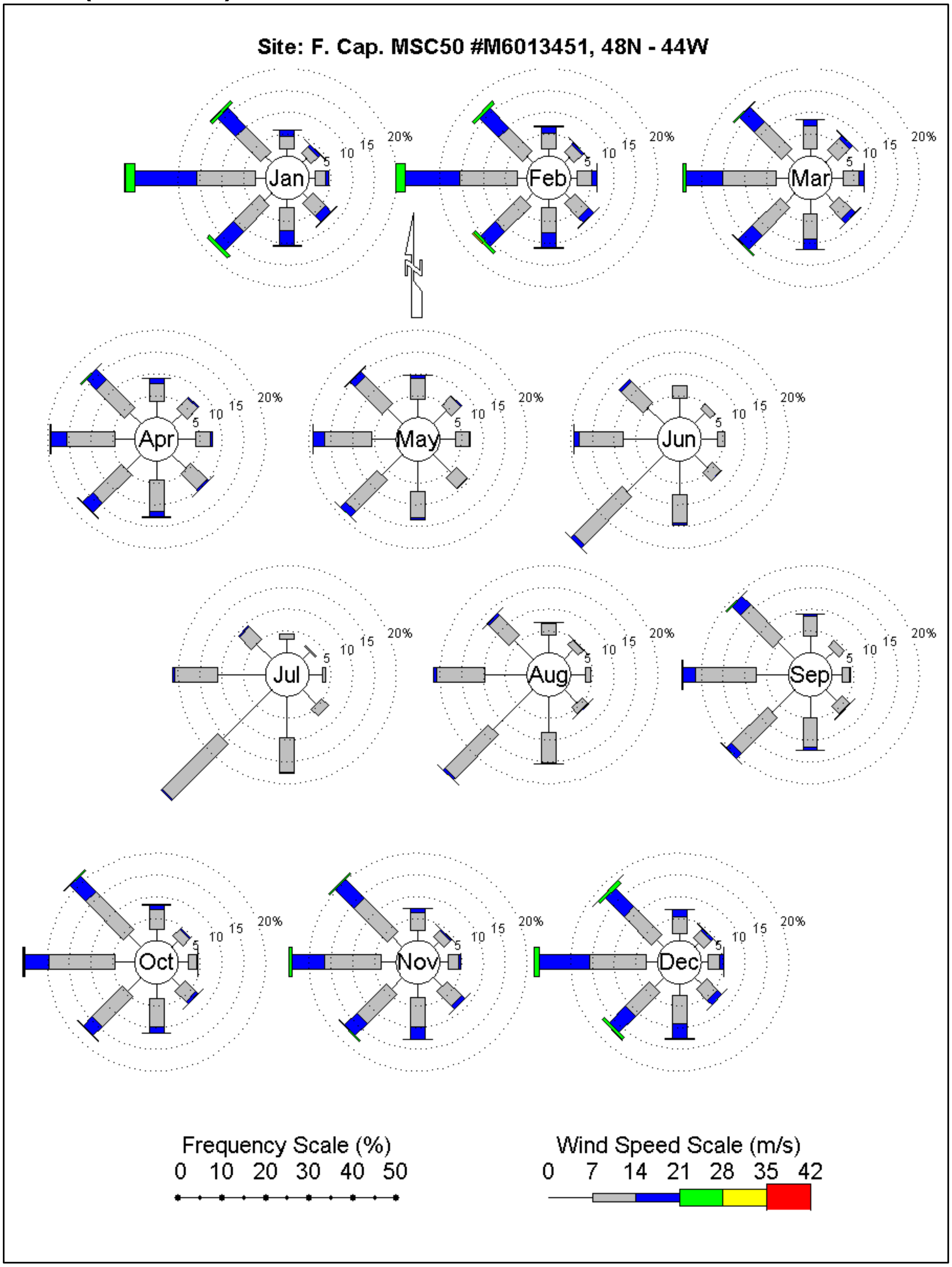


Table 4.2 Wind Speed and Direction Descriptive Statistics, MSC50 Data for the Flemish Cap (1954 – 2011)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean hourly speed (m/s)	12.5	12.2	11.0	9.3	8.1	7.4	6.7	7.1	8.6	10.1	10.8	11.9	9.6
Most frequent direction (from)	W	W	W	W	W	SW	SW	SW	W	W	W	W	W
Maximum hourly speed (m/s)	32.2	31.2	32.4	25.6	27.1	23.9	19.7	29.0	26.1	29.3	28.3	35.8	35.8
Maximum 1-min speed (m/s)	35.7	34.6	36.0	28.4	30.1	26.5	21.9	32.2	29.0	32.5	31.4	39.7	39.7
Direction of max. hourly speed (from)	W	SW	W	W	NW	W	S	S	SW	NW	W	NW	NW

Grand Banks

In this sub-region, the prevailing winds annually are southwesterly (22.7 percent) or westerly (20.0 percent) direction (Figure 4.14). The monthly plots show that westerly winds are dominant during the period from October to March, while southwesterly winds are most frequent from May to September (Figure 4.15). Mean hourly wind speeds range from 6.2 m/s (July) to 11 m/s (January), while maximum wind speeds of 32.3 m/s from the northwest are reported in February. Table 4.3 indicates that gale force winds, in the range from 17.5 to 24.2 m/s (MSC 2012), occur in all months of the year, and storm force winds, in the range from 24.7 to 32.4 m/s, occur in all months except May through July.

Figure 4.14 Annual Directional Distribution of Wind Speed for the Grand Banks, MSC #11595 (1954-2011)

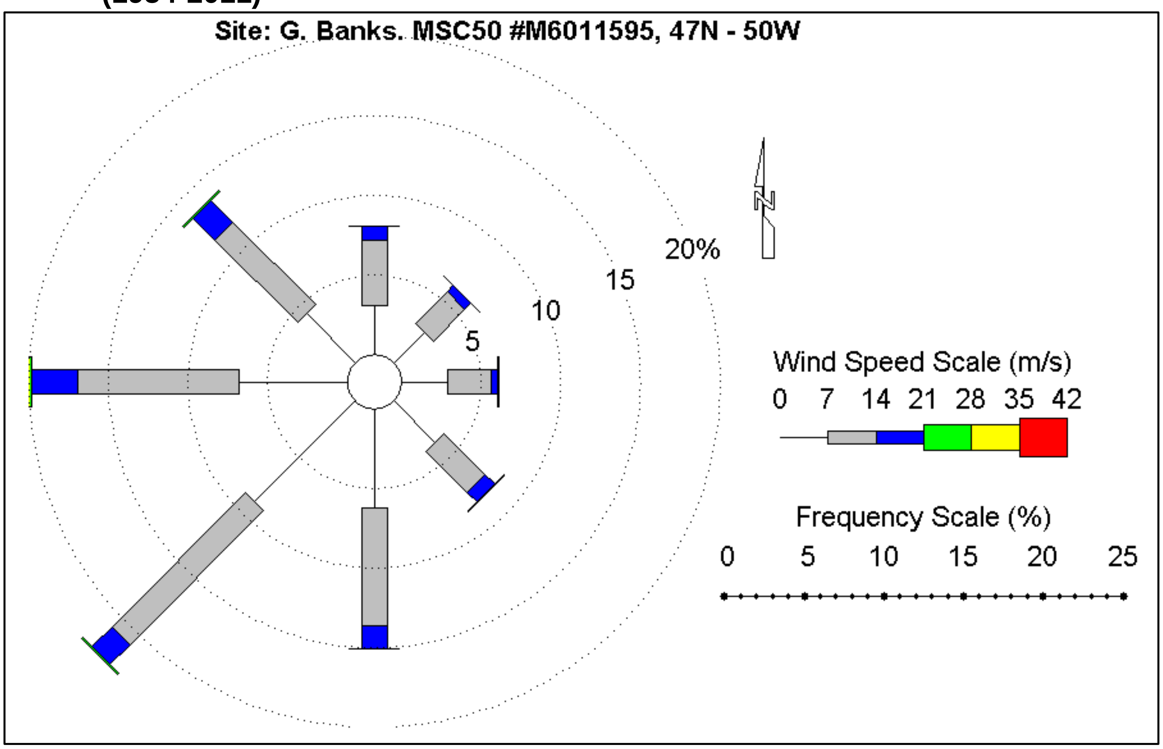


Figure 4.15 Monthly Directional Distributions of Wind Speed for the Grand Banks, MSC #11595 (1954 – 2011)

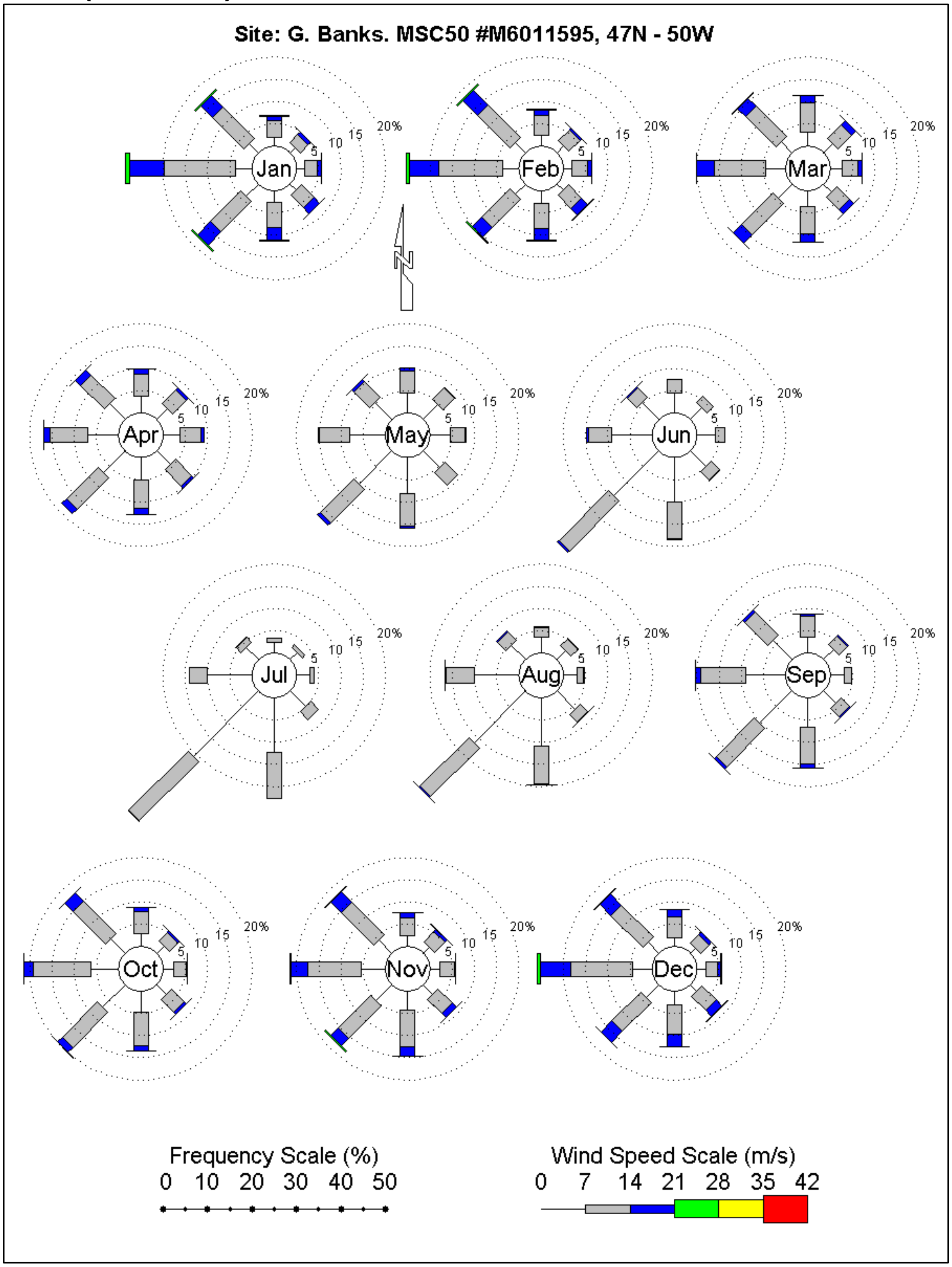


Table 4.3 Wind Speed and Direction Descriptive Statistics, MSC50 Data for the Grand Banks (1954 – 2011)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean hourly speed (m/s)	11.0	10.8	9.8	8.4	7.1	6.6	6.2	6.6	7.7	8.9	9.7	10.6	8.6
Most frequent direction (from)	W	W	W	SW	SW	SW	SW	SW	SW	W	W	W	SW
Maximum hourly speed (m/s)	27.9	32.3	26.7	25.0	21.4	23.6	19.9	26.5	29.8	30.8	26.4	28.4	32.3
Maximum 1-min speed (m/s)	31.0	35.9	29.6	27.8	23.8	26.2	22.1	29.4	33.1	34.2	29.3	31.5	35.9
Direction of max. hourly speed (from)	SE	NW	N	N	NW	NW	SW	SE	SW	W	NW	NW	NW

Tail of the Banks

In this sub-region, winds are from the south, southwest, west or northwest 16 to 18 percent of the time for each direction annually (Figure 4.16). The monthly plots reveal that northwesterly and westerly winds are most frequent during the period from October to April, while southwesterly winds are most frequent during the warmer months from May to September (Figure 4.17). Mean hourly wind speeds range from 5.7 m/s (July) to 10.3 m/s (January and February), while the strongest winds in excess of 30 m/s are most likely to occur in September (31.5 m/s) and in December (30.3 m/s), January (30.1 m/s) and February (36.1 m/s) all from the west (Table 4.4). Gale force winds, in the range from 17.5 to 24.2 m/s occur throughout the year; storm force winds, in the range from 24.7 to 32.4 m/s, can be expected in each month from October through March. Sustained hurricane force winds (stronger than 32.9 m/s) occur in February.

Figure 4.16 Annual Directional Distribution of Wind Speed for the Tail of the Banks, MSC #3889 (1954-2011)

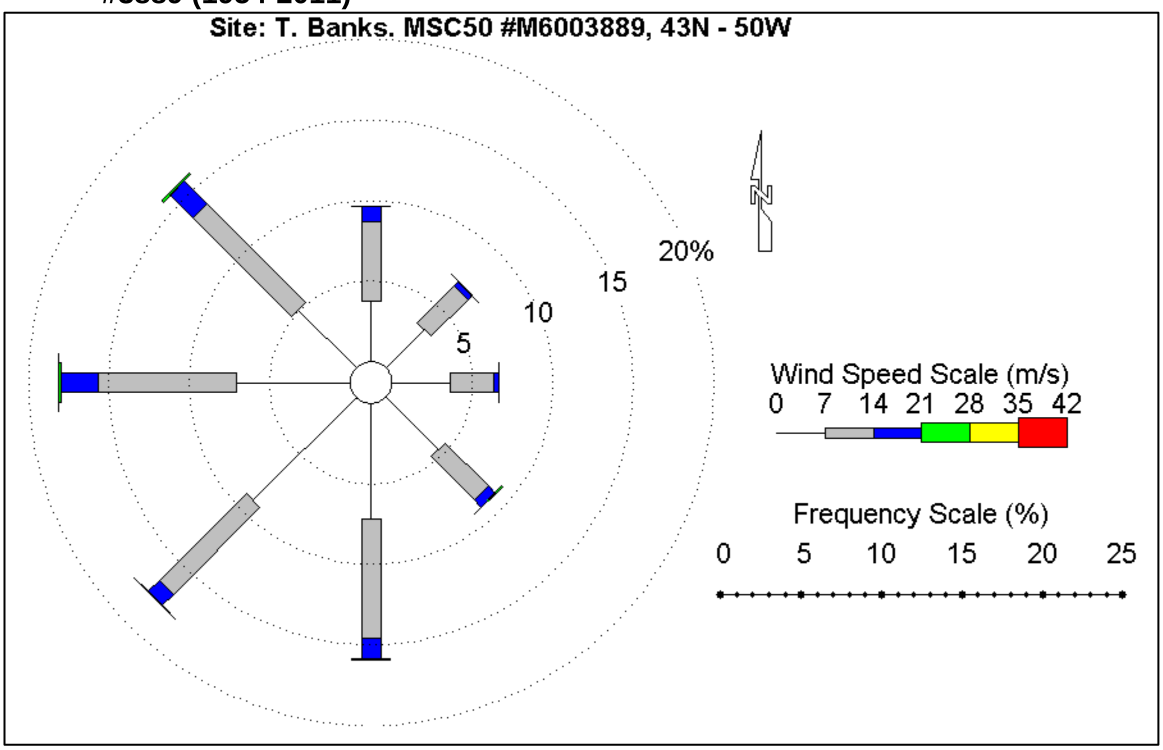


Figure 4.17 Monthly Directional Distributions of Wind Speed for Tail of the Banks, MSC #3889 (1954 – 2011)

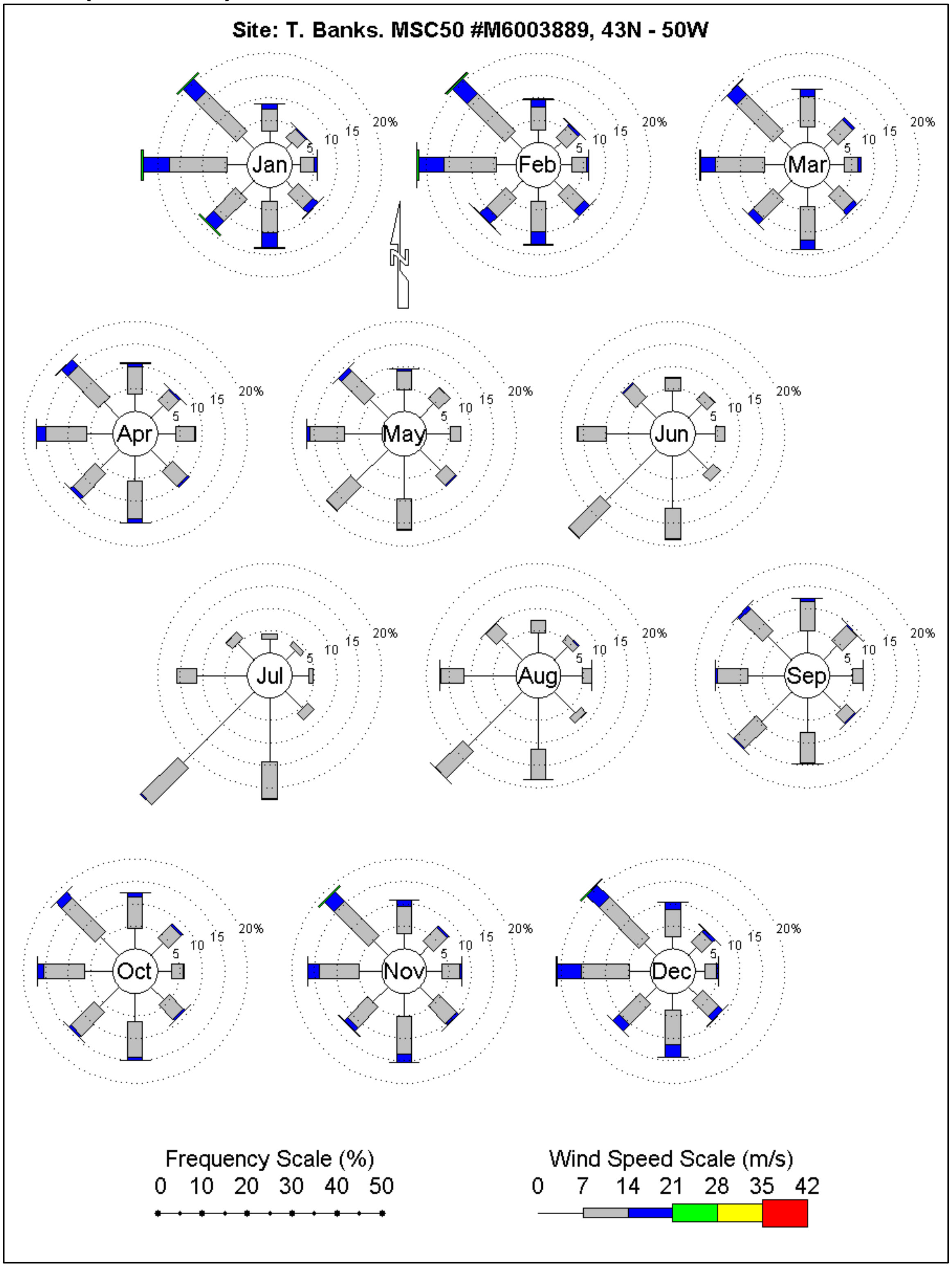


Table 4.4 Wind Speed and Direction Descriptive Statistics, MSC50 Data for the Tail of the Banks (1954 – 2011)

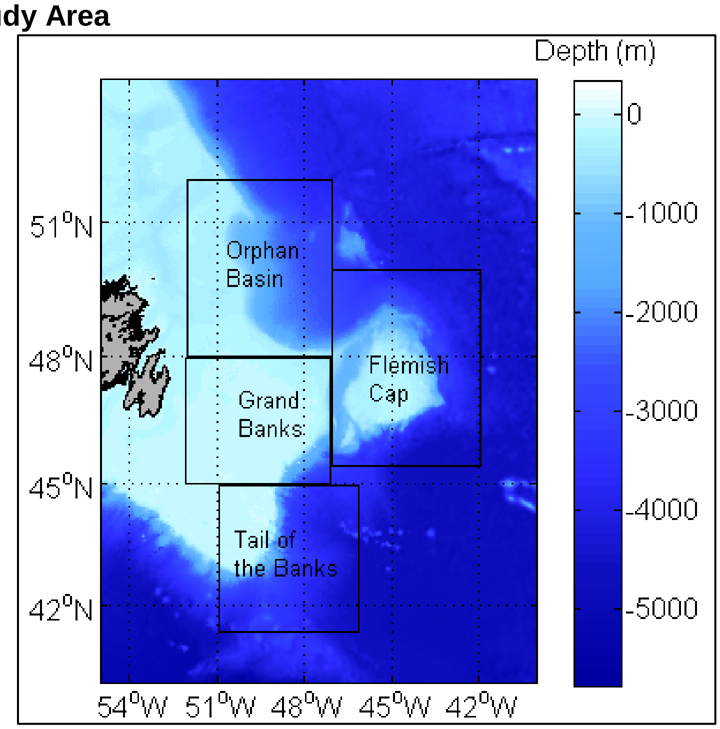
Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean hourly speed (m/s)	10.3	10.3	9.4	8.3	6.9	6.2	5.7	5.9	7.1	8.2	9.1	10.1	8.1
Most frequent direction (from)	W	W	W	W	SW	SW	SW	SW	SW	NW	NW	W	W
Maximum hourly speed (m/s)	30.1	36.1	28.3	24.5	21.6	20.2	20.0	24.4	31.5	28.9	26.6	30.3	36.1
Maximum 1-min speed (m/s)	33.4	40.1	31.4	27.2	24.0	22.4	22.2	27.1	35.0	32.1	29.5	33.6	40.1
Direction of max. hourly speed (from)	W	W	W	NW	N	W	S	S	W	S	W	W	W

4.1.3.2 Air Temperatures

The atmospheric properties over the ocean surface broadly spanning the SEA Study Area have been characterized using the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), as it represents the most extensive available database of observations of atmospheric and sea conditions. The dataset consists of global marine observations recorded from 1662 to the present, compiled by the United States National Centre for Atmospheric Research (NCAR 2012). The period from January 1950 to December 2012, inclusive was selected for the analysis, as data in the area of interest are relatively scarce for the period prior to 1950.

The following subsections present monthly statistics in which the seasonal trends and changes are noted for air temperature, precipitation and visibility. Monthly estimates of vessel icing potential derived from both atmospheric and sea surface properties are also presented. Again, four sub-regions of the SEA Study Area were selected, as shown in Figure 4.18, to be representative of overall conditions.

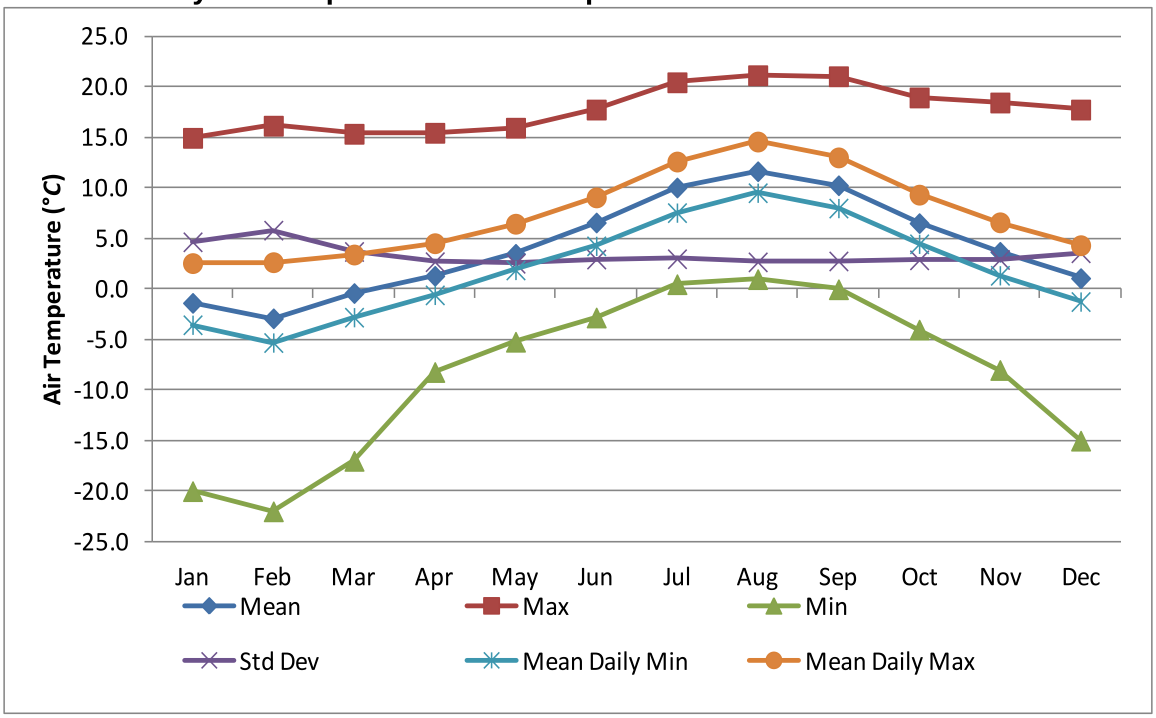
Figure 4.18 Approximate Subregions Selected for the Description of Air Temperatures in the SEA Study Area



Orphan Basin

Monthly air temperature statistics for this sub-region are plotted in Figure 4.19 and presented in Table 4.5. The air temperature values exhibit strong seasonal variations, with mean temperatures ranging from -2.9°C in February to 11.7°C in August. The coldest observed air temperature on record (-22°C) was in February, while during the summer months the coldest observed temperatures were around -2.8°C in June. The highest observed temperatures during winter months are approximately 16.2°C, while in summer the values reach as high as 21.2°C. Throughout the year the mean daily minimum and maximum temperatures generally stay within about 3°C of the mean temperature.

Figure 4.19 Monthly Air Temperature for the Orphan Basin



Based on ICOADS 1950-2012

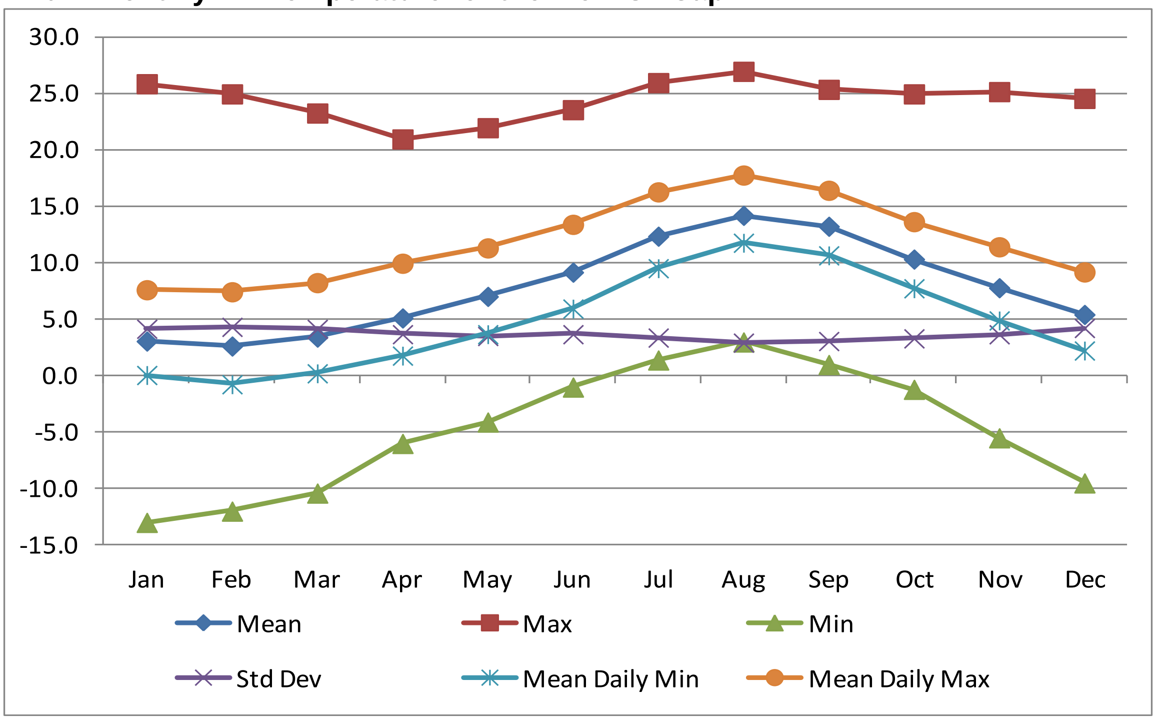
Table 4.5 Monthly Air Temperature (°C) Statistics for the Orphan Basin

Month	Mean	Max	Min	Std Dev	Mean Daily Min	Mean Daily Max
January	-1.4	15.0	-20.0	4.7	-3.5	2.6
February	-2.9	16.2	-22.0	5.9	-5.3	2.7
March	-0.4	15.4	-17.0	3.7	-2.8	3.4
April	1.3	15.5	-8.2	2.7	-0.6	4.6
May	3.5	16.0	-5.2	2.6	1.9	6.5
June	6.6	17.8	-2.8	3.0	4.3	9.1
July	10.1	20.5	0.5	3.0	7.6	12.7
August	11.7	21.2	1.0	2.7	9.6	14.6
September	10.3	21.1	0.0	2.8	8.0	13.1
October	6.6	19.0	-4.0	2.9	4.5	9.4
November	3.7	18.5	-8.0	3.0	1.4	6.6
December	1.1	17.8	-15.0	3.6	-1.2	4.4
Based on ICOADS 1950-2012						

Flemish Cap

In this sub-region, air temperature values exhibit strong seasonal variations, with mean temperatures ranging from 2.6°C in February to 14.2°C in August. The coldest observed air temperature on record (-13°C) was in January, while during the summer months the coldest observed temperatures were around -1°C in June. The highest observed temperatures during winter months are approximately 26°C, while in summer the values reach as high as 27°C. Throughout the year the mean daily minimum and maximum temperatures generally stay within about 3°C of the mean temperature.

Figure 4.20 Monthly Air Temperature for the Flemish Cap



Based on ICOADS 1950-2012

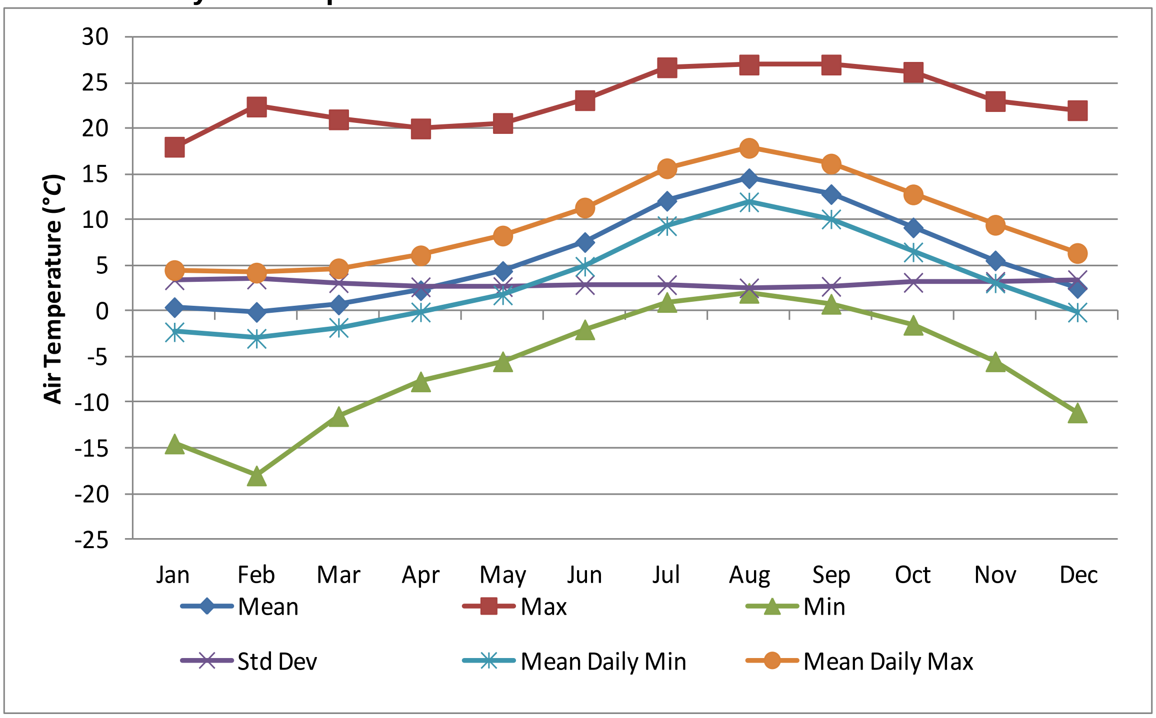
Table 4.6 Monthly Air Temperature (°C) Statistics for the Flemish Cap

Month	Mean	Max	Min	Std Dev	Mean Daily Min	Mean Daily Max
January	3.1	25.9	-13.0	4.2	0.1	7.6
February	2.6	25.0	-12.0	4.3	-0.8	7.5
March	3.4	23.3	-10.4	4.2	0.2	8.3
April	5.1	21.0	-6.0	3.7	1.8	10.0
May	7.0	22.0	-4.1	3.5	3.7	11.3
June	9.2	23.6	-1.0	3.7	6.0	13.4
July	12.4	26.0	1.4	3.4	9.5	16.3
August	14.2	27.0	3.0	2.9	11.8	17.8
September	13.3	25.4	1.0	3.1	10.7	16.5
October	10.4	25.0	-1.2	3.3	7.8	13.7
November	7.8	25.2	-5.5	3.7	4.9	11.4
December	5.4	24.6	-9.5	4.2	2.2	9.2
Based on ICOADS 1950-2012						

Grand Banks

For this sub-region, mean temperatures range from -0.1°C in February to 14.6°C in August. The coldest observed air temperature on record (-18°C) was in February, while during the summer months the coldest observed temperatures were around -2°C in June. The highest observed temperatures during winter months are approximately 22°C, while in summer the values reach as high as 27°C. Throughout the year the mean daily minimum and maximum temperatures generally stay within about 3°C of the mean temperature.

Figure 4.21 Monthly Air Temperature for the Grand Banks



Based on ICOADS 1950-2012

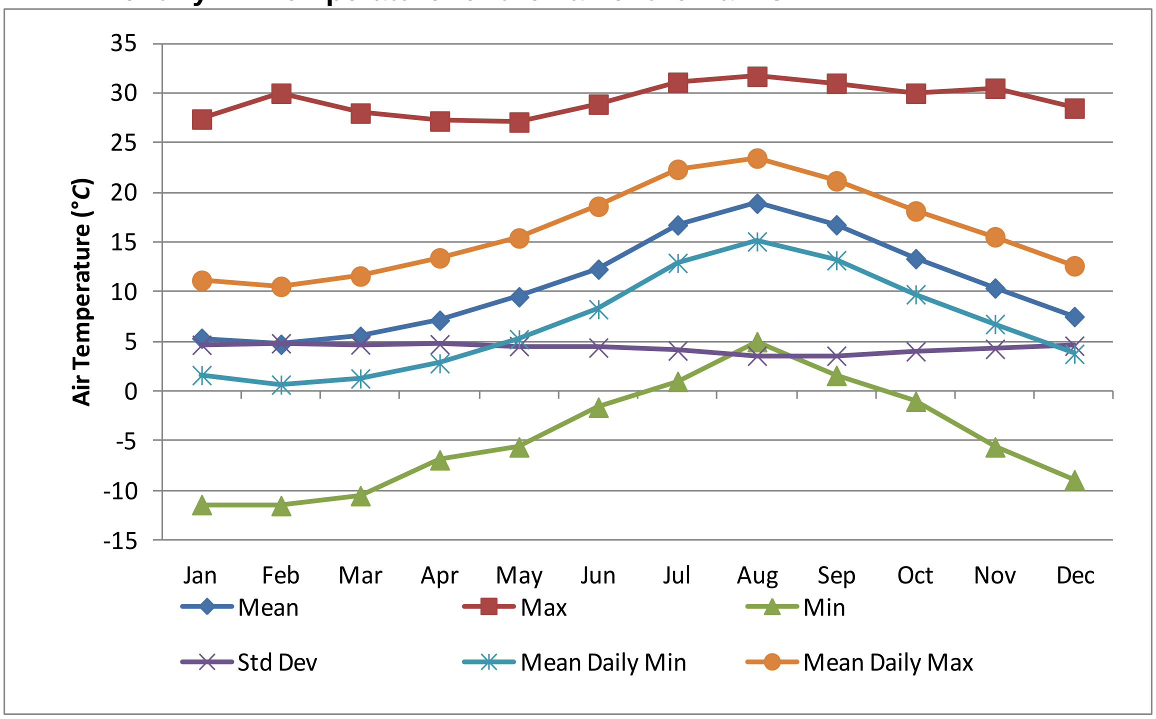
Table 4.7 Monthly Air Temperature (°C) Statistics for the Grand Banks

Month	Mean	Max	Min	Std Dev	Mean Daily Min	Mean Daily Max
January	0.4	18.0	-14.5	3.4	-2.3	4.5
February	-0.1	22.4	-18.0	3.5	-3.0	4.2
March	0.7	21.0	-11.5	3.1	-1.8	4.7
April	2.3	20.0	-7.7	2.7	-0.1	6.1
May	4.4	20.6	-5.5	2.7	1.8	8.3
June	7.6	23.1	-2.0	2.9	4.9	11.3
July	12.1	26.7	1.0	2.9	9.4	15.6
August	14.6	27.0	2.0	2.5	12.0	17.9
September	12.8	27.0	0.8	2.7	10.1	16.2
October	9.2	26.2	-1.5	3.2	6.5	12.8
November	5.6	23.0	-5.5	3.3	3.1	9.5
December	2.5	22.0	-11.1	3.4	-0.1	6.4
Based on ICOADS 1950-2012						

Tail of the Banks

For this sub-region, mean temperatures range from 4.7°C in February to 18.9°C in August. The coldest observed air temperature on record (-11.5°C) was in February, while during the summer months the coldest observed temperatures were around -1.6°C in June. The highest observed temperatures during winter months are approximately 30°C, while in summer the values reach as high as 31.7°C. Throughout the year the mean daily minimum and maximum temperatures generally stay within about 3°C of the mean temperature.

Figure 4.22 Monthly Air Temperature for the Tail of the Banks



Based on ICOADS 1950-2012

Table 4.8 Monthly Air Temperature (°C) Statistics for the Tail of the Banks

Month	Mean	Max	Min	Std Dev	Mean Daily Min	Mean Daily Max
January	5.3	27.4	-11.4	4.7	1.6	11.2
February	4.7	30.0	-11.5	4.8	0.7	10.6
March	5.5	28.0	-10.5	4.7	1.3	11.6
April	7.2	27.2	-6.9	4.7	2.8	13.4
May	9.5	27.1	-5.6	4.6	5.2	15.4
June	12.3	28.9	-1.6	4.4	8.3	18.6
July	16.7	31.1	1.0	4.1	12.9	22.3
August	18.9	31.7	5.0	3.6	15.1	23.5
September	16.8	31.0	1.6	3.6	13.2	21.2
October	13.4	30.0	-1.0	4.0	9.8	18.2
November	10.4	30.5	-5.6	4.3	6.8	15.6
December	7.5	28.5	-8.9	4.6	3.8	12.6
Based on ICOADS 1950-2012						

4.1.3.3 Precipitation

The ICOADS database contains observations of several precipitation types and thunderstorm occurrence. Every occurrence of a weather state is recorded and categorized as an event based on the type (but not the amount), of precipitation during that event. The frequency of occurrence of the different precipitation types and thunderstorms have been calculated as a percentage of the total monthly and annual weather observations for the period 1950 to 2012.

It is expected that there would be a considerable degree of variability of precipitation patterns within localized regions of the SEA Study Area. Therefore, it would be prudent for project-specific planning and implementation to consider and account for the expected site-specific conditions and variability in the occurrence and rates of precipitation based on the nearest and most current weather records applicable to the site. The statistics shown below are the percentage of a certain distinct weather state (e.g., rain, thunderstorms, hail, etc.) for all weather reports available on record for that month (e.g., January). The weather states have been consolidated from 50 different ICOADS classifications; separating (without overlap) rain from freezing rain and snow (although some overlap may exist between these states and mixed rain/snow, hail and thunderstorm, which represent a small percentage of the data). The frequency of occurrence – or, the percent of time the given condition(s) occurs in a given month (or annually) - can most closely be characterized as representing unspecified periods of time, for a percentage of all days.

Lightning strikes are also a possibility during thunderstorm activity, and lightning climatology based on the Canadian Lightning Detection Network data (Burrows and Kochtubajda 2010) is available for parts of the SEA Study Area.

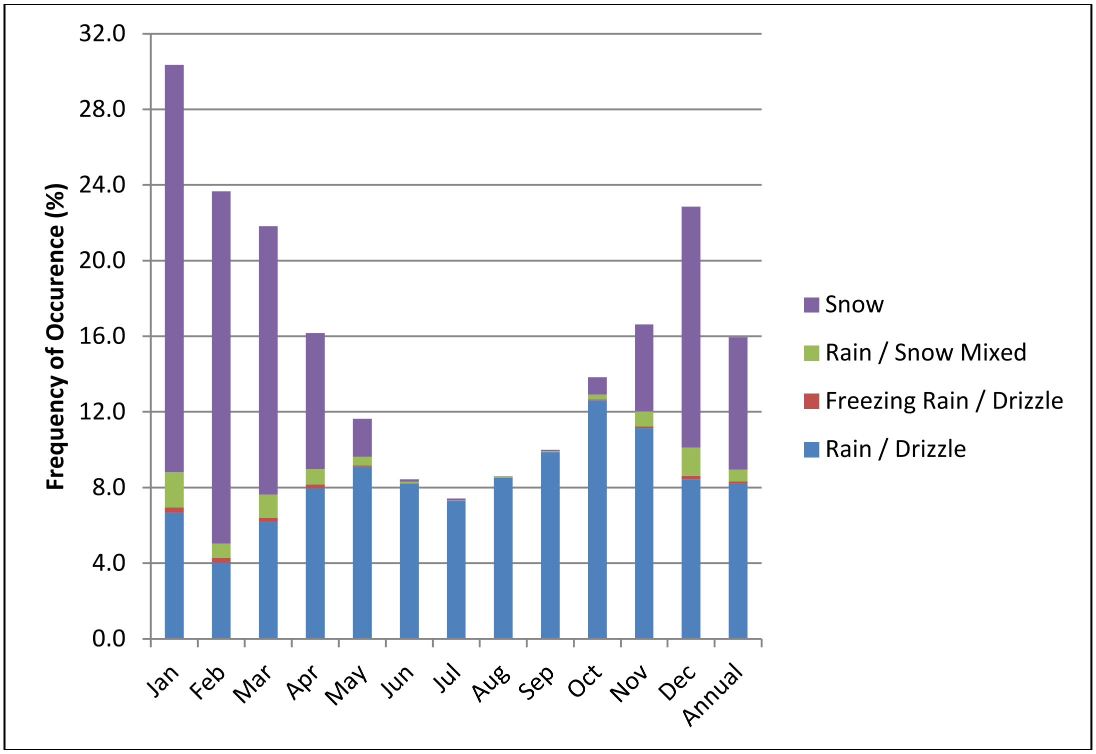
Orphan Basin

For this sub-region, the data indicate that most of the observed precipitation events are in the form of rain or snow, while other precipitation types, such as mixed rain and snow, freezing rain, and hail, occur far less frequently. The monthly frequency of rain events is lowest in January and February, when the snow occurrence frequency is at its peak. The situation is somewhat reversed between May and November, with maximum rain frequency in October, and minimum snow frequency from June to September.

Freezing rain and drizzle are relatively infrequent, occurring less than one percent of the time during any given month, and do not occur at all between June and October. Thunderstorms are the main generating mechanism of hail, and therefore the observation of hail is expected during thunderstorms.

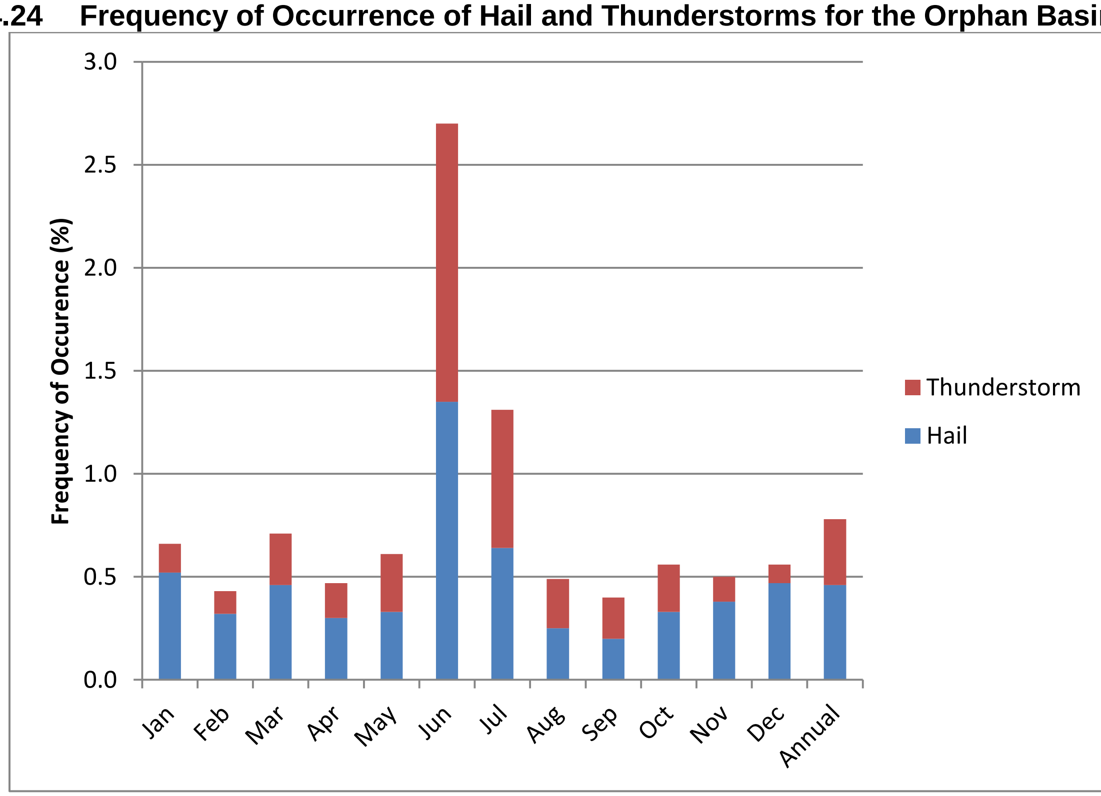
The data show that hail and thunderstorms indeed occur with similar frequencies, although during some months the frequency of hail is higher than that of thunderstorms. This may be due to other forms of precipitation, such as ice pellets, being inaccurately categorized as hail by observers. There is a year-round potential for thunderstorms and hail, with the highest frequency of occurrence occurring in the month of June.

Figure 4.23 Frequency of Occurrence of Several Precipitation Types for the Orphan Basin



Based on ICOADS 1950-2012

Figure 4.24 Frequency of Occurrence of Hail and Thunderstorms for the Orphan Basin



Based on ICOADS 1950-2012

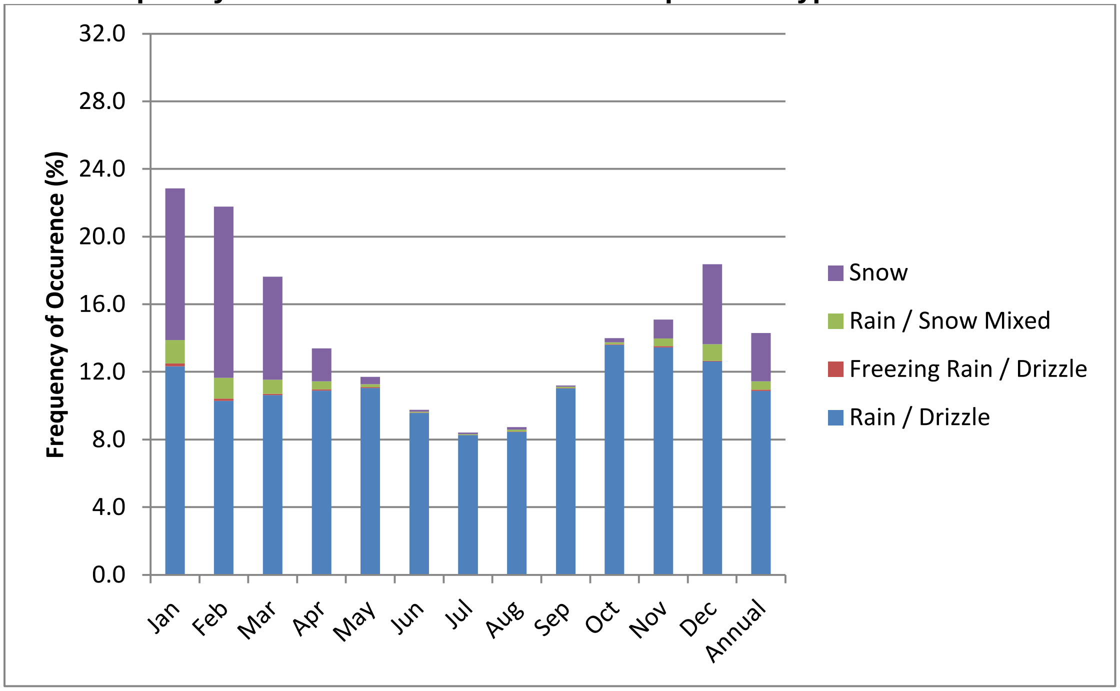
Table 4.9 Monthly and Annual Frequency of Occurrence of Precipitation and Thunderstorms for the Orphan Basin

Month	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Thunderstorm
Jan	6.7	0.3	1.9	21.5	0.5	0.1
Feb	4.0	0.3	0.8	18.6	0.3	0.1
Mar	6.2	0.2	1.2	14.2	0.5	0.3
Apr	8.0	0.2	0.8	7.2	0.3	0.2
May	9.1	0.1	0.5	2.0	0.3	0.3
Jun	8.2	0.0	0.1	0.1	1.4	1.4
Jul	7.3	0.0	0.0	0.1	0.6	0.7
Aug	8.5	0.0	0.0	0.0	0.3	0.2
Sep	9.9	0.0	0.1	0.1	0.2	0.2
Oct	12.6	0.0	0.3	0.9	0.3	0.2
Nov	11.1	0.1	0.8	4.6	0.4	0.1
Dec	8.4	0.2	1.5	12.7	0.5	0.1
Annual	8.2	0.1	0.6	7.0	0.5	0.3
Based on ICOADS 1950-2012						

Flemish Cap

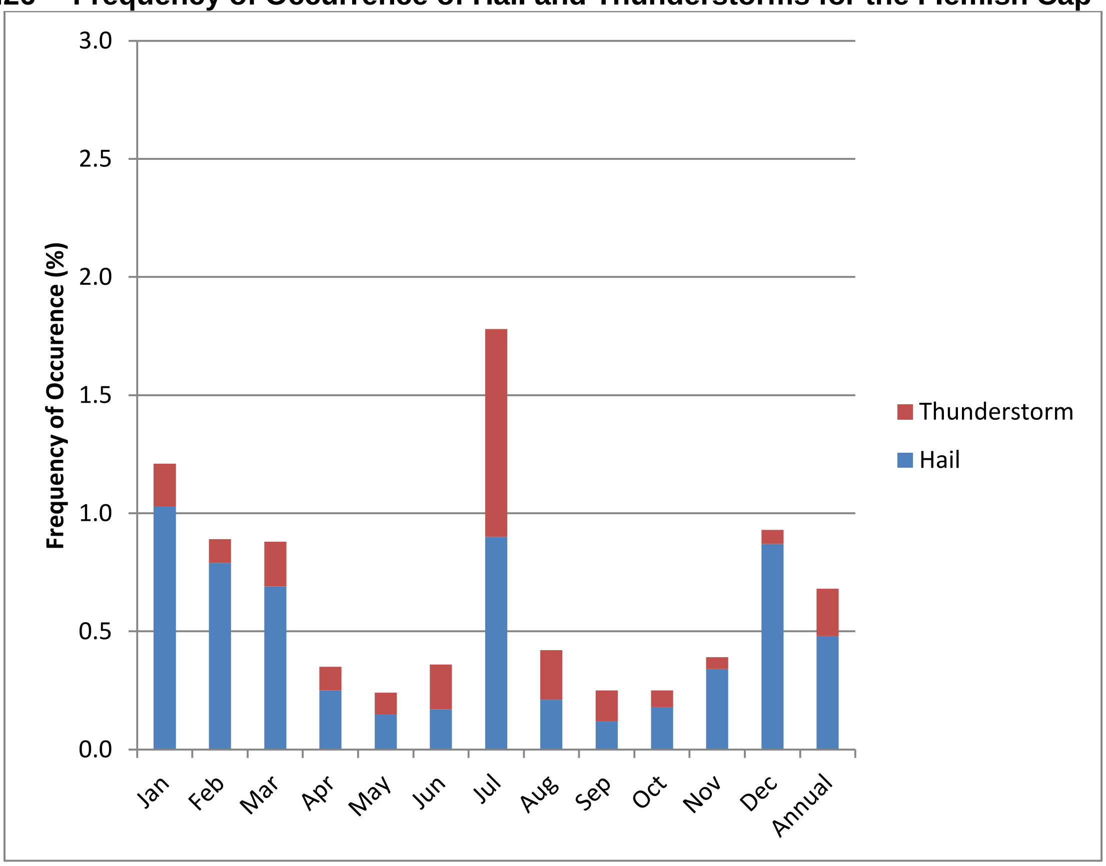
In this sub-region, the data again indicate that most of the observed precipitation events are in the form of rain or, in the winter, snow, while other precipitation types, such as mixed rain and snow, freezing rain, and hail, occur far less frequently. The monthly frequency of rain events is lowest in July and August. The snow occurrence frequency is at its peak in January and February. Maximum rain frequency occurs in October and November, and minimum snow frequency from June to October. Freezing rain and drizzle are relatively infrequent, occurring less than one percent of the time during any given month, and do not occur at all between July and October. There is a year-round potential for thunderstorms and hail, with the highest frequency of occurrence occurring in the month of July.

Figure 4.25 Frequency of Occurrence of Several Precipitation Types for the Flemish Cap



Based on ICOADS 1950-2012

Figure 4.26 Frequency of Occurrence of Hail and Thunderstorms for the Flemish Cap



Based on ICOADS 1950-2012

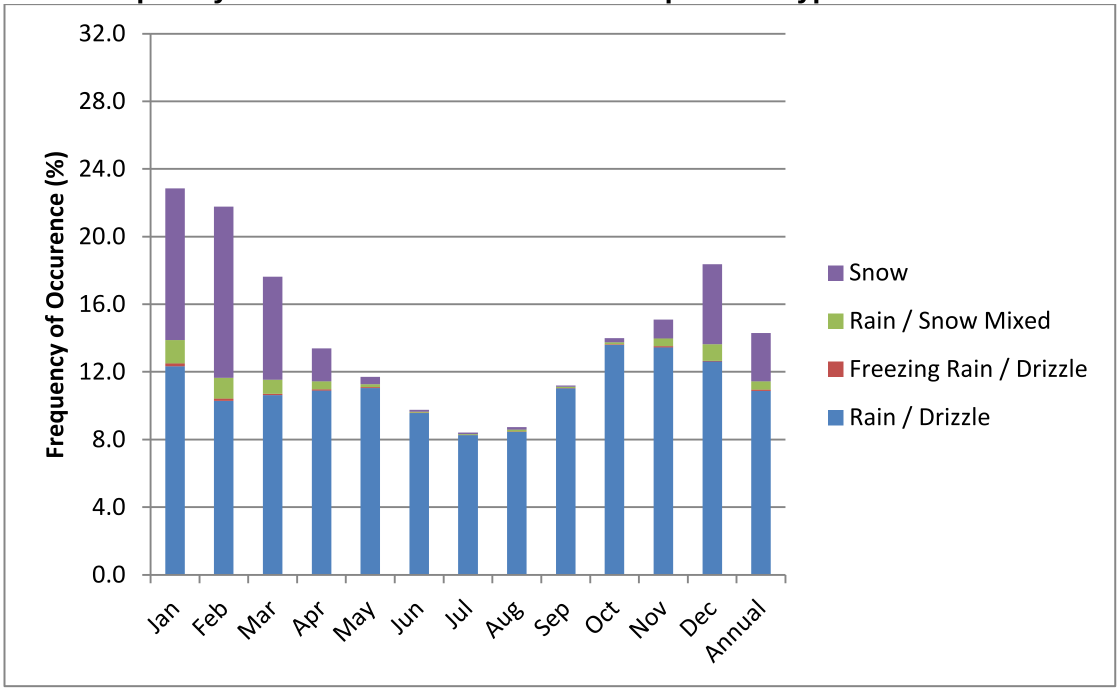
Table 4.10 Monthly and Annual Frequency of Occurrence of Precipitation and Thunderstorms for the Flemish Cap

Month	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Thunderstorm
Jan	12.3	0.2	1.4	9.0	1.0	0.2
Feb	10.3	0.1	1.2	10.1	0.8	0.1
Mar	10.6	0.1	0.8	6.1	0.7	0.2
Apr	10.9	0.1	0.5	2.0	0.3	0.1
May	11.0	0.1	0.2	0.4	0.2	0.1
Jun	9.6	0.0	0.1	0.1	0.2	0.2
Jul	8.3	0.0	0.1	0.1	0.9	0.9
Aug	8.5	0.0	0.1	0.1	0.2	0.2
Sep	11.0	0.0	0.1	0.1	0.1	0.1
Oct	13.6	0.0	0.1	0.3	0.2	0.1
Nov	13.5	0.1	0.4	1.1	0.3	0.1
Dec	12.6	0.1	1.0	4.7	0.9	0.1
Annual	10.9	0.1	0.5	2.9	0.5	0.2
Based on ICOADS 1950-2012						

Grand Banks

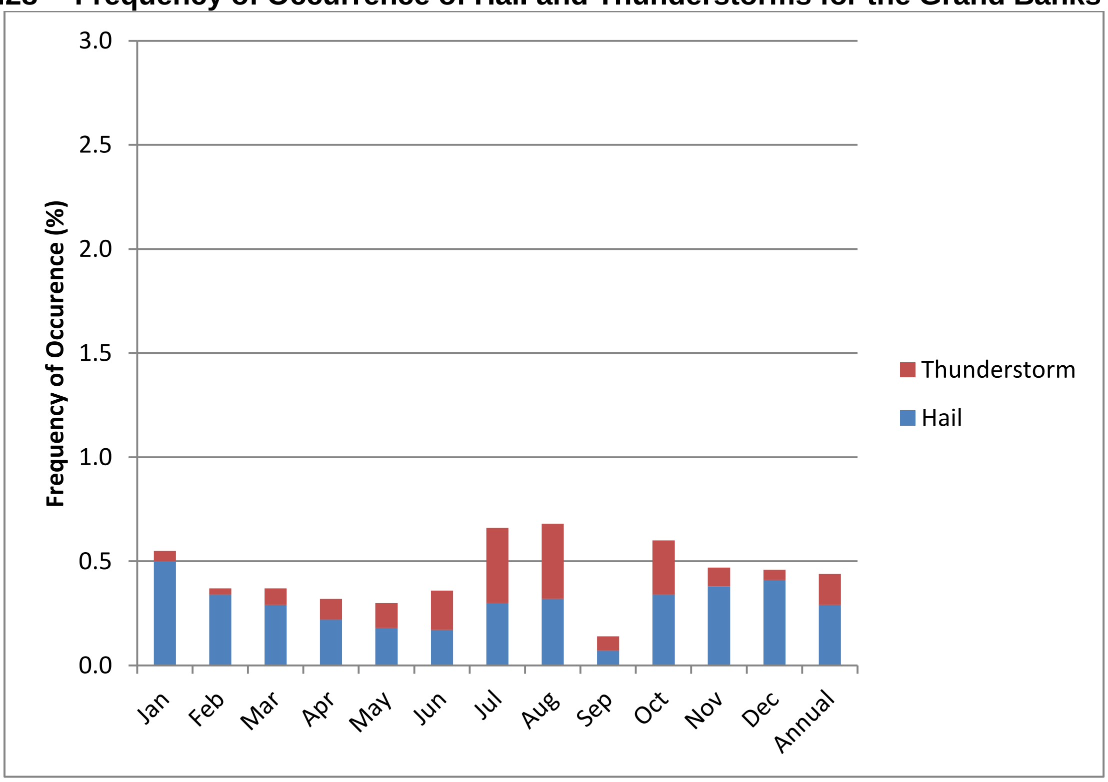
In this sub-region, the data indicate that most of the observed precipitation events are in the form of rain or snow, while other precipitation types, such as mixed rain and snow, freezing rain, and hail, occur far less frequently. The monthly frequency of rain events is lowest in July and August. The snow occurrence frequency is at its peak during January and February. Maximum rain frequency occurs in October and November, and minimum snow frequency from June to August. Freezing rain and drizzle are relatively infrequent, occurring less than one percent of the time during any given month, and do not occur at all between June and October. There is a year-round potential for thunderstorms and hail, with the highest frequency of occurrence occurring in the months of July and August.

