2019 Oyster Reef Monitoring Report

Analysis of Data from Large-Scale Sanctuary Oyster Restoration Projects in Maryland Collected from Fall 2019 through Summer 2020

December 2020

Produced in partnership with the Maryland Oyster Restoration Interagency Workgroup under the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team

Executive Summary

Context

- The 2014 Chesapeake Bay Watershed Agreement[1] includes a goal to restore oyster populations in 10 Chesapeake Bay tributaries by 2025 (hereafter, the ‘10 tributaries initiative’).
- In Maryland, partners including the National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers’ Baltimore District (USACE), Oyster Recovery Partnership (ORP), and the Maryland Department of Natural Resources (DNR) are working to achieve this goal through the Maryland Interagency Oyster Restoration Workgroup (hereafter, the Workgroup). The Workgroup is convened under the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program.
- A set of oyster restoration success criteria, commonly known as the Chesapeake Bay Oyster Metrics[2], was developed prior to implementing restoration work in the ten tributaries. This report describes the success of each Maryland reef monitored in 2019, relative to the six Oyster Metrics success criteria: oyster density, oyster biomass, multiple year classes, shell budget, reef height, and reef footprint.

Trends observed in previous monitoring years generally continued in 2019, with the wide majority of restored reefs meeting all six oyster metrics success criteria.

- Restored reefs are monitored three years and six years after initial restoration. A subset of reefs in Harris Creek, Little Choptank River, and Tred Avon River are now either three or six years old, and were due for monitoring in fall 2019.
- Trends observed in previous monitoring years generally continued in 2019, with the wide majority of restored reefs meeting all six Oyster Metrics success criteria.
- Data and analyses in this report can be used by restoration partners to help inform what adaptive management measures, if any, should be taken on each of the monitored reefs. These results may also guide restoration in other tributaries.

Scenes from fall 2019 oyster monitoring. Photos: Oyster Recovery Partnership.

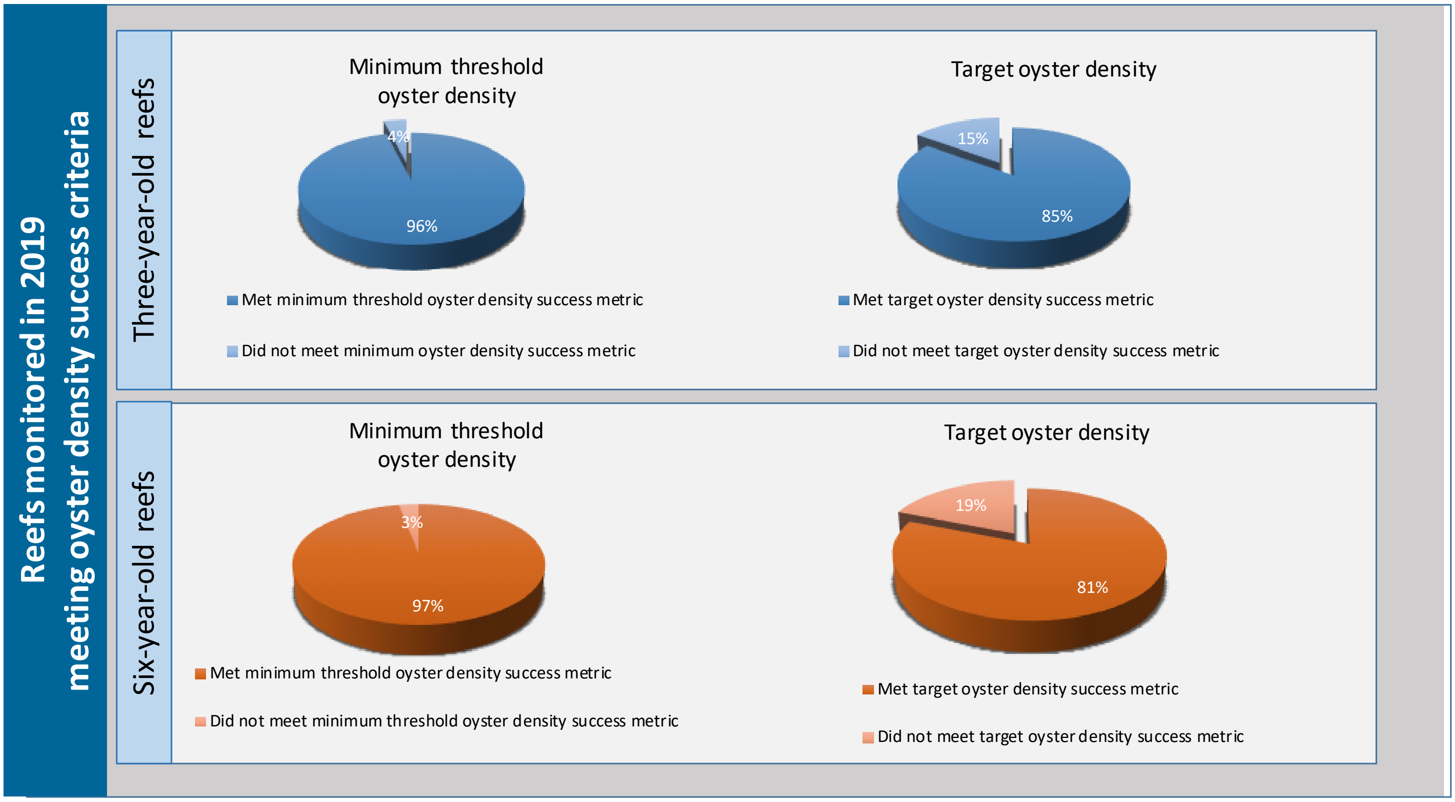
Executive Summary

Key 2019 Monitoring Results

- In 2019, 53 three-year-old restored reefs (171.73 acres) were monitored in the Little Choptank and Tred Avon rivers combined, and 31 six-year-old restored reefs (92.18 acres) were monitored in Harris Creek.
- The figure below shows the percentage of three-year-old and six-year-old restored reefs monitored in 2019 that met the oyster density minimum threshold (15 oysters per m^2) and target (50 oysters per m^2) success criteria.
- More than 95% of all restored reefs monitored in 2019 met the minimum threshold oyster density success criterion, and more than 80% met the ideal, target oyster density. Oyster density tracked closely with oyster biomass.
- All restored reefs monitored in 2019 for the multiple year class, shell budget, reef height, and reef footprint metrics were successful. (Not all three-year-old reefs were monitored for each of these metrics; see Table 2, Section 3.1).

More than 95% of all restored reefs monitored in 2019 met the minimum threshold oyster density criterion, and more than 80% met the ideal, target oyster density.

- See Section 3: Results Summary and Appendix A: Table of Summary Data by Reef for more complete information on 2019 monitoring results.

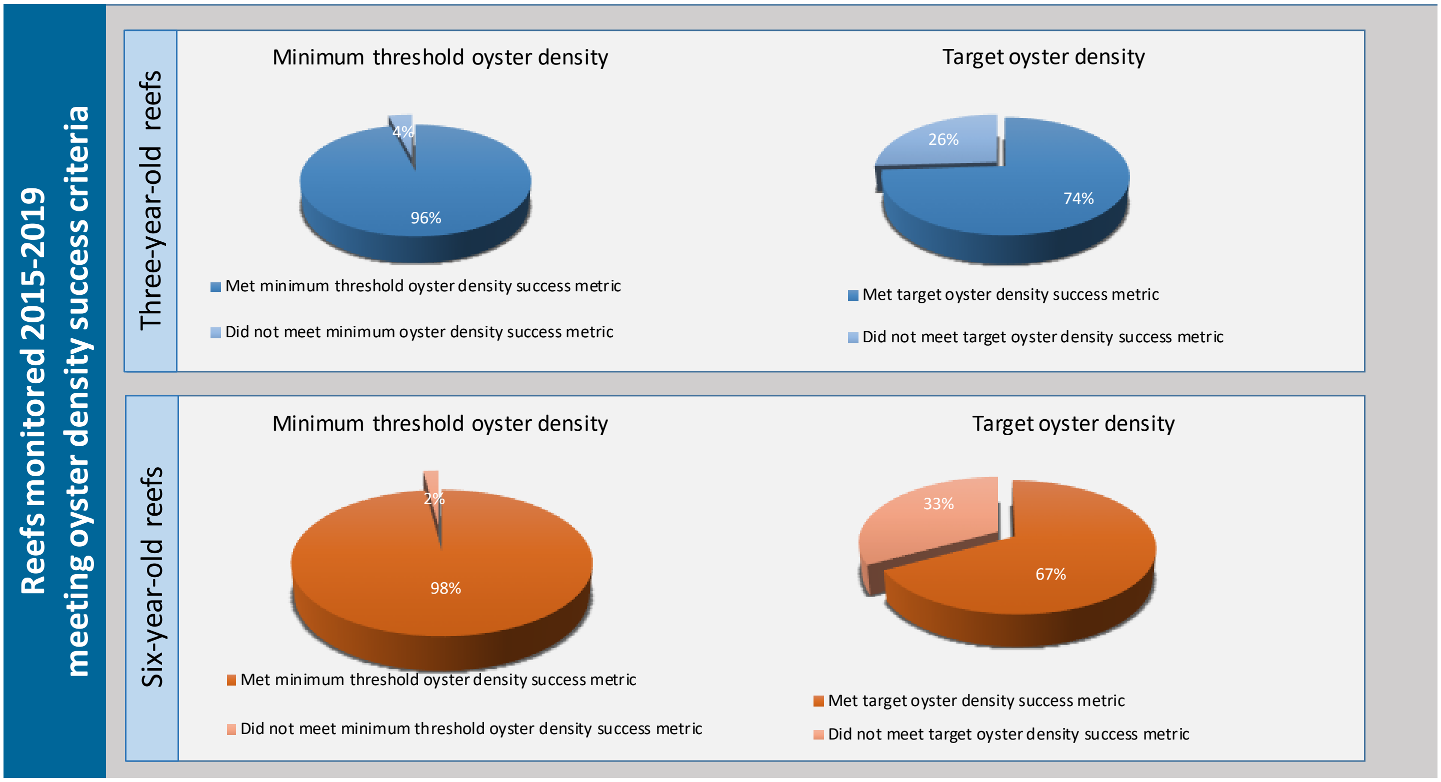


Executive Summary

Key Cumulative Monitoring Results 2015-2019

- The figure below shows the percentage of all three-year-old and six-year-old restored reefs monitored to date that meet the oyster density minimum threshold (15 oysters per m^2) and target (50 oysters per m^2) success criteria.
- More than 96% of all restored reefs monitored in 2015-2019 met the minimum threshold oyster density success criterion, and more than 65% met the ideal target oyster density. Oyster density tracked closely with oyster biomass.
- In regards to other Oyster Metrics success criteria for reefs monitored from 2015 to 2019:
    - 100% of the restored reefs met the multiple year class metric
    - 100% of restored six-year-old reefs met the shell budget metric; three-year-old reefs are not measured for shell budget
    - 100% of restored six-year-old reefs met the reef height and footprint metric. Reef height and footprint cannot be calculated on all three-year-old reefs, but where calculated, 100% of the reefs met the metrics.
- See Section 3: Results Summary and Appendix A: Table of Summary Data by Reef for more complete information on 2015-2019 monitoring results.

More than 96% of all restored reefs monitored in 2015-2019 met the minimum threshold oyster density criterion, and more than 65% met the ideal, target oyster density.



Contents

Section 1: Background and Overview

Section 1.1: Policy Drivers, Oyster Metrics Success Criteria, and Oyster Restoration Planning

The 2014 Chesapeake Bay Watershed Agreement[1] oyster outcome calls for restoring oyster populations in 10 Chesapeake Bay tributaries by 2025. The Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team (Fisheries GIT) is charged with working to achieve this goal. Driven by Executive Order 13508 (Chesapeake Bay Protection and Restoration) of 2009, some work toward tributary-scale oyster restoration was under way even before the Chesapeake Bay Watershed Agreement was signed. The Fisheries GIT had convened the Chesapeake Bay Oyster Metrics Workgroup, which, in its 2011 report "Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries"[2] (hereafter, 'Oyster Metrics'), established Bay-wide, science-based, consensus success criteria for oyster restoration to be tracked three years and six years following restoration efforts (Table 1).

Table 1: Oyster Metrics reef-level success criteria.

Biological Metrics	Oyster density	Minimum threshold = 15 oysters per m^2 over 30% of the reef area. Target = 50 oysters per m^2 over 30% of the reef area.
	Oyster biomass	Minimum threshold = 15 grams dry weight per m^2 over 30% of the reef area. Target = 50 grams dry weight per m^2 over 30% of the reef area.
	Multiple year classes	Presence of multiple year classes on the reef, as defined by oysters in at least two of the following size classes: market (>76 mm); small (40-75 mm); spat (<40 mm).
	Shell budget	Stable or increasing shell budget on the reef.
Structural Metrics	Reef footprint	Stable or increasing reef footprint compared to baseline.
	Reef height	Stable or increasing reef height compared to baseline.

Once these success criteria were adopted, the Fisheries GIT convened interagency workgroups in Maryland and Virginia to plan and coordinate restoration work in each state. In Maryland, the Maryland Oyster Restoration Interagency Workgroup (hereafter, the Workgroup) is chaired by the National Oceanic and Atmospheric Administration (NOAA) and includes members from the Maryland Department of Natural Resources (DNR), Oyster Recovery Partnership (ORP), and the U.S. Army Corps of Engineers' Baltimore District (USACE). The Workgroup developed oyster restoration tributary plans (also known as "blueprints") for Harris Creek,[3] Little Choptank River,[4] Tred Avon River,[5] upper St. Marys River,[6] and Manokin River[7] in consultation with a group of consulting scientists and the public. In-water restoration work has not yet commenced in upper St. Marys and Manokin rivers.

Section 1.2: Overview of Report Content

Restored reefs are monitored at three and six years per Oyster Metrics recommendations and each river's tributary plan. Restored reefs in Harris Creek, Little Choptank River, and Tred Avon River have matured to three or six years, and therefore were monitored in fall 2019. Data and analysis for these reefs, plus reference reefs (controls that received no restoration action) and sentinel reefs (restored sites that are monitored annually) are included in this report. Data summaries for each reef, including average oyster density, oyster biomass, and how each reef fared relative to each Oyster Metrics success criteria are in Appendix A, available at https://www.chesapeakebay.net/documents/Appendix_A_Table_of_Summary_Data_for_each_Reef.xlsx.

Past monitoring reports are available at https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams.

In addition to Oyster Metrics success criteria monitoring, other information—primarily water-quality data and oyster disease data—is also collected to aid in diagnosing why reefs succeed or fail. With funding from The Nature Conservancy, DNR monitored three water-quality stations in Harris Creek. NOAA maintains a vertical profiler on the Tred Avon River to collect water-quality data. All data from these stations are available on DNR's Eyes on the Bay website, http://eyesonthebay.dnr.maryland.gov/. Disease data is available in DNR's annual Fall Survey Report, https://dnr.maryland.gov/fisheries/pages/shellfish-monitoring/reports.aspx.

Section 1.3: Funding and Acknowledgements

- Monitoring data for the biological success metrics (oyster density, oyster biomass, multiple year classes, and shell budget) were collected, managed, and analyzed by ORP, Coastal Marine Sciences Inc., and contracted commercial watermen, with assistance from Workgroup partners, with funding from:
  - A $130,000 award from NOAA to ORP, and
  - A $178,855 programmatic agreement from USACE to ORP.
- Reef structural metrics data (reef height and reef footprint) were collected and analyzed by the NOAA Chesapeake Bay Office. This report was drafted by NOAA, with guidance from the Workgroup. Results of these analyses will be used to document the status of restoration efforts, to guide adaptive management of these reefs, and to inform future oyster restoration efforts. Technical review of this report was provided by the Workgroup members and by additional technical reviewers, per NOAA research communications guidelines.

Healthy oysters from a restored reef in Harris Creek. Photo: NOAA Chesapeake Bay Office.

Section 2: Methods Overview

Section 2.1 Location of Reefs Monitored in 2019

The following maps (Figs. 1-3) show the locations of reefs sampled during fall 2019 monitoring. For reef restoration type and status relative to Oyster Metrics success criteria, cross-referenced by reef number, see Appendix A: Table of Summary Data by Reef. Definitions of reef types can be found in Section 5: Definitions, p. 16.

Figure 1: Locations of Harris Creek reefs monitored in fall 2019. Three-year monitoring is complete on all reefs.

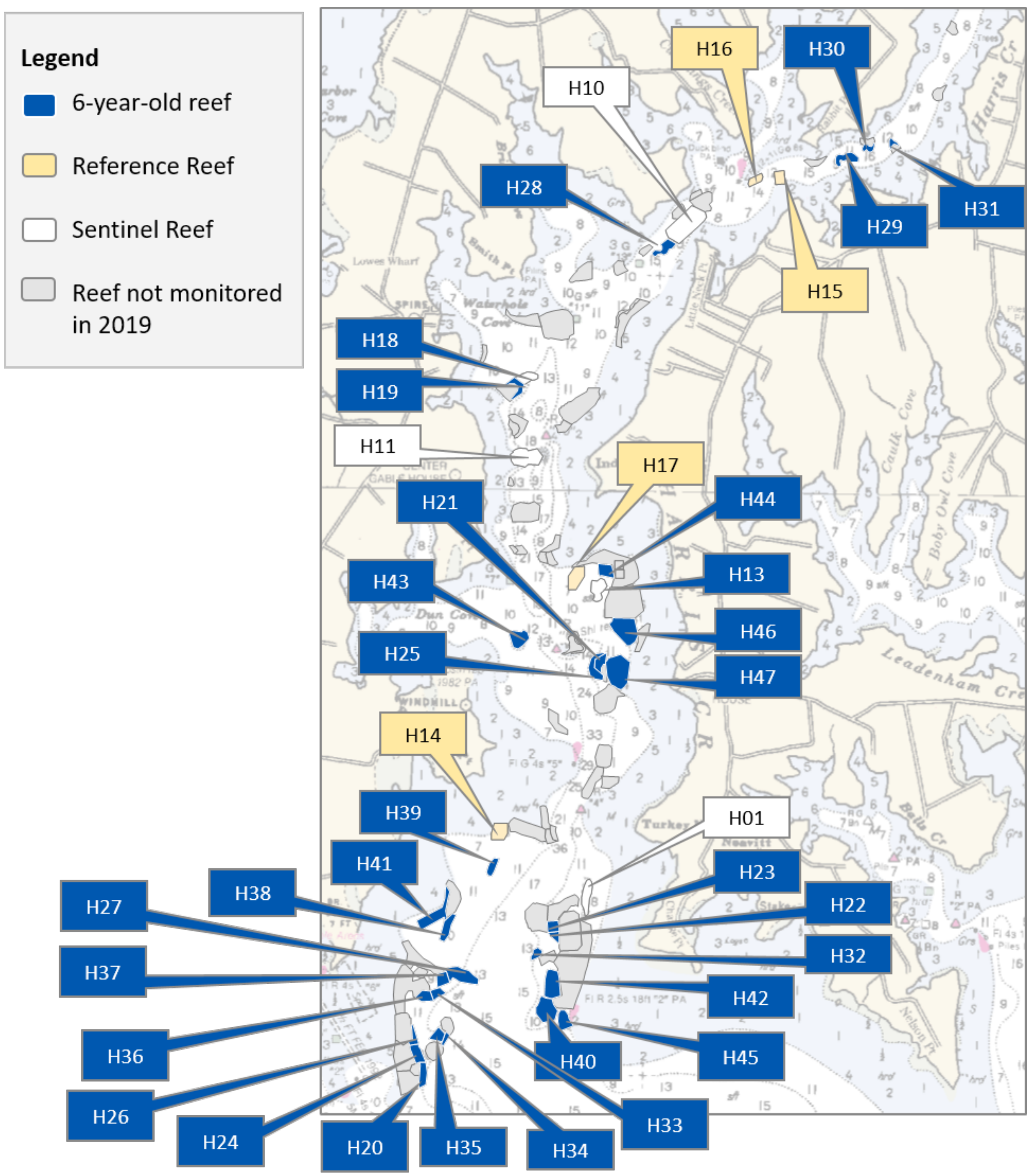
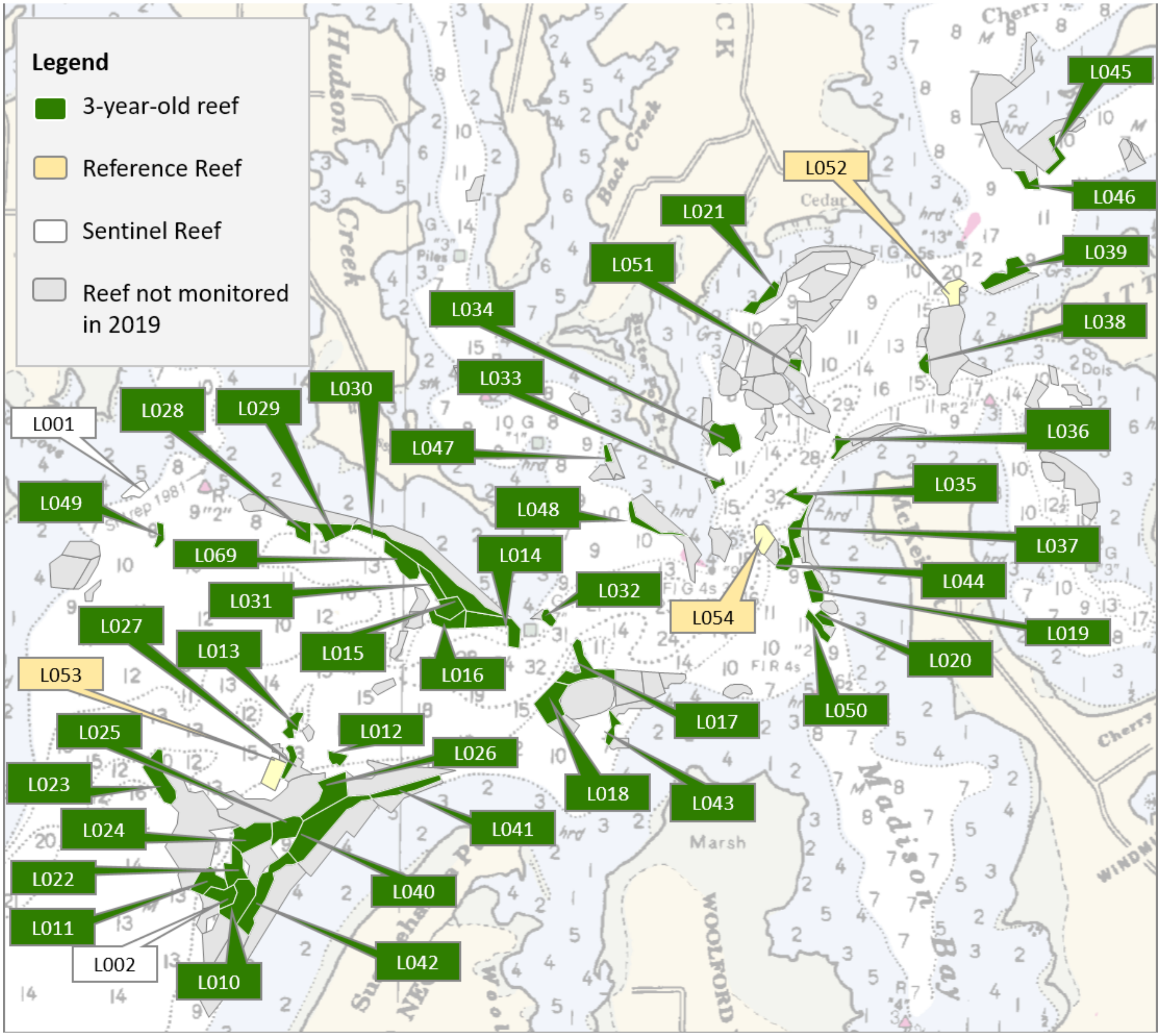
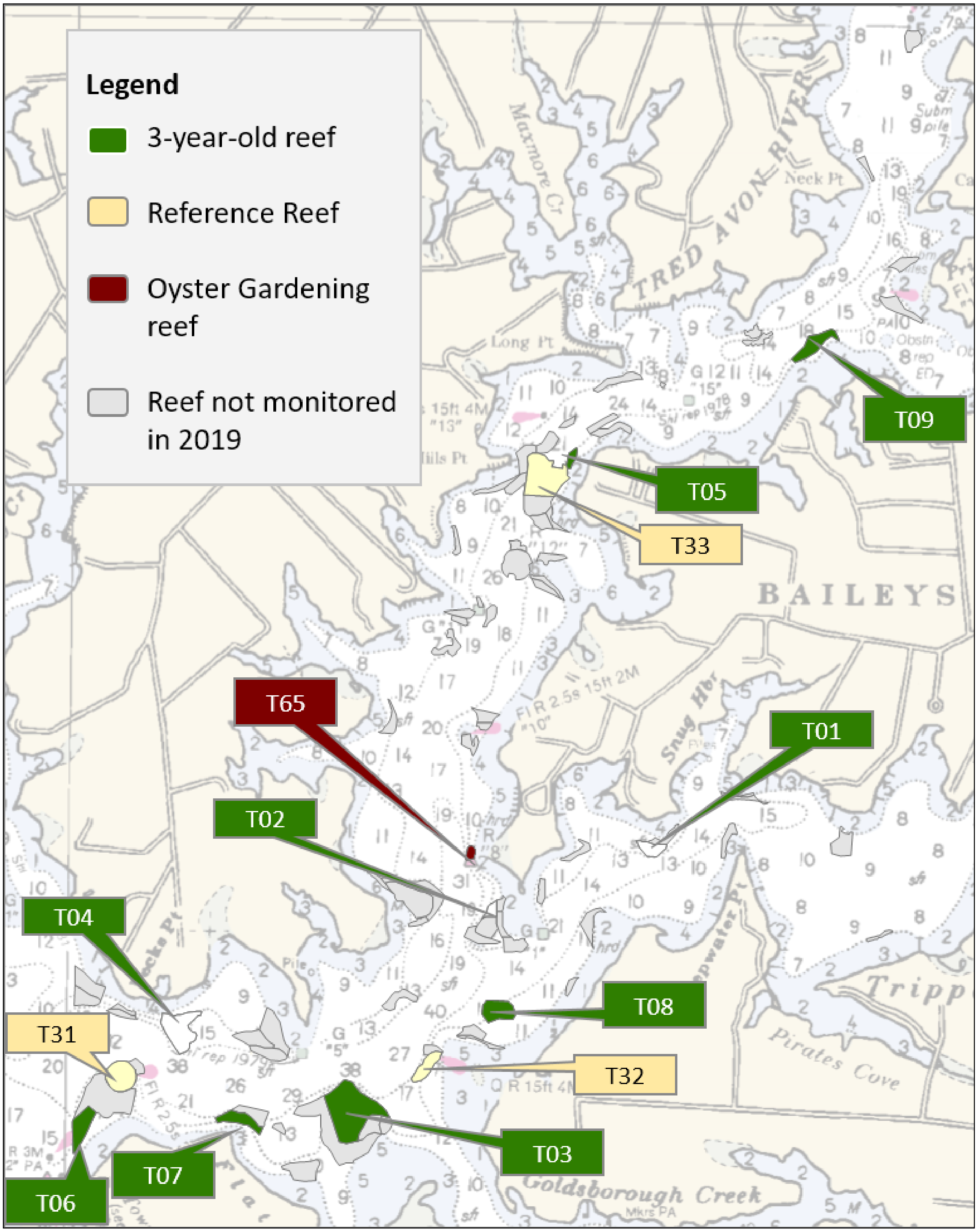


Figure 2: Locations of Little Choptank River reefs monitored in fall 2019.



