CONTRACT REPORT TO FISHERIES AND OCEANS CANADA FROM OCEAN NETWORKS CANADA

Contract No. F1570-171045

Heat mapping of the intensity of activities in the Endeavour Hydrothermal Vents Marine Protected Area (EHVMPA).

March 15, 2018

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Tasks

4.1 ONC will provide a report that utilizes the submersible dive tracks and geodatabase info collected to create "heat maps" of activities highlighting the intensity of the activities within the EHVMPA and its major vent fields: Main Endeavour Field, Sasquatch, Salty Dawg, High Rise and Mothra. Point maps will be produced showing separately the locations of observed anthropogenic debris, target species, and habitats. The report will include a description of the methodology on how maps were produced, and include comments about spatial and temporal trends in an 'interpretation' section.

4.2 Outline document must be provided electronically in MS Word 10 format for DFO review and input.

4.2 FINAL document must be provided electronically in MS Word 10 format and 1 hard copy.

4.3 Acknowledgement from ONC that all components of the heat maps are available (in a common digital format to be agreed upon by DFO and ONC); for unrestricted use and reproduction by DFO.

Background

The Endeavour hydrothermal vents Marine Protected Area (EHVMPA), located ~250 km offshore of Vancouver Island, BC, Canada, has been studied internationally with hundreds of submersible dives and many samples taken since its discovery in 1982 (Fisheries and Oceans Canada (DFO), 2010). Ocean Networks Canada (ONC) has been monitoring and operating in this area since 2007, with a combination of submersible dives, and fixed sensors on a subsea cabled observatory. As the number of submersible dives, for Remotely-Operated, Human-Occupied Vehicles, and Autonomous Underwater Vehicles (ROVs, HOVs, and AUVs) is now in the hundreds, with repeated visits to many areas, navigation track points alone are no longer sufficient for identifying which areas are visited most often and are well known, versus which areas are visited infrequently and less explored. In order better document the intensity of sampling and submersible visits, and related observations and potential disturbance to an area, "heat maps" (kernel density maps) can be created using ESRI ArcGIS spatial analysis tools to address the following questions at the scale of the entire EHVMPA, and for each of the major hydrothermal vent fields (Mothra, Main Endeavour Field, High Rise, Salty Dawg, and Sasquatch):

1. Where are the most-visited and least-explored areas?
2. Where are the concentrations of sampling activities (geological, biological, vent fluid samples), and related potential disturbance?

Question one is addressed using dive tracks as a proxy of where research occurs. Question two is addressed using the physical samples table classified by sample type (geological, biological, and fluid samples).

One overview heat map for submersible visits is generated, plus one per aggregated 9-year interval; and, one overview heat map for physical sampling is generated, and one for each of the three sampling types (geological, biological, fluid samples).

In addition, an analysis was conducted using these data to determine the percentage of submersible time and sample collections occurring within management areas versus outside management areas in the MPA. This will help determine how time spent in the MPA is being utilized and if new or modified management areas are required.

DFO requires an assessment of introduced anthropogenic materials to determine compliance with the management plan (Fisheries and Oceans Canada, 2010, p.37). DFO also needs to know the relative density of target species and available habitats in the EHVMPA in order to fulfill the information needs identified in the management plan (Fisheries and Oceans Canada, 2010, p.25). Point maps are provided to help meet these requirements illustrating:

a) Relevant ONC dive observations for anthropogenic debris classified by types (experiment materials such as plastic cable ties, ballast weights, and other materials such as aluminum cans),
b) Relevant ONC dive observations for target species (e.g. Corals, Sponges, and Annelids), and
c) Relevant ONC dive observations (or other available sources) for habitats of target species (e.g. vent species).

Results from the maps are shown here along with the methods used, assumptions made, and an analysis of the findings.

Document Versioning

Version	Date	Description	Editor(s)
1.0	2017-03-15	Outline document for DFO review	Karen Douglas
2.0	2017-03-27	Final document for contract	Karen Douglas
3.0	2018-03-09	Outline document for DFO review	Karen Douglas and Mark Rankin
4.0	2018-03-15	Final document for contract	Karen Douglas, Kim Juniper and Mark Rankin

Question 1: Where are the areas of high research pressure and where are the poorly explored areas? - Methodology and Assumptions Made

Environmental stress from research and exploration coverage is assessed here using dive track point navigation data and clustering techniques, as research in these areas to date has been done solely with underwater vehicles (ROVs, HOVs, and AUVs). These vehicles are equipped with cameras and often a CTD allowing for further analysis of the areas post cruise. Here, we assume that areas under the highest research pressure and therefore best explored are those where there are higher densities of vehicle navigation track points. Areas that are poorly explored and under low pressure from research are those for which there are lower densities of vehicle navigation track points or areas of no submersible presence at all. The ArcGIS Spatial Analyst Toolbox kernel density tool is used here as it provides control over the more than 30 input parameters. It outputs a continuous surface that is easier to interpret than data products from other point-based tools (ESRI, 2017a). Although this tool can accept both point and line data, point data are used to enable analysis in both time and space rather than only spatially with lines alone.

There are clusters of points at the positions of vehicle ascent and descent, when available. As the water column is a part of the marine protected area, this is considered an accepted bias. Based on three separate submersible dives, this time is typically ~110 minutes on the descent and ~120 minutes on the ascent. Altitude data are only available for later cruises, so filtering on 'time on bottom' is not available as a comparison.

Processing Steps:

Navigation data for ONC and DFO dives are downloaded from the ONC data portal Oceans 2.0 (Data Search tool) by cruise into 1-minute clean averaged Ocean Data View standard text files for the respective remotely operated vehicles (http://dmas.uvic.ca/DataSearch?location=ROV).

Third party data are sourced from the Interdisciplinary Earth Data Alliance (IEDA) including dives from Oregon State University, the National Oceanic and Atmospheric Administration, the University of Washington, the University of Massachusetts, Washington State University, Woods Hole Oceanographic Institution, University of Georgia, and the University of California Santa Cruz (IEDA, 2017). These data are resampled to median 1-minute intervals using a Python script. The median value is used to exclude any bias by outliers.

Averaging data into equal time intervals is important, as biases will occur if different numbers of points appear per time period. Timestamp, latitude, longitude, and depth are then parsed into comma-separated value (CSV) files by dive and loaded into a file geodatabase table. Timestamps are converted from strings to ArcGIS date formats using the "Convert time field (Data Management)" tool. The location data are in WGS84 geographic coordinates at the source. In order to have a symmetrical grid that does not create a north-south bias, the data are projected into a WGS84 UTM Zone 9N coordinate system providing metres for units.

The population field is set to 'none' as all submersible models are assumed to provide equal stressors and each point represents the presence of one submersible.

Output cell size is set to 1 m. As the along-axis basemap is using 1 m resolution bathymetry, the output cell size matches the value in the environment (ESRI, 2017b).

A search radius needs to be set for the range from each point that the algorithm uses to look for clusters, and this choice affects the calculated density (ESRI, 2017b). In order to choose a reasonable search radius several factors were considered:

- Horizontal uncertainty of acoustic navigation for most submersibles is 1% of water depth. As we are dealing with depths between 1959 m and 2481 m within the MPA bounds and a mean of 2240 m (based on Ocean Networks Canada 30-m resolution bathymetry), this gives a suitable minimum radius range of 20 m to 25 m.
- Stress on the environment from sediment disturbance: the range for disturbance of sediment from the submersible is not easily quantifiable, as no known quantifiable studies have been identified at this time. It is assumed to be less than 25 m.
- Stress on the environment from lighting: effective distance travelled by artificial lighting is less than 70 m. This is known from light sources not being visible on cameras at a distance of 70 m. From photogrammetry studies, imaging with a camera is limited to 10 m or less and light up to 30 m would influence the environment (Tom Kwasnitchka, personal communication, 2017).
- Stress from electromagnetic fields from technology are argued to be shielded by water and are unlikely to be a factor (Tom Kwasnitchka, personal communication, 2017).
- The noise from the submersible Jason II was quantified using a hydrophone at ONC's Barkley Canyon at 138 DB for a 1 m distance at 2016-06-25 02:53:06 UTC. For ONC's target of 140 DB, Jason is under this threshold, so this is not considered as a source of high stress on the environment, particularly since the sound source is not stationary.
- Trialing the kernel density tool using values within the range of 20 m to 100 m helped to determine a radius that would alleviate empty spaces of overlap between radii. The radius chosen in the end that met all of these considerations is 25 m.

The 'processing extent' (the boundary processed), by default in ArcGIS is limited to the maximum boundaries of the furthest points in each direction. This was manually extended in the environment variables to the published bounds of the Marine Protected Area (Fisheries and Oceans Canada, 2010) for the overview maps and for the area of the map in the vent fields maps. This prevented clipping of the density radius at the edges of the furthest points.

This process was applied to the entire dataset (Figures 1,3,5,7,9,11) and then to the data filtered into nine-year intervals (Figures 2,4,6,8,10,12) in order to assess changes in environmental pressure over time.

Results provide a coverage density per unit area in the form of intensity of submersible activity per square metre. Note that kernel density values are given in exact numbers but are best treated as relative numbers due to the assumptions made (Krause, 2013). The coverage is provided for each of the EHVMPA bounds (Figures 1 and 2) and each of the major vent fields: Mothra (Figures 3 and 4), Main Endeavour Field area (Figures 5 and 6), High Rise (Figures 7 and 8), Salty Dawg (Figures 9 and 10), and Sasquatch (Figures 11 and 12).

Processing Notes:

- Some older Alvin (HOV), Jason I, Jason II, ABE, Tiburon, and ROPOS ROV dives did not have ascent and descent navigation data
- The Woods Hole Oceanographic Institution ROV Jason Dive J0888 was aborted during descent. No navigation data exists for this dive.
- There are no navigation data available for the Oceaneering ROV Millennium Plus dives M0001, M0002, and M0003 due to hardware issues.
- Other than these exceptions, the ONC dataset is complete. However, only available third party data were included from IEDA. More data may exist at local institutions and could be added as availability permits. ONC is currently working with IEDA to try and acquire more of these datasets.

Maps – Question 1

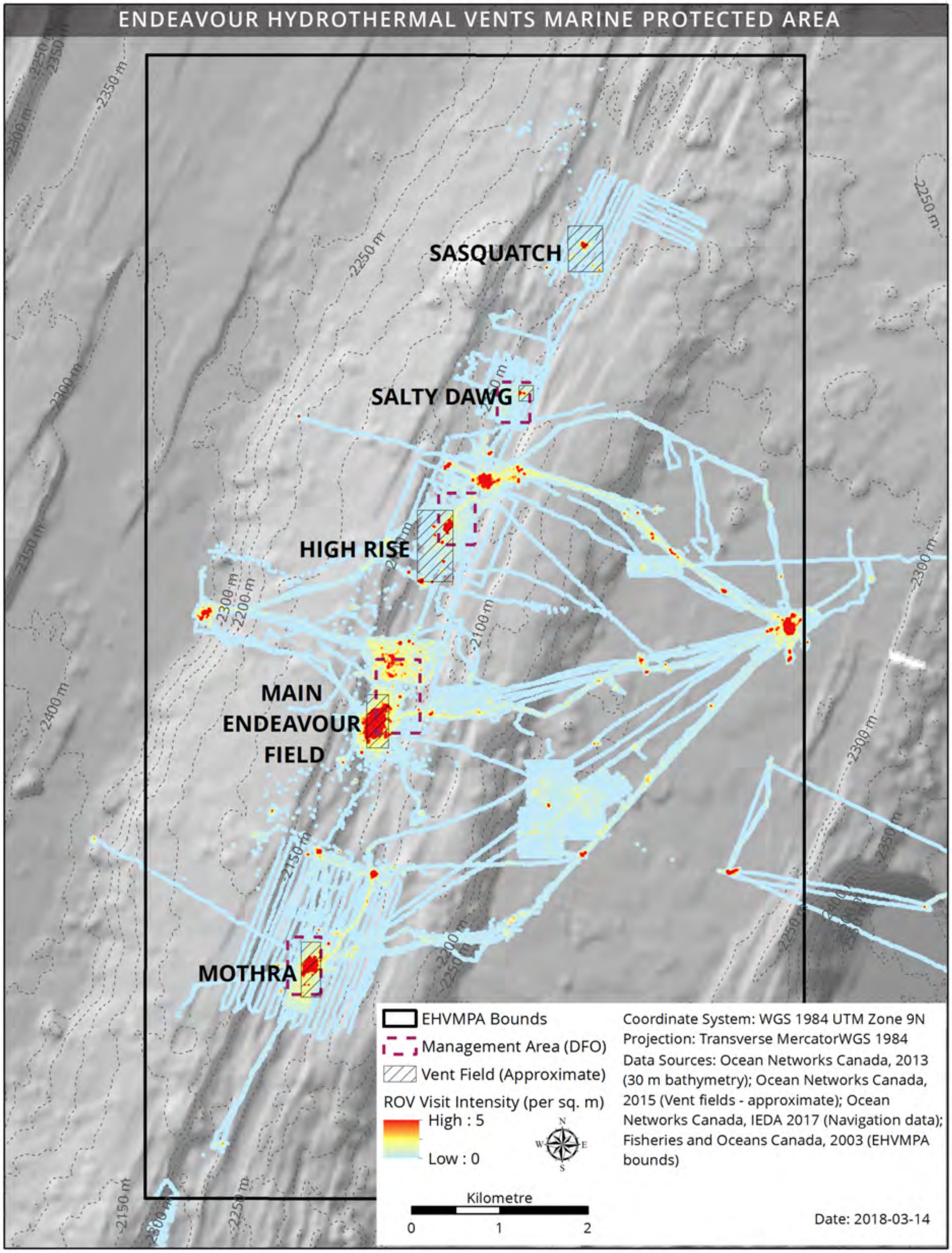

Figure 1. Kernel density map of track points indicating the intensity of submersible visits per square metre for the bounds of the Endeavour Hydrothermal Vents Marine Protected Area for all ONC dives and available third party dives between 2000 and 2017

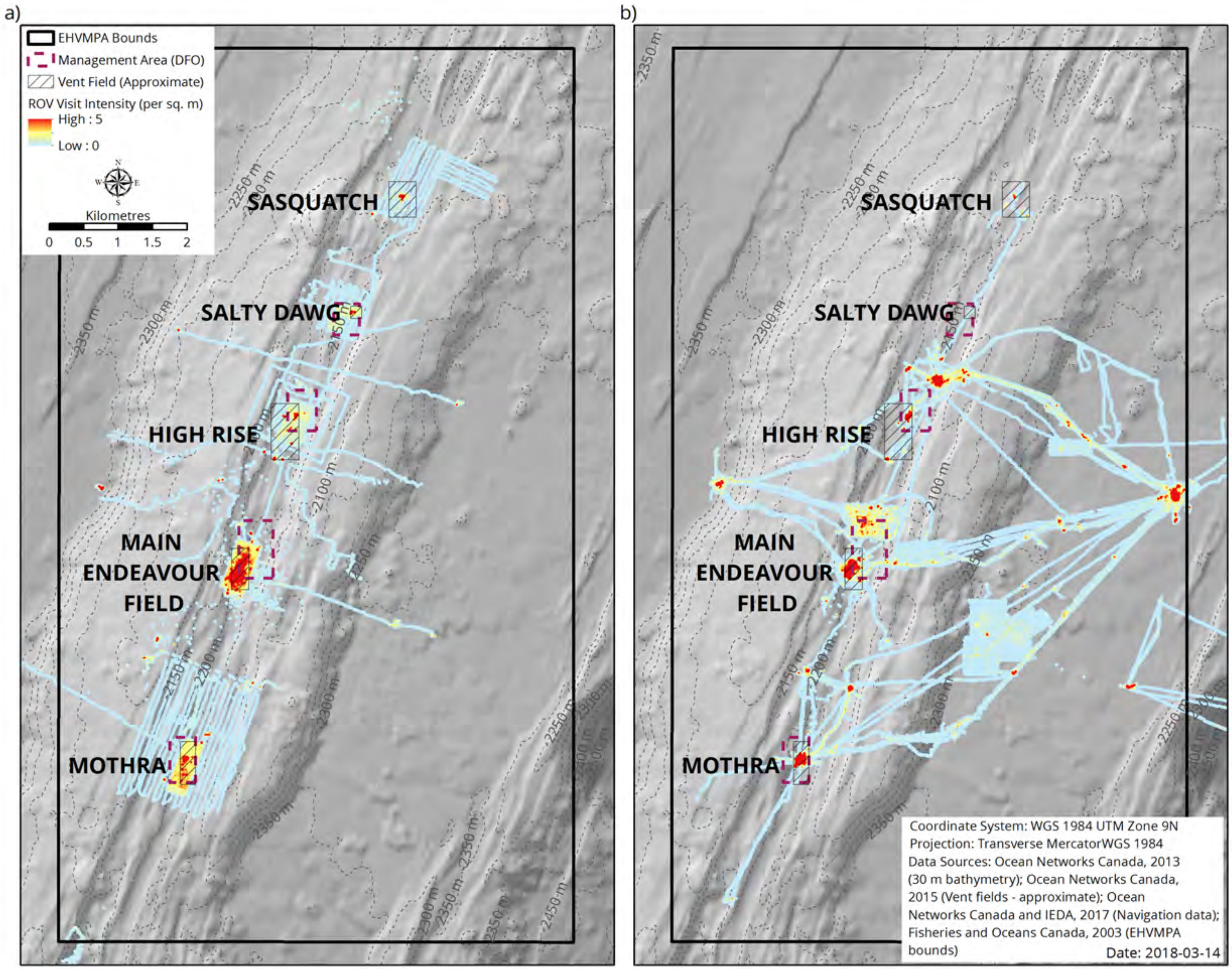

Figure 2. Kernel density map of track points indicating the intensity of submersible visits per square metre per nine-year interval for the bounds of the Endeavour Hydrothermal Vents Marine Protected Area for a) dives between 2000 and 2008 inclusive, and b) dives between 2009 and 2017 inclusive.