Figure 4.27 Frequency of Occurrence of Several Precipitation Types for the Grand Banks



Based on ICOADS 1950-2012

Figure 4.28 Frequency of Occurrence of Hail and Thunderstorms for the Grand Banks



Based on ICOADS 1950-2012

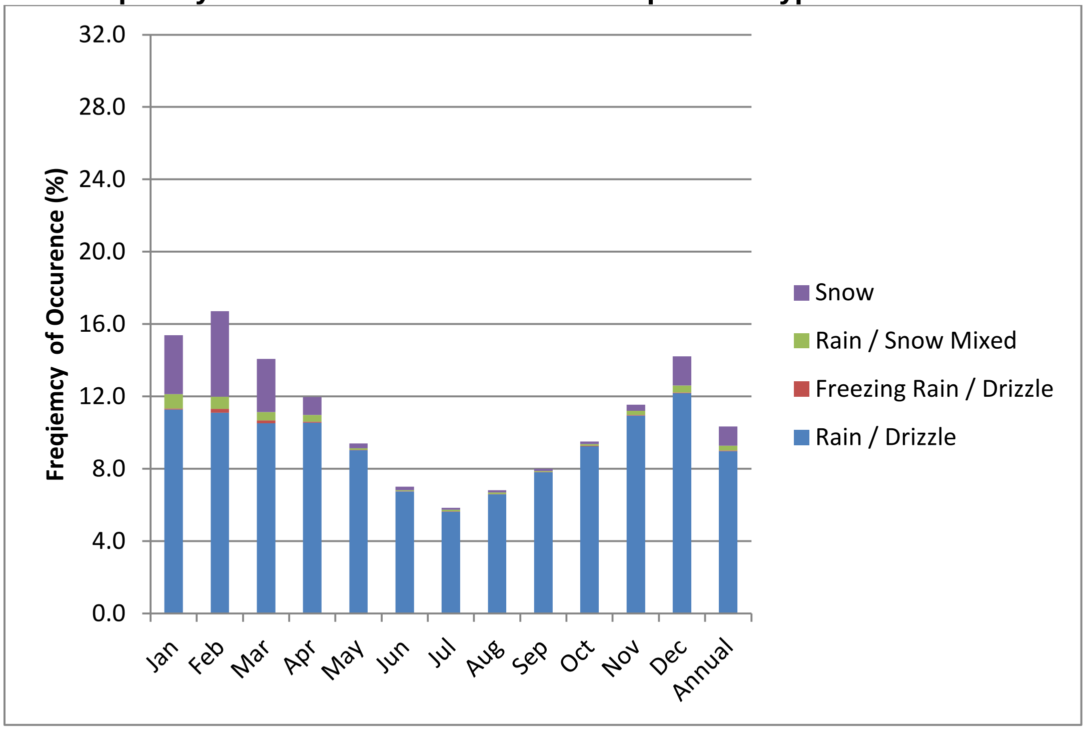
Table 4.11 Monthly and Annual Frequency of Occurrence of Precipitation and Thunderstorms for the Grand Banks

Month	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Thunderstorm
Jan	10.1	0.4	0.7	14.4	0.5	0.1
Feb	8.2	0.6	0.6	14.8	0.3	0.0
Mar	8.8	0.7	0.5	9.8	0.3	0.1
Apr	10.2	0.2	0.3	3.7	0.2	0.1
May	10.0	0.1	0.1	0.8	0.2	0.1
Jun	9.6	0.0	0.1	0.1	0.2	0.2
Jul	8.4	0.0	0.1	0.1	0.3	0.4
Aug	9.6	0.0	0.1	0.1	0.3	0.4
Sep	10.6	0.0	0.1	0.1	0.1	0.1
Oct	14.1	0.0	0.1	0.3	0.3	0.3
Nov	14.2	0.1	0.4	2.8	0.4	0.1
Dec	12.0	0.1	0.8	8.5	0.4	0.1
Annual	10.4	0.2	0.3	4.4	0.3	0.2
Based on ICOADS 1950-2012						

Tail of the Banks

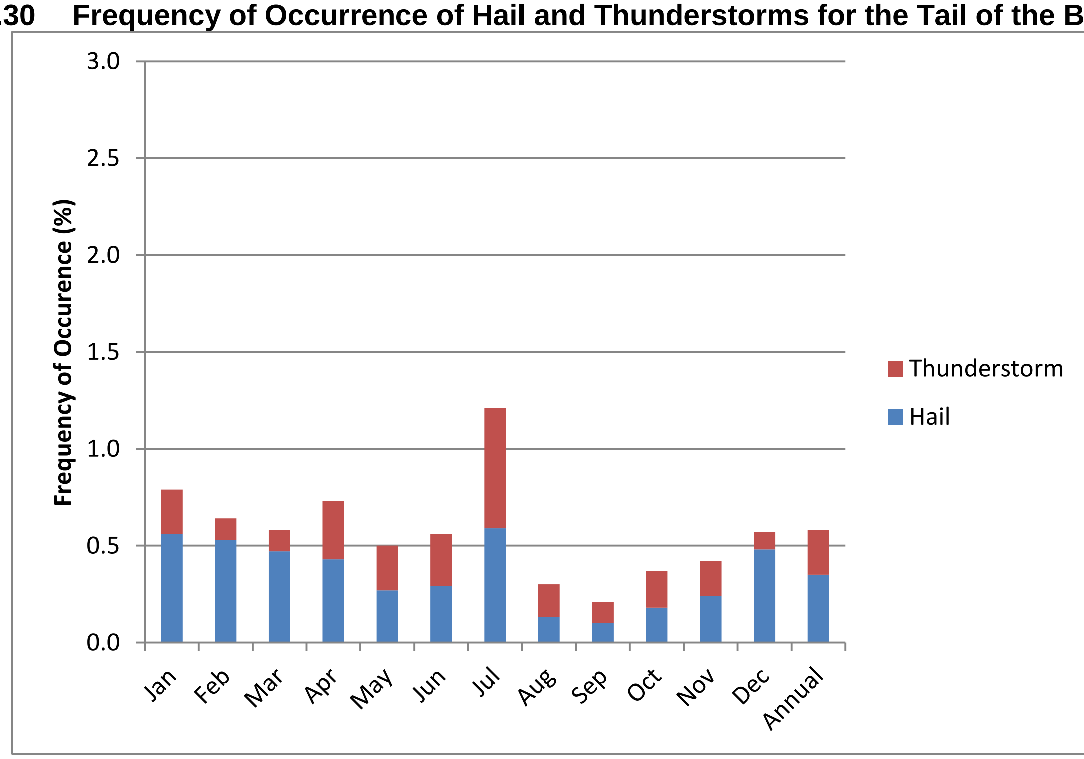
In this sub-region, the data indicate that most of the observed precipitation events are in the form of rain or snow, while other precipitation types, such as mixed rain and snow, freezing rain, and hail, occur far less frequently. The monthly frequency of rain events is lowest from June to September. The snow occurrence frequency is at its peak in January and February. The maximum rain frequency peak is in December, and minimum snow frequency from May to November. Freezing rain and drizzle are relatively infrequent, occurring less than one percent of the time during any given month, and do not occur at all between May and December. There is a year-round potential for thunderstorms and hail, with the highest frequency of occurrence occurring in the month of July.

Figure 4.29 Frequency of Occurrence of Several Precipitation Types for the Tail of the Banks



Based on ICOADS 1950-2012

Figure 4.30 Frequency of Occurrence of Hail and Thunderstorms for the Tail of the Banks



Based on ICOADS 1950-2012

Table 4.12 Monthly and Annual Frequency of Occurrence of Precipitation and Thunderstorms for the Tail of the Banks

Month	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Thunderstorm
Jan	11.3	0.1	0.8	3.3	0.6	0.2
Feb	11.1	0.2	0.7	4.7	0.5	0.1
Mar	10.5	0.2	0.5	2.9	0.5	0.1
Apr	10.6	0.1	0.4	1.0	0.4	0.3
May	9.0	0.0	0.1	0.3	0.3	0.2
Jun	6.7	0.0	0.1	0.2	0.3	0.3
Jul	5.6	0.0	0.1	0.1	0.6	0.6
Aug	6.6	0.0	0.1	0.1	0.1	0.2
Sep	7.8	0.0	0.1	0.1	0.1	0.1
Oct	9.2	0.0	0.1	0.1	0.2	0.2
Nov	11.0	0.0	0.2	0.3	0.2	0.2
Dec	12.2	0.0	0.4	1.6	0.5	0.1
Annual	9.0	0.1	0.3	1.1	0.4	0.2
Based on ICOADS 1950-2012						

4.1.3.4 Fog and Visibility

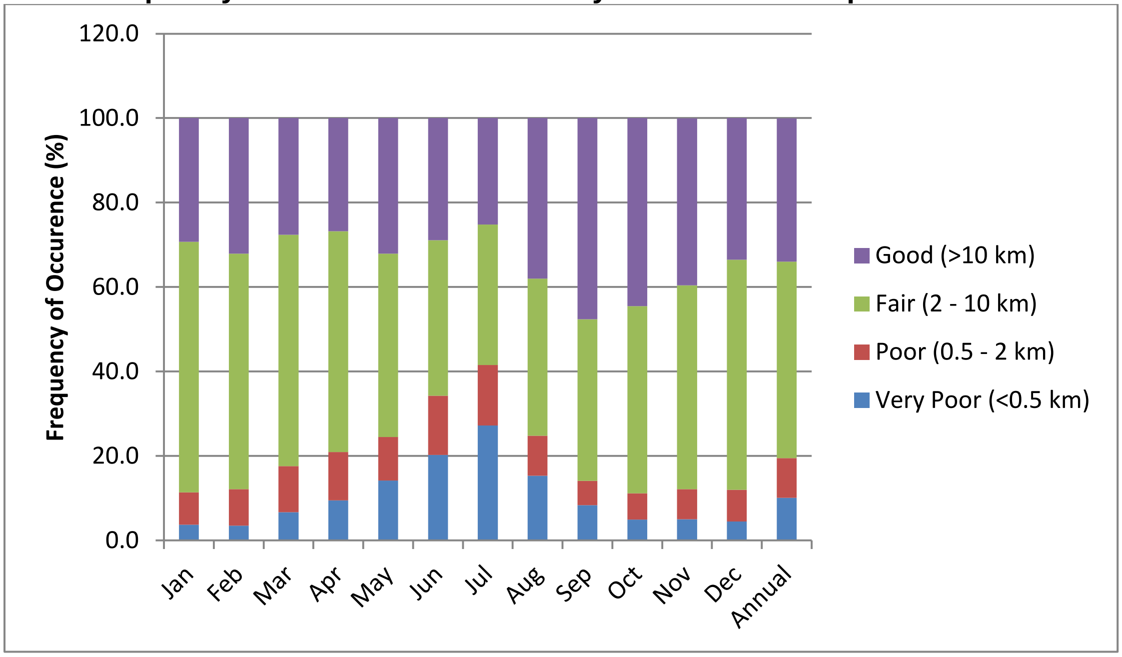
The SEA Study Area has some of the highest occurrence rates of marine fog in North America. Fog for the marine SEA Study Area is often of the advection type. Advection fog is formed when warm moist air flows over a cold surface such as the cold Northwest Atlantic Ocean, and can persist for days or weeks. Advection fog is most prevalent in spring and summer. Visibility is affected by the presence of fog, the number of daylight hours, as well as frequency and type of precipitation. For this characterization, visibility from the ICOADS dataset has been classified as very poor (<0.5 km), poor (0.5 to 2 km), fair (2 to 10 km) or good (> 10 km). The monthly and annual frequencies of occurrence of each state are shown in the Figures and Tables which follow.

Fog and visibility conditions and seasonal variability are expected to vary across the SEA Study Area, along with air temperatures and precipitation rates. Therefore site-specific conditions and the possible implications of these would have to be characterized from local visibility datasets for project-specific planning and analysis.

Orphan Basin

It is clear from the ICOADS database that visibility within this sub-region varies considerably throughout the year. Good or fair visibility combined occur 81 percent of the time annually. Good visibility (greater than 10 km) is most frequent during September and October, and least frequent in March and April. Visibility is poorest in the spring and summer. The combined percent occurrence of very poor and poor visibility ranges from 25 percent in May and August to 34 percent in June and 41 percent in July including very poor visibility 27 percent of the time. During others months of the year visibility is poor or very poor about 11 or 12 percent in most months to as high as 21 percent in April. Annually, visibility is very poor 10 percent of time, poor 9 percent of the time, fair 47 percent of the time, and good 34 percent of the time.

Figure 4.31 Frequency of Occurrence of Visibility States for the Orphan Basin



Based on ICOADS 1950-2012

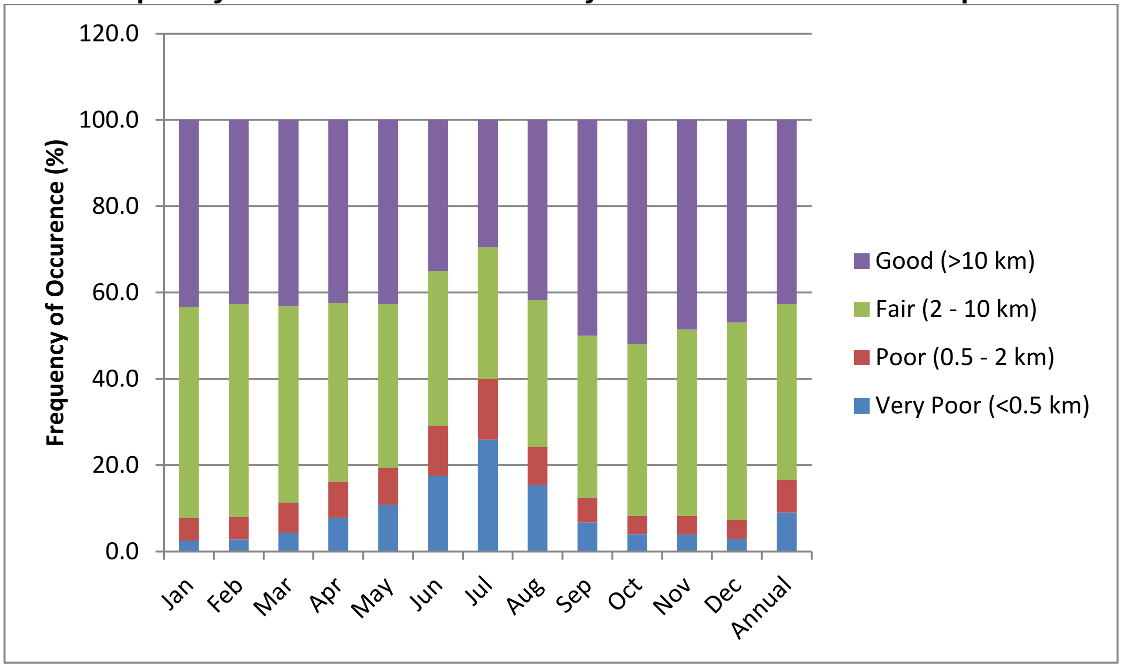
Table 4.13 Monthly and Annual Frequencies of Occurrence of Visibility States for the Orphan Basin

Month	Very Poor (<0.5 km)	Poor (0.5 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
Jan	3.7	7.6	59.3	29.3
Feb	3.5	8.7	55.7	32.1
Mar	6.7	10.9	54.8	27.6
Apr	9.5	11.4	52.3	26.8
May	14.2	10.3	43.4	32.1
Jun	20.2	14.1	36.8	28.9
Jul	27.2	14.3	33.3	25.2
Aug	15.3	9.4	37.2	38.0
Sep	8.4	5.7	38.3	47.6
Oct	4.9	6.2	44.3	44.5
Nov	5.0	7.2	48.3	39.6
Dec	4.5	7.5	54.5	33.5
Annual	10.1	9.4	46.5	34.0
Based on ICOADS 1950-2012				

Flemish Cap

For the Flemish Cap sub-region, good or fair visibility combined occur 83 percent of the time annually. Good visibility (greater than 10 km) is most frequent during September and October, and least frequent in June and July. Visibility is poorest in the spring and summer. The combined percent occurrence of very poor and poor visibility ranges from 7 to 12 percent each month in fall and winter to a maximum of 40 percent in July when visibility is very poor for 26 percent of the time. In spring and late summer, very poor or poor visibility occurs from 19 percent in May to 29 percent in June. Annually, visibility is very poor nine percent of time, poor seven percent of the time, fair 41 percent of the time, and good 43 percent of the time.

Figure 4.32 Frequency of Occurrence of Visibility States for the Flemish Cap



Based on ICOADS 1950-2012

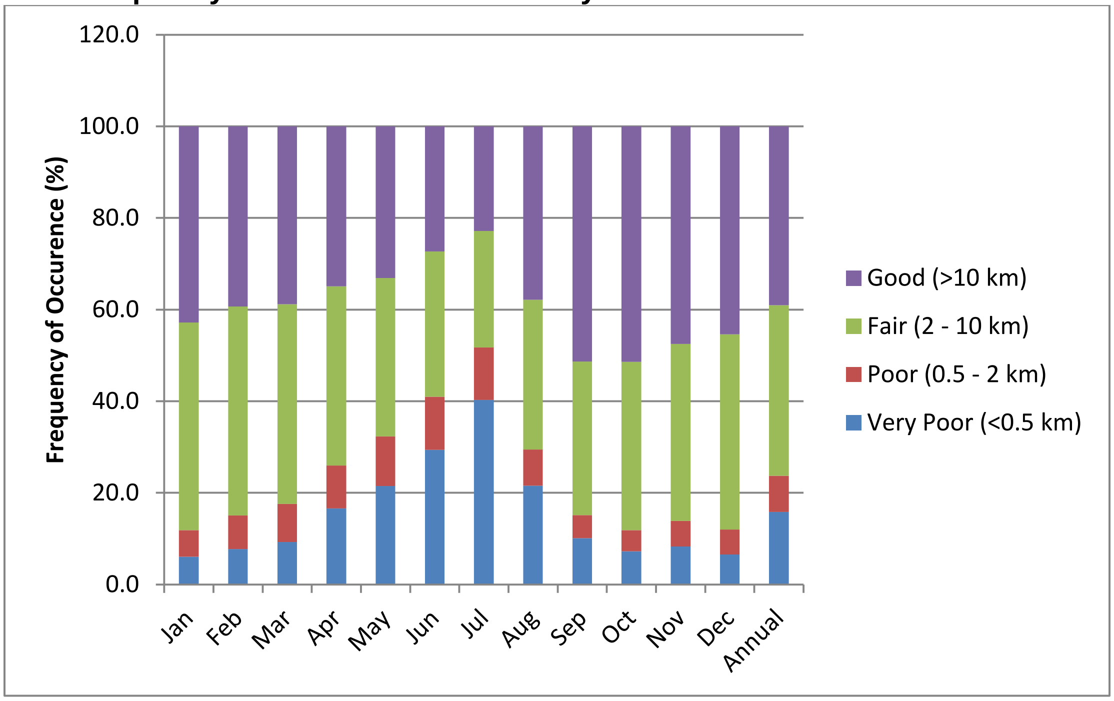
Table 4.14 Monthly and Annual Frequency of Occurrence of Visibility States for the Flemish Cap

Month	Very Poor (<0.5 km)	Poor (0.5 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
Jan	2.5	5.2	48.9	43.4
Feb	2.8	5.2	49.3	42.7
Mar	4.4	7.0	45.6	43.1
Apr	7.8	8.5	41.4	42.4
May	10.8	8.6	37.9	42.7
Jun	17.6	11.5	35.9	35.0
Jul	26.0	14.0	30.5	29.6
Aug	15.4	8.8	34.1	41.7
Sep	6.8	5.6	37.7	50.0
Oct	4.0	4.2	39.9	51.9
Nov	3.9	4.3	43.1	48.6
Dec	2.9	4.4	45.7	47.0
Annual	9.1	7.5	40.7	42.7
Based on ICOADS 1950-2012				

Grand Banks

Within this sub-region, good or fair visibility combined occur 76 percent of the time annually. Good visibility (greater than 10 km) is most frequent during September and October (51 percent of the time both months), and least frequent in July (23 percent). Visibility is poorest in the spring and summer. Annually, visibility is very poor or poor 24 percent of the time. The combined percent occurrence of very poor and poor visibility ranges is as high as 41 percent in June and 52 percent in July. During others months of the year visibility is poor or very poor from 12 percent of the time in winter to 26 to 32 percent for April, May and August. Annually, visibility is very poor 16 percent of time, poor 8 percent of the time, fair 37 percent of the time, and good 39 percent of the time.

Figure 4.33 Frequency of Occurrence of Visibility States for the Grand Banks



Based on ICOADS 1950-2012

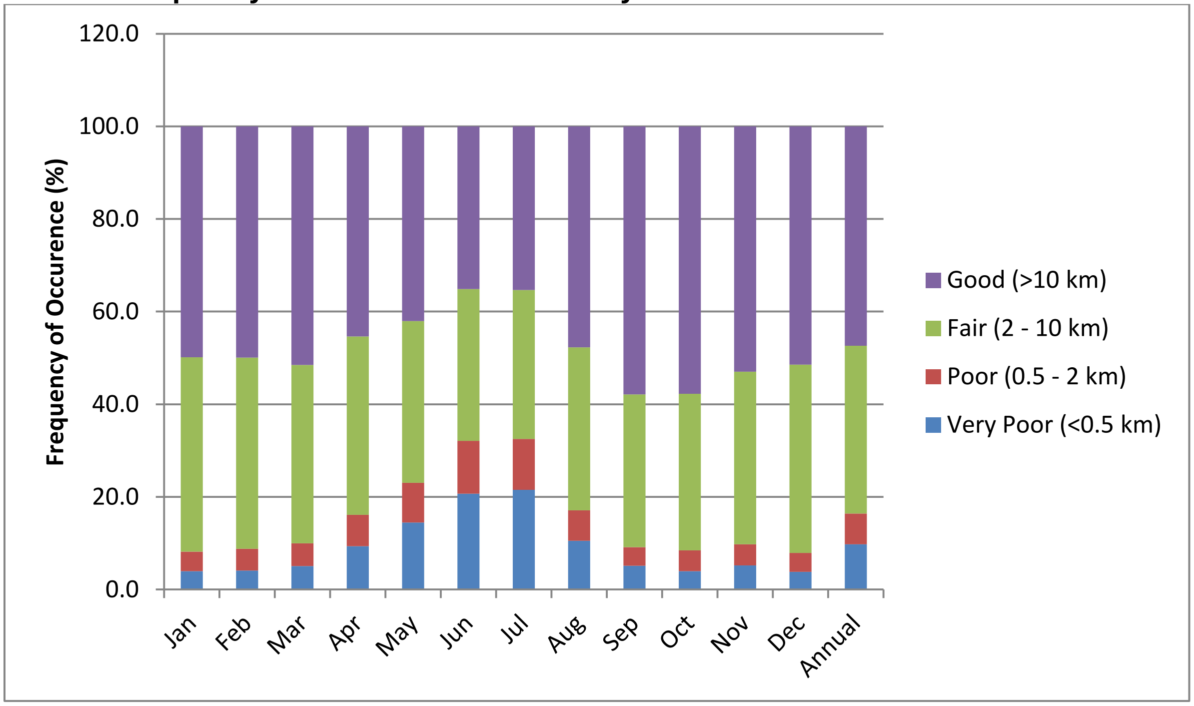
Table 4.15 Monthly and Annual Frequency of Occurrence of Visibility States for the Grand Banks

Month	Very Poor (<0.5 km)	Poor (0.5 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
Jan	6.0	5.9	45.3	42.9
Feb	7.7	7.3	45.6	39.3
Mar	9.2	8.4	43.5	38.9
Apr	16.6	9.3	39.2	34.9
May	21.5	10.9	34.6	33.1
Jun	29.3	11.6	31.8	27.3
Jul	40.3	11.5	25.4	22.9
Aug	21.5	7.9	32.7	37.9
Sep	10.1	5.0	33.5	51.3
Oct	7.3	4.6	36.8	51.4
Nov	8.3	5.6	38.6	47.5
Dec	6.5	5.5	42.6	45.4
Annual	15.8	7.9	37.2	39.1
Based on ICOADS 1950-2012				

Tail of the Banks

For the Tail of the Banks sub-region, good or fair visibility combined occur 84 percent of the time annually. Good visibility (greater than 10 km) is most frequent during September and October (58 percent of the time both months), and least frequent in June and July (35 percent of the time both months). Visibility is poorest in June and July when the combined percent occurrence of very poor and poor visibility is 32 percent in both months. From September through March the monthly occurrence of very poor or poor visibility ranges from 8 to 10 percent; in April and August it is 16 and 17 percent respectively, and 23 percent in May. Annually, visibility is very poor 10 percent of time, poor 7 percent of the time, fair 36 percent of the time, and good 47 percent of the time (the greatest of the four sub-regions considered).

Figure 4.34 Frequency of Occurrence of Visibility States for the Tail of the Banks



Based on ICOADS 1950-2012

Table 4.16 Monthly and Annual Frequency of Occurrence of Visibility States for the Tail of the Banks

Month	Very Poor (<0.5 km)	Poor (0.5 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
Jan	4.0	4.2	42.0	49.8
Feb	4.1	4.7	41.3	49.9
Mar	5.1	4.9	38.5	51.5
Apr	9.4	6.8	38.5	45.3
May	14.5	8.6	34.9	42.0
Jun	20.7	11.4	32.8	35.1
Jul	21.6	11.0	32.1	35.3
Aug	10.6	6.6	35.2	47.7
Sep	5.1	4.0	33.0	57.9
Oct	4.0	4.5	33.8	57.8
Nov	5.2	4.5	37.3	53.0
Dec	3.8	4.1	40.6	51.5
Annual	9.8	6.6	36.2	47.4
Based on ICOADS 1950-2012				

4.1.3.5 Tropical Systems

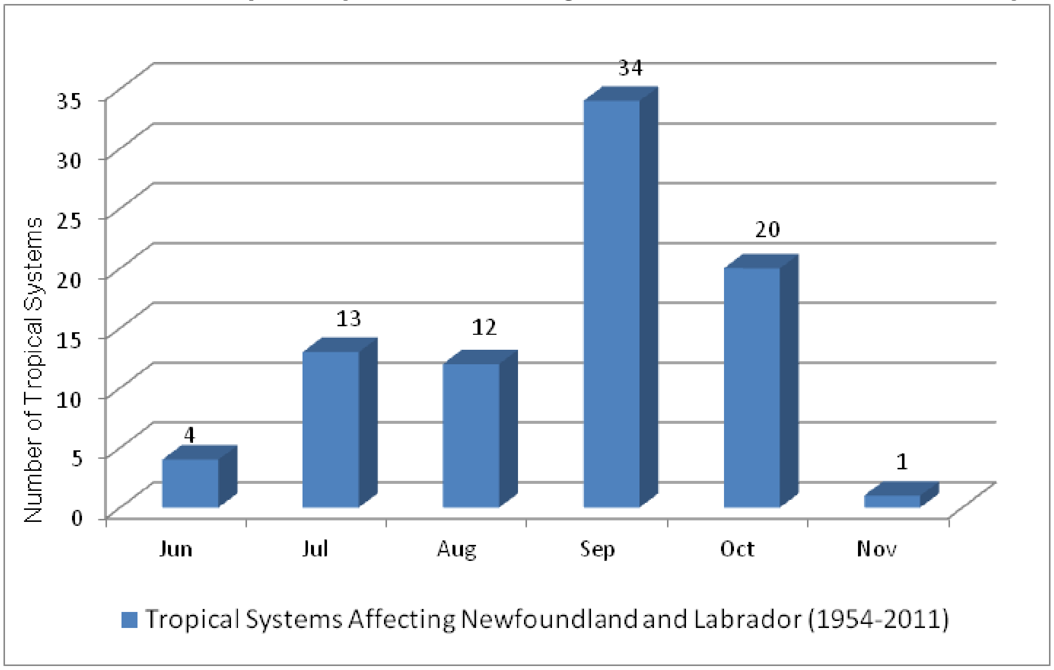
Hurricanes making landfall in Newfoundland and Labrador are relatively rare occurrences. Tropical systems, whether they are weakened hurricanes, tropical storms or post-tropical (extra tropical) storms, do however affect portions of the province and the marine offshore once or twice each year on average. Hurricanes and tropical systems feed off warm ocean waters south of the Gulf Stream. Tropical systems tend to weaken considerably once they approach Newfoundland and Labrador due to the colder water temperatures. On occasion, tropical storms and hurricanes maintain their strength or weaken slowly as they approach the province for various reasons. Two important possibilities for stronger tropical systems affecting this area are the forward speed of the system and sea surface temperature anomalies. If the tropical storm/hurricane is travelling at a higher than average speed, the system does not have time to weaken, despite the cooler waters entering its core. Also, if sea surface temperatures south of Newfoundland are warmer than average (especially late in the summer and in early fall), the storm may be able to survive slightly longer as it approaches Atlantic Canada.

Low pressure systems that form in the tropical Atlantic Ocean that develop into tropical storms typically transition into post-tropical storms when they reach Canadian waters. This means that tropical storms obtain characteristics of extratropical (northern latitude) storms: they develop frontal systems or merge with existing low pressure systems that have frontal systems. That is, the energy of the storm changes from being mainly due to the heat and moisture of the warm waters of the South Atlantic to energy due to cold versus warm air temperature contrasts. Post-tropical storms often retain energy due to high moisture content and deep convection, this energy can be released into kinetic energy (winds) when a significant pool of cold air moves into the west side of the storm. For this reason, post-tropical storms are often more volatile than typical extratropical storms and can regenerate in intensity, often very rapidly.

Tropical systems can affect Newfoundland anytime during the Atlantic hurricane season (June 1 to November 30), but most activity generally occurs in the fall season (September and October). One of the main reasons for the increased activity during this time of year is the shift of the Bermuda High to the east, allowing systems over the Caribbean to track northward towards Atlantic Canada. The Bermuda High is a dominant ridge of high pressure over the Atlantic typically centred near Bermuda, which guides weather systems over the southern Atlantic Ocean towards the southeastern United States, and provides the dominant southwesterly flow to Eastern Canada during the summer. The sea surface temperatures south of Newfoundland typically reach their peak in late September, allowing systems that approach from the south to maintain their strength as they track towards Newfoundland. The numbers of tropical systems that have affected Newfoundland and Labrador, by month from 1954 to 2011, are shown in Figure 4.35 which illustrates that the most frequent occurrence takes place in September and October.

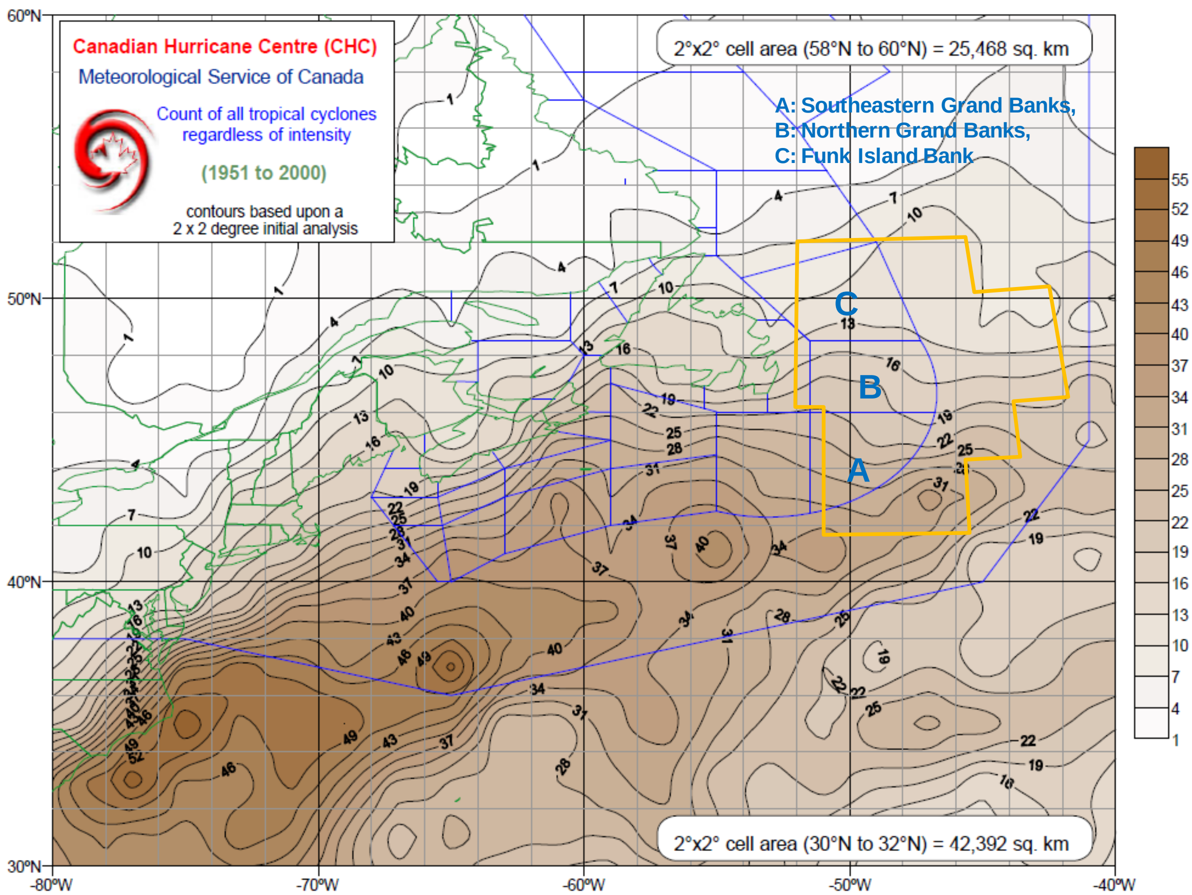
For the SEA Study Area, tropical storms are more frequent to the south, and are less frequent farther north as the storm strengths generally weaken. Figure 4.36 shows a count of all tropical cyclones – gale force (34-47 knots) or stronger – from 1951 to 2000 over the Atlantic, including the SEA Study Area (shown in orange). The contours are based on a 2° x 2° grid cell, where it is noted due to the fixed degree size, cell sizes decrease with increasing latitude. Thus, storm counts farther north are more significant (i.e., they are over a smaller area) than to the south. As shown over the Study Area, the storm count ranges from 31 in the southeast to between 1 and 10 to the northwest.

Figure 4.35 Number of Tropical Systems Affecting Newfoundland and Labrador by Month



Source: CHC (2012), NHC (2012)

Figure 4.36 Hurricanes and Tropical Storms, Grid Statistics - 2° Latitude by 2° Longitude Cells, 1951-2000 (All Intensities)

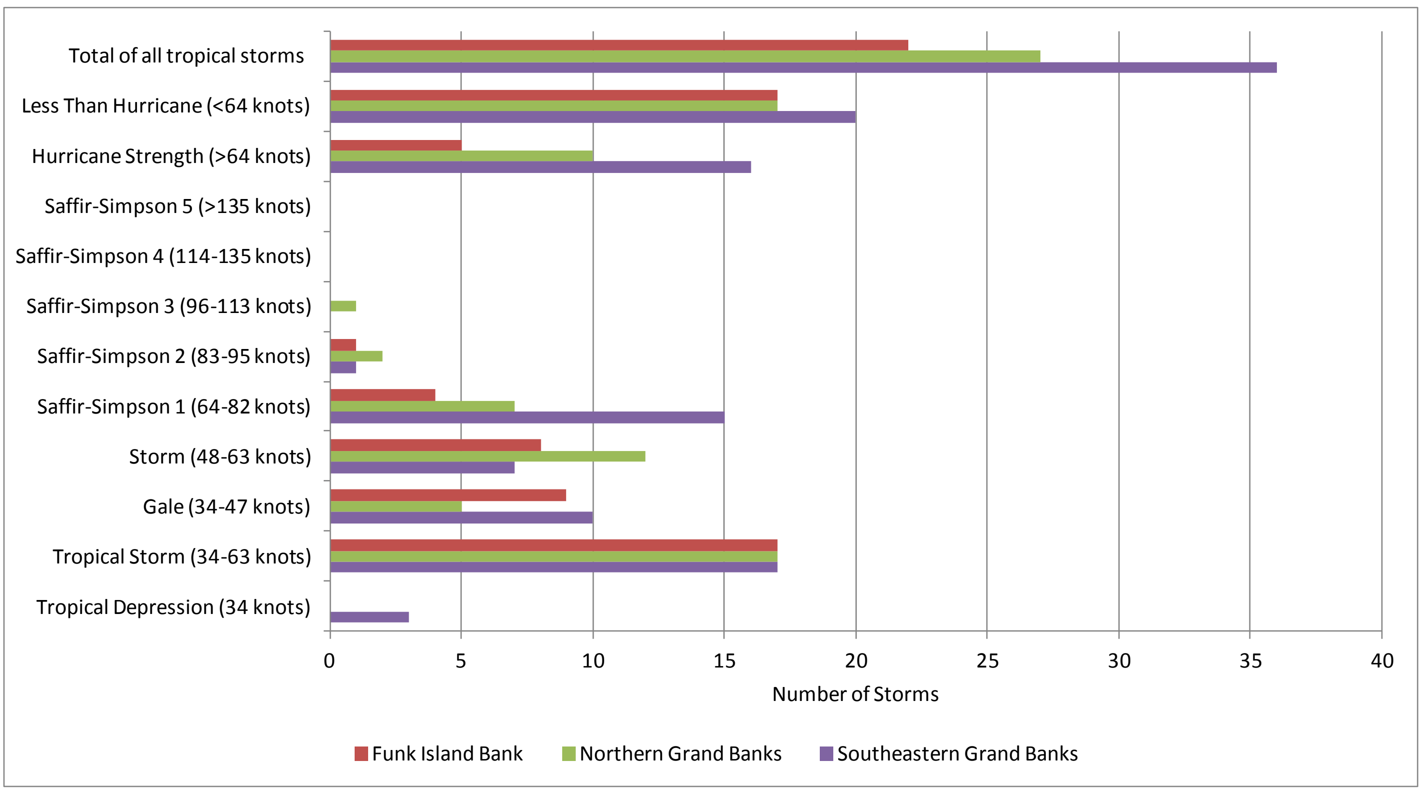


Source: Environment Canada (2008)

A 50-year (1951-2000) storm statistics summary for the three (Environment Canada forecast) Newfoundland marine areas that cover the SEA Study Area (Southeastern Grand Banks, Northern Grand Banks, Funk Island Bank is presented in Figure 4.37. The total number of tropical systems affecting these areas is greatest to the south: Southeastern Grand Banks with 36, Northern Grand Banks with 27, Funk Island Bank with 22. The total number of hurricane strength storms is similarly greatest from south to north: Southeastern Grand Banks with 16, Northern Grand Banks with 10, Funk Island Bank with five.

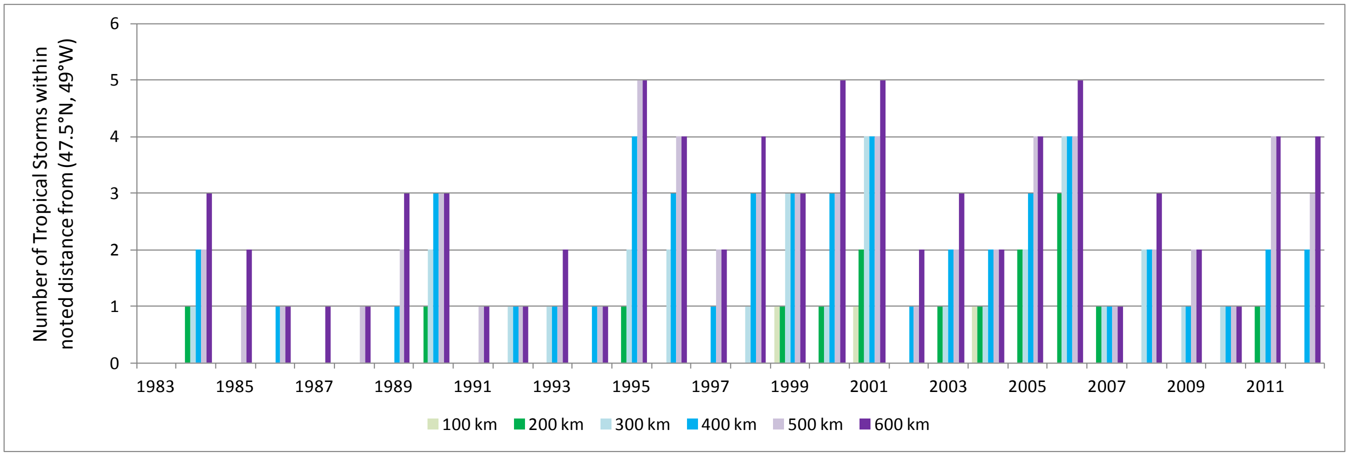
Based on a review of the tropical cyclone seasonal summaries since 2000, a total of 23 tropical cyclones have tracked through these three Newfoundland marine areas (Environment Canada 2013). This includes four hurricanes, 15 tropical storms and four post-tropical storms, where the storm statuses are those at the time the storm first passed through one of the marine areas. There were from one to three tropical cyclones each year, with the majority of them (10) occurring in September. The earliest was Tropical Storm Alberto on 16 June 2006, and the latest was Post-Tropical Storm Rapheal on 18 October 2012.

Figure 4.37 Atlantic Canada Individual Marine Area Statistics 50 Year Summary Statistics



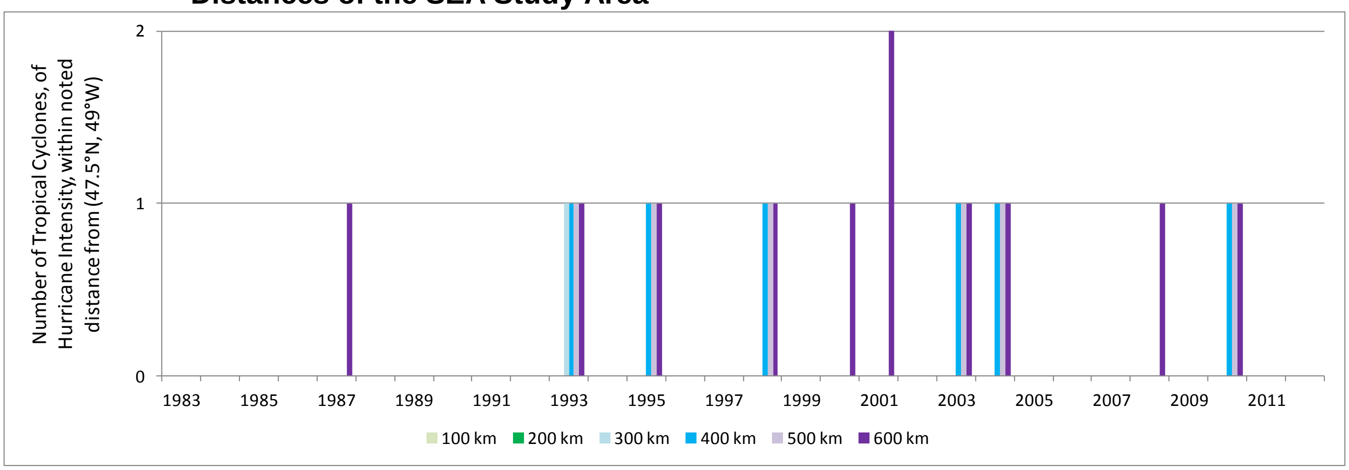
An additional characterization of the tropical storm history is provided through the tropical cyclone re-analysis database HURDAT which includes best-track estimates at 6-hourly intervals for tropical cyclone activity in the North Atlantic for the period 1851 to 2012 (NOAA 2013). Table 4.17 and Figure 4.38 present the counts of tropical cyclones for the past 30 years that tracked within distances of 100 km to 600 km from 47.5°N, 49°W located near the centre of the SEA Study Area. Figure 4.39 presents the counts of tropical cyclones, of hurricane intensity (greater than 64 knots or 32.9 m/s) that tracked within distances of 100 km to 600 km from 47.5°N, 49°W. Table 4.17 also lists the total number of tropical cyclones (of all strengths) that have tracked within the given distances of this location for the period 1983 to 2012 and historically.

Figure 4.38 Number of Tropical Cyclones Passing Within Select Distances of the SEA Study Area



Source: NOAA (2013)

Figure 4.39 Number of Tropical Cyclones, of Hurricane Intensity, Passing Within Select Distances of the SEA Study Area



Source: NOAA (2013)

Table 4.17 Number of Tropical Cyclones Passing Within Select Distances

Year	Number of Tropical Storms within noted distance from (47.5°N, 49°W)					
	100 km	200 km	300 km	400 km	500 km	600 km
1983	0	0	0	0	0	0
1984	0	1	1	2	2	3
1985	0	0	0	0	1	2
1986	0	0	0	1	1	1
1987	0	0	0	0	0	1
1988	0	0	0	0	1	1
1989	0	0	0	1	2	3
1990	0	1	2	3	3	3
1991	0	0	0	0	1	1
1992	0	0	1	1	1	1
1993	0	0	1	1	1	2
1994	0	0	0	1	1	1
1995	0	1	2	4	5	5
1996	0	0	2	3	4	4
1997	0	0	0	1	2	2
1998	0	0	1	3	3	4
1999	1	1	3	3	3	3
2000	0	1	1	3	3	5
2001	1	2	4	4	4	5
2002	0	0	0	1	1	2
2003	0	1	1	2	2	3
2004	1	1	1	2	2	2
2005	0	2	2	3	4	4
2006	0	3	4	4	4	5
2007	0	1	1	1	1	1
2008	0	0	2	2	2	3
2009	0	0	1	1	2	2
2010	0	0	1	1	1	1
2011	0	1	1	2	4	4
2012	0	0	0	2	3	4
1983 to 2012	3	16	32	52	64	78
1851 to 2012	15	63	114	172	220	274
Source: NOAA (2013)						

4.1.4 Oceanography

The following sections provide an overview of the key oceanographic conditions and characteristics of the SEA Study Area, including waves, ocean currents, seawater properties (temperature, salinity and density), and extreme winds and waves.

4.1.4.1 Waves

The wave climate within the SEA Study Area has been characterized by descriptive statistics derived from the aforementioned MSC50 wind and wave hindcast dataset. The wind hindcast involved the kinematic reanalysis of all significant tropical and extra-tropical storms in the North Atlantic for the continuous period 1954 – 2011. The wave hindcast was conducted by using the wind field reanalysis to force a third generation wave model (Swail et al 2006) over the North Atlantic Ocean. The model used was Oceanweather's OWI-3G, adopted onto a 0.5 degree grid on a basin-wide scale. Inscribed in the 0.5 degree model was a further refined 0.1 degree shallow water implementation of the OWI-3G model, which allowed for shallow water effects to be accounted for in the maritime region. The MSC50 methodology and results have been extensively documented and validated (Swail and Cox 2000, Woolf et al 2002, Caires et al 2004).

As presented earlier for wind conditions, four MSC50 grid point locations were selected to provide a representative illustration of conditions over the SEA Study Area. Again, this is in keeping with the approach for, and the type and level of information that has been included in, other SEAs in the NL Offshore Area. It should be reiterated, however, that the intent here is to provide a regional overview for general illustration, rather than detailed oceanographic information for design and operational purposes.

The wave climate is described in terms of the significant wave height (Hsig, defined as four times the square root of the total variance of the wave energy spectrum), and the peak wave spectral period (Tp, defined as the period of waves with the highest contribution to the energy spectrum). Both parameters are reflective of the dominant atmospheric forcing, both within the SEA Study Area as well as farther offshore, and are expected to exhibit significant seasonal variability.

The descriptive statistics for wave height, peak period, and direction are provided in the Tables and Figures that follow for each of the four select MSC50 nodes spanning the SEA Study Area:

- 6017801 (51°N, 49°W) for the Orphan Basin;
- 6013451 (48°N, 44°W) for the Flemish Cap;
- 6011595 (47°N, 50°W) for the Grand Bank; and
- 6003889 (43°N, 49°W) for the Tail of the Grand Banks

Regional Wave Summary

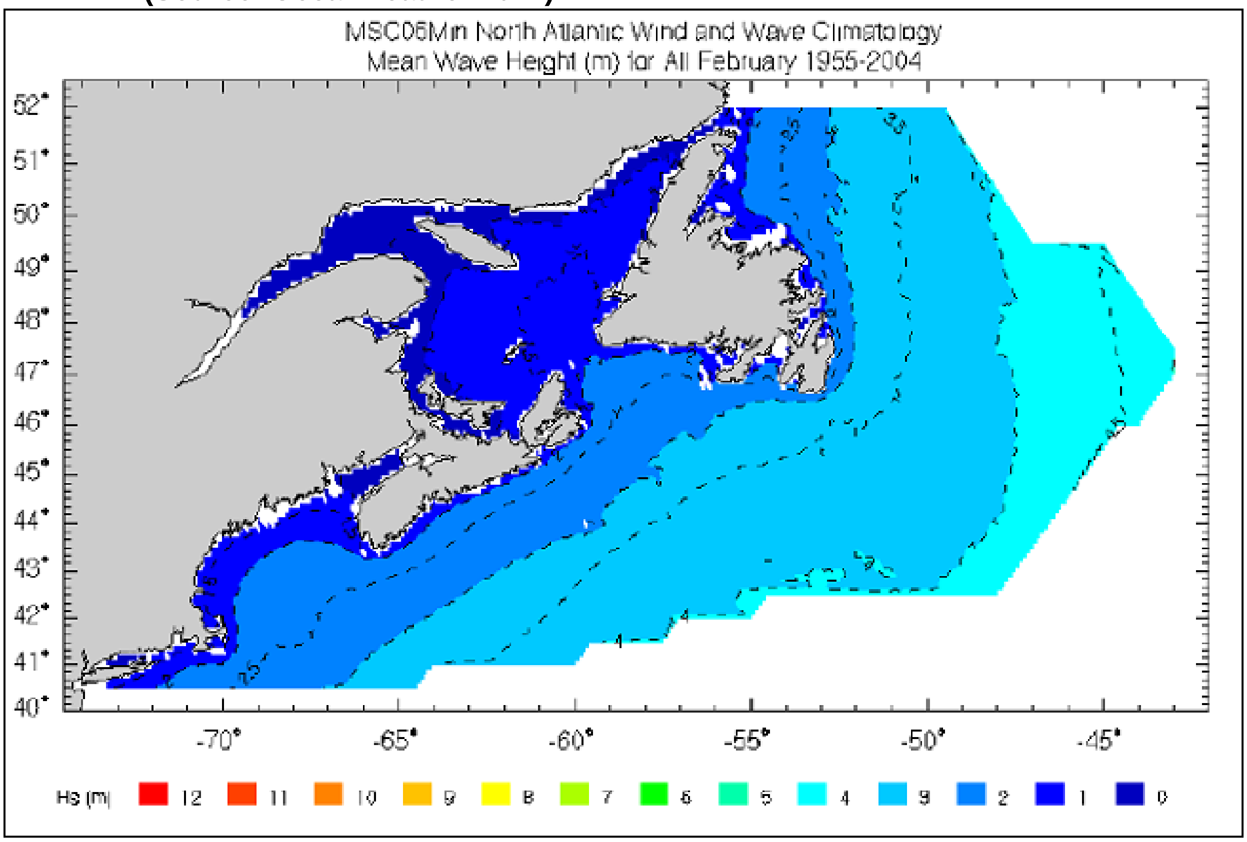
Due to the spatial and interannual variability in ice cover and other conditions throughout the SEA Study Area, the wave climate is expected to vary among different locations, particularly during the winter period, with ice presence as a modifying variable for wave climate statistics at specific locations. Inspection of the regional wave climate as reported in the MSC50 hindcast climatology (Oceanweather 2011) does not indicate a large variation in the climate, and the four points as selected above are therefore considered to provide a reasonable and illustrative coverage.

Maps of the mean and 99th percentile wave height for February, as an indication of winter time when conditions are generally least favourable, are presented in Figures 4.40 and 4.41.

Mean wave heights in February range from about 3 to 3.5 m for the western half of the SEA Study Area to about 4.5 m for the eastern half (Figure 4.40). Inspection of the corresponding August map shows corresponding mean wave heights in the 1.5 to 2 m range uniformly across the entire SEA Study Area.

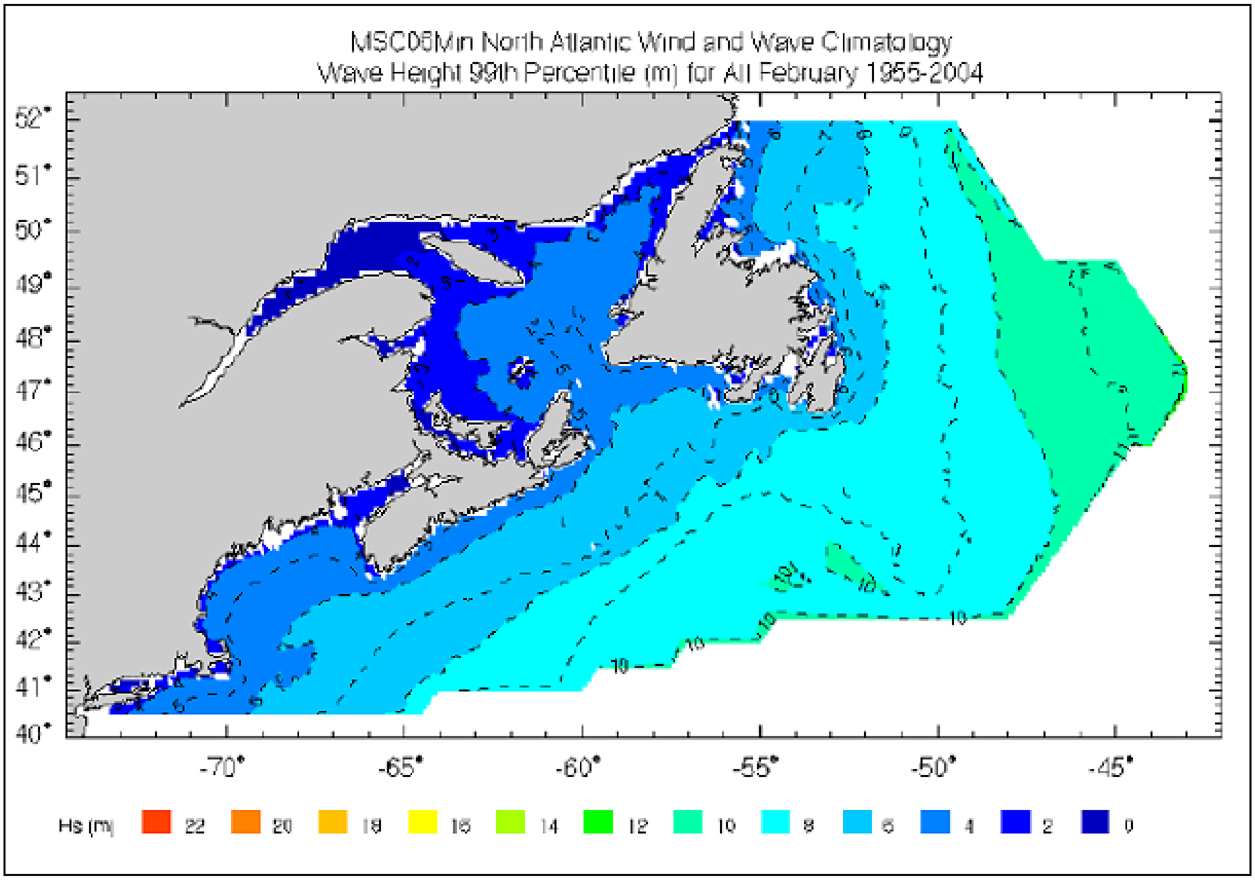
Figure 4.41 reports the 99th percentile wave height values for February. Values range from about 8 m in the northwest to 10 m in the south and up to 12 m to the east. Inspection of the corresponding August map shows corresponding 99th percentile wave heights range from 3 to 4 m in the northwest quadrant to about 5 m in the remainder of the SEA Study Area.

Figure 4.40 MSC50 Wind and Wave Climatology, Regional Mean Wave Height, February (Source: Oceanweather 2011)



Source: Oceanweather (2011)

Figure 4.41 MSC50 Wind and Wave Climatology, Regional 99th Percentile Wave Height, February



Source: Oceanweather (2011)

Orphan Basin

For this sub-region, the statistics indicate that the most severe sea states would occur between December and January, when maximum significant wave heights of up to 15.9 m from the northwest are expected, with an associated peak period of 15.8 s. In contrast, the maximum expected significant wave height is lowest (6.3 m) in July, with an associated peak period of 10.8 s. Significant wave heights in excess of 6 m are expected to occur during every month (Table 4.18). The values of the peak wave period associated with the maximum significant wave heights are generally in the range of 10 to 16 s, while the mean peak period is on average about 8.9 s.

Table 4.18 Wave Direction, Significant Wave Height and Peak Period for the Orphan Basin (Descriptive Statistics, MSC50 Data 1954 – 2011)

MSC#6014618 Wave Parameters													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Mean Hsig (m)	4.3	3.6	3.3	2.9	2.3	1.9	1.7	1.8	2.6	3.2	3.7	4.3	3.0
Most frequent direction (from)	NW	NW	SW	N	N	S	S	S	SW	NW	NW	NW	S
Mean Tp (s)	10.1	9.0	9.1	9.0	8.3	7.9	7.5	7.6	8.7	9.4	9.7	10.3	8.9
Maximum Hsig (m)	15.9	13.4	12.1	11.5	10.9	8.7	6.3	11.1	12.1	12.7	13.1	15.1	15.9
Direction of max Hsig (from)	NW	N	N	N	N	N	N	S	NW	NW	W	NW	NW

MSC#6014618 Wave Parameters													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Tp of max. Hsig (s)	15.8	14.7	14.2	13.3	13.2	11.3	10.8	15.3	13.5	13.8	14.3	14.7	15.8
Max. Tp (s)	16.1	15.9	15.9	15.9	17.5	16.4	17.3	17.6	17.3	16.2	15.9	16.0	17.6

Figure 4.42 Annual Directional Distribution of Significant Wave Height for the Orphan Basin, MSC#17801 (1954-2011)

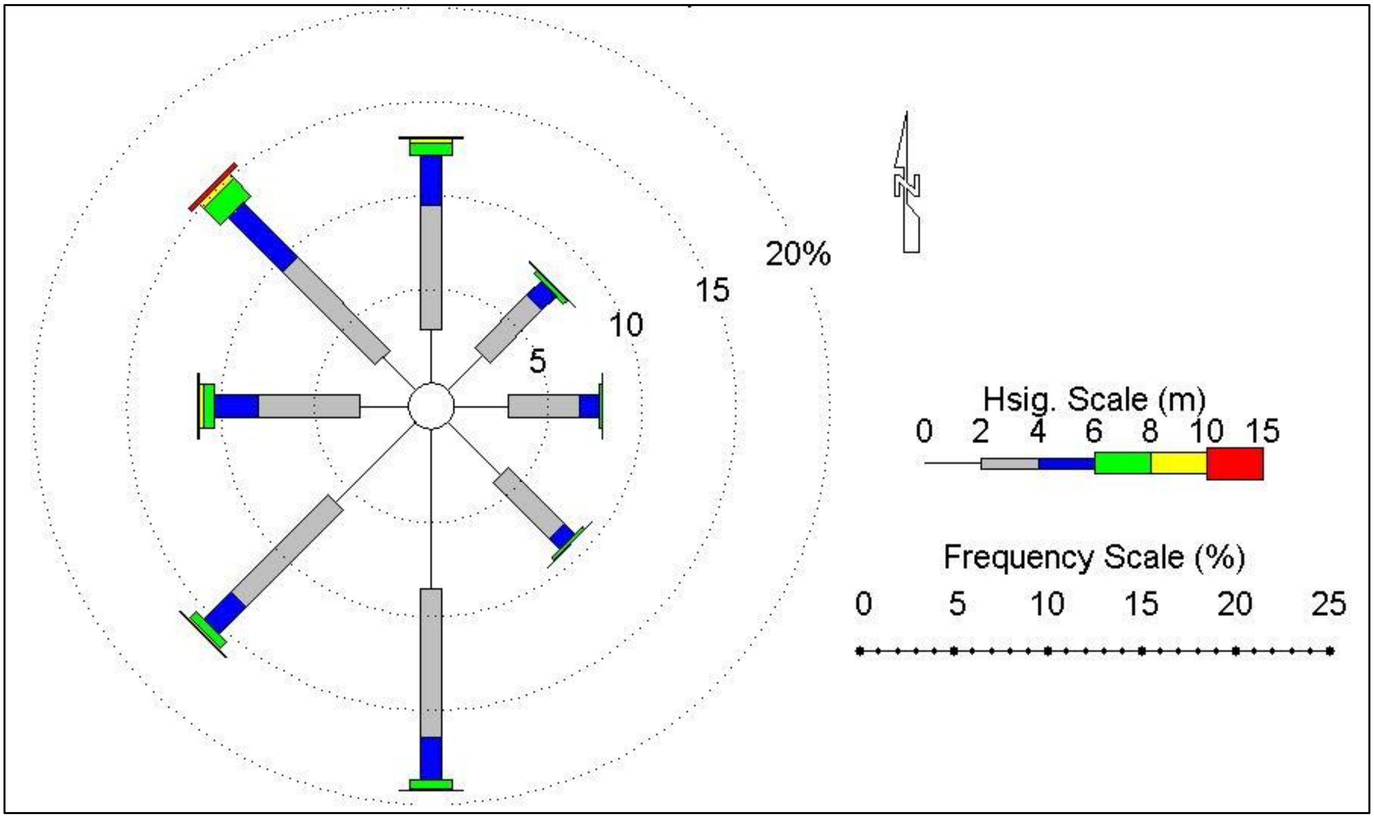
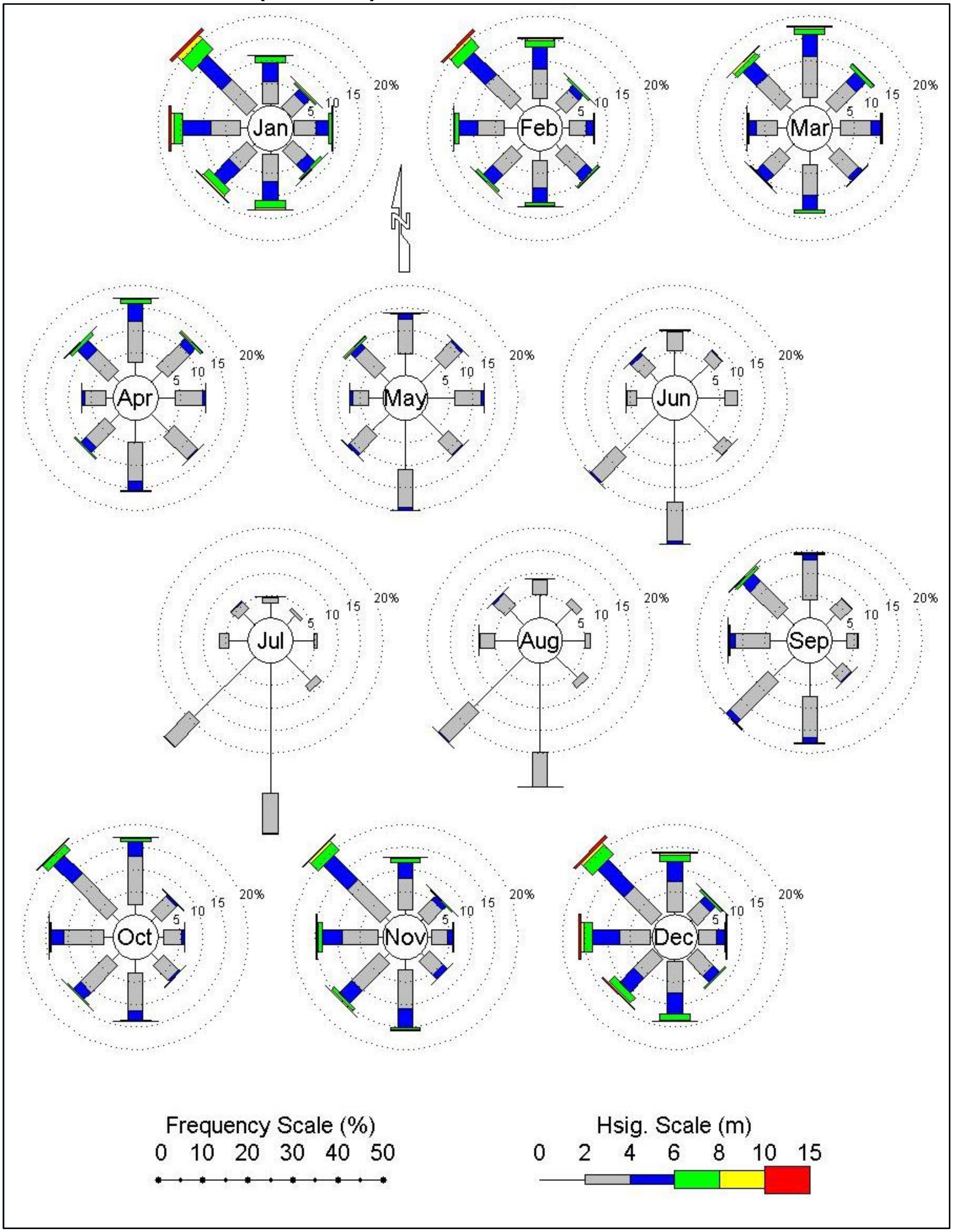


Figure 4.43 Monthly Directional Distributions of Significant Wave Height for the Orphan Basin, MSC #17801, (1954-2011)



Flemish Cap

In this sub-region, the most severe sea states occur between November and January, with a peak in February when maximum significant wave heights of up to 15.8 m from the southwest are expected, with an associated peak period of 16.9 s. In contrast, the maximum expected significant wave height is lowest (6.8 m) in July, with an associated peak period of 11.3 s. Significant wave heights in excess of almost 7 m are expected to occur during every month (Table 4.19). The values of the peak wave period associated with the maximum significant wave heights are generally in the range of 13 to 17 s, while the mean peak period is on average about 16.6 s.