Definitions for technical terms used throughout this document can be found in Section 5: Definitions.

Figure 2: Locations of Tred Avon River reefs monitored in fall 2019.



Section 2.2 Methods Summary

Below is a summary of the data collection and analysis methods used in this report. For a full description of methods, see Appendix B: Methods for Data Collection and Analysis. Reefs that aged to three years or six years in 2019 were monitored in fall 2019. Actual data collection extended from fall 2019 through early summer 2020.

Summary of Structural Metrics Methods (reef height, reef footprint)

Staff from the NOAA Chesapeake Bay Office conducted multibeam bathymetric (depth) surveys following the construction of substrate reefs, and again at three years and six years post restoration. Results were compared to determine persistence of reef height and footprint at three years and six years post restoration. Sonar surveys were not conducted on seed-only reefs immediately following planting with spat-on-shell. Therefore, no comparison of reef height or footprint can be made at three years post-restoration on these reefs. Sonar data will be collected on these reefs when they are six years old, and will be compared with three-year data to determine success relative to the structural metrics. For six-year-old seed-only reefs, three-year postrestoration data was compared to six-year postrestoration data to determine success relative to the structural metrics.

Summary of Biological Metrics Methods (oyster density, oyster biomass, multiple year classes, and shell budget)

Data to determine success relative to the four biological metrics were collected at the same time, using a stratified random survey design. Hydraulic patent tongs were used to sample on seed-only reefs, mixed-shell-base reefs, reference reefs, and premet reefs (see definitions, p. 18). Divers were used to sample on fossil-shell-base reefs, stone-base reefs topped with mixed shell, and stone-based reefs topped with fossil shell. Oyster density and oyster biomass information were standardized based on area sampled.

Gear Types Used for Data Collection

- For structural metrics (reef height; reef footprint): Data collection and analysis methods were identical for all reef-restoration treatment types (reference reefs, seed-only reefs, mixed-shell-base reefs, stone-base reefs, etc.)
- For biological metrics (oyster density, oyster biomass, multiple year classes, and shell volume):
  - Methods used to select sampling sites, analyze samples, and assess success relative to each metric were identical for all reefs.
  - Two different types of gear were used to collect samples, depending on reef substrate type. Divers were used to collect samples from reefs with substrate materials that were not amenable to patent tong sampling (stone and fossil shell substrate reefs). Patent tongs were used to collect samples from all other reef types (seed only, mixed-shell base, reference, and premet reefs) because it is more cost efficient than using divers. Previous field comparisons[8] on natural oyster reefs revealed no difference in sampling efficiency between oyster densities estimated using divers and those estimated using patent tongs. A similar field comparison on restored reefs[9] showed that densities estimated using patent tongs resulted in statistically significantly smaller numbers of oysters than those estimated using divers. Monitoring results in this report show oyster densities and biomass relative to the established Oyster Metrics benchmarks (e.g., minimum threshold oyster density of 15 oysters per m^2 to be considered successful). Because two different gear types were used for sampling, and results of research[8,9] on the relative sampling efficiencies of those gears vary, it may not be appropriate to use data in this report to compare relative efficacy among reef treatment type.

Section 3: Results Summary

Section 3.1: Summary of Fall 2019 Monitoring Results

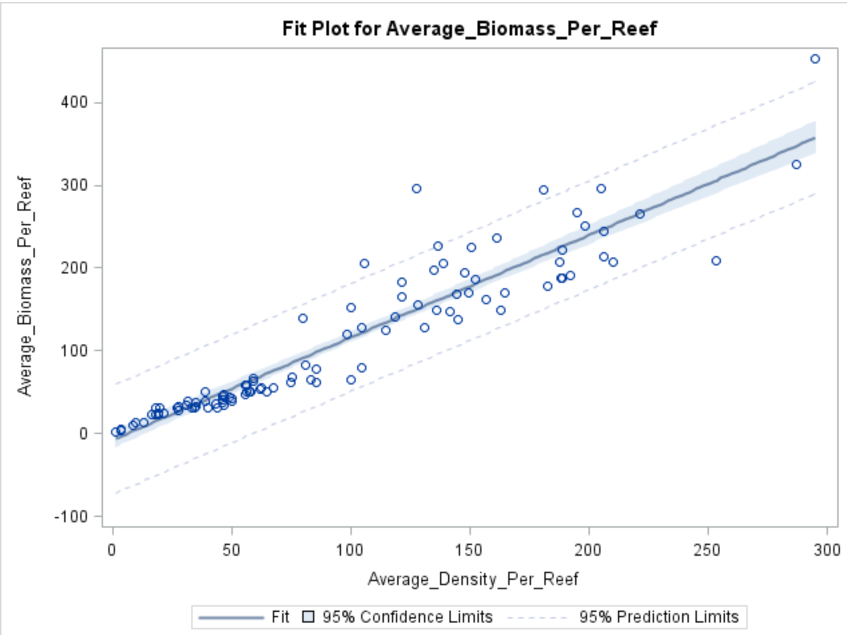
On reefs monitored in 2019 (Table 2):

- For three-year-old reefs, across all tributaries:
  - 96% of restored reefs met the minimum oyster density success criterion, and 85% met the higher, ideal target density.
  - Oyster biomass tracked closely with oyster density (Figure 4).
  - 100% of restored reefs met the multiple year class, reef height, and reef footprint success criteria.
- For six-year-old reefs (Harris Creek only):
  - 97% of restored reefs met the minimum oyster density success criterion, and 81% met the higher, ideal target density.
  - Oyster biomass tracked closely with oyster density (Figure 4).
  - 100% of restored reefs met the multiple year class, shell budget, reef height, and reef footprint success criteria.

Table 2: Description of restoration treatment types and sampling gear used to collect data for the biological metrics.

Treatment Type	Reef-building substrate added?	Substrate Material	Cap Material	Reef seeded?	Gear type used to collect biological metrics data
Seed Only	No	None	None	Yes (spat-on-shell)	Patent tongs
Mixed shell	Yes	Mixed shell (clam, conch, and whelk)	None	Yes (spat-on-shell)	Patent tongs
Fossil shell	Yes	Fossil shell	None	Yes (spat-on-shell)	Divers
Oyster gardening reef	No	None	None	Yes (adult oysters)	Patent tongs
Stone	Yes	Amphibolite (stone)	None	Yes (spat-on-shell)	Divers
Stone topped with mixed shell	Yes	Amphibolite (stone)	Mixed shell (clam, conch, and whelk)	Yes (spat-on-shell)	Divers
Stone topped with fossil shell	Yes	Amphibolite (stone)	Fossil shell	Yes (spat-on-shell)	Divers
Reference	No	None	None	No	Patent tongs
Premet	No	None	None	No	Patent tongs

Figure 4: Fit plot describing the relationship between oyster density and oyster biomass on all reefs monitred in fall 2019. R2 = .87; P value = <.0001; slope of the fitted line = 1.2.



Section 3.2 Summary of 2015-2019 Monitoring Results

Looking at all restored reefs monitored from 2015-2019 combined (Table 3):

- Of the three-year-old reefs (these reefs are in Harris Creek, Little Choptank River, and Tred Avon River):
  - 96% met the minimum threshold for oyster density, and 74% met the higher, ideal target density.
  - 100% met the multiple year class, reef height, and reef footprint criteria.
- Of the six-year-old reefs (all of these reefs are in Harris Creek; no other tributary has reefs that have aged to six years):
  - 98% met the minimum threshold for oyster density, and 67% met the higher, ideal target density.
  - 100% met the multiple year class, reef height, and reef footprint criteria.
  - 95% met the shell budget success criterion.

Table 3: Percent of three-year-old, six-year-old, and reference reefs monitored in 2019 that met each Oyster Metrics success criteria. In 2019, only Little Choptank River and Tred Avon River had three-year-old reefs. All Harris Creek reefs had reach three years of age by 2018.

Reef type	Tributary	# of reefs monitored in fall 2019	Oyster Density		Oyster Biomass		Multiple year classes	Shell budget	Reef footprint	Reef height
			% meeting minimum threshold	% meeting target	% meeting minimum threshold	% meeting target	% with multiple year classes present	% with stable/ increasing	% of reefs stable/ increasing	% of reefs stable/ increasing
3-year-old	All tribs combined	53	96%	85%	98%	77%	100%	TBD @ 6 yrs	100%	100%
	Little Choptank	43	100%	98%	100%	86%	100%	TBD @ 6 yrs	100%	100%
	Tred Avon	10	80%	30%	90%	30%	100%	TBD @ 6 yrs	100%	100%
6-year-old	Harris Creek	31	97%	81%	97%	65%	100%	100%	100%	100%
Reference	Harris Creek	4	75%	0%	75%	0%	100%	100%	NMA**	NMA**
	Little Choptank	3	100%	67%	100%	67%	100%	TBD @ 6 yrs	NMA**	NMA**
	Tred Avon	3	33%	0%	33%	0%	100%	TBD @ 6 yrs	NMA**	NMA**

*Reef shell volume at three years will be compared to that at six years to determine success relative to the shell budget metric.

**Not measured annually on reference reefs

Section 4: Discussion

Data and analysis in this report can be used by restoration partners to understand the success or failure of reefs relative to the six Oyster Metrics criteria, and to inform future restoration and adaptive management.

Trends observed in previous monitoring years generally continued in 2019, with a large majority of restored reefs meeting all six Oyster Metrics success criteria.

Per Oyster Metrics, a reef is considered successfully restored if, at six years post restoration, it meets the minimum threshold oyster density, biomass, and the other success criteria. (Ideally all restored reefs would meet the higher, target oyster density and biomass, but they do not need to do so to be considered successfully restored.) The first reefs restored under the 10 tributaries initiative aged to six years in 2018 and 2019 (total of 43 reefs over both years; 12 in 2018 and 31 in 2019). Of these, all but one reef (98%) met the minimum criteria for oyster density and biomass, and all but two reefs (95%) met the criteria for shell budget. 100% met the minimum for multiple year classes, reef height, and reef footprint (see Table 4).

Workgroup members considered all available information concerning the one six-year-old Harris Creek reef that failed to meet oyster density and biomass success criteria when monitored in 2019 (reef H45; see map in Section 2 and Appendix A: Table of Summary Data by Reef).

- This three-acre reef was not originally on the list for restoration, as it did not meet all of the prerestoration criteria the other sites met for receiving 'seed only' restoration treatment. In the Harris Creek Tributary Plan, this site does not show as a planned restoration site. However, because it was early in the transition to Tributary Plan implementation, the site was planted with spat-on-shell because it met the seed-planting criteria used prior to the development of the Tributary Plan. Once planted, the Workgroup made the decision to include it as one of the restoration polygons and track and monitor it along with the others in the Tributary Plan.
- NOAA-produced sonar images from 2016 and 2019 show no signs of poaching (e.g., dredge marks, unusual benthic disturbance). Because the river bottom at this site is very soft, such marks would likely be evident.
- This reef also failed to meet the minimum oyster density success criterion when monitored in 2016, which was three years post initial restoration. The reef received a second-year-class seeding in 2017.
- Patent tong surveys done by ORP in 2019 show that the river bottom on this site is softer and muddier than typical restoration sites in Harris Creek.
- It is the best professional judgement of the Workgroup that the reason this reef failed to meet the minimum threshold oyster density criteria is that the river bottom was too soft prior to restoration treatment. Adding spat-on-shell in 2013, and again in 2017, did not improve conditions to the point where oysters would survive well. This helps confirm that future sites must meet established prerestoration criteria for river bottom type to maximize the chance of post-restoration success. Since this reef was created, prerestoration ground truthing has been increased to ensure that restoration occurs on suitable hard bottom.

It is worth noting that of the 43 restored reefs that turned six years old in 2018 or 2019, 32 received the second-year-class seeding four years post restoration, as was planned in the Harris Creek Tributary Plan. These reefs received the planned second-year-class seeding because they performed as projected in the Harris Creek Tributary Plan. Only two of these 32 reefs were stone-base reefs; the others were seed-only or mixed-shell-

Definitions for technical terms used throughout this document can be found in Section 5: Definitions.

base reefs. The other 11 reefs did not require the planned second-year-class seeding, as they were performing better than projected (i.e., they had higher oyster densities at three years post restoration than was projected in the Harris Creek Tributary Plan). All 11 of these reefs were constructed from a stone base.

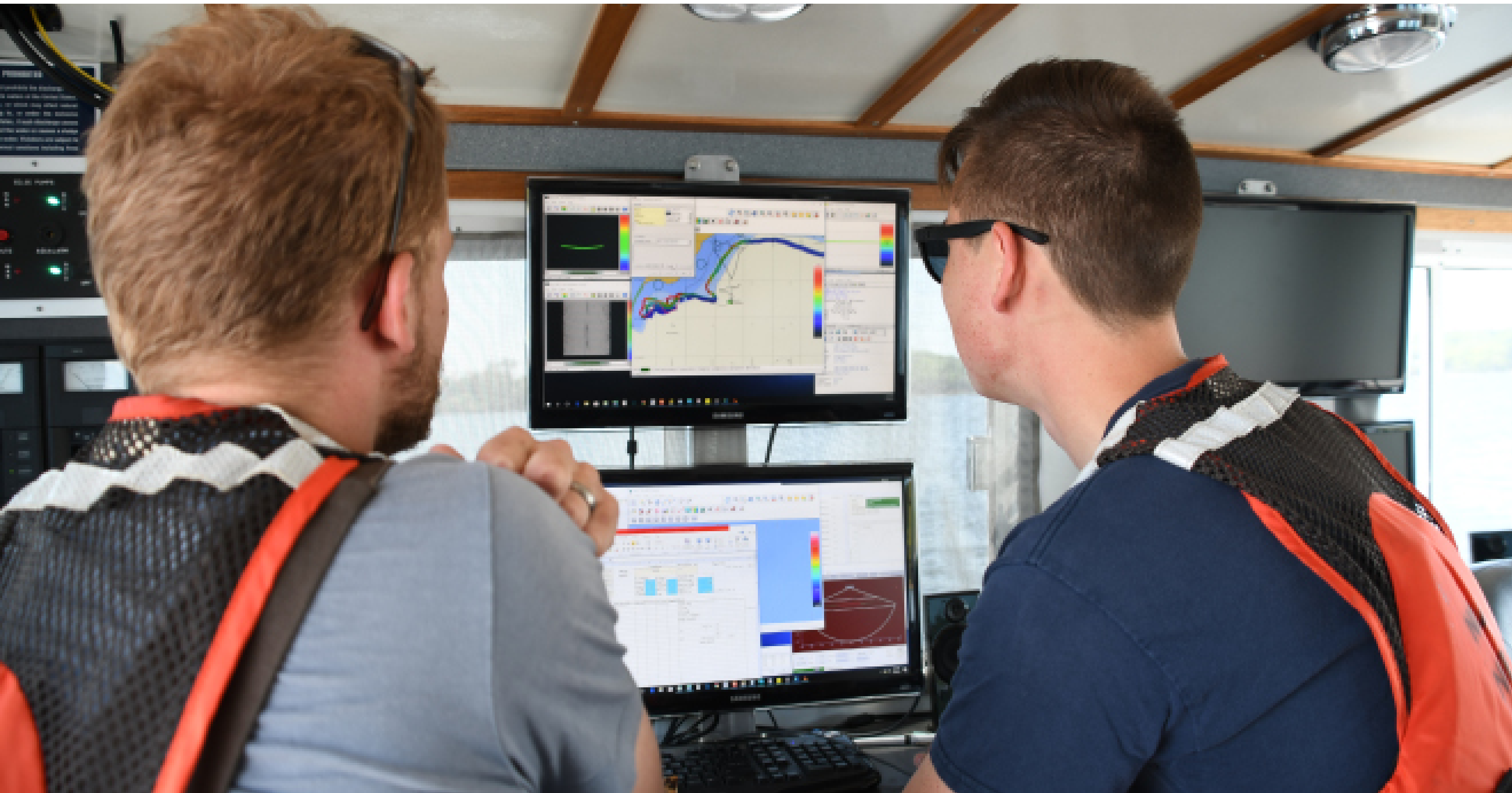
The monitoring undertaken three years post restoration is considered an adaptive management checkpoint. Information from this interval is used by restoration partners to determine whether a reef requires the second-year-class seeding called for in each river's tributary plan, and if unsuccessful reefs should receive other management action. One of the reefs that did not meet the minimum oyster density criterion (reef T65, see map in Section 2 and Appendix A: Table of Summary Data by Reef) was planted only with an unknown number of adult oysters from various oyster gardening programs over several years. The intent is to now plant this reef with spat-on-shell to increase the oyster density. The other (reef T07) is a mixed-shell-base reef. The average density on the reef in 2019 was 8.8 oysters per m^2. The intent is to treat this reef with the planned second-year-class seeding in 2020 to increase the oyster density.

For both three- and six-year-old reefs monitored in 2019, the highest oyster densities among restored reefs were found on reefs constructed of stone or fossil shell bases, or from those material combined. The lowest densities among restored reefs were found on mixed shell and seed-only reefs (see Appendix A: Table of Summary Data by Reef). It is unclear if these differences are due to reef treatment type, differences in sampling gear, or a combination (see Section 2.2: Methods Summary, Gear types used for data collection).

Although the information in this report looks promising for success in Harris Creek, Little Choptank River, and Tred Avon River, several factors could affect continued success. These include future water-quality issues, oyster disease, funding, and poaching (illegal oyster harvesting).

Salinity levels in 2018 the first half of 2019 were unusually low in the Maryland waters of the Chesapeake Bay due to high rainfall and streamflow. It does not appear that reefs monitored by DNR in fall 2019 throughout Maryland experienced elevated mortalities, despite the low salinities.[10] Similarly, reefs reported on in this document show oyster densities generally in the range expected based on monitoring in past years,[11-14] showing little evidence for high levels of salinity-related mortality.

Habitat survey work on board NOAA's R/V* Potawaugh. *Photo: NOAA Chesapeake Bay Office.



Section 5: Definitions

3-year-old reef
Reef that received restoration treatment in 2016, and—per Oyster Metrics and tributary plans—was monitored in 2019 (three years post restoration).

6-year-old reef
Reef that received restoration treatment in 2013, and—per Oyster Metrics and tributary plans— was monitored in 2016 (three years post restoration) and again in 2019 (six years post restoration).

Fall 2019 monitoring
Monitoring undertaken on restored reefs that turned three or six years old in fall 2019. Monitoring was also done on reference reefs and sentinel reefs. Actual data collection extended from fall 2019 through June 2020.

Fossil shell
Consolidated fossil oyster shell material from Florida used as a base to construct reefs. This is oyster shell cemented into a fossilized limestone, and is a true fossil, mined from 30 to 40 feet under dry land, as opposed to the Chesapeake Bay dredged shell.

Mixed shell
A mixture of scallop, conch, and clam shell from seafood processing plants.

Oyster gardening reef
A reef planted with oysters from various community-based oyster gardening programs, where volunteers grow oysters in cages hanging from docks.

Oyster Metrics
Success criteria for restored oyster reefs targeted for restoration under the 2014 Chesapeake Bay Watershed Agreement. These are defined in the report "Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries."[2] See Table 1 for description of the six reef-level criteria.

Premet reef
Reefs that were assumed to have met the Oyster Metrics density target criteria (50+ oysters per m^2) when surveyed prior to commencement of large-scale restoration efforts, and therefore did not initially receive further restoration treatment. However, the prerestoration data on some reefs was at an insufficient resolution to determine definitively whether or not the reefs met the density target. Thus, it is an assumption that the reefs in fact met the density success metric at that time, but it is not certain. These reefs are monitored every three years, as are other reefs, to determine appropriate adaptive management needs.

Reference reefs
Reefs left unrestored (untreated) to serve as comparisons to restored (treated) reefs. Typically, these would be called 'control' reefs, but they are not true controls, as it is not possible to ensure that restoring nearby reefs would not influence these reference reefs. That is, these reefs might receive larvae from nearby restored reefs, so the term 'reference reefs' is used. Per oyster population data collected prior to commencing large-scale restoration work in Harris Creek, the reference reefs did not meet the 50 oysters per m^2 Oyster Metrics target success criterion.

Second-year-class seeding

A second planting of spat-on-shell some reefs receive approximately four years after initial restoration. This is intended to ensure that each reef has at least two year classes, which is an Oyster Metrics criteria. It can also help ensure that reefs meet the oyster density and biomass criteria. Second-year-class seedings are called for in each river's oyster restoration tributary plan. If a reef shows higher-than-expected oyster density when monitored three years post restoration, and a second year class is present, a second-year-class seeding may not be required.

Note: Table 2 in Section 2.2 also describes the different types of reef restoration treatments.

Seed-only reefs

Reefs treated only with hatchery-produced oyster seed (spat-on-shell). No base reef-building substrate was added prior to seeding. This treatment was generally used on reefs where the prerestoration population was five oysters per m^2 or greater, but fewer than 50 oysters per m^2 (see Harris Creek Tributary Plan[2], Little Choptank Tributary Plan[3], and Tred Avon Tributary Plan[4] for detailed description of how the Workgroup determined treatment type for each reef).

Sentinel reefs

A subset of the restored reefs that are monitored annually (rather than only three years and six years after restoration, which is the standard for other restored reefs).

Spat-on-shell

Hatchery-produced juvenile oysters attached to the shells of dead oysters. Shell typically comes from shucking houses.

Stone substrate reefs

Reefs constructed using a type of stone that is geologically classified as amphibolite. The stone was graded to fit through a six-inch mesh screen. These reefs were then seeded with spat-on-shell.

Stone reefs topped with mixed shell

Reefs constructed from a stone base, then capped with mixed shell and seeded with spat-on-shell.

Stone reefs topped with fossil shell

Reefs constructed from a stone base, then capped with fossil shell and seeded with spat-on-shell.

Substrate + seed reefs

Reefs treated with reef-building substrate, generally to a height of six inches to one foot above the surrounding soft bottom. Substrate was either mixed shell, fossil shell, stone, or a combination. Substrate placement was followed by planting with hatchery-produced spat-on-shell. Substrate + seed treatment type was typically used where prerestoration oyster populations were below five oysters per m^2, or where sonar surveys found no evidence of shell.

References

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2. Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries. Report to the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program. Oyster Metrics Workgroup. 2011. https://www.chesapeakebay.net/channel_files/17932/oyster_restoration_success_metrics_final.pdf.

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Planting spat-on-shell in Harris Creek from the Oyster Recovery Partnership's* Robert Lee*.
Photo: NOAA Chesapeake Bay Office.

Appendix A: Table of Summary Data by Reef

This table shows summary data on each reef, including average oyster density, oyster biomass, and how each reef fared relative to each Oyster Metrics success criteria. It is available at https://www.chesapeakebay.net/documents/Appendix_A_Table_of_Summary_Data_for_each_Reef.xlsx.

A flourishing restored oyster reef. Photo: Oyster Recovery Partnership.

Appendix B: Methods for Data Collection and Analysis

Section B.1: Methods for determining success relative to biological Oyster Metrics criteria (oyster density, oyster biomass, multiple year classes, shell budget)

Survey Design

A stratified random survey is used to collect biological data on restored reefs. Each reef is its own stratum, and a random number of sample points are assigned based on reef size, reducing relative error among samples. ArcGIS is used to generate sampling points for each reef. All reefs that are due for monitoring are compiled into a shapefile, and samples are generated within the area of the reef that was planted with spat on shell. This ensures that sample points are created within the area that received oysters.

Field Component

Data are typically collected in the fall. The gear used depends on the reef material. Hydraulic patent tongs are used to sample on seed-only reefs, mixed-shell-base reefs, reference reefs, and premet reefs. Divers are used to sample on fossil-shell-base reefs, stone-base reefs topped with mixed shell, and stone-based reefs topped with fossil shell. Because two different gear types are employed, it is not appropriate to directly compare oyster density and biomass on reefs sampled with patent tongs versus divers (see Section 2.2: Methods summary). Oyster density and oyster biomass information are standardized based on area sampled.

Sampling is conducted during daylight hours. Navigation to sampling locations and sample coordinate documentation is done using a differential global positioning system (DGPS) attached to a laptop with ArcView 10.2 used as the navigational program. The vessel navigates as closely as possible to the designated random points, and a waypoint (virtual GPS marker) is created at the location of each sample.

Patent Tong

Hydraulic patent tongs are a specialized commercial fishing gear used to harvest oysters in the Chesapeake Bay. The patent tong design functions much like a benthic grab, collecting oysters and underlying substrate from a known fixed area of the bottom. The tongs used in 2019 sampled an area equal to 1.928 m^2 of the seafloor. The patent tongs are suspended from a boom over one side of the vessel and deployed to the bottom at each sampling location. A DGPS antenna is positioned adjacent to location where the patent tongs are deployed and a waypoint with the geographic coordinates of each sample location is documented.

Diver Surveys

Diver surveys are used to collect samples on reefs constructed with either a stone or fossil shell base, and are conducted by navigating the vessel to each sampling location and deploying buoys with anchors to mark each sample location. Divers descend to the bottom at each buoy with a 0.71 m x 0.71 m (0.5041 m^2) quadrat and sample collection crates. The quadrat is placed up-current of the buoy anchor.

Before disturbing the reef surface, the diver makes observations on the number of oysters visible and the percent of reef substrate within the quadrat. Any material contained within the quadrat, including loose oysters, loose shell, and any reef substrate, are removed and transported to the vessel for processing.

Sample Processing

In each sample, all oysters are counted and identified as live or dead, and a minimum of 30 live oysters are measured for each sample. Oyster clumps, the number of oysters associated with a clump, and the substrate type that oysters are attached to are documented. The shell height and total count of dead (old box) and recently dead (gapers) oysters are documented from each sample. The percent of the sample covered by tunicates or mussels is documented for each sample. Additionally, field crews record the volume of each sample that is black (anoxic, shell) and measure oyster and shell volume to the nearest half liter using graduated buckets. Surface and bottom water temperature, dissolved oxygen, pH, and salinity are collected during each sampling event using a YSI pro-plus water quality sonde (YSI Corporation, Yellow Springs, Ohio). Other environmental and station specific variables collected at each site include sample number, date and time, weather information, depth of water, Yates Bar name, vessel name, and staff conducting the monitoring.

Data Entry and Analysis

All data are entered into a Microsoft Access database. QA/QC protocols are used to review data for nonsensical values and typos. Oyster lengths and counts are used to derive density estimates for each reef. Graphs are made to visually display size class information and proportion of live to dead oysters at the reef level. Additionally, all sample locations are plotted in ArcGIS to ensure that samples are collected on the reef footprint.