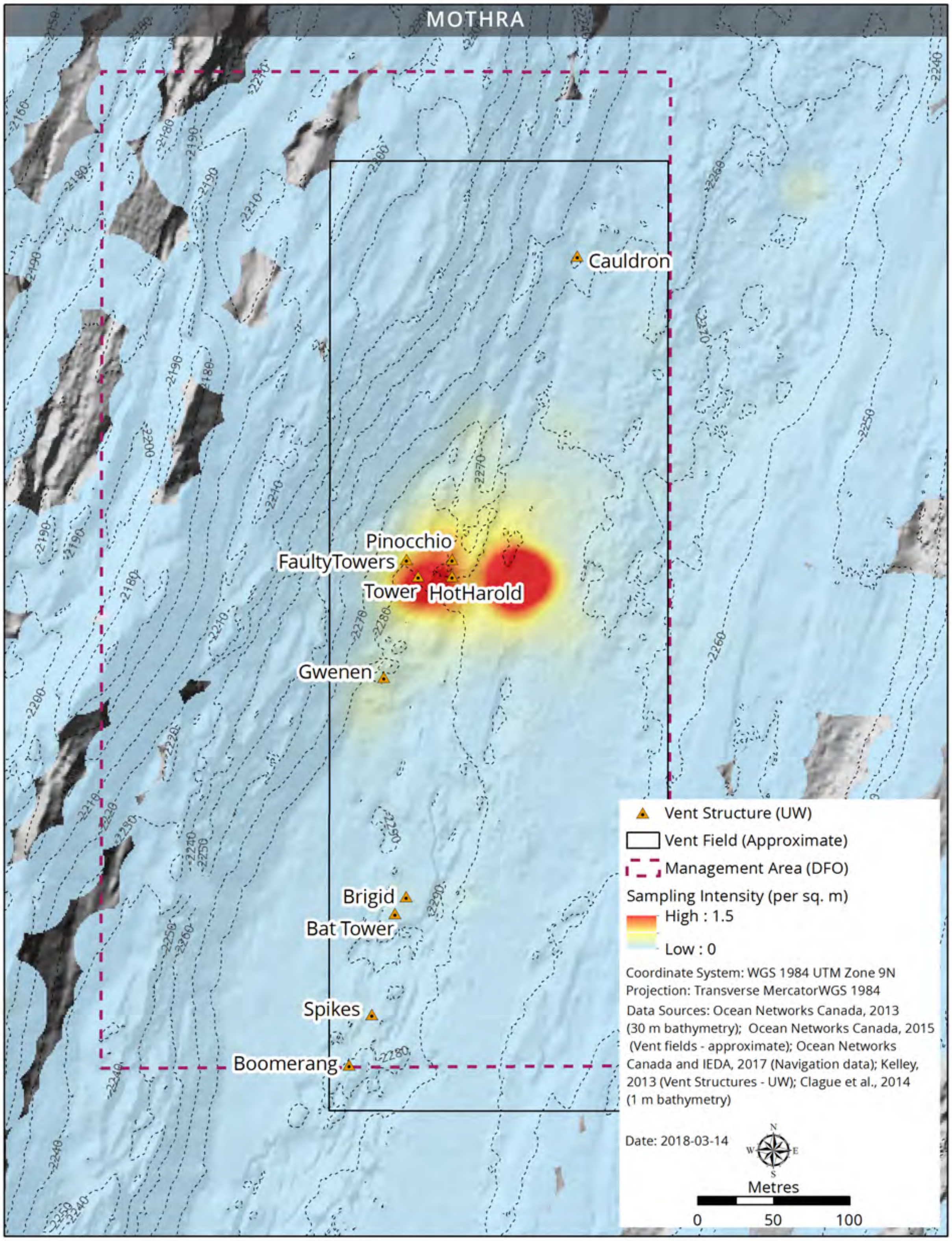

Figure 3. Kernel density map of track points indicating the intensity of submersible visits per square metre for the Mothra area for all ONC dives and available third-party dives between 2000 and 2017

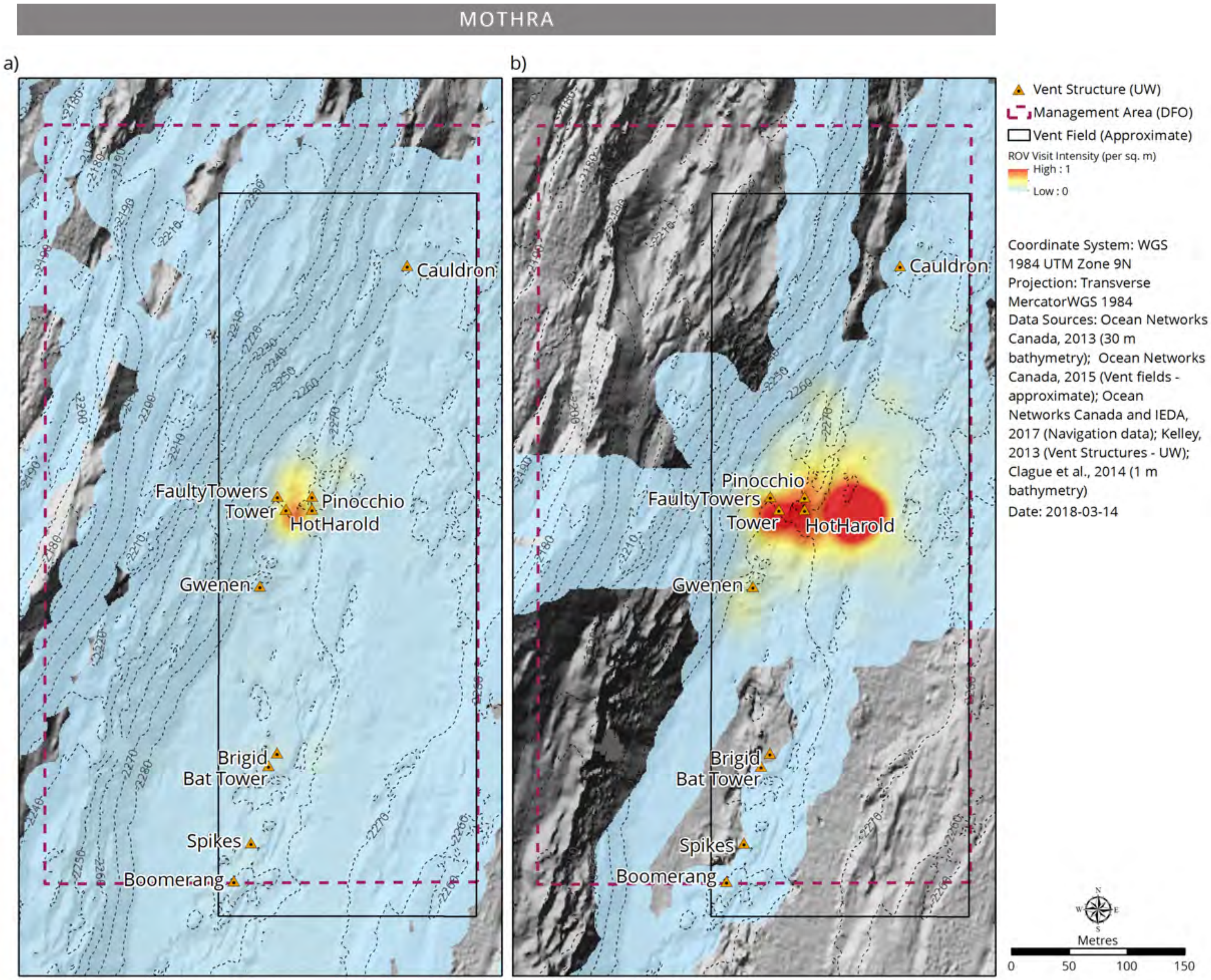

Figure 4. Kernel density map of track points indicating the intensity of submersible visits per square metre per nine-year interval for the Mothra area for a) dives between 2000 and 2008 inclusive, and b) dives between 2009 and 2017 inclusive.

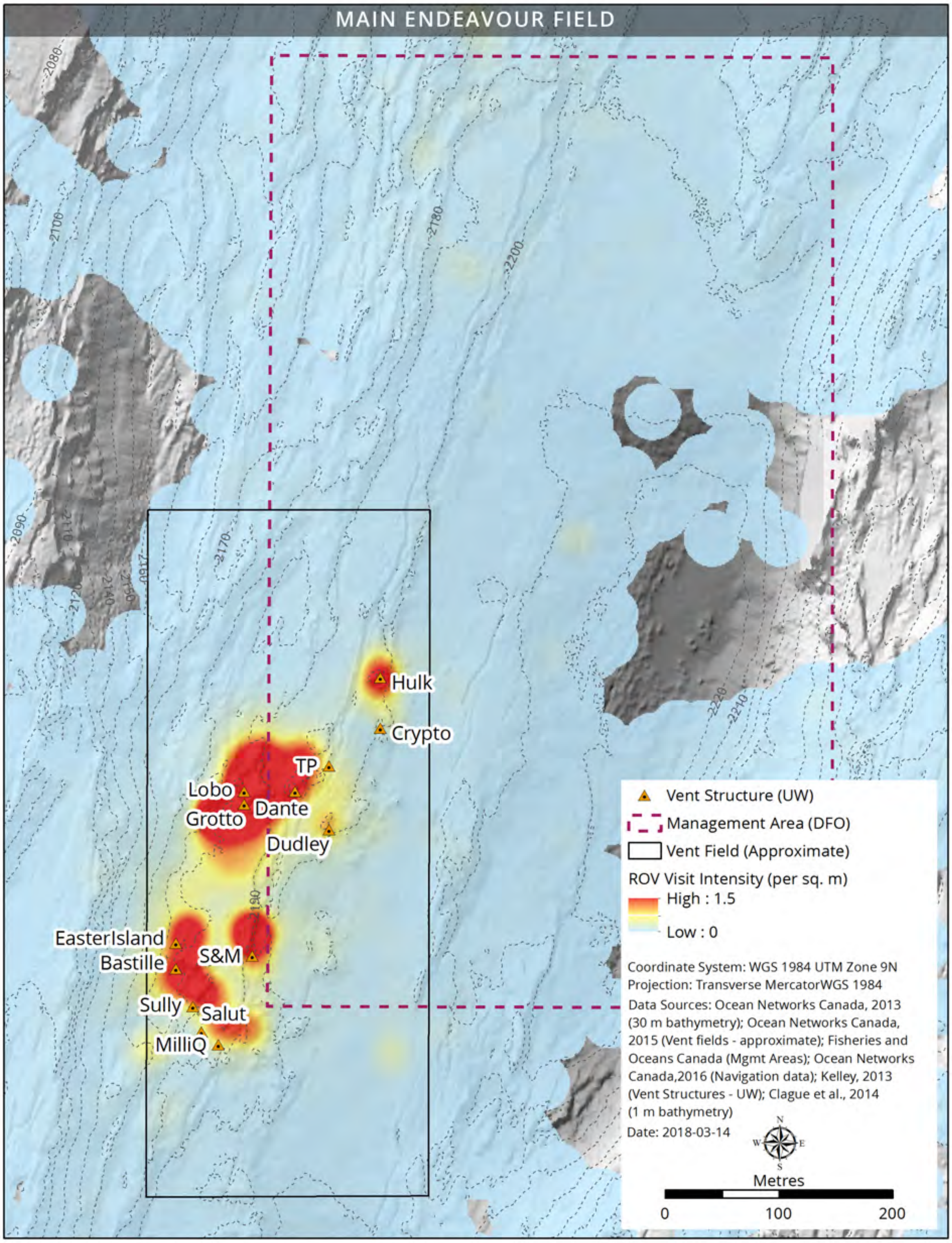

Figure 5. Kernel density map of track points indicating the intensity of submersible visits per square metre for the Main Endeavour Field area for all ONC dives and available third-party dives between 2000 and 2017

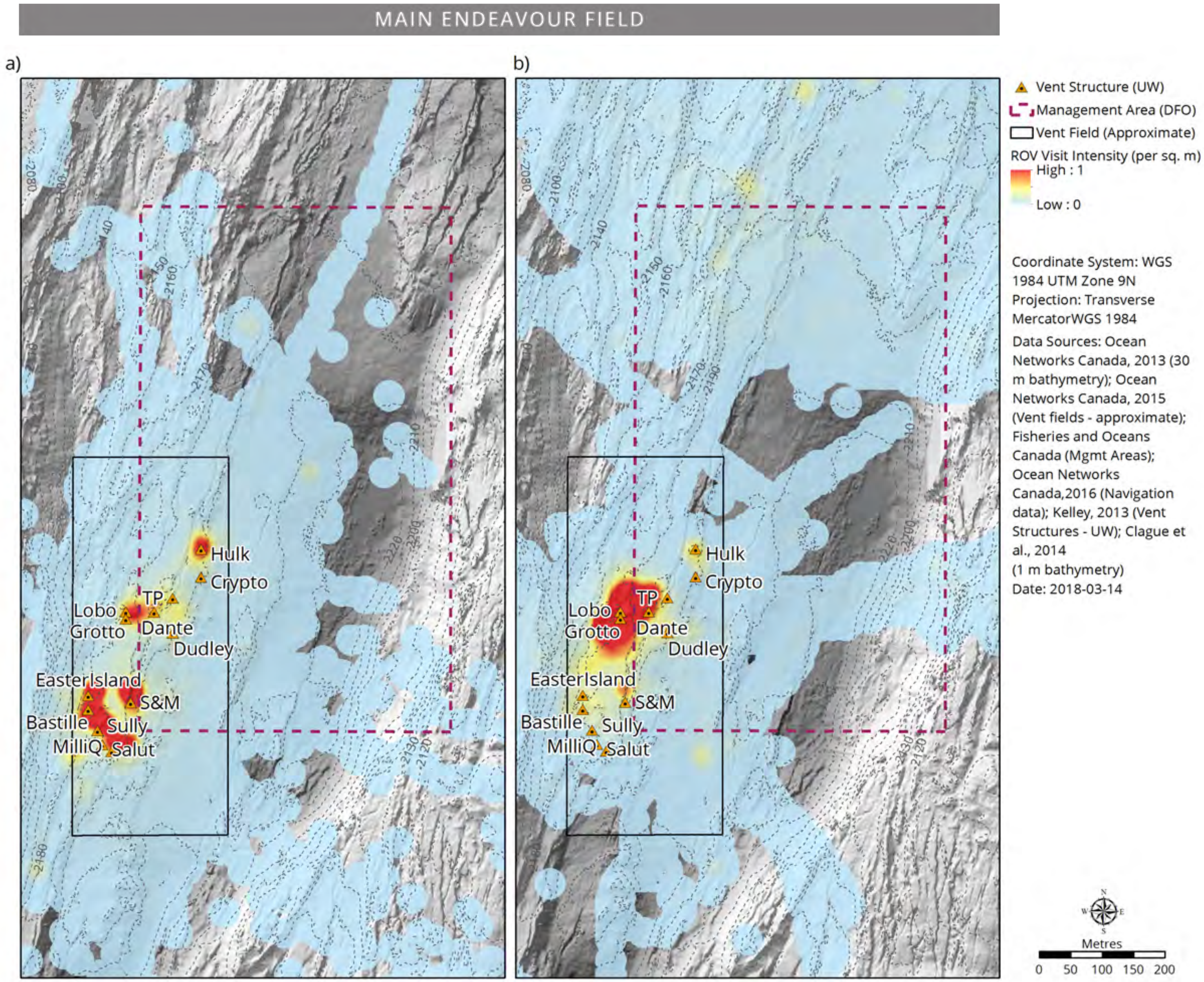

Figure 6. Kernel density map of track points indicating the intensity of submersible visits per square metre per nine-year interval for the Main Endeavour Field area for a) dives between 2000 and 2008 inclusive, and b) dives between 2009 and 2017 inclusive.