Table 4.19 Wave Direction, Significant Wave Height and Peak Period for the Flemish Cap (Descriptive Statistics, MSC50 Data 1954 – 2011)

MSC#6014618 Wave Parameters													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Mean Hsig (m)	4.9	4.6	4.0	3.2	2.5	2.1	1.8	2.0	2.7	3.4	3.8	4.5	3.3
Most frequent direction (from)	W	W	SW	SW	SW	SW	SW	SW	W	NW	NW	W	SW
Mean Tp (s)	10.8	10.6	10.2	9.5	8.6	8.1	7.8	7.8	8.9	9.5	10	10.5	9.4
Maximum Hsig (m)	14.8	15.8	15.6	11.7	11.8	11.4	6.8	9.8	12.9	13.8	14.2	16.5	16.5
Direction of max Hsig (from)	W	SW	NW	NW	NW	W	SW	SW	W	N	W	NW	NW
Tp of max. Hsig (s)	16.2	16.9	15.7	13.8	13.5	13.6	11.3	13.8	15.3	14.8	15.7	16.6	16.6
Max. Tp (s)	16.9	16.9	17.4	15.8	17.2	20.9	17.4	18	19	15.9	17.8	16.6	20.9

Figure 4.44 Annual Directional Distribution of Significant Wave Height for the Flemish Cap, MSC #13451 (1954-2011)

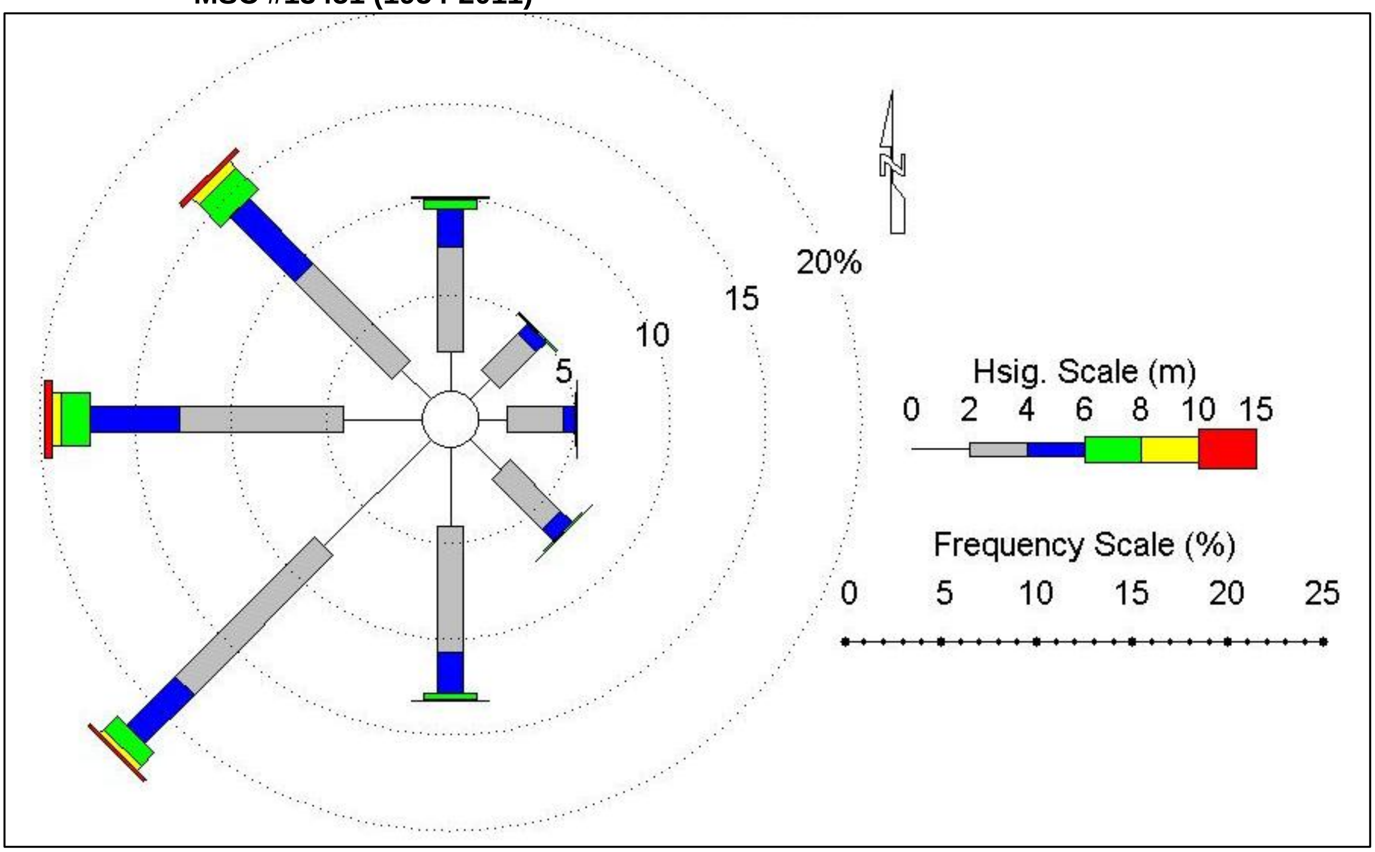
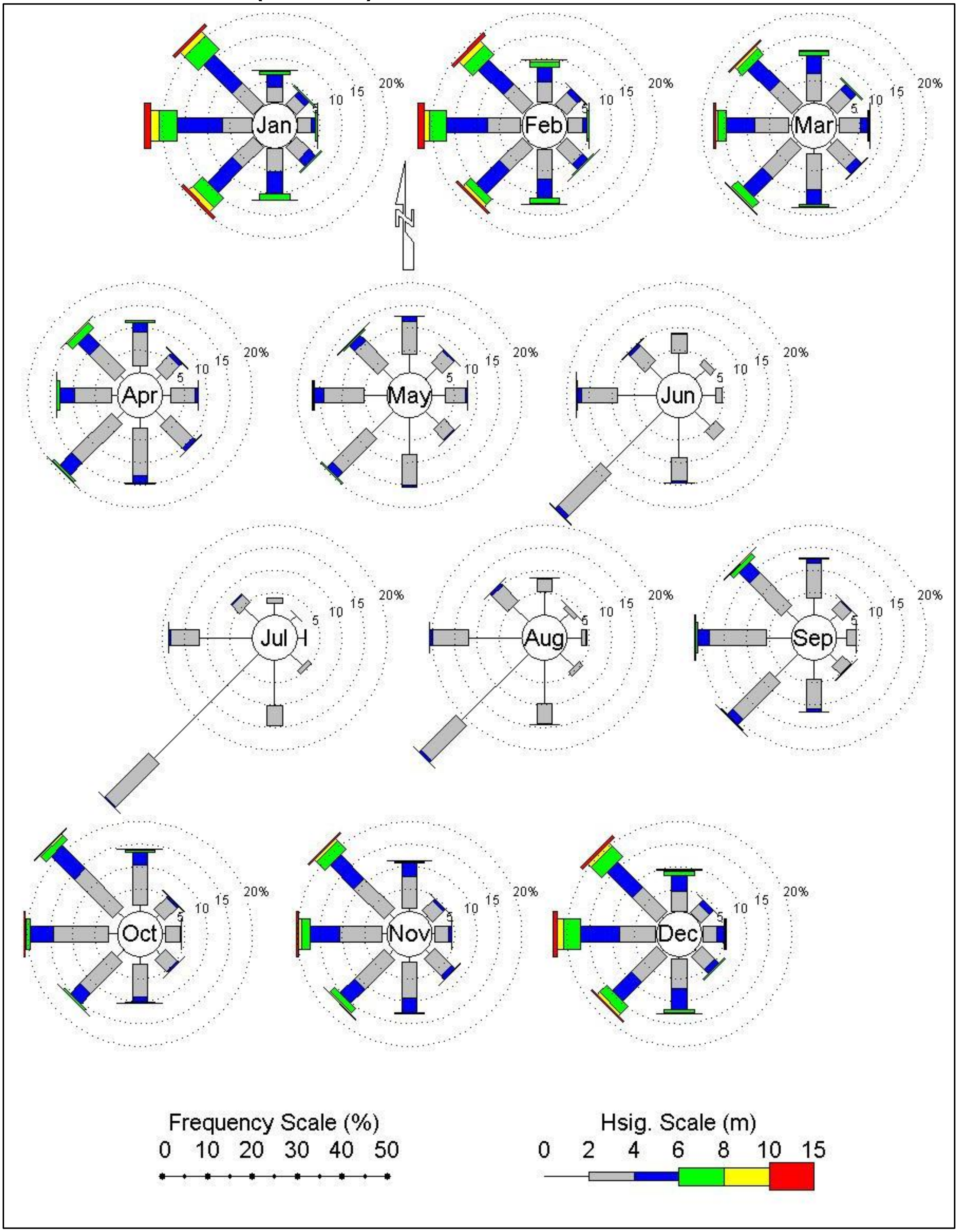


Figure 4.45 Monthly Directional Distributions of Significant Wave Height for the Flemish Cap, MSC #13451 (1954-2011)



Grand Banks

In this sub-region, the most severe sea states occur between December and February, with a peak in February, when maximum significant wave heights of up to 13.3 m from the southwest are expected, with an associated peak period of 15.7 s. In contrast, the maximum expected significant wave height is lowest (6.0 m) in July, with an associated peak period of 10.8 s. Significant wave heights of 6 m or more are expected to occur during every month (Table 4.20). The values of the peak wave period associated with the maximum significant wave heights are generally in the range of 13 to 16 s, while the mean peak period is on average about 8.8 s.

Table 4.20 Wave Direction, Significant Wave Height and Peak Period for the Grand Banks (Descriptive Statistics, MSC50 Data 1954 – 2011)

MSC#6014618 Wave Parameters													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Mean Hsig (m)	3.7	3.3	2.8	2.5	2.2	1.9	1.7	1.8	2.3	2.9	3.2	3.8	2.7
Most frequent direction (from)	W	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
Mean Tp (s)	9.8	9.1	8.5	8.6	8.4	7.9	7.6	7.6	8.7	9.3	9.6	10.1	8.8
Maximum Hsig (m)	11.5	13.3	10.4	10.3	9.6	9.1	6.0	8.5	12.8	10.5	10.7	12.1	13.3
Direction of max Hsig (from)	SW	SW	SW	N	NW	NW	SW	SW	SW	SW	N	N	SW
Tp of max. Hsig (s)	14.7	15.7	14.1	13.0	13.9	12.7	10.8	13.0	14.6	13.9	13.1	15.5	15.7
Max. Tp (s)	17.0	18.5	17.7	16.2	17.3	14.2	17.3	17.3	17.3	17.6	16.3	17.2	18.5

Figure 4.46 Annual Directional Distribution of Significant Wave Height for the Grand Banks, MSC #11595 (1954-2011)

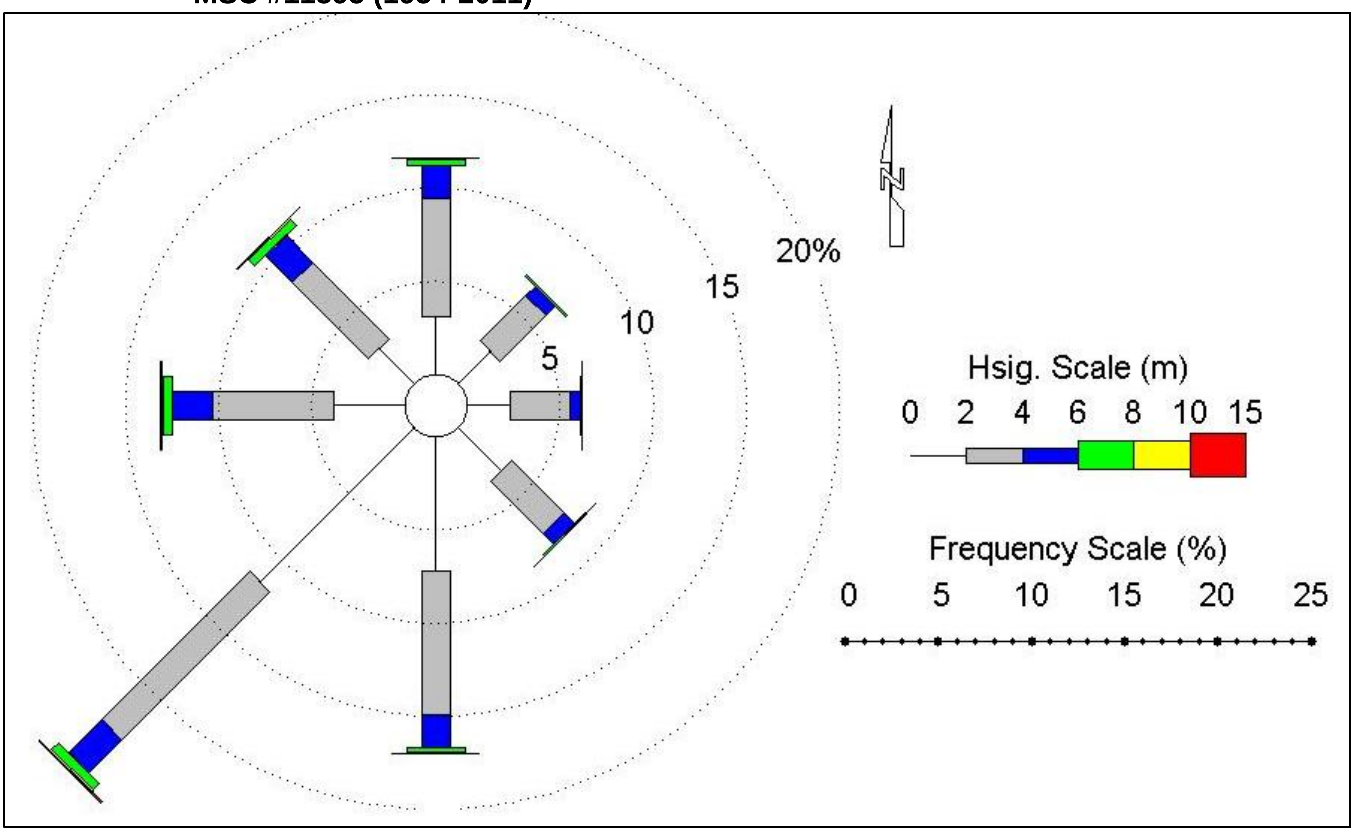
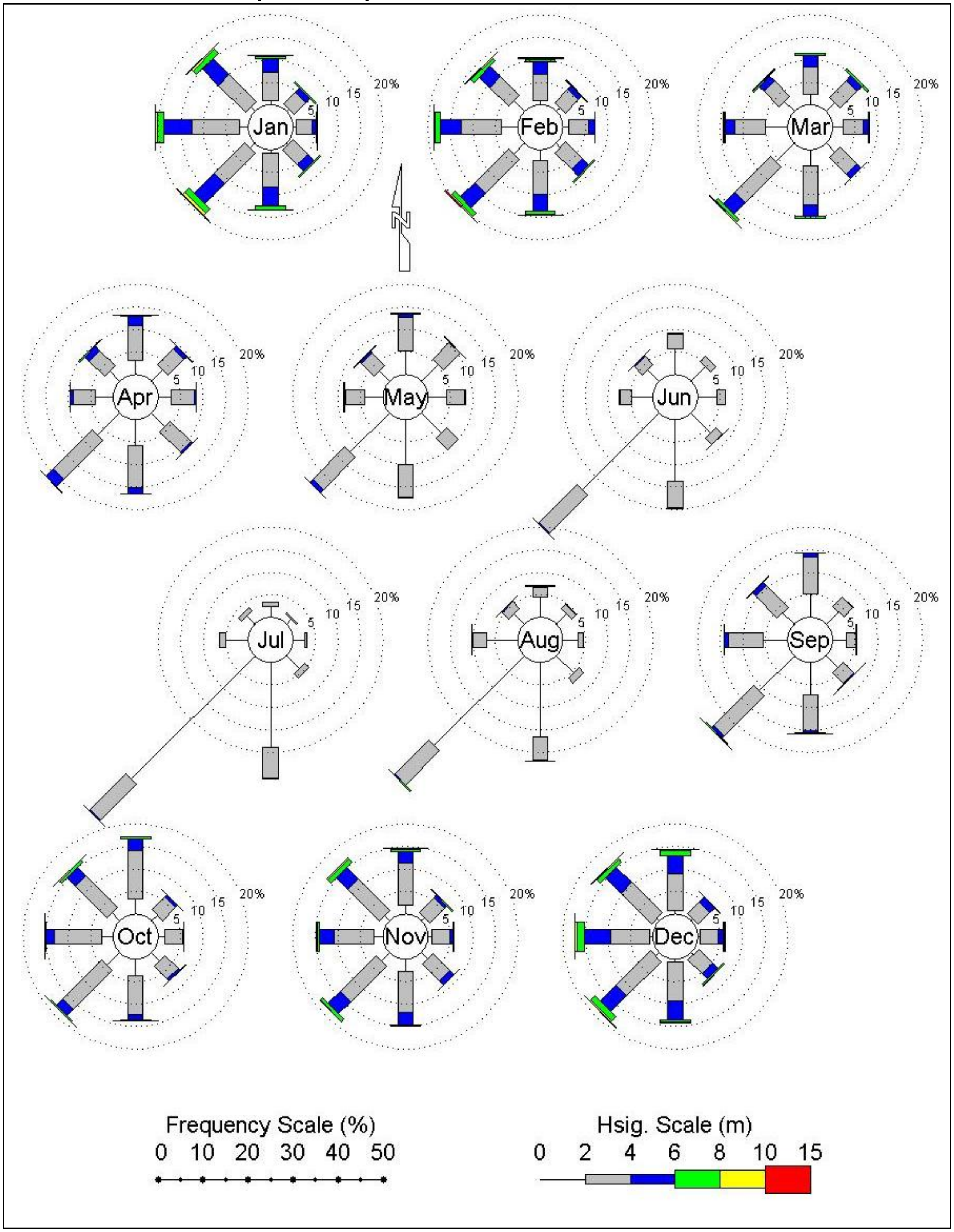


Figure 4.47 Monthly Directional Distributions of Significant Wave Height for the Grand Banks, MSC #11595 (1954-2011)



Tail of the Banks

In this sub-region, the most severe sea states would occur between February and March, with a peak in February, when maximum significant wave heights of up to 13.3 m from the northwest are expected, with an associated peak period of 14.4 s. In contrast, the maximum expected significant wave height is lowest (5.9 m) in July, with an associated peak period of 10.5 s. Significant wave heights of 8.5 m or greater occur in all months except July (Table 4.21). The values of the peak wave period associated with the maximum significant wave heights are generally in the range of 13 to 16 s, while the mean peak period is on average about 9 s.

Table 4.21 Wave Direction, Significant Wave Height and Peak Period for the Tail of the Banks (Descriptive Statistics, MSC50 Data 1954 – 2011)

MSC#6014618 Wave Parameters													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Mean Hsig (m)	3.9	3.8	3.4	2.8	2.2	1.8	1.6	1.7	2.3	2.8	3.2	3.8	2.8
Most frequent direction (from)	W	W	W	W	SW	SW	SW	SW	W	W	W	W	SW
Mean Tp (s)	10.3	10	9.8	9.0	8.4	7.9	7.6	7.7	8.7	9.2	9.6	10.2	9.0
Maximum Hsig (m)	12.0	13.3	12.6	11.5	8.5	8.7	5.9	9.7	10.9	11.9	12.1	12.1	13.3
Direction of max Hsig (from)	NW	NW	W	N	NW	W	S	W	SW	W	N	N	NW
Tp of max. Hsig (s)	13.8	14.4	14.5	14.0	12.1	13.9	10.5	15.1	15.5	15.4	14.2	14.4	14.4
Max. Tp (s)	15.9	18.7	16.7	15.8	14.8	16.9	17.3	17.4	16.1	17.4	18.3	15.5	18.7

Figure 4.48 Annual Directional Distribution of Significant Wave Height for the Tail of the Banks, MSC #3889 (1954-2011)

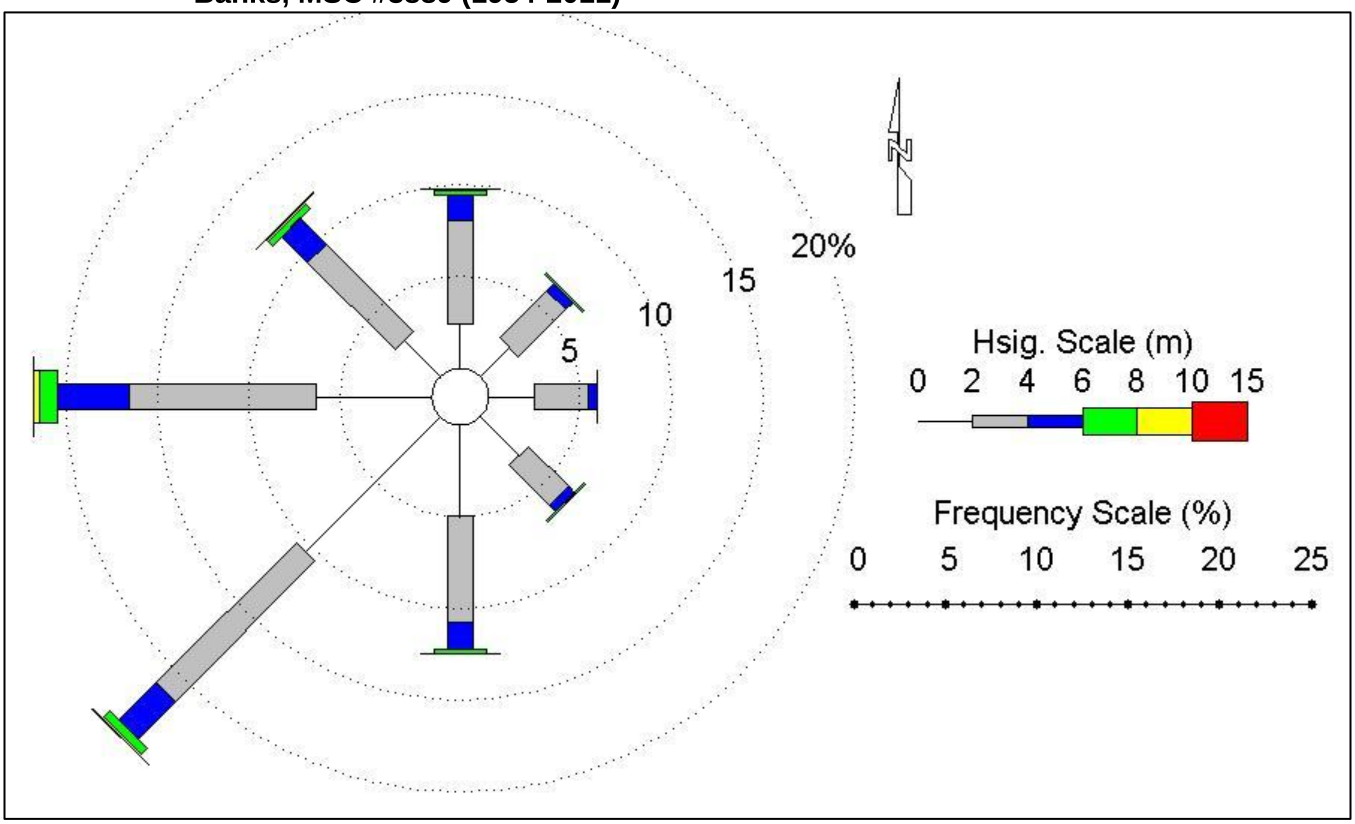
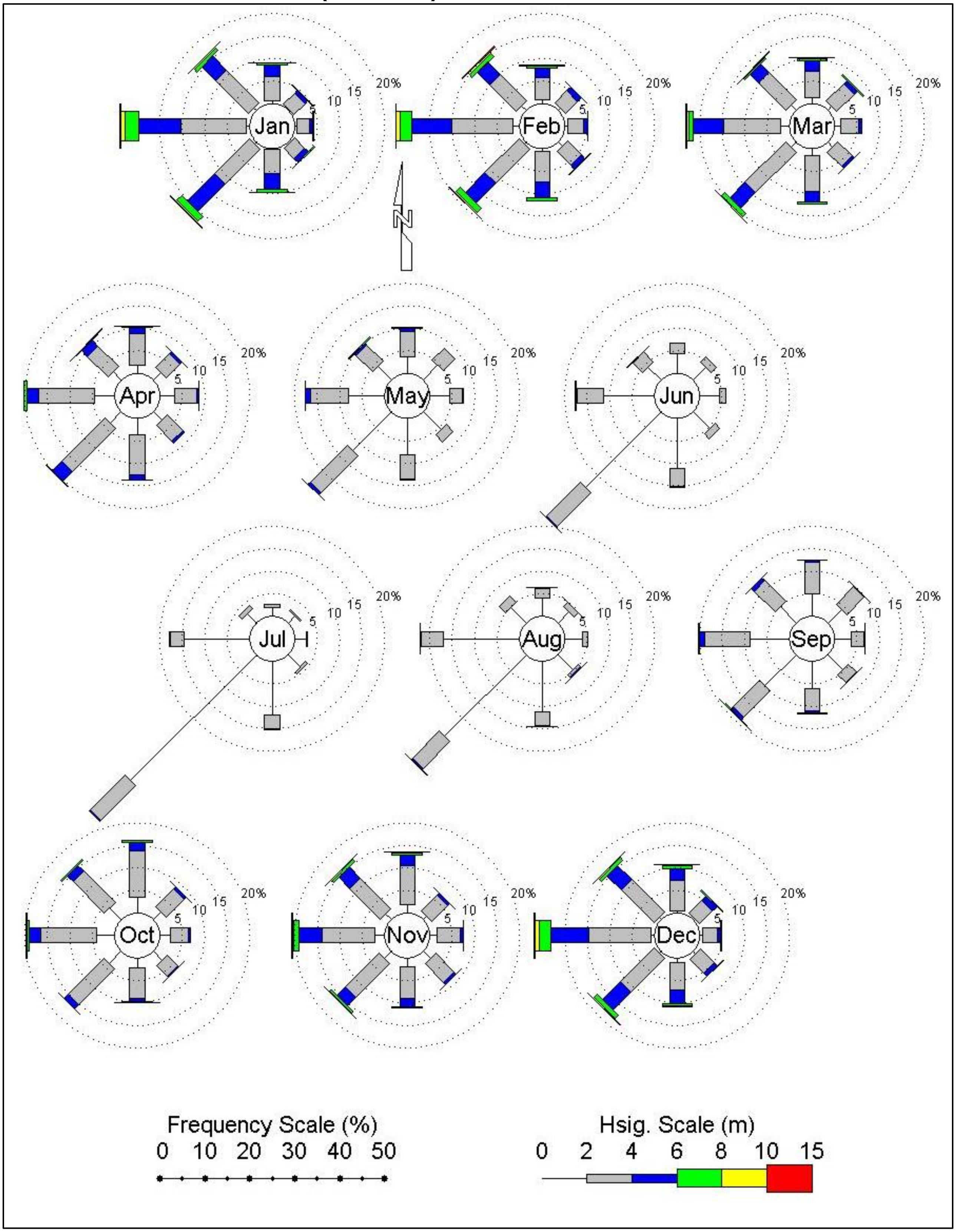


Figure 4.49 Monthly Directional Distributions of Significant Wave Height for the Tail of the Banks, MSC #3889 (1954-2011)



4.1.4.2 Ocean Currents

The cold Labrador Current dominates the general circulation over the Eastern Newfoundland Offshore Area. The Labrador Current is divided into two streams: 1) an inshore branch that flows along the coast on the continental shelf and 2) an offshore branch that flows along the outer edge of the Grand Banks (Figure 4.50).

The current's inshore branch tends to flow mainly in the Avalon Channel closely along the coast of the Avalon Peninsula but may sometimes also spread out farther out on the Grand Banks. The offshore branch flows over the upper Continental Slope at depth, and through the Flemish Pass.

The flow in the offshore stream is characteristically stronger than in the inshore stream. When it reaches Hamilton Bank (northwest of the Orphan Basin), the inshore branch of the Labrador Current typically has average speeds of approximately 0.15 m/s, carrying approximately 15 percent of the total transport. The offshore Labrador Current (which remains bathymetrically trapped over the upper Continental Slope) has average speeds of approximately 0.40 m/s, carrying approximately 85 percent of the total transport, mainly between the 400 and 1200 m isobaths (Lazier and Wright 1993). Over areas of the Grand Banks with water depths less than 100 m, the mean currents are generally weak (< 10 cm/s) and flow southward, dominated by wind-induced and tidal current variability (Seaconsult Ltd. 1988).

Through the SEA Study Area, in the western portion the southeasterly flowing stream from the inshore and offshore branch of the Labrador Current is at a mean rate of 8 nautical miles per day (about 17 cm/s). The main branch further offshore ranges from 13 nautical miles per day (28 cm/s) in the northern half of the SEA Study Area to about 10 to 11 nautical miles per day (21 to 23 cm/s) for the southern half. Current statistics for all current meter data on the Grand Banks from the Bedford Institute of Oceanography (BIO) have been queried from the Ocean Data Inventory (ODI) database (Gregory 2004, DFO 2013a). Overall, these provide a good representation of the regional current regime for the SEA Study Area. The database consists of all current meter records that have a record length of at least five days within a given month.

A summary of mean and maximum currents is presented in Figure 4.51. The database was queried for the area extending from 42 °N to 52 °N, 42 °W to 52 °W (DFO 2013a) with statistics tabulated by 5°x5° quadrants (simply for reporting convenience and to provide a further breakdown of the Study Area conditions) and for select depth regimes. A total of 3,001 records were returned, as reported in Figure 4.52, which illustrates just over one third of the measurements both from depths of 100 m or less, and also for the south-west quadrant.

Mean current speeds range from 5 cm/s or less (in the south-west in waters of 500 m or deeper) to 37 cm/s (in the south-east in the 200 to 500 m depth range). Maximum current speeds range from 35 cm/s (in the north-east in depths up to 200 m) to 206 cm/s (in the south-west in depths up to 100 m).

Figure 4.50 Ocean Currents in the Eastern Newfoundland Offshore Area and Overall Region

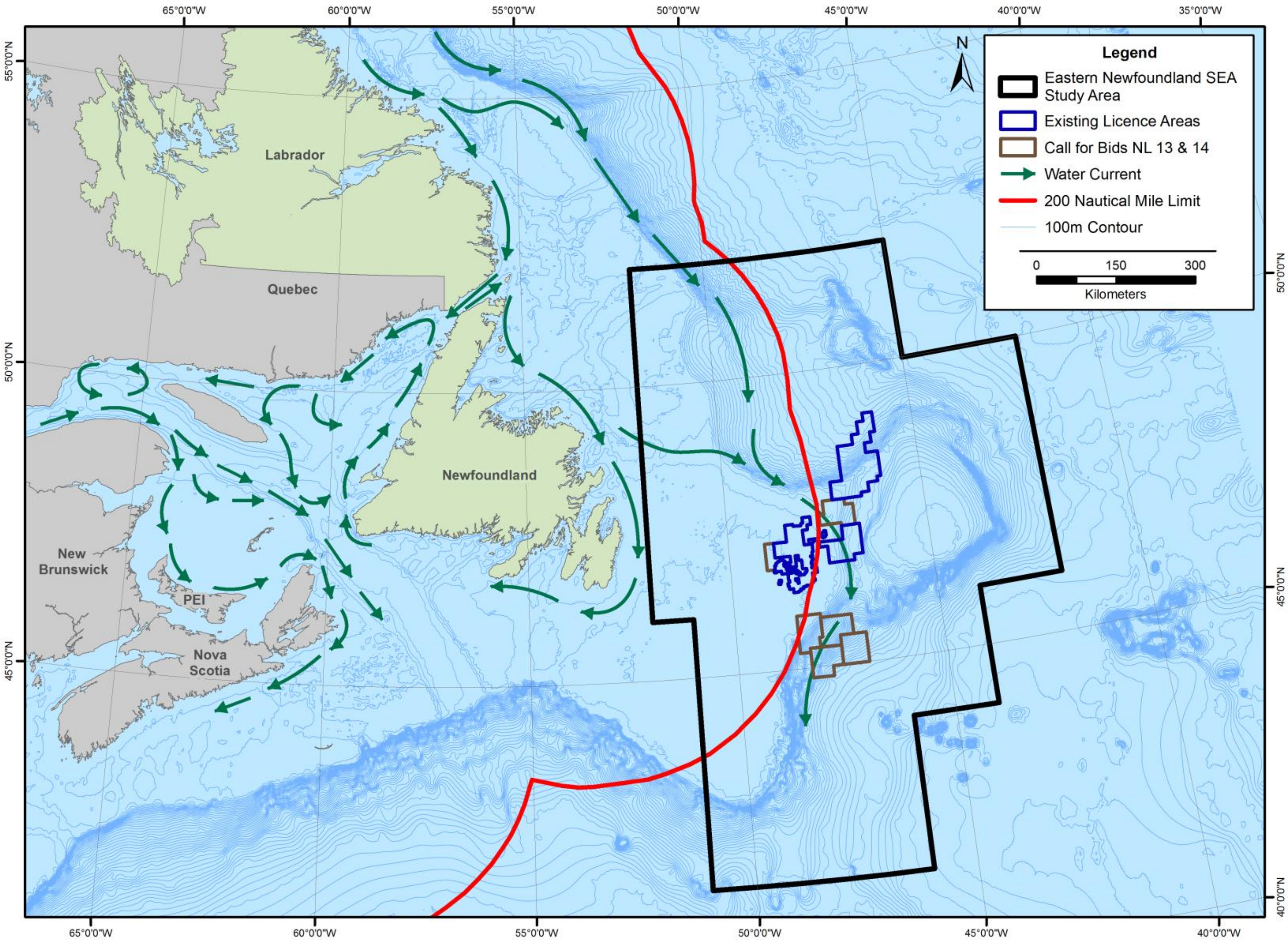
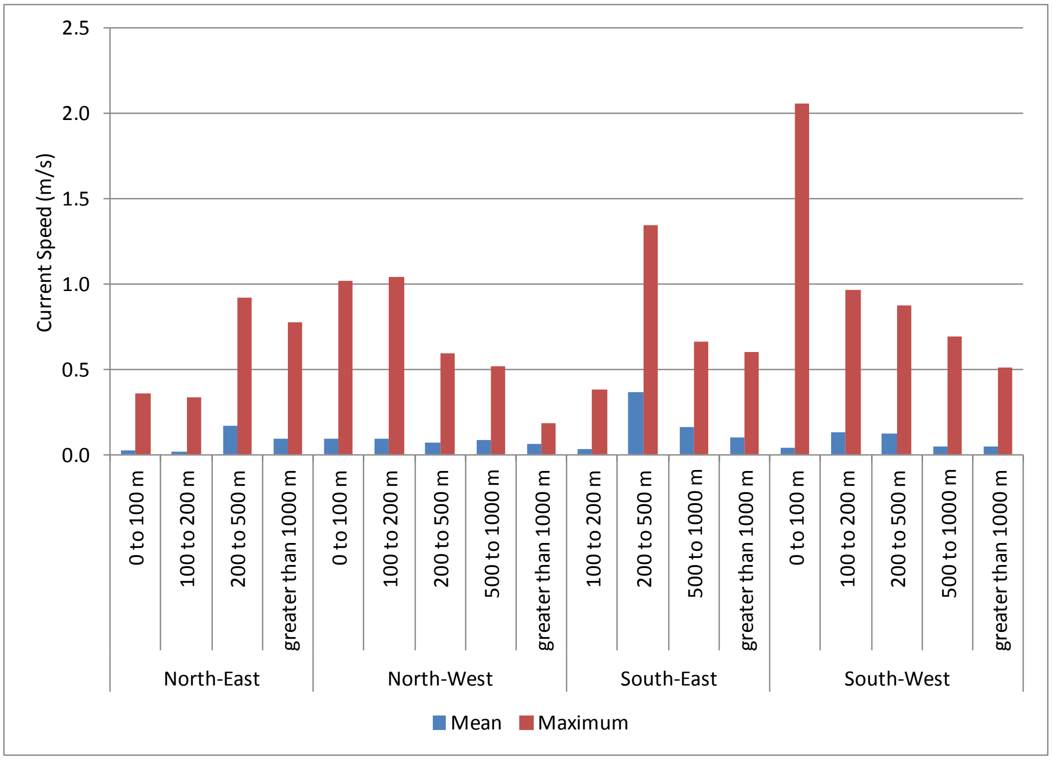


Figure 4.51 Mean and Maximum Ocean Currents



Source: Ocean Data Inventory database query # 4102, October 2013, for region 42 °N to 52 °N, 42 °W to 52 °W (DFO 2013a)

Figure 4.52 East Coast Ocean Currents: Number of Records

Quadrant	Number of Records
North-East	**167**
0 to 100 m	7
100 to 200 m	7
200 to 500 m	37
greater than 1000 m	116
North-West	**814**
0 to 100 m	385
100 to 200 m	162
200 to 500 m	226
500 to 1000 m	40
greater than 1000 m	1
South-East	**722**
100 to 200 m	4
200 to 500 m	58
500 to 1000 m	169
greater than 1000 m	491
South-West	**1298**
0 to 100 m	765
100 to 200 m	64
200 to 500 m	115
500 to 1000 m	73
greater than 1000 m	281
Grand Total	**3001**

4.1.4.3 Seawater Properties (Temperature, Salinity, Density)

Seawater temperature and salinity on the Newfoundland and Labrador continental shelf have been extensively measured over the last several decades. The statistics presented here have been extracted from the Ocean Data Inventory, the Hydrographic Climate Database, and the Sea-Surface Temperature Database of DFO (DFO 2012a). The Hydrographic Climate Database consists of data from a variety of sources, including hydrographic bottles, CTD casts, profiling floats, spatially and temporally averaged Batfish tows, expendable, digital or mechanical bathythermographs, as well as near real-time observations of temperature and salinity from the Global Telecommunications System (Gregory 2004). While initial data validation is carried out by the originating institute, all data are additionally validated by the Integrated Science Data Management (ISDM) (formerly MEDS, Marine Environmental Data Service) of DFO and the Bedford Institute of Oceanography (BIO). Climatologies have been calculated from this data and are available from the DFO Climatological website (DFO 2012a).

In order to generally characterize overall conditions within the SEA Study Area, data have been extracted from a geographic region consisting of areas 30 (Orphan Basin), 38 (Flemish Cap), 46 (Grand Banks), and 52 (Tail of the Banks) from the Newfoundland continental shelf hydrographic climatology database. These regions closely approximate the SEA Study Area, and align with areas selected from within the MSC50 and ICOADS databases as well. The data retrieved from the Sea Surface Temperature Database consist of Pathfinder 5, seven day average composite data at a resolution of 4 km, spanning the period from 1985 to 2009, and provided by the Physical Oceanography Archive Centre of the Jet Propulsion Laboratory in Pasadena, California.

The statistics shown here represent the broad regional conditions, and local seawater properties would exhibit considerable spatial and temporal variability that can only be revealed through a detailed, site-specific statistical analysis and possibly additional measurement programs. The results for seawater temperature, salinity and density are given in the following Tables, including the monthly minimum, maximum, and standard deviation.

It should be noted that variability at the sea surface is rapid and CTD casts are relatively sparse through time. Therefore, the data from the hydrographic climate database are likely under sampled and surface conditions not represented correctly, with the possibility of a single CTD cast affecting the mean, as well as minimum and maximum statistics for the top 250 m. Robust climatological analyses of sea surface temperatures therefore rely on more frequently sampled satellite data. Sea surface temperature statistics from within the SEA Study Area derived from satellite measurements (DFO 2012a) are shown for comparison in the Tables that follow (from DFO 2012a).

The temperature, salinity and density information can be used to infer vertical stratification which influences vertical mixing and with it biological production, biogeochemical fluxes, and potentially distribution of any spilled hydrocarbons.

Table 4.22 Monthly Sea Surface Temperature Statistics over the Orphan Basin

Sea Surface Temperature (°C)												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	-2.0	-2.0	-2.0	-2.0	-1.7	-0.6	1.9	4.1	4.4	1.1	-0.4	-1.4
Max	7.1	7.7	6.8	8.4	9.5	11.8	15.8	17.3	16.9	13.8	11.2	9.6
Mean	0.9	0.4	0.7	1.2	2.5	4.8	8.4	11.3	10.6	7.7	4.7	2.5
Std Dev	0.9	0.7	0.7	0.7	1.1	1.4	1.5	1.4	1.1	1.1	0.9	1.1
Data Months	25	25	24	25	25	25	25	25	25	25	25	25

Table 4.23 Monthly Sea Surface Temperature Statistics over the Flemish Cap

Sea Surface Temperature (°C)												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	-1.0	-1.6	-1.4	-1.9	-1.9	0.6	2.9	5.9	7.4	3.4	1.7	0.7
Max	14.9	14.7	15.8	15.9	16.4	18.9	20.9	22.9	22.1	20.5	19.2	17.5
Mean	4.8	3.8	4.1	4.8	6.3	8.4	11.4	13.7	13.7	11.4	9.2	6.5
Std Dev	1.2	1.2	1.3	1.4	1.6	1.4	1.5	1.4	1.3	1.2	1.3	1.2
Data Months	25	25	24	25	25	25	25	25	25	25	25	25

Table 4.24 Monthly Sea Surface Temperature Statistics over the Grand Banks

Sea Surface Temperature (°C)												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	-2.0	-2.0	-2.0	-2.0	-2.0	-0.5	1.9	5.9	7.1	1.7	0.8	-1.1
Max	8.8	8.3	8.0	7.9	11.9	14.6	18.6	20.1	19.4	17.5	15.1	12.2
Mean	0.9	0.0	0.1	0.7	2.6	5.5	10.3	14.0	13.5	10.5	6.8	3.5
Std Dev	0.9	0.6	1.0	0.8	1.3	1.4	1.7	1.6	1.3	1.3	1.5	1.4
Data Months	25	25	24	25	25	25	25	25	25	25	25	25

Table 4.25 Monthly Sea Surface Temperature Statistics over the Tail of the Banks

Sea Surface Temperature (°C)												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	-1.7	-2.0	-2.0	-2.0	-1.9	1.6	5.5	8.8	10.1	4.5	2.3	-0.6
Max	20.2	19.0	19.1	19.4	21.1	24.1	26.6	27.8	27.0	25.1	23.9	22.1
Mean	10.9	10.3	10.2	11.8	13.1	15.2	19.2	21.1	20.1	17.9	15.8	12.8
Std Dev	1.7	2.7	2.8	2.1	1.9	1.5	1.3	1.1	1.1	1.2	1.8	2.8
Data Months	25	25	24	25	25	25	25	25	25	25	25	25

The temperature statistics exhibit considerable seasonal variability, particularly in the upper part of the water column, while the monthly mean salinity values are comparatively more stable throughout the year. The Tail of the Banks experiences warmer temperatures, followed by the Flemish Cap, the Grand Banks, with the Orphan Basin experience the coldest sea surface temperatures.

Orphan Basin

The seasonal trends of temperature and salinity are reflected mainly in the density statistics near the surface, with the surface seawater density anomaly[1] (σ_t) reaching a maximum of 26.7 kg/m^3 in February, when the temperature is near its minimum, and the salinity is at its maximum. The minimum density anomaly (24.3 kg/m3) is seen in August, when the surface temperature and salinity trends are reversed. The mean density anomaly at 100 m and below is relatively constant year round, staying close to 27.3 kg/m^3 at 100 m, 28.6 kg/m^3 at 250 m, and 29.5 kg/m^3 at 400 m.

[1] The density anomaly σ_t represents the last two digits of seawater density expressed in [kg/m^3] at sea level, therefore density is equivalent to σ_t + 1000 kg/m^3.

Table 4.26 Monthly Temperature Statistics for Selected Depths for the Orphan Basin

Seawater Temperature (°C)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	-0.7	-1.1	-0.7	-0.5	1.2	3.4	8.5	10.8	9.3	4.8	2.5	1.0
10	-0.7	-1.1	-0.6	-0.6	1.0	2.7	7.5	9.3	8.4	4.8	2.6	0.9
20	-0.7	-1.1	-0.7	-0.7	0.5	1.6	4.2	5.8	6.8	4.4	2.4	0.9
30	-0.5	-1.1	-0.7	-0.6	0.1	0.7	2.0	2.4	3.7	3.4	2.2	0.9
50	-0.4	-0.9	-0.7	-0.9	-0.4	-0.5	-0.2	-0.2	-0.1	0.6	1.6	0.9
75	-0.3	-0.4	-0.5	-0.8	-0.6	-0.8	-0.4	-0.3	-0.5	-0.6	0.5	0.6
100	-0.1	-0.1	-0.2	-0.4	-0.3	-0.5	0.0	0.1	-0.1	-0.4	0.2	0.7
150	0.4	1.1	1.0	0.5	0.1	0.2	0.8	0.6	0.6	0.4	0.4	0.9
200	0.8	1.6	1.7	1.3	0.9	1.1	1.6	1.5	1.2	1.2	1.0	1.5
250	1.3	2.2	2.3	2.1	1.8	1.8	2.4	2.2	1.9	1.9	1.7	2.1
300	2.0	2.7	2.5	2.7	2.4	2.5	2.8	2.8	2.5	2.4	2.4	2.4
400	2.6	3.0	2.9	2.9	2.5	3.2	3.3	3.4	3.4	3.0	3.1	3.3
500		3.2		3.6	3.2	3.4	3.7	3.5	3.4		3.6	3.9
600				3.4	3.3	3.3		3.3			3.9	4.0

*Note: The sea surface temperatures presented here are considered less robust than the satellite-derived SST in the previous Table
Source: DFO (2012a)

Table 4.27 Monthly Salinity Statistics for Selected Depths for the Orphan Basin

Seawater Salinity (psu)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	33.0	33.2	33.0	33.0	32.7	32.4	32.1	31.8	32.2	32.4	32.5	32.8
10	33.0	33.2	33.1	32.9	32.6	32.4	32.0	31.8	32.4	32.5	32.3	32.9
20	33.1	33.3	33.0	33.0	32.8	32.7	32.6	32.4	32.6	32.7	32.7	33.0
30	33.0	33.3	33.1	33.1	32.9	32.9	32.9	32.7	32.8	32.9	32.8	32.9
50	33.2	33.5	33.1	33.2	33.1	33.1	33.3	33.1	33.3	33.3	33.0	33.1
75	33.2	33.4	33.2	33.3	33.3	33.3	33.5	33.4	33.5	33.5	33.3	33.2
100	33.3	33.6	33.2	33.5	33.4	33.5	33.7	33.5	33.7	33.7	33.5	33.4
150	33.6	34.0	33.8	33.8	33.7	33.8	34.0	33.8	34.0	34.0	33.8	33.7
200	33.9	34.2	34.2	34.1	34.0	34.1	34.2	34.1	34.1	34.2	34.0	34.0
250	34.1	34.4	34.3	34.3	34.3	34.3	34.4	34.4	34.4	34.4	34.2	34.2
300	34.3	34.5		34.5	34.5	34.5	34.6	34.6	34.5	34.6	34.5	34.3
400	34.7	34.6		34.7	34.7	34.8	34.8			34.7	34.6	34.5
500		34.6		34.8	34.8	34.8	34.8	34.9			34.6	34.7
600				34.8	34.8	34.8		34.9				34.8

Source: DFO (2012a)

Table 4.28 Monthly Density Anomaly Statistics for Selected Depths for the Orphan Basin

Seawater Density Anomaly (σ_t, kg/m^3)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	26.5	26.7	26.5	26.5	26.2	25.8	24.9	24.3	24.9	25.6	26.0	26.3
10	26.6	26.7	26.6	26.5	26.2	25.9	25.1	24.6	25.2	25.8	25.8	26.4
20	26.7	26.9	26.6	26.6	26.4	26.2	26.0	25.6	25.7	26.0	26.2	26.5
30	26.7	26.9	26.8	26.8	26.5	26.5	26.4	26.3	26.2	26.3	26.3	26.5
50	26.9	27.1	26.8	26.9	26.8	26.8	27.0	26.8	26.9	26.9	26.6	26.7
75	27.0	27.2	27.1	27.1	27.1	27.1	27.3	27.2	27.3	27.3	27.0	27.0
100	27.2	27.5	27.2	27.4	27.3	27.4	27.5	27.4	27.5	27.6	27.3	27.3
150	27.7	27.9	27.8	27.9	27.8	27.8	27.9	27.8	28.0	28.0	27.8	27.8
200	28.1	28.3	28.3	28.3	28.2	28.3	28.3	28.3	28.3	28.4	28.2	28.2
250	28.5	28.6	28.6	28.6	28.6	28.6	28.7	28.6	28.7	28.7	28.6	28.5
300	28.9	28.9		29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	28.8
400	29.6	29.4		29.6	29.6	29.6	29.6			29.6	29.5	29.3
500		29.9		30.1	30.1	30.1	30.0	30.1			29.8	29.9
600				30.6	30.5	30.5		30.6				30.5

Source: DFO (2012a)

Flemish Cap

Surface seawater density anomaly (σ_t) reaches a maximum of 26.9 kg/m^3 in January and February, when the temperature is near its minimum, and the salinity is at its maximum. The minimum density anomaly (25.0 kg/m^3) is seen in September, when the surface temperature and salinity trends are reversed. The mean density anomaly at 100 m and below is relatively constant year round, staying close to 27.7 kg/m^3 at 100 m, and 28.5 kg/m^3 at 200 m.

Table 4.29 Monthly Temperature Statistics for Selected Depths for the Flemish Cap

Seawater Temperature (°C)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	4.3	3.4	3.5	4.1	5.5	8.0	11.7	12.8	12.8	9.7	9.3	7.3
10	4.1	3.2	3.8	4.0	5.2	7.7	11.1	12.3	12.9	10.2	9.4	7.1
20	4.2	3.1	3.6	4.0	5.0	6.7	9.8	10.8	11.8	9.9	9.3	7.0
30	4.2	3.1	3.3	3.8	4.8	6.3	8.2	8.6	10.2	9.7	9.1	7.1
50	4.2	3.2	3.3	3.5	4.0	4.6	4.9	5.0	5.8	6.9	6.8	6.4
75	4.1	3.1	3.3	3.3	3.5	3.4	3.6	3.5	4.4	4.6	5.2	5.2
100	4.0	3.3	3.3	3.2	3.4	3.1	3.3	3.3	3.8	3.2	3.7	3.7
150	3.9	3.5	3.6	3.4	3.5	3.2	3.4	3.4	3.7	3.3	4.2	3.3
200	4.4	4.1	3.7	3.8	3.8	3.7	3.7	4.1	4.3	3.2		
250	4.2					5.0	4.6	4.2	5.0			
*Note: The sea surface temperatures presented here are considered less robust than the satellite-derived SST in the previous Table Source: DFO (2012a)												

Table 4.30 Monthly Salinity Statistics for Selected Depths for the Flemish Cap

Seawater Salinity (psu)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	34.0	33.8	34.1	34.0	34.0	33.8	33.5	33.3	33.2	33.4	33.2	33.4
10	33.9	33.8	34.0	33.8	33.7	33.8	33.5	33.3	33.2	33.2	33.2	33.4
20	33.9	33.8	34.1	34.0	34.0	33.9	33.6	33.5	33.4	33.3	33.3	33.4
30	33.9	33.8	34.0	34.0	34.0	33.9	33.7	33.6	33.7	33.3	33.3	33.5
50	33.9	33.9	34.1	34.1	34.0	34.0	33.9	34.0	34.0	33.6	33.7	33.5
75	34.0	33.9	34.1	34.1	34.1	34.1	34.1	34.2	34.3	34.2	34.1	33.8
100	34.2	34.0	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.4	34.2	34.3
150	34.5	34.3	34.5	34.5	34.5	34.5	34.5	34.5	34.6	34.4	34.4	34.4
200	34.7		34.6	34.7	34.7	34.7	34.7	34.8				
250	34.8							34.9				
Source: DFO (2012a)												

Table 4.31 Monthly Density Anomaly Statistics for Selected Depths for the Flemish Cap

Seawater Density Anomaly (σ_t, kg/m^3)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	26.9	26.9	27.1	27.0	26.8	26.3	25.5	25.1	25.0	25.7	25.6	26.1
10	26.9	27.0	27.0	26.9	26.7	26.4	25.6	25.3	25.1	25.6	25.7	26.2
20	27.0	27.0	27.2	27.1	27.0	26.6	26.0	25.7	25.5	25.8	25.8	26.3
30	27.0	27.0	27.2	27.2	27.0	26.7	26.4	26.2	26.0	25.8	25.9	26.3
50	27.1	27.2	27.4	27.4	27.3	27.1	27.1	27.1	27.0	26.6	26.7	26.5
75	27.3	27.3	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.3	27.1
100	27.6	27.5	27.7	27.7	27.8	27.8	27.7	27.8	27.8	27.8	27.7	27.7
150	28.1	28.0	28.1	28.1	28.1	28.2	28.1	28.1	28.2	28.1	28.0	28.1
200	28.5		28.4	28.5	28.5	28.5	28.5	28.5				
250	28.8							28.9				
Source: DFO (2012a)												

Grand Banks

Surface seawater density anomaly (σ_t) reaches a maximum of 26.4 kg/m^3 in March and April, when the temperature is near its minimum, and the salinity is at its maximum. The minimum density anomaly (24.0 kg/m^3) is seen in August, when the surface temperature and salinity trends are reversed. The mean density anomaly at 100 m and below is relatively constant year round, staying close to 27.2 kg/m^3 at 100 m.

Table 4.32 Monthly Temperature Statistics for Selected Depths for the Grand Banks

Seawater Temperature (°C)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	0.6	0.1	-0.1	0.7	2.6	5.3	10.2	13.8	12.1	8.9	6.1	3.3
10	0.5	0.1	0.0	0.6	2.7	5.1	9.7	13.1	11.7	8.7	5.8	3.1
20	0.6	0.0	-0.1	0.5	2.1	4.2	7.6	9.1	9.6	8.6	5.6	3.1
30	0.5	0.1	0.0	0.3	1.8	3.3	5.3	4.8	6.9	7.4	5.2	3.1
50	0.4	0.0	-0.2	0.0	0.6	0.9	1.0	0.7	0.6	1.6	2.6	1.9
75	-0.1	-0.2	-0.3	-0.5	-0.2	-0.1	-0.1	0.1	0.1	0.1	0.0	0.4
100	-0.6	-0.1	-1.4	-0.4	-0.4	-0.4	0.0	-0.6	-0.4	-0.6	-0.6	-0.2
150			-0.1		-0.5	-0.8					0.3	0.6
200			1.3		0.7	0.9					0.5	0.6
250				0.5	1.4							0.5
300		1.8	-0.1		1.6							0.2
400					2.4							-0.1
500					4.0							
600					4.1							
*Note: The sea surface temperatures presented here are considered less robust than the satellite-derived SST in the previous Table Source: DFO (2012a)												

Table 4.33 Monthly Salinity Statistics for Selected Depths for the Grand Banks

Seawater Salinity (psu)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	32.7	32.8	32.9	32.9	32.8	32.7	32.4	32.1	32.2	32.1	32.0	32.2
10	32.7	32.8	32.9	32.8	32.7	32.6	32.4	32.1	32.2	32.1	32.0	32.4
20	32.7	32.7	32.9	32.9	32.8	32.7	32.5	32.4	32.4	32.1	32.0	32.4
30	32.7	32.7	32.9	32.9	32.8	32.7	32.6	32.6	32.5	32.2	32.1	32.3
50	32.7	32.8	33.0	33.0	32.9	32.9	32.9	32.9	33.0	32.9	32.5	32.7
75	33.0	32.8	33.0	33.1	33.1	33.1	33.1	33.1	33.1	33.0	33.0	33.2
100		33.1	33.2	33.3	33.2	33.2	33.1	33.2	33.3	33.2	33.2	33.4
150					33.4	33.4						
200						33.7						
250												
300												
400												
500												
600												
Source: DFO (2012a)												

Table 4.34 Monthly Density Anomaly Statistics for Several Depths for the Grand Banks

Seawater Density Anomaly (σ_t, kg/m^3)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	26.2	26.3	26.4	26.4	26.1	25.8	24.9	24.0	24.4	24.9	25.2	25.7
10	26.3	26.4	26.5	26.4	26.1	25.8	25.0	24.2	24.5	24.9	25.3	25.8
20	26.3	26.3	26.5	26.5	26.3	26.1	25.5	25.1	25.0	25.0	25.4	25.9
30	26.3	26.4	26.6	26.6	26.4	26.2	25.9	26.0	25.6	25.3	25.5	25.8

Seawater Density Anomaly (σ_t, kg/m^3)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
50	26.5	26.6	26.7	26.7	26.6	26.6	26.6	26.6	26.7	26.5	26.2	26.3
75	26.8	26.7	26.9	27.0	26.9	27.0	27.0	26.9	26.9	26.8	26.8	27.0
100		27.1	27.2	27.2	27.2	27.2	27.1	27.2	27.2	27.2	27.1	27.3
150					27.6	27.6						
200						28.0						
250												
300												
400												
500												
600												
Source: DFO (2012a)												

Tail of the Banks

Surface seawater density anomaly (σ_t) reaches a maximum of 26.3 kg/m^3 in March and April, when the temperature is near its minimum, and the salinity is at its maximum. The minimum density anomaly (23.6 kg/m^3) is seen in August, when the surface temperature and salinity trends are reversed. The mean density anomaly at 100 m and below is relatively constant year round, staying close to 27.1 kg/m^3 at 100 m.

Table 4.35 Monthly Temperature Statistics for Selected Depths for the Tail of the Banks

Seawater Temperature (°C)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	2.3	1.3	1.2	1.5	3.5	7.6	12.3	16.1	14.8	10.7	6.3	4.9
10	2.1	1.6	1.5	1.6	3.8	7.3	11.4	14.6	13.3	10.5	5.9	4.3
20	2.2	1.5	1.3	1.2	2.7	5.3	7.9	9.3	9.9	8.7	5.7	4.6
30	2.1	1.3	1.2	1.0	2.2	3.8	4.6	5.2	5.7	6.4	5.0	4.2
50	2.1	1.3	1.1	0.7	1.2	1.7	2.7	1.9	1.8	2.1	2.5	3.6
75	1.6	2.0	0.9	0.8	1.1	0.8	2.9	1.2	0.7	2.5	1.0	1.4
100	0.1	1.3	-0.3	1.3	-0.2	0.1	-1.2	-0.9		-1.1	0.5	1.3
150	0.0	0.8		1.2	-0.5	-0.6	0.0	-1.0		0.0	-0.4	2.6
200	0.1		0.0	1.2		0.1		-0.2		0.4	1.1	2.6
250	0.3			2.5		1.1		1.1			1.1	2.6
300	1.2		0.8	1.3	1.6	1.6		1.8		1.3	0.9	2.5
400	2.2			2.7		3.1		3.0				2.4
500	3.0					3.6						1.6
600				3.9		3.6						1.2
800				4.0		3.9						
1000						3.7						
*Note: The sea surface temperatures presented here are considered less robust than the satellite-derived SST in the previous Table Source: DFO (2012a)												

Table 4.36 Monthly Salinity Statistics for Several Depths for the Tail of the Banks

Seawater Salinity (psu)												
Depth (m)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0	32.7	32.8	32.8	32.9	32.8	32.7	32.5	32.3	32.2	32.1	32.5	32.5
10	32.8	32.9	32.8	32.8	32.8	32.7	32.5	32.3	32.3	32.2	32.4	32.6
20	32.7	32.9	32.9	33.0	32.9	32.8	32.7	32.6	32.5	32.3	32.6	32.5
30	32.7	32.8	32.9	33.0	32.9	32.9	32.8	32.8	32.8	32.4	32.6	32.6
50	32.8	33.0	33.0	33.1	33.0	33.0	33.0	33.0	33.0	32.9	32.9	32.8
75	33.2	33.2	33.1	33.3	33.3	33.3	33.4	33.1	33.1	33.1	33.1	33.0
100	33.1	33.2	33.6	33.5	33.2	33.3	33.2	33.3		33.1	33.2	
150	33.1	33.3		33.7	33.4	33.4	33.8	33.5		33.1		

Seawater Salinity (psu)												
Depth (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
200			33.9	34.0		33.6		33.7		34.0		
250				34.7		33.9		34.2				
300			34.1	34.1	34.3	34.2		34.4		34.1		
400				34.5		34.7		34.7				
500						34.8						
600				34.9		34.9						
800				34.9		34.9						
1000						34.9						
Source: DFO (2012a)												

Table 4.37 Monthly Density Anomaly Statistics for Selected Depths for the Tail of the Banks

Seawater Density Anomaly (σ_t, kg/m^3)												
Depth (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	26.1	26.2	26.3	26.3	26.1	25.5	24.6	23.6	23.9	24.6	25.5	25.7
10	26.2	26.3	26.3	26.3	26.1	25.6	24.8	24.0	24.3	24.7	25.6	25.9
20	26.2	26.4	26.4	26.5	26.3	26.0	25.6	25.3	25.1	25.2	25.8	25.9
30	26.3	26.4	26.5	26.6	26.4	26.2	26.1	26.0	25.9	25.6	25.9	26.0
50	26.5	26.6	26.7	26.8	26.7	26.7	26.5	26.6	26.6	26.5	26.5	26.3
75	26.9	26.9	26.9	27.0	27.0	27.0	27.0	26.9	26.9	26.8	26.9	26.8
100	27.0	27.1	27.5	27.3	27.2	27.2	27.2	27.3		27.1	27.1	
150	27.3	27.4		27.7	27.6	27.5	27.8	27.7		27.3		
200			28.2	28.2		28.0		28.1		28.2		
250				28.9		28.4		28.6				
300			28.8	28.8	28.9	28.8		29.0		28.7		
400				29.4		29.5		29.6				
500						30.0						
600				30.6		30.5						
800				31.5		31.5						
1000						32.5						
Source: DFO (2012a)												

4.1.4.4 Extreme Wind and Wave Events

Each of the oceanographic and climatological parameters presented above have the potential to affect the planning and execution of marine operations, with the occurrence of severe winds and waves associated with extreme storm events being of particular interest. The available hindcast data allow for an analysis of extreme values for these parameters.

For the SEA Study Area, extremal analysis was performed to determine the highest expected values for (hourly average – see Section 4.1.3.1) wind speed, significant wave height and the associated peak wave period. The analysis was based on the Gumbel distribution to which the data were fitted using the maximum likelihood method. The analysis includes both tropical and extra-tropical storms over the entire period.

Extreme values were computed for four different return periods: 1, 10, 50 and 100 years for each of the four MSC50 nodes that span various representative portions of the SEA Study Area (Tables 4.38 to 4.41).