- Oyster Density
    - Oyster Metrics success criteria: Minimum threshold = 15 oysters per m^2 over 30% of the reef area; Target = 50 oysters per m^2 over 30% of the reef area.
    - Method: Oyster density was calculated as the number of individual live oysters collected in the area of a patent-tong grab or diver quadrat standardized to a square meter. To meet the Oyster Metrics threshold or target, at least 30% of the samples collected must meet the specified densities. This represents a change from the previous survey design, in which the area of the sampled grid cells meeting the target or threshold must have been equal to or greater than 30% of the reef area. Past years of monitoring data were analyzed using this method to ensure that the methods are comparable.
- Oyster Biomass
    - Oyster Metrics success criteria: Minimum threshold = 15 grams dry weight per m^2 over 30% of the reef area; Target = 50 grams dry weight per m^2 over 30% of the reef area.
    - Method: Oyster biomass per m^2 was calculated from the size of individual live oysters within each sample, using the equation $W = 0.000423 * L^{1.7475}$ where W = dry tissue weight in g and L = shell height in mm. Biomass was then summed for the entire sample and standardized to a square meter. The biomass value is scaled based on oysters measured out of total oysters counted. The same approach as oyster density (above) was employed, in which at least 30% of samples collected had to meet the threshold or target to demonstrate restoration success. Past years of monitoring data were analyzed using this method to ensure that the methods are comparable.
- Multiple Year Classes
    - Oyster Metrics success criterion: Presence of two or more year classes of live oysters.
    - Method: Year-class presence was approximated by examining length frequency data of all oyster heights measured at each reef. Sampling teams are trained to measure and record all oysters, regardless of size. For simplicity, a reef was determined to have multiple year classes when oysters from at least two standard size class categories (market: >76 mm; small: 40–75 mm; spat: <40mm) were present. There is no differentiation between hatchery-produced oysters and natural oysters.

- Shell Budget
    - Oyster Metrics success criterion: Neutral or positive shell budget on the reef.
    - Method: Changes to the shell budget at individual reefs were analyzed using shell volume data from 2016 and 2019, with 2016 data used as a baseline. All samples on a given reef are included in the statistical analysis. Sites that did not have significant differences between measurements in 2016 and measurements in 2019 were assumed to have a stable shell budget. In the case of a significantly lower average volume in 2019, the reef is considered to have failed this metric.

Statistical Analysis for Biological Metrics

Oyster density estimates were standardized to number per m^2 from the area sampled by patent tong or by diver quadrat. Total counts of live oysters or other variables (e.g., oyster size class, shell volume) were averaged over all samples collected at the individual reef. The volume of sampled shell is measured with graduated buckets and standardized to square meter based on the area sampled by patent tong. Field measurements of shell resources included total shell volume and the percent of black (buried) shell estimated in a sample. Surface shell estimates were calculated as the percent of the total sampled shell volume that was not considered black shell, as shown below:

*Surface shell volume=Total shell volume-(Total shell volume*Percent Black Shell)*

Calculating shell volume is conducted similarly for diver sampling. The volume of sampled shell is measured in graduated buckets and standardized to square meter based on the size of the diver quadrat for each sample. Alternative substrates (fossil shell, granite) are not included in this volume measurement. Again, the percent of black (buried) shell is visually estimated. 2018 was the first year in which the shell budget metric was assessed. The Workgroup determined that total shell volume was a more appropriate metric than surface shell volume to reduce bias. Analysis of variance was used, followed by Tukey HSD post-hoc, to determine significant differences between years. Sites that did not have significant differences between measurements in 2016 and measurements in 2019 were concluded to have a stable shell budget.

Section B.2: Methods for determining success relative to Oyster Metrics reef structural criteria (reef footprint; reef height)

Staff from the NOAA Chesapeake Bay Office conducted multibeam bathymetric (depth) surveys to determine reef success relative to the Oyster Metrics structural criteria. All multibeam survey data are acquired and processed to the standards set forth in NOAA/National Ocean Service Hydrographic Surveys Specifications and Deliverables, 2017. Surfaces derived from the processed data are exported from QPS Qimera bathymetry processing software at a 0.25m resolution rasterized grid using the CUBE model mean depth estimate, a repeatable method.

Reef Footprint (Spatial Extent)

Oyster Metrics success criterion: Neutral or positive change in reef spatial extent (footprint) as compared to baseline measurements

Methods:

- Substrate + Seed Reefs: Perimeter change was evaluated using the postconstruction bathymetric surface (grid) and the three years post construction bathymetric surface. Reef boundaries were visually compared to identify differences that may have resulted from a portion of the reef being lost due to subsidence or removal. If no observable loss was detected, the reef spatial extent was reported as meeting the metric.
- Seed-Only Reefs: Bathymetric surface data was not collected on seed-only reef sites immediately following seed planting prior to 2016.*

Reef Height

Oyster Metrics success criterion: Neutral or positive change in reef height as compared to baseline measurements

Methods:

- Substrate Reefs: To evaluate reef height, the difference between the postconstruction surface and the three-years-postconstruction surface was calculated by subtracting grid cell elevation of the former from the latter. To establish a common baseline elevation between multiple surfaces, the depth values for the two sources were compared at eight points around the outside of the restored site. The mean difference from the eight points was calculated to adjust the two surfaces to be on a common elevation and helps to remove any tidal artifacts between the two surveys. ArcGIS Spatial Analyst extension raster math tool calculated differences between all of the cells within the restoration site polygon. Observed reef elevation differences can be attributed to oyster growth as well as moving construction equipment, deposition of seed, scouring from currents, deposition of sediments, loss from poaching, loss from subsidence of the site base, or artifacts within the sonar data. If the mean calculated difference for the surface within the site boundary was neutral or positive, then the reef height was reported as meeting the metric. A greater than two-centimeter change must be observed in either growth or subsidence in order to be deemed a meaningful change to reef height (see Table App B1).

Table App B1: Determination of whether a reef is considered successful relative to the reef height metric. "Reef height change" is the difference, per sonar surveys, between mean reef height immediately postrestoration and the mean reef height three years postrestoration.

Reef height change	Did the reef meet the reef height success criterion?
Zero	Yes
Greater than zero	Yes
Between zero and -2 cm	Yes
Reef subsidence greater than 2 cm	No

- Seed-Only Reefs: Surface data were not collected on seed-only reef sites immediately following seed planting prior to 2016. Therefore, it is not possible at this time to determine whether or not the seed-only reefs meet the reef height success criteria.*

*Methods for determining success relative to Oyster Metrics reef structural criteria:

For substrate + seed reefs, staff from the NOAA Chesapeake Bay Office conducted multibeam bathymetric (depth) surveys immediately following reef substrate placement (‘time zero’ data), and again three and six years post restoration. Time zero data could then be compared to three year data to determine success relative to the structural criteria.

On reefs receiving seed-only treatment, however, reefs treated in earlier years (2012-2015) did not undergo ‘time zero’ multibeam surveys immediately after seed was planted because bathymetric updates to nautical charts are not required. (In a few instances, surveys of substrate + seed reefs overlapped with seed-only reefs, and therefore immediate post-seeding survey data was captured.) Because these early, seed-only reefs had no ‘time zero’ multibeam data, it was not possible to determine in year three whether the reefs had met the structural metrics standard of a ‘stable or increasing’ footprint and reef height. These are labeled ‘TBD’ in the table in Appendix A. For these reefs, year three data will be compared to year six data to determine success relative to structural metrics.

Reefs receiving seed-only treatment in later years (from 2016 forward) were surveyed with multibeam immediately post-planting, and therefore data collected three years postrestoration could be compared to ‘time zero’ data to determine success of structural metrics at year three.

Appendix C: Reef Pages—Sonar Images and Length-Frequency Histogram for Each Reef

Reef locations are indicated on maps in Section 2 of this report.

Figure A: Legend for bathymetry and reef boundaries for Harris Creek sonar images.

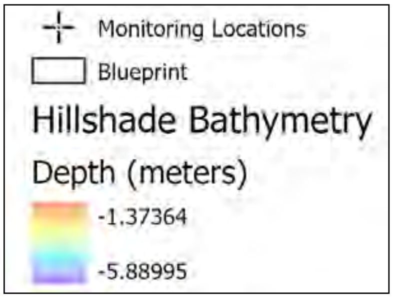


Figure B: Legend for bathymetry and reef boundaries for Little Choptank River sonar images.

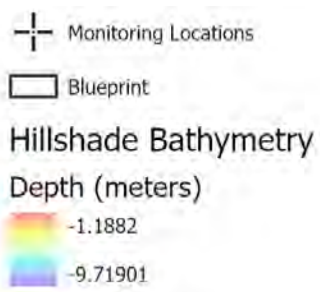


Figure C: Legend for bathymetry and reef boundaries for Tred Avon River sonar images.

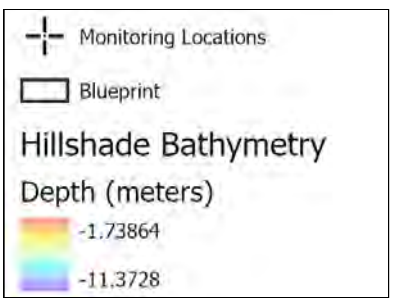
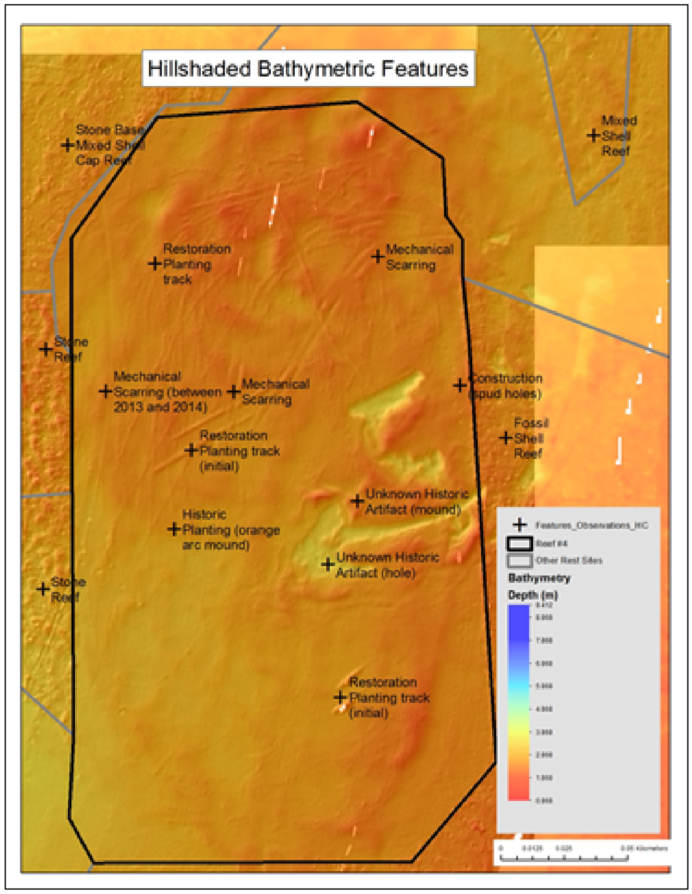
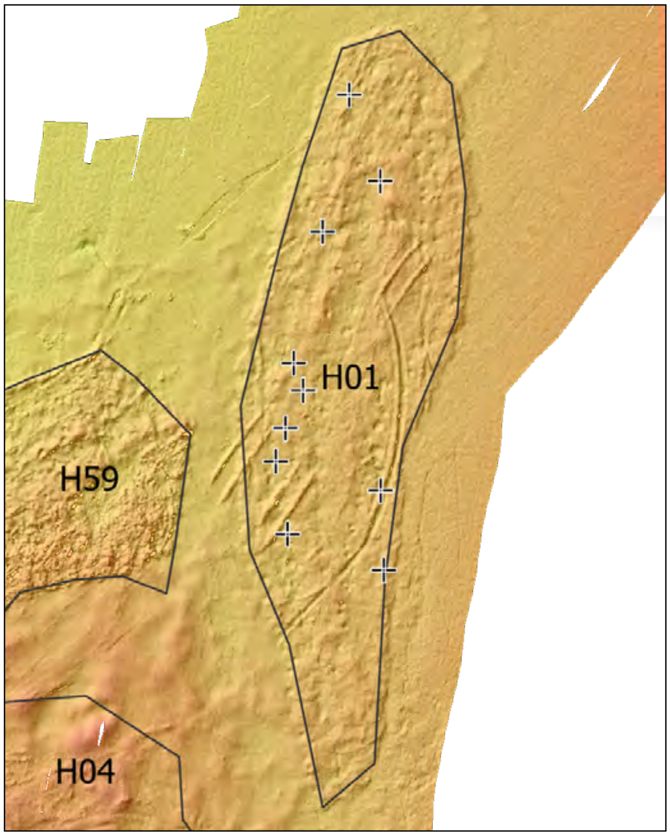
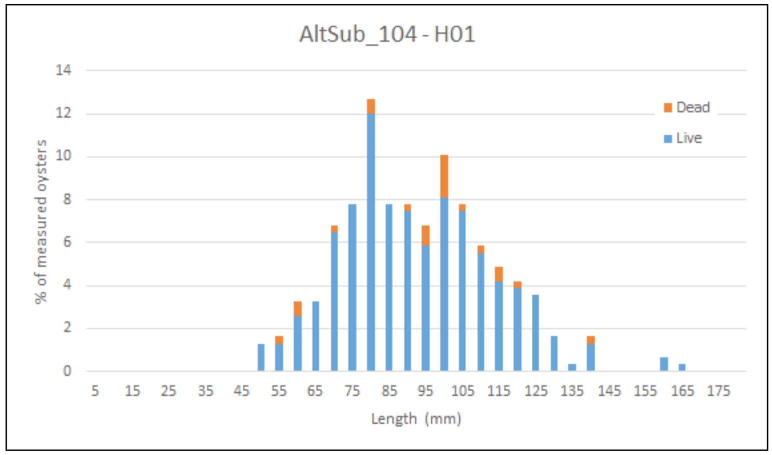


Figure D: Interpretation of common bathymetric features visible in sonar images on oyster reefs. This figure applies to all sonar images that follow.



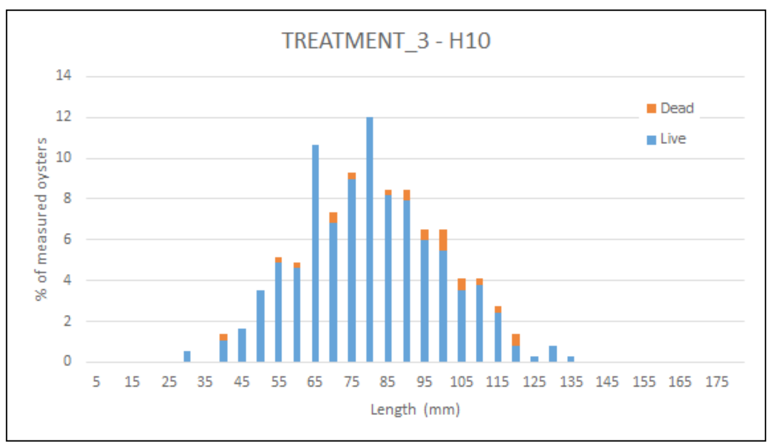
Reef H01



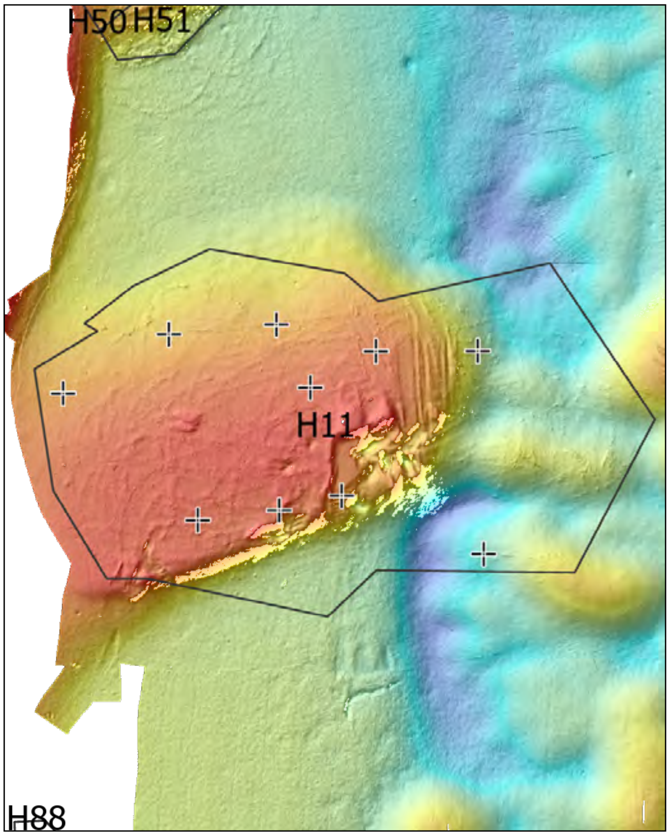


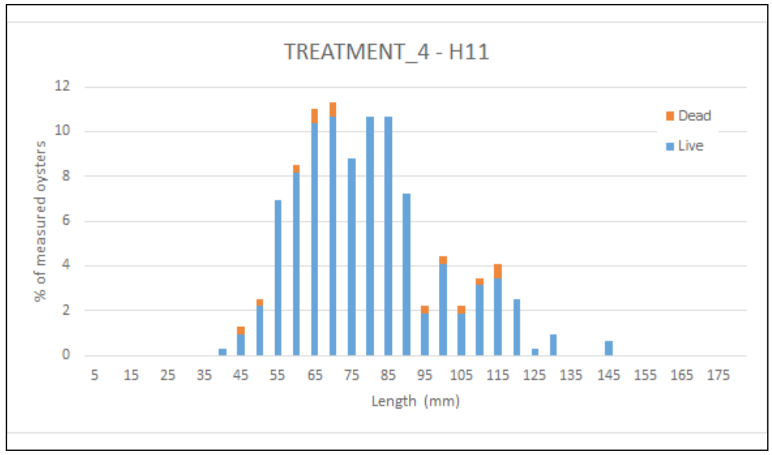
Reef H10

Sonar images not produced annually on all sentinel reefs.

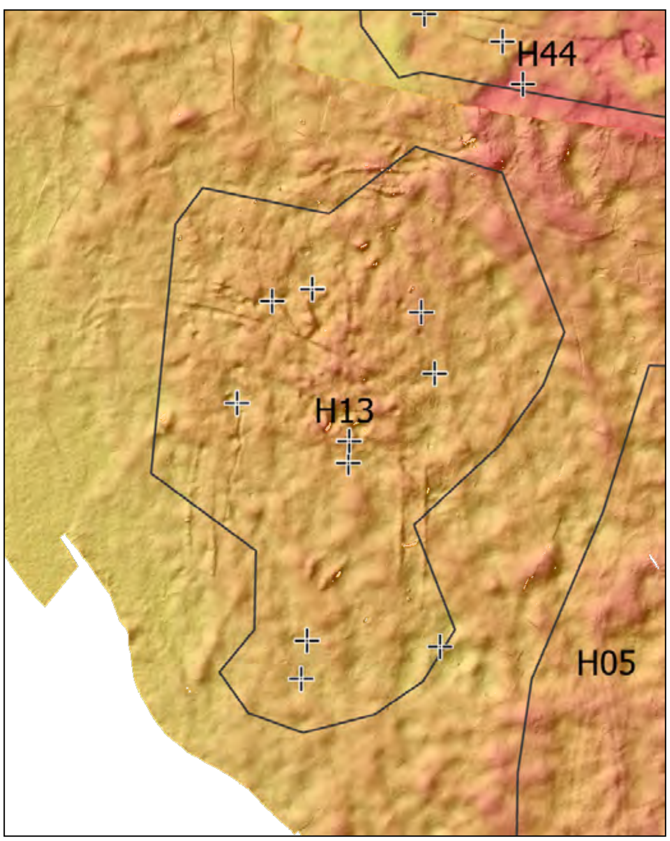


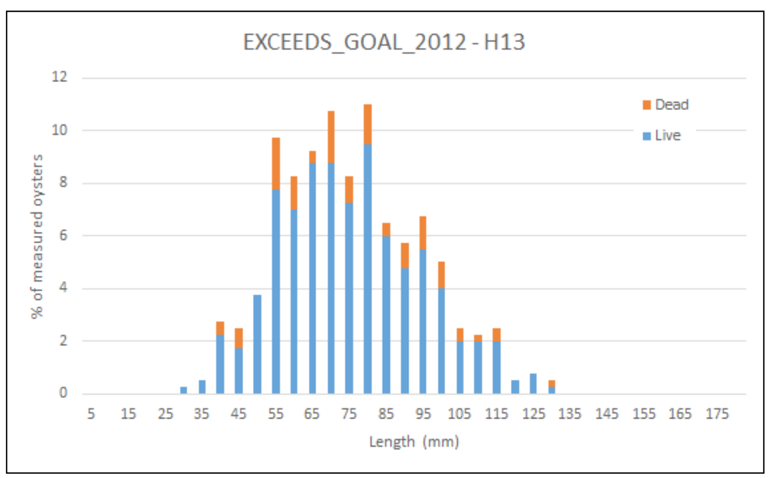
Reef H11





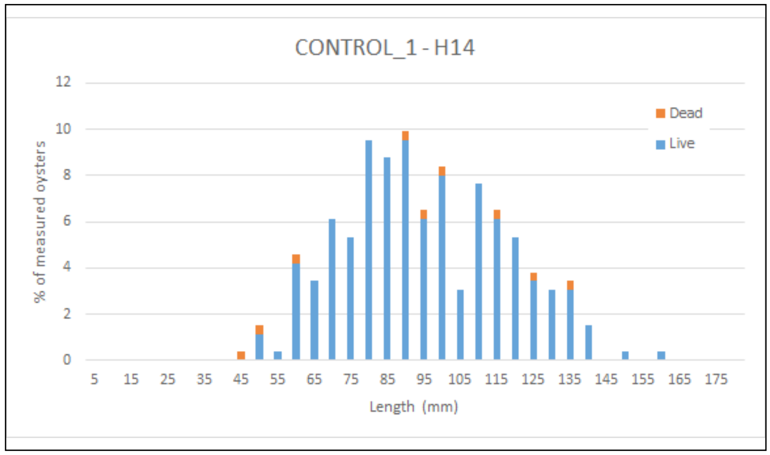
Reef H13





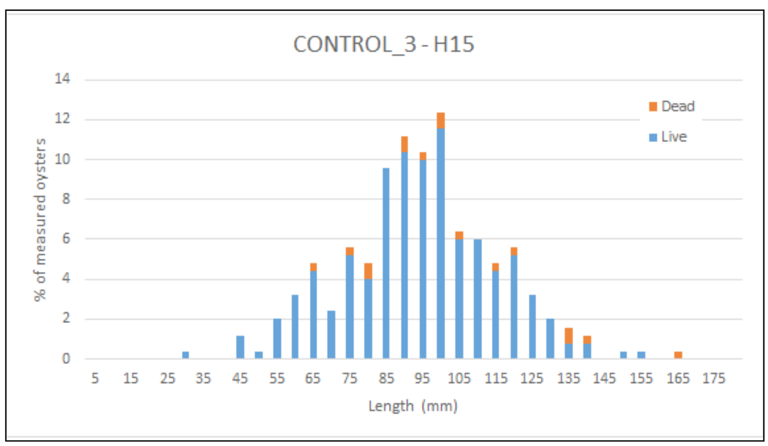
Reef H14

Sonar images not produced annually on all sentinel reefs.



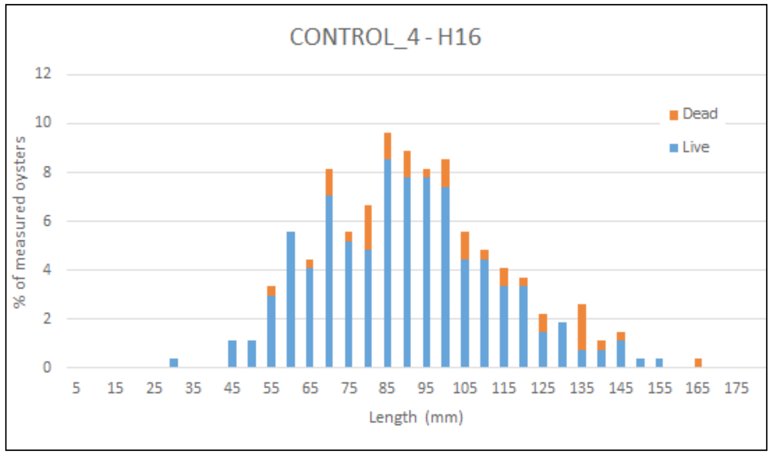
Reef H15

Sonar images not produced annually on all sentinel reefs.

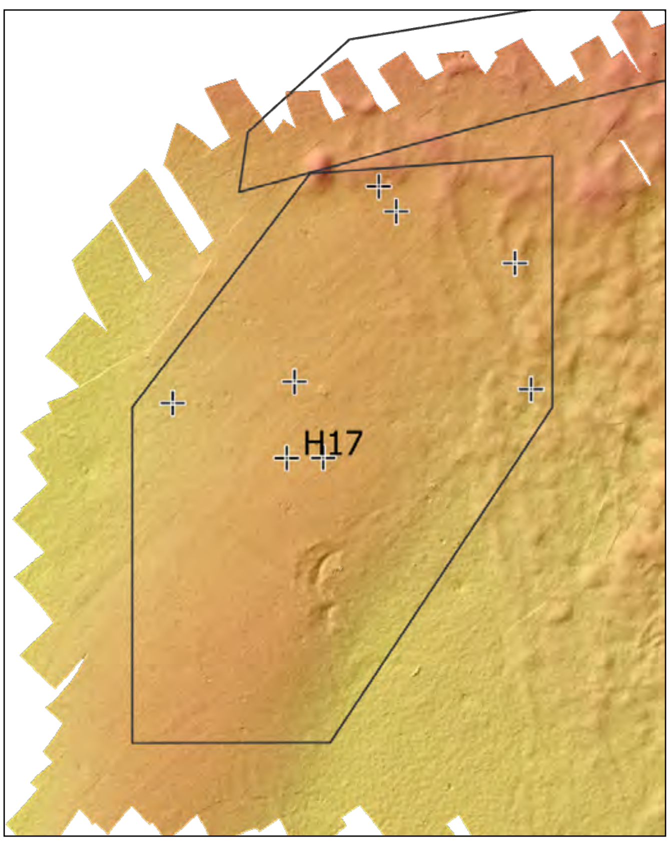


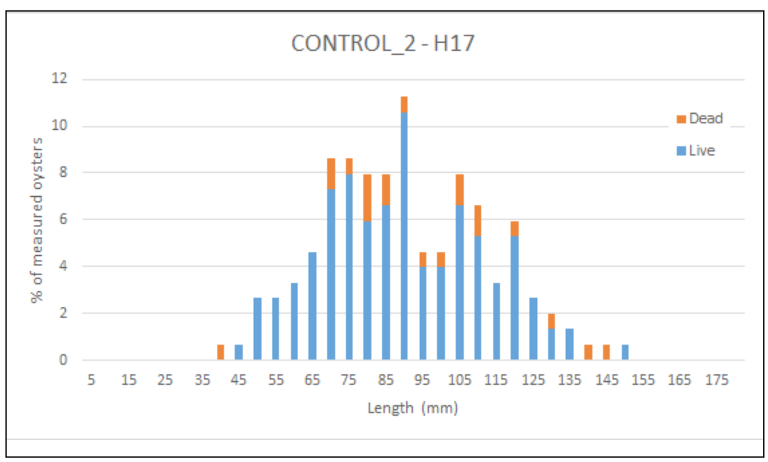
Reef H16

Sonar images not produced annually on all sentinel reefs.