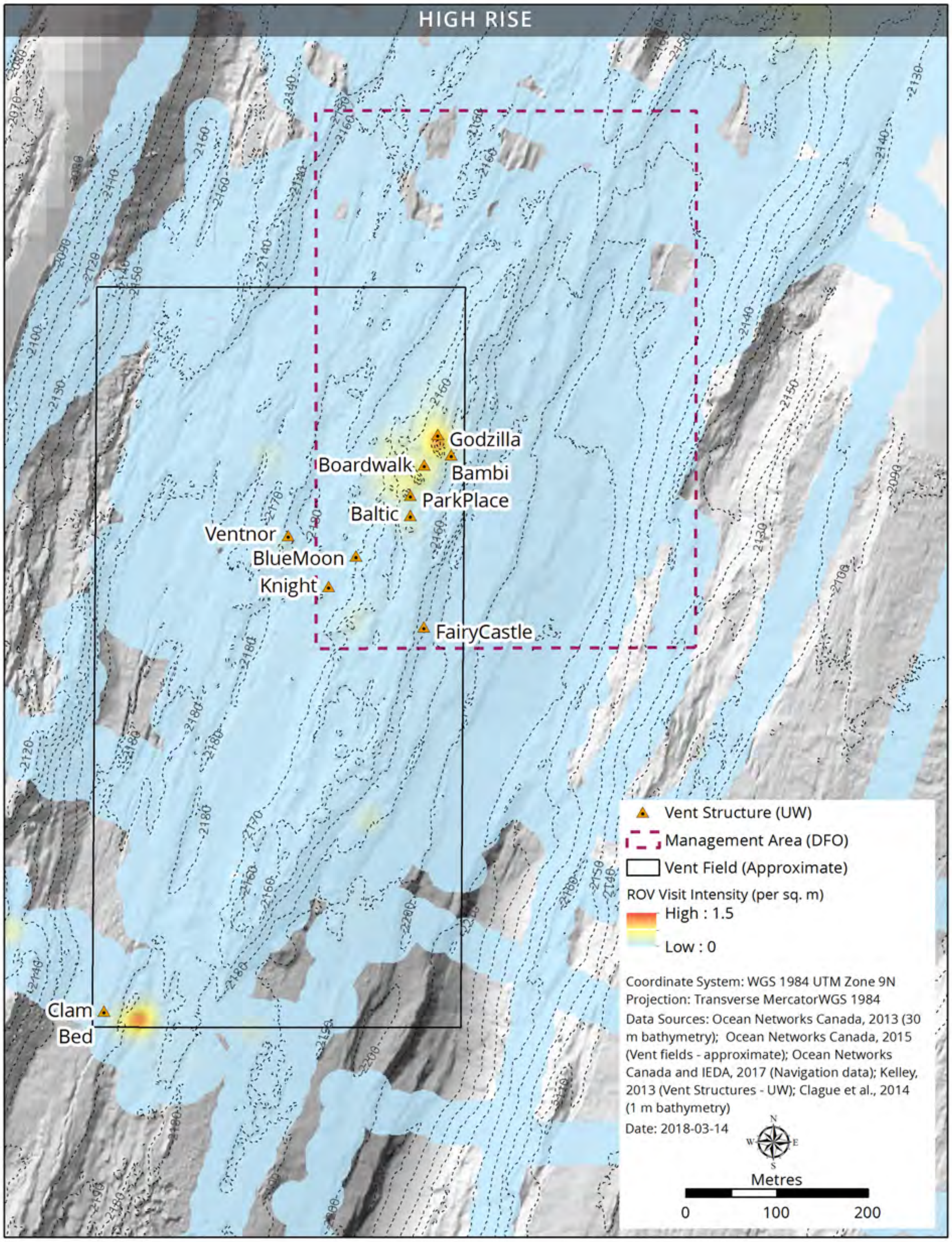

Figure 7. Kernel density map of track points indicating the intensity of submersible visits per square metre for the High Rise area for all ONC dives and available third-party dives between 2000 and 2017

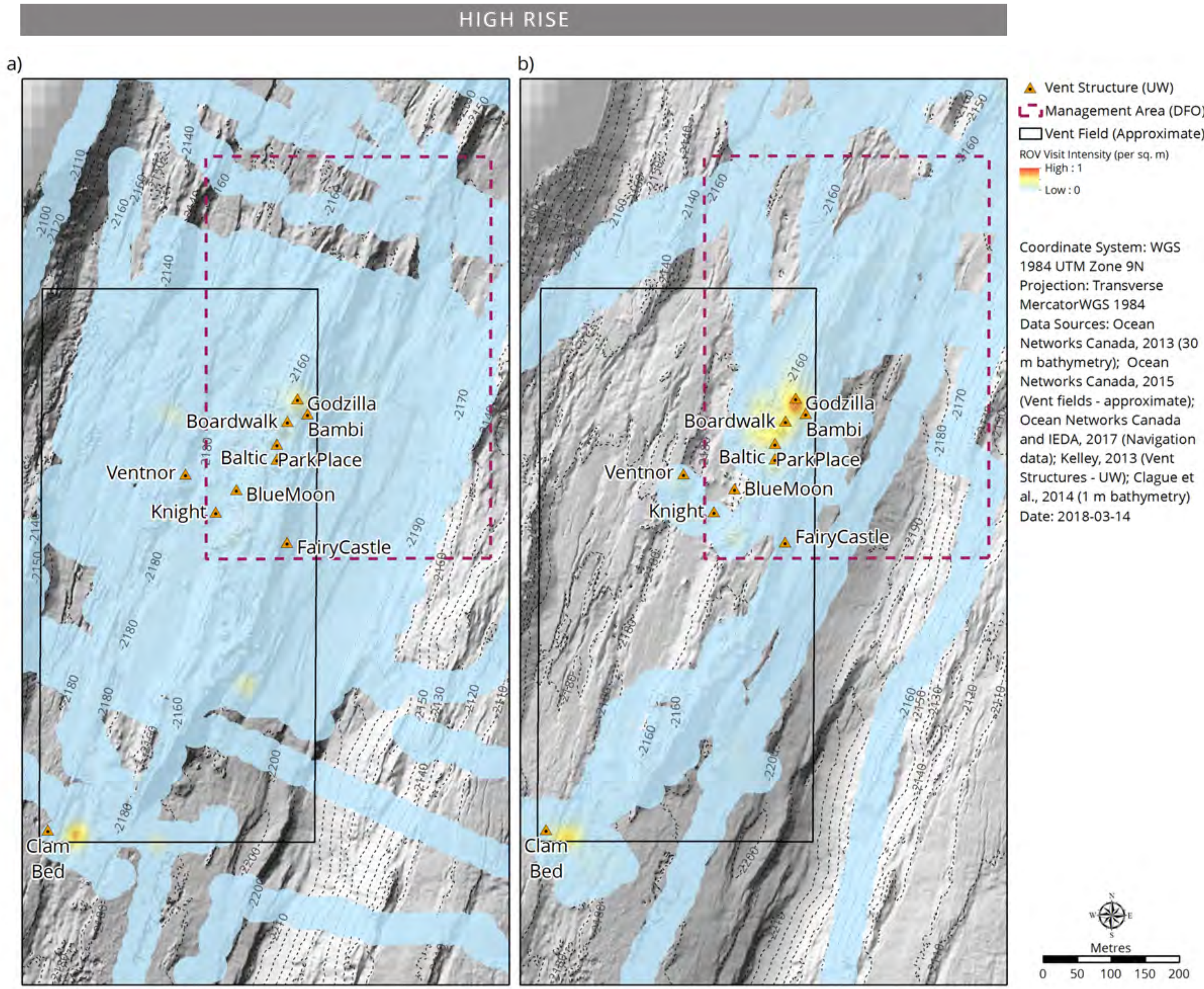

Figure 8. Kernel density map of track points indicating the intensity of submersible visits per square metre per nine-year interval for the High Rise area for a) dives between 2000 and 2008 inclusive, and b) dives between 2009 and 2017 inclusive.

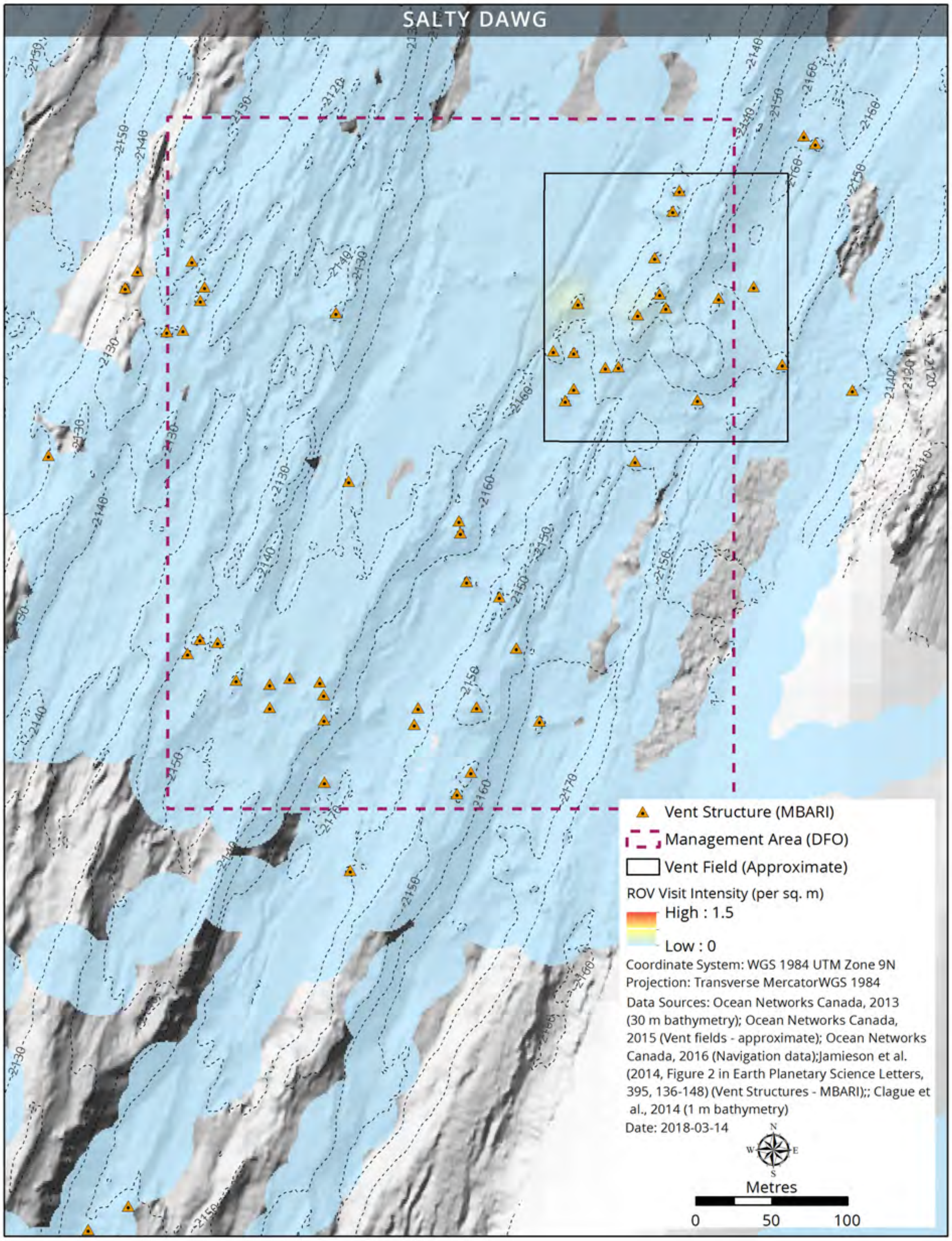

Figure 9. Kernel density map of track points indicating the intensity of submersible visits per square metre for the Salty Dawg area for all ONC dives and available third-party dives between 2000 and 2017

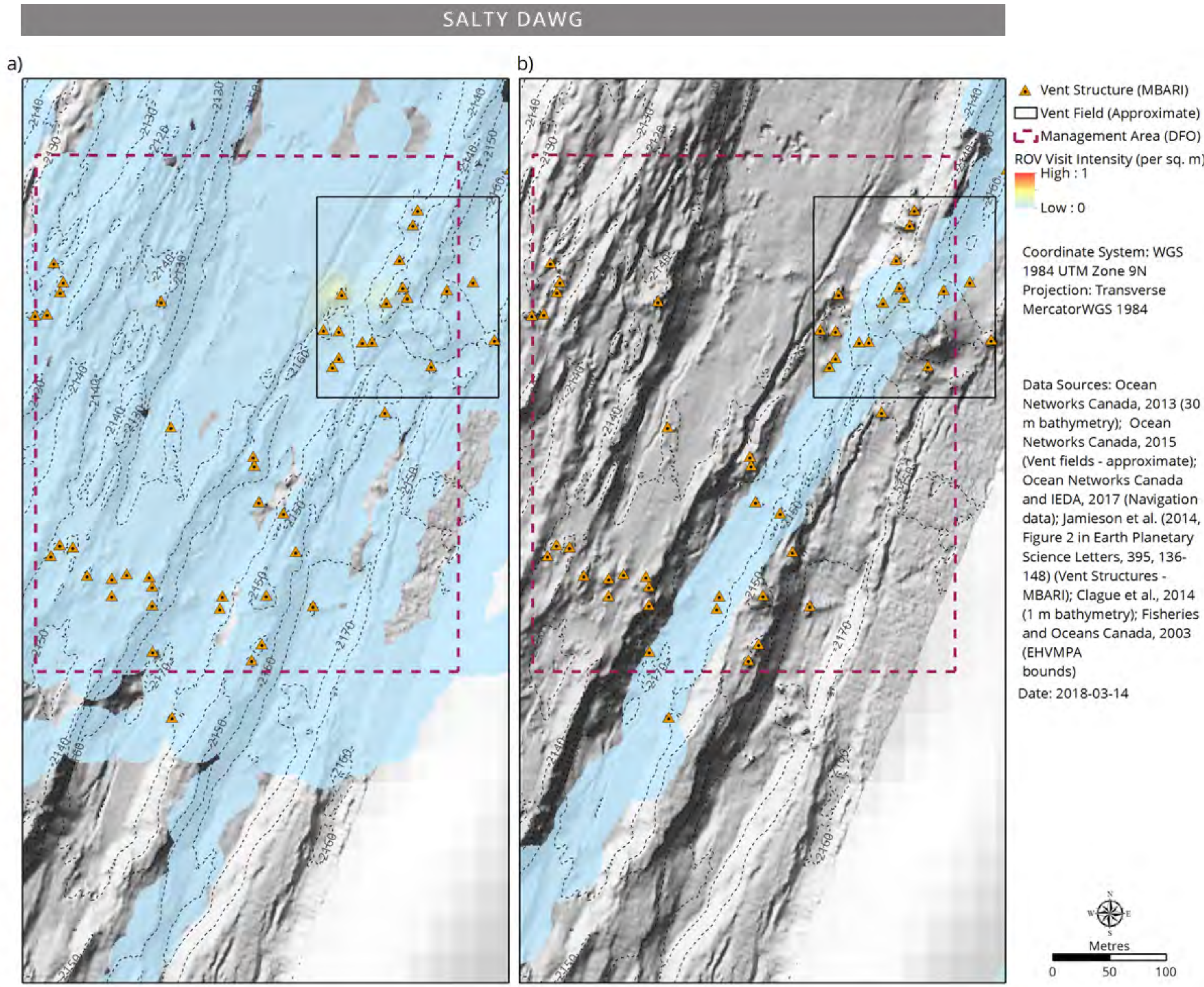

Figure 10. Kernel density map of track points indicating the intensity of submersible visits per square metre per nine-year interval for the Salty Dawg area for a) dives between 2000 and 2008 inclusive, and b) dives between 2009 and 2017 inclusive.