Table 4.38 Extreme Values of Wind Speed, Wave Height and Associated Peak Wave Period for MSC #17801, Orphan Basin

Return Period (years)	1	10	50	100
Significant Wave Height (m)	11.5	13.7	15.5	16.3
Associated Peak Wave Period (s)	13.4	14.9	15.8	16.2
Wind Speed (m/s)	21.9	30.9	34.3	35.8

Table 4.39 Extreme Values of Wind Speed, Wave Height and Associated Peak Wave Period for MSC #13451, Flemish Cap

Return Period (years)	1	10	50	100
Significant Wave Height (m)	12.8	15.5	17.7	18.6
Associated Peak Wave Period (s)	14.8	16.3	17.4	17.9
Wind Speed (m/s)	23.8	31.1	34.4	35.8

Table 4.40 Extreme Values of Wind Speed, Wave Height and Associated Peak Wave Period for MSC #11595, Grand Banks

Return Period (years)	1	10	50	100
Significant Wave Height (m)	9.9	11.9	13.6	14.3
Associated Peak Wave Period (s)	13.2	14.9	16.2	16.7
Wind Speed (m/s)	21.5	29.7	33.3	34.8

Table 4.41 Extreme Values of Wind Speed, Wave Height and Associated Peak Wave Period for the Tail of the Banks

Return Period (years)	1	10	50	100
Significant Wave Height (m)	10.4	12.4	14.0	14.7
Associated Peak Wave Period (s)	13.5	15.0	16.2	16.8
Wind Speed (m/s)	21.8	29.2	32.6	34.0

The seasonal variability of the extreme values of significant wave height and wind speed was further analyzed by estimating extremes of different return periods using a three month running window centred on each month. This produced monthly estimates of extreme values, plotted in the two panels in Figures 4.53 to 4.56.

The plots illustrate a general pattern of high values during winter (October to March) and lower values during summer (May to July). The severe winter conditions generally begin dropping in March, followed by more favourable conditions in summer. These tend to end quickly with a rapid increase in severity in August that peaks between November and December. Winter storms characterize the months of December to February with high wind and wave conditions.

Extreme wave heights, from largest to smallest, occur for Flemish Cap, Orphan Basin, Tail of the Banks, and then the Grand Banks. Extreme wind speeds, from largest to smallest, occur for Flemish Cap, Orphan Basin, Grand Banks, and then the Tail of the Banks.

Figure 4.53 Extreme Values for Significant Wave Height and Wind Speed for MSC #17801, Orphan Basin (MSC50 Data: 1954 – 2011)

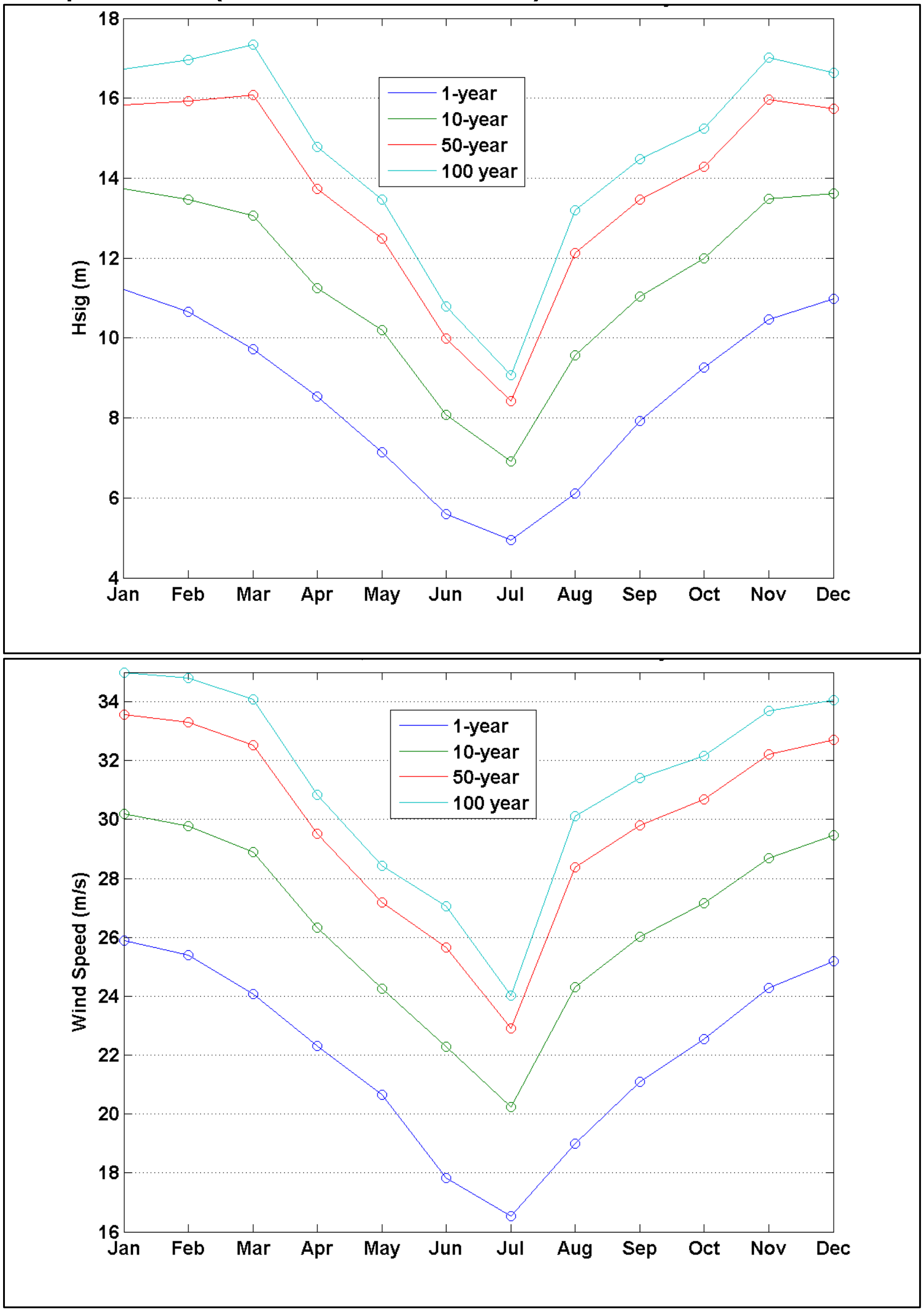


Figure 4.54 Extreme Values for Significant Wave Height and Wind Speed for MSC #13451, Flemish Cap (MSC50 Data: 1954 – 2011)

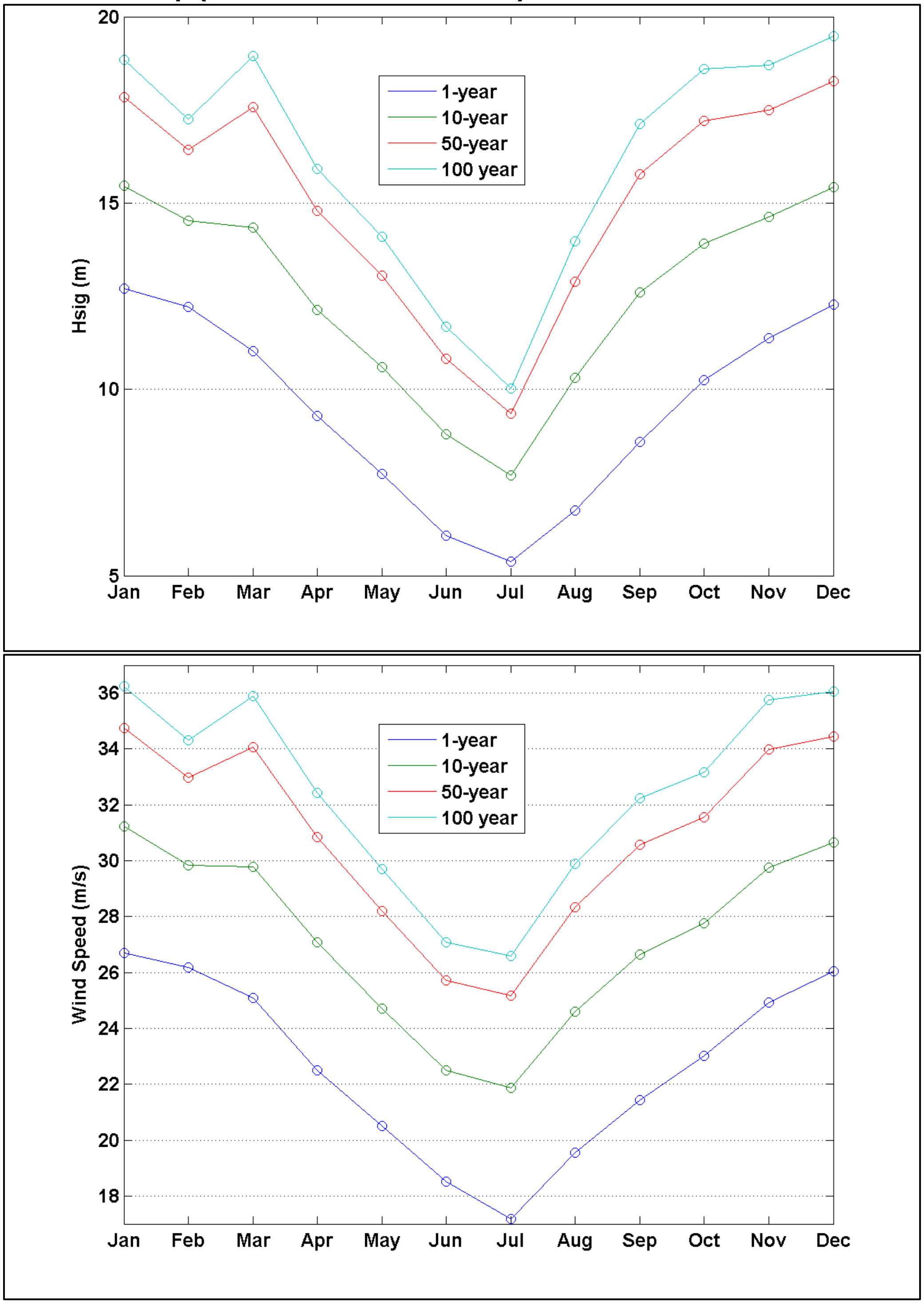


Figure 4.55 Extreme Values for Significant Wave Height and Wind Speed for MSC #11595, Grand Banks (MSC50 Data: 1954 – 2011)

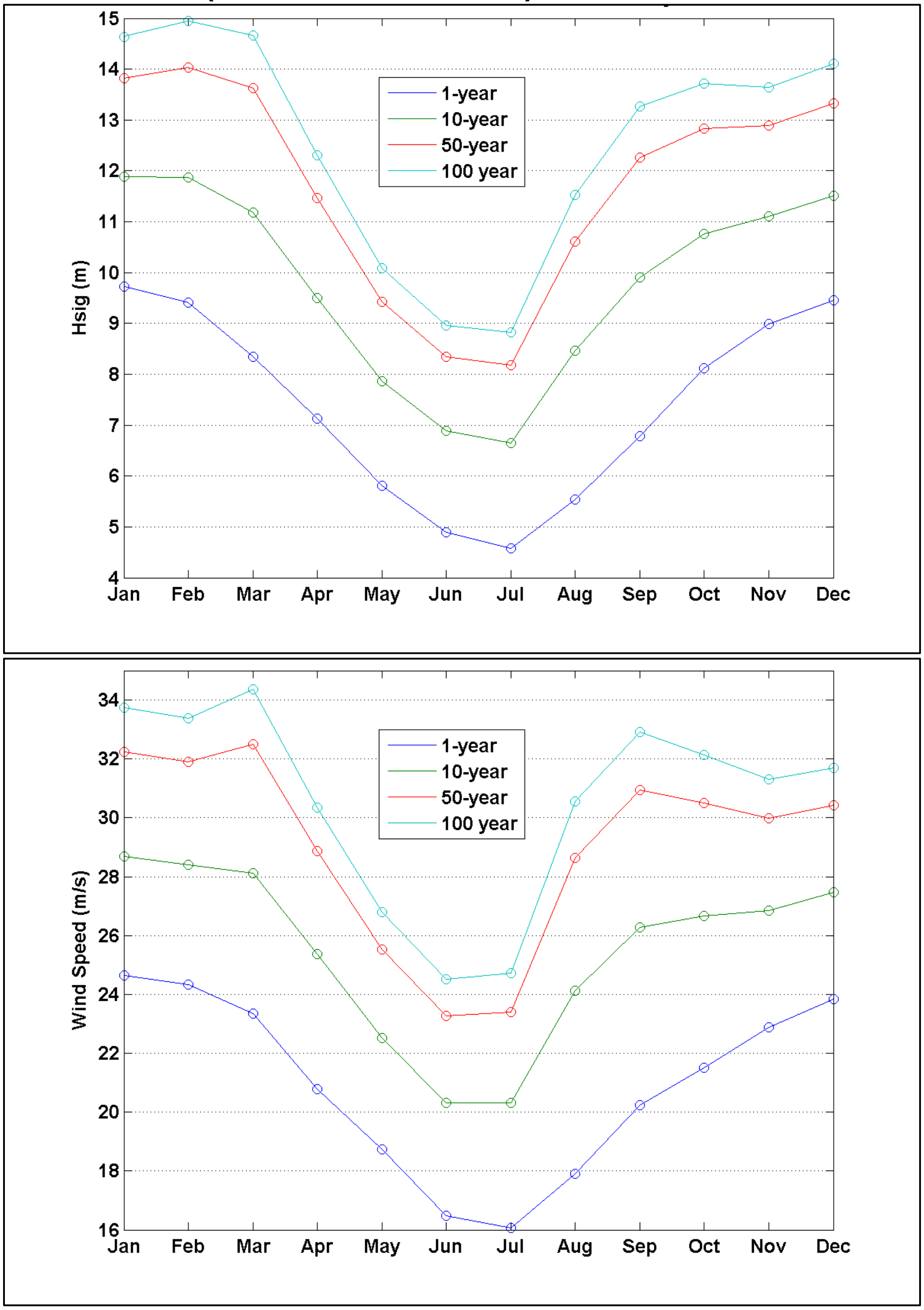
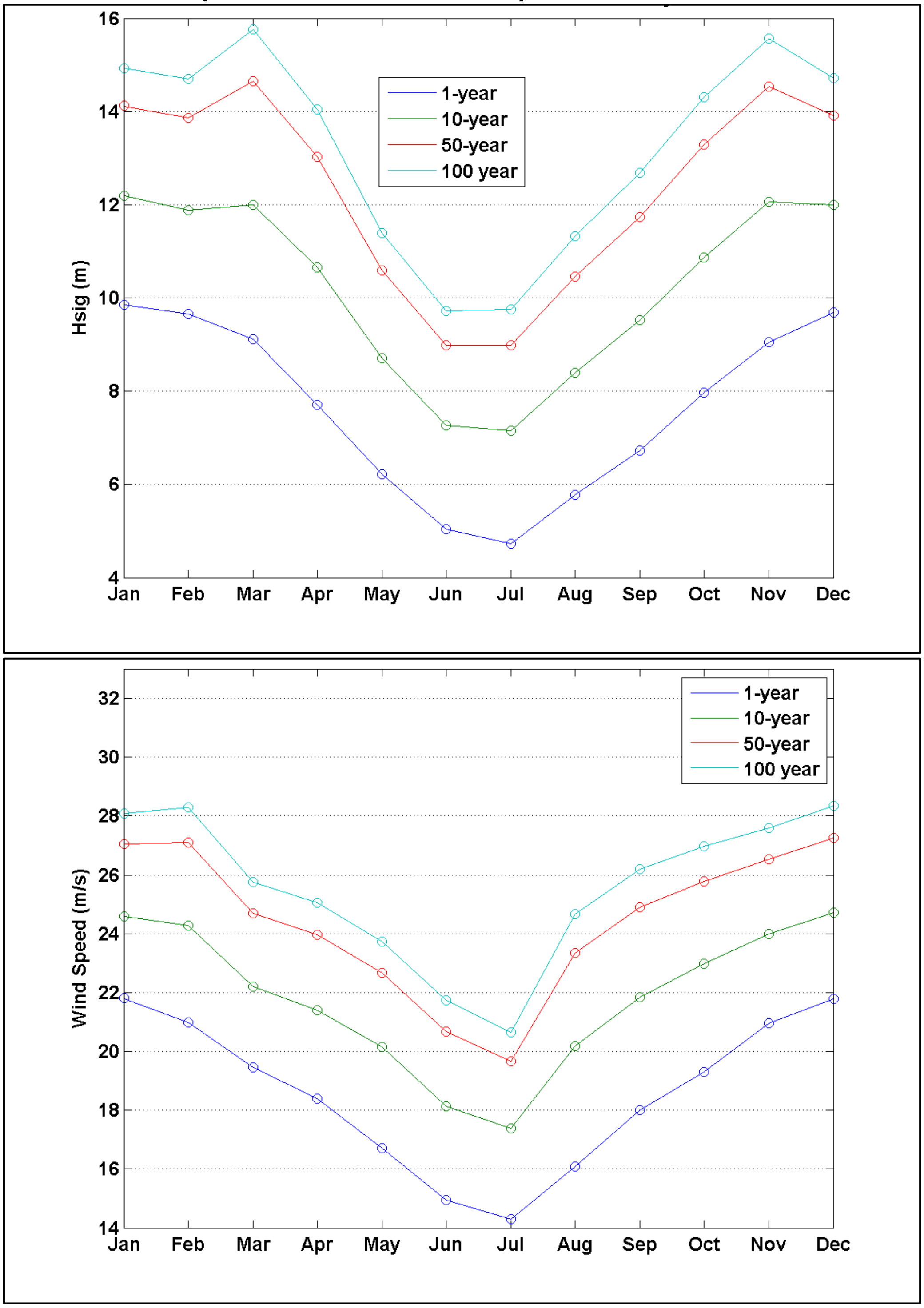


Figure 4.56 Extreme Values for Significant Wave Height and Wind Speed for MSC #3889, Tail of the Banks (MSC50 Data: 1954 – 2011)



4.1.5 Ice Conditions

Sea ice is produced when the surface layer of the ocean freezes. Icebergs occur when ice from glaciers that have extended to the coast break off and enter the ocean. The Eastern Newfoundland Offshore Area is subject to seasonal intrusions of sea ice and icebergs, which are important factors in the planning and implementation of offshore petroleum exploration and development activities in the SEA Study Area.

Knowledge and monitoring of sea ice and iceberg conditions is required for marine vessel navigation and ice management as part of offshore marine seismic survey activities and oil and gas exploration and development. Ice can pose a risk of damage to vessels as well as resulting in additional costs due to delays or downtime. Consideration of potential ice-structure interaction is an essential element of ship, drilling rig or platform design and selection. Several particular risks include bergy bits and growlers which may be difficult to detect, icebergs which due to their size or shape or the sea conditions at the time are difficult to tow or deflect, and hard, multi-year ice (expected to be less of a factor outside the northern regions of the study area).

4.1.5.1 Sea Ice

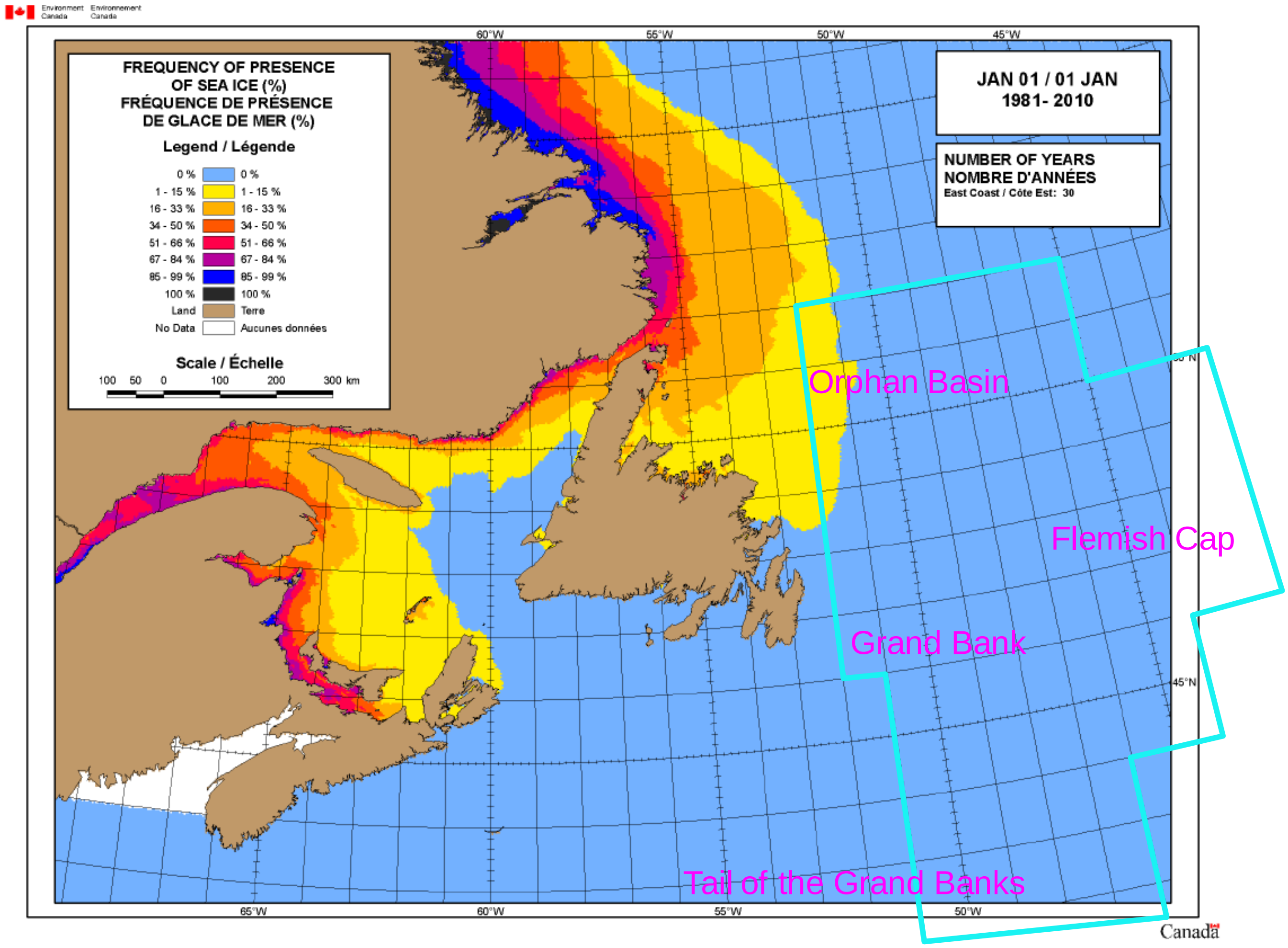
This section provides an illustration of the sea (or pack) ice conditions most likely to be encountered in the Eastern Newfoundland Offshore Area. Information is drawn from the Sea Ice Climatic Atlas for the East Coast 1981-2010 (CIS 2011). As noted in the Ice Atlas, variations in the extent of ice over East Coast waters, and hence the Study Area, are great due to both winds and temperatures being effective in changing the location of the ice edge. In an especially cold winter (such that encountered in 1990-91), sea ice could persist to as late as the third week of July in Eastern Newfoundland waters. Conversely, in a relatively mild winter (such as 2005-06), the ice could clear from the same regions before the end of April (CIS 2011). A large variability in sea ice conditions can therefore be experienced from year to year, and also in any given year on time scales of days to weeks and over comparatively small geographic scales of tens of kilometres.

The section that follows provides a summary overview of how frequently sea ice is present, its concentration when present, and its predominant ice type (and hence thickness) in the SEA Study Area. The summary quantifies conditions over a typical ice season for the four representative sub-regions of the Orphan Basin, Flemish Cap, Grand Bank and Tail of the Grand Banks. These locations are shown in Figure 4.57 together with outline of the overall SEA Study Area (in light blue).

Figure 4.57 illustrates the frequency sea ice presence in the first week of January, as historically the earliest sea ice might be expected to reach the Study Area in the northwest corner from 1 to 15 percent of the time or perhaps as often as about every six years. As shown in Table 4.42, it is typically three weeks later before ice reaches the Orphan Basin about 150 km to the east. It is not until a further two weeks during the week of February 5 that the Grand Banks area, located another 400 km to the south, might expect to sea ice, and this is about once every six years on average. The far eastern and southern portions of the SEA Study Area, as reflected by statistics at the Flemish Cap and Tail of the Grand Banks locations, might not experience ice until the second or third week of March, and then typically for just one or two weeks, and once every six years or less frequent. Due to its northern position, sea ice might be expected about every six years or so at the Orphan Basin in late May and again in late June, in both cases as thick first year ice (greater than 120 cm in thickness).

The ice season for the Orphan Basin and Grand Bank sub-regions may last for as long as 14 weeks from the third week of January to the third week of April. At the Grand Bank location, there is a greater likelihood of sea ice being present from mid- to late February to mid-March, about 16 to 33 percent of the time, or about every three or four years.

Figure 4.57 Frequency of Presence of Sea Ice (%), Week of Jan 1st 1981-2010



Source: CIS (2011)

Table 4.42 Frequency of Presence of Sea Ice

Week	Orphan Basin	Flemish Cap	Grand Bank	Tail of the Grand Banks
Jan-01				
Jan-08				
Jan-15				
Jan-22	1 to 15 %			
Jan-29	16 to 33 %			
Feb-05	1 to 15 %		1 to 15 %	
Feb-12	1 to 15 %		1 to 15 %	
Feb-19	1 to 15 %		16 to 33 %	
Feb-26	1 to 15 %		16 to 33 %	
Mar-05	1 to 15 %		16 to 33 %	
Mar-12	1 to 15 %		16 to 33 %	1 to 15 %
Mar-19	1 to 15 %	1 to 15 %	1 to 15 %	
Mar-26	16 to 33 %		1 to 15 %	
Apr-02	1 to 15 %		1 to 15 %	
Apr-09	1 to 15 %		1 to 15 %	

Week	Orphan Basin	Flemish Cap	Grand Bank	Tail of the Grand Banks
Apr-16	1 to 15 %		1 to 15 %	
Apr-23	1 to 15 %		1 to 15 %	
Apr-30				
May-07				
May-14				
May-21	1 to 15 %			
May-28				
Jun-04				
Jun-11	1 to 15 %			
Jun-18				
Jun-25	1 to 15 %			
Source: Data from CIS (2011)				

The median ice concentration when ice is present for the Orphan Basin is typically 4/10 to 6/10, although concentrations of 1 to 3/10 are also common and maximum concentrations of 9/10 to 9+/10 typical in late February and early March (Table 4.43). For the Grand Bank sub-region, 4/10 to 6/10 concentration is most frequent, with a median of 7/10 to 8/10 for the first three weeks of March, and concentrations as large as 9/10 to 9+/10 in February. By April any ice present is typically at 3/10 or less. Concentrations for the Flemish Cap (in the several weeks of the year they might be expected) do not generally exceed a 3/10 concentration. Ice concentrations as large as 9/10 to 9+/10 have been experienced in mid-March for the Tail of the Grand Banks.

Table 4.43 Median Ice Concentration When Ice is Present

Week	Orphan Basin	Flemish Cap	Grand Bank	Tail of the Grand Banks
Jan-01				
Jan-08				
Jan-15				
Jan-22	7 to 8/10			
Jan-29	4 to 6/10			
Feb-05	1 to 3/10		7 to 8/10	
Feb-12	7 to 8/10		9 to 9+/10	
Feb-19	4 to 6/10	1 to 3/10	4 to 6/10	
Feb-26	9 to 9+/10		9 to 9+/10	
Mar-05	9 to 9+/10		7 to 8/10	
Mar-12	9 to 9+/10		7 to 8/10	
Mar-19	4 to 6/10		7 to 8/10	9 to 9+/10
Mar-26	4 to 6/10		4 to 6/10	
Apr-02	4 to 6/10		4 to 6/10	
Apr-09	7 to 8/10		1 to 3/10	
Apr-16	1 to 3/10		1 to 3/10	
Apr-23	4 to 6/10		1 to 3/10	
Apr-30				
May-07				
May-14				
May-21	4 to 6/10			
May-28				
Jun-04				
Jun-11	7 to 8/10			
Jun-18				
Jun-25	7 to 8/10			
Source: Data from CIS (2011)				

Table 4.44 presents the predominant ice type (and hence ice thickness) when ice is present for the four identified SEA Study Area sub-regions. New ice, recently formed ice including frazil and grease ice, slush and shuga, and that of thicknesses of 10 cm or less is experienced early in the season at Orphan Basin. Young ice, consisting of grey ice and grey-white ice, with thickness 10-30 cm, is experienced for the first few weeks of February at the Grand Bank location. First-year (FY) ice (namely, that of not more than one winter's growth), is categorized as thin (30-70 cm), medium (70-120 cm), and thick (> 120 cm). Thin FY ice is the predominant ice type for the Orphan Basin for mid-February through late March with medium and thick FY ice predominant in April. Ice thicknesses are generally less further to the south in February and March. For the Grand Banks area, young ice is more frequent than FY ice in February. By April, however, medium and thick FY become the predominant ice types. The ice that is encountered later in the year at Orphan Basin is thick FY. For the Flemish Cap and Tail of the Grand Banks the ice is predominantly 70 cm thickness or less.

Table 4.44 Median of Predominant Ice Type when Ice is Present

Week	Orphan Basin	Flemish Cap	Grand Bank	Tail of the Grand Banks
Jan-01				
Jan-08				
Jan-15				
Jan-22	new ice (< 10 cm)			
Jan-29	thin FY ice (30-70 cm)			
Feb-05	grey ice (10-15 cm)		grey-white ice (15-30 cm)	
Feb-12	thin FY ice		grey-white ice	
Feb-19	thin FY ice		grey-white ice	
Feb-26	new ice		thin FY ice	
Mar-05	thin FY ice		thin FY ice	
Mar-12	thin FY ice		thin FY ice **	
Mar-19	thin FY ice	thin FY ice	thin FY ice	grey-white ice
Mar-26	thin FY ice		medium FY ice (70-120 cm)	
Apr-02	thick FY ice (> 120 cm) **		thin FY ice	
Apr-09	thick FY ice		thick FY ice	
Apr-16	medium FY ice		medium FY ice	
Apr-23	medium FY ice		thick FY ice	
Apr-30				
May-07				
May-14				
May-21	thick FY ice			
May-28				
Jun-04				
Jun-11	thick FY ice			
Jun-18				
Jun-25	thick FY ice			

Note: ** a 1 to 15 % frequency of presence of old ice
Source: Data from CIS (2011)

4.1.5.2 Icebergs

Newfoundland and the East Coast in particular can be a high traffic area for many icebergs in their journeys south from the fjords of Greenland. Icebergs are masses of fresh water ice which calve each year from the glaciers along West Greenland. Icebergs are moved by both the wind and ocean currents, and typically spend one to three years travelling a distance up to 2897 km (1800 miles) to the waters of Newfoundland. The West Greenland and Labrador Currents are major ocean currents which move the icebergs about the Davis Strait, along the coast of Labrador, to the northern bays of Newfoundland, and offshore to the SEA Study Area.

The presence of easterly and northeasterly winds can strongly influence the numbers of icebergs that make their way into the coast or remain offshore. Icebergs will exhibit little or no melting in sea temperatures of about 5°C or less while waves and warm air temperatures will tend to erode them in their travels. A medium iceberg will deteriorate in sea water of 4.4°C in about 10 days. Generally, larger icebergs can survive until late into the summer as they reach Newfoundland.

A comprehensive dataset of iceberg sightings in the SEA Study Area is the NRC-PERD Iceberg Sighting Database, recently updated in October 2013 (NRC 2013). The oldest entry dates back to 1619; with 93 percent of observations since 1921. A summary of iceberg conditions is reported from the iceberg sighting database for the past 30 years using eight sub-regions defined to span the SEA Study Area as shown in Table 4.45

Table 4.45 Regions Selected for Iceberg Characterization of the SEA Study Area

Region	Southern Latitude	Northern Latitude	Western Longitude	Eastern Longitude
Orphan Basin N	50.00°N	52.00°N	52.00°W	47.00°W
Orphan Basin S	48.00°N	50.00°N	52.00°W	47.00°W
Flemish Cap N	48.00°N	50.00°N	47.00°W	42.00°W
Flemish Cap S	46.00°N	48.00°N	47.00°W	42.00°W
Grand Banks N	46.50°N	48.00°N	52.00°W	47.00°W
Grand Banks S	45.00°N	46.50°N	52.00°W	47.00°W
Tail of the Banks N	43.25°N	45.00°N	51.00°W	46.00°W
Tail of the Banks S	41.50°N	43.25°N	51.00°W	46.00°W

The iceberg sighting database observations are from various sources (e.g., IIP, industry, aircraft, ship) and methods (e.g., radar, visual, measured) including some which are missing or unknown in the database. For this analysis, only those records designated as the first berg sighting (i.e., excluding resightings of the same iceberg) and have one of the iceberg sizes listed in Table 4.46 or are given an unknown size, were selected. These criteria yield 25,162 icebergs from 1983 to 2012.

Table 4.46 Iceberg Size Classes

Iceberg Type	Mass (t)	Height (m)	Length (m)
Growler	500	< 1 m	< 5 m
Bergy Bit	1,400	1 - 5 m	5 - 15 m
Small Iceberg	100,000	5 - 15 m	15 - 50 m
Medium Iceberg	750,000	15 - 50 m	50 – 100 m
Large Iceberg	5,000,000	50 - 100 m	100 - 200 m
Very Large Iceberg	>5,000,000	> 100 m	> 200 m

The U.S Coast Guard International Ice Patrol (IIP) has monitored the number of icebergs crossing 48°N since 1914 as part of its core purpose to promote safe navigation of the Northwest Atlantic Ocean when the danger of iceberg collision exists. In 2011 there were 18 icebergs within SEA Study Area, (17 in Orphan Basin North, 1 in Orphan Basin South); in 2012 there were 696 (Figure 4.58).

The number of icebergs observed in the SEA Study Area for the period 1983 to 2012 is also shown in Figure 4.58 and Table 4.47. The greatest numbers are seen in both the northern and southern halves of the Orphan Basin and in the Northern Grand Banks, with the three sub-regions accounting for 72 percent of the total number of icebergs observed. Bergy bits and growlers account for 14 percent of the icebergs; 55 percent are small or medium icebergs, and about 11 percent are large or very large. Very large icebergs have not been observed as frequently in the Flemish Pass North and Tail of the Banks compared with the other sub-regions.

Figure 4.58 Iceberg Sightings: 2011 and 2012

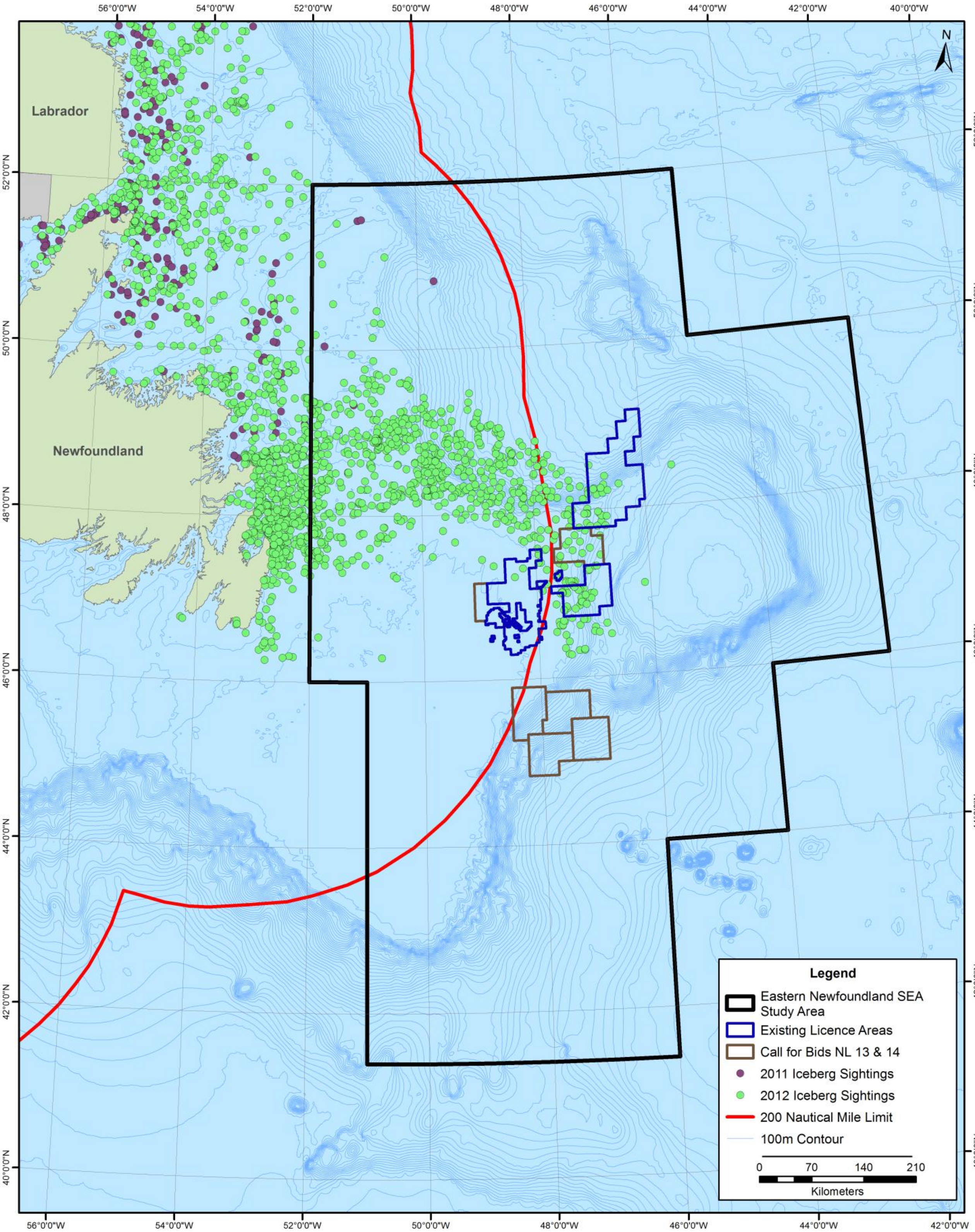


Figure 4.59 Iceberg Sightings in the SEA Study Area, by Size Category

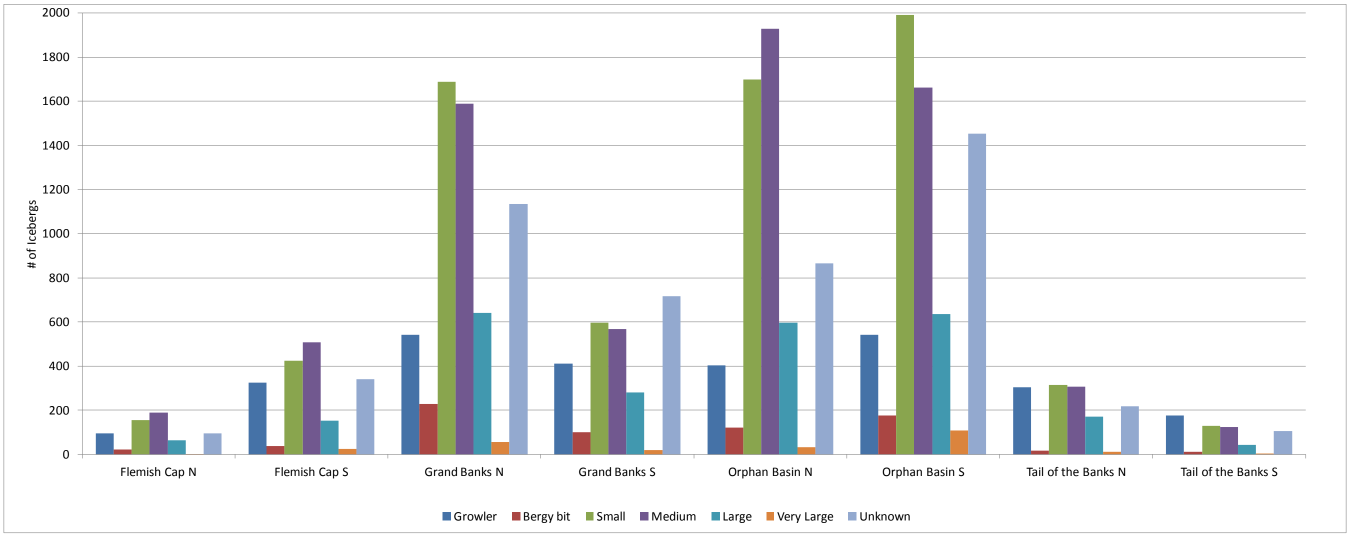


Table 4.47 Iceberg Sightings in the SEA Study Area by Size Category

Area	Growler	Bergy Bit	Small	Medium	Large	Very Large	Unknown	Total
Flemish Cap N	95	21	156	190	65	2	96	**625**
Flemish Cap S	325	37	424	509	152	25	341	**1,813**
Grand Banks N	542	229	1,689	1,590	641	55	1,135	**5,881**
Grand Banks S	412	100	597	569	281	20	717	**2,696**
Orphan Basin N	403	121	1,699	1,929	596	33	866	**5,647**
Orphan Basin S	542	176	1,990	1,663	635	109	1,453	**6,568**
Tail of the Banks N	305	17	315	306	171	12	217	**1,343**
Tail of the Banks S	175	12	128	123	43	3	105	**589**
Total	**2,799**	**713**	**6,998**	**6,879**	**2,584**	**259**	**4,930**	**25,162**

The seasonal distribution of observed icebergs in the SEA Study Area for the period 1983 to 2012 is shown in Figure 4.60 and Table 4.48. The majority of the icebergs (95 percent) have been observed from February through July in all eight sub-regions. Icebergs have been rarely reported outside these times of year for the eastern and southern portions of the SEA Study Area. Icebergs have been most frequently observed in March for the Flemish Cap South, April for the Grand Banks South and Tail of the Banks, May for the Orphan Basin South, Flemish Cap North, and Grand Banks North, and July for the Orphan Basin North.

Figure 4.60 Iceberg Sightings in the SEA Study Area, by Month

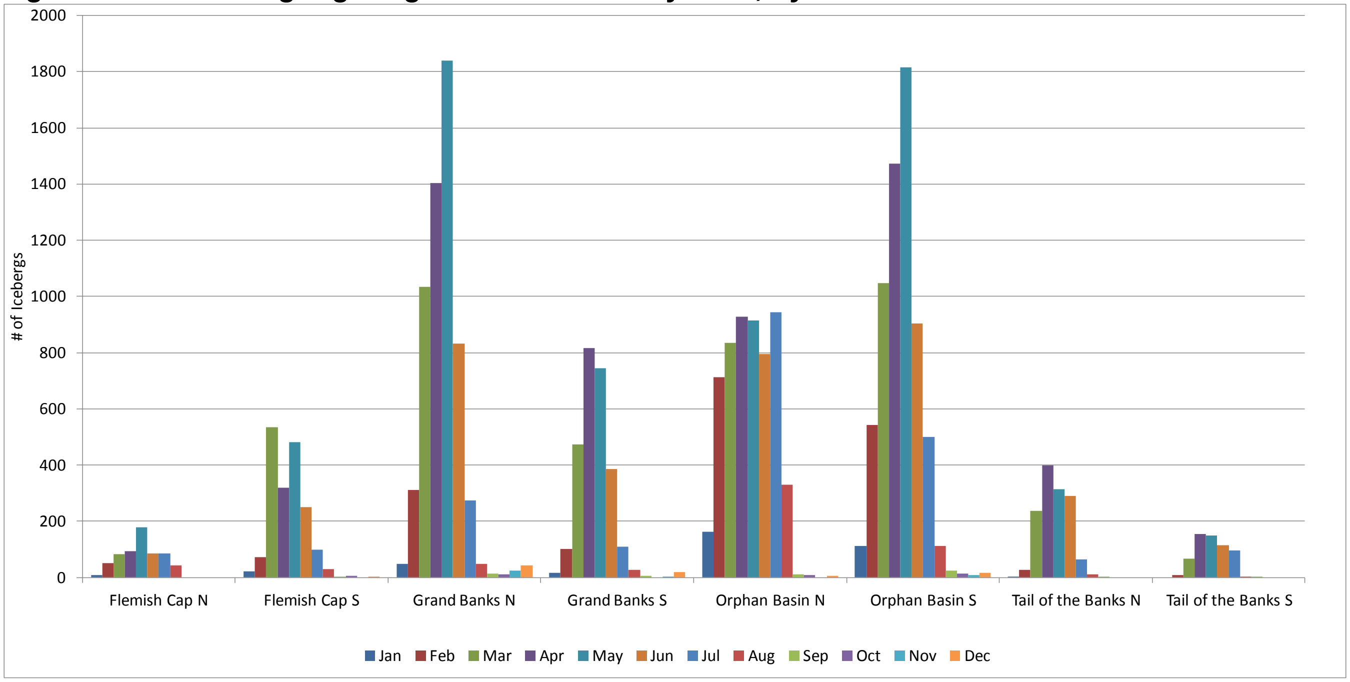


Table 4.48 Iceberg Sightings in the SEA Study Area by Month

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Flemish Cap N	8	51	82	93	179	84	86	42					**625**
Flemish Cap S	21	72	534	319	480	251	98	29	3	5		1	**1,813**
Grand Banks N	48	310	1,034	1,405	1,840	832	274	47	13	12	23	43	**5,881**
Grand Banks S	16	100	474	816	744	385	108	27	5		1	20	**2,696**
Orphan Basin N	162	713	834	927	914	796	945	329	12	9		6	**5,647**
Orphan Basin S	111	543	1,047	1,472	1,816	904	500	113	23	14	9	16	**6,568**
Tail of the Banks N	1	26	236	398	314	289	65	11	3				**1,343**
Tail of the Banks S		7	66	155	148	115	96	1	1				**589**
Total	**367**	**1,822**	**4,307**	**5,585**	**6,435**	**3,656**	**2,172**	**599**	**60**	**40**	**33**	**86**	**25,162**

The annual distribution of observed icebergs in the SEA Study Area from 1983 to 2012 is shown in Figure 4.61 and Table 4.49 The total number of icebergs within the eight sub-regions has ranged from none in 2005 and 2006 to 2,042 in 1993 and 2,081 in 2003; the annual average being 839. Note that there are no entries for 2005 and 2006 in the Figure and Table since no icebergs were observed those years. There are no entries for 2007 or 2008 either although iceberg observations are in the database; however, they have a blank resighting flag which makes it difficult to discriminate between first sightings and resightings. With these limitations noted, 2007 reports 1,091 icebergs over all sub-regions except Flemish Cap North and Tail of the Banks South, and 2008 reports 4,801 icebergs over all sub-regions.

As shown in Table 4.49, icebergs have been observed in all sub-regions in most years from 1983 to 2012 excluding 2005, 2006, and, except for the Orphan Basin, 2010 and 2011.

Figure 4.61 Iceberg Sightings in the SEA Study Area, by Year

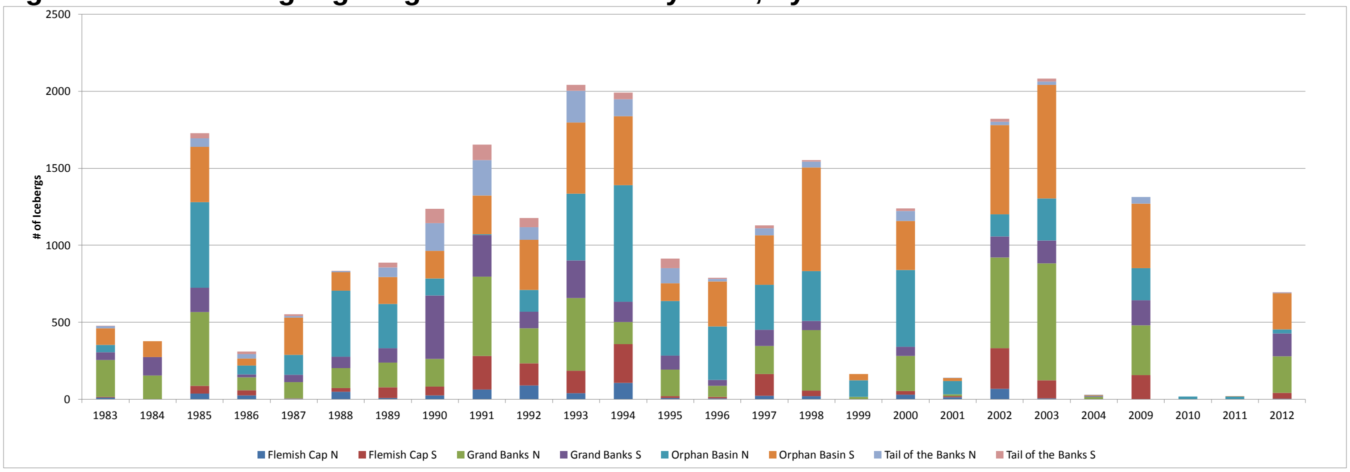


Table 4.49 Iceberg Sightings in the SEA Study Area, by Year

Year	Flemish Cap N	Flemish Cap S	Grand Banks N	Grand Banks S	Orphan Basin N	Orphan Basin S	Tail of the Banks N	Tail of the Banks S	Total
1983	10	5	239	52	46	109	13	2	**476**
1984		1	152	122		101			**376**
1985	36	50	480	158	555	359	55	35	**1,728**
1986	24	34	83	20	58	46	27	18	**310**
1987	2	4	105	49	128	242	9	13	**552**
1988	48	24	131	74	429	118	8	3	**835**
1989	9	68	160	94	287	175	63	30	**886**
1990	24	58	181	411	111	179	180	92	**1,236**
1991	63	218	514	271	6	250	231	100	**1,653**
1992	90	144	227	107	141	326	83	58	**1,176**
1993	40	146	470	246	433	461	207	39	**2,042**
1994	105	252	144	132	757	448	111	43	**1,992**
1995	8	13	171	91	356	115	96	64	**914**
1996	5	11	72	38	347	291	17	8	**789**
1997	23	140	182	107	292	321	44	19	**1,128**
1998	19	36	394	59	325	673	37	10	**1,553**
1999	1		14		108	40			**163**
2000	29	25	226	61	498	318	66	15	**1,238**
2001	13	8	12		84	21	1		**139**
2002	68	264	589	137	142	580	23	19	**1,822**
2003	6	116	760	149	272	739	20	19	**2,081**
2004			16	4	3	4	2		**29**
2009		157	322	164	209	418	43		**1,313**
2010					17				**17**
2011					17	1			**18**
2012	2	39	237	150	26	233	7	2	**696**
Total	**625**	**1,813**	**5,881**	**2,696**	**5,647**	**6,568**	**1,343**	**589**	**25,162**

About five percent of the NRC-PERD iceberg sighting database entries include iceberg dimensions. There are no entries for the Tail of the Banks. Table 4.50 presents the mean and maximum iceberg length, width, height and draft for each of the sub-regions. The statistics are reported for those icebergs with measured or estimated dimensions; the total number of values is also reported in the table. Over the entire SEA Study Area the mean iceberg length is 85 m and the maximum length is 500 m. Iceberg mean draft ranges from 41 m for Grand Banks South to 73 m for Orphan Basin South, and is 48 m for the entire SEA Study Area. Maximum iceberg draft ranges from 70 m for Flemish Cap North (though this is based on just three icebergs) to 185 m for Grand Banks North.

Table 4.50 Iceberg Length, Width, Height and Draft in the SEA Study Area

Iceberg Dimension		Orphan Basin N	Orphan Basin S	Flemish Cap N	Flemish Cap S	Grand Banks N	Grand Banks S	Total
Length	# of Values	115	198	2	11	728	242	1296
	Mean (m)	67	135	88	130	82	57	85
	Maximum (m)	231	500	100	350	480	422	500
Width	# of Values	114	198	2	11	723	240	1288
	Mean (m)	45	92	38	85	56	37	57
	Maximum (m)	150	290	40	250	733	314	733
Height	# of Values	115	197	2	11	729	242	1296
	Mean (m)	21	29	13	12	17	12	18
	Maximum (m)	80	95	20	25	83	100	100
Draft	# of Values	3	47	3	7	586	378	1024
	Mean (m)	68	73	65	66	50	41	48
	Maximum (m)	80	151	70	151	185	144	185

4.1.5.3 Ice Islands

In addition to icebergs ranging in size from growlers to very large, ice islands have also been experienced historically in the Arctic and off the coasts of Labrador and Newfoundland. An ice island is defined as “a large piece of floating ice protruding about 5 m above sea level, which has broken away from an Arctic ice shelf. They have a thickness of 30-50 m and an area of from a few thousand square metres to 500 sq. km or more. They are usually characterized by a regularly undulating surface giving a ribbed appearance from the air.” (Environment Canada 2005).

Ice islands pose an additional, unique, potential risk for offshore seismic survey or drilling activities due to their size, which may render them “unmanageable” through conventional towing or deflection methods. Although their mass may be significant, their drafts are usually not large enough (80 m or less) to cause grounding on the continental shelf, and so they are often free to drift as smaller icebergs into marine areas such as that off Eastern Newfoundland. Further risks may result as they deteriorate and calve or break off large numbers of smaller icebergs, bergy bits and growlers which introduces further iceberg hazards for offshore exploration or production and general marine navigation.

As with icebergs, ice islands do not occur every year. The NRC-PERD iceberg sighting database reports 358 ice islands (346 ice island size and 12 island shape entries) from 1889 to 2012. The most recent record includes six ice islands from the 1950s, 11 in 2011 (10 in July, one in August) and one in March 2012. In all instances, these 18 ice islands since the 1950s were not observed to drift into the SEA Study Area.

Of the historical 358 sightings (including 17 resightings) 150 were located inside the SEA Study Area in each of the eight sub-regions except Orphan Basin N. The most recent of these 150 ice island observations include one in the Grand Banks N sub-region and two observations in the Orphan Basin S sub-region in May 1946. Summary statistics of the ice island length, width and height estimates (there are no measurements, nor any draft estimates) from the database are reported in Table 4.51.

Table 4.51 Ice Island Length, Width, Height Estimates – Sightings within the SEA Study Area

	Length	Width	Height
# of Values	105	6	95
Minimum (m)	275	150	9
Mean (m)	1,003	506	79
Maximum (m)	7,408	800	213
Source: NRC (2013)			

Although not included within the NRC-PERD database, Peterson (2005) notes that in 2002, "Grand Banks operators reported an unusually large number of ice islands and large tabular icebergs which were up to 2 km long and over 20 million tonnes, with a draft of 65 to 80 m and a freeboard of 9 to 10 m; large numbers were also observed the following ice season". These are believed to be from the Petermann glacier. Valuable additional descriptions of the observations, Petermann ice glacier and satellite imagery of the glacier is provided in Peterson (2005).

4.1.5.4 Superstructure Icing Potential

Several factors can contribute to vessel icing potential at any given time. These include environmental parameters such as air and sea temperature, wind speed, wave height and precipitation. The size, shape and configuration of the vessel itself are also critical factors for icing potential. With sub-zero temperatures and strong winds very common, especially in the northern parts of the SEA Study Area, icing of the ships superstructure can be serious. A few tens of centimetres of ice over a complex deck and superstructure represents many tonnes of loading. Even moderate sized craft, such as trawlers, are occasionally lost, usually because they capsize due to the instability caused by the raised centre of gravity. Ship and rig operators must be aware of the risks of severe icing and the craft designed to minimize risk.

A standardized way to determine the potential ice build-up rate has been developed by Overland (1990), who based his algorithm on empirical observations and the heat balance equation of an icing surface[2]. This algorithm has been used to derive an estimate of icing potential in the SEA Study Area by using concurrent air and sea temperature and wind speed data from ICOADS. The results have been sorted into four different categories based on the severity (light, moderate, heavy and extreme), and are presented in the form of monthly and annual frequencies of occurrence in the Figures and Tables that follow. An additional resource to note includes the NRC Canadian Hydraulics Centre central database of icing events for Canadian waters particularly for the Grand Banks[3].

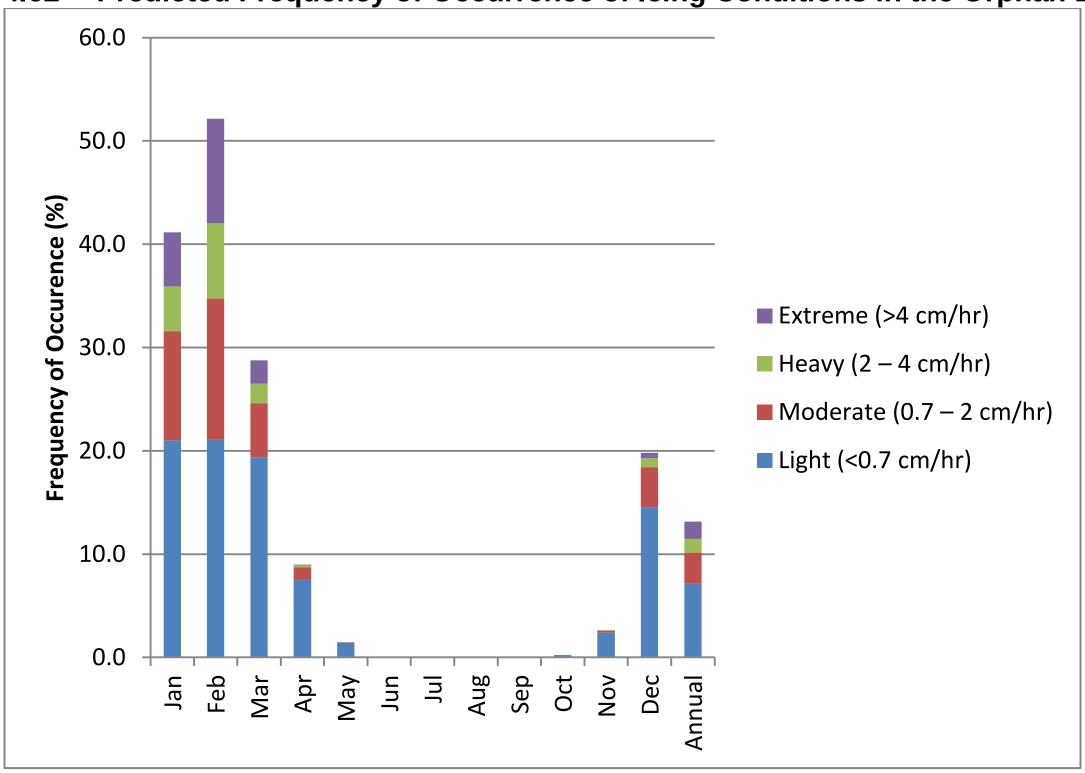
[2] An additional algorithm one could consider is that of Stallabrass for freezing spray potential, which includes wave heights and salinity as input parameters, and therefore may be a useful estimate near the ice edge: Stallabrass, J.R., 1980. "Trawler Icing. A compilation of Work done at N.R.C." Mechanical Engineering Report MD-56. N.R.C. NO.19372. December 1980. 103 pp.

[3] *See ftp://ftp2.chc.nrc.ca/CRTreports/PERD/NRC_Marine%20Icing_05.pdf* , and *ftp://ftp2.chc.nrc.ca/CRTreports/PERD/NRC_Marine_Icing_Database.mdb*

Orphan Basin

Vessel icing in this sub-region is expected to occur in the period between November and May, with the highest frequency in February. During February the highest frequency of extreme icing reaches a peak of about 10.1 percent of the time, heavy icing 7.3 percent of the time, moderate icing 13.7 percent of the time, and light icing about 21.0 percent of the time. Icing is expected to occur with a high frequency in January, March, and with relatively smaller frequencies during April, November and December.

Figure 4.62 Predicted Frequency of Occurrence of Icing Conditions in the Orphan Basin



Source: Calculations based on ICOADS 1950-2012

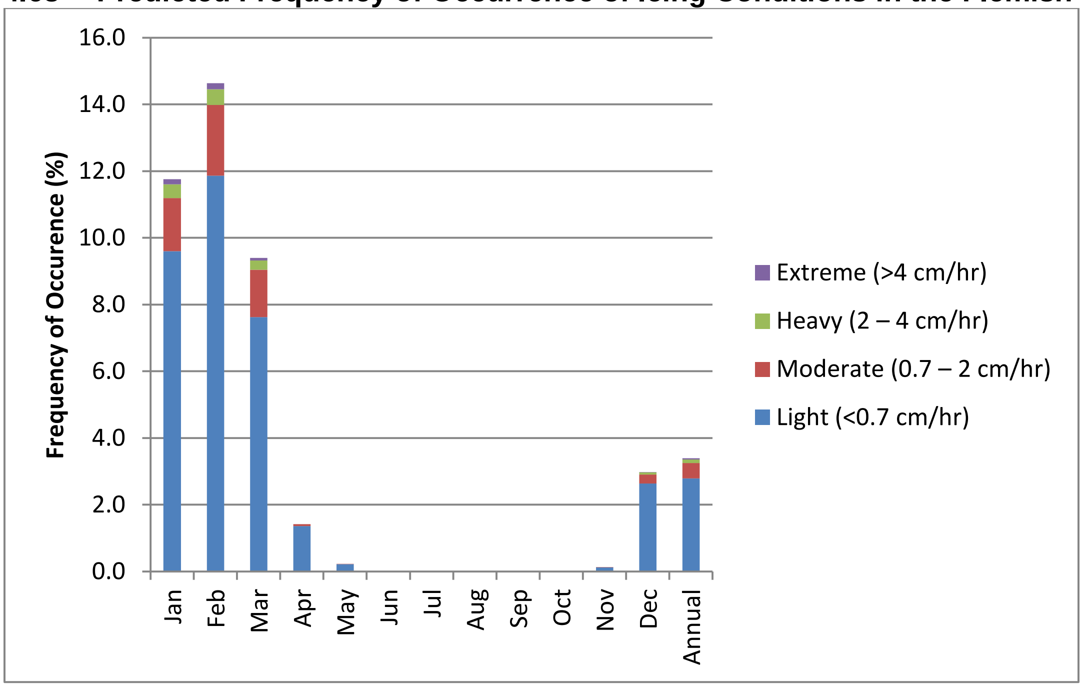
Table 4.52 Monthly and Annual Frequencies of Occurrence of Icing in the Orphan Basin

Month	Light (<0.7 cm/hr)	Moderate (0.7 – 2 cm/hr)	Heavy (2 – 4 cm/hr)	Extreme (>4 cm/hr)
Jan	21.0	10.6	4.4	5.2
Feb	21.1	13.7	7.3	10.1
Mar	19.4	5.2	1.9	2.3
Apr	7.5	1.2	0.3	0.0
May	1.4	0.1	0.0	0.0
Jun	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0
Oct	0.2	0.0	0.0	0.0
Nov	2.4	0.1	0.1	0.0
Dec	14.6	3.9	0.9	0.5
Annual	7.2	3.0	1.3	1.7
Source: Based on ICOADS (1950-2012)				

Flemish Cap

Vessel icing in this sub-region is expected to occur in the period between December and March, with the highest frequency in February. During February the highest frequency of extreme icing reaches a peak of about 0.2 percent of the time, heavy icing 0.5 percent of the time, moderate icing 2.1 percent of the time, and light icing about 11.9 percent of the time. Icing is expected to occur with a high frequency in January, March, and December.