Reef H17





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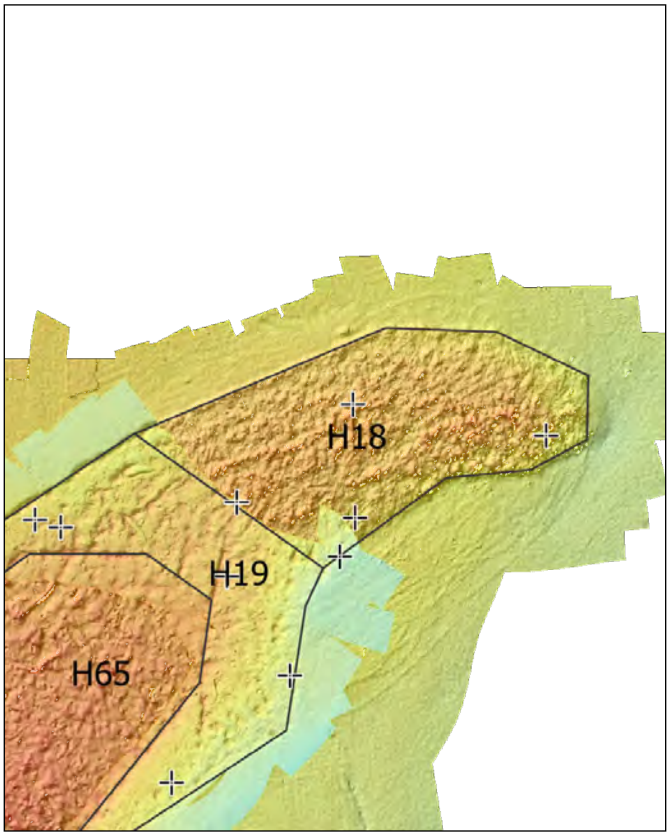

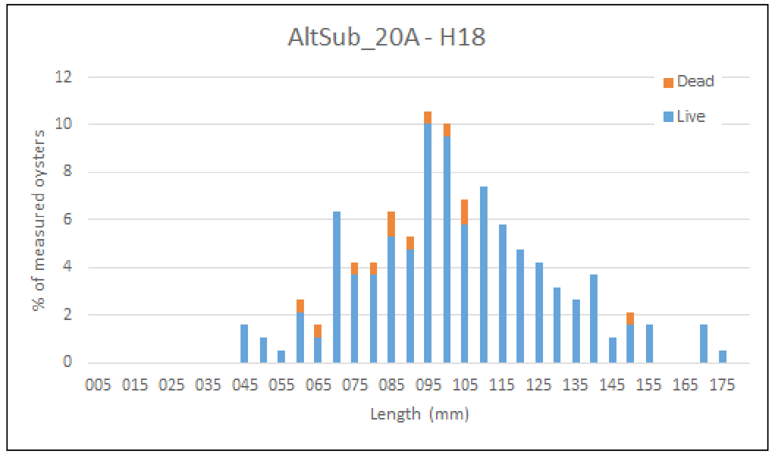

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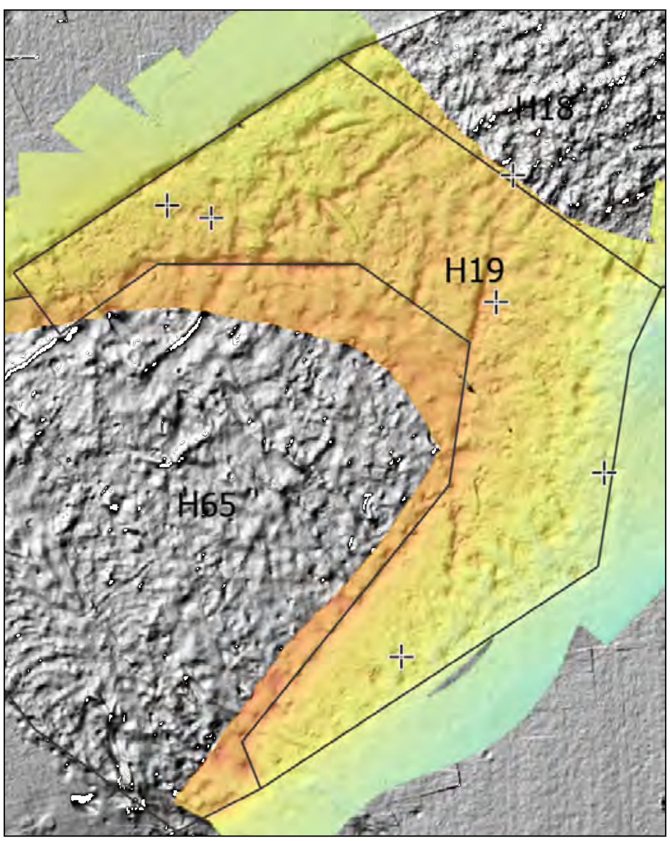

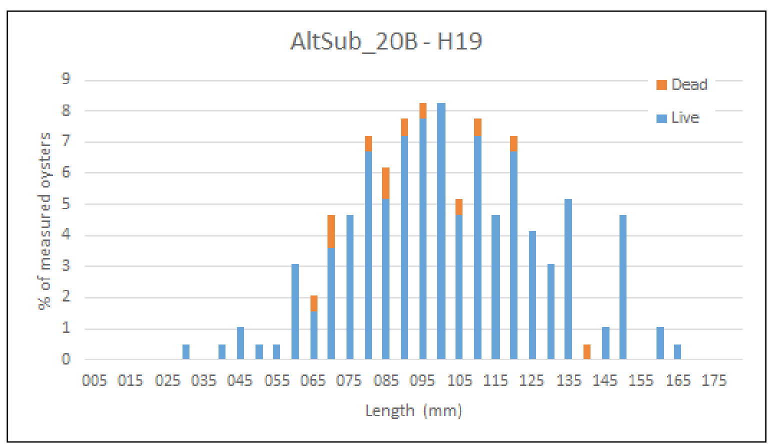

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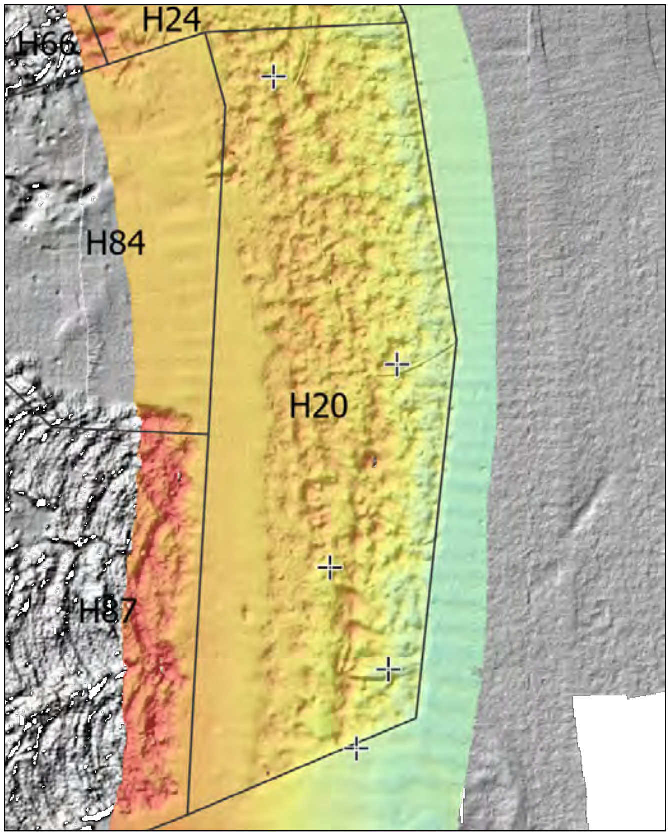

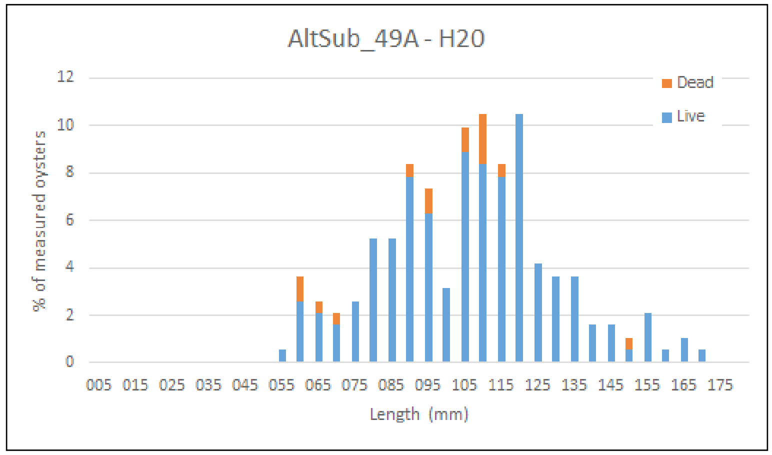

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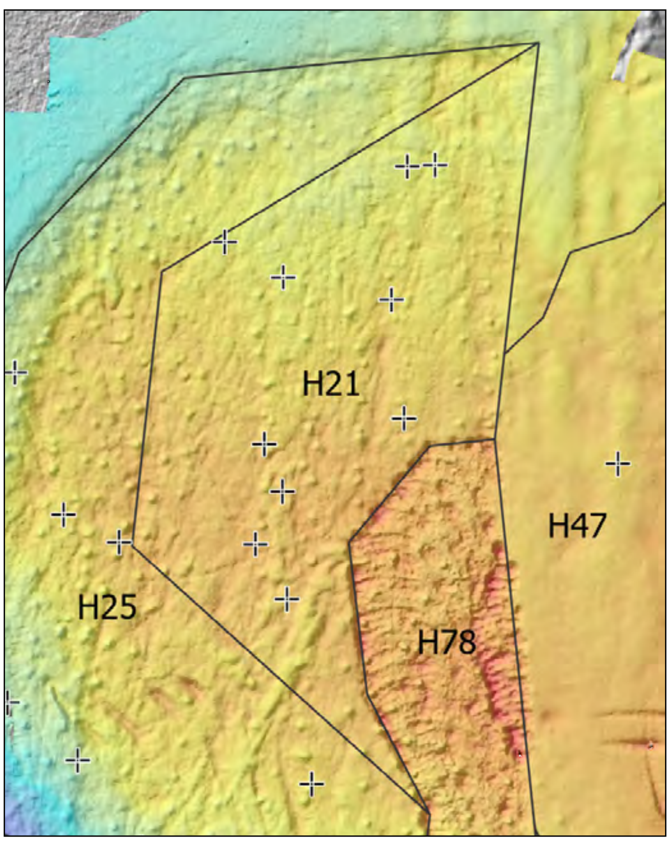

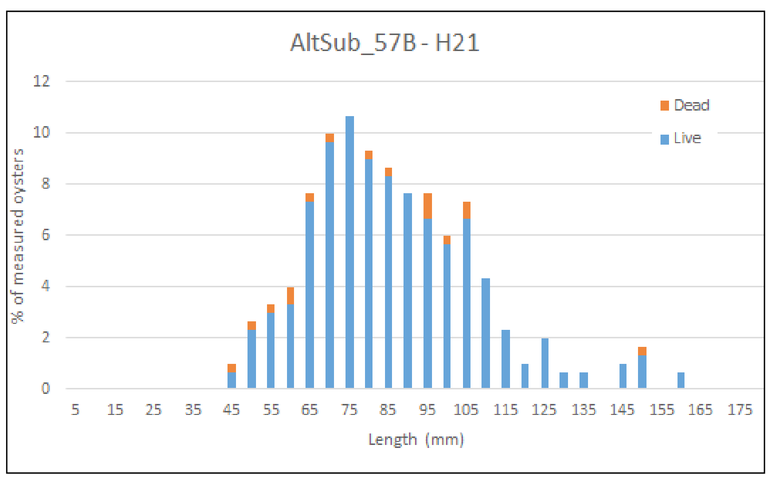

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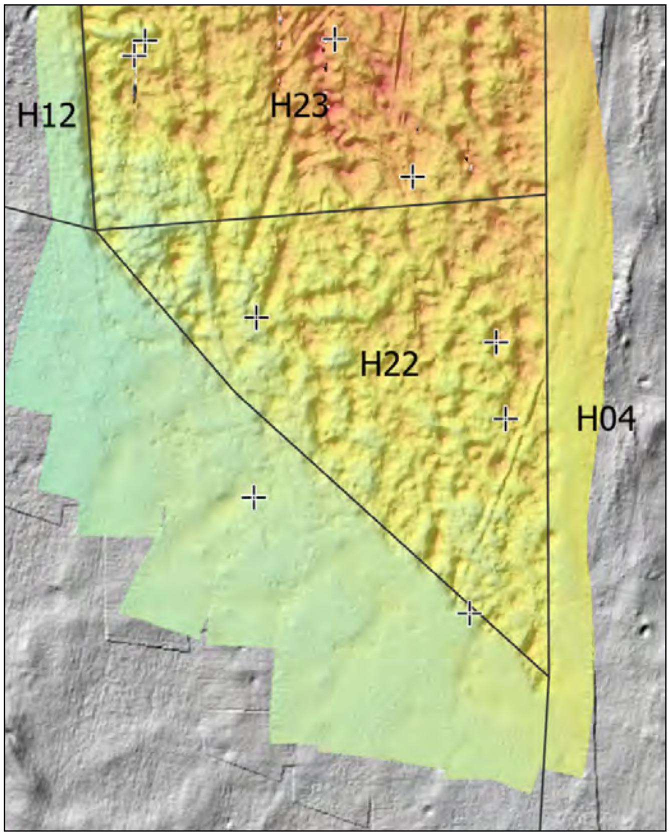

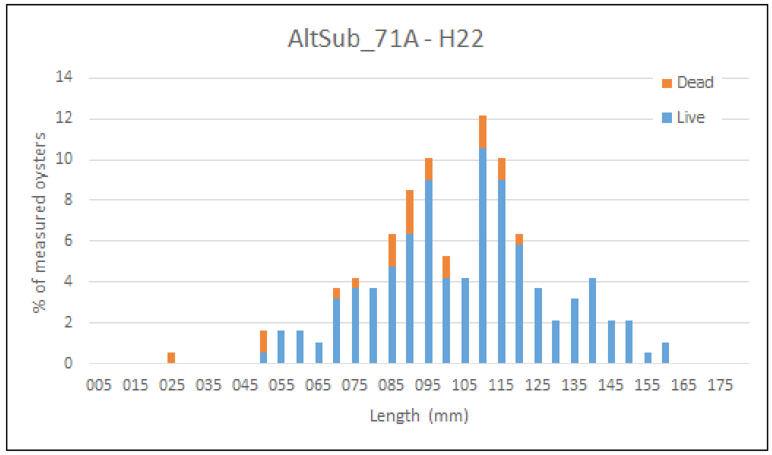

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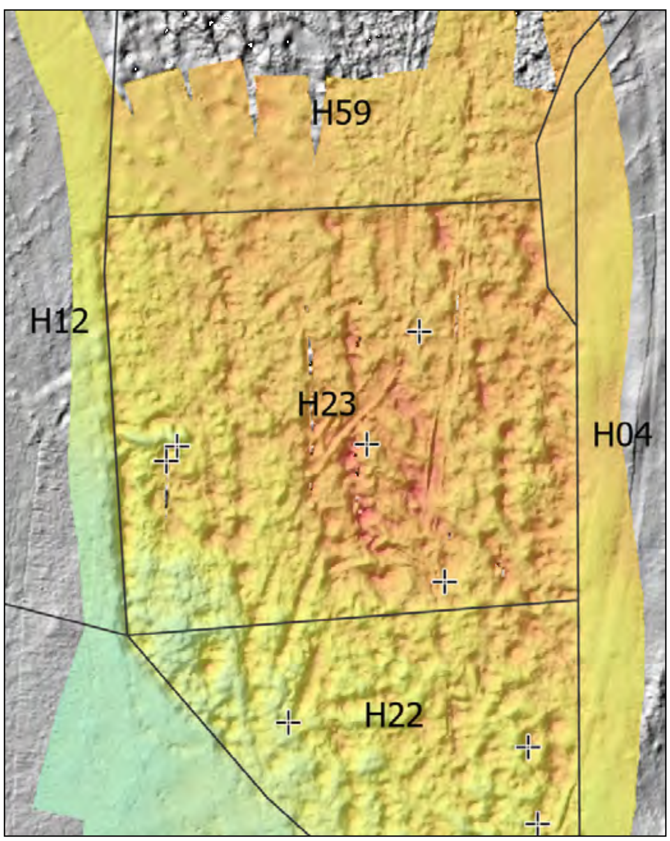
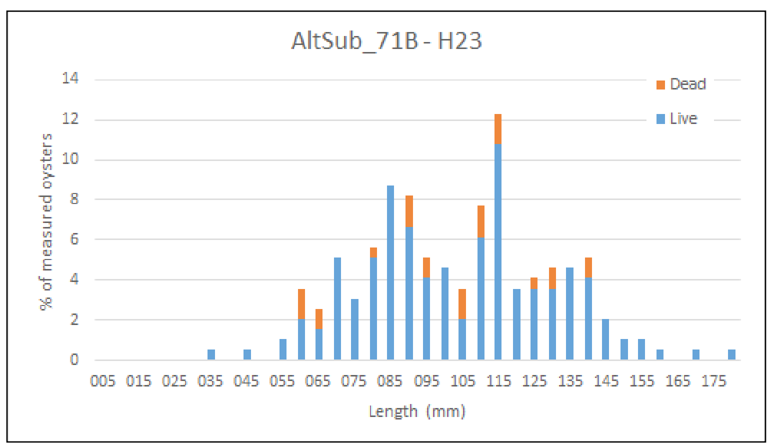
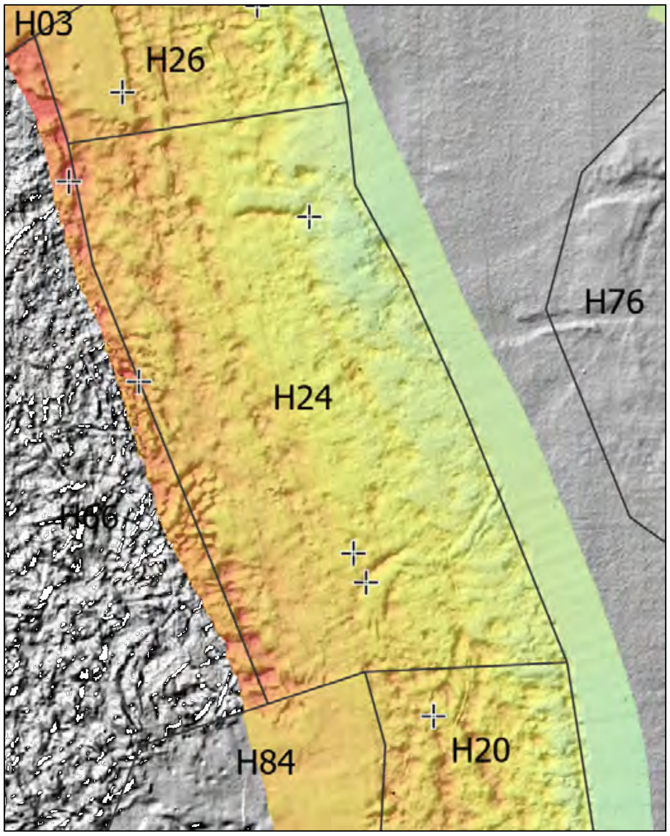
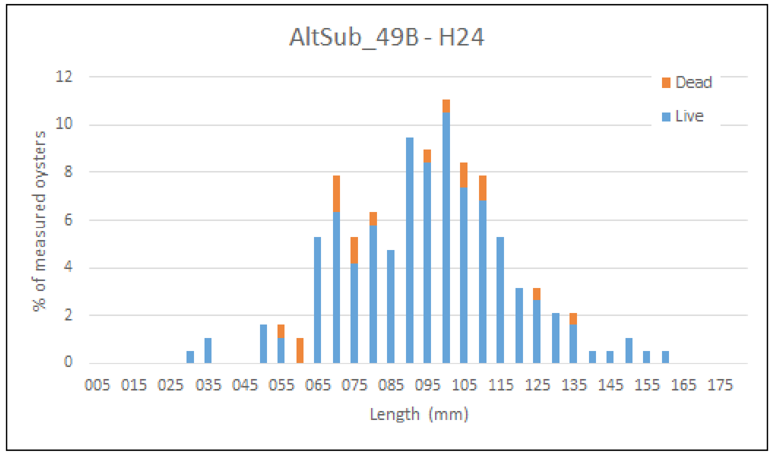