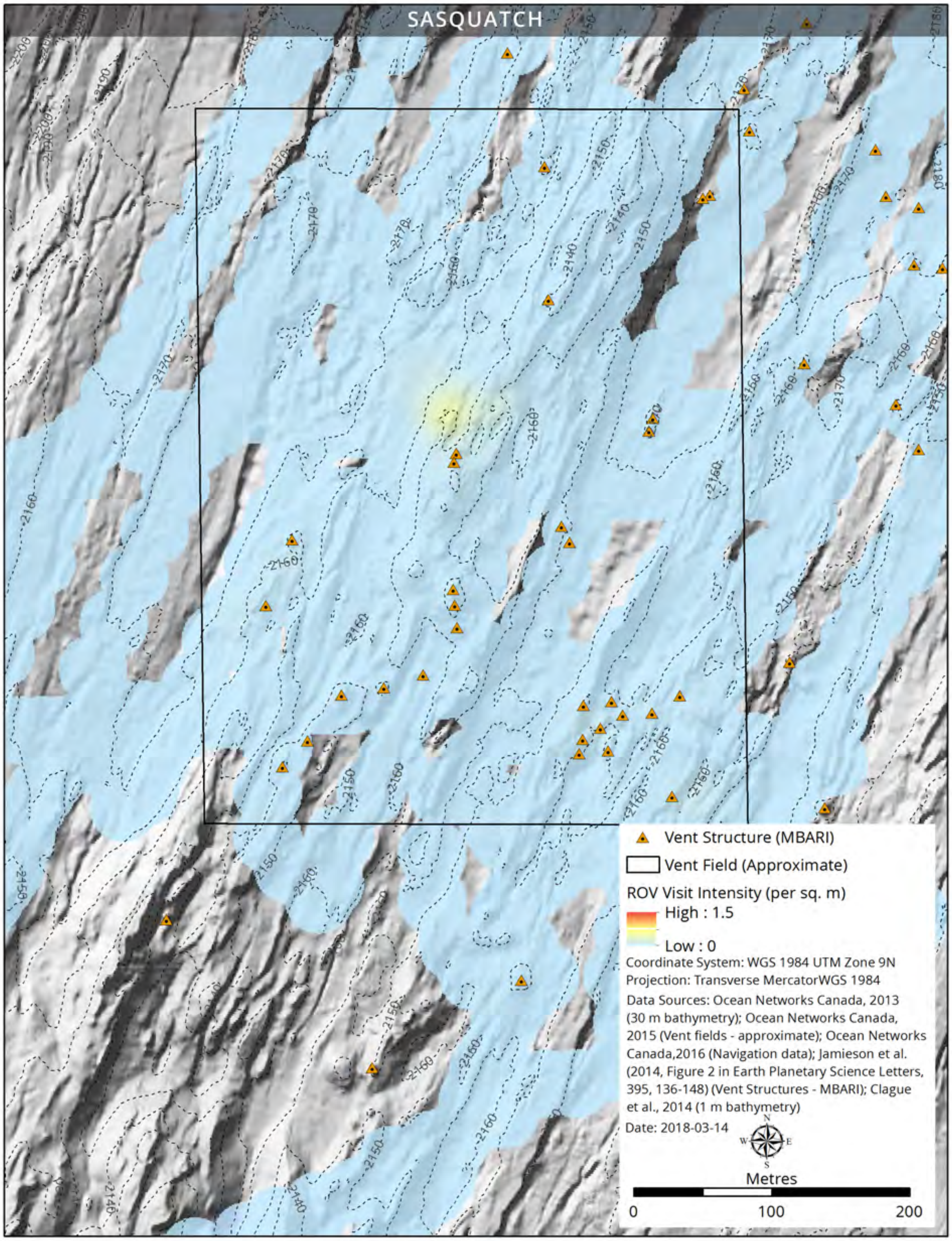

Figure 11. Kernel density map of track points indicating the intensity of submersible visits per square metre for the Sasquatch area for all ONC dives and available third-party dives between 2000 and 2017

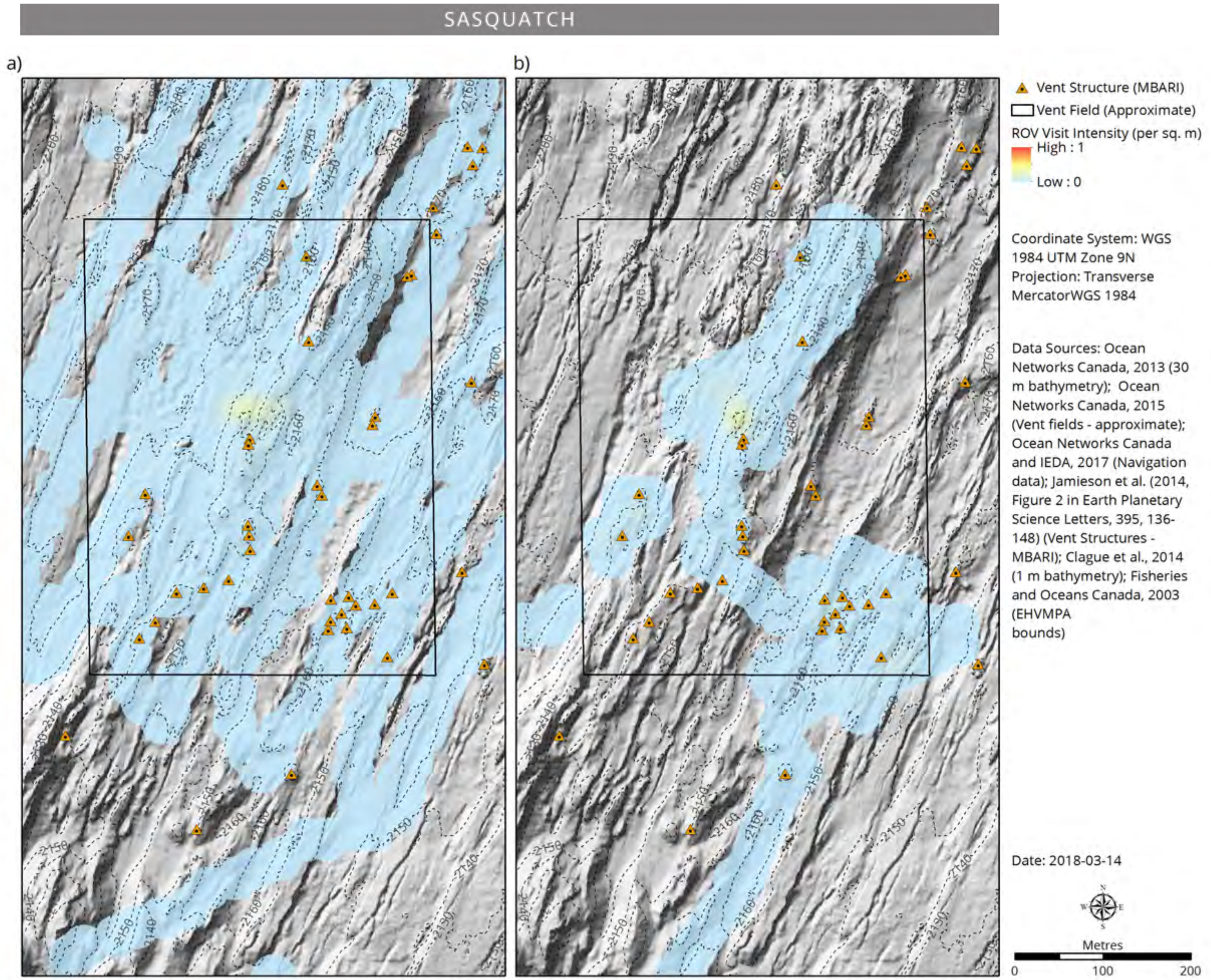

Figure 12. Kernel density map of track points indicating the intensity of submersible visits per square metre per nine-year interval for the Sasquatch area for a) dives between 2000 and 2008 inclusive, and b) dives between 2009 and 2017 inclusive

Analysis for Question 1

As seen in Figures 1 and 2, the intensity of submersible tracks as a proxy for research pressure and exploration coverage shows that the majority of research is focused in the central third of the EHVMPA. Highest values (symbolized in red) are found primarily in the vent fields and the areas of ONC cabled instrumentation; and, lowest values (symbolized in blue) are found mostly in between and along exploratory survey paths. There are other pockets of high intensity east of the ridge axis where there is no currently installed infrastructure and these areas have clearly been revisited over the years. The submersible tracks represent both a presence of a stressor but also where there is a legacy of video and CTD data to provide a knowledge base of the area. Two of the largest clusters with high pressure exist at Main Endeavour Field and Mothra. As these management areas are designated for research, the resulting high research pressure is expected (Fisheries and Oceans Canada, 2010).

The high intensity area in the east of the EHVMPA is centered on the Ocean Networks Canada node. As all cables are connected at this point, repeated submersible visits are anticipated here. While outside of the designated management areas, this is still within the bounds of the EHVMPA. The high intensity area northeast of High Rise is where the ONC Regional Circulation Moorings North site is located. There have been many dives here to service platforms and moorings. Two smaller concentrations of activity occur between the Mothra and Main Endeavour Field (southern Regional Circulation Moorings) and there is another on the west ridge flank of the ridge (broad band seismometer site). Third party data over the past 18 years has been primarily focused on the ridge-axis with highest densities around the five major vent fields, including a northern section of the Main Endeavour DFO Management Area. In contrast to the high research pressure areas of the Main Endeavour and Mothra fields, the maps show that there has been less research pressure in the Salty Dawg and Sasquatch vent fields, in alignment with the management directions for these areas (Fisheries and Oceans Canada, 2010).

Figure 2 demonstrates how research pressure and exploration coverage have evolved over the last eighteen years. In Figure 2a, the first nine years (2000-2008) saw more time spent on the ridge axis. As the ridge axis is host to the major vent fields, this is an area of active interest. During the subsequent nine years (2009-2017), visits have been primarily by ONC to survey, install and maintain a cabled observatory. Distribution of time off-axis results from ONC's quest to determine the best locations for instruments in its early years (2007-2010), with more repeat time spent along cable routes extending from a node in the east to each of Main Endeavour Field, Mothra, and an area north of High Rise. The area on the East Ridge Flank in particular, was well studied during this time in order to find a good position for the node. In the last five years, the density of submersible visits is higher in specific areas and spatial extent is less. This is related to ONC's operational status, where time spent in the EHVMPA is primarily to maintain the existing infrastructure.

Figures 3 and 4 show the relative intensity of submersible tracks specifically at Mothra. Here, the highest pressure is seen around Faulty Towers, Pinocchio, Hot Harold and Tower hydrothermal vents. Research pressure around these vents has seen an increase in the past nine years. ONC instrumentation has been centered in this area since 2011, accounting for much of the activity here. The Cauldron, Gwenen, Brigid, Bat Tower, Spikes, and Boomerang vents remain less explored, but may have seen more activity by other organizations prior to the year 2000.

Figures 5 and 6 show the relative intensity of submersible tracks specifically at Main Endeavour Field. Here, the highest pressure is seen around the Grotto, Lobo, Easter Island, Bastille, Sully, Salut, MilliQ, Smoke & Mirrors, and Hulk hydrothermal vents. Pressure around these vents is more or less evenly distributed with a slight partiality to the south in the first nine years. In contrast, the subsequent nine years show higher pressure primarily in the north around Grotto and Lobo vents. Grotto has hosted the bulk of ONC instrumentation in this area since 2010 and so this is not unexpected. Presently, the vents to the south are less explored and under lower research pressure by ONC. Instrumentation is planned for this area in 2018, which may result in more widely distributed research pressure within the Main Endeavour Field in future. There are also areas at Main Endeavour Field that remain unexplored, but may have been covered by other organizations prior to the year 2000.

Figures 7 and 8 show the relative intensity of submersible tracks specifically at High Rise Vent Field. Here, the highest pressure is seen around Clam Bed, Godzilla, Bambi, Boardwalk, and Park Place hydrothermal vents. Research pressure at these vents is much less than at Mothra or Main Endeavour Field and this is consistent with the objectives set out in the management plan reserving this area for education and outreach as opposed to research and sampling at the other two fields (Fisheries and Oceans Canada, 2010). Research pressure is highest at Clam Bed and this has been consistent over the past eighteen years, possibly for observation of the rare presence of hydrothermal vent clams in the area. Godzilla, Bambi, Boardwalk, and Park Place have seen an increase in research activity in the past nine years over the previous nine years. ONC is installing some autonomous sensors for outreach and geological monitoring in this area and has surveyed some locations for site selection. DFO also visited High Rise in 2016. This may account for the recent slight increase in activity. Ventnor, Knight, Fairy Castle, Baltic, and Blue Moon remain less explored, but may have seen more activity by other organizations prior to the year 2000.

Figures 9 and 10 show the relative intensity of submersible tracks specifically at Salty Dawg Vent Field. Research pressure at these vents is minimal, and this is consistent with the management plan that the highest level of precaution is to be taken in this area (Fisheries and Oceans Canada, 2010). Research pressure has decreased in the last nine years for this area in comparison the previous nine years.

Figures 11 and 12 show the relative intensity of submersible tracks specifically at Sasquatch Vent Field. Research pressure at these vents is also minimal and has decreased in the last nine years for this area in comparison the previous nine years. The management plan does not specify management objectives for this area or a particular boundary at this time, so only general trends are assessed here (Fisheries and Oceans Canada, 2010).

Question 2: What areas are under the most and least pressure from the three main types of sampling (geological, biological, and fluid samples)? - Methods and Assumptions Made

Pressure from physical sampling is assessed here with data representing the occurrence of sampling and the number of samples ("quantity") taken with a kernel density clustering technique. The "quantity" field in the "physical samples" geodatabase table is defined as the number of samples or replicates of samples taken at one location during one sampling event (Ocean Networks Canada, 2016). Here, we assume that areas under the most pressure from sampling are areas where there are many clusters of large quantities of samples taken. Areas under the least amount of pressure from sampling are areas where there are few clusters of small quantities of samples taken. As this is a kernel density value, these are treated as relative high to low for counts per unit area. As geological, biological, and fluid samples have different impacts on the region but also collectively represent sampling pressure, these are assessed both by sample type and together as a "physical samples" dataset. The kernel density tool is appropriate for this use as it creates a magnitude per unit areal surface from point or line inputs and the population field can be used to weight the samples based on quantity (ESRI, 2017b). Other tools of this type exist and were considered, such as Openshaw's geographical Analysis Machine (Openshaw et al., 1988), the local G-statistic, and optimized hot-spot analysis. Openshaw's tool is run in third-party software and ongoing support for the tool is unknown. It was deemed prudent to remain with ArcGIS built-in tools that are likely to have continued support and development and therefore also provide the ability to reproduce results and build on future datasets. The local G-statistic would require conversion to aggregate polygons and calculates where hotspots and cold spots are co-located (ESRI, 2017c). As there were no established boundary areas within vent fields on which to aggregate, this tool was not deemed suitable. Optimized hot spot analysis returns statistically significant clusters but control over parameters is lacking and the output format is in points, which are not easily interpreted in comparison to surface outputs. The decision was made to keep the analysis simple and easily reproducible to determine areas where the sampling density magnitude is high and low in order to enable assessment for the impact of sampling. Therefore, the kernel density tool was selected.

Processing Steps:

ONC sample occurrences were curated through dive logs, and third-party sampling data were sourced from VentDB (Mottl, 2012). The data were tabled in the geodatabase in their raw source WGS84 geographic coordinates. In order to have a symmetrical grid that does not create a north-south bias, the data were projected into a WGS84 UTM Zone 9N coordinate system providing metres for units. Data were then copied into three additional feature classes defined by sample type: geological samples, biological samples, and fluid samples.

Geologic samples included sediment or rocks collected with scoops, grabs, push cores, suction samples, or a sediment trap. Quantities ranged between one and twenty-one per sample occurrence.

Biological samples included tubeworms, plankton, benthic organisms, crustaceans, and molluscs collected with water samples, grabs, suction samples, plankton nets, or attached to instruments during recoveries. Quantities ranged between one and nine per sample occurrence.

Fluids were a combination of water and hydrothermal fluid samples collected with suction samples, gas tights, Niskins, major element hydrothermal fluid samplers ('major samplers'), or in a biobox. Number of samples ranged between one and forty-eight per sample occurrence.

The "population_field" was the field that denotes the values upon which the feature was weighted. The "quantity" field was used as the weighted value.

Output cell size was set to 1 m. Since the basemap along-axis uses 1 m resolution bathymetry, the output cell size matches the value in the environment (ESRI, 2017b).

In order to choose a search radius the same factors were considered as for question 1, with the following additions:

- The distances between vent fields are vast, but distance between individual vents within each field ranged between ~ 10 m and ~550 m
- Sampling by ONC is sparse and mainly concentrated in certain areas at Endeavour, so a higher search radius was needed to obtain overlap at the scale of the EHVMPA in order for results to be visible on the map.

The radius chosen was 100 m for the EHVMPA extent analysis and 25 m for the management area analyses.

The processing extent was set to the same as for the question one analysis in the environment variables in order to prevent clipping of the density radius at the edges of the furthest points.