Figure 4.63 Predicted Frequency of Occurrence of Icing Conditions in the Flemish Cap



Source: Calculations based on ICOADS 1950-2012

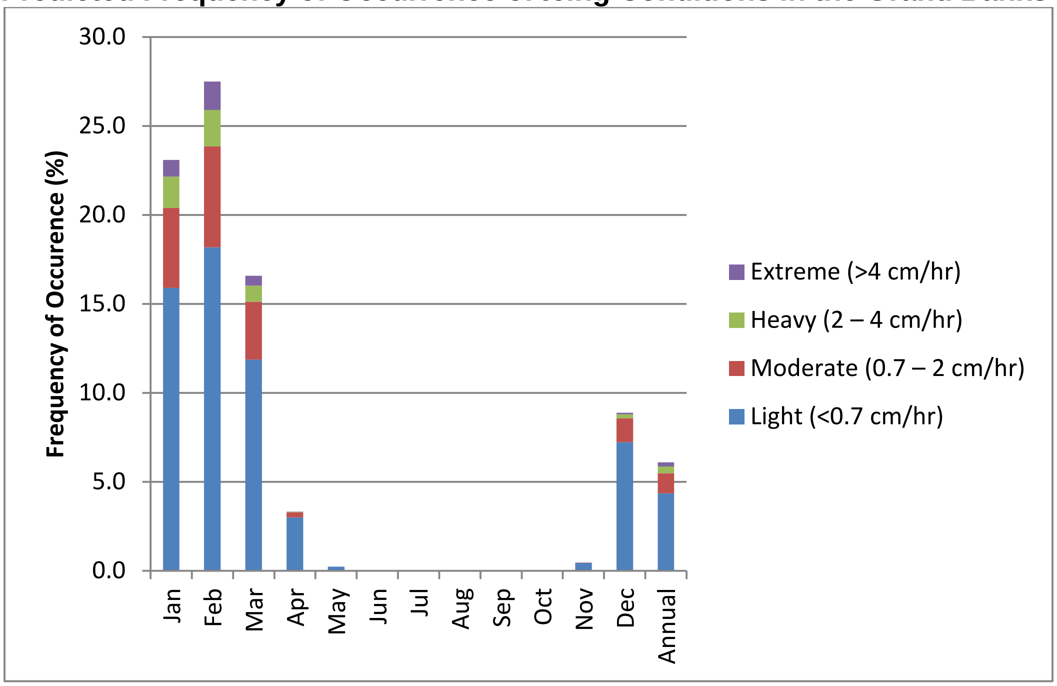
Table 4.53 Monthly and Annual Frequencies of Occurrence of Icing in the Flemish Cap

Month	Light (<0.7 cm/hr)	Moderate (0.7 – 2 cm/hr)	Heavy (2 – 4 cm/hr)	Extreme (>4 cm/hr)
Jan	9.6	1.6	0.4	0.2
Feb	11.9	2.1	0.5	0.2
Mar	7.6	1.4	0.3	0.1
Apr	1.4	0.1	0.0	0.0
May	0.2	0.0	0.0	0.0
Jun	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0
Oct	0.0	0.0	0.0	0.0
Nov	0.1	0.0	0.0	0.0
Dec	2.6	0.3	0.1	0.0
Annual	2.8	0.5	0.1	0.0
Source: Based on ICOADS (1950-2012)				

Grand Banks

Vessel icing in this sub-region is expected to occur in the period between November and April, with the highest frequency in February. During February the highest frequency of extreme icing reaches a peak of about 1.6 percent of the time, heavy icing 2.1 percent of the time, moderate icing 5.7 percent of the time, and light icing about 18.2 percent of the time. Icing is expected to occur with a high frequency in January, March, and December and with relatively smaller frequencies during November and April.

Figure 4.64 Predicted Frequency of Occurrence of Icing Conditions in the Grand Banks



Source: Calculations based on ICOADS 1950-2012

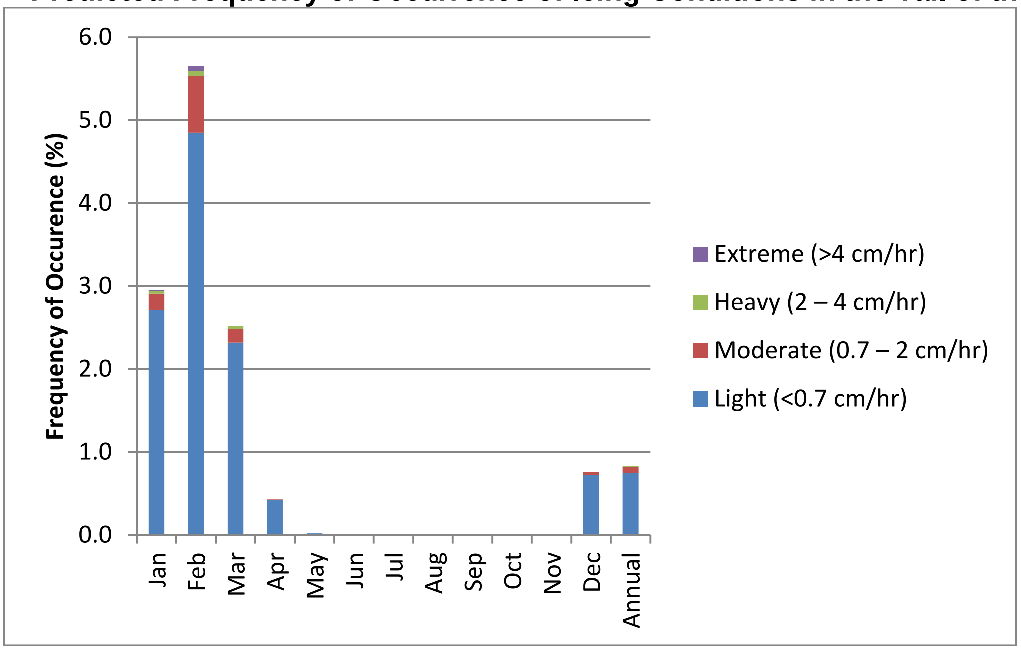
Table 4.54 Monthly and Annual Frequencies of Occurrence of Icing in the Grand Banks

Month	Light (<0.7 cm/hr)	Moderate (0.7 – 2 cm/hr)	Heavy (2 – 4 cm/hr)	Extreme (>4 cm/hr)
Jan	15.9	4.5	1.8	0.9
Feb	18.2	5.7	2.1	1.6
Mar	11.9	3.3	0.9	0.6
Apr	3.0	0.3	0.0	0.0
May	0.2	0.0	0.0	0.0
Jun	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0
Oct	0.0	0.0	0.0	0.0
Nov	0.4	0.0	0.0	0.0
Dec	7.2	1.4	0.2	0.1
Annual	4.3	1.1	0.4	0.2
Source: Based on ICOADS (1950-2012)				

Tail of the Banks

Vessel icing in this sub-region is expected to occur in the period between December and April, with the highest frequency in February. During February the highest frequency of extreme icing reaches a peak of about 0.1 percent of the time, heavy icing 0.1 percent of the time, moderate icing 0.7 percent of the time, and light icing about 4.9 percent of the time. Icing is expected to occur with a high frequency in January and March, and with relatively smaller frequencies during December and April.

Figure 4.65 Predicted Frequency of Occurrence of Icing Conditions in the Tail of the Banks



Source: Calculations based on ICOADS 1950-2012

Table 4.55 Monthly and Annual Frequencies of Occurrence of Icing in the Tail of the Banks

Month	Light (<0.7 cm/hr)	Moderate (0.7 – 2 cm/hr)	Heavy (2 – 4 cm/hr)	Extreme (>4 cm/hr)
Jan	2.7	0.2	0.0	0.0
Feb	4.9	0.7	0.1	0.1
Mar	2.3	0.2	0.0	0.0
Apr	0.4	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0
Jun	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0
Oct	0.0	0.0	0.0	0.0
Nov	0.0	0.0	0.0	0.0
Dec	0.7	0.0	0.0	0.0
Annual	0.8	0.1	0.0	0.0
Source: Based on ICOADS (1950-2012)				

The heaviest and most extreme icing takes place in the Orphan Basin area, followed by the Grand Banks, the Flemish Cap, and the least icing occurring in the Tail of the Banks.

4.1.6 Climate Change

This section presents a brief overview of climate change as additional background and context for the SEA, including general information and recent projections for a selection of physical environment parameters for the SEA Study Area. These include: 1) air temperature; 2) sea temperature; 3) sea level; 4) sea ice and icebergs; and 5) waves. This discussion is based on the key findings from the latest Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) (IPCC 2013) and other relevant literature.

Climate affects a broad range of physical and ecological processes as well as human social and economic activities and interests. As summarized in the IPCC AR5, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC 2013).

The Earth's energy budget is altered by natural and anthropogenic substances and processes. "Radiative forcing - in units of watts per square metre (W•m-2) - quantifies the change in energy fluxes caused by changes in these drivers for 2011 relative to 1750, unless otherwise indicated. Positive RF leads to surface warming, negative RF leads to surface cooling. RF is estimated based on in-situ and remote observations, properties of greenhouse gases and aerosols, and calculations using numerical models representing observed processes" (IPCC 2013).

Over the 21st century, radiative forcing is projected to increase. Projections in the IPCC AR5 are relative to the reference period 1986 to 2005 and use four new Representative Concentration Pathways (RCP) scenarios. These scenarios include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover. They are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 W•m-2 for RCP2.6 (least warming), 4.5 W•m-2 for RCP4.5, 6.0 W•m-2 for RCP6.0, and 8.5 W•m-2 for RCP8.5 (greatest warming). Projections for the next few decades show spatial patterns of climate change similar to those projected for the later 21st century but with smaller magnitude (IPCC 2013).

4.1.6.1 Air Temperature

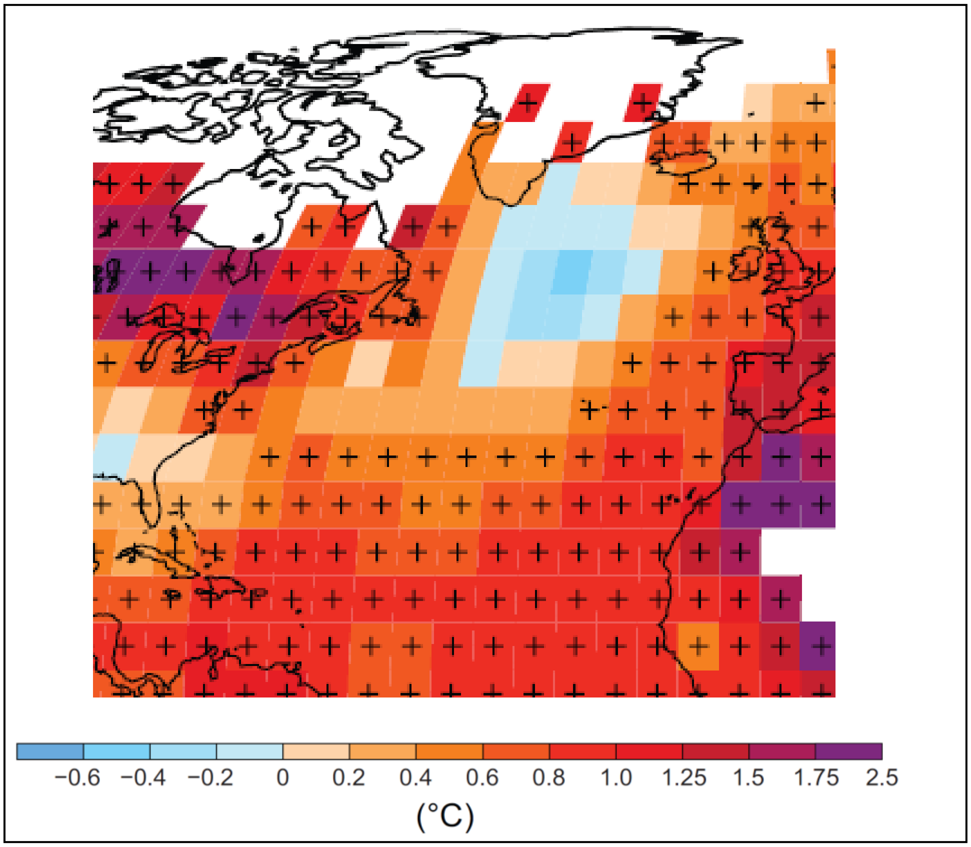
In the Northern Hemisphere, the years 1983 to 2012 were likely the warmest 30-year period of the last 1,400 years (IPCC 2013). The IPCC AR5 indicates that "Global surface temperature change for the end of the 21st century is likely [4] to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6." (IPCC 2013)

The IPCC AR5 further notes that "warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform ... relative to natural internal variability, near-term increases in seasonal mean and annual mean temperatures are expected to be larger in the tropics and subtropics than in mid-latitudes (high confidence)" (IPCC 2013). For the SEA Study Area, which spans latitudes 46.4 to 52°N, this may mean temperature increases will not be as large as elsewhere on a global basis.

[4] The IPCC Summary for Policymakers uses the following terms to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely: 95–100%, more likely than not >50–100%, and extremely unlikely 0–5%) may also be used when appropriate.

Inspection of the global overall change in surface temperature from 1901 to 2012 indicates a change of -0.2 to 0.0°C in the eastern portion of the SEA Study Area to 0.2 to 0.4°C in the western portion. For the majority of the Northwest Atlantic the change is 0.2 to 0.8°C warmer. For the Island of Newfoundland the change is 0.6 to 0.8°C warmer (IPCC 2013) (Figure 4.66). The likely ranges of projected change in global mean surface temperature for mid-century (2046-2065) are 0.4 to 1.6°C (RCP2.6) to 1.4 to 2.6°C (RCP8.5). For late century (2081-2100) likely changes range from are 0.3 to 1.7°C (RCP2.6) to 2.6 to 4.8°C (RCP8.5). These projections are given relative to the 1986–2005 average (IPCC 2013).

Figure 4.66 Predicted Observed Change in Surface Temperature, (1901-2012, North Atlantic)



Source: IPCC (2013)

Projected changes for temperature and precipitation for the Island of Newfoundland were recently prepared for the Government of Newfoundland and Labrador as part of regional climate change predictions (Finnis 2013). Seven regional simulations from four global climate models were employed yielding a 50 km x 50 km projection area. Although these projections do not cover the SEA Study Area or offshore environments in general, they do provide a useful regional perspective. Daily mean temperatures are projected to increase throughout the province, with the greatest increases in winter. Projections for St. John's for 2038 to 2070 in winter (December - February) include an increase of 2.3°C (with an uncertainty of 1.1°C) from the 20th century mean of -3.5°C. Summer (June-July) temperatures are projected to rise 1.8 °C (uncertainty of 0.4°C) from the 20th century mean of 14.1°C. Daily minimum temperatures are expected to increase by 1.7°C in fall to 2.8°C in winter for the period 2038 to 2070. Daily maximum temperatures are expected to increase by 1.7°C in spring to 2.0°C in winter (Finnis 2013).

4.1.6.2 Sea Surface Temperature

The IPCC AR5 reports that there is high confidence that ocean warming dominates the increase in energy stored in the climate system and accounts for more than 90 percent of the energy accumulated between 1971 and 2010. The strongest warming is found near the sea surface, above 700 m. On a global scale, it is virtually certain the upper 75 m warmed by 0.11°C per decade over the period 1971 to 2010. Confidence in the assessment of change is high based on increased data coverage, and a high level of agreement among independent observations of subsurface temperature, sea surface temperature, and sea level rise, which is known to include a substantial component due to thermal expansion. Confidence has been enhanced with the identification and reduction of instrumental biases in upper-ocean temperature records since the IPCC Fourth Assessment Report in 2007 (AR4) (IPCC 2013). It is likely that the ocean warmed at depths between 700 and 2,000 m from 1957 to 2009. Sufficient observations are available for the period 1992 to 2005 for a global assessment of temperature change below 2,000 m. There were likely no significant observed temperature trends between 2,000 and 3,000 m for this period. It is likely that the ocean warmed from 3,000 m to the bottom for this period, with the largest warming observed in the Southern Ocean.

There is no observational evidence of a trend in the Atlantic Meridional Overturning Circulation[5] (AMOC), based on the decade-long record of the complete AMOC and longer records of individual AMOC components. It is very likely that the AMOC will weaken over the 21st century. It is likely that there will be some decline in the AMOC by about 2050, but there may be some decades when the AMOC increases due to large natural internal variability (IPCC 2013). Future changes in the AMOC could have important climatic effects related to the sink of CO_2 in the North Atlantic, the Atlantic storm track, rainfall and marine ecosystems (as noted in Srokosz et al 2012).

It is very likely that regions of high salinity where evaporation dominates have become more saline, while regions of low salinity where precipitation dominates have become fresher since the 1950s. These regional trends in ocean salinity provide indirect evidence that evaporation and precipitation over the oceans have changed (medium confidence) (IPCC 2013).The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect circulation. Strongest warming is projected for the surface in tropical and Northern Hemisphere sub-tropical regions. At greater depths the warming will be most pronounced in the Southern Ocean (high confidence). Best estimates of ocean warming in the top 100 m are about 0.6°C (RCp2.6) to 2.0°C (RCP8.5) and about 0.3°C (RCP2.6) to 0.6°C (RCP8.5) at a depth of about 1,000 m by the end of the 21st century (IPCC 2013).

On a regional basis, the SEA Study Area is greatly influenced by the cold waters of the Labrador Current which flow through the area. Together with increased glacial melt from Greenland, these influences may moderate sea temperatures somewhat.

An overview of the observed ecological implications of warming water temperatures in the SEA Study Area is provided in the description of the biological environment that follows (Section 4.2). Warmer temperatures may also, for example, allow improved conditions for the survival and reproduction of

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[5] The AMOC consists of a complex warm northward flow near-surface, with a return southward flow of colder water at depth. Atmospheric heat loss at high latitudes in the North Atlantic cools the northward flows making them denser causing them to sink to considerable depths. There is a strong transfer of oceanic heat to the atmosphere at mid-latitudes which contributes to the temperate climate of northwest Europe.

aquatic invasive species (AIS) which can change the structure and function of aquatic ecosystems and/or negatively affect the fishing industry (Finnis 2013).

4.1.6.3 Sea Level

The IPCC AR5 reports with high confidence that the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (IPCC 2013). From 1901 to 2010 global mean sea level (GMSL) rose by 0.19 m. Confidence in sea level projections is increased (since the 2007 AR4) due to better understanding of the physical components of sea level, improved agreements between models and observations, and the inclusion of ice sheet dynamics.

The mean rates of GMSL rise were: 1.7 (1.5 to 1.9) mm/yr between 1901 and 2010; 2.0 (1.7 to 2.3) mm/yr between 1971 and 2010; and 3.2 (2.8 to 3.6) mm/yr between 1993 and 2010. Tide gauge measurements satellite radar altimetry (since 1993) are consistent with this latter rate. Since the early 1970s about 75 percent of the GMSL rise is explained by glacier mass loss and thermal expansion due to ocean warming. Warming of the upper 700 m of the ocean has very likely contributed an average of 0.6 mm/yr of sea level rise (IPCC 2013).

Kolker and Hameed (2007) examined meteorological drivers of the long-term trends in global sea level rise. They found that atmospheric indices like the North Atlantic Oscillation (NAO) explain a major fraction of the variability and trend at five Atlantic Ocean tide gauges since 1900. They state that: "Debate has centered on the relative contribution of fresh water fluxes, thermal expansion and anomalies in Earth's rotation". They also note that variability in local mean sea level from year-to-year is one or two orders of magnitude greater than the long-term trend, with the cause of the variability unknown. When they subtracted out factors such as the NOA from their analysis of the long-term rise, they found that the "residual" sea level rise was between 0.49 +/-0.25 mm/yr, and 0.93 +/-0.39 mm/yr. This residual rise could be due to rising global temperatures. A study by Hu et al (2009) found that moderate to high rates of ice melt from Greenland could cause sea levels off the northeast coast of North America to rise by 30 to 51 cm more than other coastal areas. They also found that oceans will not rise uniformly as the world warms, since ocean dynamics would push water in different directions.

The likely ranges for projected GMSL rise for mid-century (2046-2065) are 0.17 to 0.32 m (RCP2.6) to 0.22 to 0.38 m (RCP8.5). For late century (2081-2100) likely changes range from are 0.26 to 0.55 m (RCP2.6) to 0.45 to 0.82 m (RCP8.5) (IPCC 2013). In these projections, ocean warming – thermal expansion – accounts for 30 to 55 percent of the increase, and loss of mass from glaciers and ice sheets accounts for 15 to 35% (IPCC 2013). The IPCC AR5 indicates it is virtually certain that GMSL rise will continue beyond 2100, with sea level rise due to thermal expansion to continue for many centuries.

Batterson and Liverman (2010) prepared projections of sea level rise by 2049 and 2099 relative to 1990 levels for four geographical zones in Newfoundland and Labrador. The projections were based on the IPCC AR4 predicted global sea level rises (approximately 30 mm by 2049; 59 mm by 2099), potential accelerated ice melt (approximately 20 mm by 2099), and regional trends of crustal rebound (uplift or subsidence) ranging from -1 to 2 mm/yr. Sea level increases of 70 cm to over 100 cm were projected across the province. These longer term changes are cumulative to the short-term changes.

Offshore Newfoundland, and within the SEA Study Area, historically, there were about 100 water level data sources found near White Rose, Hibernia and Terra Nova; the duration of data collection from each site generally ranging from one to six months. There is a total of about nine years worth of data collected between 1980 and 2000; however, there are presently no permanent gauges.

4.1.6.4 Sea Ice and Icebergs

The Arctic has undergone substantial warming since the mid-20th century. Greenland ice sheets have been losing mass and glaciers have continued to shrink almost worldwide over the past two decades. The average rate of ice loss from the Greenland ice sheet has very likely increased from 34 Gt/yr over the period 1992 to 2001 to 215 Gt/yr over the period 2002 to 2011. Sea surface temperatures were anomalously high in at least the last 1,450 years (IPCC 2013).

Based on reconstructions over the past three decades, the annual mean Arctic sea ice extent decreased over the period 1979 to 2012 with a rate very likely in the range of 3.5 to 4.1 percent per decade, and the summer sea ice minimum has similarly decreased in the range 9.4 to 13.6 percent per decade. Since 1979, the sea ice spatial extent has decreased in every season, and in every successive decade (IPCC 2013).

Year-round reductions in Arctic sea ice extent are projected by 2100. There is medium confidence in the projection that a nearly ice-free Arctic Ocean in September before mid-century is likely for RCP8.5 (IPCC 2013). The reductions range from 43 percent for RCP2.6 to 94 percent for RCP8.5 in September and from 8 percent for RCP2.6 to 34 percent for RCP8.5 in February (medium confidence). (IPCC 2013).

Based on these historical trends and projections for shrinking Arctic sea ice cover, it is possible that sea ice extent and ice thicknesses will be reduced in the future for offshore Newfoundland and Labrador in general, including the SEA Study Area, especially the timing of freeze-up and melting and the variability and severity of ice seasons. This would be in keeping with increased northern warming as projected by Finnis (2013) for the province, with air temperatures increasing 4 to 6°C in Northern Labrador.

Newfoundland and Labrador, including the offshore, presently lacks a set of completed downscaled global climate model predictions for sea ice. Measurement of ice thickness can serve to validate sea ice predictions. While remote sensing technologies such as satellite imagery are used in the preparation of operational daily and weekly ice chart products (such as those from the Canadian Ice Service of Environment Canada), there have been no dedicated in-situ observations of sea ice thickness in Newfoundland and Labrador since the mid-1990s (the nearest active station is located in Iqaluit, Nunavut).

The regional iceberg climate consists of the rate at which icebergs calve from glacial regions to the north (particularly Greenland, and to lesser extent ice caps on Ellesmere, Devon and Baffin Islands), and their size distribution (e.g., mass and draft, and geographic distribution and circulation). These are, in turn, affected by a number of factors, including local oceanic and atmospheric circulation patterns, water temperature, the frequency and duration of open water conditions (influenced by sea ice extent - iceberg drift is impeded through regions of sea ice) and by a variety of factors affecting the principal iceberg source regions.

The IPCC AR5 indicates with medium confidence that by the end of the 21st century, the global glacier volume, excluding glaciers on the periphery of Antarctica, is projected to decrease by 15 to 55 percent for RCP2.65 and by 35 to 85 percent for RCP8.5 (IPCC 2013).

With these projections for glacier melt, and those for warming air and ocean environments noted above in mind, it is again possible that the future iceberg climate for offshore Newfoundland and Labrador and for the SEA Study Area will change from what has been observed this past century. One possible scenario would be a less severe iceberg climate in terms of numbers, sizes, and spatial and temporal distribution.

4.1.6.5 Waves

Waves are also an important marine variable of interest to consider when examining potential climate change effects for the Newfoundland and Labrador offshore. A study by Wang and Swail (2001) looked at trends in extreme significant wave heights based on a 40-year hindcast. They found statistically significant trends only in the winter months, and these were found to be connected with the NAO. If the period of study is extended back 100 years, no significant trends were found. A later study by Wang et al. (2004) extended their results to an examination of wave heights in the North Atlantic under accepted climate change scenarios. They found that very significant increases in wave height were expected in the northeast North Atlantic (closer to Europe), but that negligible or negative increases were found in the vicinity of the Grand Banks.

Perrie et al (2004) used high resolution modelling on a current data set of winter storms, and then produced simulations of storms based on a climate change scenario for the period 2041 to 2060. They found that while there were fewer total storms in the climate change scenario, there were more strong storms with larger waves, and fewer weaker storms with associated lower wave heights (Perrie et al 2004). Another study by Lambert (2004) had very similar findings. While it did not explicitly examine wave heights, it found that while there were fewer cyclones in a warmer world, there were an increased number of intense events. One could infer from this that there would also be associated higher significant wave heights, in that a warmer world would mean a decreased pole-equator temperature gradient, and less total energy available for storms. It is, however, not clear what might be driving any greater intensity of storms. One possibility would be more frequent tropical storms, since presumably there would be a larger pool of warm water available to support such systems. Some of these considerations are discussed in the Tropical Storms sub-section below.

The IPCC AR5 concludes that there is medium confidence that mean significant wave height has increased since the 1950s over much of the North Atlantic north of 45°N, with typical winter season trends of up to 20 cm per decade. This is based on ship observations and reanalysis forced wave model hindcasts (IPCC 2013).

4.1.6.6 Tropical Storms

The main conclusions from the IPCC AR5 evaluation of changes in frequency and intensity of storms are that there is low confidence of any trend or long term change in tropical or extratropic storm frequency or intensity in any ocean basin (IPCC 2013).

For the North Atlantic basin, assessments since the AR4 in 2007 indicate that it is unlikely that annual numbers of tropical storms, hurricanes and major hurricanes have increased over the past 100 years. However, evidence suggests a virtually certain increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in that region, although there are differing views on the cause of the increase and debate on the fidelity of these trends on longer time scales (IPCC 2013).

It is possible the SEA Study Area would be more susceptible to tropical storms in a warmer climate. Typically storms die out when hitting colder ocean water south of Nova Scotia. In a warmer climate, they would potentially be able to maintain intensity farther northward, and would therefore be more intense on average as they track over the Grand Banks. This would suggest higher associated peak wave heights. Since the tropical cyclone season lasts from June until November (with a peak in August and September), one might expect to see an increase in peak wave heights during the summer months and also in late fall.

The IPCC AR5 also reports that there is low confidence in any large-scale trends in storms over the last century due to inconsistencies between studies or a lack of long-term data in some parts of the world, particularly in the Southern Hemisphere. For similar reasons there is also low confidence for trends in small-scale severe weather events such as hail or thunderstorms (IPCC 2013).

In addition to the direct temperature-related influences of changing climate, there are other physical characteristics and processes that can affect marine biota, including other environmental climate-related changes such as through ocean acidification.

An overview of the observed ecological implications of warming water temperatures and these other climate change related phenomena in the SEA Study Area is provided in the description of the biological environment that follows (Section 4.2).

4.2 Biological Environment

The following sections present an overview of relevant aspects of the biological environment of the SEA Study Area, including Fish and Fish Habitat, Marine Birds, Marine Mammals and Sea Turtles. A listing of the common and scientific names for all species referenced in these sections is provided in Appendix B.

4.2.1 Fish and Fish Habitat

Key elements of the SEA Study Area's marine ecosystem range from primary producers such as phytoplankton to consumers such as zooplankton, benthic invertebrates and fish. These ecosystem components form the bulk of the marine food web, have components that form the foundation of commercially important fisheries in the SEA Study Area, and have historic, socio-cultural and economic significance.

For the purposes of providing an overview of the existing environmental setting of the Eastern Newfoundland Offshore Area, the following includes a discussion of relevant fish species, as well as plankton, algae and benthos and relevant components of their habitats, given the clear interrelationships between these components of the marine environment.

4.2.1.1 Approach and Key Data Sources

The following sections include a description and discussion of key marine faunal assemblages and ecologically important and/or sensitive areas, as well as illustrating the rather dynamic nature of the SEA Study Area's marine communities. In addition, general ecological information is provided for many of the taxa that characterize the habitats of the SEA Study Area. While the majority of this information has been obtained from existing and available literature, further analysis of available data has also been conducted to characterize the contemporary distributions of abundant, commercially important and/or protected and otherwise ecologically significant marine fish and invertebrate species.

Two regulatory jurisdictions occur in the SEA Study Area. The Government of Canada manages fish stocks within the 200 mile limit and sedentary species across the entire continental shelf. The federal *Fisheries Act* (2012) provides protection to commercial, recreational, and Aboriginal fisheries by protecting the fish resources and habitats that support these activities. Beyond that 200 mile limit, the North Atlantic Fisheries Organization (NAFO) manages groundfish activities and other resources (such as corals) (NAFO 2013a).

In addition to information provided through the published literature, fish survey (distribution and abundance) data from Fisheries and Oceans Canada (DFO) for the period up to 2009 were available for use, presentation and analysis in this SEA. These data, based on random, stratified sampling methodologies, provide the most up-to-date and useful information available that can be applied in a consistent manner across a large portion of the SEA Study Area and for a variety of species. As a result, these data are used as the foundation for prioritizing focal species and for describing contemporary distributions. The methods used for doing so are further described below. A consequence of using a standardized approach is that some species-specific survey data have not been reanalyzed (e.g. DFO-Industry collaborative snow crab surveys) but are incorporated for context through existing literature.

It is recognized that the sampling approach and area for these DFO survey data exclude portions of the SEA Study Area (e.g. particularly those under NAFO jurisdiction) and that certain taxa (e.g. pelagic, abyssal and infaunal species) are relatively less represented than others. Nonetheless, the available data and approach provide useful and illustrative information for a considerable portion of the SEA Study Area related to many ecologically and commercially important taxa.

Canadian Research Vessel Multi-Species Surveys

The long-term monitoring and management of fish resources in the Newfoundland and Labrador Region is based primarily on information derived through standardized, trawl-based, scientific surveys. DFO has jurisdiction over the Labrador Shelf south to the Grand Banks including NAFO Divisions 2GHJ3KLNMOPs (see Section 4.3.4). DFO's Newfoundland and Labrador Region surveys take place in different but overlapping areas, in the spring (1975-2009) in Divisions 3LNOPs and in the fall (1977-2009) in Divisions 2HJ3KLMNO. While survey design has remained somewhat constant, additional strata have been included in recent decades along with modifications to some of the original strata (Bishop 1994), including the addition of shallower (less than approximately 50 m depth) and deeper (greater than approximately 700 m) areas after 1993. Furthermore, whereas several demersal trawl gears have been deployed over the life of the NL Region surveys, both the spring and fall surveys have used the Campelen 1800 shrimp trawl since the fall of 1995.

Given these changes to the DFO surveys, and the overall recognition that fish distributions and community compositions have changed off Newfoundland in recent decades (Dawe et al 2012), data from the most recent period available (2005-2009) were used to describe general fish distributions in the SEA Study Area. Where available, both spring and fall survey data (3LNO) were used to characterize fish distributions, although mapping of fish distributions in 3K were derived from fall data only. Qualitative examination suggests that for most fish species, distributions are similar for the spring and fall survey in 3LMNO.

The data from the DFO surveys were further screened to identify the key fish species that occurred in high abundance (cumulatively exceeded greater than 90 percent of individuals captured) and had a relatively high degree of overlap with the SEA Study Area. From this screening process, 15 taxa (11 fish and 4 invertebrate species) were identified, and their distributions are described further and mapped in the following sections.

To produce these generalized distribution maps, the SPANS potential mapping surface function was used in a GIS system. The method is well suited for spatially analyzing research survey data because it converts point estimates (in this case, individual survey set catch rates) into continuous surfaces (density subareas) that perform as survey density strata with minimal extrapolation. Because observed fish density is used as the stratifying variable, it potentially reduces the variability of density within strata. Extent and location of density constant subareas is allowed to vary according to distributional changes of the fish. That is, the technique makes use of the geo-referenced survey catch rate data to define spatial differences in fish density. The strata vary over time taking into account stock distributional shifts with a resulting lower within strata variability. Application of this technique has also been further evaluated by overlaying the point data and their values to ensure that the surface properly represents density patterns in the catch rate data, and the method does not extrapolate beyond the data. Creation of a surface representative of the data is superior to a simple expanding symbol plot because it avoids the problem of masking of patterns in the data when the circles overlap.

This is a well established approach and has been used to describe fish distributions in numerous previous studies (e.g., Kulka 1998a, 1998b; Kulka et al 2003a, 2003b; Kulka et al 2007; Han and Kulka 2007; Kulka 2009).

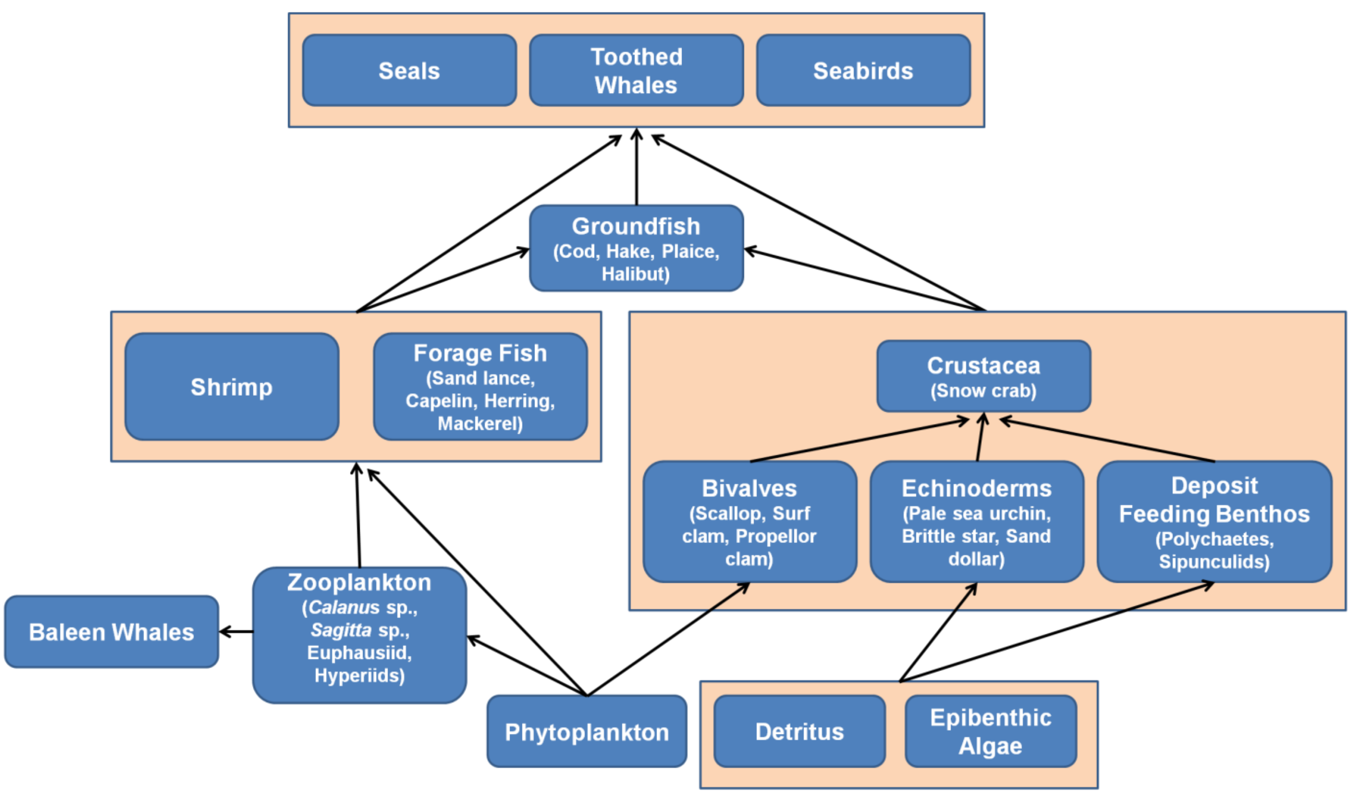
4.2.1.2 Key Taxa, Assemblages, Ecological Regimes

Marine species abundances and distributions have often been looked at independently and not as components of a complete ecosystem. Species vary in terms of their ecological, commercial, cultural and legislative importance but understanding of individual species is enhanced through knowledge of their interactions with the other species and through the environment. All taxa are associated with habitat-specific assemblages where they play a trophic role that interacts with many other taxa, either directly or indirectly (e.g. Gomes et al 1992; Templeman 2010; Dawe et al 2012; Figure 4.67).

In the SEA Study Area, primary production is derived through phytoplankton. These tiny photosynthetic organisms form the base of the food chain which flows through primary consumers such as zooplankton, through to planktivorous fish and invertebrates to fish, marine mammals and birds, and ultimately to the detritivores which return nutrients from dead flora and fauna back into the food chain.

This holistic, multi-species perspective and approach has helped researchers to better understand how the trophic and assemblage structure in the SEA Study Area's ecosystem has been changing as a result of anthropogenic (e.g. fishing) and environmental (e.g. temperature changes) disturbances (Rose 2004; Koen-Alonso et al 2010; Devine and Haedrich 2011; Dawe et al 2012).

Figure 4.67 Overview of Key Ecosystem Elements and Trophic Links in the SEA Study Area



Adapted from Gomes et al (1992) and Templeman (2010)

Recent work has, for example, indicated that the ecosystem structure of the Northwest Atlantic underwent a "regime shift" in the late 1980s to early 1990s, that included a decrease in the population of many long-lived groundfish species such as cod and redfish, an increase in invertebrate species such as shrimp and snow crab (deYoung et al 2004; Koen-Alonso et al 2010; Dawe et al 2012) and an increase in primary production (deYoung et al 2004). The eventual collapse of the groundfish stocks were attributed to fishing pressure and colder environmental conditions (deYoung et al 2004; Rose 2004; Koen-Alonso et al 2010) that favoured invertebrate species such as snow crab and shrimp (deYoung et al 2004). For at least shrimp, the collapse of groundfish stocks and associated release from predation, further augmented their abundance (Worm and Myers 2003; Dawe et al 2012). Coincident declines in capelin, an important prey species along the Newfoundland Shelf, also forced species like cod to rely more heavily on lower quality prey such as shrimp (Dawe et al 2012) and deepwater species such as Greenland halibut to resort to feeding on alternate prey species such as grenadier.

The new regime, dominated by invertebrates, was maintained along the Newfoundland Shelf despite a refocus of fishing effort toward shrimp and crab and a great reduction in groundfish fishing activity (deYoung et al 2004). Notwithstanding relatively low levels of groundfish bycatch, fishing pressure on invertebrates has been linked, along with environmental conditions, to low groundfish abundance in many prominent groundfish species (Koen-Alonso et al 2010). The mechanism of this relationship, however, remains unknown.

Currently, the waters in the SEA Study Area are on a warming trend, which is coinciding with reports from fishermen (see Consultation Report, Appendix A) and scientists (Koen-Alonso et al 2010; Templeman 2010; Dawe et al 2012) regarding associated declines in snow crab and signals that some groundfish species are showing signs of recovery. These changes demonstrate the dynamic nature of the ecology of the SEA Study Area, and underscore the need for adaptive management in this climate sensitive ecosystem, particularly when climate effects in the northwest Atlantic are expected to be elevated relative to other areas (Greene et al 2008).

Key Marine Assemblages

Fauna in the North Atlantic have physiological, morphological, life history and trophic characteristics that dictate their distribution. Correspondingly, depth and temperature are important factors in species distributions, where increased species richness is generally observed in progressively warmer waters (Rose 2005a). Within these depth and temperature zones, differences in assemblages can be delineated with habitat types (e.g. Houston and Haedrich 1984; Baker et al 2012; Cote et al 2013). When distributions of fish overlap consistently in time and space, these groups of co-occurring species form an assemblage (Haedrich and Merritt 1990).

As is also often found at larger geographic and temporal scales, faunal assemblages within the SEA Study Area remain influenced by temperature and depth (Rose 2005a), but they can change across relatively short distances because of the varying prominence of cold (Labrador Current) and warm currents (Gulf Stream) as well as depth (shelf vs. slope vs. abyss) and habitat complexity (Houston and Haedrich 1984; Schneider et al 1987; Baker et al 2012). While some generalist species may be present in many areas (e.g. American plaice, Atlantic cod, thorny skate and striped wolffish; Gomes et al 1992), each assemblage has defining elements.

For example, the southwest edge of the Grand Banks has an assemblage that resembles the eastern Scotian Shelf, and has many species that are found near the northern extent of their range (e.g. white hake, argentine, silver hake, Atlantic halibut, longfin hake, butterfish, billfish). In contrast, the northern portion of the Grand Banks away from the shelf edge is perpetually cold on the bottom and is inhabited by species typically found further north on the inner shelf where bottom waters are coldest (e.g. Arctic sculpin, Arctic cod, northern shrimp and snow crab).

Depth can also operate as a distinguishing environmental factor across relatively fine spatial scales (Gomes et al 1992; Baker et al 2012). Yellowtail flounder, sea ravens and longhorn sculpin, for example, are associated with the shallows of the Grand Banks (40-100 m). These species transition to slope species such as Greenland halibut and redfish and other less abundant species such as wolfish. At depths primarily greater than 400 m, shelf assemblages give way to semi pelagic and demersal species such as lanternfish, grenadiers, Greenland halibut, blue hake, deepwater eels and rocklings, many of which can extend beyond the SEA Study Area to abyssal depths. Some species such as deep sea lizardfish and Bean's sawtooth eel, for example, are found only at great depths (Baker et al 2012).

Structural habitat complexity further segregates these assemblages for both fish and benthos (Houston and Haedrich 1984; Schneider et al 1987; Baker et al 2012). On the Grand Banks, for example, Baker et al (2012) found snub-nosed eels exclusively in low complexity habitats.

At a relatively coarse scale, the SEA Study Area extends over at least four different functional ecosystem production units: 1) Grand Bank, which transitions at its northern extent; 2) the Newfoundland-Labrador Shelf (both parts of the Newfoundland-Labrador Shelves marine ecosystem); 3) the Flemish Cap; considered a relatively closed marine ecosystem (Perez-Rodriquez et al 2012); and 4) oceanic waters beyond the continental shelf break. Furthermore, the SEA Study Area includes the transition areas between these ecosystems. For example, the shelf break forms an important ecotone (Pepin et al 2010), and given the large range in depths involved in SEA Study Area, it may be argued that it also spans bathypelagic and abyssal oceanic ecosystems. Such functional divisions are recognized by NAFO and suggested for use in fisheries and ecosystem management (NAFO 2013b).

These functional units described above may differ based on the ecological processes that influence the ecosystem, the interactions among species and the composition of the species communities. For example, the Newfoundland shelves are thought to be heavily influenced by ice dynamics, the state of the lower trophic levels (i.e. bottom up regulation) (Buren et al 2014) and fishing (DFO 2012g; Shelton and Morgan 2013), while the Flemish Cap is not influenced by ice (Colbourne et al 2011). Other environmental drivers influence recruitment success along with fishing, while predators are thought to have a greater regulatory influence over juvenile fish (e.g. Perez-Rodriquez et al 2013).

In many cases, the key species of a marine assemblage can be determined based on dominance (e.g. numerical abundance or biomass), which can serve as a surrogate for a species' importance in the food chain and the resources they consume and pass through the ecosystem. Alternatively, the importance of a species can be considered through the number and strength of its linkages to other species. In the SEA Study Area, capelin and corals are classic examples of taxa whose presence affects the distribution and activities of many other species.

In the following sections, key species from each taxonomic group are identified where possible. In most cases such species were determined through numerical dominance, although where available studies supported other definitions of key species these are also identified in the descriptions.

4.2.1.3 Plankton

Plankton consists of small marine organisms that move passively in aquatic ecosystems, drifting according to currents and other oceanographic processes. Taxa in this group include microscopic marine plants (phytoplankton), invertebrates (zooplankton), vertebrate eggs and larvae (ichthyoplankton), bacteria, fungi, and even viruses. Plankton comprise the largest group of organisms in the ocean in terms of both diversity and biomass. Consequently, marine plankton play a foundational role in the marine environment as they serve as the base layers of most food webs (primary and secondary production). For example, copepods are important food for larval commercial fish such as capelin. Other zooplankton, such as krill, are also an important food source for large marine mammals. In addition to being a food source, most commercial finfish and invertebrate species spend at least one of their life stages in the water column as plankton. Plankton are also the mechanism by which nitrogen and carbon are absorbed into the marine environment from the atmosphere. For example, cyanobacteria in the ocean’s euphotic layer “fix” atmospheric nitrogen into a biologically available form. Sinking plankton and biological waste products transfers much of this usable nitrogen to deeper parts of the ocean where it remains until it is returned to the surface through upwelling. Similarly, photosynthesizing plankton consume carbon dioxide in ocean surface layers, thus reducing its availability. The reduced partial pressure of CO_2 in surface waters results in the absorption of atmospheric CO_2. This phenomena is referred as a ‘biological pump’ and is a key process in climate regulation. Recent studies have also shown the importance that zooplankton play in transferring organic matter from depth to the surface (benthic-pelagic coupling).

Although plankton are widespread across the SEA Study Area, the *Southeast Shoal and Tail of the Banks Ecologically and Biologically Significant Area* (EBSA) was identified in part based on its high primary productivity (Templeman 2007), as described further in Section 4.2.1.10.

Phytoplankton

Light and nutrients fuel phytoplankton growth in the SEA Study Area waters (Harrison et al 2013). The interaction of these limiting resources results in a spring and fall bloom in the waters of the Northwest Atlantic. Spring blooms are caused when strengthening sunlight interacts with well-mixed, nutrient-rich surface waters. The dominant bloom in the Northwest Atlantic typically occurs in early spring, usually April or May (Maillet et al 2004; Harrison et al 2013), and is dissipated over the summer as nutrient levels are prevented from replenishing by the formation of the summer thermocline (Harrison et al 2013). Fall winds and cooler temperatures break down this thermocline, permitting nutrients to recharge and facilitate a second somewhat weaker bloom (Maillet et al 2004). The timing of blooms typically progress south to north, and in waters off Newfoundland, Fuentes-Yaco et al (2007) determined that the bloom moves northward at a rate of approximately one degree latitude per week. Interestingly, the timing of the bloom has occurred progressively later in Newfoundland waters, which is counter to that observed in other areas of the North Atlantic (Harrison et al 2013).

Nitrate and silicate are considered limiting nutrients to phytoplankton and their relative abundance can affect community structure. For example diatoms, which are abundant in the SEA Study Area, are reliant on silicate for their skeletal integrity (Harrison et al 2013) and therefore depletion of this nutrient would have negative effects on their population growth. Relative to other areas of the Atlantic, SEA Study Area waters are largely nitrate limited and therefore favour growth of diatoms relative to waters of the northeastern Atlantic (Harrison et al 2013). In general, larger microplankton are dominated by diatoms (e.g. *Chaetoceros* sp.), but dinoflagellates (*Ceratium* spp.) become more abundant in fall/winter (Harrison et al 2013).

There has been an observed shift in the abundance, timing, and duration of some phytoplankton species in the Northwest Atlantic. This shift included a decrease in overall abundance in the 1970s, a return to maximum levels in the 1990s and a subsequent decline ever since (Maillet et al 2004; Head and Sameoto 2007). These changes are correlated with the Northern Atlantic Oscillation (NAO) (Harrison et al 2013) whereby an intensification of northwestern atmospheric flows cause increased mixing and sea ice extent and colder, fresher ocean conditions. These conditions are also correlated with an increased nutrient flux, which triggers higher primary productivity, and in turn, secondary productivity (zooplankton) (Maillet et al 2004).

The distribution of phytoplankton (primary producers) on the Grand Banks is controlled largely by upwelling and enhanced vertical mixing on the slopes shelf break and thermal gradients between the shelf and slope waters (Anderson and Gardner 1986; Templeman 2007). The most productive areas are typically in the waters on the shelf and the shelf break over the shelf slope. Areas of relatively high production across the Northwest Atlantic include the Southeast Shoal and the Tail of the Grand Banks (Templeman 2007).

Zooplankton (Secondary Production)

Zooplankton are the principal link between primary producers and higher trophic levels (e.g. fish, whales and seabirds) (Maillet et al 2004). Copepods make up over 85% of the zooplankton abundance, followed distantly by cladocerans (Table 4.56). Zooplankton species such as *Calanus finmarchicus* are considered keystone species (Head et al 2013), due to their importance to higher trophic levels, while others such as jellyfish may have a proportionally strong influence on the ecosystem through predation. The abundance of zooplankton on shelf waters follows that of phytoplankton populations, their primary food source, in that they peak after the spring bloom and decline later in summer. Species such as *C. finmarchicus* return to shelf waters each spring to reproduce and feed on phytoplankton. Once this food source is sufficiently depleted, they abandon the shelf environment and descend to deepwater overwintering sites (Head et al 2013).

Variation in community structure and abundance are exhibited by zooplankton at several temporal and spatial scales (Morales 1999; Dalley et al 2001). For example, the copepod *C. hyperboreaus* has been increasing in abundance for several decades (Maillet et al 2004). At shorter timescales, numerous zooplankton species alter their local abundance by undertaking diel vertical migrations (DVM); rising up in the water column at night (Dalley and Anderson 1998). In the Northwest Atlantic, *Euchaeta norvegica and C. finmarchicus* are the most important contributors to total migrating biomass (Hays 1996). These migrations form a biological mechanism that transports organic carbon and nitrogen through the water column (e.g. thermoclines) and are an important component of benthic-pelagic coupling (Morales 1999). Surveys of the Grand Banks and Newfoundland Shelf indicate a north-south cline in total zooplankton biomass, with production declining from inshore areas to the shelf edge depending on the year (Dalley and Anderson 1998). However, taxa-specific distributions vary. For example, jellyfish are predominantly found in inshore areas and on the northern Grand Banks (Dalley and Anderson 1998), while *C. hyperboreus* are confined mostly to the outer shelf and slope waters (Maillet et al 2004). Similarly, euphausids (krill), an important prey species for marine mammals (Plourde and McQuinn 2009), have the highest densities in slope waters and offshore regions (e.g. the Laurentian Channel) (Maillet et al 2004).

Table 4.56 Main Zooplankton Taxa from Invertebrate Zooplankton 1997 Survey on the Newfoundland Shelf and Grand Banks.

Rank	Taxa / Taxon	% Total Zooplankton
1	Copepods	86.8
2	Cladocerans	5.2
3	Limacina	3.0
4	Larvaveans	2.3
5	Bivalve larvae	1.1
6	Tomopteris	0.4
7	Cnidarians	0.2
8	Euphausids	0.2
9	Chaetognaths	0.1
10	Snow crab	0.1
11	Hyperids	0.0
12	Mysids	0.0
13	Other Zooplankton	0.6
Source: Modified from Dalley et al (2001)		

Ichthyoplankton

For many marine fish species, eggs and larvae are pelagic and move passively in the water currents. These lifestages therefore act as an important period of dispersal and represent a key stage that can often affect recruitment success (Cushing 1990). Spawning periods of many species are synchronized with plankton blooms to provide access to seasonally abundant food supplies. As these taxa typically exhibit passive movement, they are often entrained in oceanographic features such as gyres, (Bradbury et al 2008), upwelling zones (Ings et al 2008) and thermoclines (Frank et al 1992). Ichthyoplankton densities along the Northeast Newfoundland Shelf and the Grand Banks can vary by orders of magnitude (Dalley and Anderson 1998; Bradbury et al 1999) and community structure can differ according to year, season and location (Frank et al 1992; Dalley and Anderson 1998; Bradbury et al 2008). Assemblages on the Northeast Newfoundland Shelf are largely dominated by capelin (73.5%), sand lance (11.3%), lanternfish (5.9%) and Arctic cod (3.4%) (Table 4.57). Squid larvae were also noted for being widespread across the Grand Banks and Newfoundland Shelf and occurred in 67% of samples. Some species are generally distributed on the inner Shelf north of the Grand Banks (e.g. blennies, sculpins, squid, seasnails and alligatorfish) while others are found predominantly over the Grand Banks (sand lance and hake; Dalley and Anderson 1998).

Table 4.57: Relative Overall Abundance of Dominant Fish Species caught in the International Young Gadoid Pelagic Trawl during the Pelagic 0-group Survey (1997-1998)

Species	Scientific name	Relative Abundance (%)	Average Incidence (%)
Capelin	*Mallotus villosus*	73.5	51.1
Sand lance	*Ammodytes sp.*	11.3	36.4
Lanternfish	Myctophidae	5.9	2.5
Arctic cod	*Boreogadus saida*	3.4	56.2
Squid	Cephalopoda	3.1	67.1
Alligatorfish	Agonidae	0.9	60.3
Sculpins	Cottidae	0.8	47.9

Species	Scientific name	Relative Abundance (%)	Average Incidence (%)
Shannies / Blennies	Stichaeidae	0.4	12.9
Atlantic cod	*Gadus morhua*	0.2	33.5
Redfish	*Sebastes sp.*	0.2	17.7
Wolffish	*Anarhichas sp.*	0.1	28.8
Seasnail	*Liparis sp.*	0.1	15.6
American plaice	*Hippoglossoides platessoides*	0.1	10.6
Haddock	*Melanogrammus aeglefinus*	0.1	7.2
Witch flounder	*Glyptocephalus cynoglossus*	<0.1	4.9
Greenland halibut	*Reinhardtius hippoglossoides*	<0.1	4.9
Hake	*Urophycis sp.*	<0.1	3.4
Yellowtail flounder	*Limanda ferruginea*	<0.1	0.8
Source: Modified from Dalley et al (1999); Dalley and Anderson (1998)			

4.2.1.4 Plants and Macroalgae

Macroalgae (e.g. *Laminaria*, *Agarum cribrosum*) and sea grasses (*Zostera marina*) are important components of coastal areas of Newfoundland as they contribute to biodiversity and create important habitats for marine animals (e.g. Cote et al 2001, 2013). Their reliance on photosynthesis to produce energy, however, limits their distribution to areas reached by sunlight (Dayton 1985; Anderson et al 2002). For example, Anderson et al (2002) classified over 2,000 km of habitat in depths of 10-220 m and found the majority of algae (kelp and Irish moss) to occur in waters less than 30 m with no algae occurring in waters deeper than 50 m. Similarly, submersible surveys in coastal areas of Newfoundland (Gregory and Anderson 1997) detected most kelp at depths of less than 40 m. Nevertheless, some types of algae (such as coralline algae) persist at greater depths. Other important factors affecting macroalgae distribution include substrate, sedimentation, nutrients, water motion, salinity and temperature (Dayton 1985) and urchin predation (Himmelman and Steele 1971).

There is a paucity of published information regarding plants and macroalgae in the SEA Study Area. This is likely a reflection of the fact that this marine area contains habitat that is generally not conducive to seaweeds and macroalgae. Most of the SEA Study Area is too deep for these species, with the exception of the shallowest areas of the Grand Banks, where depths of less than 30 m can be found. In addition to the relatively deep water, most areas of the Grand Banks do not contain the hard substrates that most macroalgae need to establish holdfasts (Dayton 1985). Further illustrating the general absence of macroalgae and seaweeds in the SEA Study Area are the studies of Houston and Haedrich (1985), Schneider et al (1987) and Kenchington et al (2001), which did not characterize any habitats in their survey areas as including macroalgae.

The above notwithstanding, some areas of the SEA Study Area, such as Virgin Rocks, are known to have a diverse and profuse seaweed flora that resemble communities of Labrador. Elsewhere on the Grand Banks, a few seaweeds can be found at depths up to 100 m, but in these areas there are few species and low biomass (R. Hooper, pers. comm.). Macroalgae is likely to also benefit from the presence of drill rigs as substrate.

The dominant large seaweeds on Virgin Rocks are the kelps (Phaeophyta: Laminariales): *Laminaria digitata*, *Alaria esculenta*, *Saccharina longicruri,* and *Agarum cribrosum*. Understory seaweeds include

Desmarestia viridis, D. aculeata, Palmaria (Dulse), *Ptilota, Phycodrys, Membranoptera, Polysiphonia* and numerous other cold-water species. In past surveys, almost all available substrate was covered by coralline seaweeds: *Lithothanionglaciale*, *L. lemoineae, Clathromorphum compactum, C. circumscriptum* and *Corallina*. The deepest seaweed was the coralline *Leptophyum leave*, which was still very abundant below 70 m (R. Hooper, pers. comm.).

4.2.1.5 Benthic Communities

Benthic invertebrates are animals associated with the sea floor. They can be categorized as those that are infaunal (i.e. that live in the substrate) and those that are epifaunal (i.e. that live on or attached to the substrate). These are a group comprised of diverse taxa that play a variety of roles in the ecosystem (e.g. detritivors, filter feeders, carnivores) and form an important part of the food chain (Templeman 2010). Benthic communities are considered sensitive to anthropogenic disturbance (Husky Energy 2010; Suncor Energy 2010; Warwick 1993) and also account for the bulk of commercial fish landings in the SEA Study Area over the last two decades (Dawe et al 2012).

Despite their ecological significance, these taxa are generally poorly studied in the SEA Study Area with the exception of a few commercially valued species and in a few spatially restricted areas (LGL 2003; Templeman 2010; Gilkinson 2012). Studies to date indicate that, like fish, benthic assemblages respond to environmental variables such as depth, substrate and flow field (Houston and Haedrich 1984; Schneider et al 1987; Gilkinson and Gagnon 1991; Gilkinson 2012, 2013; Gale 2013).

Three main contemporary sources of information illustrate benthic community composition in the SEA Study Area, and are derived predominantly from the Grand Banks area. These include resource descriptions and environmental effects monitoring associated with oil and gas development (e.g. Husky Energy 2010; Suncor Energy 2010), research initiatives (e.g. Houston et al 1984; Schneider et al 1987; Kenchington et al 2001) and DFO RV Surveys. The latter provides more widespread information on benthic taxa accessible to trawls (e.g. LGL Limited 2012, 2013) but they were also supplemented in some years across the Grand Banks with benthic grab programs (Gilkinson 2012).. It is also important to note that characterizations of benthic communities are also inevitably biased according to sampling method. For example, visual assessments including ROV and drop cameras (video surveys, or photographs) often poorly assess infaunal communities whereas grabs may have challenges sampling communities over harder substrates. Bottom trawls also have challenges over some habitat types (e.g. rocky substrates) and only sample a small fraction of resident benthos, generally sampling larger epibenthic individuals

Recent oil and gas environmental monitoring associated with the White Rose and Terra Nova Oilfields indicate that polychaetes were numerically dominant (greater than 72 percent) in Grand Bank grabs followed by amphipods and bivalves (Husky Energy 2010; Suncor Energy 2010). In both of these study programs, these three taxa made up 89 percent of the individuals sampled. For Terra Nova samples, taxonomic richness was linked to areas of relatively high benthic invertebrate abundance (Suncor Energy 2010).

A number of research initiatives have also characterized benthic communities on the Grand Banks (Schneider et al 1987; Kenchington et al 2001; Gale 2013; Gilkinson 2013) and associated slopes (Houston and Haedrich 1984). Schneider et al (1987) documented benthic communities of the northeastern part of the Grand Banks using video and determined that epifaunal communities were dominated by echinoderms (brittlestars, urchins and sand dollars) as well as bivalves (primarily Icelandic scallop).

In contrast, grab samples in the vicinity of Carson Canyon (continental edge and slope) on the southeastern Grand Banks revealed communities dominated by polychaetes, hooded shrimp, sipunculid worms, amphipods, echinoderms, isopods and bivalves (Houston and Haedrich 1984). The relative dominance of these taxa depended on the substrate, although polychaetes were among the top four abundant taxa in each of sand, gravel and silt. These authors also noted a relatively low biomass of benthic invertebrates compared to other areas of the North Atlantic, which was a somewhat unexpected outcome given that these waters are known for fish production and are important areas to fishers (see Appendix A). Houston and Haedrich (1984) concluded that much of the production in the area must derive from pelagic sources instead of benthic pathways. Alternatively, based on this conflicting evidence, the sampling methods may not have been well suited to collections of large benthic invertebrates such as crabs.

Perhaps the most holistic sampling was done on the Grand Banks as part of a series of trawling impact studies (Prena et al 1999; Kenchington et al 2001). These researchers used video grabs (Kenchington et al 2001) a benthic sled and trawl bycatch (Prena et al 1999) to sample and characterize communities on the northeast slope of the Grand Banks over a three year period. Kenchington et al (2001) documented 246 benthic taxa (mostly echinoderms, polychaetes, crustaceans and molluscs), of which abundance was dominated by a polychaete (*Prionospio steenstrupi*) and a mollusk (*Macoma calcarea*), and biomass was dominated by propeller clams and sand dollars. The epibenthic sled samples were also dominated by mollusks and echinoderms such as brittle stars, sand dollars and urchins, as well as by snow crab and soft corals (Prena et al 1999). The epibenthic samples were also characterized by a reduced taxonomic richness (115 taxa detected) relative to that collected with the grab/video system. Kenchington et al (2001) also documented significant and naturally occurring variation in structure between years in the benthic invertebrate community.

In contrast to other survey types, DFO RV trawl surveys were dominated by relatively large taxa such as sponges, anemones, shrimp, crab and urchins. Other taxa included echinoids such as sand dollars, sea stars, brittle stars and basket stars (LGL 2012, 2013). As trawls would be considered an epibenthic sampling technique, it is not surprising that the sampled community aligns well with those of Prena et al (1999). However, concurrent grab samples collected during the RV survey program in the Grand Banks area (2008-2010), indicated a greater prevalence of echinoids, where 40 percent of invertebrate biomass was comprised of sand dollars. Like previous studies (e.g. Kenchington et al 2001), polychaetes were the most species rich taxa in grab samples, contributing 38 percent of the species observed. Eighty-six percent of the total observed species originated from *Annelida, Arthropoda* and *Mollusca* phyla.

Collectively, these studies confirm that benthic communities in the SEA Study Area are quite diverse compared to higher trophic levels, depending on species and habitat type, and these communities can be expected to vary over time and with changing environmental conditions. Furthermore, benthic communities can vary in sensitivity to disturbance. For example, deepwater sand habitat communities have been observed to be resilient to trawling disturbance (Kenchington et al 2001), while communities associated with slow growing sponges and corals could take decades to recover after dislodgement (Gilkinson and Edinger 2009).

Life Histories, Habitat, and Spawning (Benthos)

An overview of the key characteristics of some of the numerically dominant benthic taxa that are known to occur in the SEA Study Area is provided in Table 4.58. As DFO RV surveys do not properly represent many benthic invertebrates, the Table has also been further augmented with important taxa identified from other literature specific to the SEA Study Area, including Houston and Haedrich (1984), Schneider et al (1987), Prena et al (1999), Kenchington et al (2001), Ollerhead et al (2004) and LGL (2012, 2013). Additional information on reproduction is provided in Table 4.59, while the regional distributions of key species are further described in subsequent sections.