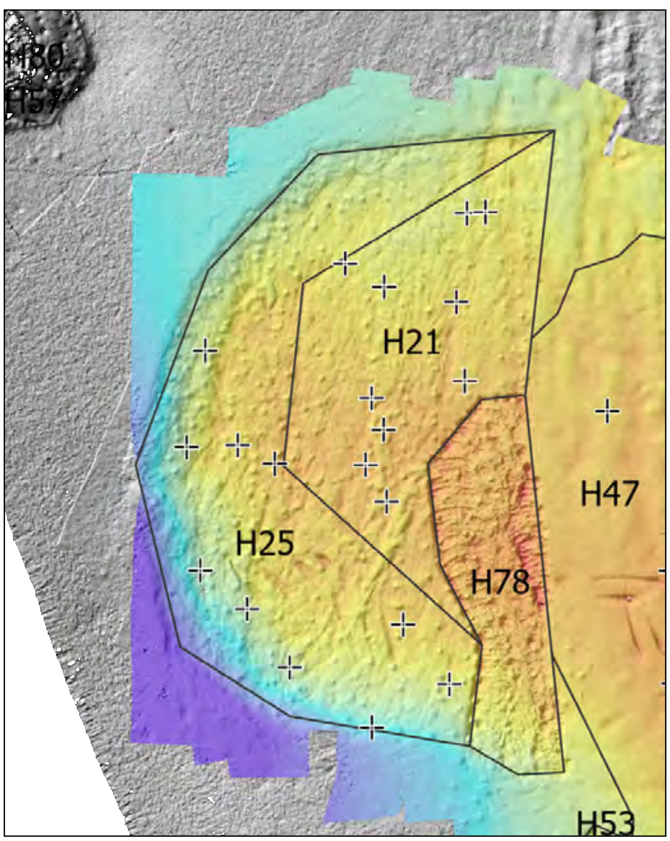


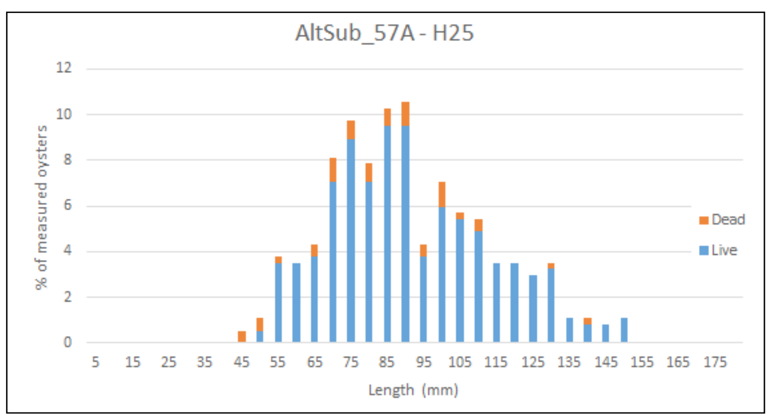
Reef H24



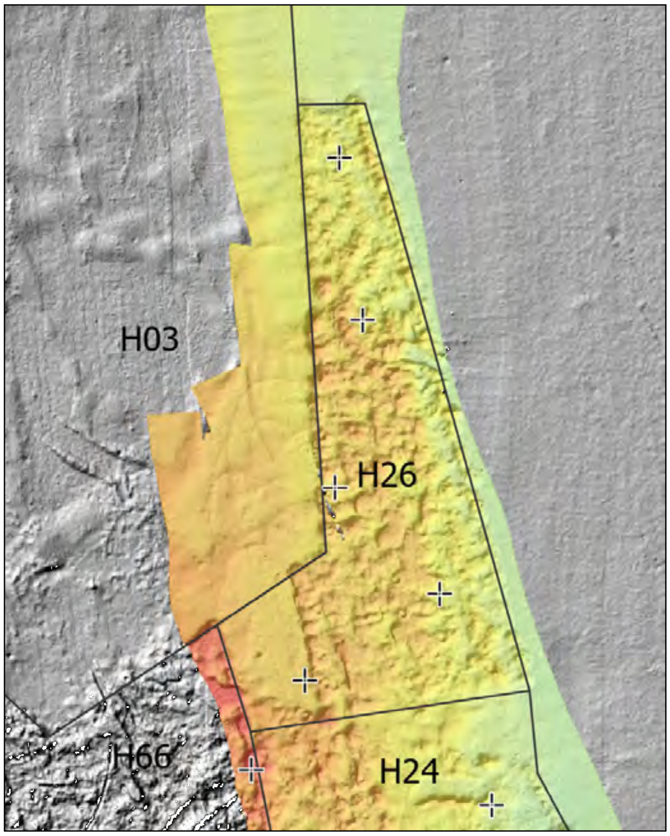


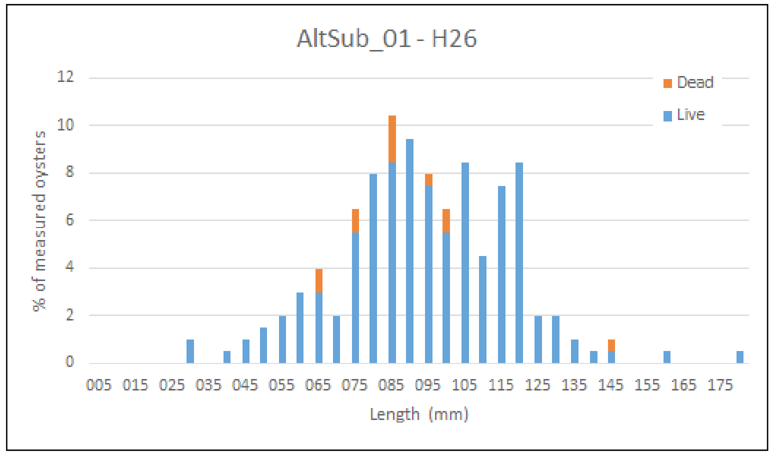
Reef H25



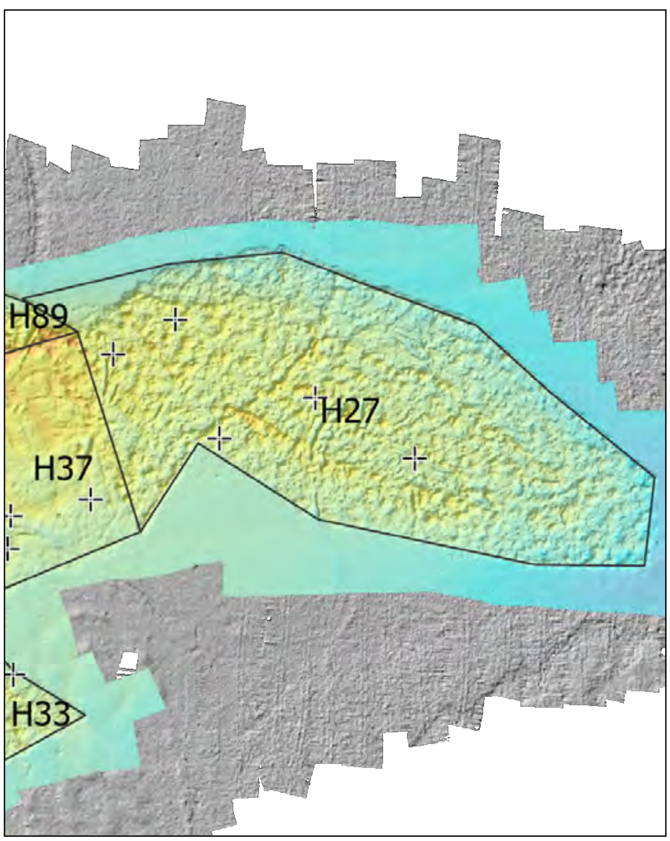


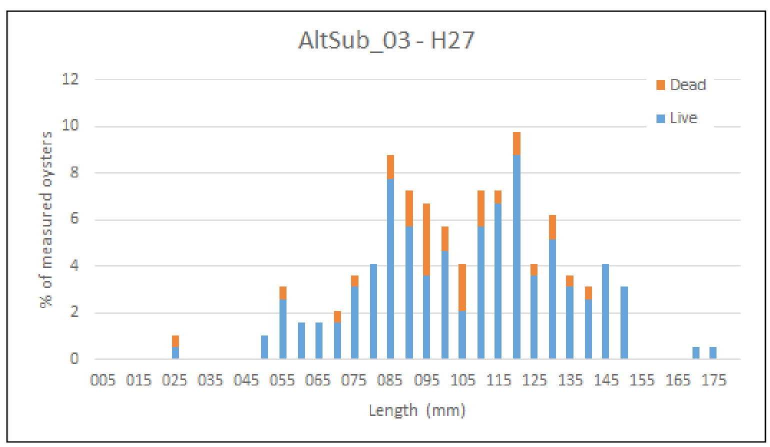
Reef H26





Reef H27





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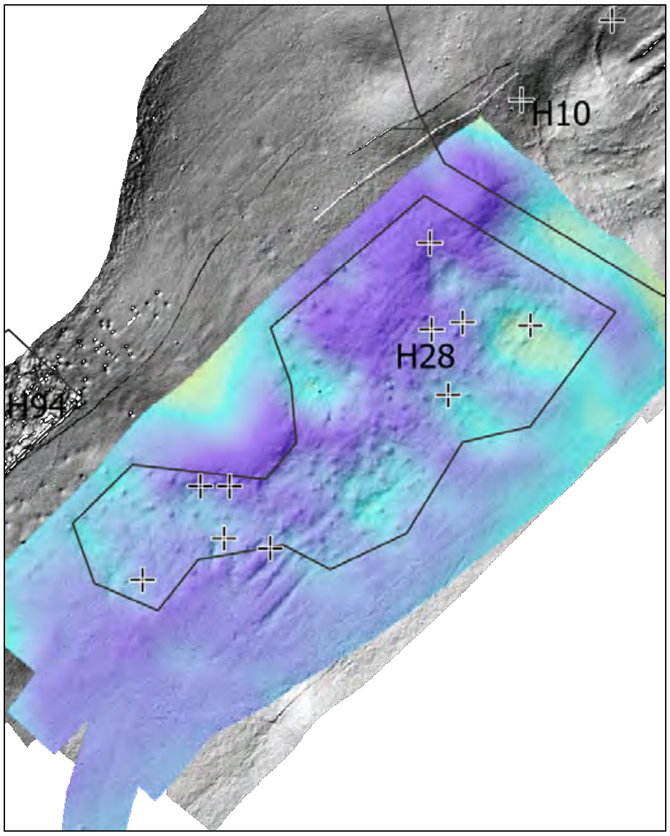

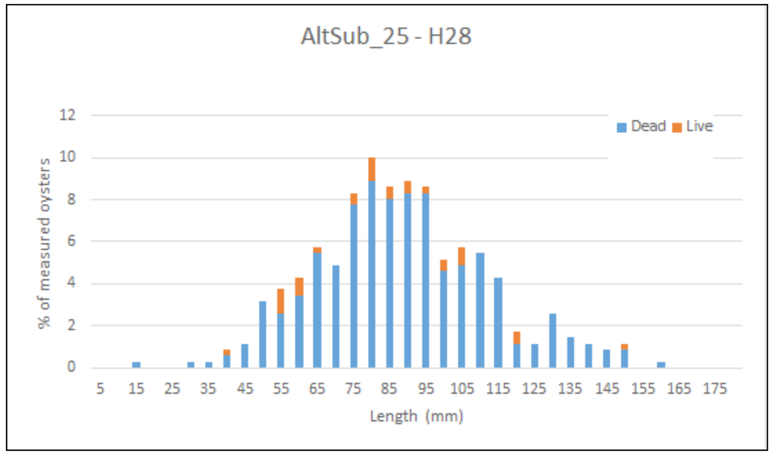

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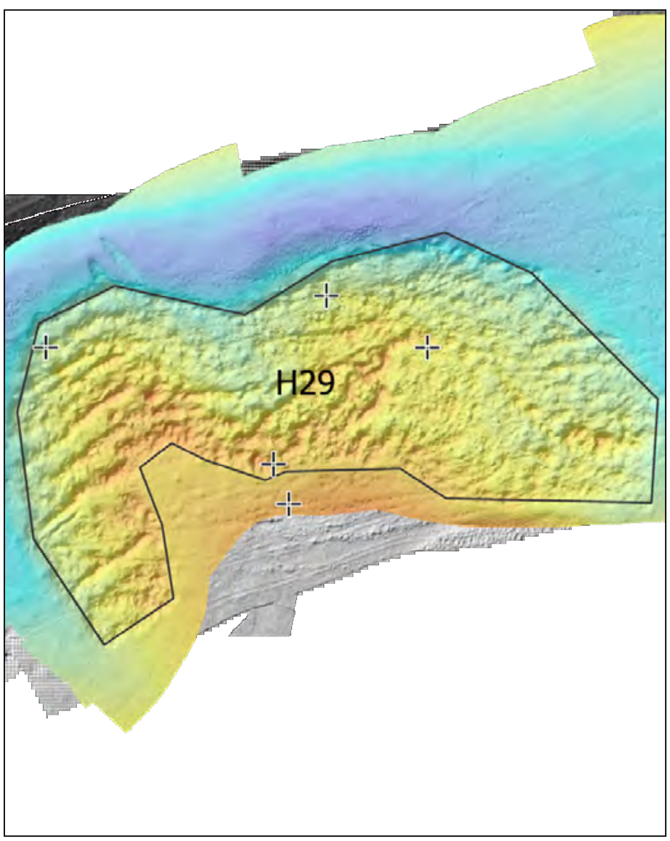

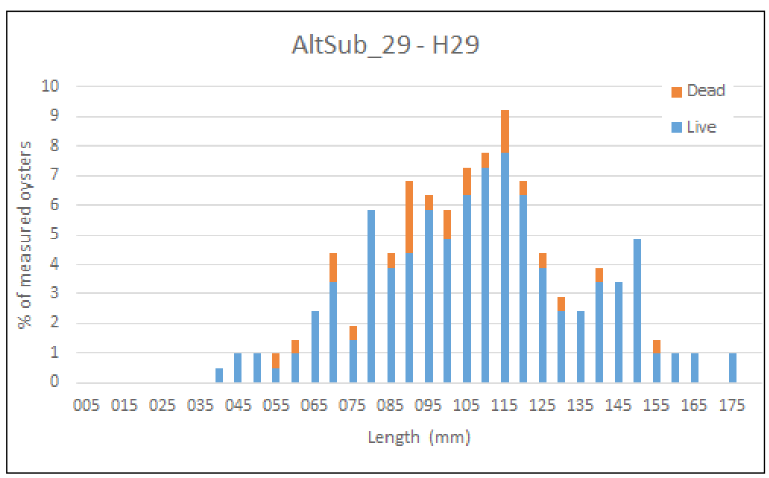

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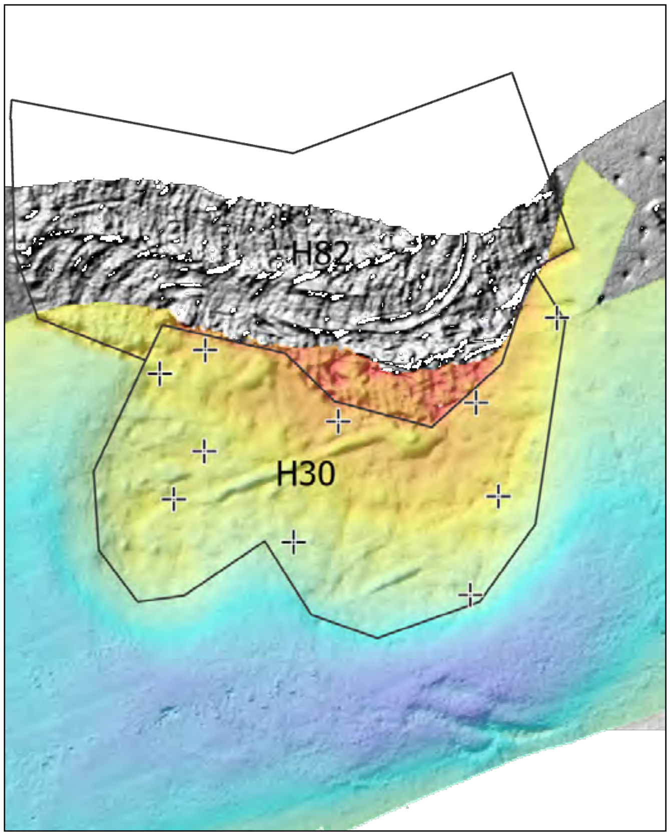

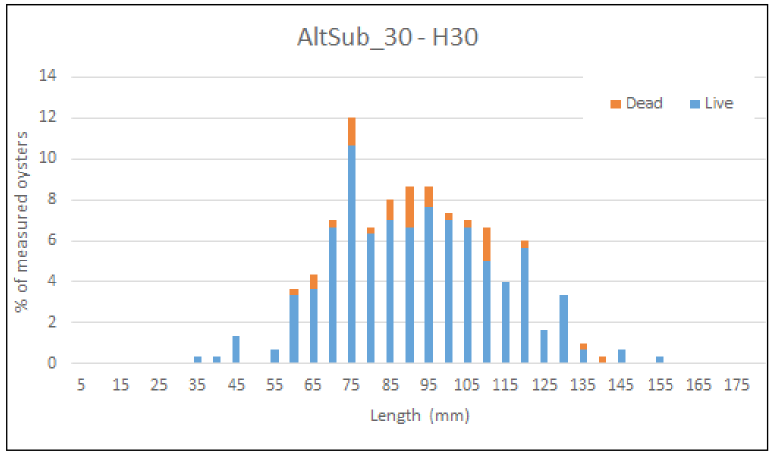

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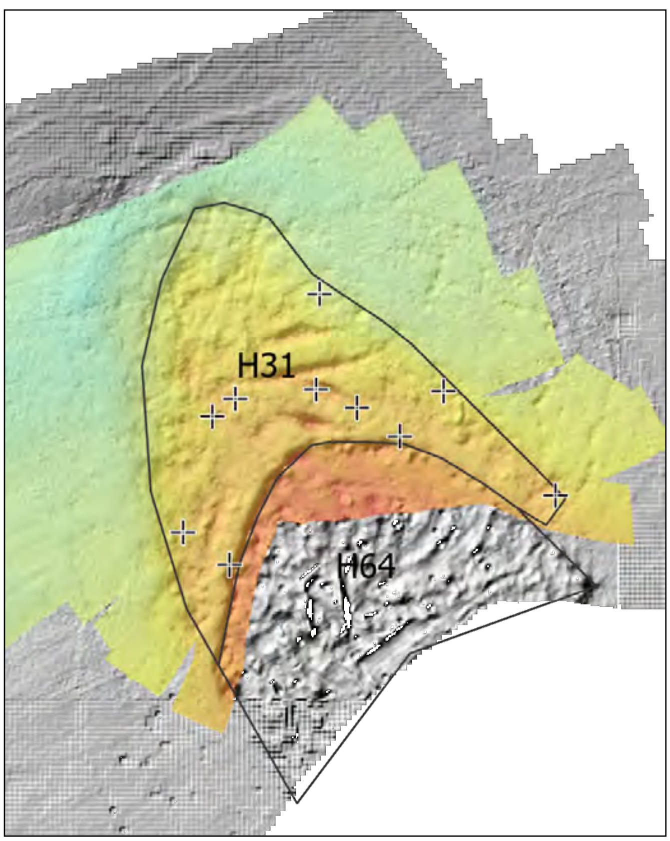

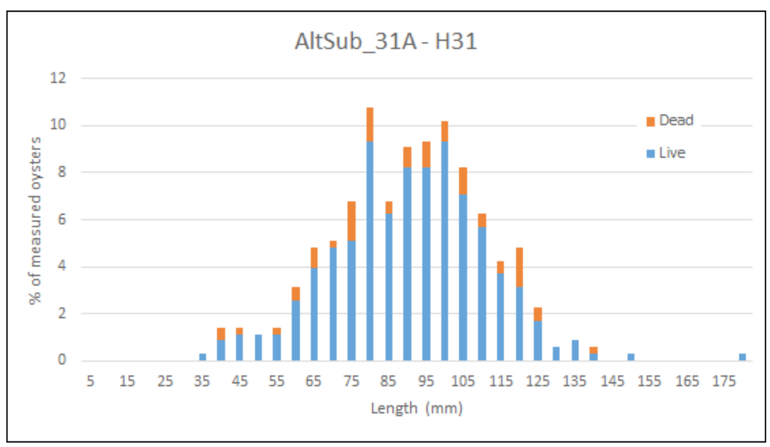

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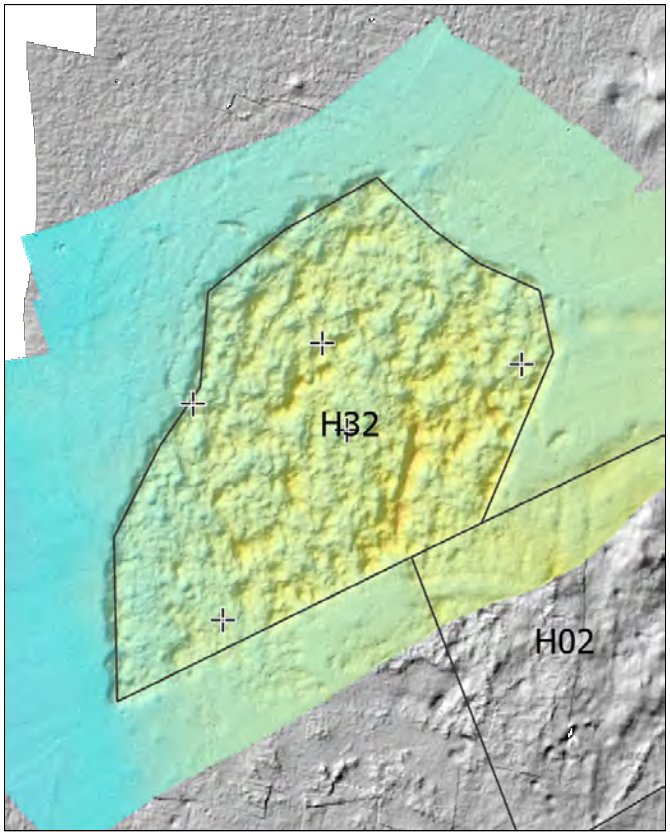

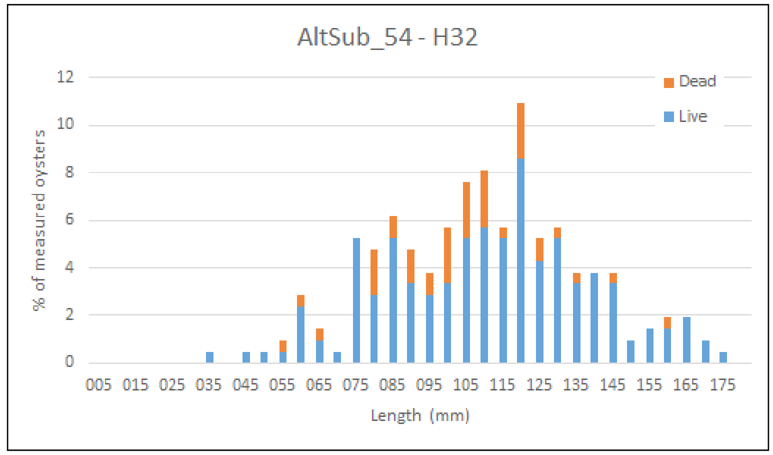

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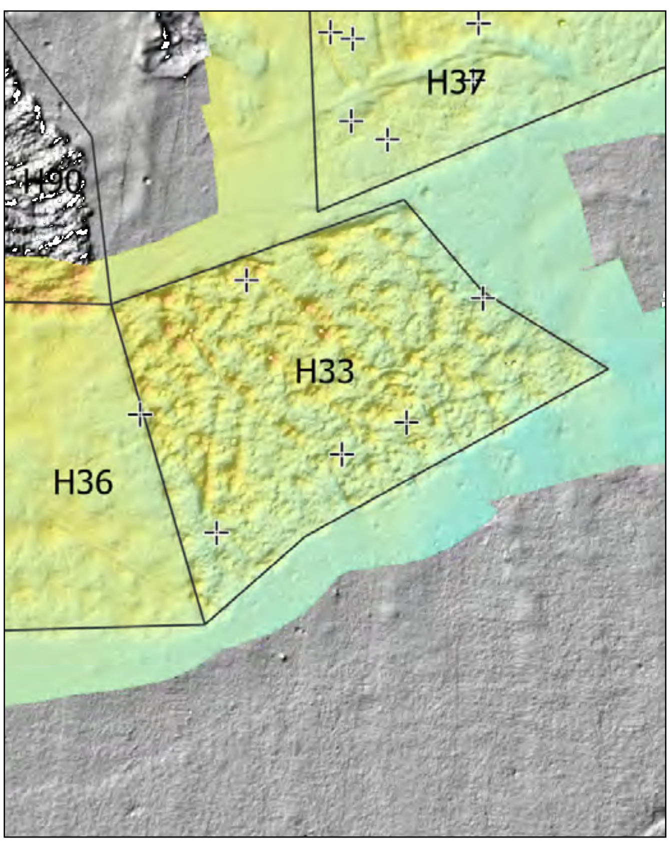

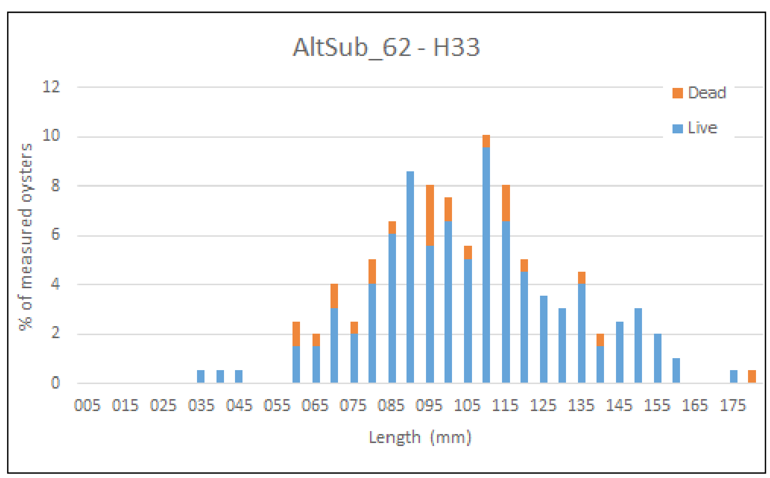

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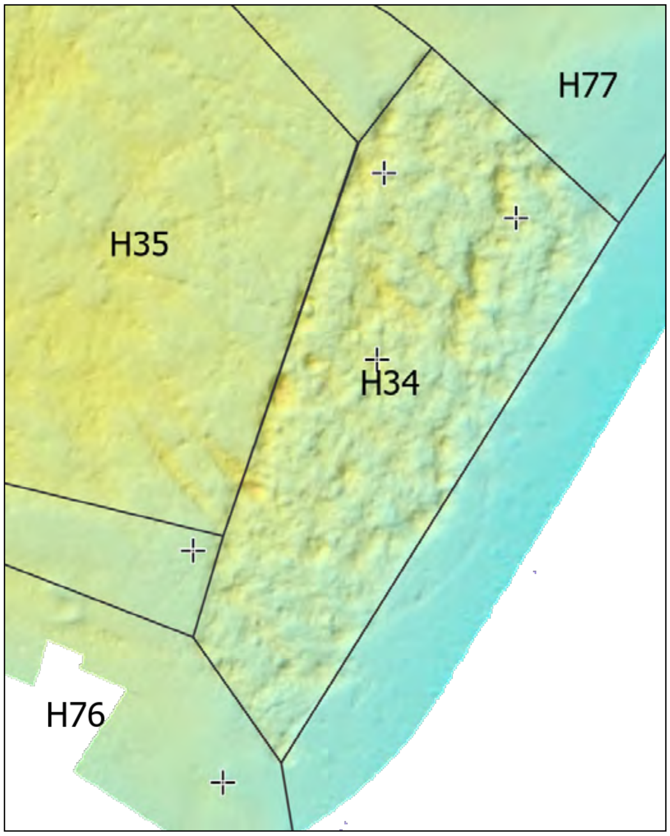

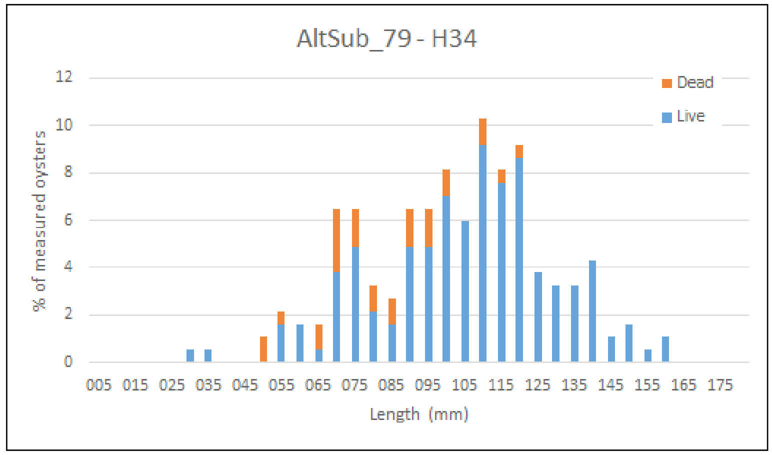

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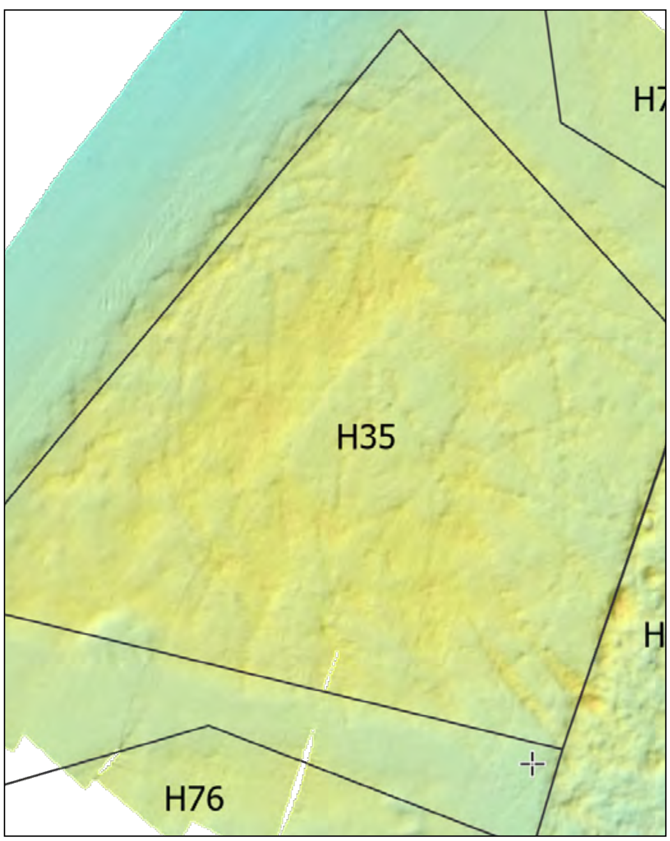

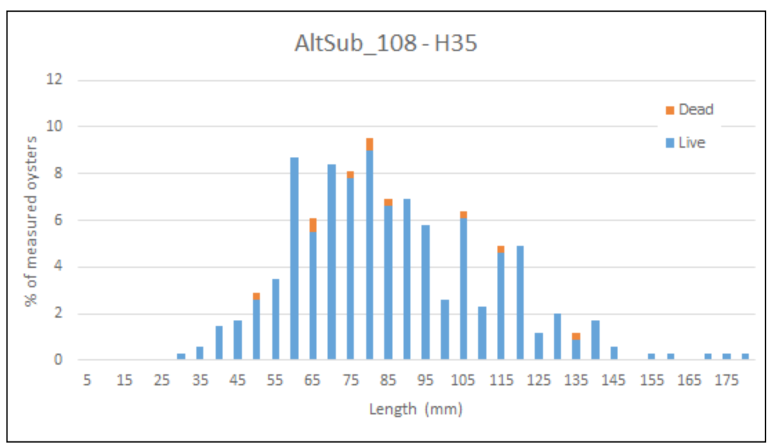

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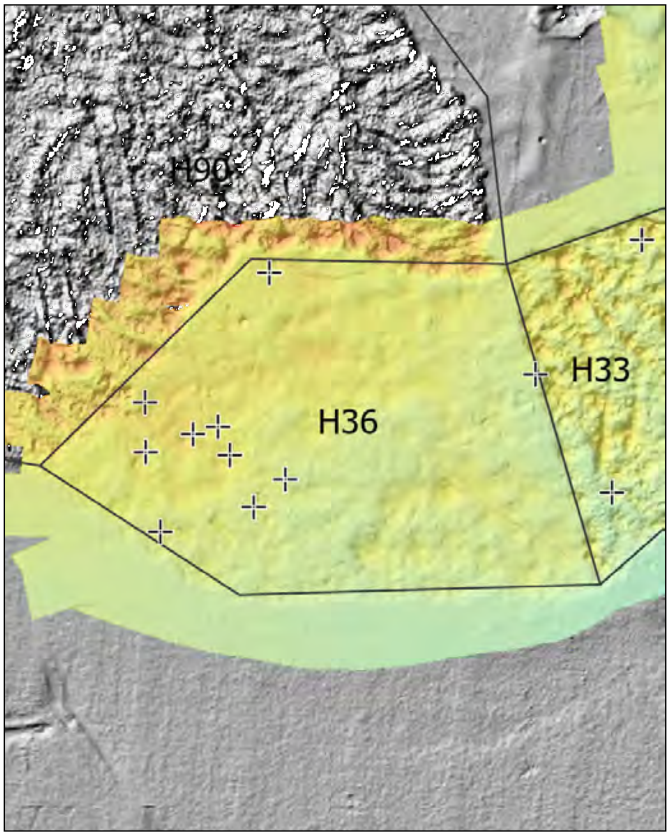