Maps – Question 2

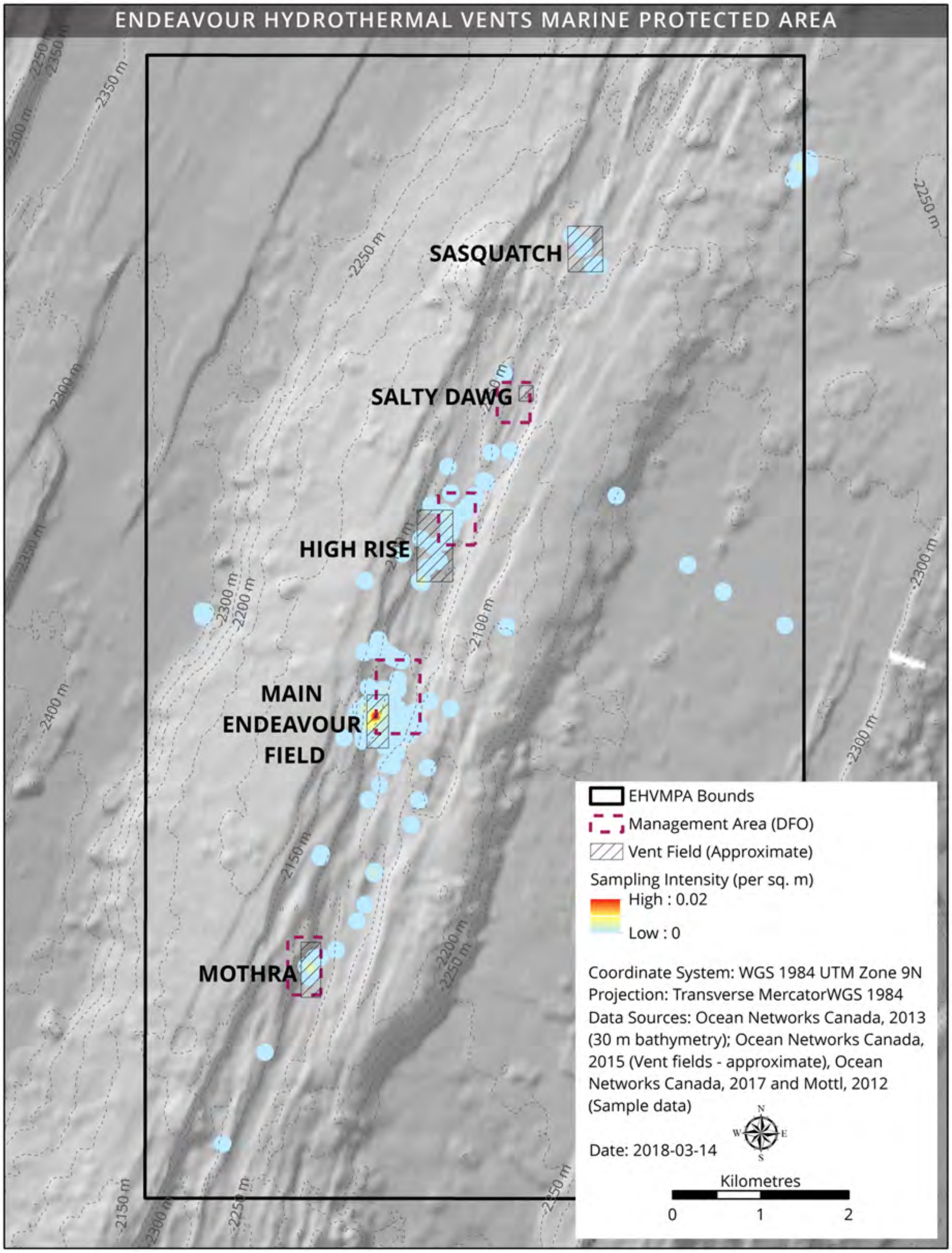

Figure 13. Kernel density map of sampling activity for the bounds of the Endeavour Hydrothermal Vents Marine Protected Area for all available Ocean Networks Canada and VentDB sampling occurrences and types between 1984 and 2017.

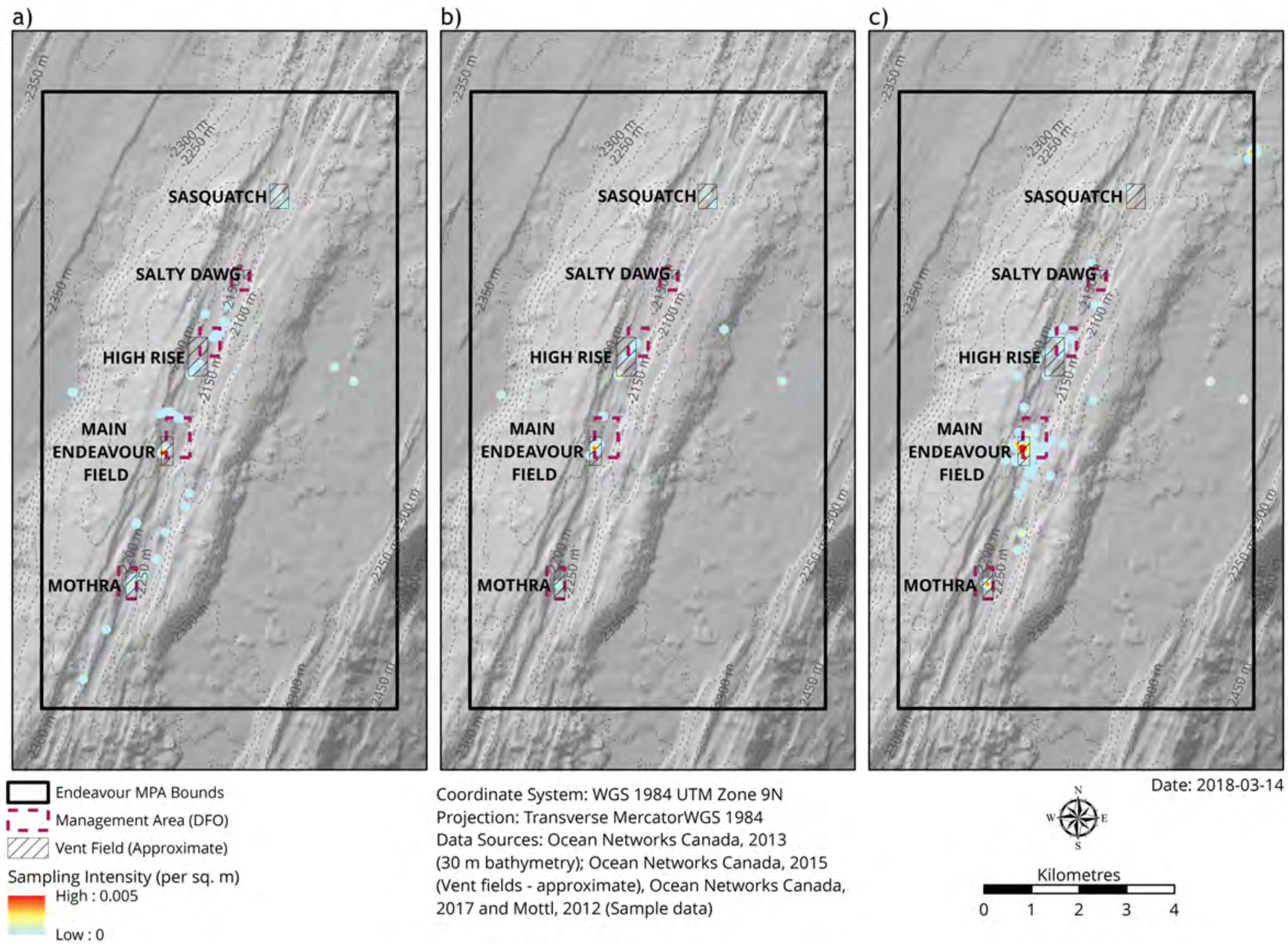

Figure 14. Kernel density map of available Ocean Networks Canada and VentDB sampling activity for the bounds of the Endeavour Hydrothermal Vents Marine Protected Area for a) geological samples, b) biological samples, and c) fluid samples, between 1984 and 2017.

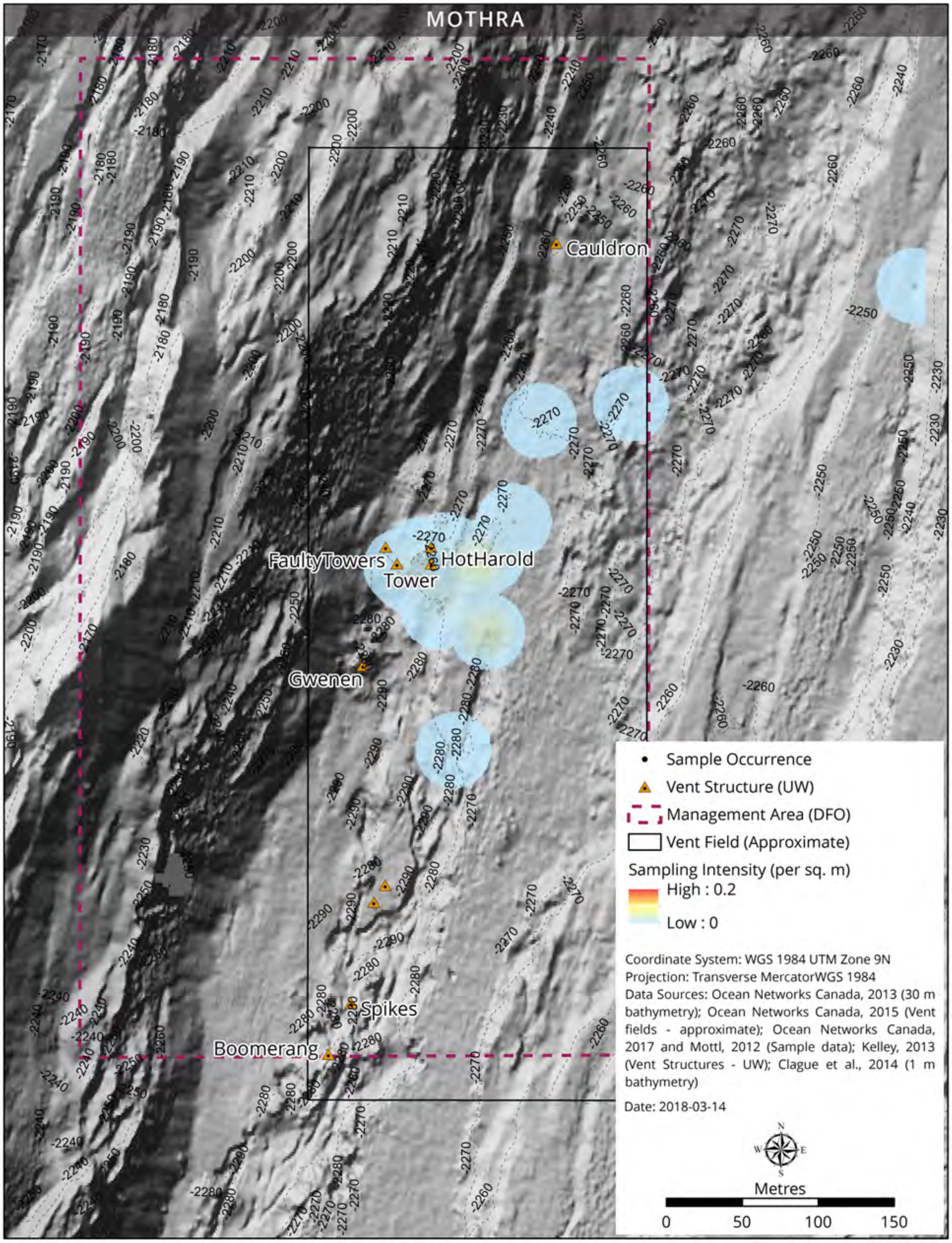

Figure 15. Kernel density map of Ocean Networks Canada and VentDB sampling activity for the Mothra Hydrothermal Vent Field area for all available sampling occurrences and types between 1984 and 2017.

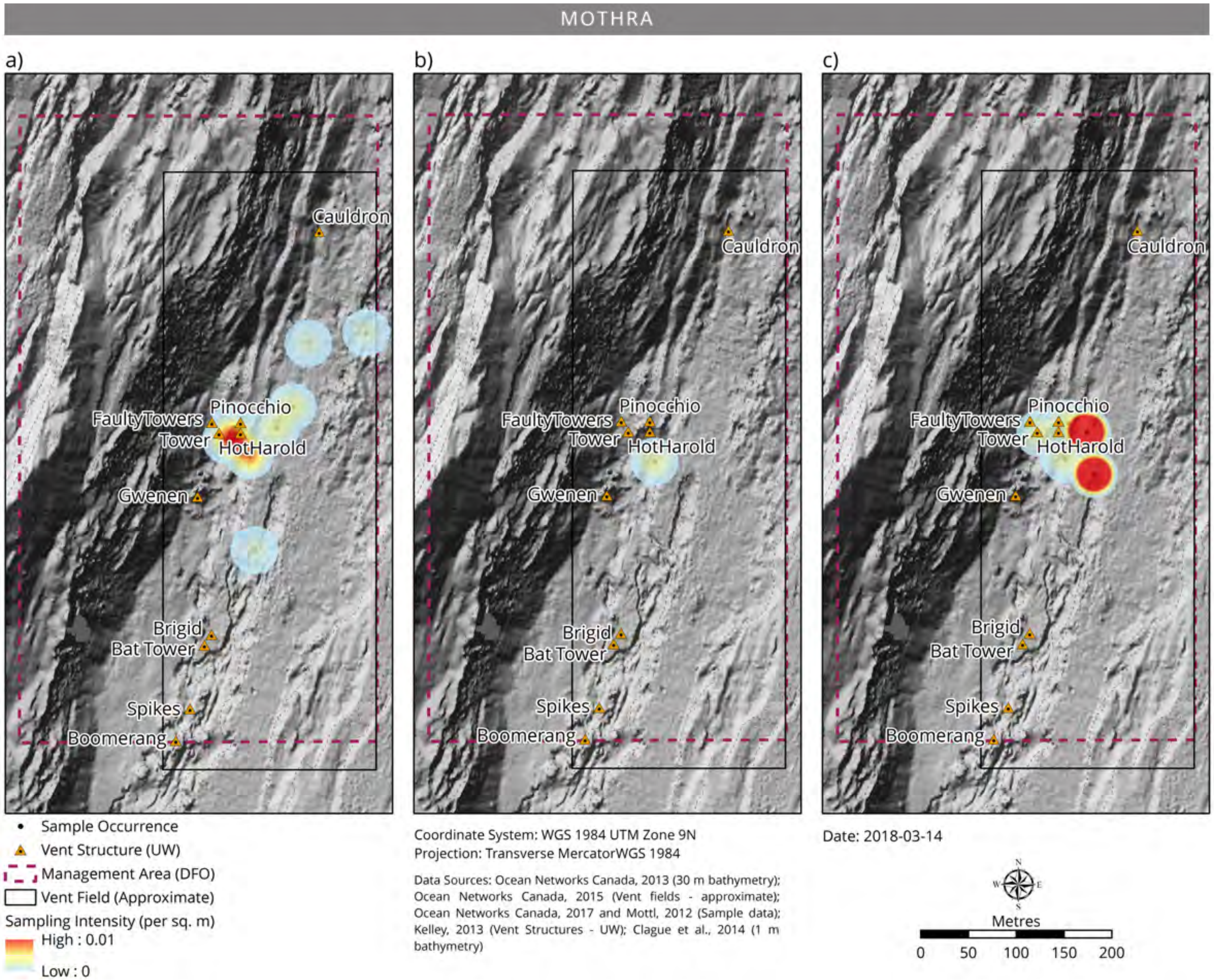

Figure 16. Kernel density map of available Ocean Networks Canada and VentDB sampling activities at the Mothra Hydrothermal Vent Field for a) geological samples, b) biological samples, and c) fluid samples, between 1984 and 2017

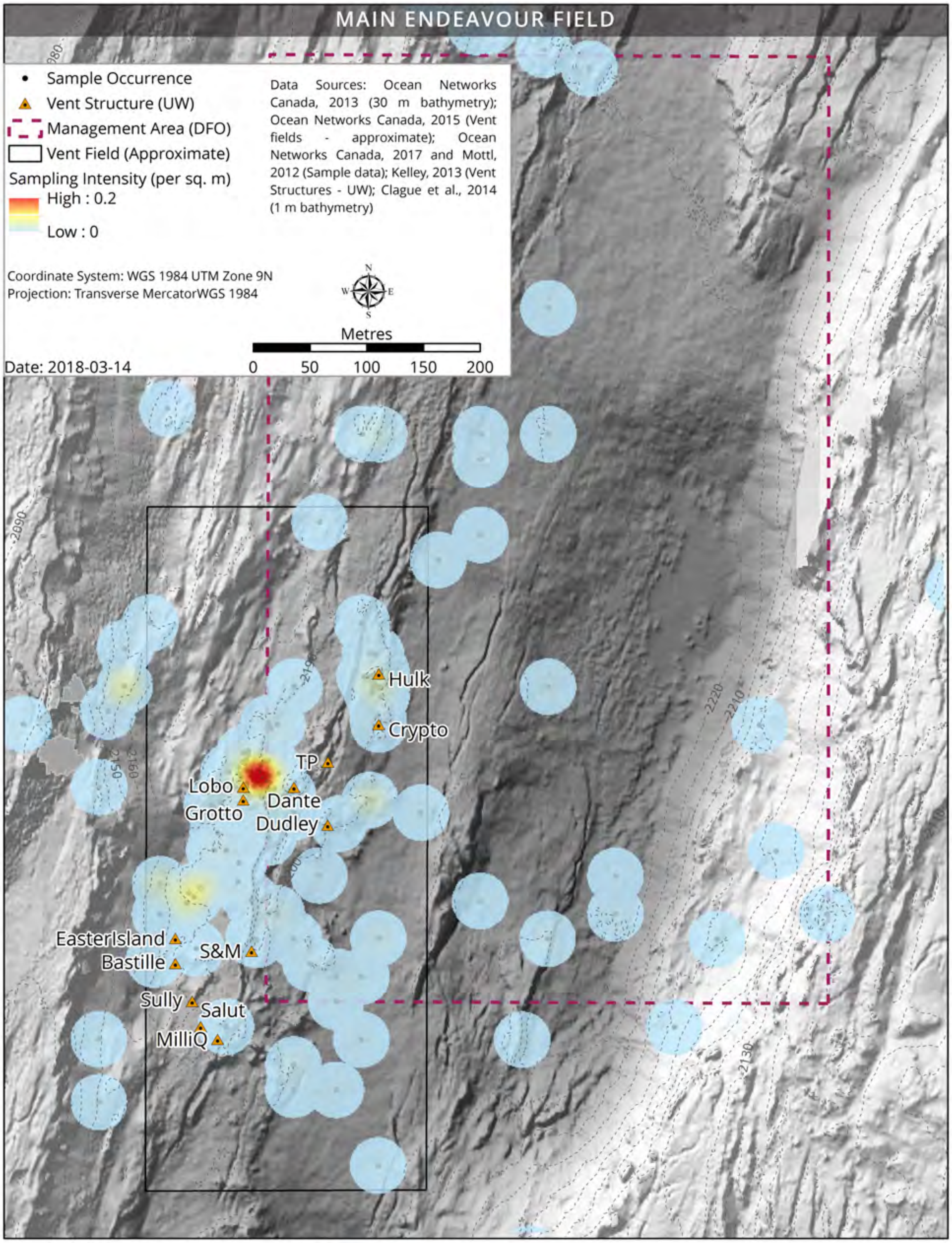

Figure 17. Kernel density map of Ocean Networks Canada and VentDB sampling activity for the Main Endeavour Field area for all available sampling occurrences and types between 1984 and 2017.