Table 4.58 Overview of Some Key Invertebrate Species in the SEA Study Area

Species	Habitat and Distribution	Biology and Ecology	Use / Importance
Icelandic scallops (*Chlamys islandica*)	• Distributed in the northwest Atlantic Ocean. • Occurs in depth ranges from subtidal depths to 180 m. • In Newfoundland waters, scallops occur generally in depths >55 m on variable hard substrates. • Icelandic scallops are associated with gravel and cobble substrates on the Grand Bank.	• Broadcast spawns in Newfoundland around April-May. • Planktonic larvae remain in the water column for 10 weeks before settling. • Spat settle primarily between August and November at depths of 10-15 m. • Spat settle in deep offshore areas (primarily on gravel on the Grand Bank ;Gilkinson and Gagnon 1991). • Suspension feeders on phytoplankton.	• Commercially significant species.
Sea scallop (*Placopecten magellanicus*)	• Distributed in the northwest Atlantic Ocean from Labrador to North Carolina. • Occurs in shallow depths of <20 m in the northern part of its range on sand, gravel and pebble substrates.	• Sea scallops spawn from September to October in Newfoundland triggered by a rise in water temperature. • Large females are able to produce over a hundred million eggs each. • Planktonic larvae remain in the water column for four weeks before settling. • Suspension feeders on phytoplankton.	• Commercially significant species.
Northern Shrimp (*Pandalus borealis*)	• Distributed from west Greenland to Georges Bank. • Occupies areas with mud and silt substrates in temperature ranges from 1-6°C. • Northern shrimp was the most commonly observed species in 3NLOPs area from RV surveys. • Northern Shelf Assemblage.	• Spawns once a year around late June or early July. • During late summer, fertilized eggs are attached to the female's abdomen. • The eggs hatch the following spring and summer. • Feeds on polychaetes, small crustaceans, detritus, marine plants, copepods and euphausiids. • Prey for Greenland halibut, Atlantic halibut, cod redfish and harp seals.	• Commercially significant species. • Important forage species.
Striped pink shrimp (*Pandalus*	• Undergoes diel vertical migrations in association with	• Eggs are laid between November and January and	• Commercially significant species.

Species	Habitat and Distribution	Biology and Ecology	Use / Importance
montagui)	pelagic feeding (Hudon et al 1992). • Northern Shelf Assemblage.	hatch by the end of April (Allen 1963). • In pelagic waters, it feeds mainly on copepods. At benthic depths, it feeds on polychaetes and foraminiferans (Hudon et al 1992). • Prey for Greenland halibut, Atlantic halibut, cod, redfish and harp seals.	Important forage species.
Snow crab (*Chionoecetes opilio*)	• Distributed in the northwest Atlantic Ocean from Greenland to the Gulf of Maine. • Occupies on soft bottoms at depth ranges from 60-400 m and temperature ranges from -1-6°C. • Commonly observed species in 3NLOPs from RV surveys. • Commonly observed during the 2005-2011 DFO RV Surveys of the Orphan Basin (LGL 2012). • Dominated otter trawl sampling on sandy areas of the Grand Bank (Prena et al 1999). • Cold Shelf Assemblage	• Fertilized eggs are attached to the hairs on the female's pleopods. • Eggs are carried for 12-27 months. • Eggs hatch during the peak phytoplankton bloom between April and June. • Larvae feed on microplankton. • Feeds on polychaetes, bivalves, echinoderms and fish carcasses. • Various groundfish, other snow crabs and seals prey on snow crabs.	• Commercially significant species.
Atlantic Surf clam (*Spisula solidissima*)	• Distributed in the northwest Atlantic Ocean along the continental shelf from southern Gulf of St. Lawrence to North Carolina. • Occurs at depths from the subtidal zone to <50 m. • High abundance along the eastern edge of the Grand Banks (Ollerhead et al 2004).	• Spawns in summer to early fall when water temperatures reach 12-15°C. • Larvae settle on sand substrates. • Suspension feeders. • Preyed upon by rock crabs, seastars, hermit crabs, moon snails, whelks and various groundfish including cod, flounder, sculpin and ocean pout.	• Commercially significant species.
Pale sea urchin (*Strongylocentrotus pallidus*)	• High abundance on sandy bottoms of the Grand Bank (Kenchington et al 2001). • Distributed in deep waters up to depths of 1600 m (Bluhm et al 1998). • Found on a mixture of cobble and sand substrates (Gilkinson et al 1998). • Dominant sea urchin at depths >60 m (Gilkinson et al 1998).	• Feeds on epibiotics on stones, infaunal meiobenthos and detritus (Bluhm et al 1998). • Preyed upon by commercially important groundfish species including American plaice (Gilkinson et al 1998).	• Not commercially significant in the region.
Hooded shrimp (Cumacea)	• Distributed from Newfoundland to Cape Cod (Gosner 1979).	• Preyed upon by American plaice, yellowtail flounder and cod (Bruno et al 2000;	• Not commercially significant in the region.

Species	Habitat and Distribution	Biology and Ecology	Use / Importance
	• Common on gravel and sand substrates on the Grand Bank (Houston and Haedrich 1984).	Pitt 1973). • Spawning varies depending on the species. As a group spawning times range from February to December (Corey 1981).	
Amphipoda	• Distributed on silt, sand and gravel substrates on the Grand Bank (Houston and Haedrich 1984).	• Spawning occurs throughout the year (Sheader 1983). • Feeding modes vary and include scavenging, predation and grazing (Duffy and Hay 1991). • Preyed upon by commercially important groundfish species including American plaice and yellowtail flounder (Pitt 1976).	• Not commercially significant in the region. • Important prey for larval fish species
Polychaete worms (Polychaeta)	• Important component of marine benthic communities on the Grand Bank (Kenchington et al 2001). • Most common polychaete species observed at 120-146 m on the Grand Bank was *Prionospio steenstrupi* (Kenchington et al 2001). • Distributed throughout the North Atlantic including the Grand Banks at depths >50m. • Common on silt substrates on the Grand Bank (Houston and Haedrich 1984).	• Spawning for *P. steenstrupi* occurs between May-August (Lacalli 1981). • Polychaetes are important prey species for a variety of invertebrates and groundfish.	• Not commercially significant in region.
Propellor clam (*Cyrtodaria siliqua*)	• High abundance on sandy bottoms of the Grand Bank (Kenchington et al 2001).	• Population dominated by older individuals to ages exceeding 100 years (Kilada et al 2009). • Prey species of American plaice and Atlantic wolffish (Templeman 1984).	• Commercially significant species.
Sipunculan worms (Sipuncula)	• Common on sand substrates on the Grand Bank (Houston and Haedrich 1984). • Burrowing worms found on sandy-mud to coral-rock substrates (Gosner 1979).	• Many species are generally deposit feeders (McMahon et al 2006). • Spawning times vary between species. • Preyed upon by groundfish and other invertebrates.	• Not commercially significant in Region.
Whelk (*Buccinum* sp.)	• Distributed throughout the northwest Atlantic Ocean from Labrador to New Jersey. • Common in cold waters from tidal levels to depths of 180 m. • Common in otter trawl sampling on sandy areas of the Grand Bank (Prena et al 1999).	• Copulates from May to July. • Fertilized eggs are laid approximately 2-3 weeks after copulation. • Eggs are enclosed in masses that may contain about 340,000 developing embryos. • Feeds on urchins,	• Commercially significant species.

Species	Habitat and Distribution	Biology and Ecology	Use / Importance
		polychaetes, amphipods, crustaceans and fish eggs. Also known to feed on animal carcasses. • Preyed upon by lobsters, cod, crabs, seastars and dogfish.	
Sponges (*Geodia* sp.)	• Commonly observed during the 2005-2011 DFO RV Surveys of the Orphan Basin (LGL 2012). • Variety of species found on the Grand Bank. • The most dominant species observed on sponge grounds on the Grand Bank, Flemish Cap and Flemish Pass (Murillo et al 2012).	• In Scandinavia, *G. barretti* undergoes sexual reproduction and releases gametes 1-2 periods per year (Spetland et al 2007). • Gamete release coincides with phytoplankton blooms (Spetland et al 2007).	• Not commercially significant in region.
Jellyfish (Scyphozoa)	• Occur inshore and offshore. • Commonly captured during plankton tows on the Grand Bank (LGL 2012). • Main species captured include *Cyanea capillata* and *Aurelia aurita*.	• Planulae larvae appear during early to mid spring. • Major predator of fish eggs and larvae.	• Not commercially significant in region.
Brittlestar (Ophiuroidea)	• Comprised of several species of brittle star. • Generally occurs from the Arctic to Cape Cod in the intertidal zone to depths >300 m.	• Undergo asexual and sexual reproduction. • Larvae settle during late July to early August. • Feeds on small crustaceans, polychaetes and detritus. • Important prey species for lobster and American plaice.	• Not commercially significant in region.
Basket star (*Gorgonocephalus arcticus*)	• Dominated otter trawl sampling on sandy areas of the Grand Bank (Prena et al 1999). • At subtidal depths to >1200m. (Gosner 1979).	• Primarily feeds on euphausids (Emson et al 1991). • Associated with deep sea corals (Rosenberg et al 2005).	• Not commercially significant in region.
Sand dollar (*Echinarachnius parma*)	• Distributed in the northwest Atlantic Ocean from Labrador to North Carolina. • Occurs mainly on sandy substrates at depths ranging from shallow waters to >800 m. • Burrows in soft substrates and reaches densities of 100 individuals/m^2. • High abundance on sandy bottoms of the Grand Bank (Kenchington et al 2001).	• Spawning occurs in late spring to early summer. • Preyed upon by American plaice (Bruno et al 2000). • Stomach gut contents include diatoms, sand grains, sponge spicules and detritus.	• Important food source for commercially important groundfish species.
Sea anemones (Actiniaria)	• Commonly observed during the 2005-2011 DFO RV surveys of the Orphan Basin (LGL 2012).	• Feed on echinoderms and other invertebrates. • Have planktonic larvae	• Not commercially significant in Region.

Species	Habitat and Distribution	Biology and Ecology	Use / Importance
	• Variety of species found on the Grand Bank.		
Sources: Summarized from Christian et al (2010) unless otherwise noted			

Table 4.59 Spawning Periods and Locations of Some Key Invertebrate Taxa

Common Name	Scientific Name	Spawning Time												Known Spawning Locations
		J	F	M	A	M	J	J	A	S	O	N	D	
Deep sea corals[1,2]	-													
Iceland scallop[3]	*Chlamys islandica*													NAFO areas 3LNP
Northern shrimp[3]	*Pandalus borealis*													NAFO areas 3LNP
Pink shrimp[4]	*Pandalus montagui*													
Sea scallop[3]	*Placopecten magellanicus*													NAFO areas 3P
Snow crab[5]	*Chionoecetes opilio*													
Sponges[6]	*Geodia* sp.													
Surf clam[3]	*Spisula solidissima*													NAFO areas 3N
Dark shading represents breeding and copulation periods, light shading indicates spawning periods. [1] Sun et al (2010); [2] Mercier et al (2011); [3] Ollerhead et al (2004); [4] Allen (1963); [5] Hooper (1986); [6] Spetland et al (2007)														

Benthic Invertebrate Distributions

Despite considerations related to the particular invertebrate species sampled, the Canadian RV surveys provide the most comprehensive and geographically extesive and "mappable" invertebrate data for the SEA Study Area. Data for the top four invertebrate taxa (snow crab, northern shrimp, pink striped shrimp, and shrimp *Pandalus propinquis*) are presented from the Canadian RV surveys (Table 4.60).. It is also important to consider recent trends and forecasts of shellfish abundance and distribution (such as crab) when evaluating the current knowledge of their distributions (Section 4.2.1.2)

Table 4.60 Representation of Invertebrates During DFO RV Surveys from 2005-2009 in the SEA Study Area

Common Name	Scientific Name	Abundance (%)
Northern Shrimp	*Pandalus borealis*	74.83
Striped Pink Shrimp, Aesop Shrimp	*Pandalus montagui*	2.51
Snow Crab	*Chionoectes opilio*	0.12
Shrimp	*Pandalus propinquus*	0.01
[1]Percentages include finfish as well as crab and shrimp species		

Shrimp

More than 30 species of shrimp are found off Newfoundland (Templeman 2010), with Northern shrimp being the most abundant and commercially important. Northern shrimp are also the most abundant of all animals captured in DFO RV surveys along the Newfoundland shelf, and constitute the bulk of commercial fish landings (Dawe et al 2012). Pink striped shrimp were the fourth most abundant species collected in the RV surveys over this period, and this species and *P. propinquus* are considerably less studied than Northern shrimp.

Northern shrimp experienced an increase in numbers prior to the collapse of groundfish stocks and another increase following the collapse. It is thought that the latter event was caused in part by a release from the predation pressure of groundfish (Lilly et al 2000; Ramseier et al 2000). Consequently, with the observed recovery of some groundfish and ocean temperatures returning to pre 1990s levels, shrimp have shown signs of decline, particularly in southern parts of its range (Orr et al 2011). Recent assessments for Northern shrimp, in waters beyond the Canadian EEZ, indicate that stocks are at (Div. 3LNO) or below (Div. 3M) the biomass limit reference point and therefore directed fisheries have not been advised by NAFO (NAFO 2014).

Northern shrimp can live up to eight years, with the early years being spent as males before they morph into females later in life (Fuentes-Yaco et al 2007; Templeman 2010). Northern shrimp typically live in association with the bottom, particularly older individuals, but younger males undergo vertical feeding migrations at night (Fuentes-Yaco et al 2007). At larval stages, survival and recruitment is closely linked to the extent of phytoplankton blooms and sea surface temperatures (Ouellet et al 2011). Later in life, growth rates are influenced by the amount of particulate organic carbon (e.g. detritus from decomposing phytoplankton; Ramseier et al 2000) and latitude (Fuentes-Yaco et al 2007).

The 2005-2009 DFO RV surveys indicate that Northern Shrimp have been concentrated in the northeast portions of the SEA Study Area, at the edge of the continental shelf and in the Flemish Pass (Figure 4.68). They are at relatively low biomass across the shallow sections of the Grand Banks. Similarly, striped pink shrimp are distributed primarily in the northern parts of the SEA Study Area, but compared to northern shrimp they are found in greater abundance in coastal areas and on the Grand Banks (Figure 4.69). *P. propinquus* are the most spatially restricted of the shrimp species being found primarily along the northern portions of the shelf slope in the SEA Study Area (Figure 4.70).

Snow Crab

Since the early 1990s, snow crab has become an important component of the fishery in the SEA Study Area (Dawe et al 2012). Snow crab hatch in the spring and undergo several planktonic larval stages before settling to the ocean bottom (DFO 2008). The species is sexually dimorphic, with males achieving larger sizes than females (Mullowney et al 2013). Springtime molts allow crabs to grow, but females cease molting upon sexual maturity at sizes that exclude them from commercial exploitation. Similarly, not all males undergo their termial molt at a size that makes them accessible by the fishery. Males can live 6-8 years as adults, where they are most common over mud or mud / sand bottom types, while smaller crabs are common on harder substrates. Crabs feed on a variety of animals that include polychaetes, brittle stars, crustaceans, shrimp and fish, and they in turn are preyed upon by groundfish, seals and other snow crabs (DFO 2008).

Cold ocean conditions are believed to improve crab recruitment (DFO 2008). Unusually cold ocean temperatures in the SEA Study Area resulted in a rapid increase in crab abundance in the early 1990s, although snow crab stocks have declined in recent years and are expected to continue to decline in the near to mid term due to unfavourable environmental conditions (Dawe et al 2012; Mullowney et al 2012). In the SEA Study Area, DFO RV surveys indicate that snow crab are widely distributed, with the exception of the shallows of the Grand Banks and the deep continental slopes (Figure 4.71). Concentrations occur in the colder waters of the northern slopes of the Grand Banks and Flemish Pass as well as in northern portions of the Newfoundland Shelf. These distributions roughly correspond to crab grounds indicated by fishermen during SEA consultations (Appendix A), who indicated the northwest portion of the SEA Study Area was used most frequently for this fishery.

Figure 4.68 Distribution and Abundance of Northern Shrimp in the SEA Study Area (2005-2009 Surveys)

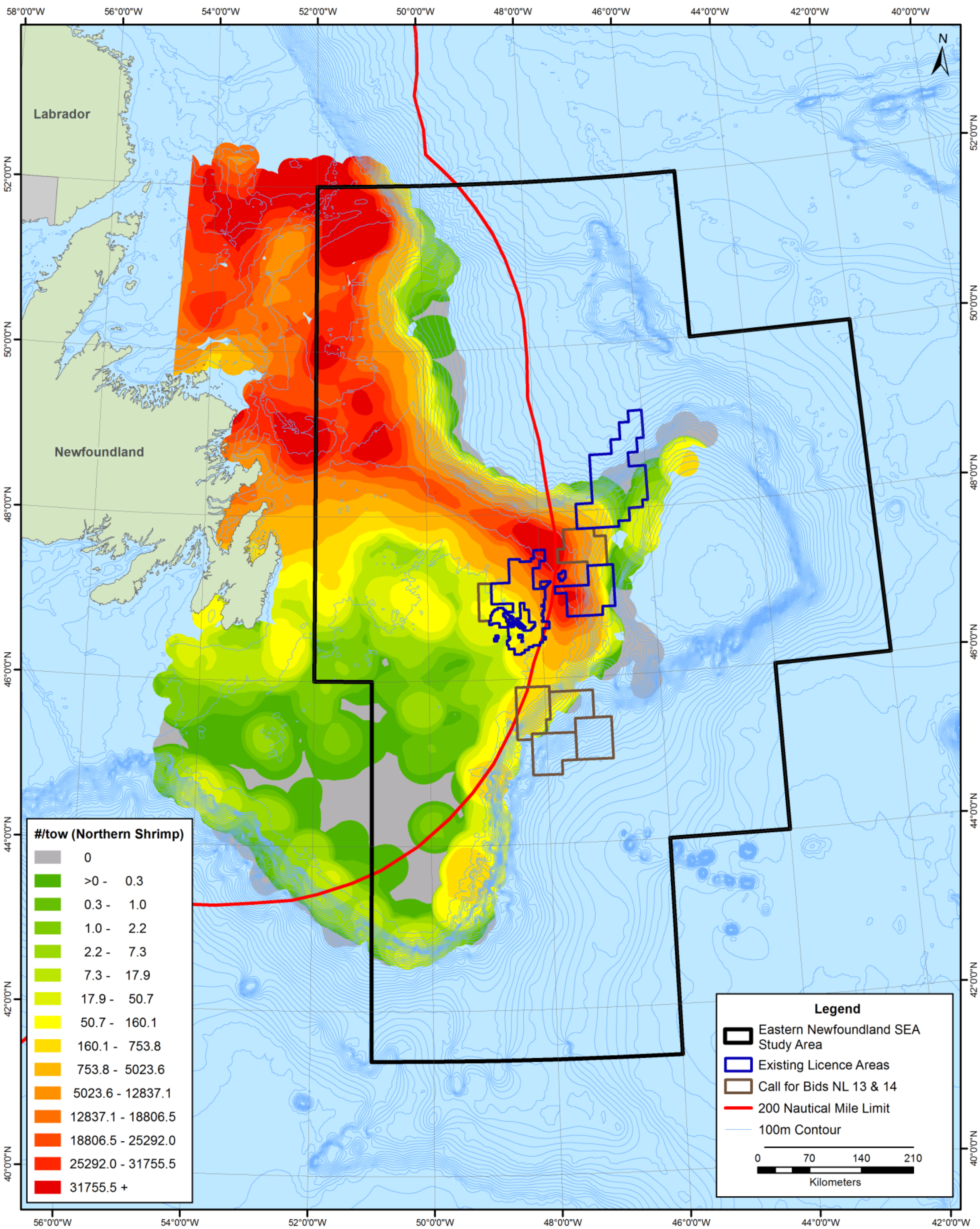


Figure 4.69 Distribution and Abundance of Striped Pink Shrimp in the SEA Study Area (2005-2009 Surveys)

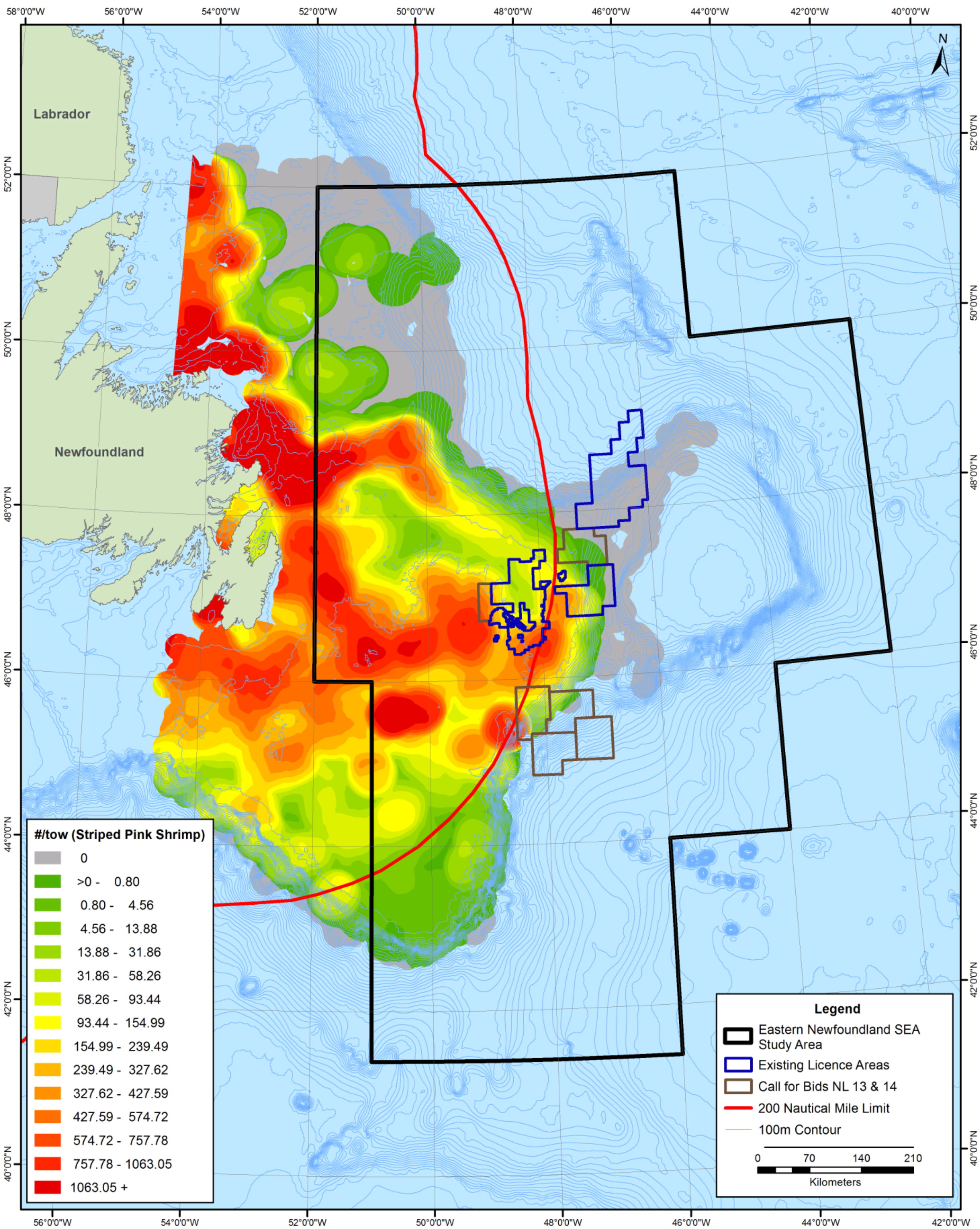


Figure 4.70 Distribution and Abundance of Shrimp *Pandalus propinquus* in the SEA Study Area (2005-2009 Surveys)

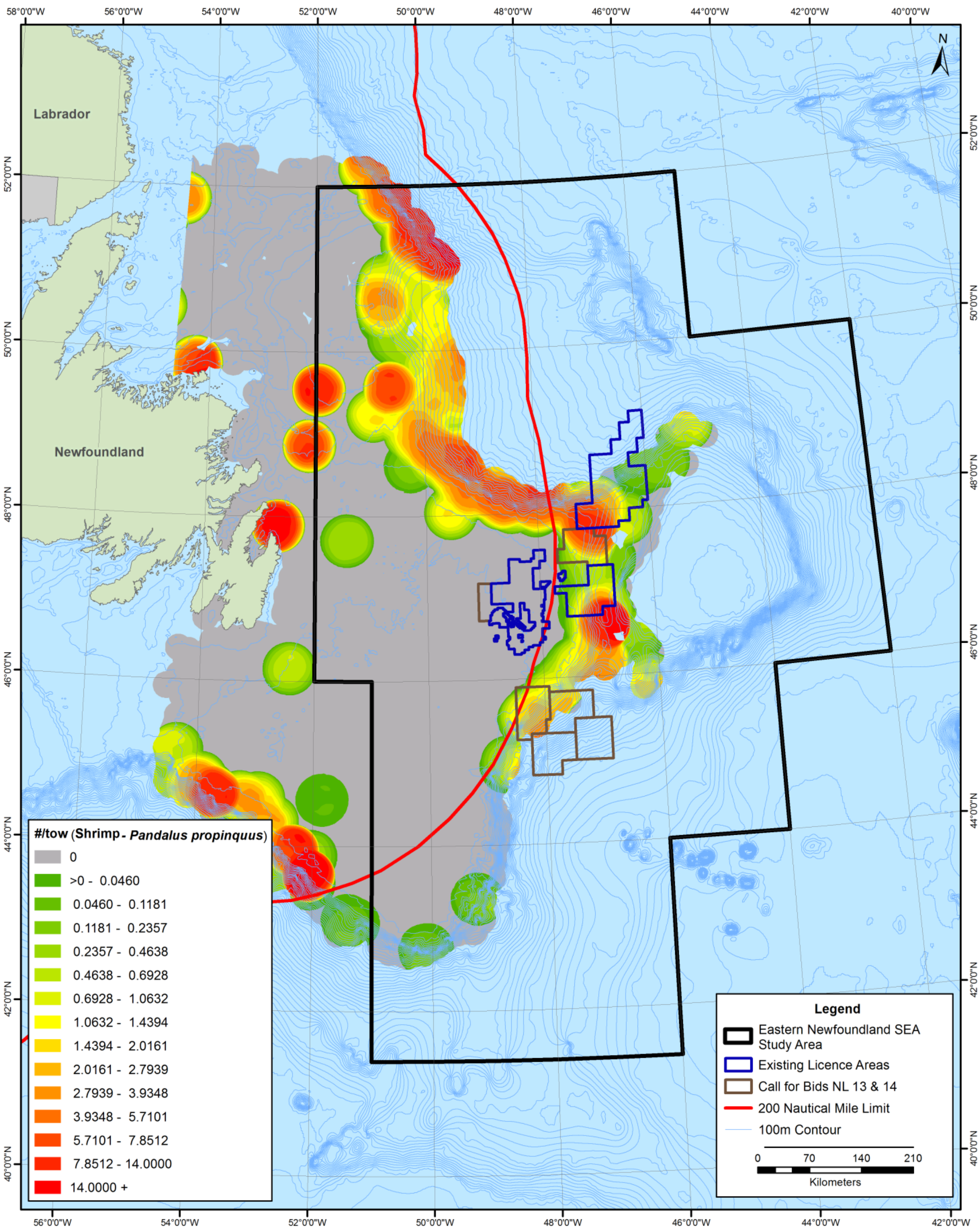
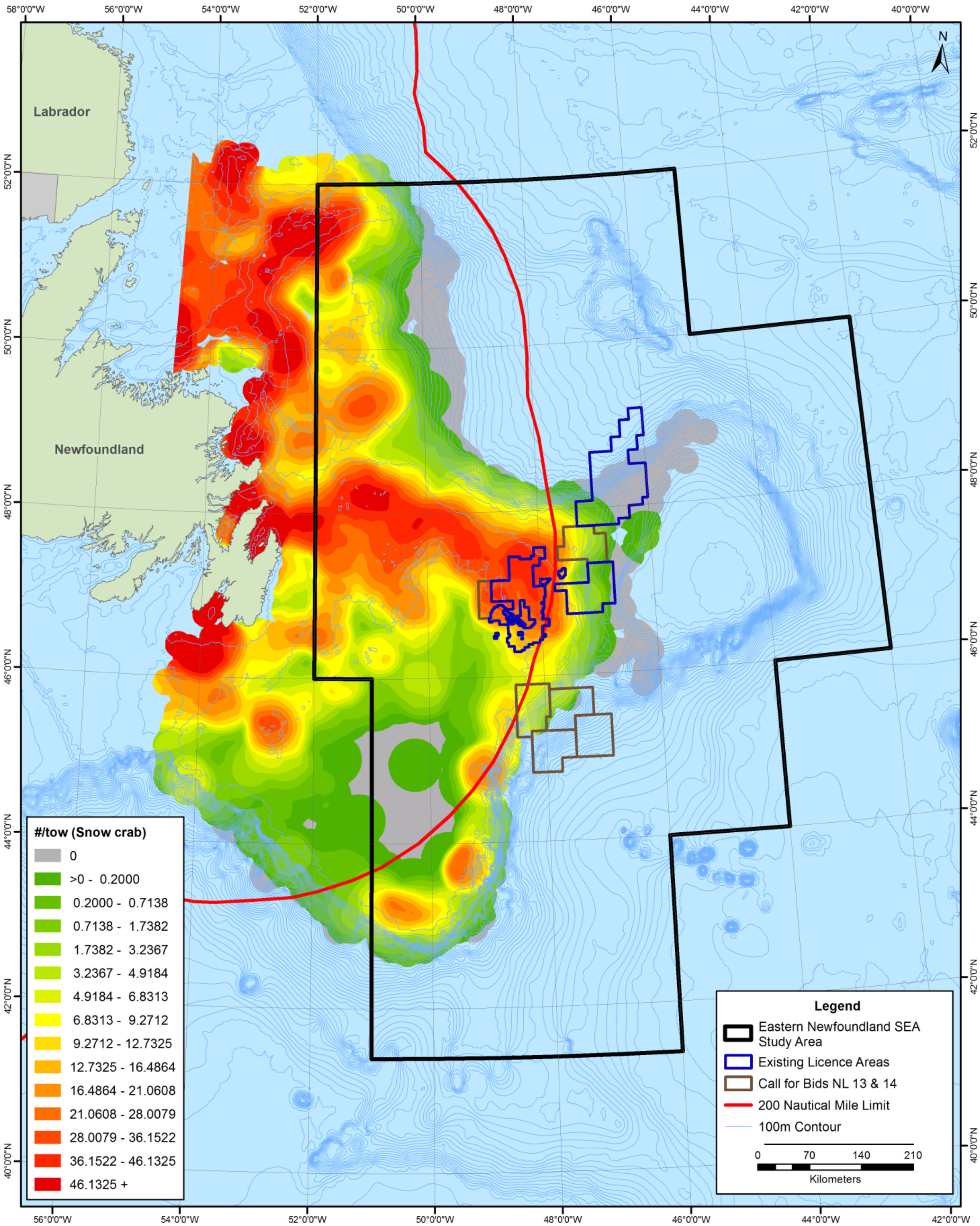


Figure 4.71 Distribution and Abundance of Snow Crab in the SEA Study Area (2005-2009 Surveys)



Corals, Sea Pens and Sponges

Deep-sea corals, sea pens and sponges are sessile, habitat-forming organisms that are an important component of the deep sea environment. They provide structural complexity on the seafloor, thus creating refuge and foraging habitat for a variety of fish and invertebrates (Watanabe et al 2009; NAFO 2013b) including those harvested commercially (Gilkinson and Edinger 2009; Baillon et al 2012). The provision of such habitat is reflected by the increased biodiversity associated with deep-sea corals, sea pens and sponges (Buhl-Mortensen et al 2010; Beazley et al 2013; NAFO 2013b). Other contributions of sponges and sea pens have been reviewed by NAFO (2013b). For example, the immense filter feeding capacity of sponges also contribute to benthic-pelagic coupling through nitrogen and carbon cycling. Even the spicule mats left behind by dead sponges can contribute to unique faunal communities. Other organisms such as sea pens can use peristaltic movements to bioturbate the sea floor, bringing food and nutrients to the surface where they are accessible to a variety of animals..

Corals, sea pens and sponges are sensitive to bottom disturbance such as trawling and oil and gas infrastructure placement due to their vertical structure, fragile nature and slow growth (Campbell and Simms 2009, Watanabe et al 2009). Within the coral group, black corals, and large and small gorgonians are considered most vulnerable to disturbance due to the inability of these organisms to reattach to the substrate after being dislodged (Gilkinson and Edinger 2009).

Collectively, sea pens, soft corals, stony corals, and sponges are represented across the shelf, slopes and banks of the Study Area but are found at their highest densities along the slopes (Wareham and Edinger 2007; Gilkinson and Edinger 2009; DFO 2010; Murillo et al 2011). This widespread distribution is reflected from RV survey sponge and coral data collected on the Grand Banks (Figure 4.72). Beyond the Canadian EEZ, corals are abundant along the slopes of the Flemish Cap (600 m to 1,300 m; Murillo et al 2011) and along the western Tail of the Grand Banks. The Orphan Knoll (specifically Tobin's Point) is also a high density area for black corals (Wareham and Edinger 2007). The coral diversity of the Flemish Cap include 21 species of soft corals and gorgonian sea fans (alcyonaceans), 11 species of sea pens (pennatulaceans), two species of cup corals (solitary scleractinians), and three species of black coral (antipatharians) (Table 4.61; Murillo et al 2011). Mud substrates were used by sea pens and cup corals while black corals, soft corals and sea fans were common on bedrock and gravel. NAFO models derived from known coral locations (Knudby et al 2013), indicate that the slopes of the Flemish Cap (except the southern portion) and the Tail of the Grand Banks are important for sea pens, the eastern slopes of the Flemish Cap and the northern Flemish Pass are important for large gorgonians and the slopes around the entire Flemish Cap are important for black corals. The Flemish Cap, the Flemish Pass and the Tail of the Grand Banks are considered important for sponges (NAFO 2011). The slopes of the Flemish Cap are dominated by axinellid and polymastid sponges, while deeper areas of the Flemish Pass were characterized by geodiids and Asconema sp. (Beazley et al 2013).

Areas of high abundance for corals, sea pens and sponges have been identified by DFO and NAFO in the SEA Study Area (Figure 4.73; NAFO 2014). For example, large gorgonians are found at relatively high density on the Flemish Pass, the eastern tip of the Flemish Cap and along the continental slope in the northern parts of the region. High densities of small gorgonians are also found on the northern slope but other locations occur on the Tail of the Grand Banks. Black corals are found at their highest densities in the Flemish Pass, the northern Flemish Cap and Tobin's Point (Orphan Knoll) while important areas for sea pens are aggregated in the Flemish Pass, the northern Flemish Cap and in one location on the Tail of the Grand Banks. Sponges, in contrast, are more widely distributed and high densities can be found along the eastern slopes of the Grand Banks, around the Flemish Cap and along the northern slopes of the SEA Study Area.

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In response to the known sensitivity of coral and sponge grounds, many important coral and sponge areas have been designated as Vulnerable Marine Ecosystems (VMEs) (DFO 2012c) and are protected from damaging fishing activities in Canadian and NAFO waters (Campbell and Simms 2009, NAFO 2013a; Figure 4.73). However, some other areas that host considerable diversity (Beazley et al 2013), such as the southern slope of the Flemish Cap are unprotected (NAFO 2013b).

More recently other taxa groups have been identified as indicators of VMEs. Of 500 taxa examined, NAFO (2011) determined that crinoids, erect bryozoans and the large sea squirts met their criteria of fragility, vulnerability, recoverability and all played a significant role in the ecosystem as structure forming entities. Areas of concentration are not well understood (NAFO 2011) but are thought to occur in highest densities on the Tail of the Grand Banks (erect bryozoans and large sea squirts), the Sackville Spur, Flemish Pass and on the slopes of the Flemish Cap (crinoids) (NAFO 2014).

Table 4.61 Coral Occurrence Within the SEA Study Area

Order	Family	Species	Area				Occurrence (%)
			Flemish Cap	Flemish Pass	Grand Banks	Northeastern Slope	
Alcyonacea		Alcyonacea indet.	●				1.23
	Clavulariidae	Clavulariidae indet.	●		●		1.47
		Telestula septentrionalis	●				2.7
	Alcyoniidae	*Anthomastus* spp.	●	●	●		4.17
		Anthomastus sp.	●	●	●		14.22
	Nephtheidae	*Duva florida*	●	●	●	●	62.25
		Gersemia rubiformis		●	●		6.13
		Nephtheidae indet.	●	●	●	●	25
	Anthothelidae	*Anthothela grandiflora*	●				0.74
	Paragorgiidae	*Paragorgia arborea*		●		●	0.49
		Paragorgia johnsoni	●				0.98
	Acanthogorgiidae	*Acanthogorgia armata*	●	●			2.7
	Plexauridae	*Paramuricea* sp.	●				0.25
		Paramuricea spp.	●	●		●	3.68
		Placogorgia sp.	●				0.49

Order	Family	Species	Area: Flemish Cap	Area: Flemish Pass	Area: Grand Banks	Area: Northeastern Slope	Occurrence (%)
		Swiftia sp.	●				0.74
	Chrysogorgiidae	*Radicipes gracilis*	●	●	●		4.66
	Isididae	*Acanella arbuscula*	●	●	●	●	12.5
		Keratoisis sp.	●	●	●		1.23
	Primnoidae	*Parastenella atlantica*	●				0.25
		Primnoa resedaeformis	●			●	0.74
Pennatulacea	Kophobelemnidae	*Kophobelemnon stelliferum*	●				2.7
	Funiculinidae	*Funiculina quadrangularis*	●	●	●		12.5
	Protoptilidae	*Distichoptilum gracile*	●	●	●		1.23
		Protoptilum sp.	●				0.25
	Umbellulidae	*Umbellula lindahli*	●	●	●		8.09
	Anthoptilidae	*Anthoptilum grandiflorum*	●	●	●	●	29.9
	Halipteridae	*Halipteris finmarchica*	●	●	●		13.48
		Halipteris cf. *christii*	●				3.43
	Virgulariidae	*Virgularia* sp.	●				0.25
	Pennatulidae	*Pennatula aculeata*	●	●	●	●	12.01
		Pennatula grandis	●	●	●	●	7.6
Antipatharia	Antipathidae	*Stichopathes* sp.	●				0.25
	Leiopathidae	*Leiopathes* sp.		●			0.49
	Schizopathidae	*Stauropathes arctica*	●	●		●	6.62
Scleractinia	Caryophylliidae	*Desmophylllum dianthus*	●	●			0.25
	Flabellidae	*Flabellum alabastrum*	●	●	●	●	13.48
Total Species		**37**	**34**	**22**	**17**	**11**	
Source: Murillo et al (2011)							

Figure 4.72 Distribution of Corals on the Grand Banks (NAFO Zones 3MNLO) Derived from DFO RV Surveys (2000-2012)

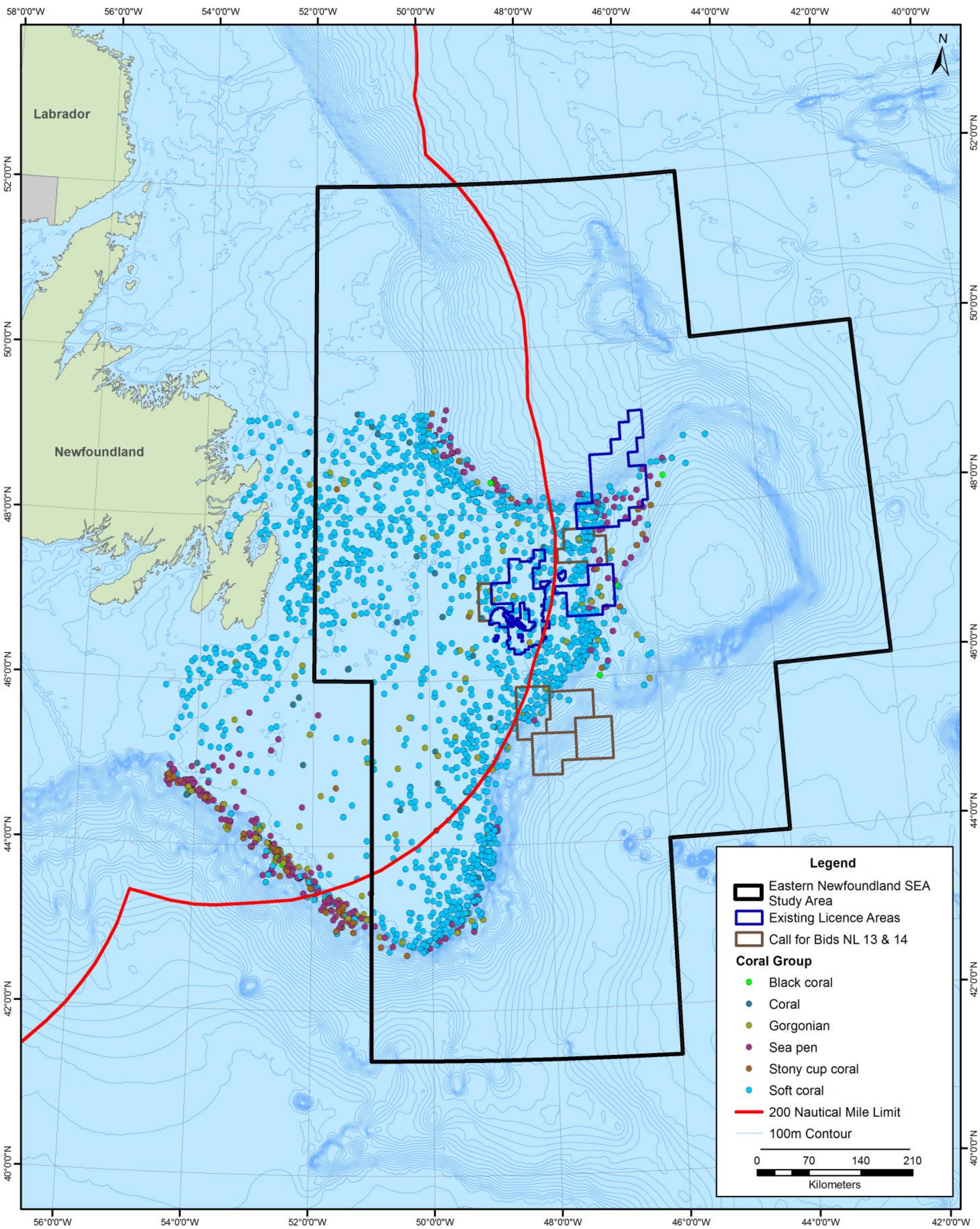
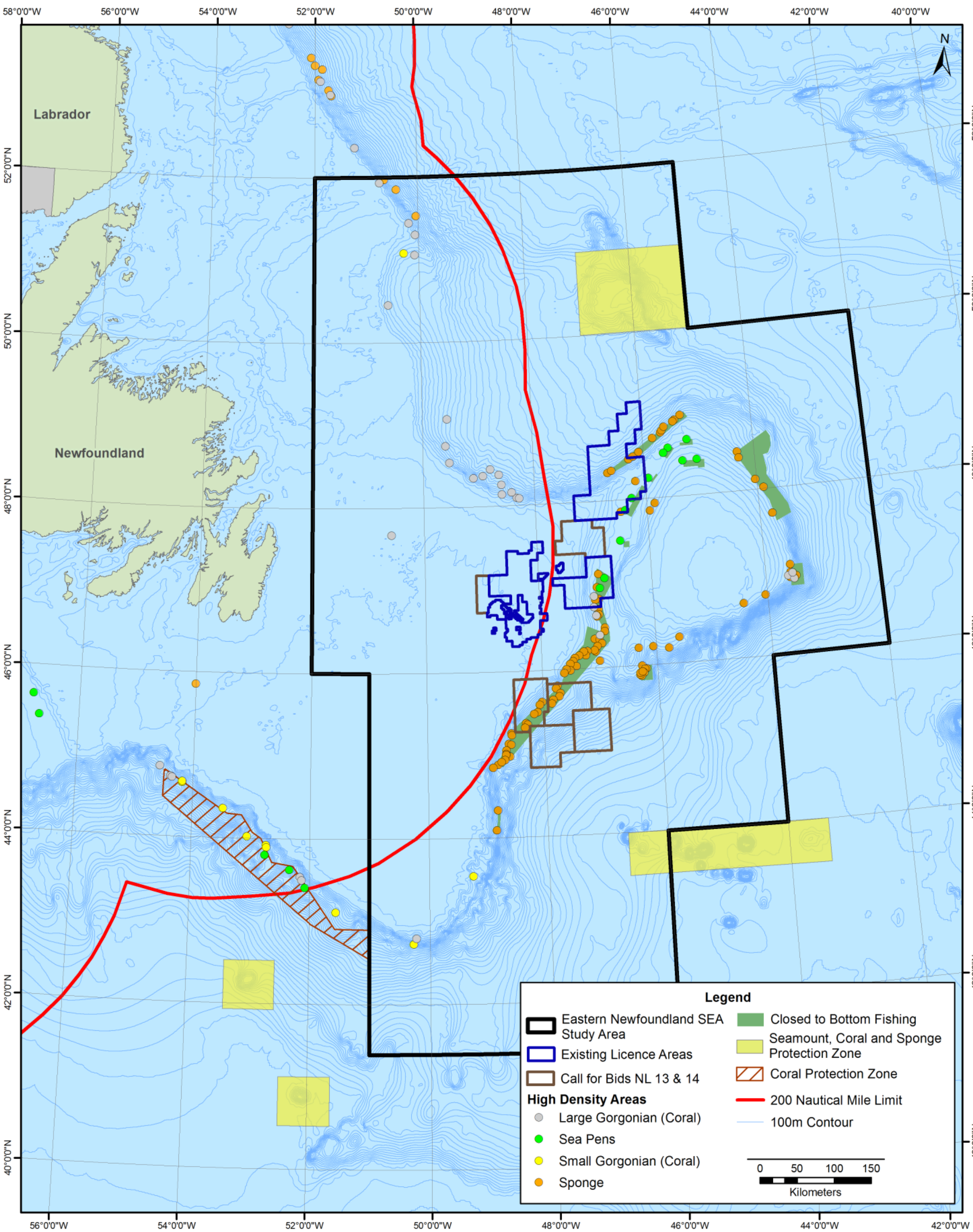


Figure 4.73 Identified Sensitive Coral Areas and Protection Zones for Corals, Seamounts and Sponges Within and Adjacent to the SEA Study Area



4.2.1.6 Marine Fish

A large number (approximately 188) and variety of marine fish species are known to occur in Newfoundland and Labrador waters (Templeman 2010). The occurrence of these species reflects their physiological and life history requirements, and their presence may vary according to habitat, environmental conditions and life history stage.

This section gives an overview of key marine fish species in the SEA Study Area, including general (and summarized) information on their ecology including life history, habitat preference and reproduction. Again, the tables and text that follow are not intended to provide an exhaustive list of every fish species that occurs in the region. Rather, the focus is on those that are known to represent the most numerically abundant, ecologically relevant and/or societally important species. This is followed by general information related to fish distribution and migration.

Life Histories, Habitat, and Spawning (Finfish)

Tables 4.62 and 4.63 describe demersal and pelagic marine fish species that are of particular ecological, socioeconomic and/or conservation importance in the SEA Study Area. These include their preferred habitats, distributions, spawning behaviour, and highlighting their known ecological and/or socioeconomic importance. Additional information on marine fish spawning, migration and regional distributions within the SEA Study Area is provided in subsequent sections.

Table 4.62 Overview of Some Key Groundfish Species in the SEA Study Area

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
Atlantic cod (*Gadus morhua*)	• Occurs on both sides of the North Atlantic. • Found in cool-temperature to subarctic waters from inshore regions to the edge of the continental shelf. • Depth of habitat is usually related to temperature; cool temperatures are preferred, in 0.5–10°C range. • Cod occur throughout the Canadian Atlantic Area, and each region has unique stocks. • Juveniles are found in greater abundance in inshore areas (Gregory and Anderson 1997). • Commonly observed species in 3NLOPs from RV surveys. • Widespread Shelf Assemblage. • Applicable Designatable unit: Newfoundland and Labrador	• Over the whole Canadian Atlantic region, spawning begins in the north as early as February and ends in the south as late as December. • Due to the fact that cod spawn over such a large area, it is difficult to generalize about specific conditions. • The depth at which cod spawn varies according to the particular stock, locality, and temperature and can vary from 110 m to 182 m. • Cod are broadcast spawners and fertilized eggs drift toward nursery areas in surface currents. • EBSA sites Southeast Shoal and Tail of the Banks and Virgin Rocks are spawning areas for Atlantic cod (Templeman 2007).	• Has COSEWIC (Newfoundland and Labrador Population) and IUCN status. • Commercially significant species. • Culturally and ecologically important species.
American plaice *(Hippoglossoides platessoides)*	• Usually considered a coldwater species, with a preference for temperatures from just below 0 to 1.5°C and a depth range of 90–250 m.	• Spawning occurs in spring, beginning early April on the Flemish Cap and Late April on the Grand Bank. • Eggs float near the surface	• Has COSEWIC status (Newfoundland and Labrador Population). • Commercially significant species.

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
	• Occurs on both sides of the Atlantic, can tolerate lowered salinities and have been reported in salinities as low as 20 – 22 ppt. • Commonly observed species in 3NLOPs from RV surveys. • Widely distributed on the shelf. • Widespread Shelf Assemblage. • Applicable Designatable units: Division 3LNO, Division 3Ps and Division 2J3K (DFO 2012h).	and drift widely from their point of origin. • Time to hatching depends on water temperature in the surface layers, but at 5°C hatching occurs in 11 – 14 days. • EBSA sites Southeast Shoal and Tail of the Banks and Virgin Rocks are spawning areas for American plaice (Templeman 2007). • Feeds on polychaetes, echinoderms, molluscs, crustaceans and fish.	
Atlantic halibut (*Hippoglossus hippoglossus*)	• The largest of the flat fishes, and typically found along the slopes of the continental shelf. • Atlantic halibut move seasonally between deep winter waters and the shallow waters of the Gulf where they feed. • The migration allows them to avoid temperatures below 2.5°C. • Found almost exclusively in the spring in the Southwest Shelf Edge and Slope EBSA. • Warm Southern Shelf Assemblage.	• Spawning grounds of the Atlantic halibut are not clearly defined. • Fertilized eggs are slightly positively buoyant so that they naturally disperse and only gradually float toward the ocean's surface. • Once hatched, the developing larvae live off their yolk for the next six to eight weeks while their digestive system develops so they can begin feeding on zooplankton. • Feeds on polychaetes, molluscs, crustaceans and fish.	• Commercially significant species.
Atlantic wolffish (*Anarhichas lupus*)	• Occurs on both sides of the North Atlantic Ocean. • Commonly an inhabitant of deep water along the shelf (Dutil et al 2010). • In the Newfoundland area, it occurs over a variety of substrates at depths of <100-400 m and bottom temperatures of -0.5 to 6.5°C (Kulka et al 2004; Simpson et al 2012). • Warm Southern Shelf Assemblage.	• Shows a wide variability in time and place of spawning. • Demersal eggs. • Feeds mainly on bottom invertebrates including crustaceans and echinoderms (Simpson et al 2012; 2013). • Spring surveys indicated that Atlantic wolffish are concentrated in EBSA site Southeast Shoal and Tail of the Banks (Templeman 2007).	• Has SARA and COSEWIC status. • Not commercially significant in the region, however may be retained and sold in some areas.
Barndoor skate (*Dipturus laevis*)	• Found on a variety of substrates from shoals to depths of 750 m. Common at depths of 50-150 m (COSEWIC 2010). • Preferred Temperature range is 3-13°C. • Migrates offshore to seek cool	• Spawning likely takes place during winter months. • Eggs are laid in large yellowish egg capsules. • Feeds on bivalves, squid, rock crabs, lobster, shrimp and polychaetes.	• Has IUCN status. • Not commercially significant in the region.

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
	temperatures. • High catch rates of this species in Southeast Shoal and Tail of the Banks EBSA (Kulka et al 2002; Templeman 2007). • Warm Southern Shelf Assemblage.		
Black dogfish (*Centroscyllium fabricii*)	• Small, deepwater shark occurring near bottom, at times forming schools. • Usually occurring at depths of 350 - 500m in Canadian waters (Kulka 2006). • Bottom temperatures where most captures have occurred were 3.5 – 4.5°C. • Deep Demersal Assemblage.	• Fertilized eggs develop within the brood chamber of the female. • Feeds mainly on squid, crustaceans, jellyfish and small redfish.	• Not commercially significant in the region.
Blue hake (*Antimora rostrata*)	• Benthopelagic species associated with mud bottoms. • Distributed in slope waters along the eastern Grand Bank at depths >1400m (Kulka et al 2003) • Bottom temperatures where most captures have occurred were 3 – 4.5°C (Kulka et al 2003b). • Deep Demersal Assemblage.	• Little is known about the reproductive phase of this species. Blue hake may spawn in Canadian waters though it has not been confirmed (Kulka et al 2003b). • Feeds on benthic invertebrates including crustaceans and squids.	• Not commercially significant in the region.
Cusk (*Brosme brosme*)	• Lives on hard, rough or rocky bottom, preferring relatively warm water and intermediate depths. • Found in moderately deep water on both sides of the North Atlantic. • In the Canadian region more common on southwestern Scotian Shelf and Slope and Fundian Channel. • Warm Southern Shelf Assemblage	• Reproductive biology not known for the northwest Atlantic. • Larvae are pelagic until they reach about 50 mm, after which they seek bottom areas. • Feeds on fish, crustaceans, molluscs and echinoderms (Bowman et al. 2000). • Monotypic species.	• Has COSEWIC status. • Not commercially significant in the region.
Greenland halibut (*Reinhardtius hippoglossoides)*	• A deepwater flatfish species that occurs in water temperatures ranging from -0.5 to 6°C but appears to have a preference for temperatures of 0 to 4.5°C. • Occupies an extensive depth range from 200m to 2200 m. • Unlike many flatfishes, the Greenland halibut spends considerable time in the pelagic zone (Morgan et al 2013). • Distributed across areas of the	• These halibut are believed to spawn in Davis Strait during the winter and early spring at depths ranging from 650 to 1,000 m. • The large fertilized eggs are benthic but the hatched young move upwards in the water column and remain at about 30 m below surface until they attain an approximate length of 70 mm. • As they grow, the young fish	• Commercially significant species

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
	Grand Bank and Flemish Pass (Morgan et al 2013). • Aggregates in Northeast Shelf and Slope EBSA in the spring (Templeman 2007). • Deep Demersal Assemblage.	move downward in the water column and are transported by the currents in the Davis Strait southward to the continental shelf and slopes of Labrador and Newfoundland. • Bathypelagic predator that feeds on capelin, Atlantic cod, polar cod, roundnose grenadier, redfishes, sand lance, shrimp, squid and other benthic invertebrates.	
Haddock (*Melanogrammus aeglefinus*)	• Found in southwest Newfoundland and St. Pierre Bank. • High concentrations observed in the Southwest Slope of the Grand Banks EBSA (Templeman 2007). • Found in water depths of 27 to 366 m and prefer temperatures of 1 to 13°C. • Occurs in a variety of habitats; juveniles have higher survival rates when they settle on sand or gravel bottoms.	• Generally haddock spawning on the Grand Banks begins in March and continues through to August or September. Spawning peaks in March. • Pelagic eggs and larvae. Larvae seek the bottom once they reach about 50 mm. • Haddock on the Grand Banks primarily spawn in Southwest Shelf Edge and Slope EBSA (Templeman 2007). • Bottom feeding fishes that consume crustaceans, molluscs, echinoderms, polychaetes and fish.	• Commercially significant species
Longnose eel (*Synaphobranchus kaupi*)	• Occurs on both sides of the North Atlantic Ocean to South Atlantic Ocean, in the Pacific Ocean and Gulf of Mexico. • Bottom-dwelling fish occurring in deep water between 240-3650 m. • Commonly observed in the Grand Bank and Eastern Offshore SEA Study Area (Baker et al 2012; LGL 2012). • Deep Demersal Assemblage.	• Spawns during summer months.	• Not commercially significant in the region.
Longfin Hake (*Physis chesteri*)	• Deepwater species that occupies a depth range of 160-1290 m. • Occurs along Labrador to the southern edge of the Grand Bank. • Commonly observed species in 3NLOPs from RV surveys. • Warm Deep Offshore Shelf Assemblage.	• On the Grand Bank and Flemish Pass, spawning is estimated to take place between fall and winter. • Larvae and juveniles remain pelagic during winter and spring. • Juveniles and larvae are preyed upon by white hake and cod. • Feeds mainly on shrimp,	• Not commercially significant in the region

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
		euphausiids and amphipods. Also known to feed on vertically migrating fishes including lanternfish and hatchetfish.	
Marlin-spike (*Nezumia bairdi*)	• A benthic species, usually living on mud bottoms. • It has been caught at depths of 16 – 2285 m but was found to be most abundant off Newfoundland in 183 – 732 m. • Its distribution in the western Atlantic occurs in deeper parts of the Gulf of St. Lawrence; in the Bay of Fundy; from the southwestern Grand Bank; banks of the Scotian Shelf; and southward along the continental slope of the West Indies. • Bottom temperatures where marlin-spike have been found range between 3 and 8°C. • Commonly observed species in 3NLOPs from RV surveys. • Deep Demersal Assemblage.	• Information on reproduction is sparse, but the species most likely spawns in summer and autumn. • Assumed to be a long-lived, slow growing species. • Feeds on benthic euphausiids and amphipods. • Preyed upon by swordsfish.	• Not commercially significant in the region
Monkfish (*Lophius americanus*)	• Bottom-dwelling sluggish fish living over a variety of substrates, from tideline down to 668 m. • Tolerates a wide variety of temperature, 0 to 21°C. Common in areas >4°C (Kulka and Miri 2001). • Research shows that they invade shallow waters of the banks in summer and migrate to deeper waters in winter. Associated with deep waters along the western Grand Bank (Gomes et al 1992). • High concentrations observed in the Southwest Shelf Edge and Slope EBSA (Templeman 2007). • Warm Southern Shelf Assemblage	• Spawning occurs from June to September in Canadian waters. • Larvae hatch on the surface and descend to the bottom where they seek protection among algae-covered rocks. • Feeds on fish including herring, sand lance, smelt, cod, haddock, cunner, sculpin, flounder, skates and invertebrates including crab, squid, molluscs, echinoderms and polychaetes.	• Commercially significant species
Northern wolffish (*Anarhichas denticulatus*)	• Occurs in Arctic and Atlantic Oceans. • The preferred temperature of wolffish is less than -0.8-7°C (Simpson et al 2012). • Found in deep waters (150-1000 m) on the Grand Bank and Flemish Cap in the spring	• Information on reproduction is limited. • Critical spawning habitats have not been identified. • Pelagic larvae. • Feeds mainly on euphausids, shrimp, and American plaice and redfish	• Has SARA and COSEWIC status. • Not commercially significant in the region. • Mandatory live-release when captured as bycatch.

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
	and fall (Simpson et al 2012). • Grand Bank Shelf Assemblage..	(Simpson et al 2012; 2013).	
Northern Sand Lance (*Ammodytes dubius*)	• Occurs on sandy or fine gravel bottoms at offshore depths <91 m. • Inhabit localized areas. • High densities observed on the eastern and South East Shoal of the Grand Bank. • Shelf Edge Assemblage.	• On the Scotian Shelf spawning occurs from November to March. Spawning peaks from December to January. • Aggregate on the Southeast Shoal and Tail of the Banks EBSA to spawn. • Larvae are planktonic until they reach 35 mm, after which they seek bottom areas. • Burrows in substrate during part of the day and undertakes short vertical feeding migrations (Scott 1973). • Feeds mainly on copepods and other planktonic organisms. • Important forage species that are prey for a variety of fish, birds and mammals.	• Not commercially significant in the region. • Important forage fish species.
Pollock (*Pollachius virens*)	• Juveniles are common in shallow inshore waters, while adults live in deeper inshore waters or on offshore banks. • Adults prefer a depth range of 110 to 181 m. • Can withstand a range of temperatures, from 0 to 18°C, but prefer a range of 7.2 to 8.6°C. • Distributions mainly restricted to the slope waters of the Burgeo and St. Pierre Banks. • Congregates mainly in Southwest Shelf Edge and Slope EBSA (Templeman 2007). • Warm Southern Shelf Assemblage.	• On Burgeo and St. Pierre Banks, pollock of various stages of maturity are encountered during surveys indicating spawning. • An average female produces approximately 225 000 pelagic eggs. • Feed mainly on copepods.	• Not commercially significant in the region
Redfish (*Sebastes mentella*, *Sebastes fasciatus)*	• Redfish typically occur in cool waters (3.0 to 8.0ºC) along the slopes of fishing banks and deep channels in depths of 100 to 700 m. • In the western Atlantic, redfish species range from Baffin Island in the north to the waters off New Jersey in the south. • The three redfish species that	• Ovoviviparous, the fertilized eggs develop within the brood chamber of the female. • Mating occurs in the fall months and the larvae subsequently hatch from the eggs inside the female. • The larvae feed exclusively on energy stored in the yolk, develop inside the female	• Has COSEWIC (Atlantic Population and Northern Population) and IUCN status. • Commercially significant species

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
	occur in the Northwest Atlantic include *Sebastes mentella*, *S. fasciatus*, and *S. marinus*. The latter species is relatively uncommon except in the area of the Flemish Cap. • *S. mentella* is typically distributed deeper than *S. fasciatus* (Gascon 2003). • *S. mentella* a commonly observed species in 3NLOPs from RV surveys. • Redfish larvae have been found in association with sea pen fields (Baillon et al 2012). • Warm Deep Offshore Shelf Assemblage. • Applicable designatable unit: 2+3KLNO; Northern Population Designatable Unit.	and eventually are released as young fish sometime between April and July (Gascon 2003; Ollerhead et al 2004). • Redfish larvae have dominated the ichthyoplankton within the SEA area (Serebryakov et al 1987). • Southwest Shelf Edge and Slope EBSA is an important spawning area for redfish.	
Roughhead grenadier (*Macrourus berglax*)	• Mainly inhabits deep water between 600 - >1,000 m (Edinger et al 2007). • Abundant at 200-400 m in association with large gorgonian and antipatharian corals (Edinger et al 2007) • Abundant at 400-1000 m in association with soft corals (Edinger et al 2007). • On the Grand Banks, greatest catches occur in areas between 2.0 – 3.5°C and depths of 183 – 503 m. • Deep Demersal Assemblage.	• Little is known about spawning habits. • Spawning is predicted to occur between winter and early spring on the southern and southeastern slopes of the Grand Banks. • Slow growing species with late maturation. • Feeds on benthic invertebrates including bivalves, shrimp, echinoderms and some fish.	• Has COSEWIC status. • Commercially significant species.
Roundnose grenadier (*Coryphaenoides rupestris*)	• Mainly Inhabits deep water between 600 - >1,000 m (Edinger et al 2007). • Abundant at 400-600 m in association with gorgonian corals (Edinger et al 2007). • In Newfoundland waters greatest catches occurred at depths >500 m at temperatures between 3.5 – 4.5°C. • Deep Demersal Assemblage.	• Little is known about spawning habits. • Spawning is predicted to occur in late autumn and spring. • Vertically distributed by maturity. Percentage of mature fish captured increases with depth. • Feeds on small crustaceans, euphausiids, squid and small fishes.	• Has COSEWIC status. • Commercially significant species.
Sculpin (*Triglops* sp.)	• Boreal cool-water benthic marine group of species that occur from shallow to deep depths. • Commonly observed species in 3NLOPs from RV surveys. • Grand Bank Shelf Assemblage.	• Spawning generally occurs from late summer to late fall. • Feeds on small crustaceans including mysids and amphipods. • Preyed upon by cod and thick-billed murres.	• Not commercially significant in the region • Important forage fish species.