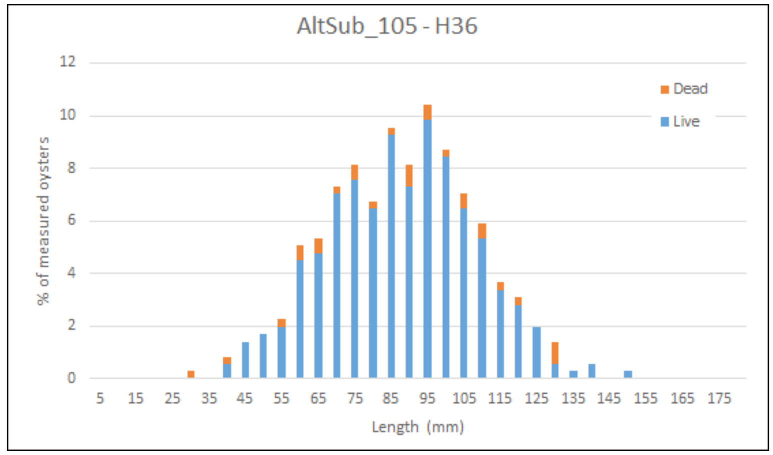

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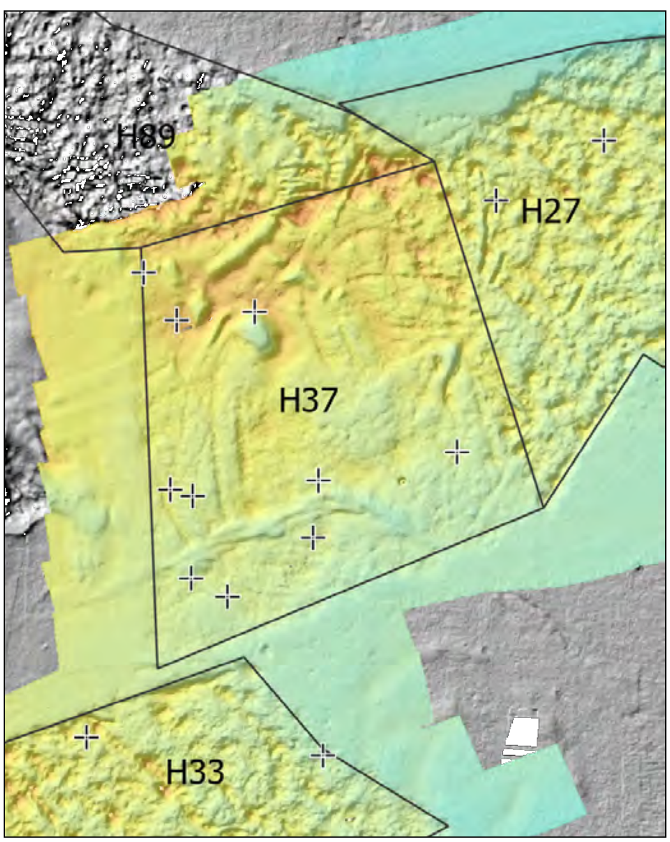

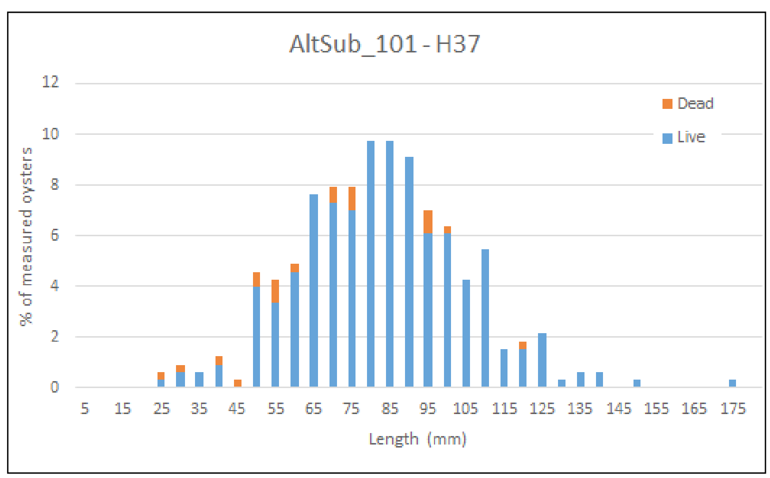

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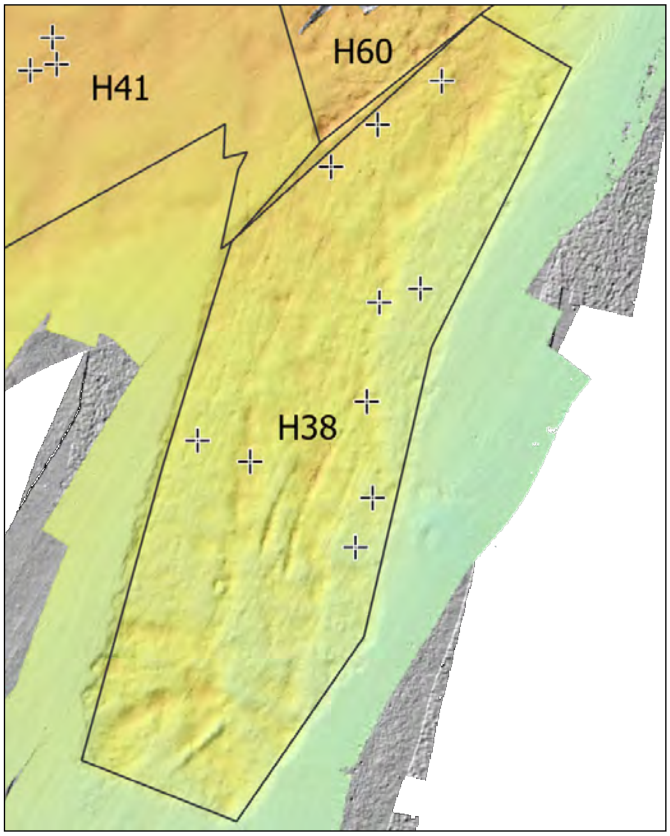

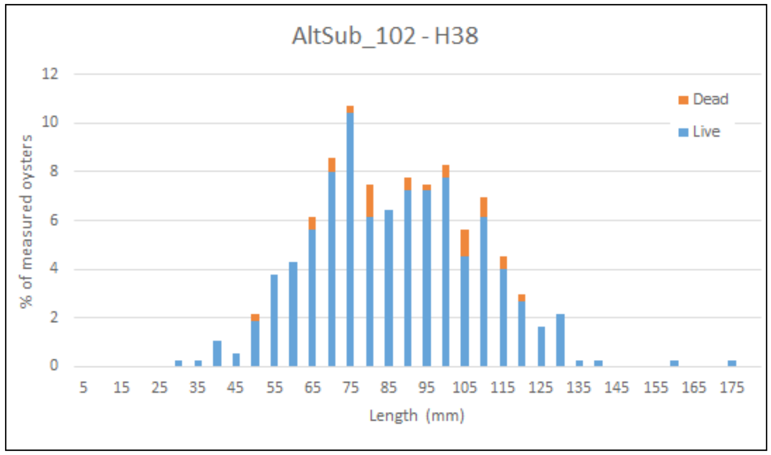

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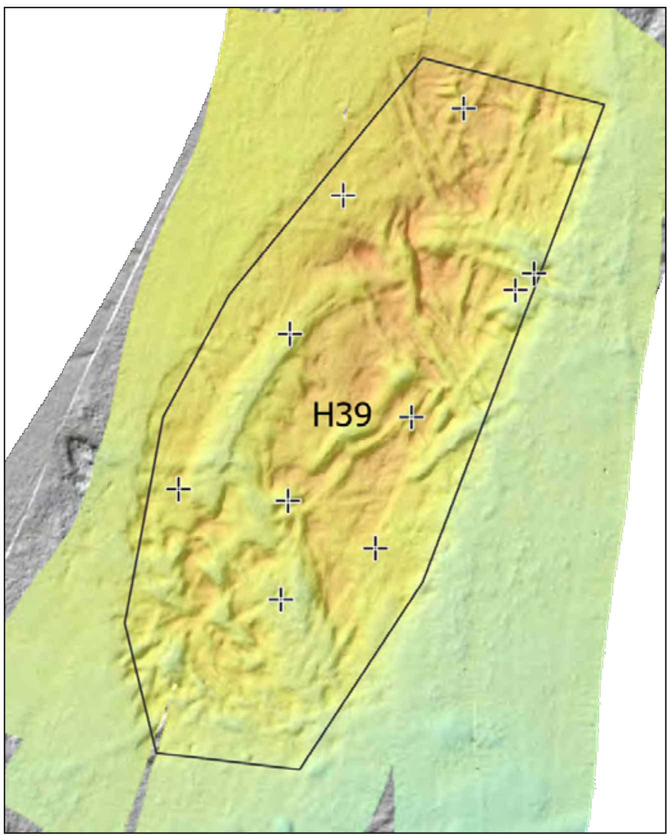

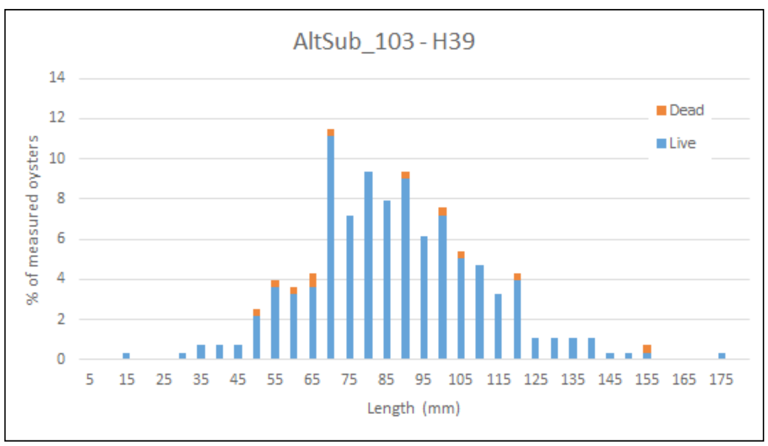

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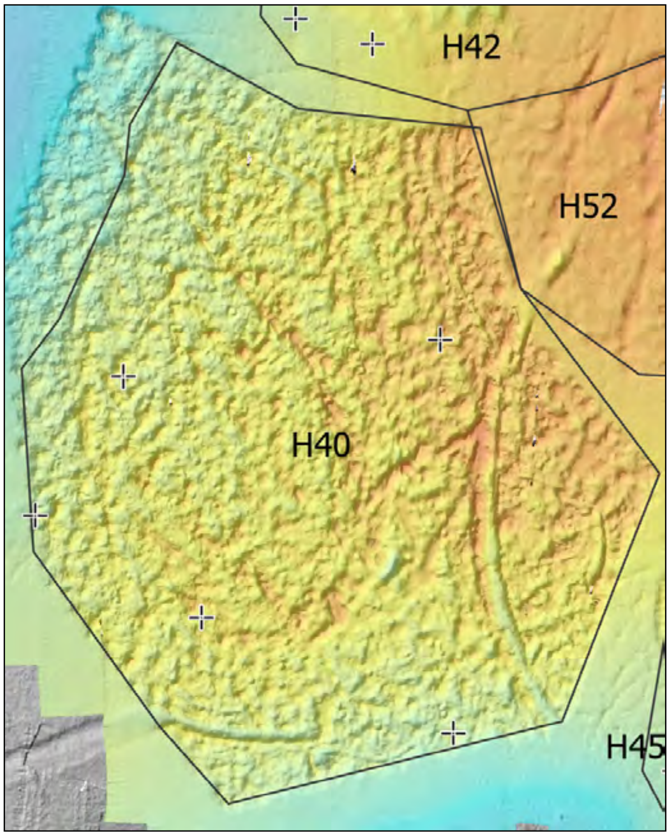

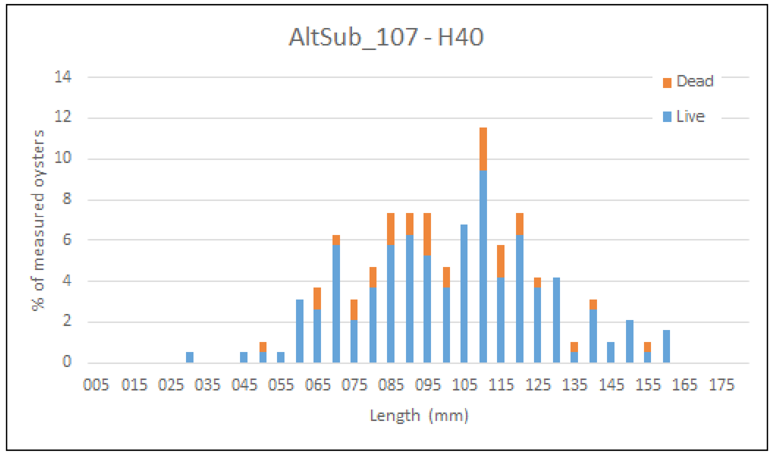

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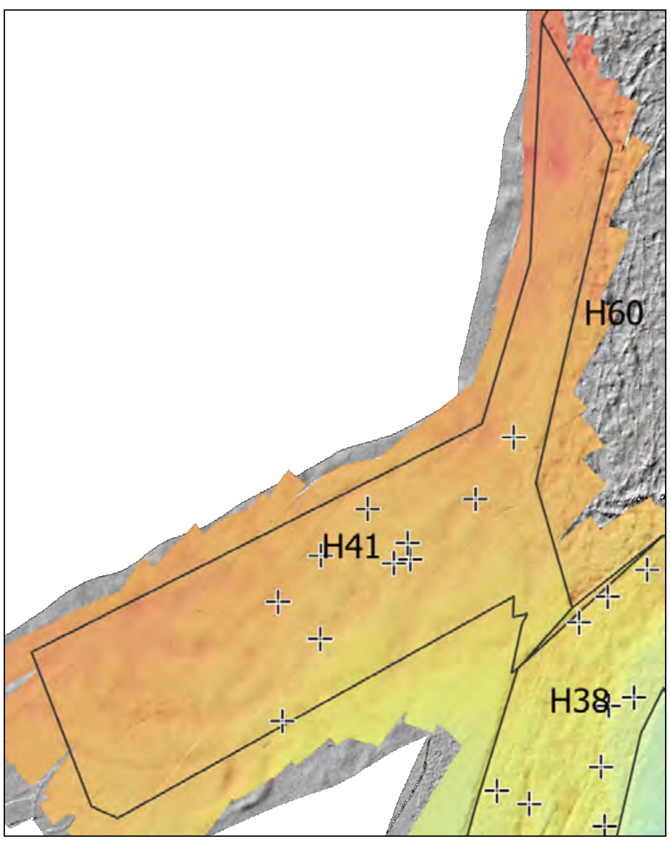

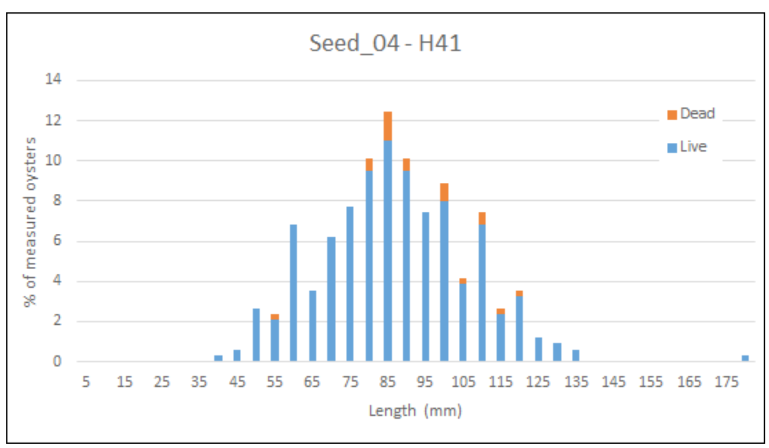

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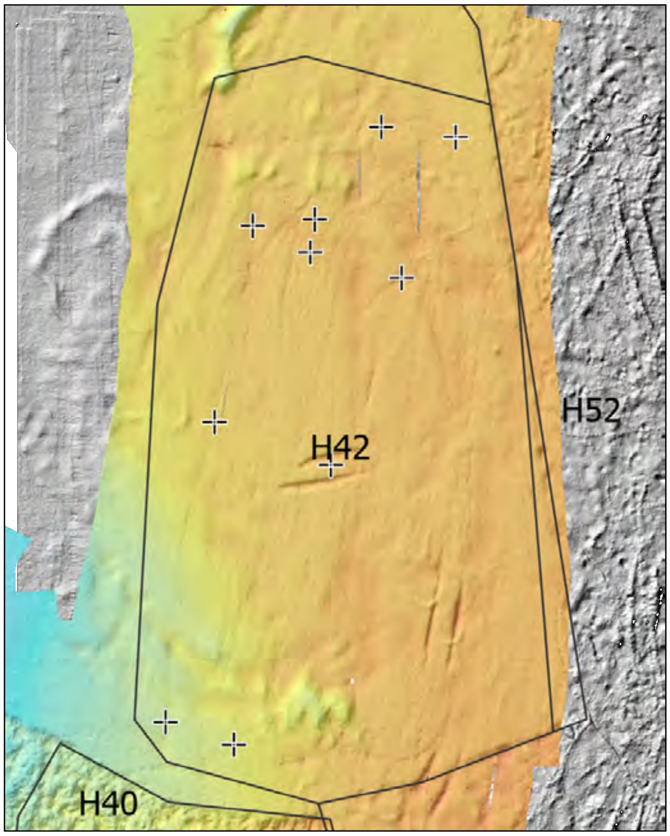

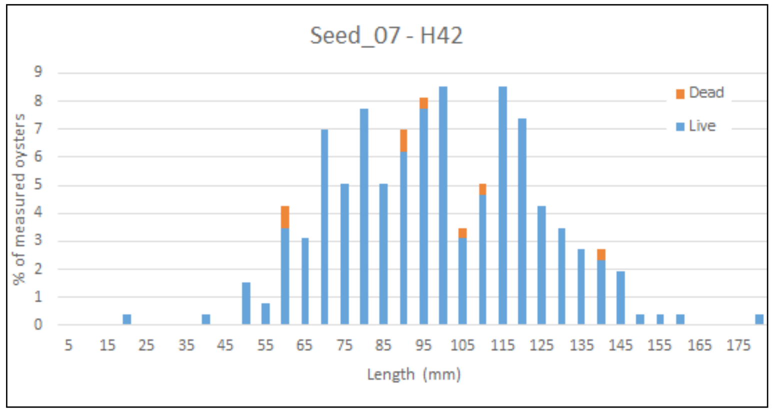

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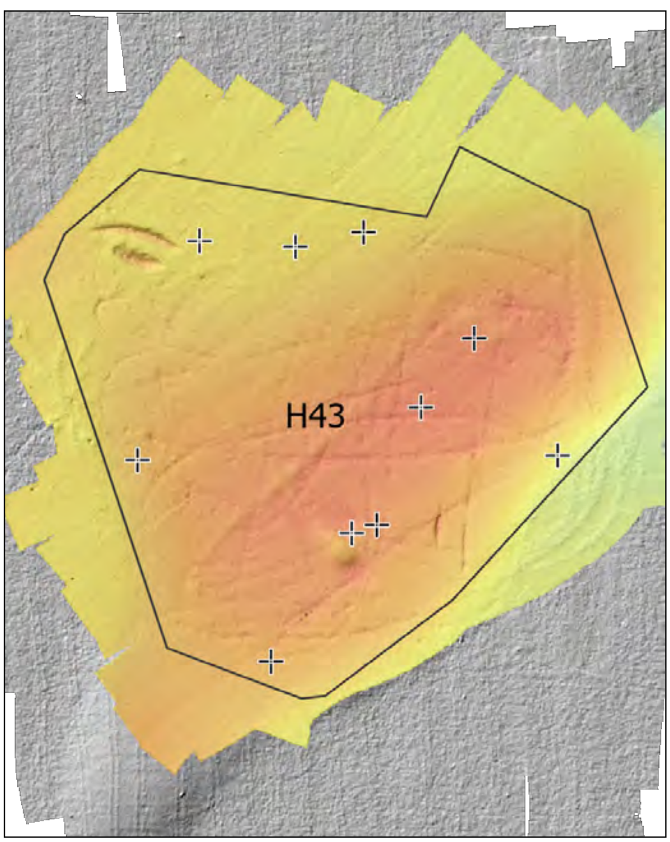

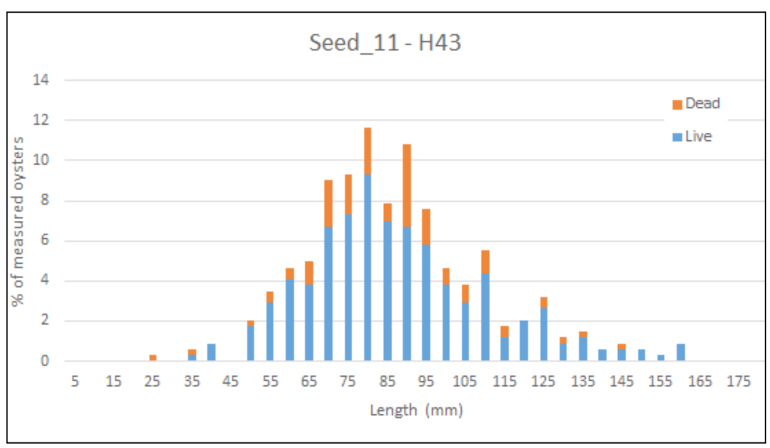

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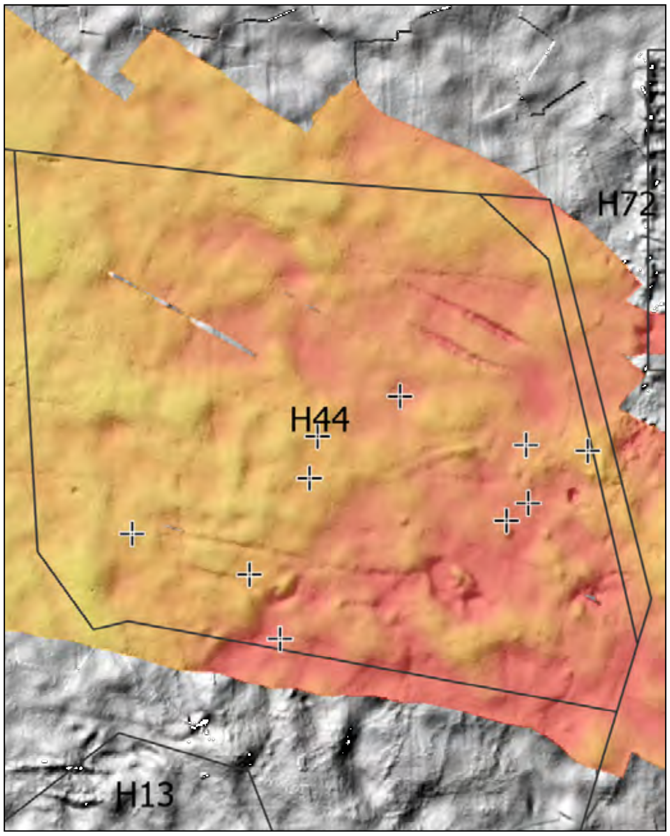

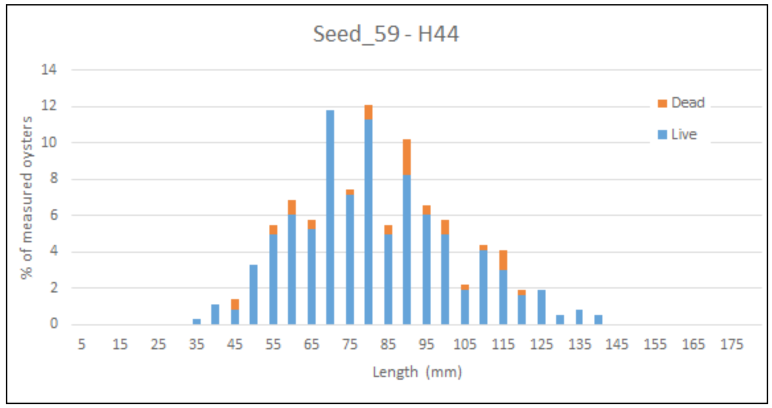

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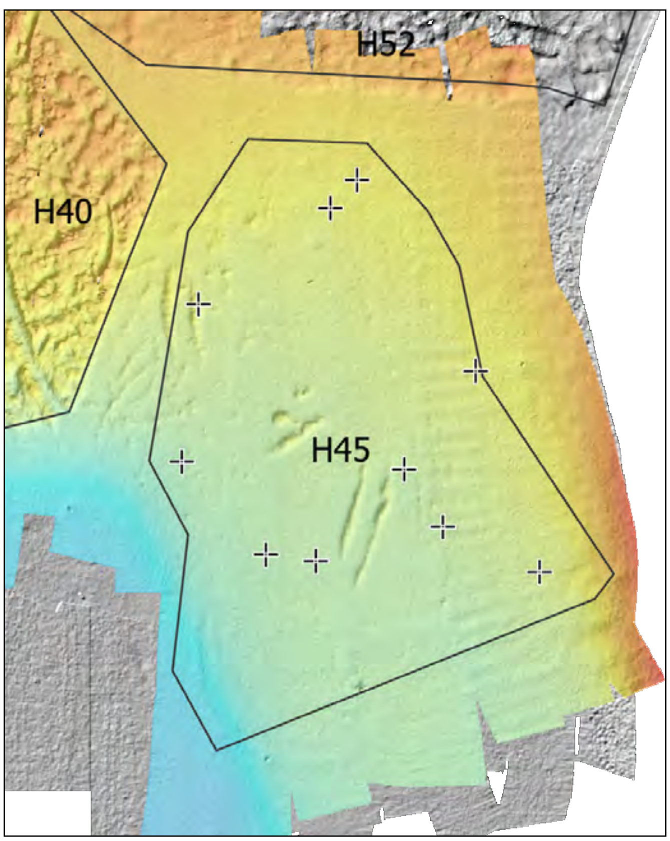