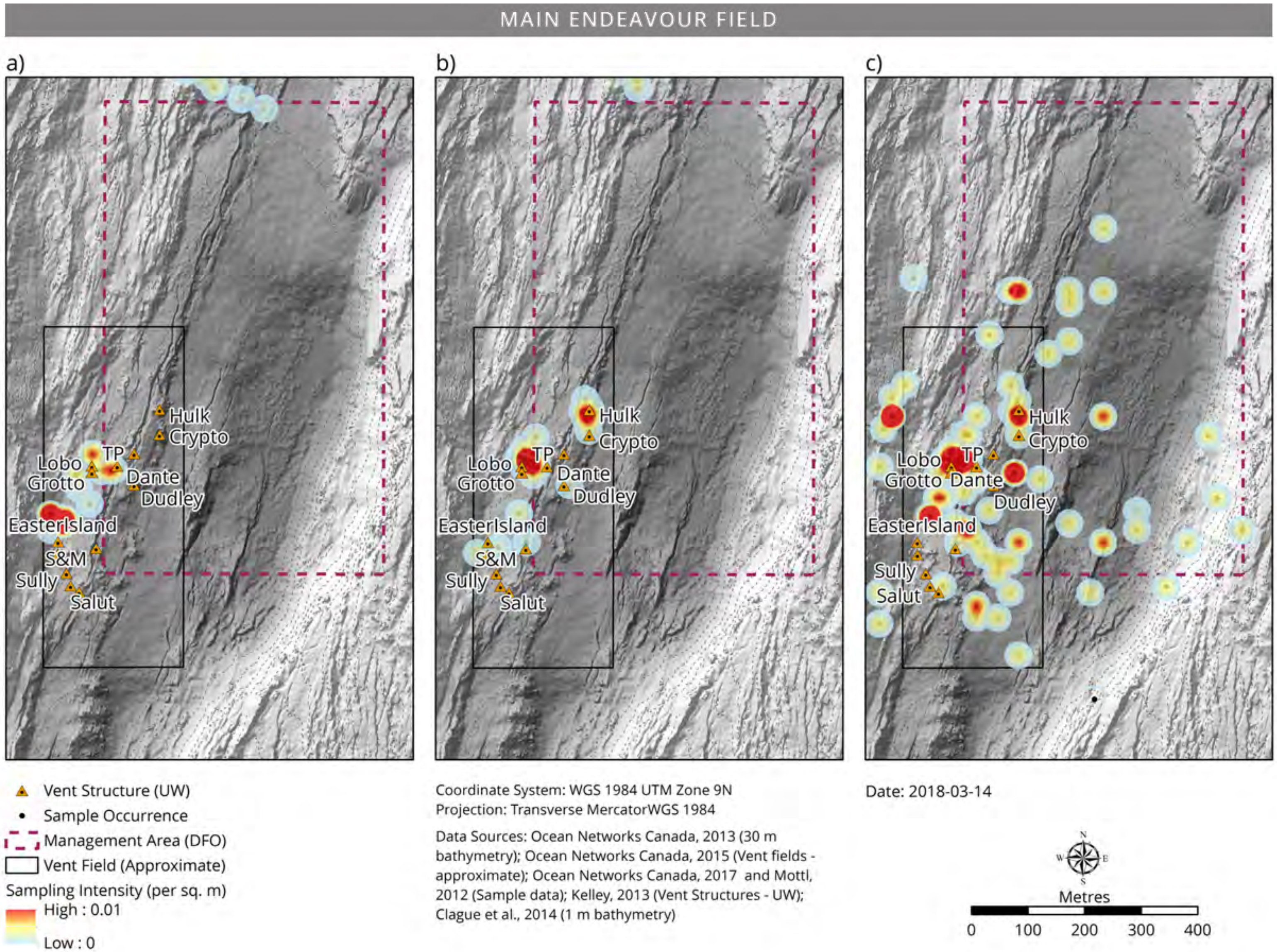

Figure 18. Kernel density map of available Ocean Networks Canada and VentDB sampling activities at the Main Endeavour Field for a) geological samples, b) biological samples, and c) fluid samples, between 1984 and 2017.

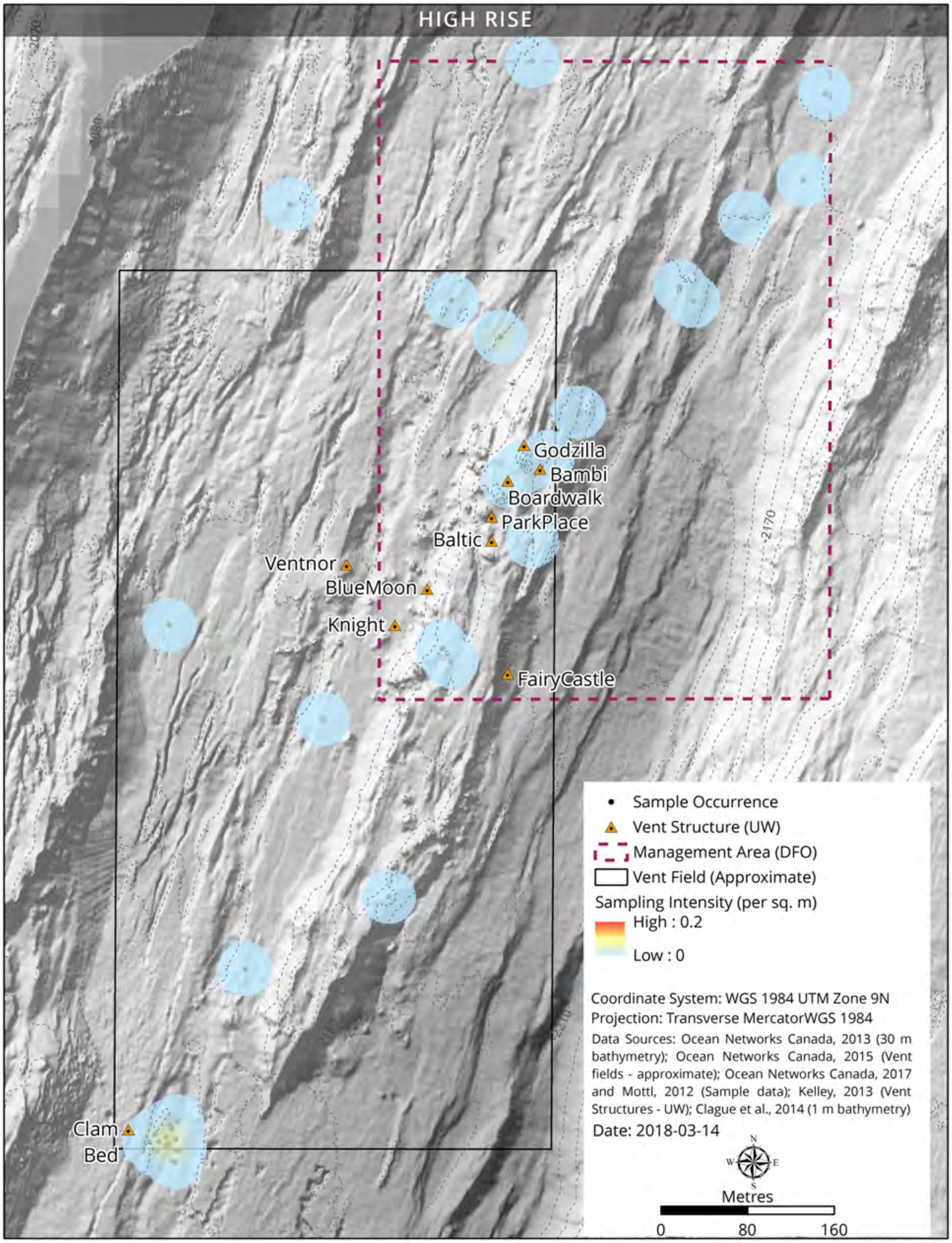

Figure 19. Kernel density map of Ocean Networks Canada and VentDB sampling activity for the High Rise Hydrothermal Vent Field area for all available sampling occurrences and types between 1984 and 2017.

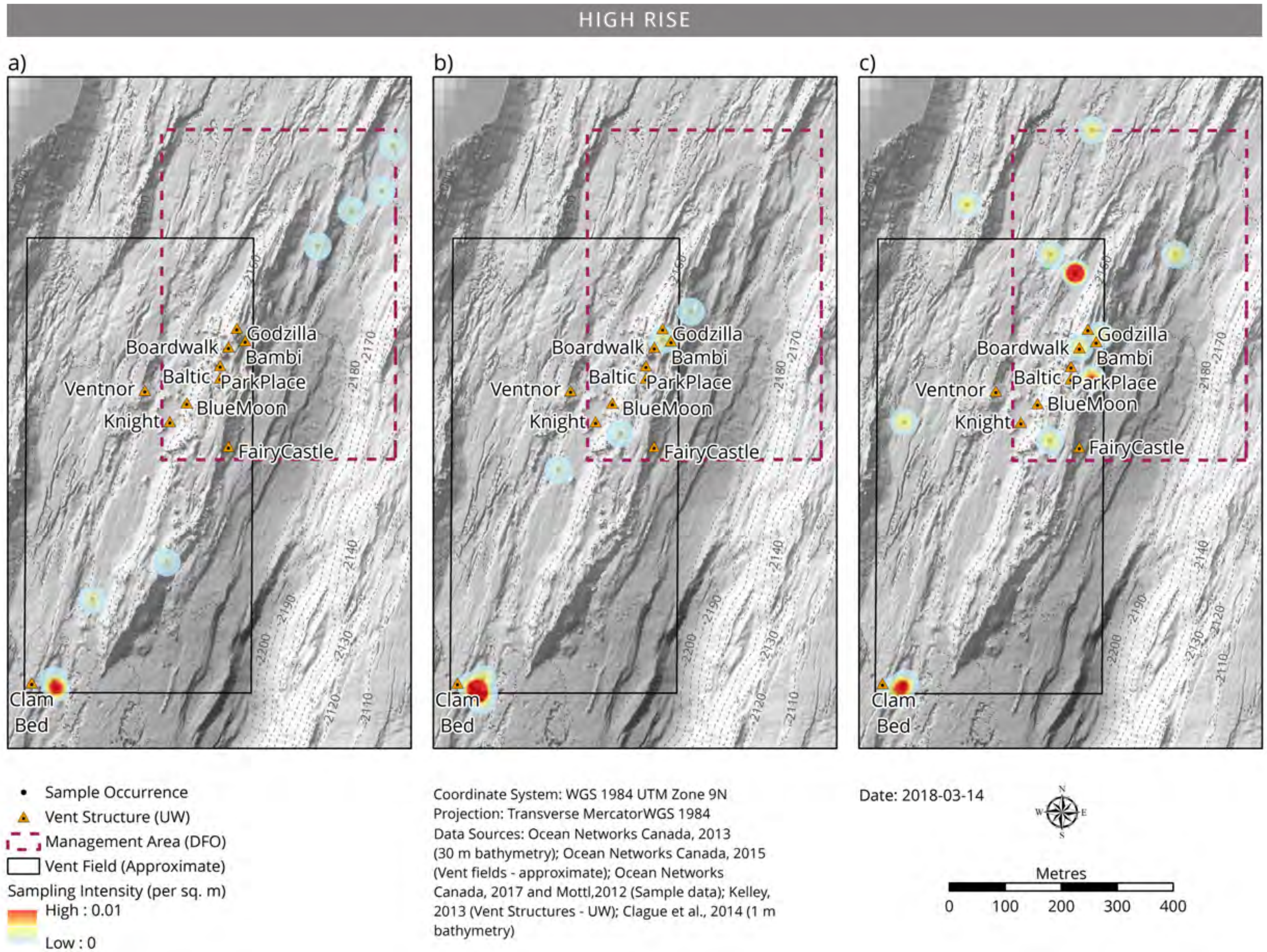

Figure 20. Kernel density map of available Ocean Networks Canada and VentDB sampling activities at the High Rise Hydrothermal Vent Field for a) geological samples, b) biological samples, and c) fluid samples, between 1984 and 2017.

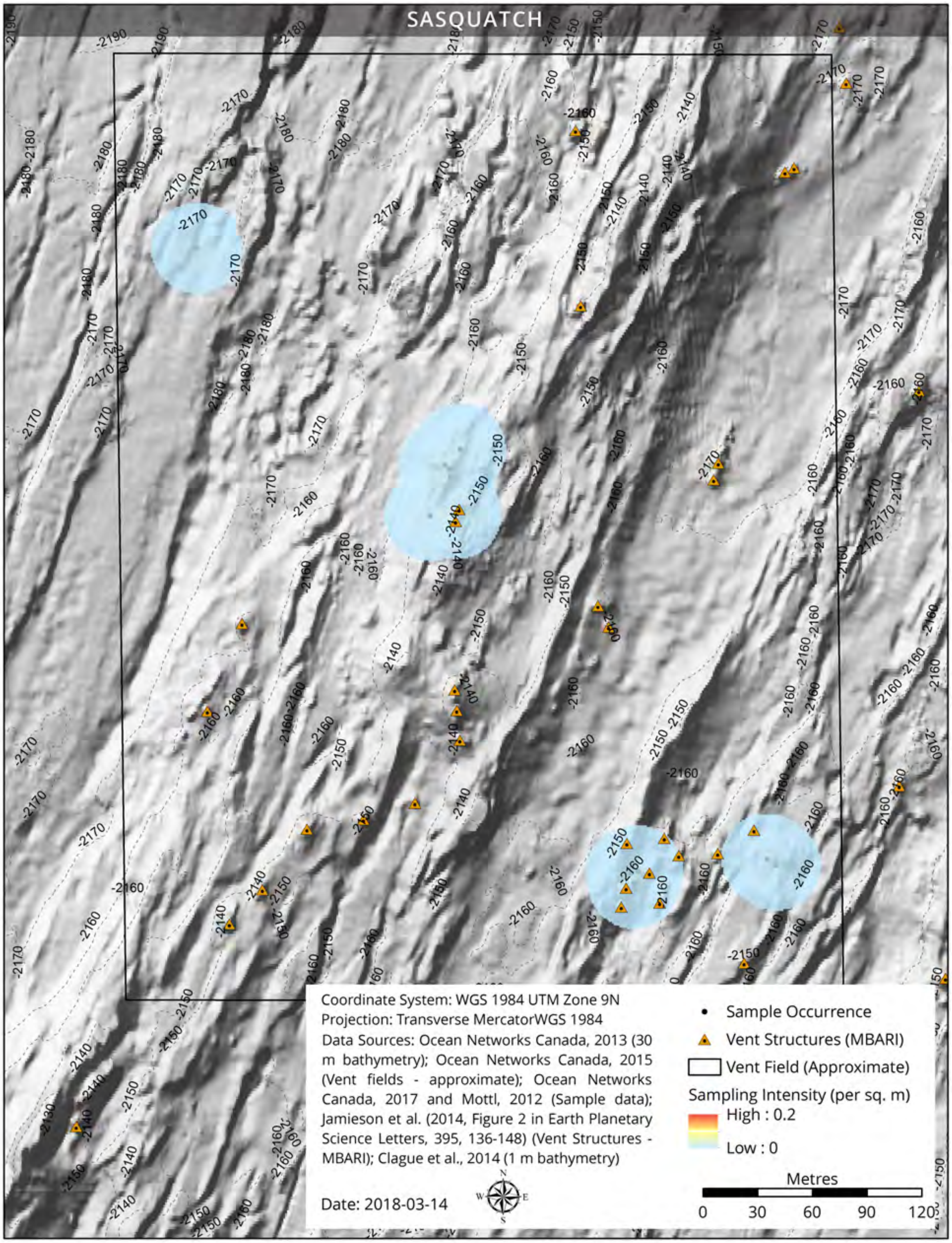

Figure 21. Kernel density map of Ocean Networks Canada and VentDB sampling activity for the Sasquatch Hydrothermal Vent Field area for all available sampling occurrences and types between 1984 and 2017.