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
Smooth skate (*Malacoraja senta*)	• Distributed between depths of 70 – 480 m (Kulka et al 2006). • Generally occur on soft mud and clay substrates over a range of depths (COSEWIC 2012a). • Densest concentrations of this species are in waters between 3 - 10°C (COSEWIC 2012a; (Kulka et al 2006). • Widespread Shelf Assemblage	• Slow to reproduce with 40-100 large egg capsules per year (COSEWIC 2012a). • Hatching takes 1-2 years and have been found on the bottom at various times of the year (COSEWIC 2012a). • Egg capsules are eaten by gastropods, halibut, monkfish and Greenland sharks (COSEWIC 2012a). • Feed mainly on crustaceans, euphausiids, mysids and some fish.	• Has COSEWIC (Funk Island Deep Population) and IUCN status. • Not commercially significant in the region.
Spotted wolffish[1] (*Anarhichas minor*)	• Occurs on both sides of the North Atlantic. • Mainly captured in deeps waters of <500 but large catches have occurred at depths of <350 m (Simpson et al 2012). • Usually occurs at temperatures of -1 - 6°C (Simpson et al 2012). • Tagging studies indicated that migrations are local and limited. • Greatest proportion of this species aggregates in the Northeast Shelf and Slope EBSA in the spring (Templeman 2007). • Warm Deep Offshore Shelf Assemblage.	• Information on reproductive activities in western North Atlantic Ocean is minimal. • Studies have shown that wolffish in the Newfoundland area spawn in mid to late summer from July to September (Templeman 1986). • Feeds mainly on invertebrates including shrimp and echinoderms (Simpson et al 2012; 2013).	• Has SARA and COSEWIC status. • Not commercially significant in the region. • Mandatory live-release required when captured as bycatch.
Spiny dogfish (*Squalus acanthias*)	• Widely distributed in coastal waters of temperate seas throughout the world. • Small, schooling shark frequenting coastal and inshore waters in cold to warm temperate oceans. Usually found at temperatures of 6 – 15°C. Tolerant at low salinities and may ascend estuaries. • Preferred depth of 100-250m (Kulka 2006). • Warm Southern Shelf Assemblage.	• Ovoviviparous, developing young are in the brood chamber of the female. • Gestation period is long, about 22 months, one of the longest for any vertebrate animal. • Spiny dogfish is slow-growing and long-lived. • Opportunistic feeder that consumes mainly small fishes. • Juvenile dogfish are prey to various fish and sharks.	• Has COSEWIC (Atlantic Population) and IUCN status. • Commercially significant species.
Thorny skate (*Amblyraja radiata*)	• A boreal to arctic species living offshore on hard and soft bottoms at depths of about 18 – 966 m and at temperatures of -1.4 to 14°C. • Occurs in eastern and western	• Spawning on the Scotian Shelf peaks in May and October. • Feeds mainly on polychaetes, amphipods, decapods and fishes.	• Has COSEWIC and IUCN status. • Commercially significant species.

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
	North Atlantic. • Widespread Shelf Assemblage	• Egg cases are eaten by Greenland sharks and halibut.	
Vahl's eelpout (*Lycodes vahlii*)	• Occurs of Newfoundland in depths of 200-600 m in temperatures from 2.0-4.5°C. • Captured at average depths of 410 m in the Orphan Basin during the spring and fall respectively (LGL 2012). • Occurs on both sides of the Atlantic Ocean. • Northern Shelf Assemblage.	• Feeds on polychaetes, small crustaceans and molluscs. • Has large eggs and low fecundity.	• Not commercially significant in the region
White hake (*Urophycis tenuis*)	• Prefer temperatures 4.0 to 8.0°C (Kulka et al 2005) • Occurs at depths between 200-1,000 m over mud bottoms however common at depths of <300 m (Han and Kulka 2009) • Occurrence on the Grand Bank mainly along the southwest slope (Templeman 2007). • Warm Southern Shelf Assemblage.	• Spawning is thought to occur in spring and early summer. • Eggs, larvae and early juveniles are pelagic and remain close to the surface (Han and Kulka 2009). • Juveniles are commonly observed in inshore areas • Sand-hiding behaviour has been observed in young hake (Han and Kulka 2009). • Feeds mainly on fish including herring, other hake species, and mackerel	• Commercially significant species.
Winter skate (*Leucoraja ocellata*)	• Restricted to the northwest Atlantic. • A benthic species living over sand or gravel bottoms usually in depths less than 110 m. • Warm Southern Shelf Assemblage.	• Mating most likely occurs throughout the year and peaks offshore in the summer. • Slow to reproduce with 40-70 egg capsules per year (McPhie and Campana 2009; Kelly and Hanson 2013). • Feeds mainly on amphipods, polychaetes, squid and some fish (e.g. sand lance are an important prey item).	• Has COSEWIC (Georges Bank-Western Scotian Shelf-Bay of Fundy Population) and IUCN status. • Not commercially significant in the region.
Witch flounder (*Glyptocephalus cynoglossus*)	• Inhabits mud or mud-sand bottoms. • Mainly occurs at depths of 185 – 366 m in areas associated with deep holes and channels between banks. • Captured at average depths of 432 and 487 m in the Orphan Basin during the spring and fall respectively (LGL 2012). • Deep Demersal Assemblage.	• Spawning occurs between March and September and peaks in July and August on the Grand Bank Region. • Eggs and larvae are pelagic. • Young flounder remain in a pelagic state for about a year before settling on the bottom. • Slow growing, long lived species. • Feeds mainly on polychaetes, amphipods,	• Commercially significant species.

Species	Habitat and Distribution	Biology and Ecology	Use and Importance[1]
		molluscs and small fishes.	
Yellowtail flounder (*Limanda ferruginea*)	• Inhabits mud or mud-sand bottoms. • On the Grand Banks mainly found at depths between 57 – 64 m and temperatures between 3.1 - 4.8°C. • Commonly observed species in 3NLOPs from RV surveys. • Grand Bank Shelf Assemblage.	• Spawning occurs between spring and summer with peaks from mid- late June on the Grand Banks. • Eggs are deposited near the bottom and float to the surface where they drift during development. • Aggregates in Virgin Rocks EBSA to spawn (Templeman 2007). • Southeast Shoal and Tail of the Banks EBSA is an important nursery area for this species (Templeman 2007). • Feeds mainly on polychaetes and amphipods and some small fish.	• Commercially significant species
Sources: Summarized from Scott and Scott (1988) unless otherwise noted [1]Species conservation status or designation is described further in a later Table			

Table 4.63 Overview of Some Key Pelagic Species in the SEA Study Area

Species	Habitat and Distribution	Biology and Ecology	Use and Impotance[1]
Albacore tuna (*Thunnus alalunga*)	• Albacore tuna is a cosmopolitan species and has been captured on the Grand Banks. • Epipelagic and mesopelagic oceanic species. • Abundant in surface waters at 15.6 - 19.4°C (Collette et al 2011). • Pelagic Assemblage.	• Spawns during spring and summer in sub-tropical waters (DFO 1998). • Spawning occurs at surface temperatures of <24°C (Collette et al 2011). • Feeds on pelagic fish, crustaceans and squid (Pusineri et al 2005).	• Has IUCN status. • Commercially significant species.
Atlantic bluefin tuna (*Thunnus thynnus*)	• Moves northward into Canadian waters in summer and southward again in late fall. • They occur over the continental shelf, off Newfoundland, and in the Gulf of St. Lawrence, at depths of 27–183 m, often in schools of less than 50 fish. • Bluefin tunas undertake extensive migrations, moving from the waters off Florida and the Gulf of Mexico as far as Newfoundland and the Gulf of St. Lawrence. • Pelagic Assemblage.	• Bluefin tuna do not reproduce in Canadian waters. Two major spawning areas in the western Atlantic are the Straits of Florida and the Gulf of Mexico. • Spawning occurs during April, May, and June in subsurface waters • At temperatures of 24.9 – 29.5°C in the Straits of Florida, hatching of eggs occurs in a few days. • Feed on pelagic and bottom fishes including capelin, saury, herring, mackerel and lanternfishes. Around Newfoundland, squid and capelin are important food sources.	• Has COSEWIC and IUCN status. • Commercially significant species.
American eel (*Anguilla*	• Found in the western North Atlantic. • Abundant in many tributaries of the	• The eel is unique to other fish in that it breeds at sea and the	• Has COSEWIC

Species	Habitat and Distribution	Biology and Ecology	Use and Impotance[1]
rostrata)	St. Lawrence River and Gulf, and rivers of Newfoundland and the Maritime Provinces. It occurs in estuaries, lakes and rivers (Jessop et al 2002) that have access to the sea. • During the freshwater phase of their life, eels move into streams, rivers, and muddy or silt-bottomed lakes.	young move into fresh water where they feed and grow. • After a number of years in freshwater they return to the sea to spawn, and presumably die. • The larvae feed on plankton. • Larvae are preyed upon by predaceous fishes.	status. • Recreational and commercial significance
Atlantic herring *(Clupea harengus harengus)*	• Primarily pelagic, and often in schools, occurring in the shallow inshore waters, or offshore from surface to depths of 200 m. • Observed at 450 m depths in multispecies surveys. • Research has demonstrated that Atlantic Herring has annual migratory patterns, such as movements to spawning grounds and feeding and wintering areas. • Occurs on both sides of the North Atlantic. It occurs in commercial quantities along the coast of southern Labrador, around the coast of Newfoundland and offshore banks, in the Gulf of St. Lawrence, along the coast of Nova Scotia and offshore banks, and the Bay of Fundy. • Pelagic Assemblage.	• Atlantic herring are demersal spawners depositing their adhesive eggs on stable bottom substrates (Reid et al 1999). • The species is known to spawn in coastal and offshore areas • Spawning times are stock specific. • Feeds mainly on plankton. • Important food source for other fishes, marine birds and marine mammals.	• Commercially significant species
Atlantic mackerel *(Scomber scombrus)*	• A pelagic fish common to the temperate waters of the open sea and is one of the most active and migratory fishes. • Occurs on both sides of the Atlantic Ocean. Mackerel are seen in Canadian coastal and inshore waters only during summer and fall. • Pelagic Assemblage.	• Usually spawn in coastal waters between Cape Cod and Cape Hatteras. • Larval hatching generally occurs within five to seven days at water temperatures of 11 to 14°C. • Strong schooling species. • Filter and selectively feeds on planktonic organisms. • Preyed upon by porbeagles, dogfish, Atlantic cod, bluefin tuna, swordfish, and marine mammals.	• Commercially significant species.
Atlantic salmon (*Salmo salar*)	• Occurs on both sides of the North Atlantic Ocean. • An anadromous species, living in fresh water and estuaries for at least the first 2 to 3 years of life before migrating to sea. • Cool rivers with extensive gravelly bottom headwaters are important habitat. • When about 15 cm long, young salmon migrate to sea, where they may live for 1, 2, or more years before returning to freshwater. • Salmon from various designated populations migrate through the SEA	• Atlantic salmon spawn in October and November in Canadian waters. • Eggs are buried in gravel by females and development continues over the winter. • The time required for the eggs to hatch varies with water temperature but is about 110 days at 3.9°C. • Atlantic salmon at sea consume amphipods and euphausiids, and fish including herring, alewives, smelt, capelin, mackerel, sand lance and cod.	• Has COSEWIC (Northwestern Newfoundland, Southern Newfoundland, and Southwestern Newfoundland Populations) and IUCN status. • Important recreational fishery.

Species	Habitat and Distribution	Biology and Ecology	Use and Impotance[1]
	Study Area.		• Historically commercially important species but no longer fished commercially in the area.
Basking Shark (*Cetorhinus maximus*)	• Highly migratory. • Pelagic shark occurring in coastal warm waters around Newfoundland during the summer and fall. • Mainly caught in waters ranging from 8-12°C. • Distributed mainly off southern Newfoundland, on the Scotian Shelf and in the Gulf of Maine (DFO 2008). • Pelagic Assemblage.	• Considered ovoviviparous with about 6 pups born at a time during summer (DFO 2008). • Aggregates from September to October for mating (Jacoby et al 2012). • Filter feeds on planktonic organisms.	• Has COSEWIC (Atlantic Population) and IUCN status. • Not commercially significant in the region.
Bigeye tuna (*Thunnus obesus*)	• Distributed worldwide in Atlantic, Indian and Pacific Oceans (FAO 2013). • Pelagic species occurring from the surface to 250 m depth in temperatures ranging from 13-29°C (FAO 2013). • Young fish school near the surface with other tuna species (DFO 1998). • Migrates through temperate waters such as the Eastern SEA Study Area after spawning. • Pelagic Assemblage.	• Spawning takes place approximately twice a year in inter-tropical waters (FAO 2013; DFO 1998). • Approximately 2.9 million to 6.3 million eggs released per spawning (FAO 2013).	• Has COSEWIC and IUCN status. • Commercially significant species.
Blue shark (*Prionace glauca*)	• A wide-ranging pelagic species in temperate waters, often occurring near the surface, preferring temperatures of 7 to 16°C. • Occurs worldwide in both inshore and offshore waters. In the western Atlantic from Newfoundland and the Gulf of St. Lawrence southward to Argentina. Most occurrences in Canadian waters are during summer months. • Pelagic Assemblage.	• As with all sharks, fertilization is internal. After eggs are fertilized, gestation requires 9 – 12 mo., and birth usually occurs during March to July. • Feeds mainly on fish and squids. Species consumed include herring, hake, cod, haddock, pollock, mackerel, butterfish, sea raven and flounders.	• Has COSEWIC (Atlantic Population) and IUCN status. • Commercially significant species.
Capelin (*Mallotus villosus*)	• A marine fish of cold, deep waters, found in the Atlantic Ocean on the offshore banks and in coastal areas. • The largest concentrations in Canadian waters are found off Newfoundland and the Labrador Coast. • Commonly observed species in 3NLOPs from spring RV surveys and in 3K2J in fall RV surveys. • Pelagic Assemblage.	• In the Northwest Atlantic spawning is typically conducted on beaches though some deepwater spawning sites are known (e.g. Southeast Shoal) • Spawning is marked by an intensive migration inshore in early spring to spawn on beaches throughout the spring-summer and return to offshore waters in autumn. • Where substrate conditions are	• Commercially significant species. • Important forage fish species.

Species	Habitat and Distribution	Biology and Ecology	Use and Impotance[1]
		suitable spawning beaches may be found in exposed, moderately exposed, and sheltered locations throughout the region. • Beach spawning is demersal with the eggs being deposited in the intertidal zone. Larvae are dispersed passively via currents. • Feeds mainly on planktonic organisms. • Major food source for other fish, marine birds and marine mammals. Preyed upon heavily by Atlantic cod.	
Greenland shark (*Somniosus microcephalus*)	• Inhabits cool northern waters from 0.6-12°C. • Occupies near surface areas in winter months in estuaries, shallow bays and coastal waters. • Occupies deep (600-1,200 m) cool waters during summer months. • Pelagic Assemblage.	• Ovoviviparous, with more than 10 pups at a time. • Feeds on a variety of fishes including herring, Atlantic salmon, Arctic char, capelin, redfish, sculpin, lumpfish, cod, haddock, halibut, and skate.	• Not commercially significant in the region.
Lanternfish (Myctophidae)	• Commonly observed species in 3NLOPs from RV surveys. • Deep sea pelagic fish. • Generally occur at depths of 300-1,200 m during the day and may migrate to surface waters at night. • Deep Pelagic Assemblage.	• Generally spawns during the spring to summer in the northwest Atlantic. • This group of fish are opportunistic planktivores that feed on copepods, euphausiids, ostracods and occasionally fish eggs and larvae.	• Not commercially significant in the region • Important forage fish species.
Porbeagle shark (*Lamna nasus*)	• A pelagic, epipelagic, or littoral shark usually more common on continental shelves but occurring sometimes well offshore. • Occurs in Atlantic, Pacific, and Indian Oceans. • More common in the Canadian region during spring, summer, and fall, usually found in temperatures below 16°C. • Pelagic Assemblage.	• Ovoviviparous, developing young are in the brood chamber of the female. Young sharks are born alive. • Mating grounds South of Newfoundland (DFO 2013c). • Little information on the rate of growth. • Feeds mainly on pelagic fish including herring, mackerel, cod, hake, haddock, and cusk. Squid are also eaten.	• Has COSEWIC and IUCN status. • Commercially significant species.
Shortfin mako shark (*Isurus oxyrinchus*)	• Extremely active, the shortfin mako shark is the fastest shark and one of the swiftest fishes. • The species is circumglobal in temperate and tropical waters. Individuals found in Atlantic Canada are considered part of a larger North Atlantic population. • Highly migratory with distribution apparently dependent on water temperatures (between 17 and 22°C). • They migrate to the Atlantic coast of	• Females mature at lengths of 2.7 to 3 m (corresponding to an age of about 17 years) and give birth to a litter size of 4 to 25 pups after a gestation period of approximately 15 to 18 months. • Lifespan has been estimated at 24 years with a maximum life expectancy of up to 45 years (DFO 2010b). • Feeds on fish including squid, mackerel, tuna, swordfish and bonitos.	• Has COSEWIC (Atlantic Population) and IUCN status. • Commercially significant species.

Species	Habitat and Distribution	Biology and Ecology	Use and Impotance[1]
	Canada generally in the late summer and fall where they are usually associated with the warm waters of the Gulf Stream (DFO 2010b). • Pelagic Assemblage.		
Swordfish (*Xiphias gladius*)	• Occurs in Canadian waters between June to November. • Distributed throughout a variety of depths from surface to over 500 m. • Pelagic Assemblage.	• Spawning occurs in the area of the Gulf of Mexico, Florida, the Caribbean Sea, south of the Sargasso Sea and waters off Brazil (Neilson et al 2006). • Eggs are buoyant. • Opportunistic feeders that feed on squid, mackerel, barracudinas, hake, redfish, herring and lanternfishes. • Young swordfish are consumed by blue shark, tunas and marlins.	• Commercially significant species.
White shark[1] (*Carcharodon carcharias*)	• Occurs in coastal and offshore waters of continental shelves, from surface waters to depths of 1,280 m. • Widespread in warm and cool temperate seas of all oceans, antitropical in Atlantic and Pacific oceans and contiguous waters. • Pelagic Assemblage.	• Reproduction is via internal fertilization with development characterized as ovoviviparous (Saïdi et al 2005). • Feeds on salmon, hake, halibut, mackerel, and tunas. Also known to consume other sharks, sea turtles, seabirds and marine mammals.	• Has SARA (Atlantic Population), and IUCN status. • Not commercially significant in the region
Sources: Summarized from Scott and Scott (1988) unless otherwise noted [1]Species conservation status or designation is described further in a later Table.			

Key Spawning Times and Areas

Various spawning behaviours are exhibited by marine fish in the SEA Study Area, which include broadcast spawners such as Atlantic cod, oviviparous spawners such as redfish, and species who leave eggs in demersal cases (e.g. skates). Moreover, spawning occurs in a variety of habitats both within and outside the SEA Study Area. Some species spawn in multiple locations across the Newfoundland Shelf, while others may be restricted to certain areas (e.g. yellowtail flounder are thought to be restricted to the Grand Banks in the SEA Study Area). Other species spawn outside the SEA Study Area in areas that include freshwater rivers (e.g. Atlantic salmon), beaches (e.g. capelin), or warm temperate or tropical waters (e.g. tunas and sharks).

A summary of spawning seasons and known spawning areas for key fish species is provided in Table 4.64. It is noteworthy that while a large number of fish species are spring and early summer spawners, a few (such as Greenland halibut) are winter spawners.

Table 4.64 Spawning Periods and Locations of Some Key Fish Species

Common Name	Scientific Name	Spawning Time[1]												Known Spawning Locations
		J	F	M	A	M	J	J	A	S	O	N	D	
Sand Lance	*Ammodytes dubius*	■	■	■								■	■	Grand Bank[2,3]
Capelin	*Mallotus villosus*						■	■						Southeast shoal of Grand Bank[4] Coastal waters beyond the SEA Study Area
Deepwater Redfish	*Sebastes mentella*				■	■								Southwest Shelf Edge and Slope of Grand Bank[4,5]
Yellowtail Flounder	*Limanda ferruginea*				■	■	■	■						Grand Bank
American Plaice	*Hippoglossoides platessoides*				■	■								Grand Bank
Sculpin	*Triglops* sp.								■	■	■	■		
Lanternfish	Myctophidae				■	■	■	■						
Atlantic Cod[6]	*Gadus morhua*				■	■	■	■	■	■	■			Southeast shoal of Grand Bank and Virgin Rocks[4]
Greenland Halibut	*Reinhardtius hippoglossoides*	■	■	■	■									Davis Strait
Blue Hake	*Antimora rostrata*													Not known to spawn in Canadian waters[7]
Roughhead Grenadier	*Macrourus berglax*	■	■	■	■									Grand Bank

Shading indicates spawning periods.

Sources: [1] Scott and Scott (1988); [2] Winters 1983; [3] Gilman 1994; [4] Templeman (2007); [5] COSEWIC (2010a); [6] COSEWIC (2010b); [7] Kulka et al (2003a).

Fish Migration Patterns

Migration is recognized as an adaptation to resources that fluctuate in their availability across space and time (Dingle and Drake 2007). Migrations are typically costly from an energetic and risk perspective, but can provide a means to exploit patterns in resource availability (food, spawning habitats, refuge etc.) and to avoid unfavourable conditions that vary in their occurrence over time. Individuals undertaking migration can accrue benefits such as higher growth and fecundity and populations of fish can have greater biomass than those that do not migrate (Robichaud and Rose 2004).

Fish species that are found in the SEA Study Area exhibit a variety of migration strategies that reflect the life history and ecology of each species and the oceanographic conditions they occupy. One general migration pattern, exhibited by important ecosystem components such as capelin and cod on the Newfoundland Shelf, entails a migration to shallow coastal areas in summer from offshore wintering habitats in deep warm water along the continental shelf edge. Capelin, are triggered by warm water to move northwards and shoreward each spring against the Labrador Current to spawn on beaches and shallow coastal areas of eastern Newfoundland (Shackell et al 1994; Carscadden et al 1997). Capelin also spawn offshore on the Southeast Shoal in areas with warm bottom temperatures (greater than 2°C) and appropriate spawning substrate (Carscadden et al 1989). Offshore components of Atlantic cod, a key predator of capelin, follow their prey to coastal areas in spring / summer using deep warm water channels and return to warm deep water along the continental shelf in the fall where they eventually spawn during winter and spring (Lear and Green 1984; Hutchings et al 1993; Rose et al 2013). Like capelin, cod rely on the currents to transport developing young to favourable nursery habitats (Lear and Green 1984; Hutchings et al 1993), which for cod occur in shallow, coastal areas (Gregory and Anderson 1997). These relatively safe and rich feeding areas are occupied by juvenile cod, despite harsh winter temperatures, for several years before they commence the onshore-offshore migration displayed by adults.

For some species, the SEA Study Area is used only during the summer. Highly migratory warm water pelagics such as tunas, swordfish and a variety of sharks spawn in southerly latitudes as far south as the Caribbean and migrate northward to feed in productive northern waters during the summer when water temperatures in the SEA Study Area and adjacent marine regions are warmest. Each fall they return southward to avoid the cold water temperatures that characterize these areas in winter.

Diadromous fish, namely those that migrate between fresh and salt water, exhibit a third migration strategy. The catadromous American eel, for example, spawns in the Sargasso Sea off Bermuda and their larvae move northward to freshwater habitats where they enter rivers along the eastern seaboard of North America including those of Newfoundland. After many years rearing in freshwater or coastal areas, adults return to southern spawning grounds. Other anadromous species such as Atlantic salmon migrate from oceanic feeding grounds in the northwest Atlantic to freshwater habitats to spawn. Migration pathways are region-specific but Atlantic salmon from Newfoundland, the Gulf of St. Lawrence, the Canadian Maritimes and Maine at least pass through (and may feed in) the SEA Study Area from January through April (Lear 1976; Reddin 1985) on their journey to and from spawning grounds.

Other species are not known to undertake notable coastal migrations. Many deep water species occupy habitats with relatively warm and stable water temperatures and can carry out their life cycle without moving to coastal habitats. These species include redfish, witch flounder, wolffish (Templeman 1984) and Greenland halibut (Bowering and Chumakov 1989). Even species that exhibit migratory strategies may have components that are resident (e.g. inshore components of Atlantic cod; Ruzzante et al 1996). Nonetheless, some of these species may exhibit migrations on smaller scales. For example, Greenland halibut are known to move to progressively deeper water as they age and many species, including redfish, undertake vertical feeding migrations (Beamish 1966).

Although defined migration corridors are perhaps less obvious in the SEA Study Area than in other marine areas (such as the Gulf of St. Lawrence, where movements are more constricted by landmasses), there remain areas where migrations can be channelled due to favourable environmental conditions. For example, warmer deep water channels (e.g. the Bonavista Corridor) that serve as refuge from cold water while providing access to inshore areas are used by Atlantic cod on their migrations (Rose et al 2013). Other areas, such as the southern Grand Banks, are likely to experience more use by migrating pelagics such as tuna, which are less likely to occur in more northerly areas of the SEA Study Area.

Marine fish species generally exhibit less population structure than freshwater and anadromous species (Ruzzante et al 1998), in part due to the prevalence of species which have eggs and/or larvae that drift passively in the ocean currents (e.g. Frank et al 1992; Nakashima 1992). Nonetheless, for some marine species, distributions are separated across the SEA Study Area. For example, Atlantic cod along the Grand Banks are segregated from more northerly conspecifics along the northeast Newfoundland Shelf (Wroblewski et al 1995; Taggart 1997; Ruzzante et al 1998; COSEWIC 2010b). Similarly, mark-recapture studies indicate that herring appear to segregate latitudinally in their migrations (Wheeler and Winters 1984). This segregation can result from oceanographic barriers (Ruzzante et al 1998) and/or genetic adaptations associated with regional environmental conditions. In the case of Atlantic cod, anti-freeze proteins that help individuals tolerate cold water temperatures are more prominent in individuals derived from more northern areas (COSEWIC 2010b).

Finfish Species Distributions

Marine habitats within the the SEA Study Area vary in their use by, and importance to, the species and assemblages that occupy them. Table 4.65 presents the 30 most abundant finfish species observed during the 2005-2009 DFO RV surveys. Distribution maps are provided for the top eleven of these species, which comprise over 90 percent of the individuals captured.

Again, while the Canadian DFO RV surveys represnet the most current and geographically extensive data set for marine fish in the Eastern Newfoundland Offshore Area, they are focussed in terms of the areas they cover, and some portions of the SEA Study Area (particularly those off the continental shelf and beyond the 200 mile limit) are not included. The distribution and relative abundance and importance of some fish species across the entire SEA Study Area may therefore be similalrly underrepresented. For example, lanternfish are considered to be amongst the most abundant fish taxa in the world's oceans, and are likely abundant in deep areas beyond the 200 mile limit. However, they represent only a very small percentage of fish species captured in the DFO RV surveys. A second consideration is that rankings of fish are reported in terms of their relative abundance, which inevitably marginalizes the importance of large bodied fish species (e.g. Atlantic cod) at the expense of small bodied individuals (e.g. sand lance).

The fish species that have been listed in the Table below, however, represent those that are dominant throughout much of the SEA Study Area, and include many of those that are of importance to commercial fisheries.

Table 4.65 Representation of Finfish Taxa During DFO RV Surveys from 2005-2009 in the SEA Study Area

Common Name	Scientific Name	Individuals Captured in RV surveys (%)[1]	Assemblage
Sand Lance	*Ammodytes* sp.	6.60	Shallow Shelf
Capelin	*Mallotus villosus*	6.09	Pelagic
Redfish	*Sebastes mentella*	4.12	Shelf/Slope
Yellowtail Flounder	*Limanda ferruginea*	1.14	Shallow Shelf
American Plaice	*Hippoglossoides platessoides*	0.92	Shelf
Sculpins	*Triglops* sp.	0.81	Shelf
Lanternfish	Myctophidae	0.55	Oceanic
Atlantic Cod	*Gadus morhua*	0.22	Shelf
Greenland Halibut, Turbot	*Reinhardtius hippoglossoides*	0.20	Shelf/Slope
Blue Hake	*Antimora rostrata*	0.15	Slope
Roughhead Grenadier	*Macrourus berglax*	0.14	Slope
Hookear Sculpin	*Artediellus* sp.	0.14	Shelf
Common Grenadier	*Nezumia bairdi*	0.14	Slope
Longnose Eel	*Synaphobranchus kaupi*	0.12	Slope
Common Alligatorfish	*Aspidophoroides monopterygius*	0.11	Shelf
Roundnose Grenadier	*Coryphaenoides rupestris*	0.10	Slope
Vahl's Eelpout	*Lycodes vahlii*	0.09	Shelf
Snake Blenny	*Lumpenus lumpretaeformis*	0.08	Shelf
Shanny	*Lumpenus maculatus*	0.07	Shelf
Thorny Skate	*Amblyraja radiata*	0.06	Shelf
Arctic Alligatorfish	*Aspidophoroides olriki*	0.06	Shelf
Eelpout sp	*Lycodes* sp.	0.06	Shelf
Arctic Cod	*Boreogadus saida*	0.06	Shelf
Northern Alligator fish	*Agonus decagonus*	0.06	Shelf
Spatulate Sculpin	*Icelus spatula*	0.05	Shelf
Witch Flounder	*Glyptocephalus cynoglossus*	0.04	Deep shelf
Barracudina	*Paralepididae*	0.04	Slope
Arctic Eelpout	*Lycodes reticulatus*	0.03	Shelf
Striped Wolffish	*Anarhichas lupus*	0.03	Shelf
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	0.02	Shelf

[1] Percentages reflect composition of total catch and include finfish as well as crab and shrimp species. Values may differ from those presented in the text which reflect the composition of a specific taxonomic group (e.g. fishes only).

Sand Lance: These are small schooling fish that occur in both inshore and offshore areas (Scott and Scott 1988), although the species found in offshore areas is *Ammodytes dubius*. Of the fish species captured in DFO RV surveys, this species was most abundant (representing about 30 percent of fish captured). Within the surveyed portion of the SEA Study Area, this species occupies shallow shelf areas of the Grand Bank and is found in high concentrations in regions of the northern Grand Bank (Figure 4.74) Relatively few captures of sand lance were obtained in areas north of Bonavista or in deep water (e.g. the Flemish Pass) within the SEA Study Area. Sand lance are a critical part of the food web in areas where they occur, and are important prey for commercially important species such as Atlantic cod, American plaice and yellowtail flounder (Gomes et al 1992). They are known to hide in the sand during part of the day and migrate vertically to feed. Sand lance are not known to undertake extensive migrations.

Capelin: A schooling pelagic, planktivorous species that is typically associated with cold waters, they are accordingly found at their highest concentrations along the northern edge of the Grand Banks and in the northwest portions of the SEA Study Area (Figure 4.75). Due to the species' abundance (27 percent of the fish caught in RV surveys) and richness in lipids, it serves as a critical prey source for a multitude of fish, marine mammals and seabirds (Scott and Scott 1988; Gomes et al 1992; Davoren and Montevecchi 2003; Rose 2005b; Templeman 2010; Dawe et al 2012). Their ecological importance is exemplified by the large variety of piscivores which shadow their migrations to and from coastal waters each year. Relatively low numbers of capelin in recent years have forced predators like Atlantic cod (Dawe et al 2012) and gannets (Montevecchi 2007) to rely to a greater extent on other prey. In addition to serving as an important prey source, capelin are also a commercially harvested species. Capelin are a temperature sensitive species and their distributions are known to respond quickly to changing environmental conditions. For this reason, Rose (2005b) proposed that they can serve as a key indicator of climate change. Outside the Canadian EEZ, capelin stocks are considered to be at a low level and NAFO has advised a moratorium on fishing to allow the stocks to rebuild (NAFO 2014).

Deepwater Redfish: A slow growing, deep water species that can live in excess of 40 years (DFO 2011a). The species is associated with the sea bottom, but moves into the water column at night to feed on zooplankton and fish (Scott and Scott 1988; Templeman 2010). Baillon et al (2012) document the linkage between seapens (corals) and redfish larvae, and make a case for seapen fields to be considered essential fish habitat for this species. Redfish are abundant along the slopes of the continental shelf, particularly along the southern edge of the Grand Banks (Figure 4.76) and it represented approximately 18 percent of the fish caught in DFO RV surveys. It is also commercially harvested and valued. COSEWIC has listed the designatable unit which encompasses the SEA Study Area as Threatened, due to its poor condition (DFO 2011a). It has, however, been showing signs of recovery since the early 1990s (DFO 2011a). In the southern portions of the SEA Study Area, the stock health of redfish is primarily influenced by environmental conditions. For example, in years of unfavourable currents, redfish larvae can be pushed off the shelf and experience low survival (Devine and Haedrich 2011). In the northern areas of the SEA Study Area, however, both exploitation and environmental conditions are linked to redfish abundance (Devine and Haedrich 2011). Currently, redfish in NAFO waters are considered stable at a high level (Div. 3M) or recently recovered (Div. 3NL) (NAFO 2014).

Yellowtail Flounder: A warm water flatfish that is common on shallow offshore banks, typically less than 100 m in depth (Scott and Scott 1988; Gomes et al 1992). In the SEA Study Area, this commercially valuable species is found primarily in the shallow regions of the Grand Bank and occurs at the highest densities on the warmer southern portions that are shielded from the cold Labrador Current (Figure 4.77). In recent years, yellowtail flounder abundance has increased from the low levels observed during the early 1990s (Templeman 2010). Having a relatively small mouth, it feeds primarily on invertebrates but can also take small fish such as sand lance (Scott and Scott 1988). In the surveyed portions of the

SEA Study Area, this species represented five percent of the catch from 2005-2009 and is one of the dominant species where it occurs (Gomes et al 1992). In NAFO waters of Divisions 3LNO, yellowtail flounder are fished as stocks are increasing and above the biological limit reference point (NAFO 2014).

American Plaice: A demersal flatfish that burrows in sandy habitats and ambushes its prey, they are widespread across the continental shelf and slope habitats in the SEA Study Area, particularly in areas to the south of Bonavista (Figure 4.78). In contrast to yellowtail flounder, American plaice are much more tolerant of colder water temperatures (Scott and Scott 1988; Morgan and Brodie 1991). Nonetheless, both species are found in their highest concentrations on the southern portion of the Grand Banks. This species does not undertake significant migrations, but its eggs float to the surface and are dispersed by the currents (Scott and Scott 1988; Frank et al 1992). This fish species was the basis for the largest flatfish fishery in the world, but over the last three generations the Newfoundland and Labrador population has declined by 96 percent due to overfishing and increased natural mortality (COSEWIC 2009a). The population is currently listed as Threatened by COSEWIC. In NAFO waters the stock is considered to be at a low level and it has been advised that directed fishing should cease to allow the stock to rebuild (NAFO 2014).

Sculpins (Triglops sp.): These small cold water sculpins are found through much of the SEA Study Area on the continental shelf and shallow slope (Figure 4.79). Within this area the highest concentrations occur on the eastern edge of the Grand Banks and along the Bonavista corridor. They are numerous (representing four percent of the fish captured in RV surveys), and could therefore be ecologically important as predators of invertebrate prey (Scott and Scott 1988). Their ecology is, however, not well studied (Scott and Scott 1988).

*Lanternfish**:*** A family of small, pelagic fishes characterized by having light producing organs on their body (Scott and Scott 1988). They occur in oceans across the world from pole to pole in deep oceanic waters, where they perform vertical feeding migrations to feed on plankton. These species can be extremely abundant in deep water habitats and form a critical prey base for commercially valued species such as cod, hake, tunas, salmon and marine mammals (Scott and Scott 1988). In the SEA Study Area, they represented only 2 percent of all the fish caught during RV surveys, but are probably amongst the most abundant species in deeper areas not reached by these DFO surveys. This is supported by the fact that their highest densities from the trawl surveys were in the deep waters of the Flemish Pass (Figure 4.80).

Atlantic Cod: Formerly a dominant groundfish in the SEA Study Area, so much so that this valued species was a primary stimulus for European settlement of Eastern Canada (COSEWIC 2010b). The fishery for this species was also a key regional economic driver for centuries until the stocks collapsed in the early 1990s from high fishing levels and unfavourable environmental conditions (DFO 2012g). This demersal groundfish was also very important from an ecological perspective through the predation pressure it exerts on other species (Worm and Myers 2003; Dawe et al 2012). Although cod remain widespread along the continental shelf of the SEA Study Area, particularly along the southern Grand Banks and the Bonavista corridor (Figure 4.81), its densities (one percent of all fish captured in RV surveys) are a small proportion of what they once were (COSEWIC 2010b) and they have shown only modest signs of recovery despite the cessation of a directed fishery for two decades (Koen-Alonso et al 2010). This has resulted in a designation of Endangered by COSEWIC for the stock that corresponds with the SEA Study Area (COSEWIC 2010b). It is expected, however, that with warming ocean temperatures groundfish such as cod will experience a re-emergence at the expense of key invertebrate species. Beyond the Canadian EEZ, cod are considered to be below the biomass limit reference point in Divisions 3NO, and consequently, NAFO has advised to eliminate directed fishing so that the stock can rebuild (NAFO 2014). In Division 3M however, the stock is increasing and is above the biomass reference point, and a fishery is currently allowed (NAFO 2014).

Greenland Halibut: A commercially pursued flatfish species that are found along the shelf and slope of the SEA Study Area, particularly in the northern areas (Figure 4.82). It is largely absent from shallow areas of the Grand Bank but can be found at modest abundance along its slopes. Unlike most flatfish, this species spends a considerable amount of time feeding off the bottom on a variety of fish and invertebrates (Scott and Scott 1988). Larger individuals are typically found at greater depth than smaller conspecifics (Bowering and Chumakov 1989). This fish is common member of the deepwater demersal assemblage.

Blue Hake: Found in deep waters over mud bottoms, it feeds on invertebrates and squid (Scott and Scott 1988; Kulka et al 2003b). In the SEA Study Area it was detected in its highest densities at the limits of the RV surveys (Figure 4.83). Therefore, its abundance in the SEA Study Area (one percent of all fish captured) likely underestimates its importance, and little is known about its ecology (Scott and Scott 1988; Kulka et al 2003b).

Roughhead Grenadier: An important member of the deepwater demersal community, this species feeds on a variety of benthic invertebrates and small fish and they themselves are prey to piscivorous fish (Scott and Scott 1988). They are typically found along the continental slope and, in the SEA Study Area, extend to depths beyond the limits of the RV surveys (Figure 4.84). The highest densities of this fish in the SEA Study Area are found along the margins of the survey area along the continental slope. Therefore, like other deep water species, their abundance across the entire SEA Study Area (one percent of the catch in RV surveys) is likely underestimated. Of the species of grenadier known to occupy the area, Roughhead grenadiers were the most abundant in RV surveys from 2005-2009.

Atlantic Salmon: This species exhibits a wide variety of life histories, but they are most commonly anadromous (spawn in freshwater and migrate to sea) (COSEWIC 2010c). Salmon spend 2-7 years in freshwater as parr before they transform to smolt and migrate to sea. Seaward migrations typically occur in spring. Salmon were not captured in RV surveys but are known to migrate through the SEA Study Area on their way to (Figure 4.85) and from (Figure 4.86) oceanic feeding grounds. These migrants originate from several areas of Atlantic Canada and Maine and are populations that are listed by COSEWIC (2010c). Known salmon rivers along the east coast of the Newfoundland are illustrated in Figure 4.87.

Figure 4.74 Distribution and Abundance of Sand Lance in the SEA Study Area (2005-2009 Surveys)

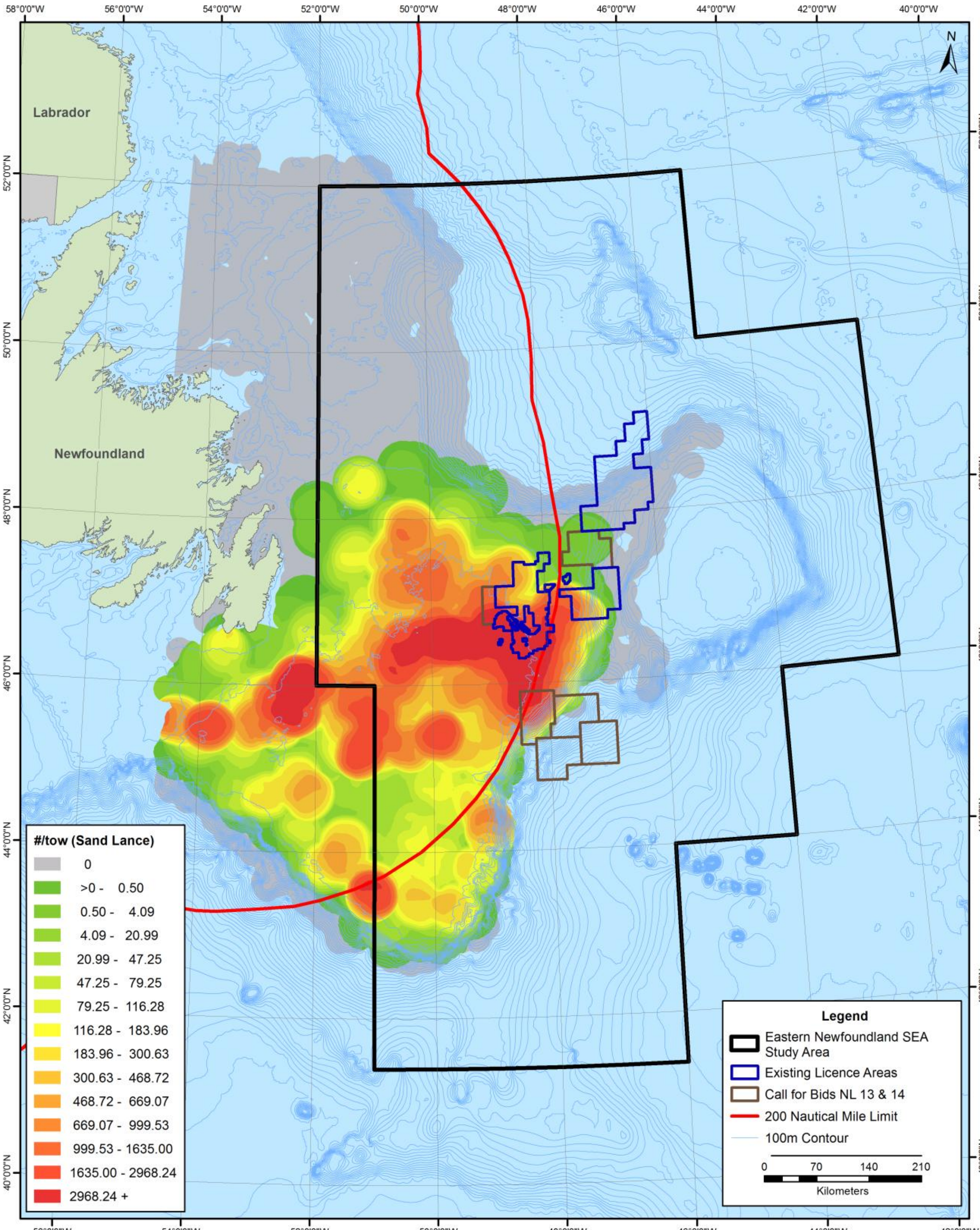


Figure 4.75 Distribution and Abundance of Capelin in the SEA Study Area (2005-2009 Surveys)

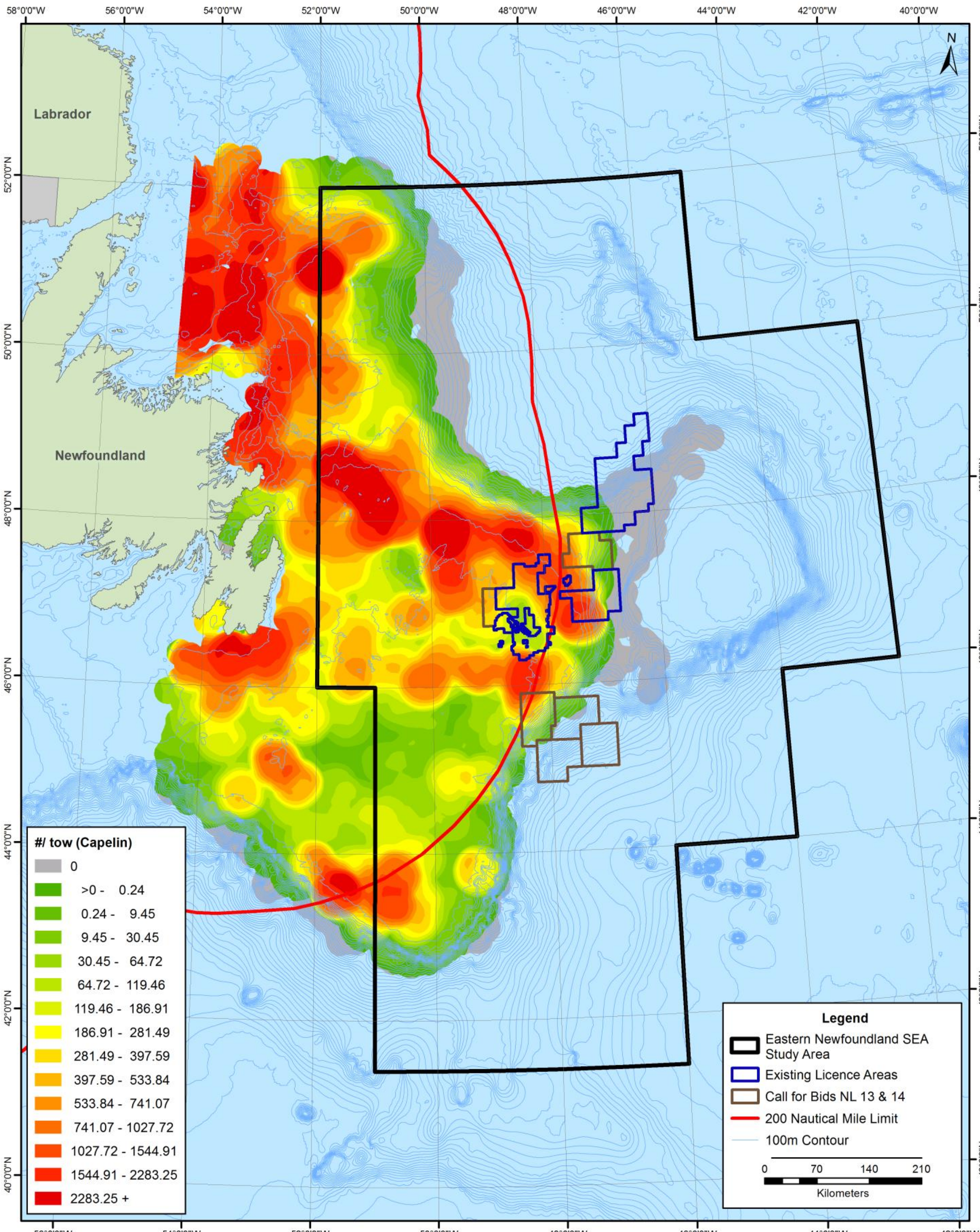


Figure 4.76 Distribution and Abundance of Redfish in the SEA Study Area (2005-2009 Surveys)

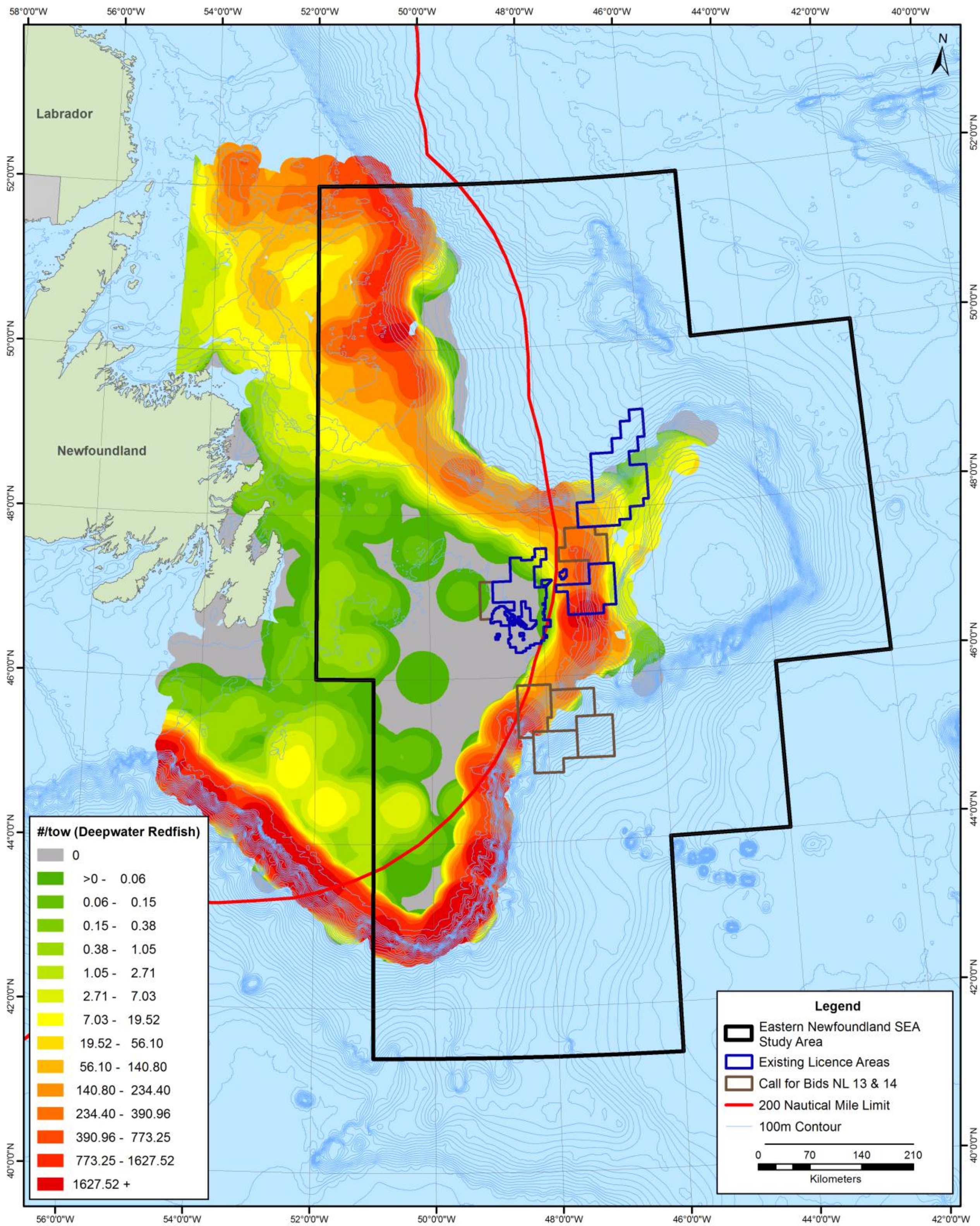


Figure 4.77 Distribution and Abundance of Yellowtail Flounder in the SEA Study Area (2005-2009 Surveys)

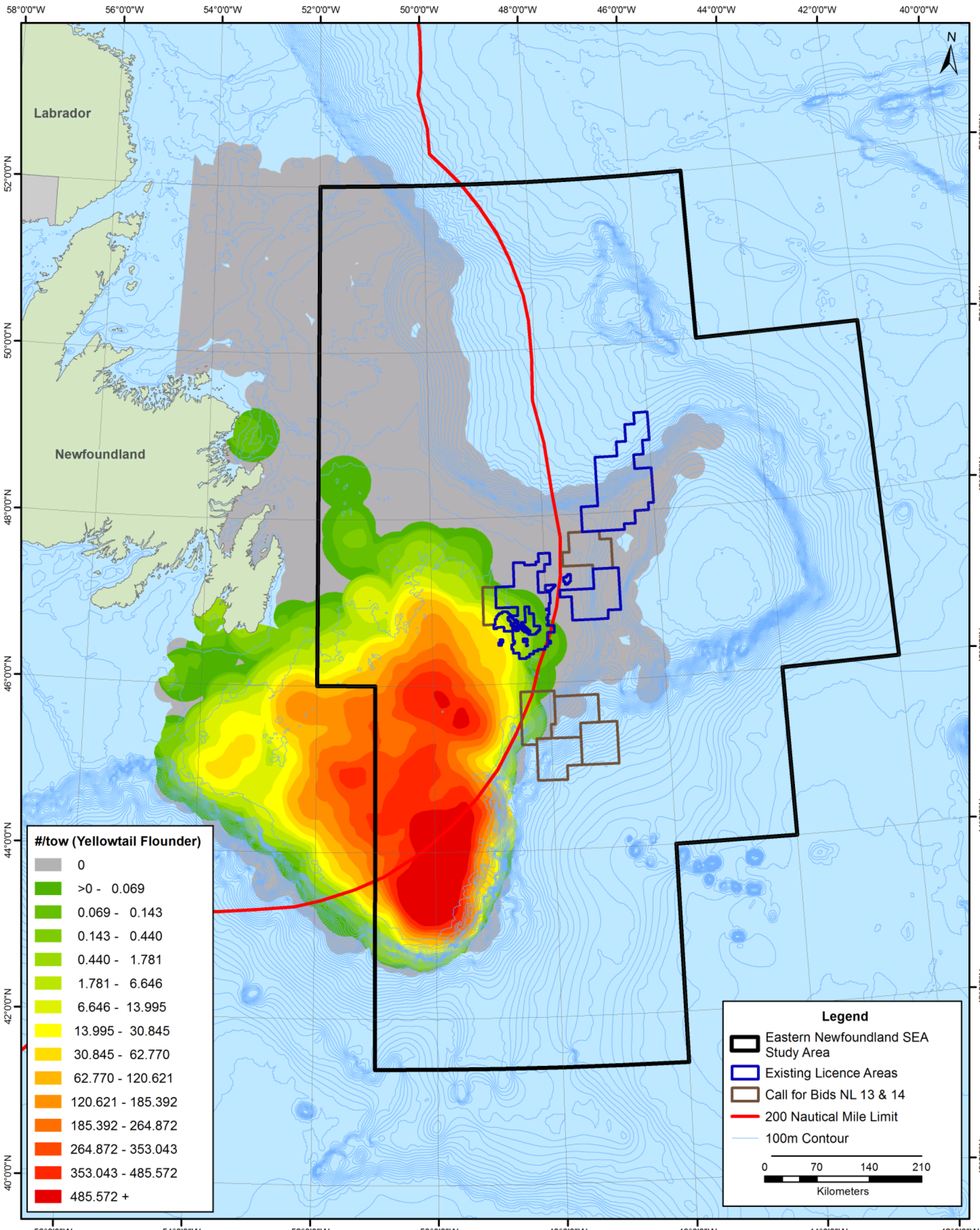


Figure 4.78 Distribution and Abundance of American Plaice in the SEA Study Area (2005-2009 Surveys)

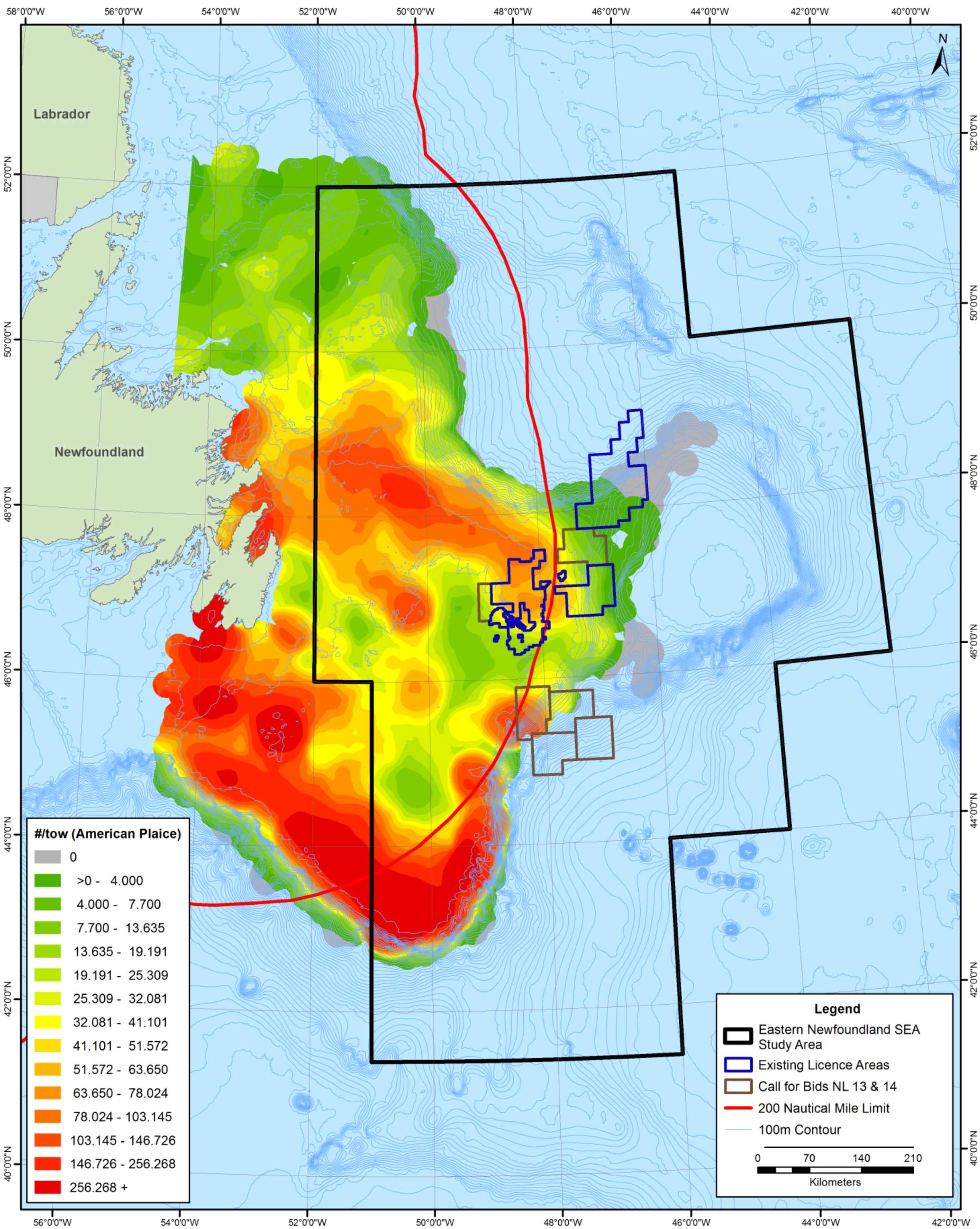


Figure 4.79 Distribution and Abundance of Sculpins in the SEA Study Area (2005-2009 Surveys)

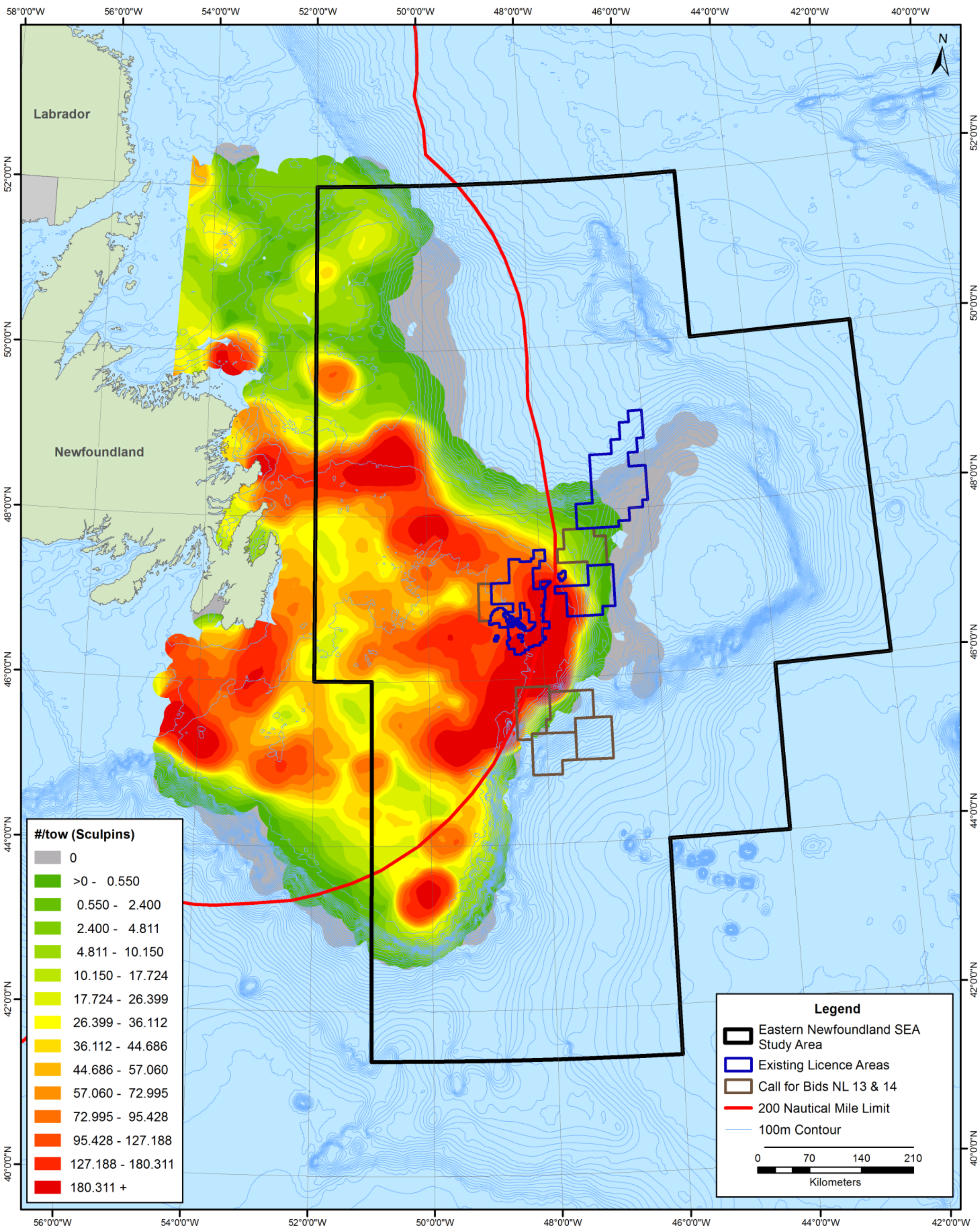


Figure 4.80 Distribution and Abundance of Lanternfish in the SEA Study Area (2005-2009 Surveys)

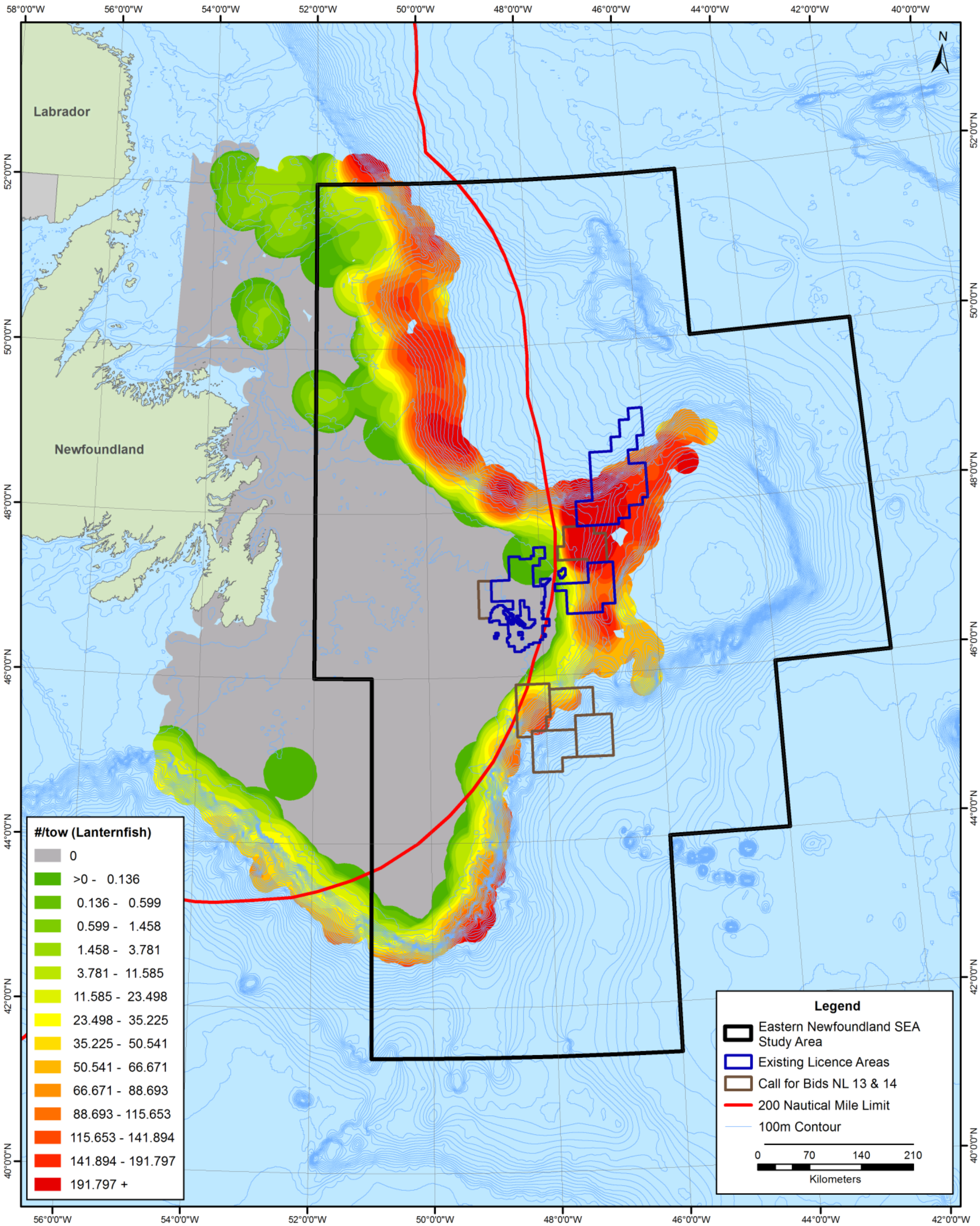


Figure 4.81 Distribution and Abundance of Atlantic Cod in the SEA Study Area (2005-2009 Surveys)