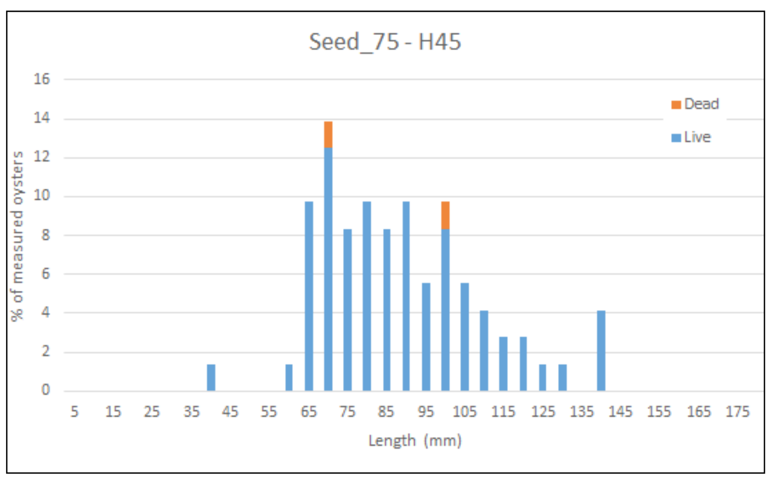

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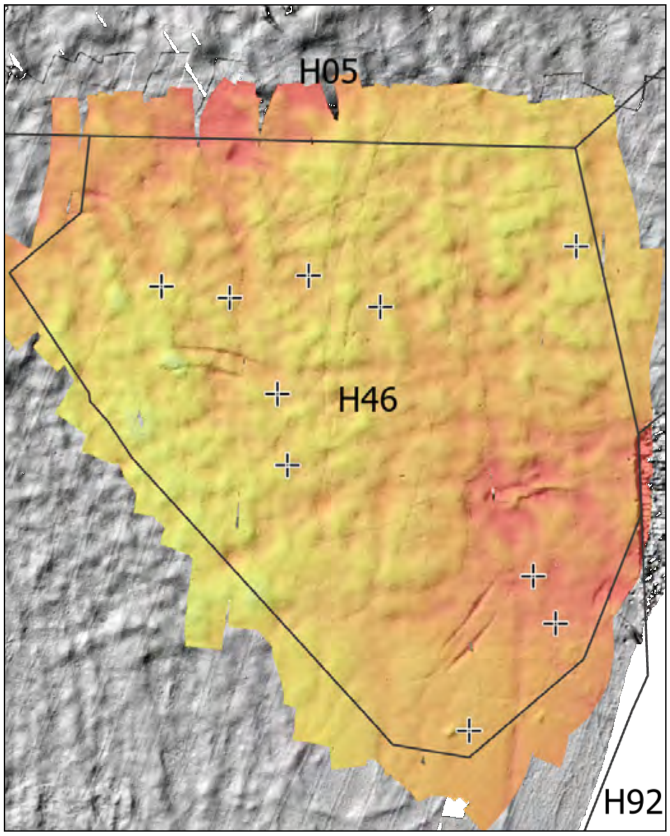

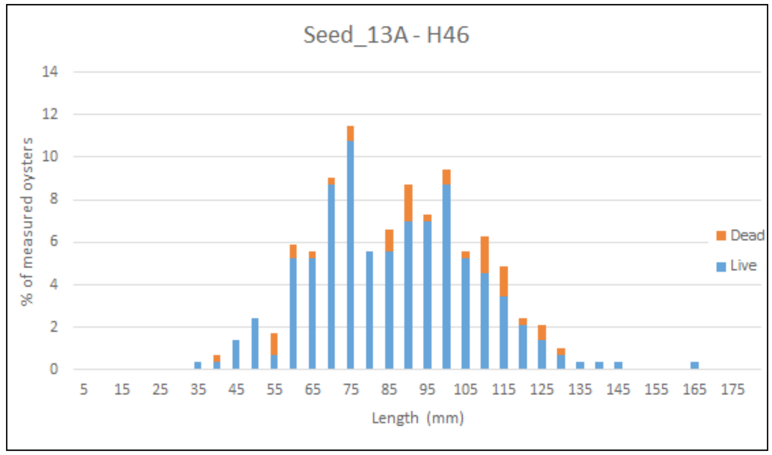

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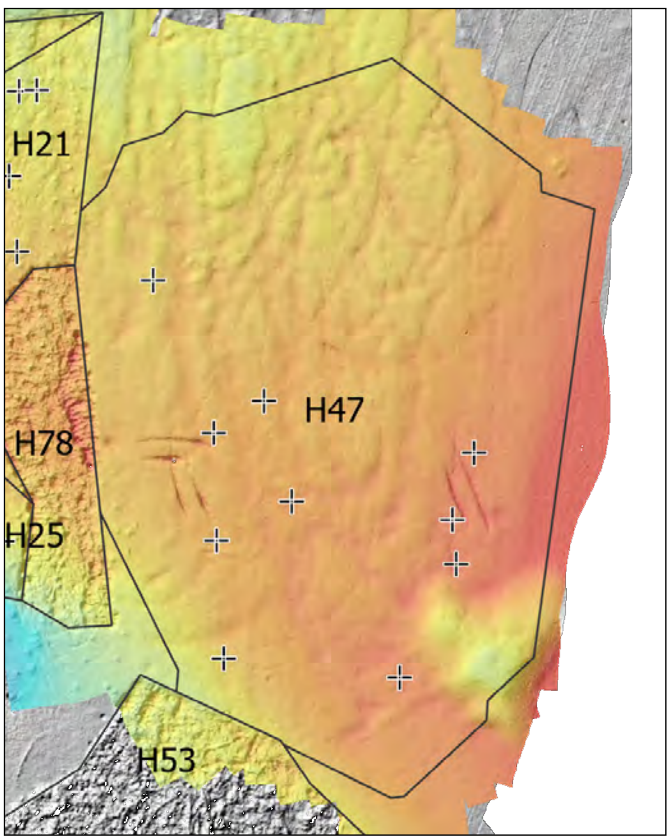

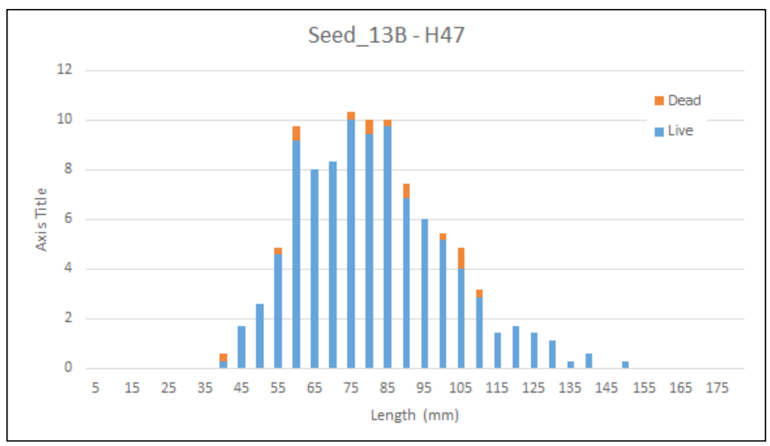

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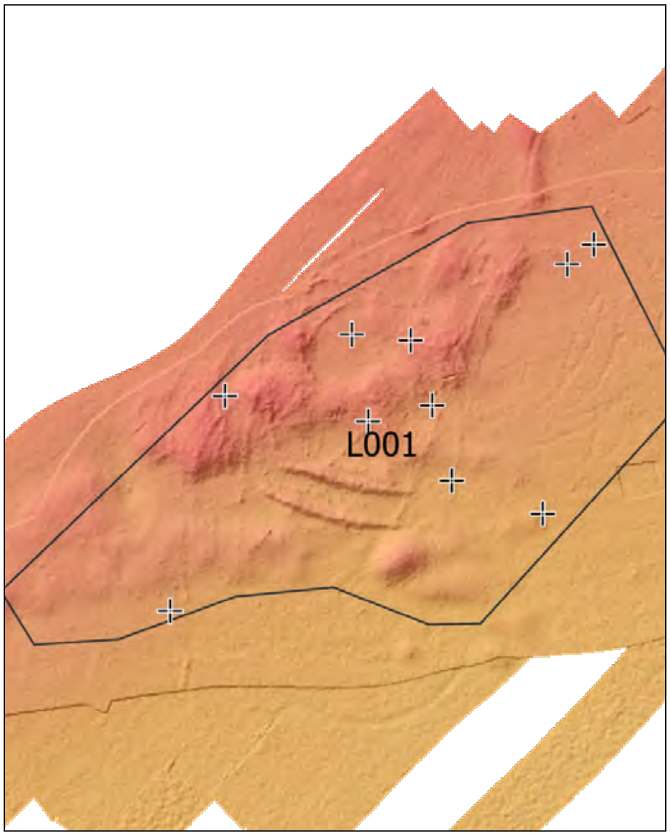

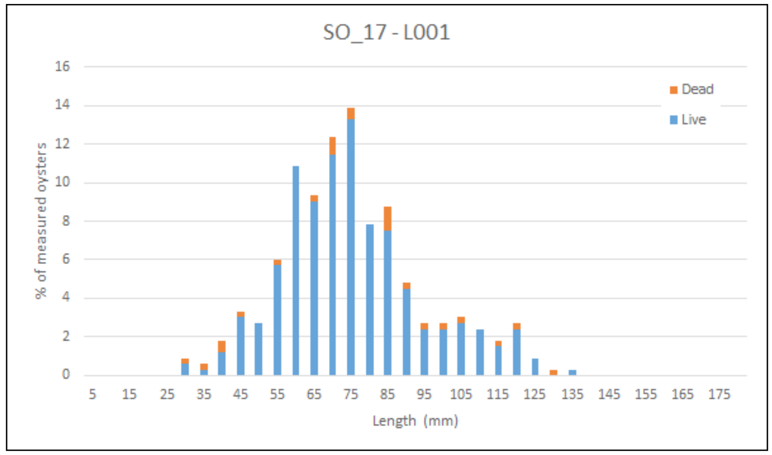

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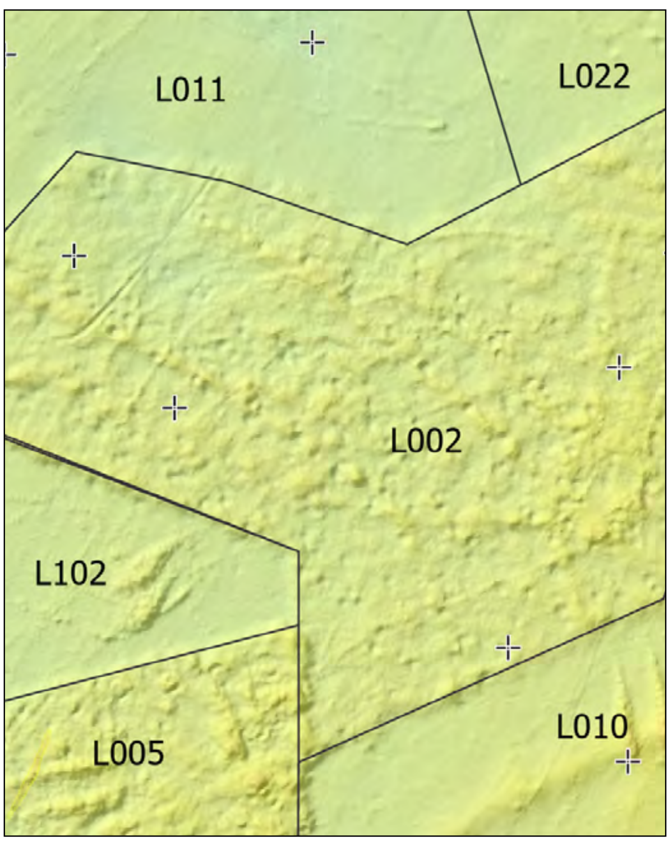

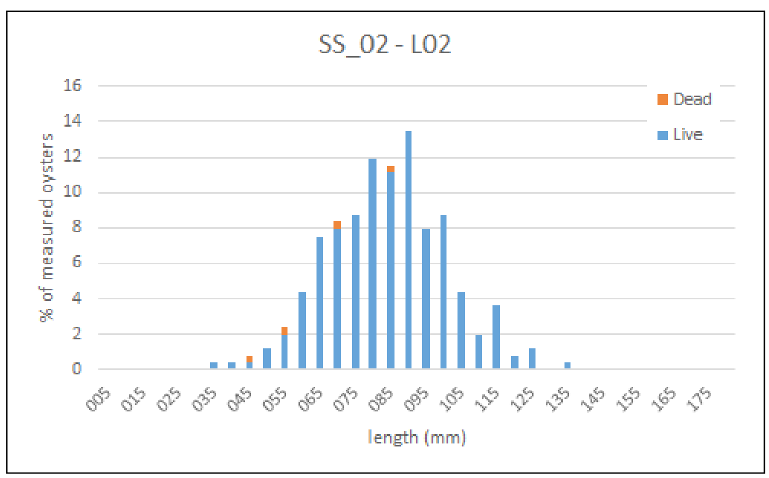

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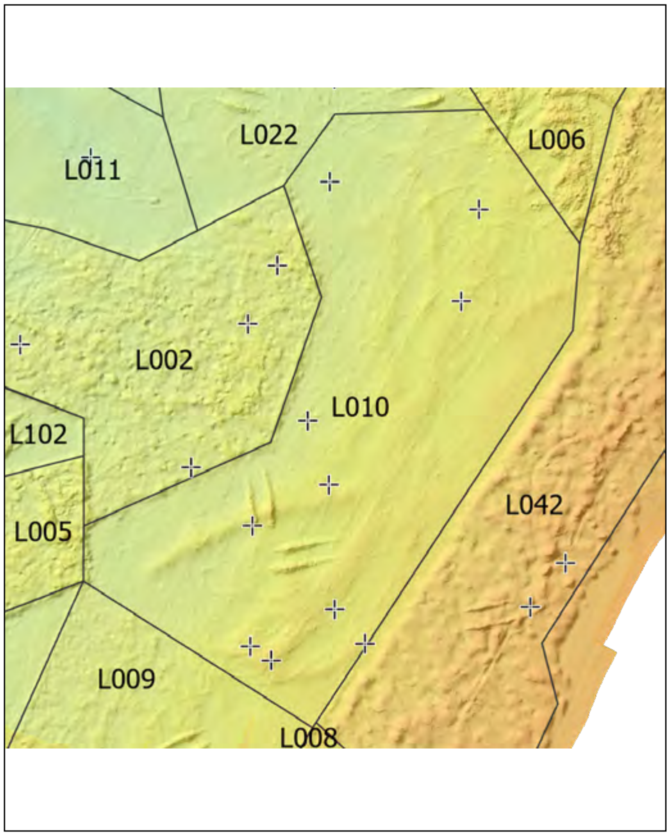

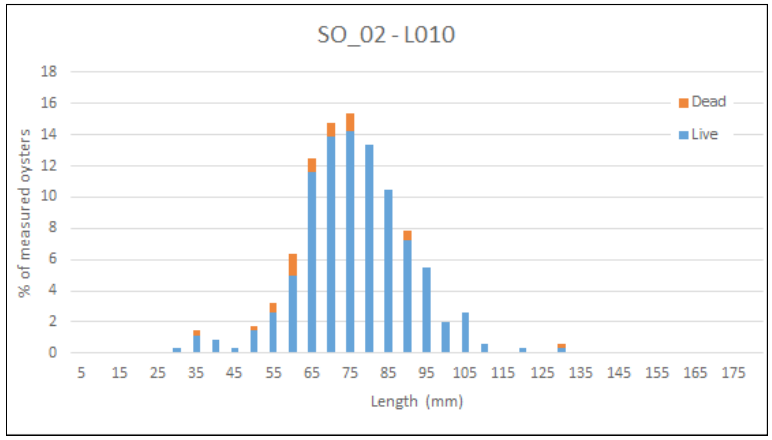

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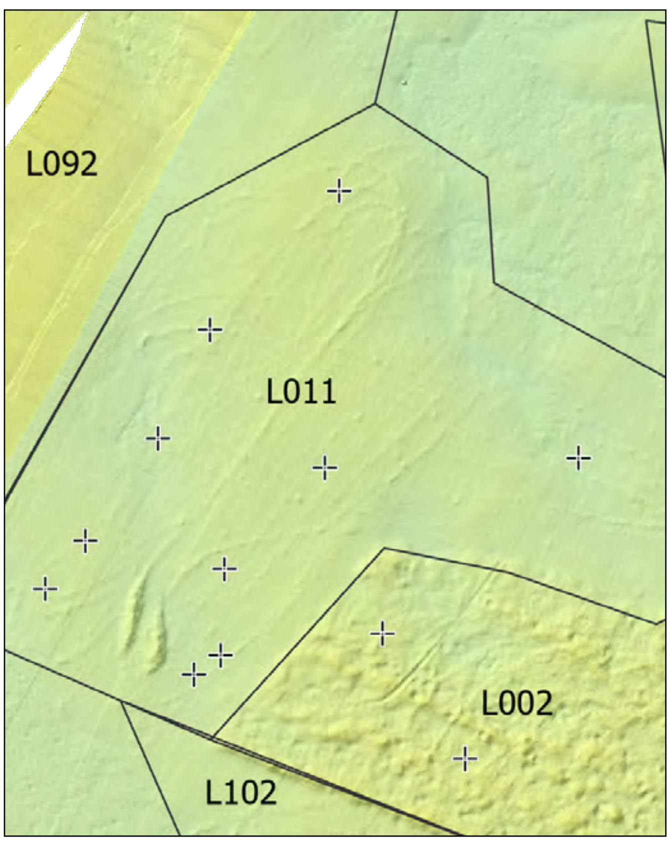

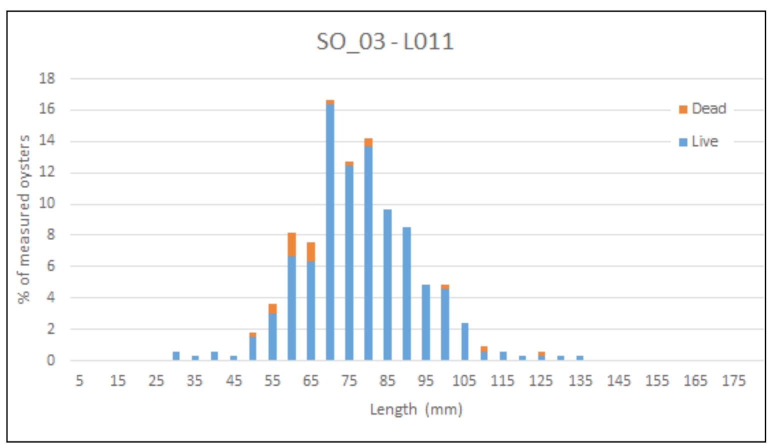

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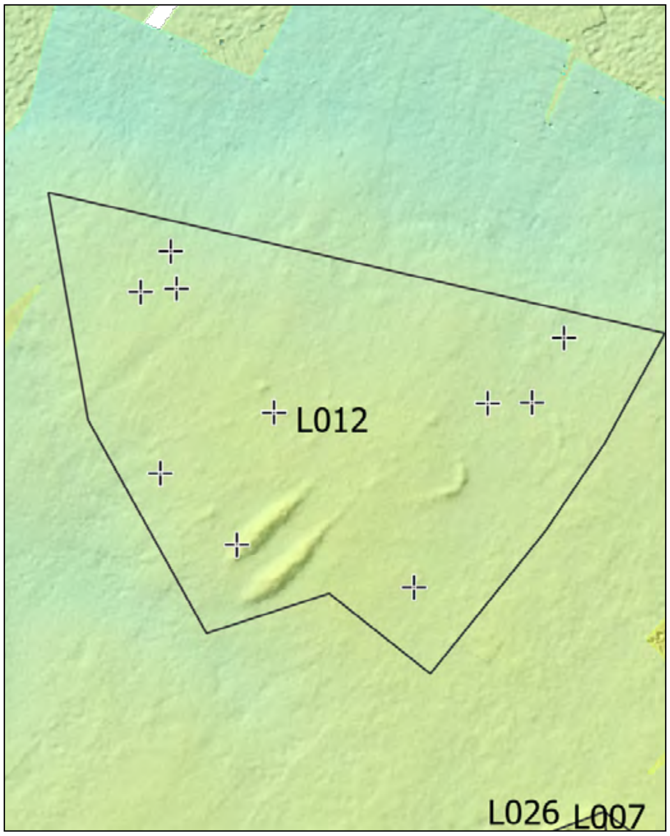

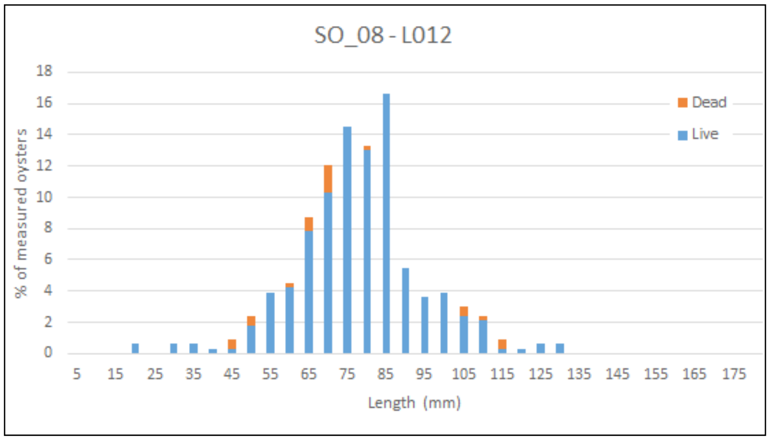

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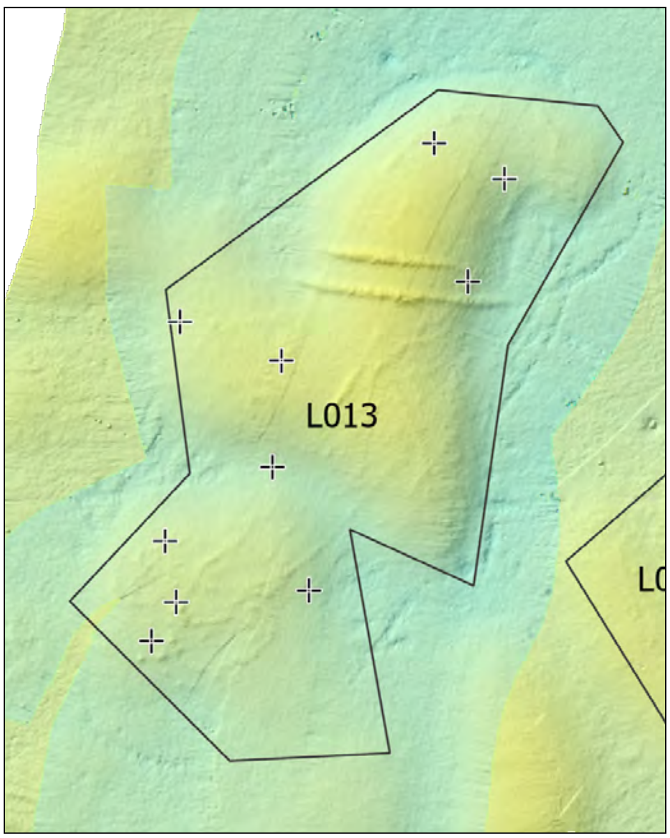

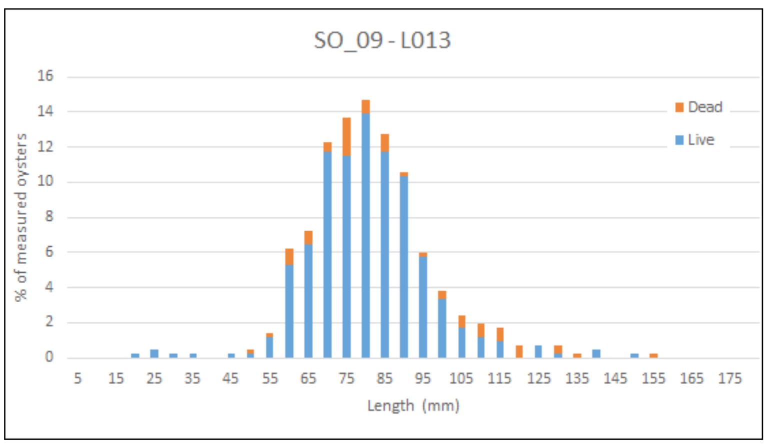

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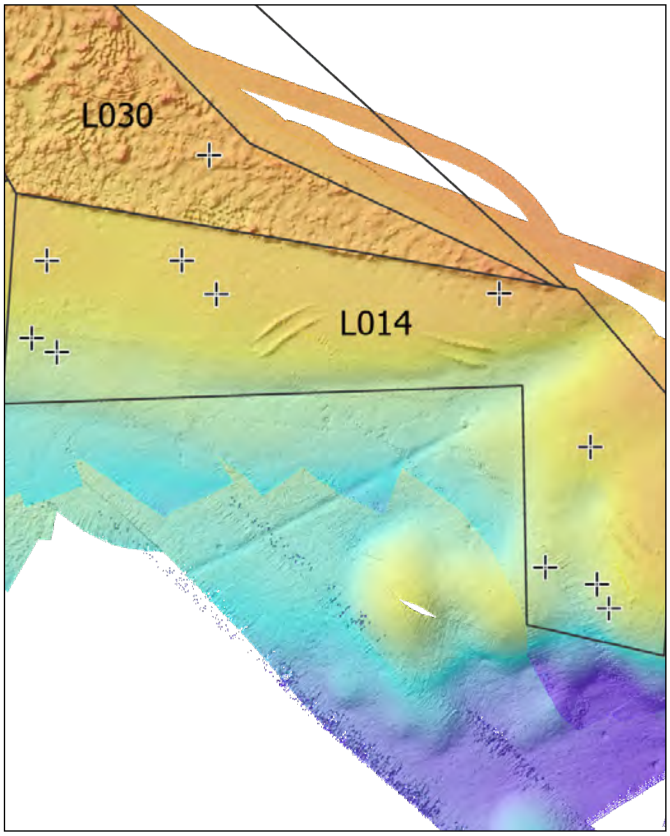