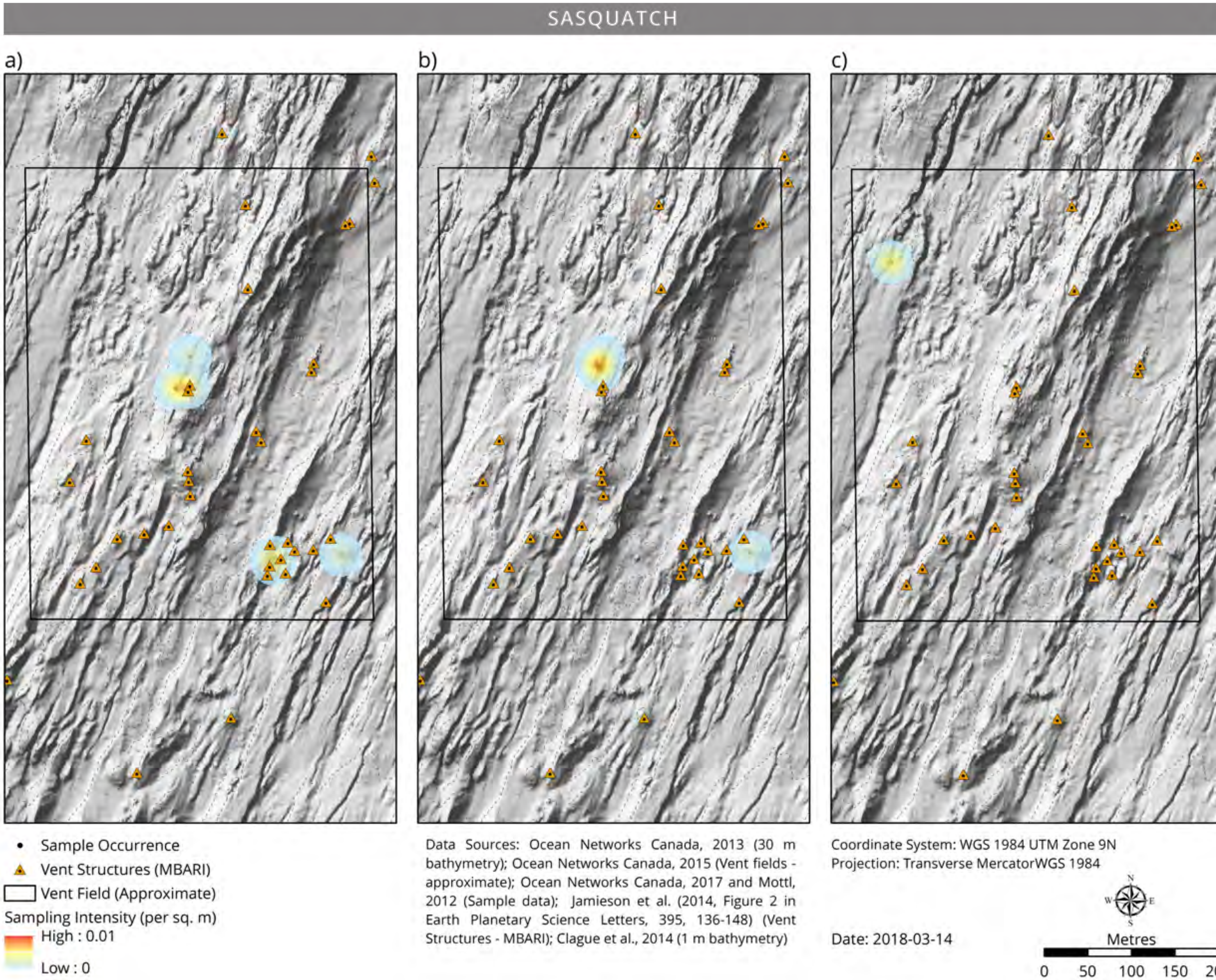

Figure 22. Kernel density map of available Ocean Networks Canada and VentDB sampling activities at the Sasquatch Hydrothermal Vent Field for a) geological samples, b) biological samples, and c) fluid samples, between 1984 and 2017

Analysis of Question 2

Figures 13 and 14 show the intensity of ONC and some (available) third-party sampling activities at the EHVMPA. Areas of high sampling pressure are shown in red and areas of low sampling pressure are shown in blue. However, sampling by ONC is sparse and available sample occurrence data are minimal at this time in the EHVMPA and therefore, heat mapping does not return a large range of "hot and cold" values. A total of 571 sampling occurrences representing 973 total samples were assessed here.

As seen in Figure 13, sampling pressure within the EHVMPA management areas by ONC and some third parties, primarily the University of Washington, is limited to Mothra, Main Endeavour Field, and High Rise. A few samples were collected between management areas, at the Sasquatch vent field, and off-axis. Available records show no sampling of any type at the Salty Dawg vent field between 1984 and 2017. The highest sampling pressure is seen at Main Endeavour Field followed by the Mothra field. As ONC maintains sampling instrumentation at these sites, this is not entirely unexpected. Other sampling mainly occurs to validate the data collected by scientific devices such as cameras, CTDs, and benthic resistivity sensors, so it is anticipated that samples (and sampling pressure) will primarily be collocated with infrastructure.

Figure 14 shows the intensity of sampling activities classified by sample type (geological samples, biological samples, and fluid samples). The highest pressure from sampling is seen at Main Endeavour field followed by Mothra for all three types. This aligns with the Management Plan for the use of the areas (Fisheries and Oceans Canada, 2010).

Figures 15 and 16 illustrate sampling pressure for the Mothra vent field area. The highest sampling pressure was near the Hot Harold hydrothermal vent, where the ONC instrumentation is primarily located. These mostly represent samples taken to validate data for other instruments or to plan for instrument deployments. Other sporadic sampling in the area mainly consisted of geological samples (rock or sediment).

Figures 17 and 18 illustrate sampling pressure for the Main Endeavour Field. The highest sampling pressure was between Grotto, Lobo and Dante hydrothermal vents, where the ONC instrumentation is primarily located. These mostly represent samples taken by cabled and autonomous sampling devices or to validate data for other instruments. The high intensity sampling between Grotto and Easter Island can be attributed to the autonomous sediment traps located in this area. Hulk was sampled frequently in 1991, 2008, and 2016 for all types of collections (biological, fluid, and geological samples).

Figures 19 and 20 illustrate sampling pressure for the High Rise vent field. Overall, sampling pressure was less than for Mothra or Main Endeavour Field, which is consistent with the Management Plan (Fisheries and Oceans Canada, 2010).

The highest sampling pressure at High Rise occurred at Clam Bed, where all of geological, biological, and fluid samples are taken. Sporadic sampling occurred throughout the rest of the vent field, with an emphasis on fluid samples.

Figures 21 and 22 illustrate sampling pressure for the Sasquatch vent field. Overall, sampling pressure is also less than for Mothra or Main Endeavour Field, but being the furthest north, this vent field is also less conveniently accessible. Most of the samples taken appear to have been geological rock grabs, sediments and biological suction samples taken by DFO in 2016, and minor fluid sampling in 2000.

There are no sampling occurrences within the dataset available that fall within the area of the Salty Dawg vent field, so no maps were generated for this location. This is consistent with the Management Plan that states that this vent field will be kept "free of potentially impacting activities" and only "infrequent water sampling" may occur (Fisheries and Oceans Canada, 2010).

Figures 14, 16, 18, 20, and 22 show highest intensity values for fluid samples followed by geological samples. This is influenced first by the majority of third-party available sampling data being from fluid samples collected in the 1980s-2000s and also by the weighting of the number of samples taken. Both of these categories include samples collected cabled and autonomous instrumentation, namely remote access pumped samplers for fluids and passive sediment traps for geological samples. For example, for geological samples, the number of samples for a single sediment trap is twenty-one. In contrast, for a scoop of sediment collected by a submersible, the number of samples could be just one. Although a scoop may be more intrusive, the sediment trap still removes potential nutrients and materials from the area. Therefore, the number of samples for each type is deliberately treated equal for evaluation of sampling pressure on the MPA. However, a bias exists in the volume of material sampled, as this is not defined nor is it supported in the metadata for some samples.

Time spent inside and outside of management areas

The submersible track point data were analyzed to determine the percentage of submersible time spent in management areas versus outside management areas within the MPA. Since the submersible position data rate is constant at 1 min intervals, these points represent a relative distribution of ROV time within and outside of the management areas.

The track points layer, the MPA boundaries layer, and the DFO vent field management areas layer were brought into ArcMap and the 'select by location' tool was used to extract the count of submersible track points that occurred within each of the two bounded areas. The total number of points assessed was 168,317, consisting of both Ocean Networks Canada and third party track lines, where available. This query yielded 166,163 points within the MPA boundary, of which 46,380 were within the four management areas. Based on the available data, **28% of submersible time was spent within the management areas** as opposed to the remainder of the MPA. Of total time spent within the MPA, **10% was spent within the Mothra** DFO Management Area, **14% within the Main Endeavour Field** DFO Management Area, **3% within the High Rise** DFO Management Area, and **less than 1% was spent in the Salty Dawg** DFO Management Area.

The same query was applied to the layer corresponding to the known, mapped boundaries of the named vent fields. These boundaries only partially overlap with the DFO vent field management areas as defined in 2003 when data and positioning accuracy were limited, compared with later available information. Track points within these vent field boundaries accounted for 75,668 points, for a total of 46% of submersible time in the MPA. This compares with 46,380 points within the DFO-defined management areas (or 28% of points within the MPA). This result indicates that the current management area boundaries only partially encompass the named hydrothermal vent fields and the areas of concentration of research activity. It is therefore recommended that these management area boundaries be revised in a future management plan.

The physical samples layer, the MPA boundaries layer, and the DFO management areas layer were brought into ArcMap and the 'select by location' tool was used to obtain the count of submersible track points where they intersect each of the two sets of boundaries. The sum of the sample quantity was taken for each of the selected points to get the total number of samples for each sampling occurrence. The total number of samples assessed was 973, consisting of both Ocean Networks Canada samples and third party fluid samples, where available. A total of 950 sampling points fall within the MPA boundary, of which 311 are within the four DFO management areas. When divided by the total, **33% of samples were taken in the management areas** as opposed to the rest of the MPA based on the available data. Of total samples taken in the MPA, **8% were from the Mothra** DFO Management Area, **20% were from the Main Endeavour Field** DFO Management Area, **5%**

were from the High Rise DFO Management Area, and **no samples were from the Salty Dawg** DFO Management Area.

As described above, the same query was applied to the approximate vent fields layer (versus DFO management areas). This resulted in a total of 637 samples taken within the vent field boundaries (versus 311 within the DFO management areas), equating to 67% of samples in the MPA (versus 33% of MPA samples taken within the DFO management areas. This result reinforces the point above regarding the validity of the current management area boundaries, and the recommendation that these management area boundaries be revised in a future management plan.

Assessment of possible ecosystem stressors

Possible ecosystem stressors identified in the management plan (Fisheries and Oceans Canada, 2010, p.25, p.37) are assessed here using data representing observations of introduced anthropogenic materials, target species, and habitats. Point maps show the distribution of observations. As such observations can be redundant in continuous video records and were made secondarily to other dive objectives, they are not considered to provide a quantitative representation of the distribution the three categories named above. Density mapping is therefore not possible, but the points still provide a qualitative assessment as a first step towards developing quantitative indicators of the baseline of species and habitats (Fisheries and Oceans Canada, 2010, p.25-26) and anthropogenic materials.

Times and positions of coral/sponge observations, tubeworm observations, vents and debris observations that occurred during submersible dives have been extracted from the dive logger comments in the Ocean Networks Canada Oceans 2.0 database. Most biological observations were not identified beyond the Phylum level in the dive logs due to the lack of available taxonomic information on these species. This layer therefore does not fully represent species distribution within the EHVMPA, nor can it be seen as a result of systematic benthic community surveys. It simply provides a record of biological, habitat and debris observations made and logged in Oceans 2.0 during ROV dives.

The relative distribution of corals, sponges, and tubeworms can be seen in Figures 23, 24 and 25. Observed corals were primarily Gorgonians (i.e., sea whips and sea fans). Observed sponges included demosponges and glass sponges. Corals and sponges were widespread and abundant. Any apparent linear distribution patterns are more likely the effect of the submersible following existing cable routes or shortest distances between observatory installations than any biological distribution. As expected, the majority of tubeworms are *Ridgea piscesae* and occur along the ridge axis. Two observations were made off-axis, but these are not symbiont-bearing tubeworms commonly associated with vent habitats. The relative distribution of vents is illustrated in Figure 26. Observed vents were plotted to relate the habitat distribution to species. As expected, within the MPA, all observed vents (and vent organisms) were located along the ridge axis.

One of the possible stressors to the ecosystem from human activities is the presence of anthropogenic debris (Fisheries and Oceans Canada, 2010, p.37). This can occur from both research activities and other sources. To better understand the sources and distribution of this potential stressor, observations of debris are represented in point maps, classified by debris type in Figure 27. These types were separated into debris from experiments (plastic cable-ties, vent markers, hockey pucks used for handles, etc.), lost or discarded fishing gear (nets, rope, etc.), ballast weights left behind by submersibles (Alvin), and other anthropogenic debris (aluminum cans, plastic bags, boxes, etc.) that do not fit into any of the first three categories. These maps represent what was observed at a single point in time and do not necessarily distinguish between debris remaining on the seafloor and that retrieved in later dives. Most debris was observed on the ridge axis, but that could be a result of observational bias since the submersibles spend most of their time there. However, since the ridge axis is where much of the experimentation has occurred over the years, this is where research-related debris is most likely to be found. Discarded fishing gear was an unexpected find, and since this is an MPA where fishing has not been permitted since 2003, this debris category may warrant monitoring to improve knowledge of spatial distribution and detect future accumulations.

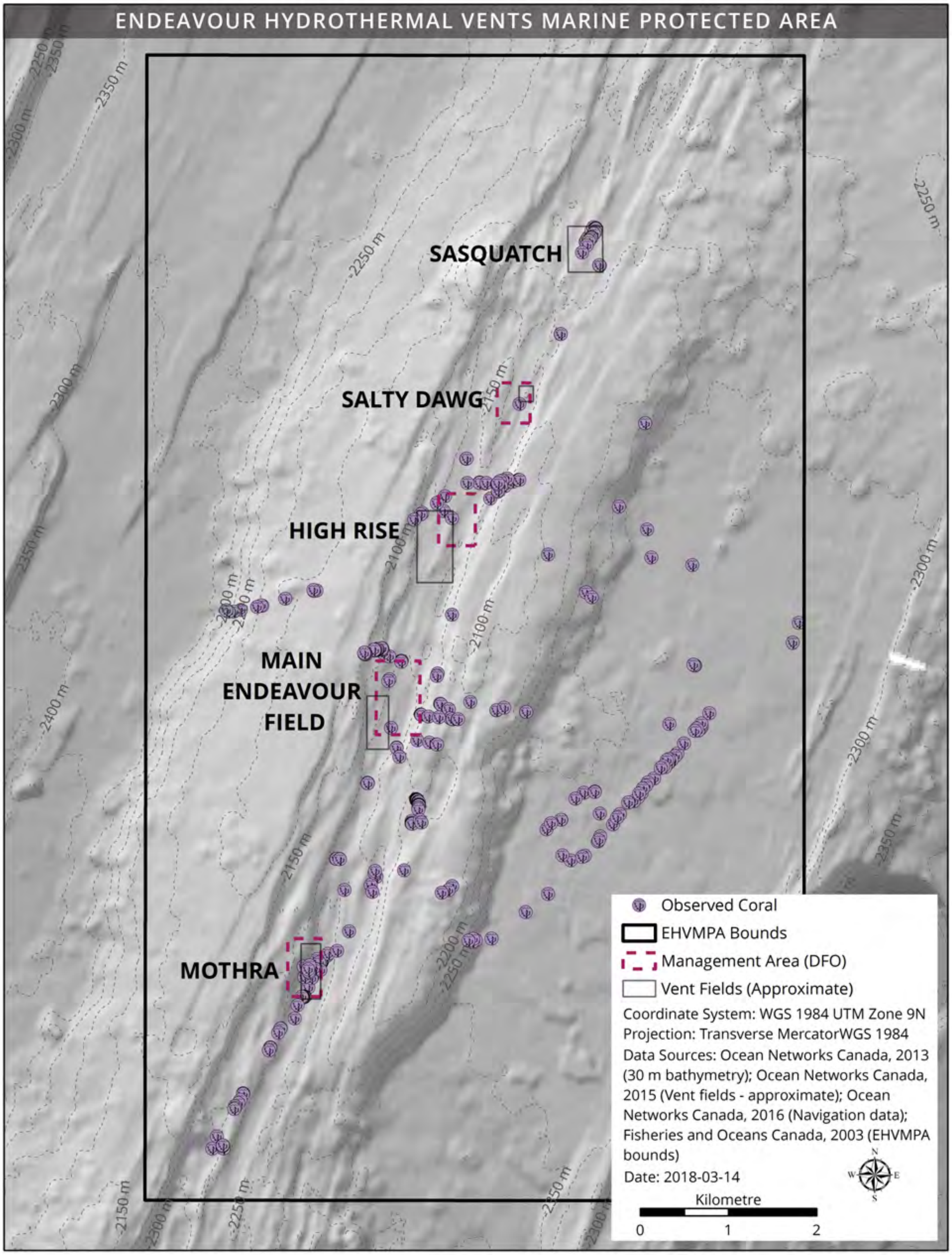

Figure 23. Distribution of coral observations at the Endeavour Hydrothermal Vents Marine Protected Area