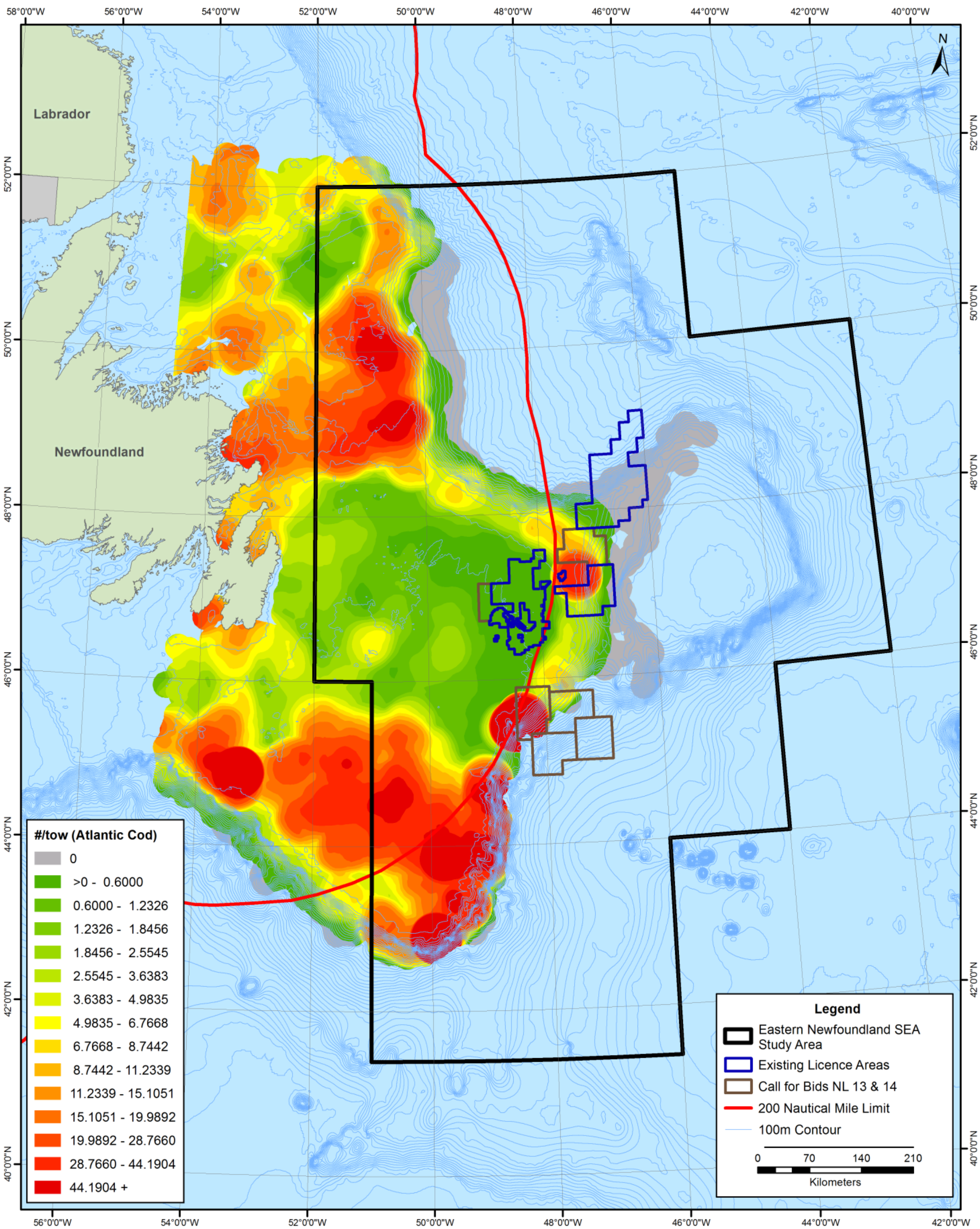


Figure 4.82 Distribution and Abundance of Greenland Halibut in the SEA Study Area (2005-2009 Surveys)

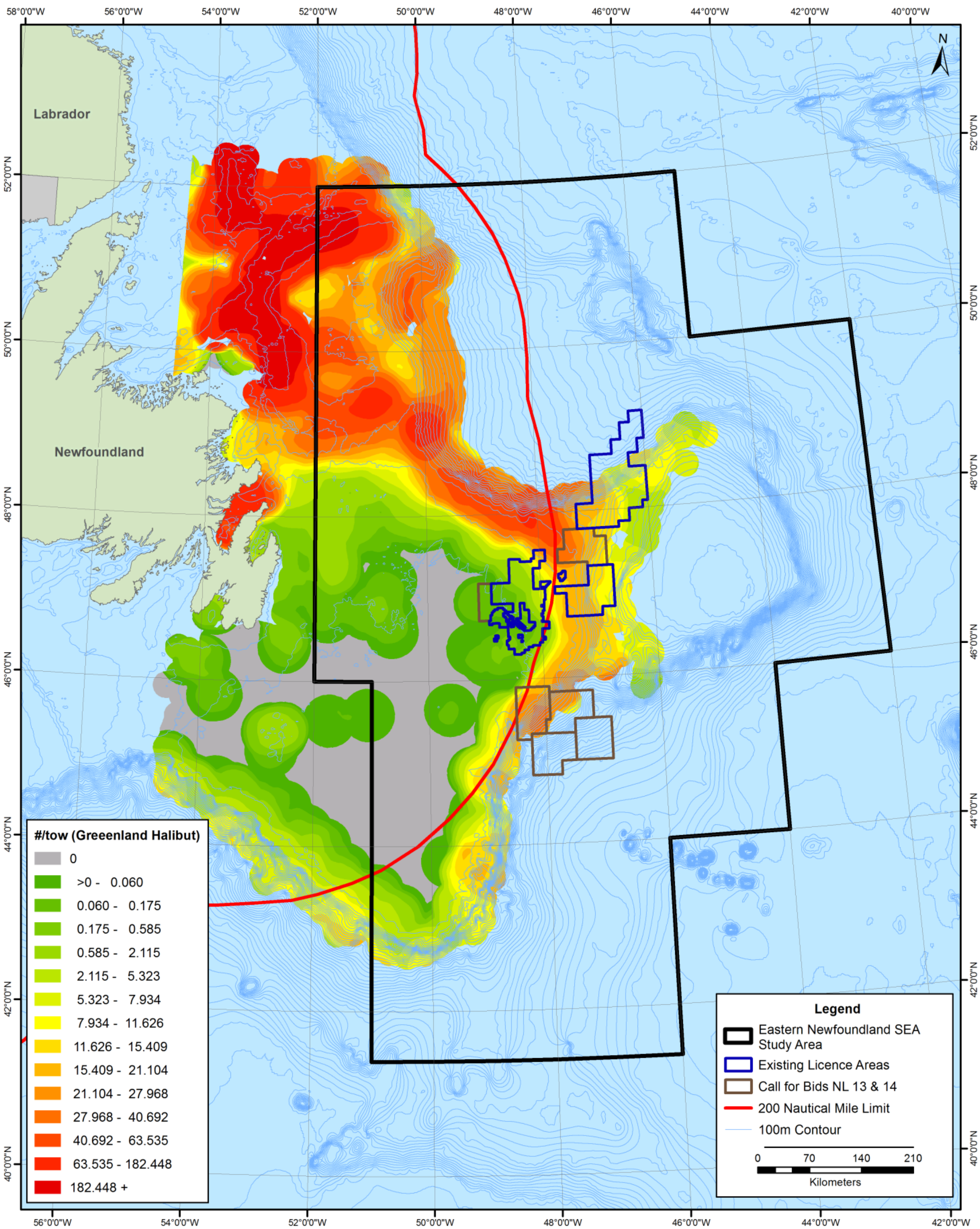


Figure 4.83 Distribution and Abundance of Blue Hake in the SEA Study Area (2005-2009 Surveys)

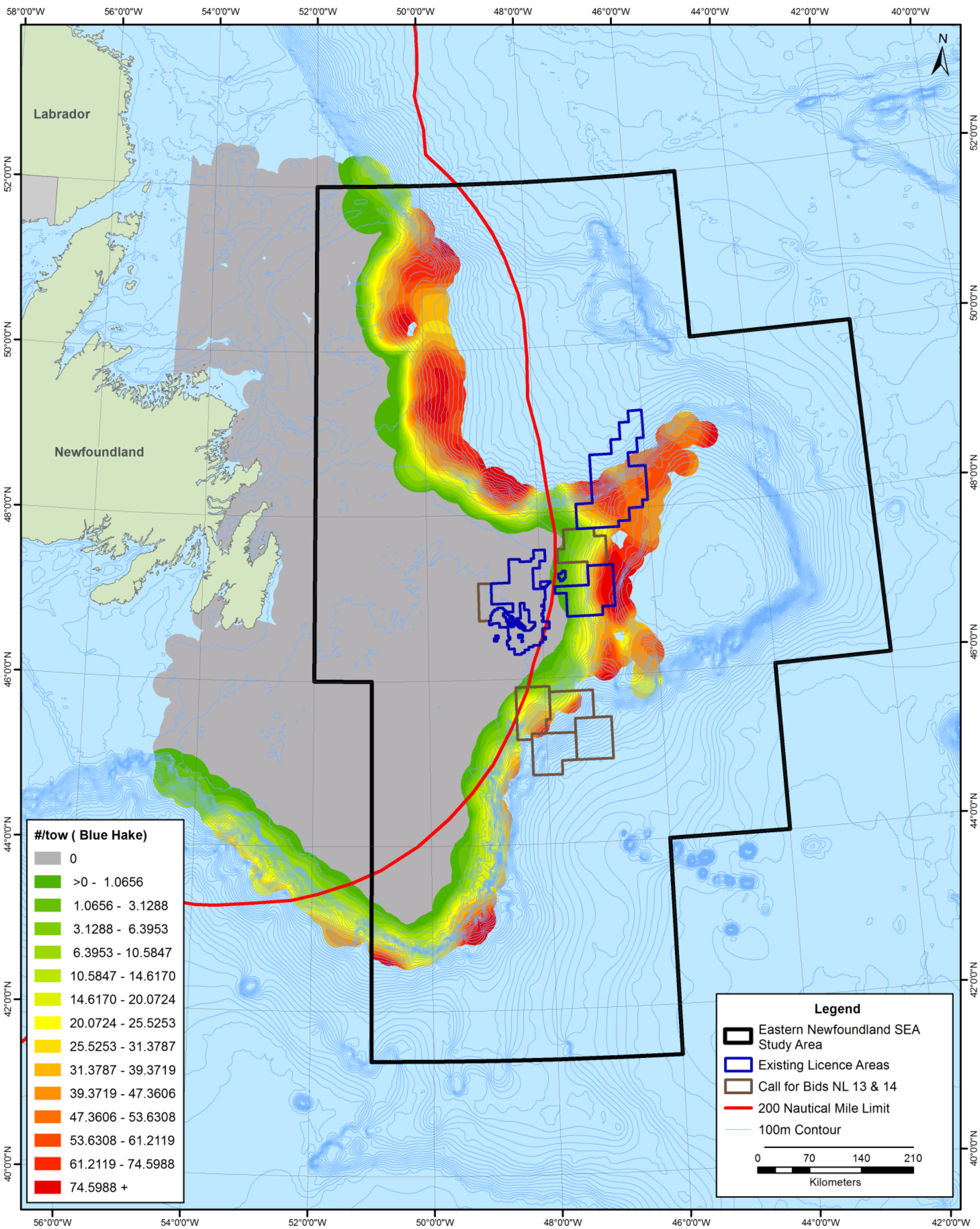


Figure 4.84 Distribution and Abundance of Roughhead Grenadier in the SEA Study Area (2005-2009 Surveys)

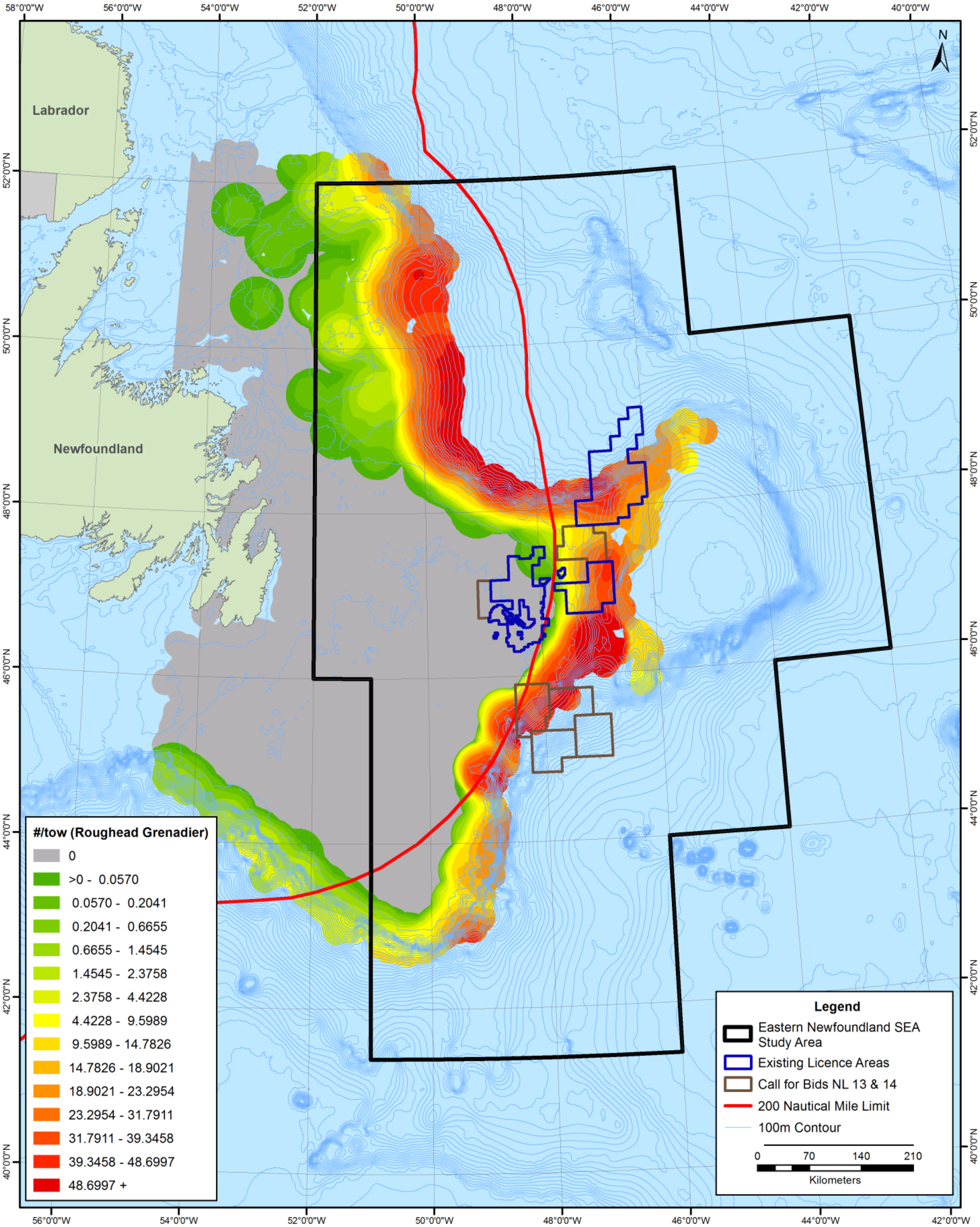


Figure 4.85 Generalized Migration Routes of Atlantic Salmon to Oceanic Feeding Grounds in Relation to the SEA Study Area

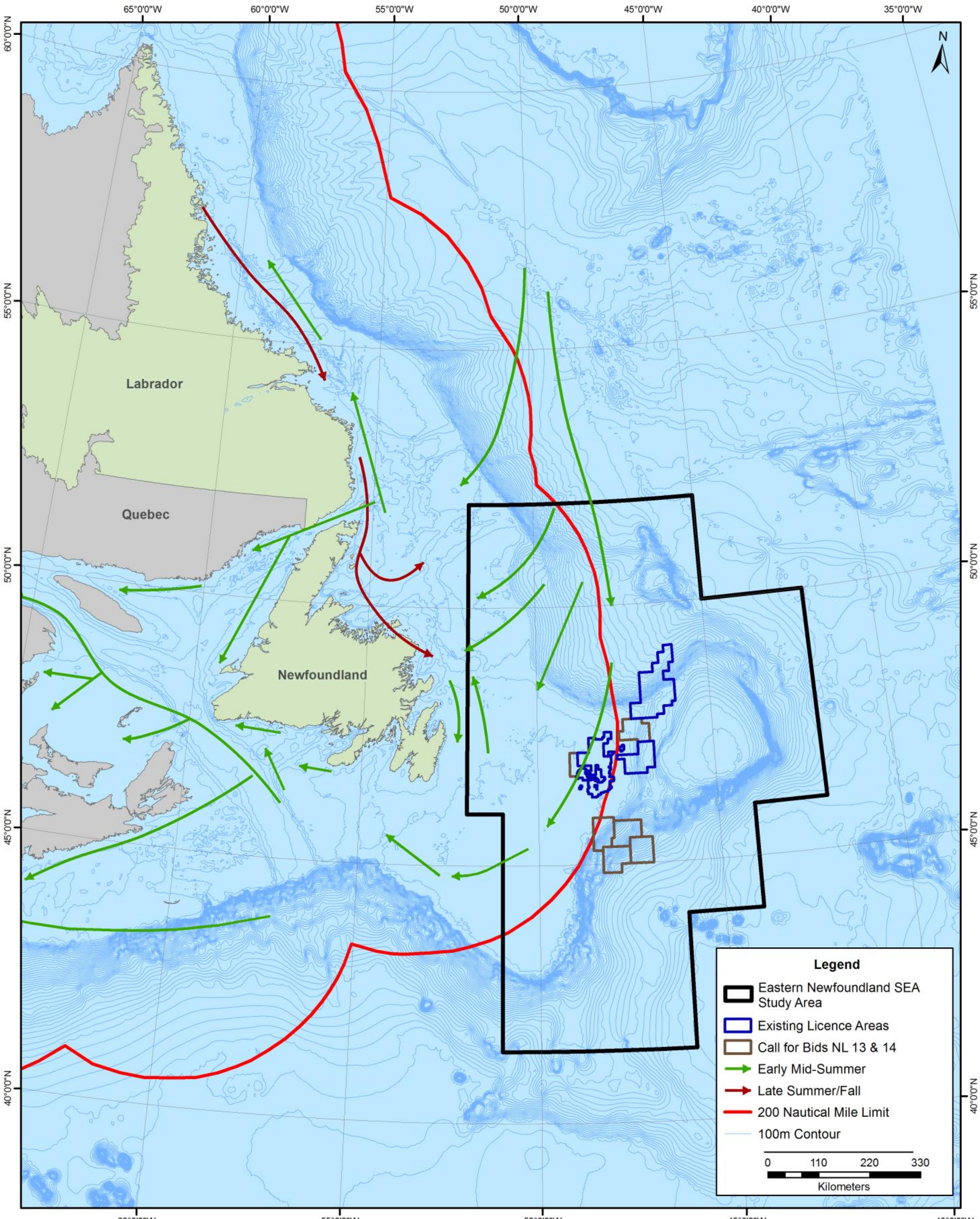


Figure 4.86 Generalized Migration Routes of Atlantic Salmon from Oceanic Feeding Grounds in Relation to the SEA Study Area

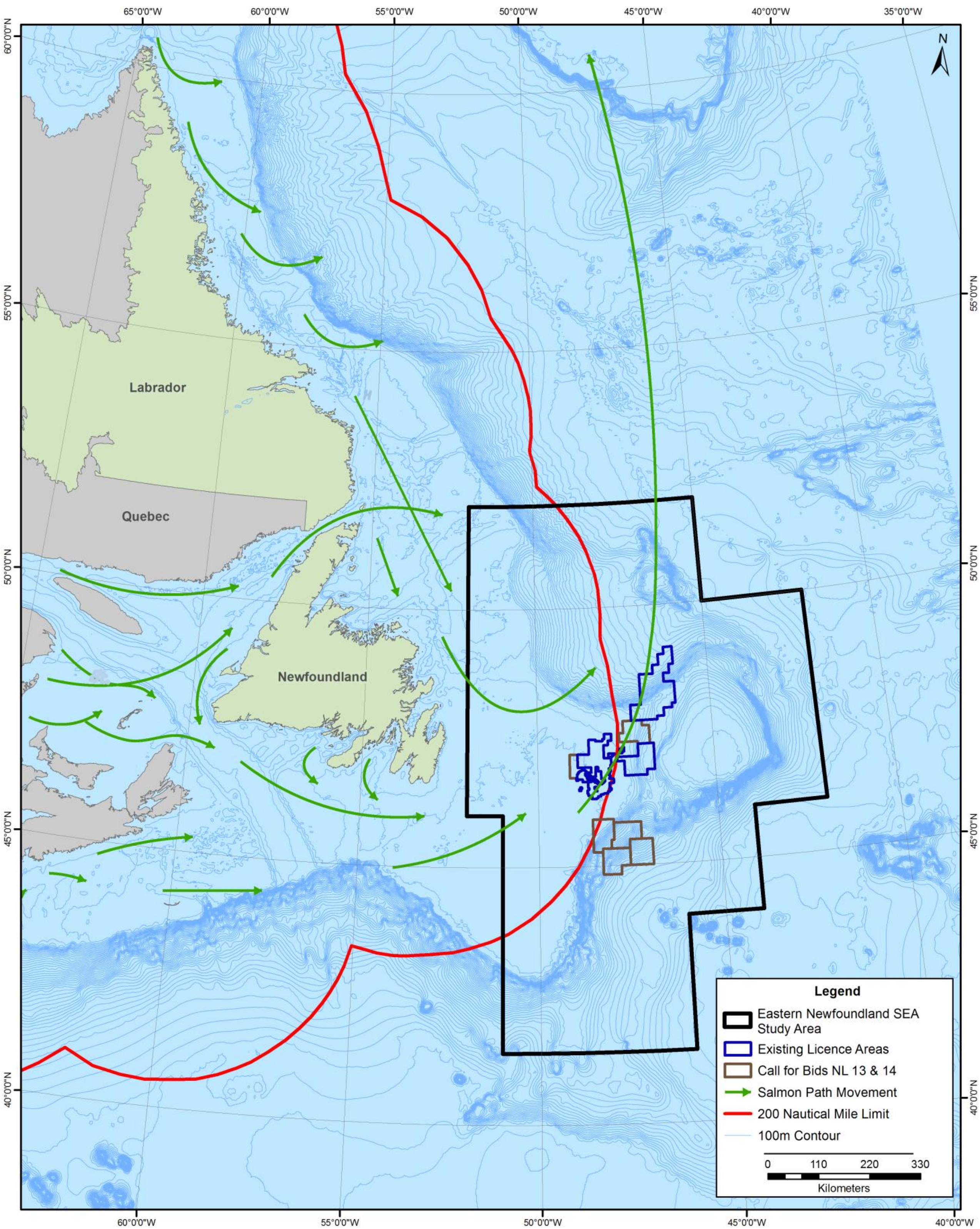
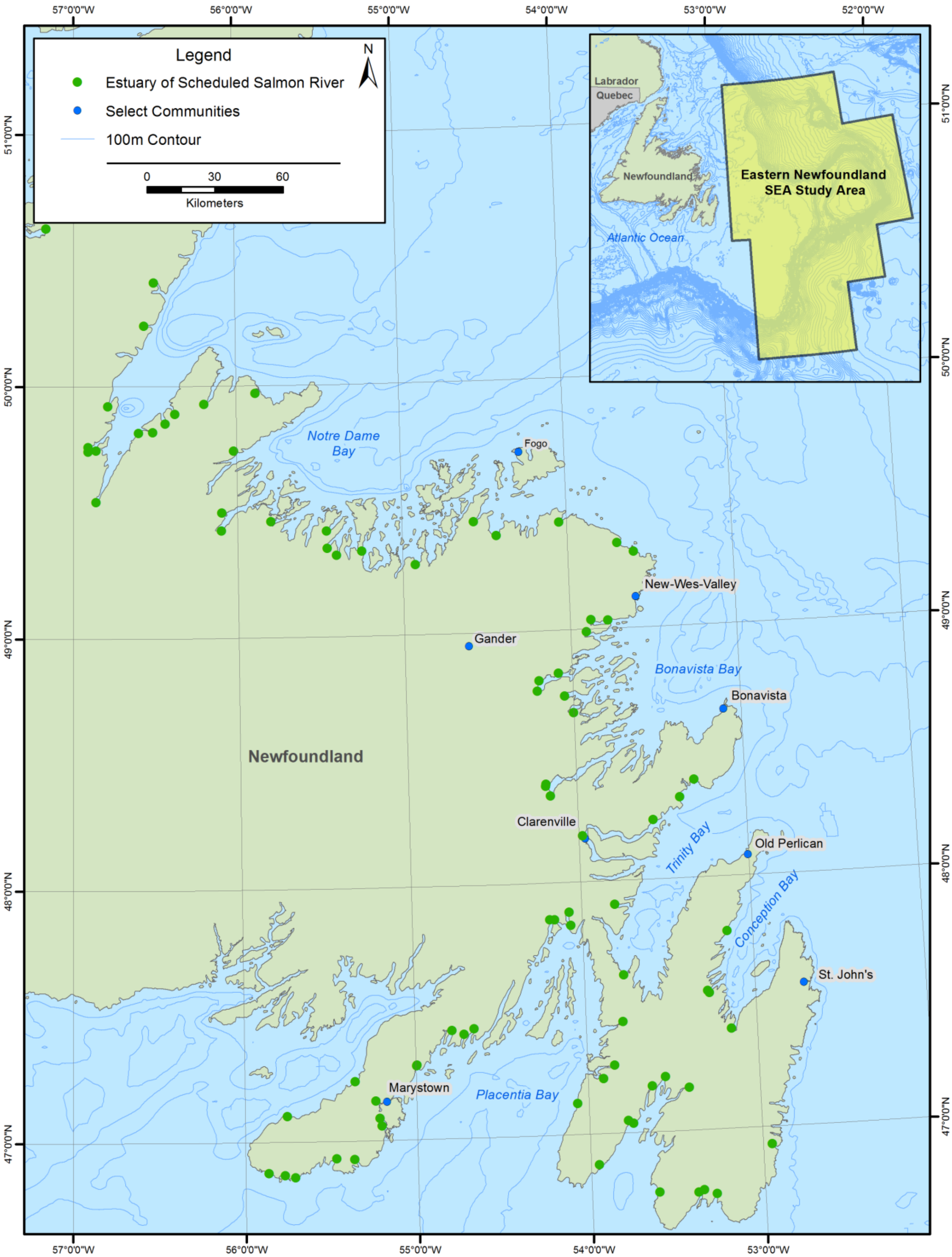


Figure 4.87 Scheduled Atlantic Salmon Rivers of Eastern Newfoundland



4.2.1.7 Fish Species at Risk

A number of species of special conservation concern occur in the SEA Study Area. These include marine fish species that have varying degrees of formal protection under provincial and/or federal legislation, or that have been otherwise identified as a conservation concern and/or regionally rare by conservation bodies such as COSEWIC (Committee on the Status of Endangered Wildlife in Canada) or the IUCN (International Union for the Conservation of Nature).

The Newfoundland and Labrador *Endangered Species* Act (NL ESA) provides protection for indigenous species, sub-species and populations considered to be endangered, threatened, or vulnerable within the province. These potential designations under the legislation are defined as follows:

- *Endangered*: A species that is facing imminent extirpation or extinction;
- *Threatened*: A species that is likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction; and
- *Vulnerable*: A species that has characteristics which make it particularly sensitive to human activities or natural events.

There are currently 35 species, subspecies, and populations designated under the *NL ESA*, of which 13 are listed as endangered, nine as threatened, and 13 as vulnerable. Designations are based on recommendations from the national Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and/or the provincial Species Status Advisory Committee (SSAC). Both COSEWIC and SSAC are independent committees that consist of government and non-government scientists who determine the status of species, subspecies and significant populations considered to be at risk of extinction or extirpation. The evaluation processes of both are independent, open and transparent, and based on the best available information on the biological status of species including scientific, community and traditional knowledge. Habitat that is important to the recovery and survival of endangered or threatened species can also be designated as critical habitat or recovery habitat, and protected under the *NL ESA*.

The Canadian *Species at Risk Act* (*SARA*) provides protection to species at the national level to prevent extinction and extirpation, facilitate the recovery of endangered and threatened species, and to promote the management of other species to prevent them from becoming at risk in the future. Designations under the Act follow the recommendations and advice provided by the COSEWIC.

There are currently various schedules associated with the SARA. Species that have formal protection are listed on Schedule 1, which includes the following potential designations:

- *Extirpated*: A species that no longer exists in the wild in Canada, but exists in the wild elsewhere;
- *Endangered*: A species that is facing imminent extirpation or extinction;
- *Threatened*: A species that is likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction; and

- *Special Concern*: A species that may become threatened or endangered because of a combination of biological characteristics and identified threats.

Schedule 2 and 3 represent those species that have been recommended by COSEWIC but are not currently protected under *SARA*. Therefore, Schedule 1 of *SARA* is the official federal list of species at risk in Canada. Once a species is listed, measures to protect and recover a listed species are established and implemented, including the development of a Recovery Strategy (Extirpated, Endangered or Threatened species) or Management Strategy (for Species of Special Concern). Recovery Strategies are detailed plans that define conservation goals and objectives, identify critical habitat, and describe the research and management activities required for the species in question, by:

- Describing the particular species and its needs;
- Identifying threats to survival;
- Identifying and classifying the species' critical habitat (namely, that which is required for the species' survival or recovery), where possible;
- Providing examples of activities that are likely to result in destruction of the critical habitat;
- Setting goals, objectives and approaches for species recovery;
- Identifying information gaps that should be addressed; and
- Stating when one or more action plans relating to the strategy will be completed.

Once a species is added to the list and protected officially under *SARA*, the Recovery Strategy must be developed within a year for Endangered species and within two years for Threatened or Extirpated (extinct in Canada) species. Action Plans summarize the projects and activities required to meet Recovery Strategy objectives and goals. They include information on habitat, details of protection measures, and evaluation of socioeconomic costs and benefits. Action Plans are the second element of the Act's two-part recovery planning process, and are used to implement projects and activities to improve species status. Management Plans (for species of Special Concern) set goals and objectives for maintaining sustainable population levels of one or more species that are particularly sensitive to environmental factors, but which are not yet considered in danger of becoming extinct. Where possible, these plans are prepared for multiple species on an ecosystem or landscape level.

Although the information presented in this SEA is considered current as of the time of writing, it should be noted that the provisions of and associated requirements under *SARA* can change over time (for example, there may be new species added to Schedule 1, new recovery strategies, action plans or management plans, identification of critical habitat). It is therefore important to refer to the *SARA Public Registry* (*www.sararegistry.gc.ca*) to get the most up-to-date information and requirements for species at risk in Canada.

In addition to species that are listed under the provincial and/or federal legislation, there is also often a degree of interest around species that are considered to be regionally rare, even though these are not necessarily provided with formal, legal protection. Although the designation of a species by COSEWIC, the IUCN or other such organizations, for example, does not in itself constitute such legal protection, they do provide a general indication of species that may be considered rare, and thus, of some degree of potential conservation interest.

There are currently 25 fish species that are listed by *SARA* (four species), *NL ESA* (one species), COSEWIC (21 species) and/or the IUCN Redlist (15 species) that do or may occur in the SEA Study Area (Table 4.66). Many of these species remain relatively common across the SEA Study Area, but exist at a small fraction of their former abundance since the groundfish collapse of the early 1990s (e.g. American plaice, Atlantic cod, redfish). Others probably never occurred in great densities relative to collapsed groundfish stocks (e.g. tunas and sharks).

The four marine fish species that have formal designation and protection under *SARA* include three species of wolffish (family *Anarhichadidae*) and the white shark (Table 4.66). These are described in further detail below.

The Northern wolffish has been designated as threatened as numbers of this large, slow-growing, long-lived, solitary, nest-building fish have declined over 95 percent in three generations, and the number of locations where the fish is found has likewise decreased. Spotted wolffish were designated for similar reasons, as its populations have declined over 90 percent in three generations, and the number of locations where the fish is found has also decreased. Although the striped wolffish has a lower designation (Special Concern), it also underwent a decline similar to that observed for the two Threatened species. Specific threats identified by COSEWIC included bycatch mortality in commercial fisheries and habitat alteration by trawling gear.

All three wolffish species were reassessed by DFO (2013b) and their recommended statuses have not changed. There is, however, a Recovery Strategy and Management Plan outlined in Kulka et al (2007) and reviewed by DFO (2013b) to increase the population levels and distributions of the three wolffish species. This includes the enhancement of biology and life history knowledge, the identification and protection of critical habitats, mitigation of human impacts and the development of education programs related to these species (DFO 2013b). Although critical habitat under *SARA* has yet to be defined, it is in progress (DFO 2013b). In the meantime, recent research indicates that Northern wolffish are found in the deepest water (300-1,200 m), with striped wolffish in the shallowest water (50-450 m) and spotted wolffish at intermediate depths (100-800 m). Interestingly, Northern wolffish are believed to spend considerable time off the bottom based on the prevalence of pelagic prey items (e.g. squid) in their diet (D. Kulka pers. comm.). Some studies have shown that spotted and striped wolffish showed no preference for substrate, while Northern wolffish were found most often on sand / shell / pebble habitats (as reviewed in DFO 2013b). Other studies however, have indicated a preference for rocky substrates for both striped (Kulka et al 2004a) and spotted wolffish (Baker et al 2012). The distributions of these wolffish species, as determined by DFO RV surveys in the SEA Study Area, are presented in Figures 4.88 to 4.90. All three species were associated with deep shelf areas but the more abundant striped wolffish was also found in areas of the continental shelf at lower abundance. The Bonavista corridor also appeared to be an area of relatively high concentration for the spotted wolffish. Of the three species, the northern wolffish was typically distributed in deeper waters.

The range of the white shark extends to the Canadian waters of the North Atlantic, although it is considered to be quite rare (with only 32 records over 132 years for Atlantic Canada; COSEWIC 2006a). Its numbers are estimated to have declined by about 80 percent over 14 years (less than one generation) in areas of the northwest Atlantic Ocean outside of Canadian waters. This species was assessed in 2006 as being endangered under Schedule 1 of *SARA*, with no update since that time. An assessment of the recovery potential of the white shark (DFO 2006) underscored a poor understanding of the species' biology, particularly in Canadian waters where it is less common. Consequently, critical habitat for this species has not been identified and designated under *SARA*. The greatest source of human induced mortality (by-catch in the American long line fishery) also does not occur in Canadian waters (DFO 2006).

Figure 4.88 Distribution and Abundance of Northern Wolffish in the SEA Study Area (2005-2009 Surveys)

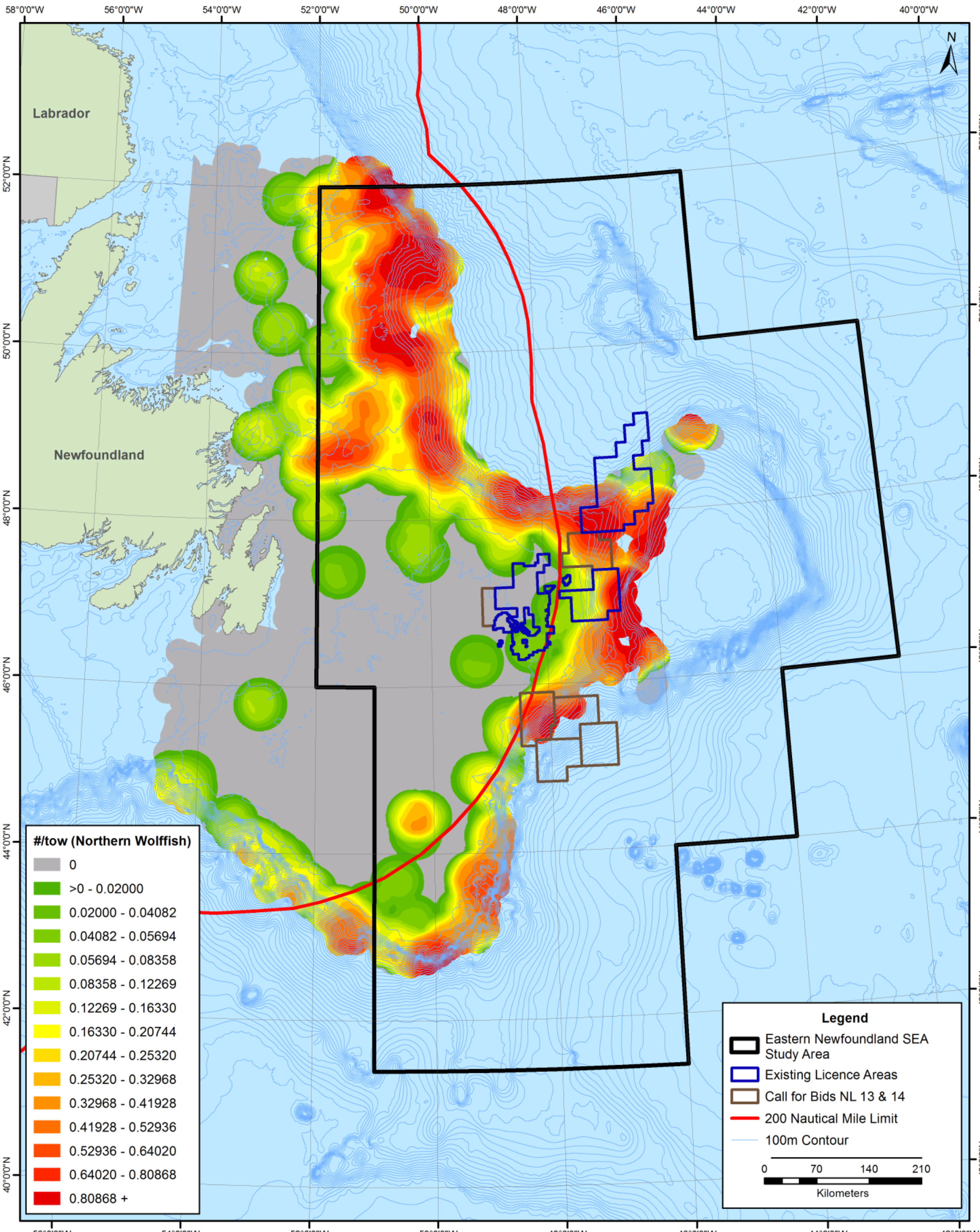


Figure 4.89 Distribution and Abundance of Atlantic (Striped) Wolffish in the SEA Study Area (2005-2009 Surveys)

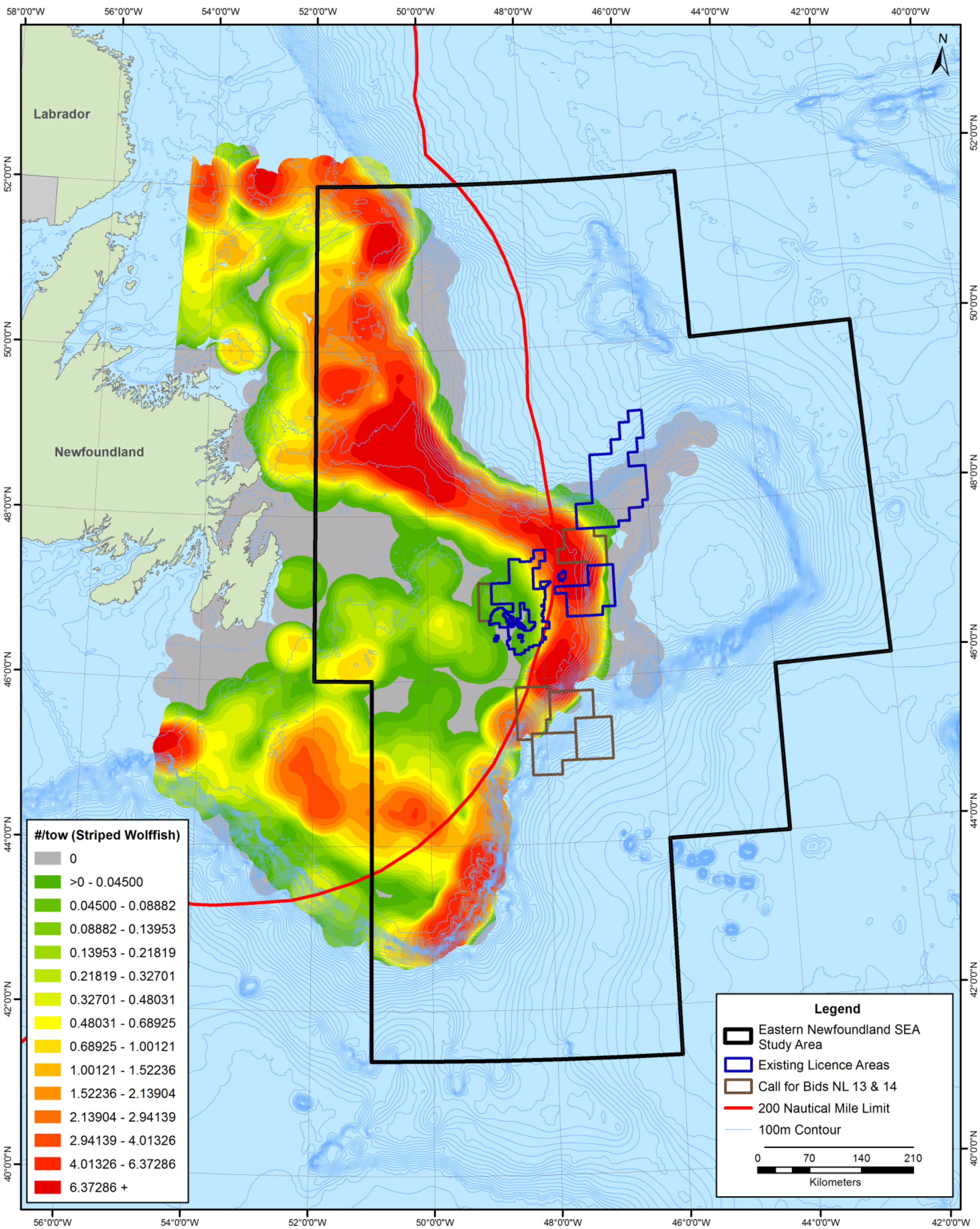


Figure 4.90 Distribution and Abundance of Spotted Wolffish in the SEA Study Area (2005-2009 Surveys)

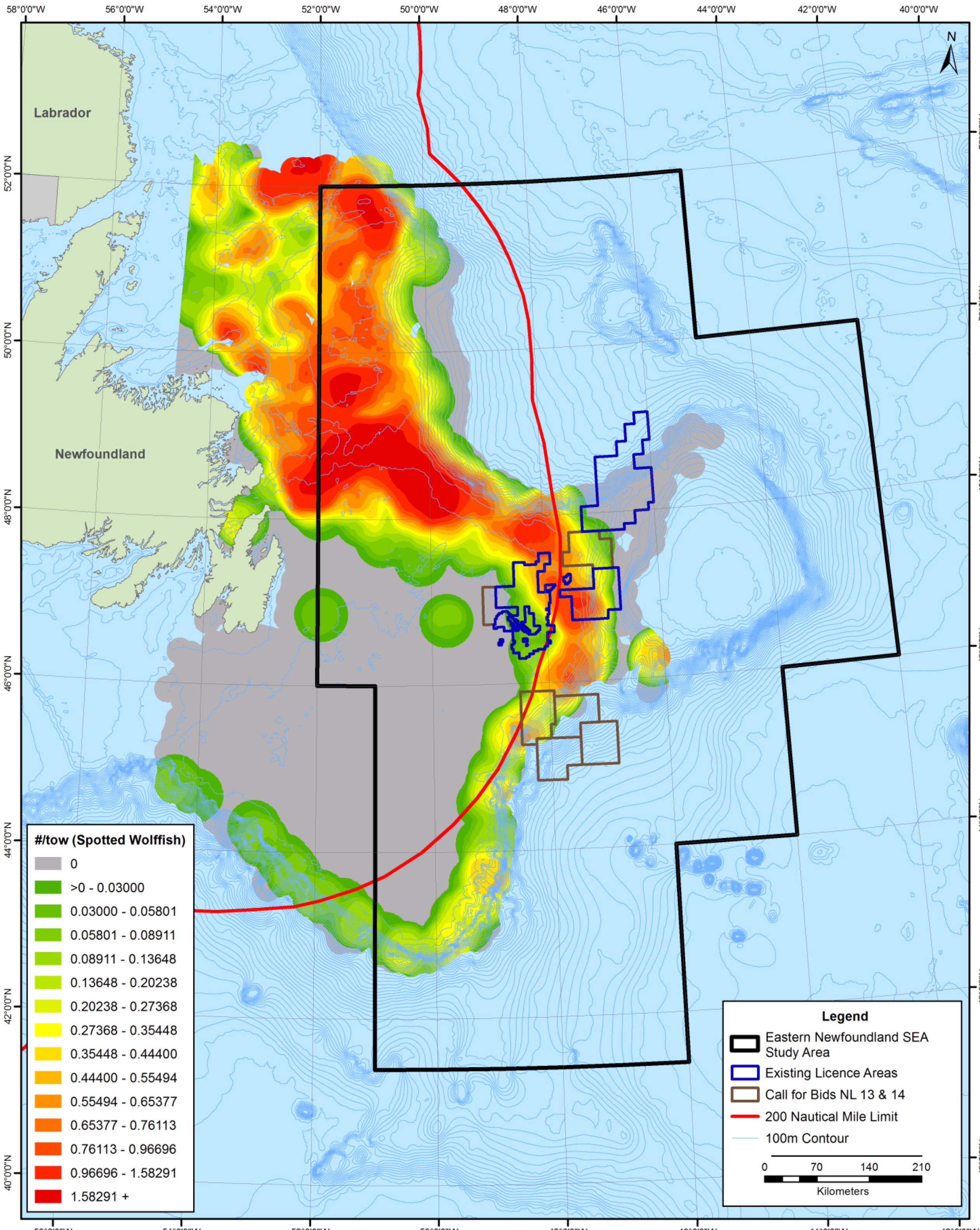


Table 4.66 Marine Fish Species at Risk that are Known to or May Occur within the SEA Study Area

Species		NL Provincial Designation			SARA Status			COSEWIC Assessment			IUCN				
Common Name	***Scientific Name***	***Endangered***	***Threatened***	***Vulnerable***	***Endangered***	***Threatened***	***Special Concern***	***Endangered***	***Threatened***	***Special Concern***	***Endangered***	***Vulnerable***	***Near Threatened***	***Least Concern***	*Population**
American Eel	*Anguilla rostrata*			●					●						AP
White Shark	*Carcharodon carcharias*				●			●				●			AP
Northern Wolffish	*Anarhichas denticulatus*					●			●						AP
Spotted Wolffish	*Anarhichas minor*					●			●						AP
Atlantic Wolffish	*Anarhichas lupus*						●			●					AP
Bluefin Tuna	*Thunnus thynnus*							●			●				AP
Atlantic Cod	*Gadus morhua*							●				●			NL
Cusk	*Brosme brosme*							●							AP
Roundnose Grenadier	*Coryphaenoides rupestris*							●							AP
Porbeagle	*Lamna nasus*							●				●			AP
Smooth Skate	*Malacoraja senta*							●			●				FI
Spiny Dogfish	*Squalus acanthias*									●		●			AP
Shortfin Mako	*Isurus oxyrinchus*								●			●			AP
American Plaice	*Hippoglossoides platessoides*								●						NL
Acadian Redfish	*Sebastes fasciatus*								●		●				AP
Deepwater Redfish	*Sebastes mentella*								●					●	NP
Atlantic Salmon	*Salmo salar*								●					●	NW, SN,SW
Roughhead Grenadier	*Macrourus berglax*									●					AP
Basking Shark	*Cetorhinus maximus*									●		●			AP
Blue Shark	*Prionace glauca*									●			●		AP
Thorny Skate	*Amblyraja radiata*									●		●			AP
Winter Skate	*Leucoraja ocellata*									●	●				GB
Barndoor Skate	*Dipturus laevis*										●				AP
Albacore Tuna	*Thunnus alalunga*												●		AP
Bigeye Tuna	*Thunnus obesus*											●			AP

* Population: AP – Atlantic Population; FI – Funk Island Deep Population; GB – Georges Bank-Western Scotian Shelf-Bay of Fundy Population; NL – Newfoundland and Labrador Population; NP - Northern Population; NW - Northwestern Newfoundland Population; SN – Southern Newfoundland Population; SW – Southwestern Newfoundland Population.

4.2.1.8 Environmental Influences and Changes

The importance of ecosystem change in the Northwest Atlantic has gained increased attention in recent years (e.g. Dawe et al 2012). Climate changes are now recognized as having a major influence over ecosystem characteristics on the Newfoundland Shelf, with fishing pressure also being a strong forcing factor (Dawe et al 2012). It has long been known to fisherman and scientists that fish and invertebrate abundance and distribution within the SEA Study Area are not static, with dramatic changes in both abundance and species composition occurring as a direct or indirect result of environmental conditions and exploitation (Worm and Myers 2003; deYoung et al 2004; Drinkwater 2006). Recognizing that such changes have happened and will occur in the future (Frank et al 1990; Drinkwater 2005) is critical when considering important and sensitive areas in time and space within the SEA Study Area. During 2013 consultations with fishers that use the SEA Study Area, it was underscored that important fishing grounds have changed from year to year. Similarly, scientific surveys have identified regime shifts of entire communities (Dawe et al 2012), distribution shifts of species (Rose 2005a) and altered migration patterns (Kulka et al 1995) that have occurred over several decades.

A key environmental driver in the North Atlantic has been the North Atlantic Oscillation (NAO), an atmospheric phenomenon that affects the movement of weather systems and currents in the region. In recent years it has fluctuated on decadal scales, and is strongly correlated with environmental variables such as sea surface temperature and rainfall (deYoung et al 2004). NAO oscillations have been linked to changes in stock health of shelf species (such as cod; Stige et al 2006) and deep water fish species (such as redfish; Devine and Haedrich 2011) and to plankton abundance and biomass (Greene and Pershing 2000; Pershing et al 2001; Head and Sameoto 2007). For example, changes to redfish abundance in the SEA Study Area vary with bottom temperature, sea surface temperature and NAO. These variables can, in turn, affect fecundity, growth and recruitment of redfish. Furthermore, changes to salinity can alter redfish larval survival and/or affect their plankton prey sources (Devine and Haedrich 2011). These effects can manifest in fish communities over years to decades.

Studies have attempted to predict ocean conditions in the Northwest Atlantic under the climate warming scenarios expected in the coming years (Frank et al 1990; Drinkwater 2005). Models predict a general warming and freshening of shelf waters that will move fish distribution of some species northward (e.g. cod, crab), extend the summer use of SEA Study Area by pelagic migrants, enhance fish growth and production and alter migration patterns (Frank et al 1990; Drinkwater 2005). In addition to these direct temperature effects, climate warming is also expected to increase stratification and alter current circulation patterns. These changes could reduce the transport of nutrients to benthic food webs and favour pelagic production (Frank et al 1990). Due to the complexity of the ecosystem and the unpredictable nature of fishing intensity, however, the authors of these studies recognize the speculative nature of these predictions.

In addition to the direct temperature-related influences of changing climate (see Section 4.1.6), there are other physical characteristics and processes that can affect marine biota, including other environmental climate-related changes such as through ocean acidification (CBD 2014a). Increased global atmospheric carbon emissions are partially absorbed by the ocean. A by-product of this process is the creation of carbonic acid and the acidification of the marine waters, which has increased by about 30 percent since the industrial revolution (DFO 2012i). An important, potential negative effect of acidification is the reduction in the ability of organisms to grow and maintain calcium carbonate structures (e.g. molluscs, corals). Increasing atmospheric carbon emissions are expected to have the largest effects on surface waters. To date, these changes have been attributed to decomposing organic matter as opposed to increased atmospheric carbon. Nonetheless, with expectations of continued climate change, both hypoxia and acidification of waters will likely become more prevalent in the future, and have the potential to further alter the distribution of marine organisms. The relevance of these issues to the marine ecosystem is reflected in, for example, the Convention on Biological Diversity's *Aichi Biodiversity Targets* (#10) which include that "By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning" (CBD 2014b).

The interconnected nature of the food webs in the SEA Study Area also means that changes to one species will inevitably affect various others (e.g. increases in cod abundance will likely negatively affect shrimp abundance; Worm and Myers 2003). Furthermore, not all species respond to perturbations in the same way. For example, deepwater species such as redfish are typically long lived, and their responses to changes in environmental conditions often lag as compared to shelf species (Devine and Haedrich 2011). In much the same way, Rose (2005a) determined that fish in the Northwest Atlantic can be classified into four general groups, which have varying responses to environmental perturbations: 1) small pelagics that frequent shallow and cool water; 2) large, warm water pelagic species; 3) cool, shallow water demersal fish; and 4) deep water species. Each group has distinct life history characteristics and population resilience that influence how they are affected by and respond to environmental conditions. For example, cold water pelagics such as capelin have a relatively small environmental tolerance range and can quickly increase their population size and therefore shift distributions and show demographic responses to environmental conditions (Rose 2005a). Variability in these distributions has been shown to align with temperature in the historical record (Rose 2005a). In contrast, more deep water species such as Greenland halibut and redfish, which occupy more stable habitats and have low rates of population increase, are expected to demonstrate less and/or delayed population responses (Rose 2005a; Devine and Haedrich 2011).

4.2.1.9 Aquatic Invasive Species

Aquatic invasive species (AIS) can threaten aquatic ecosystems, either by out-competing native species, preying on native species or through habitat disturbance. These species may show rapid population growth in the absence of natural predators and may soon become established to the point where eradication is not possible.

The most devastating recent example of this is the tunicate species *Didemnum vexillum*, which invaded Georges Bank off the New England coast. George's Bank is an area very similar to the Grand Banks, and is known for its very productive fishing grounds. This tunicate was first observed on Georges Bank in 2002 and has since covered an estimated 50-90 percent of hard substrates with a dense mat that smothers benthic organisms, reduces larval settlement, reduces shelter for juvenile fish, and prevents groundfish from feeding on benthic organisms (Leeuw at al 2013). Although this particular species has not been identified in the SEA Study Area, it is an important example of what can potentially occur. Local and international marine transport in general is implicated in many of the accidental introductions of marine AIS, as ship hulls and bilge water serve as vectors for AIS range expansion (McKenzie et al 2010). In addition to industry-related shipping, oil and gas development can also increase spread of AIS propagules when offshore drilling units and other installations are moved about the globe (Benoit et al 2012). For this reason, fishers during SEA consultations expressed concerns about increases of AIS when shipping traffic increases to support the offshore oil and gas industry.

Seven aquatic invasive species have been identified in the Newfoundland and Labrador Shelf Ecozone, including the European green crab, Japanese skeleton shrimp, golden star tunicate, violet tunicate, oyster thief algae and the coffin box bryozoan (Table 4.67). All of these species have been shown to have detrimental effects on native species and local ecosystems, but these effects are generally thought to be more important to benthic coastal communities as compared to the open ocean (Templeman 2010).

Table 4.67 Invasive Marine Species on the Newfoundland Continental Shelf

Taxa	Species	Dispersal Routes	Potential Effects
Crustacean	European green crab[1] (*Carcinas maenas*)	Spread through movement of fishing gear, and transport via ballast water.	Prey on invertebrates. Extremely efficient predators and colonizers. Destroy fish habitat (i.e. eelgrass) (Morris et al 2010)
	Japanese skeleton shrimp (*Caprella mutica*)	Spread through movement of fishing gear, offshore buoys, and boats (Cook et al 2007)	Interferes with aquaculture operations.
Tunicate	Golden star tunicate (*Botryllus schlosseri*)	Spread through movement of fishing gear, shellfish and boats Interferes with bivalve larvae settlement.	Interferes with aquaculture operations.
	Violet tunicate (*Botrylloides violaceus*)	Spread through movement of fishing gear, shellfish and boats Interferes with bivalve larvae settlement.	Interferes with aquaculture operations.
	Vase tunicate (*Ciona intestinalis*)	Spread through movement of fishing gear, shellfish and boats Interferes with bivalve larvae settlement.	Interferes with aquaculture operations.
Bryozoan	Coffin box bryozoans (*Membranipora membranacea*)	Spread through movement of boats and planktonic larvae	Devastates kelp beds.
Algae	Oyster thief (*Codium fragile* spp. *fragile*)	Spread through movement of fishing gear, shellfish and boats	Replaces native species including eel grass and kelp.

Source: Modified from DFO (2014); Matheson (2013); Templeman (2010)
[1] This is a coastal species but has been included here for completeness

4.2.1.10 Ecologically and Biologically Significant Areas (EBSAs)

A number of Ecologically and Biologically Significant Areas (EBSAs) have been identified by DFO for the Placentia Bay-Grand Banks Large Ocean Management Area (Templeman 2007). This exercise was undertaken through an analytical ranking system of candidate areas in which DFO identified various thematic layers and criteria (Table 4.68), from which 11 EBSAs were eventually identified and evaluated. For each of these EBSAs, the various layers were evaluated independently using the three primary criteria (fitness consequence, aggregations and uniqueness) and two secondary criteria (naturalness and resilience).

Table 4.68 Layers and Criteria for EBSA Designation

Attributes	Types	Description
Thematic Layers	Topography and Physical Processes	Physical information layer
	Primary Production	Biological information layers

Attributes	Types	Description
	Secondary Production	
	Meroplankton	
	Benthic Invertebrates	
	Demersal Fishes	
	Pelagic Fishes	
	Pinnipeds and Cetaceans	
Criteria/ Dimension	Uniqueness	Areas whose characteristics are unique, rare, distinct, and for which alternatives do not exist.
	Aggregation	Areas where (i) most individuals of a species are aggregated for some part of the year; or (ii) some important function in their life history; or (ii) some structural feature or ecological process.
	Fitness Consequence	Areas where the life history activity(ies) undertaken make a major contribution to the fitness of the population or species present.
	Resilience*	Areas where the habitat structure or species are highly sensitive, easily perturbed, and slow to recover.
	Naturalness*	Areas which are pristine and characterized by native species.
*Resilience and naturalness are usually captured within the first three Criteria/Dimensions and are considered secondary dimensions (Templeman 2007)		

Several EBSAs (Figure 4.91, from Templeman 2007) were selected based on their importance to marine fish, invertebrates and planktonic components and characteristics. The identified EBSAs that are located within or in close proximity to the SEA Study Area are described below using information from Templeman (2007) and DFO (2013j):

- *Southeast Shoal and Tail of the Banks:* This EBSA falls within the SEA Study Area, and has been identified due to its importance to the finfish, invertebrate, and plankton community. The Southeast Shoal has been designated primarily because of its importance as a spawning area for several commercial (American plaice, yellowtail flounder, capelin and Atlantic cod) and non-commercial (northern sand lance) fish species. For capelin, the EBSA contains a rare offshore spawning and aggregation area. It is also the single nursery area for the entire stock of yellowtail flounder. The Tail of the Grand Banks has been identified because it has the highest density of American plaice and yellowtail flounder on the Grand Banks. This area is also important to the benthic community, where wedge clams occur in extremely high densities (Hutcheson and Stewart 1994) and offshore blue mussels have the highest benthic biomass of anywhere on the Grand Bank. This is in addition to this EBSA being an area of high productivity and having the densest concentrations of the listed striped wolffish.

- *Lilly Canyon and Carson Canyon*: Key reasons for the identification of this EBSA include its importance as a feeding and high production area for Iceland scallops.

- *Northeast Shelf and Slope*: This EBSA has been identified as having the highest concentrations of Greenland halibut and spotted wolffish, which aggregate in this area in the spring.

- *Virgin Rocks*: This area includes high aggregations of capelin, as well as being a point of aggregation for several other spawning groundfish species such as Atlantic cod, American plaice and yellowtail flounder. The Virgin Rocks also are an area of relatively high macroalgae / seaweed abundance and diversity (R. Hooper, pers. comm.), although this has not been identified as a reason for EBSA designation.

- *Orphan Spur*: Corals occupy this EBSA as well as high densities of species of conservation concern (including Northern, Spotted and Striped wolffish, skates, roundnose grenadier, American plaice, redfish) and sharks.

- *Labrador Slope*: This area was designated for its biodiversity which include corals and sponges, several species of conservation concern (including Northern, Spotted and Striped wolffish, skates, roundnose grenadier) and high densities of Northern shrimp, American plaice, redfish, Atlantic cod and Greenland halibut.

- *Southern Pack Ice*: Southern Pack Ice is an EBSA that occurs in the Study Area seasonally. While important to marine mammals and seabirds, there is no direct reason for sensitivity from a benthic invertebrate or marine fish perspective.

Other identified EBSAs in general proximity to the SEA Study Area (within 100 km) include those summarized in Table 4.69.

Table 4.69 Fish and Invertebrate Characteristics of Other EBSAs within Proximity of the SEA Study Area

EBSA Name	Description as it Relates to Benthic Invertebrates and Finfish	EBSA #
Southwest Shelf and Edge and Slope	*Benthic Invertebrates:* The area has structure-forming gorgonian corals in high concentrations and high concentrations of other cold-water corals *Finfish:* This area is important to finfish as a result of the following attributes: • Host to northernmost population of haddock in NW Atlantic Ocean, with highest concentrations along the SW slope • Key area for Atlantic halibut along SW slope during spring • Haddock spawning (along edge of SW slope in spring) • Important spawning area for redfish • Migration routes for cod • A greater portion of the biomass of most of the groundfish species present occurs along the SW slope • Monkfish, pollock, and white hake in region occur exclusively along the SW slope and within the Laurentian Channel with higher concentrations in the spring	3
Eastern Avalon Coast	• Identified only in relation to marine mammals and seabirds (see subsequent sections for details)	7
Fogo Shelf	• Finfish: The area is important for beach and subtidal spawning capelin and as a migratory path and feeding area for Atlantic salmon.	12
Notre Dame Channel	• Benthic invertebrates: High densities of snow crab and shrimp occur in this area. • Finfish: High finfish diversity including high densities of smooth and thorny skates as well as high densities of capelin, American plaice and Greenland halibut	14
From Templeman (2007) and DFO (2013j)		

Figure 4.91 Ecologically & Biologically Significant Areas (EBSAs)