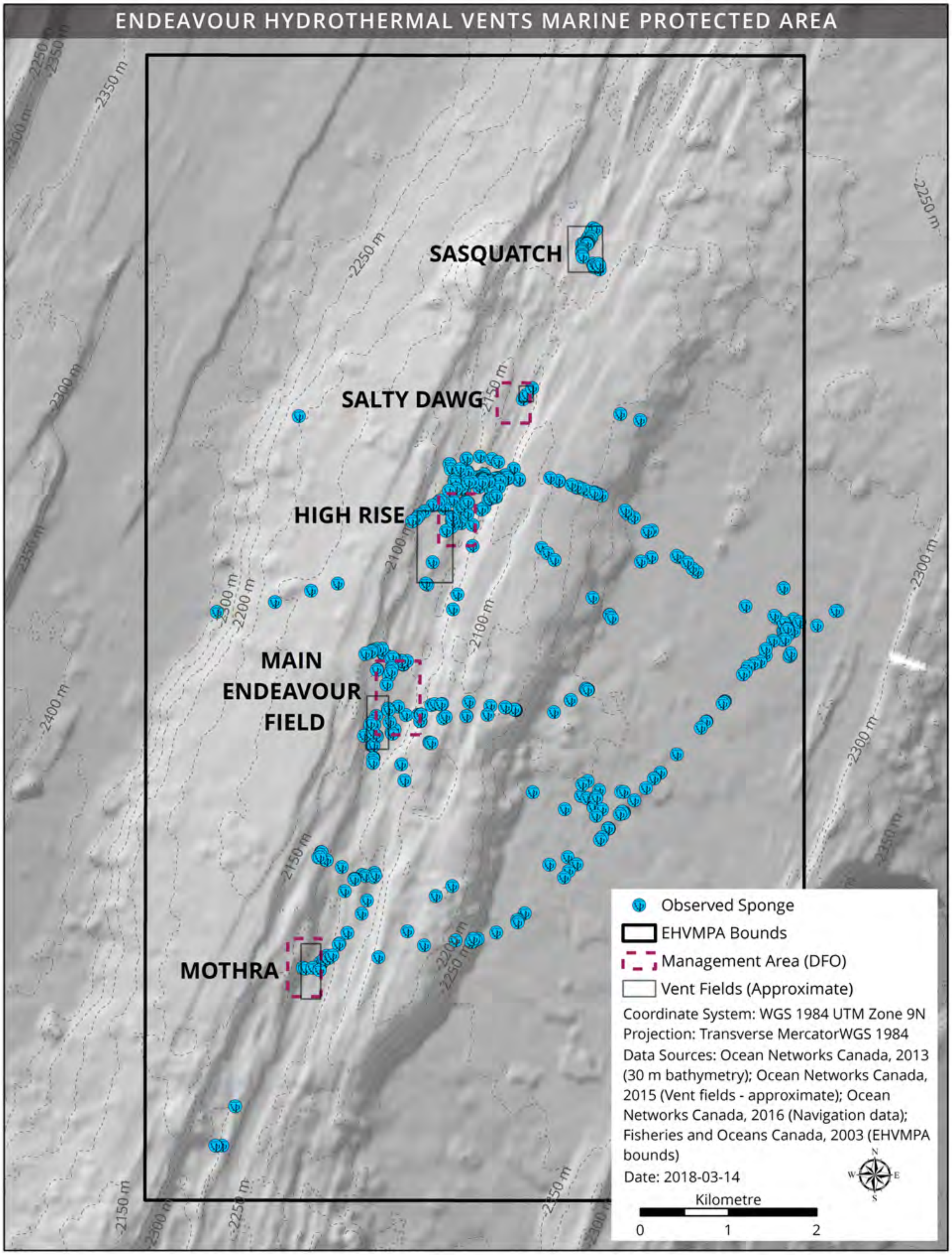

Figure 24. Distribution of sponge observations at the Endeavour Hydrothermal Vents Marine Protected Area

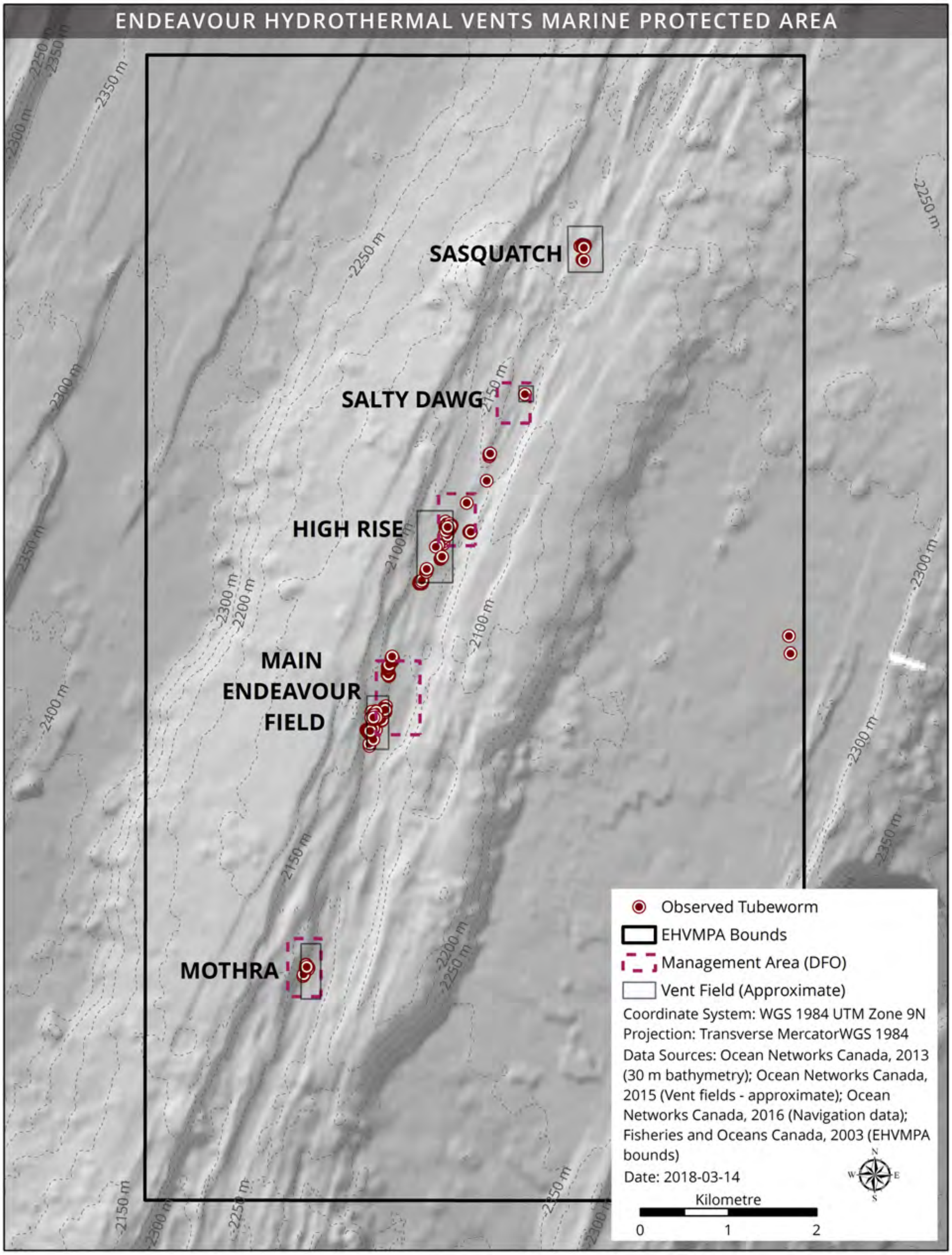

Figure 25. Distribution of tubeworm observations at the Endeavour Hydrothermal Vents Marine Protected Area

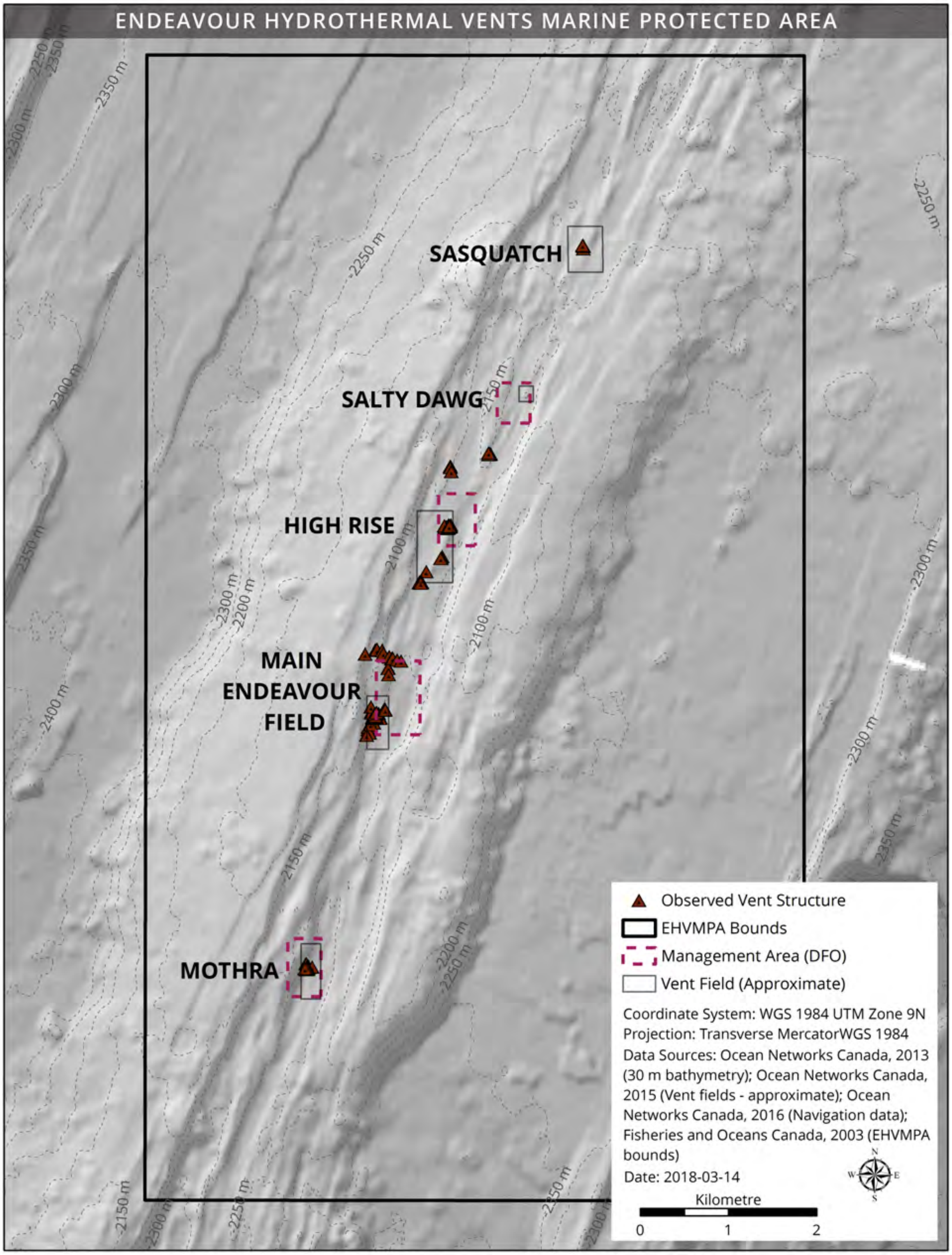

Figure 26. Distribution of vent observations at the Endeavour Hydrothermal Vents Marine Protected Area

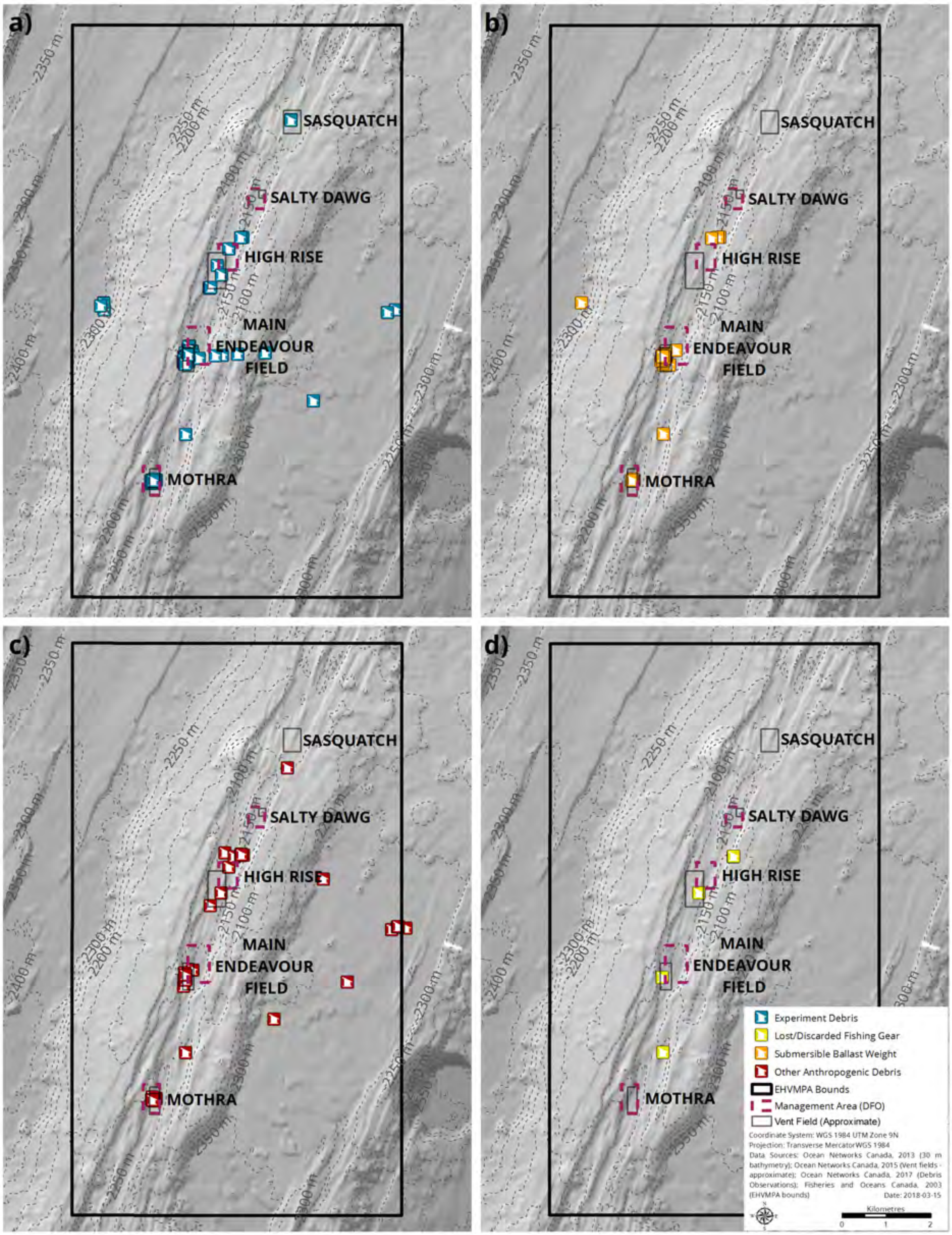

Figure 27. Distribution of anthropogenic debris observations at the Endeavour Hydrothermal Vents Marine Protected Area, classified by type a) experiment debris, b) submersible ballast weights, c) other anthropogenic debris, and d) lost or discarded fishing gear

Future Directions

This exercise has demonstrated that heat maps are an effective tool for quantifying pressure of submersible movements and sampling activity that can be used to ensure compliance of the EHVMPA with the management plan, and needs for revisions to the management plan. A future addition of third party data from 1982 to 2000, largely comprising of Alvin dives would help complete an assessment of the overall use and pressure on the EHVMPA to date since its discovery and establish a more robust basis for managing future use and assessing permits.

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