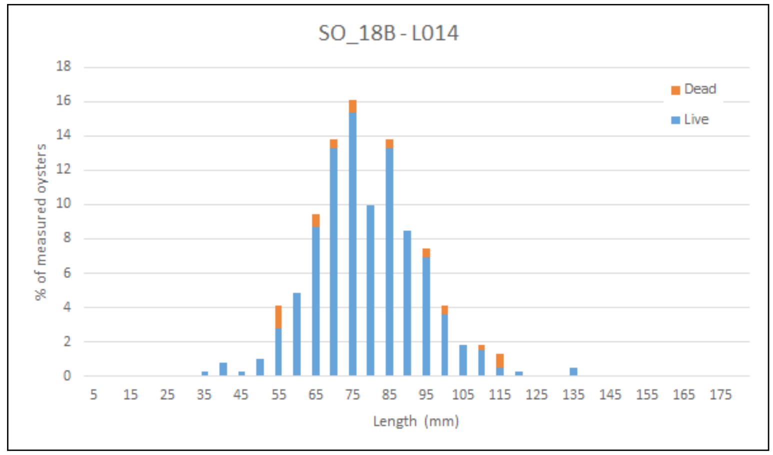

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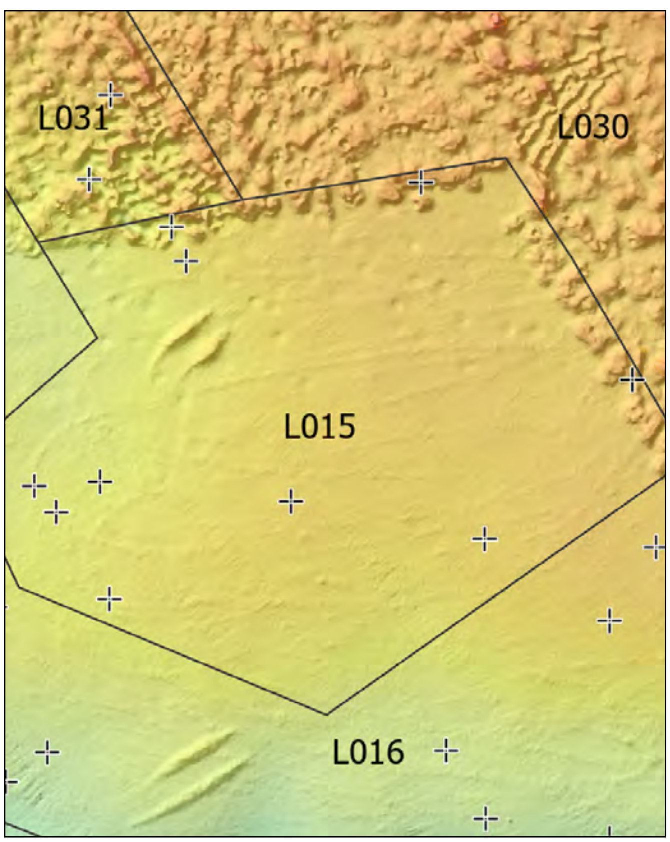

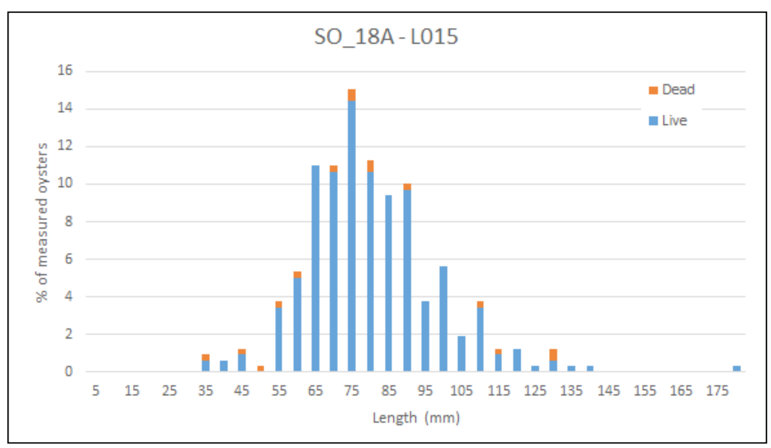

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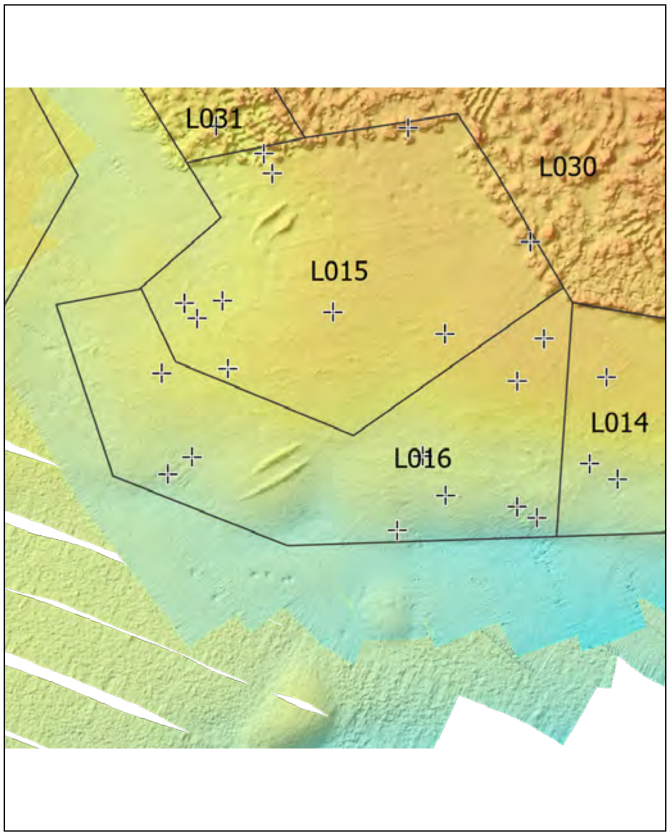

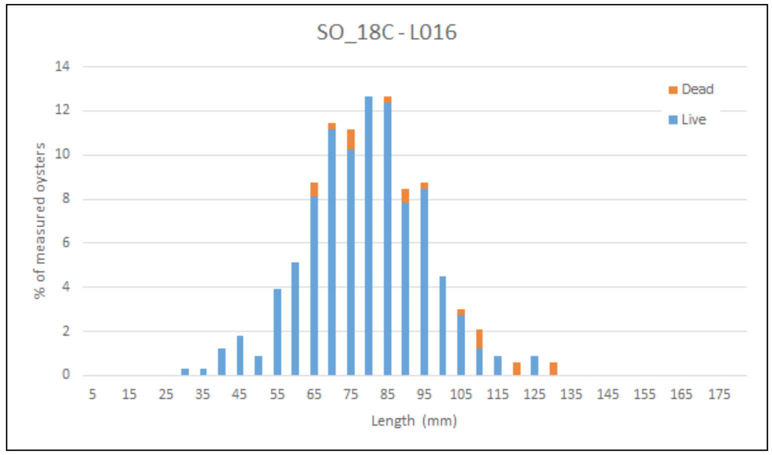

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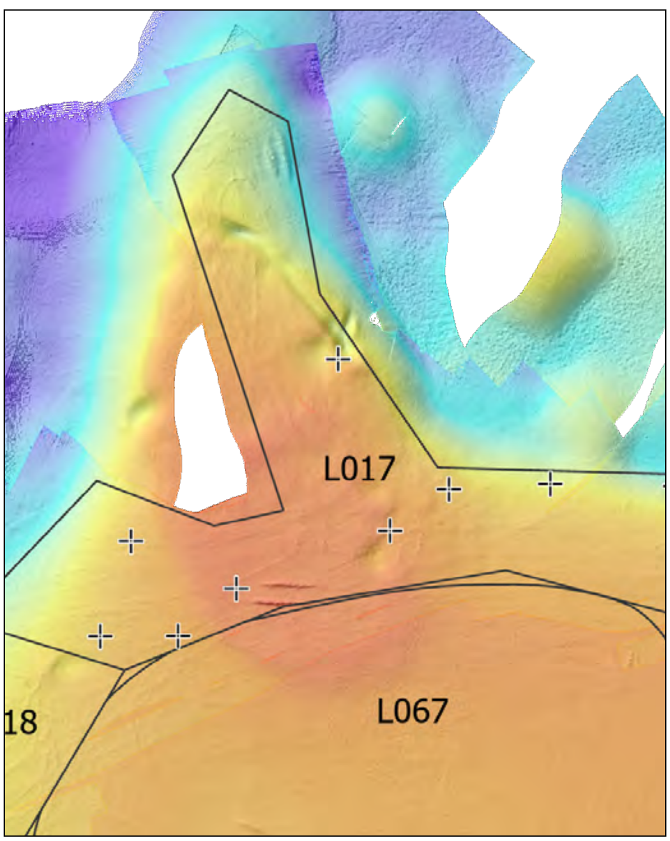

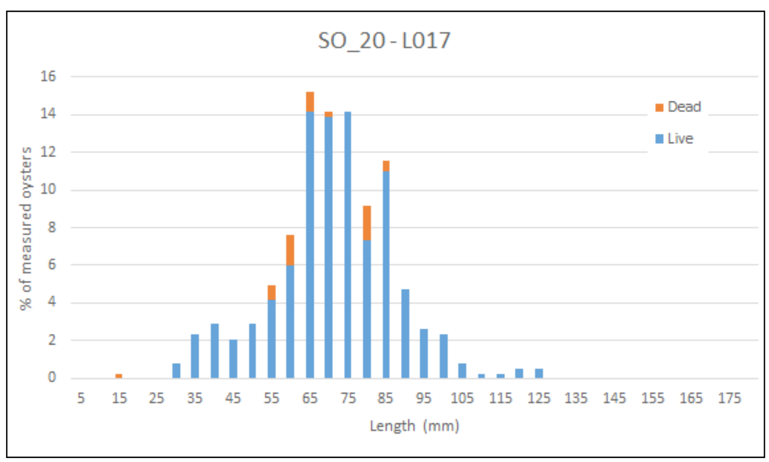

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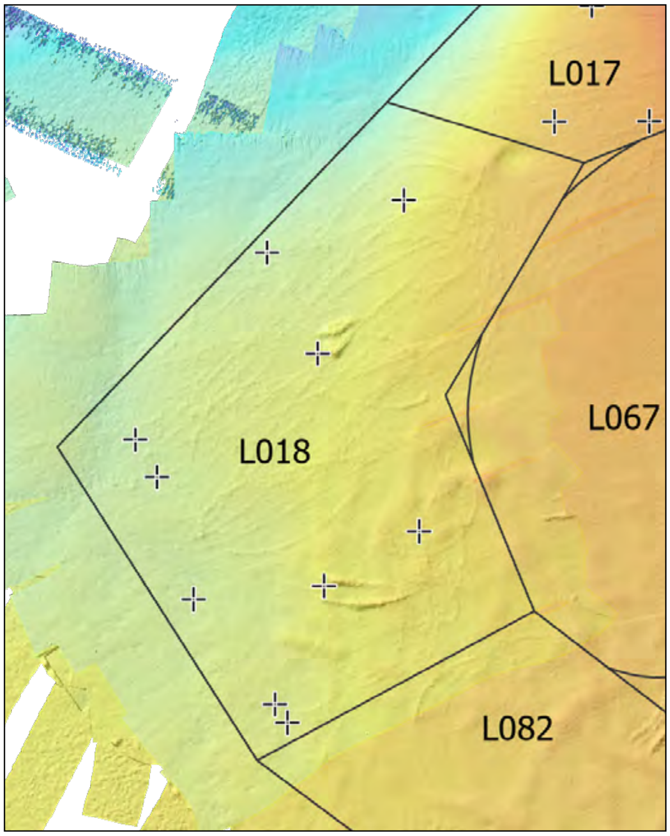

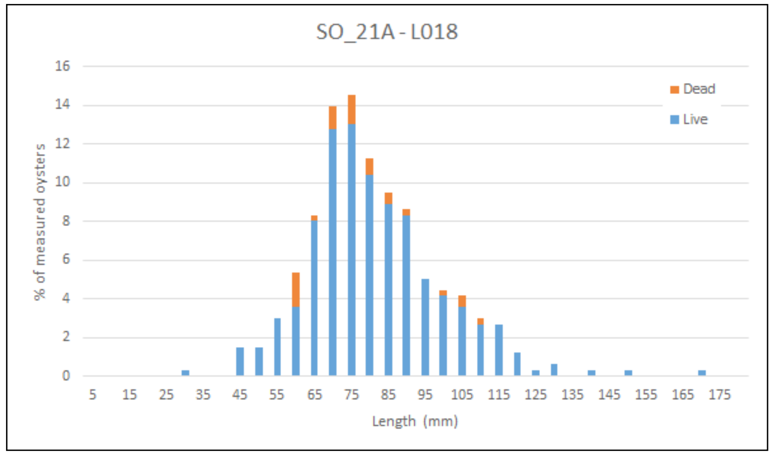

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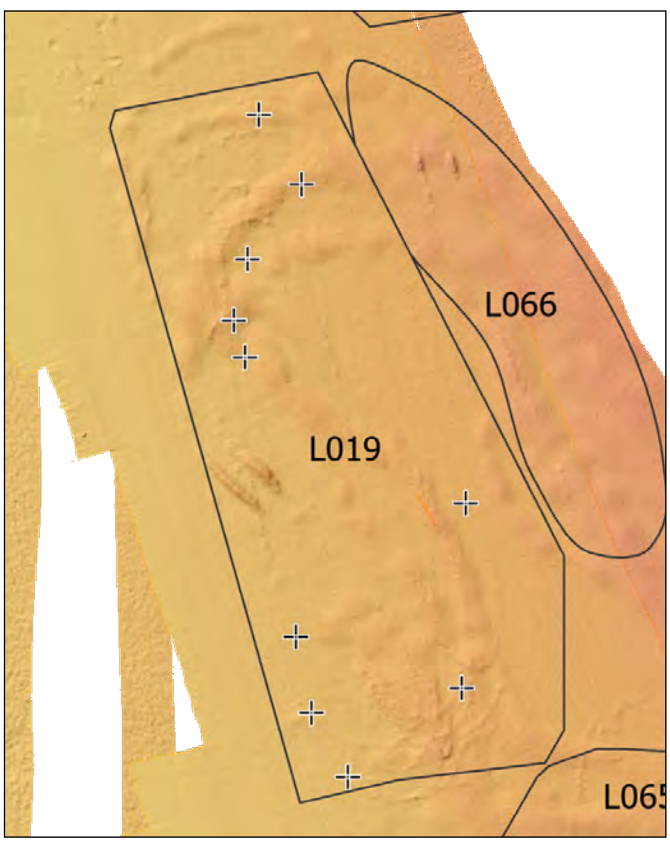

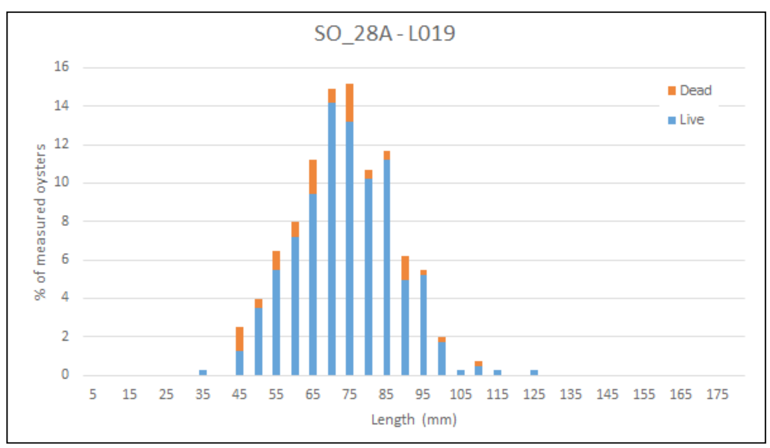

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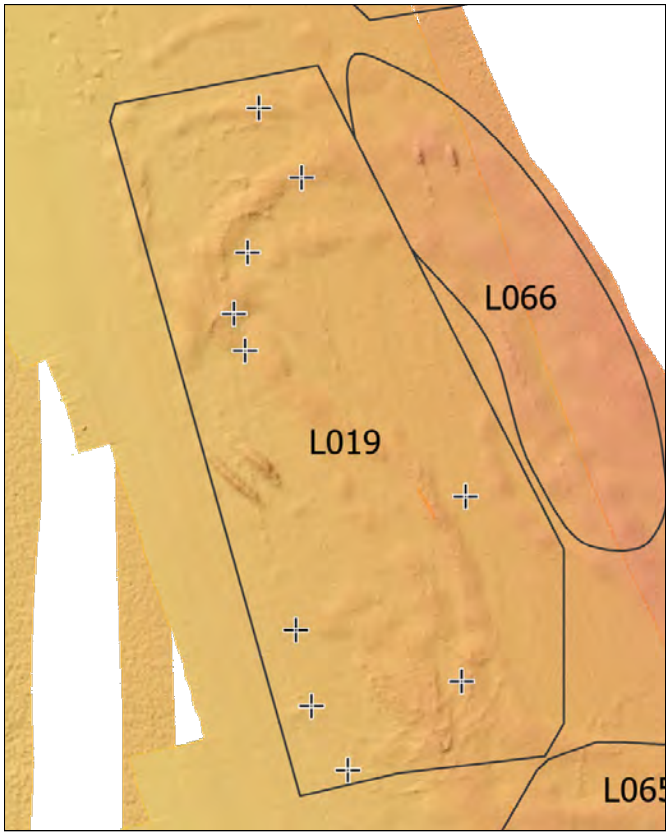

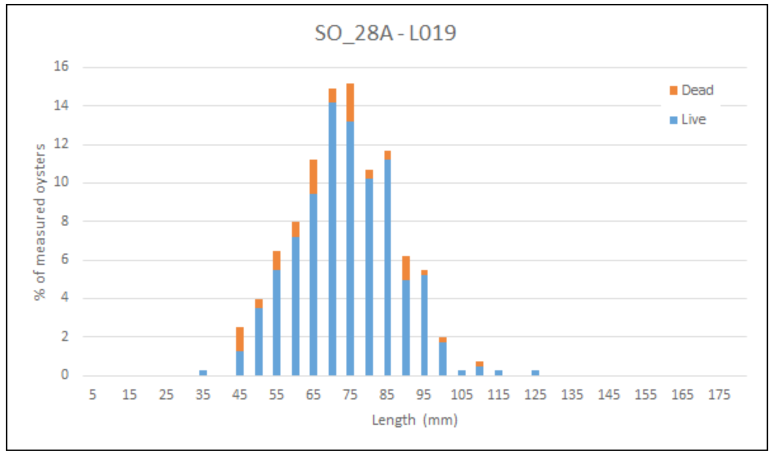

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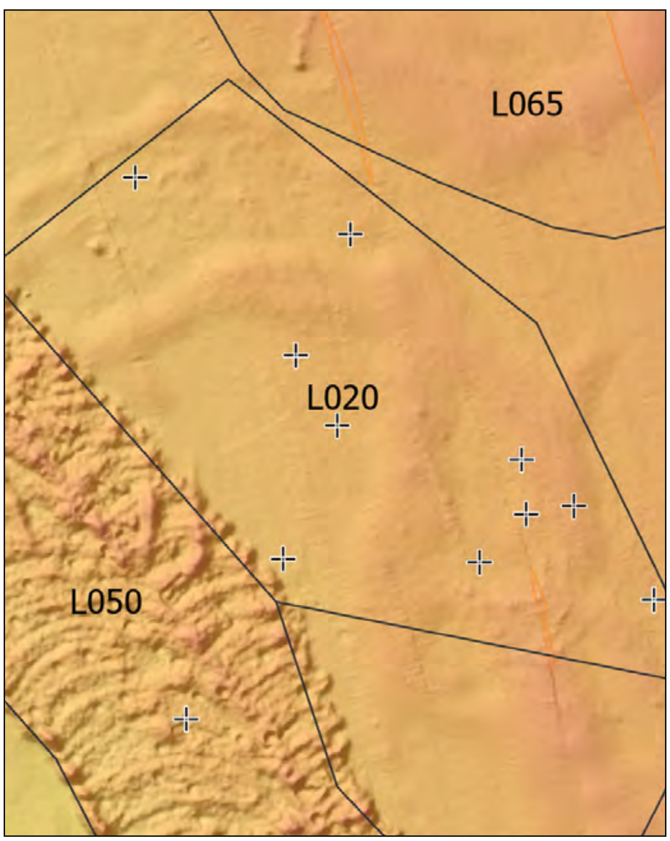

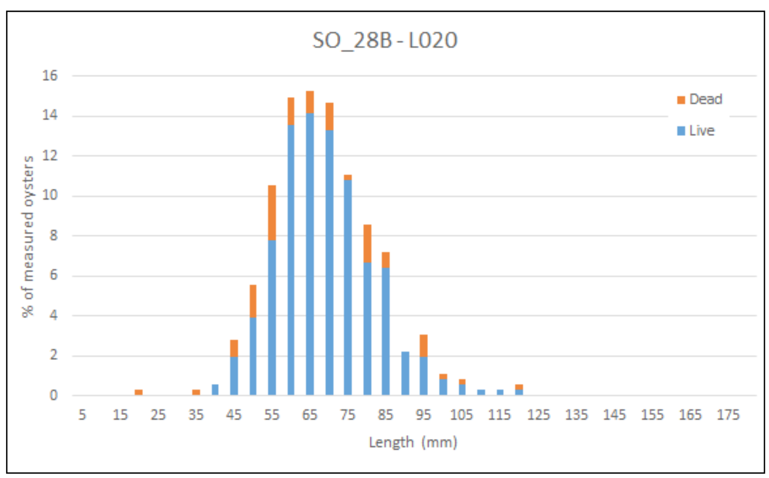

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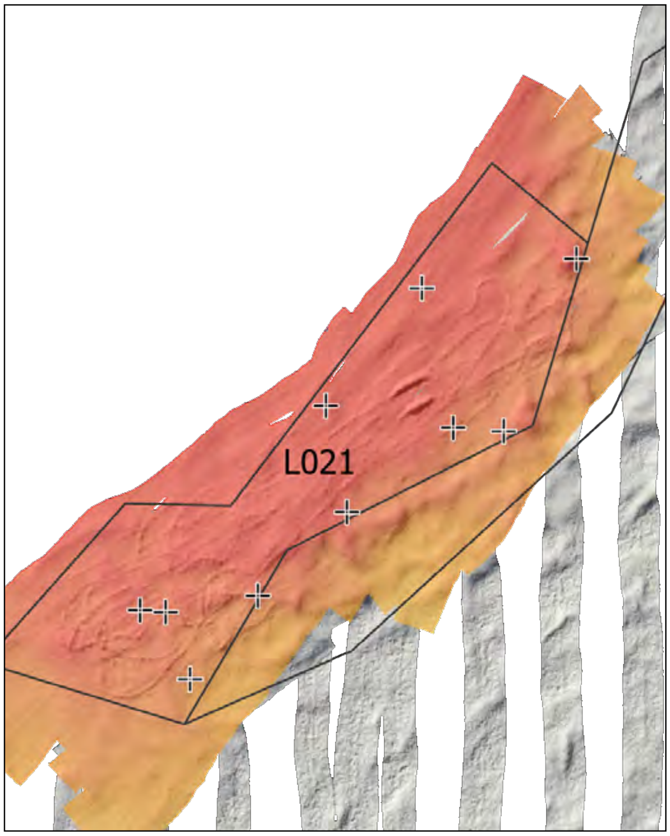

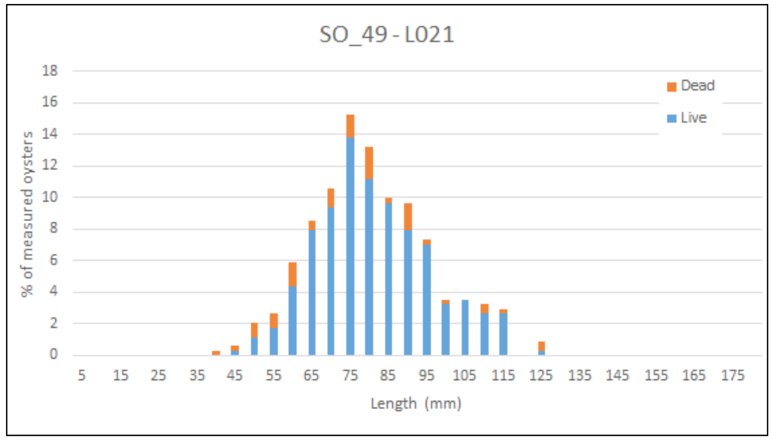

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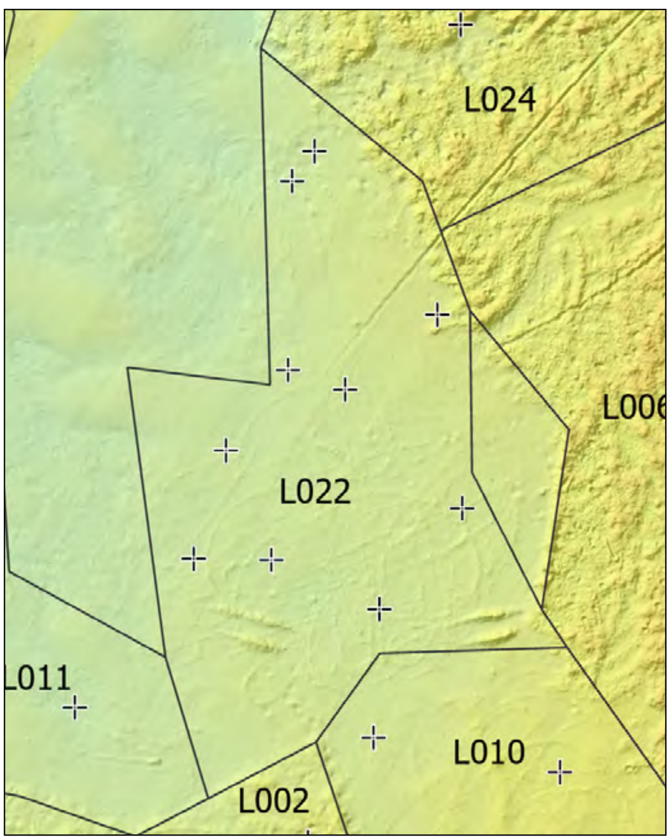

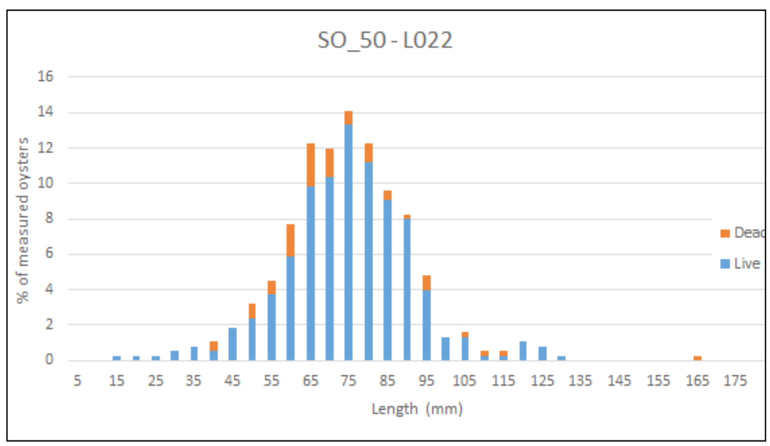

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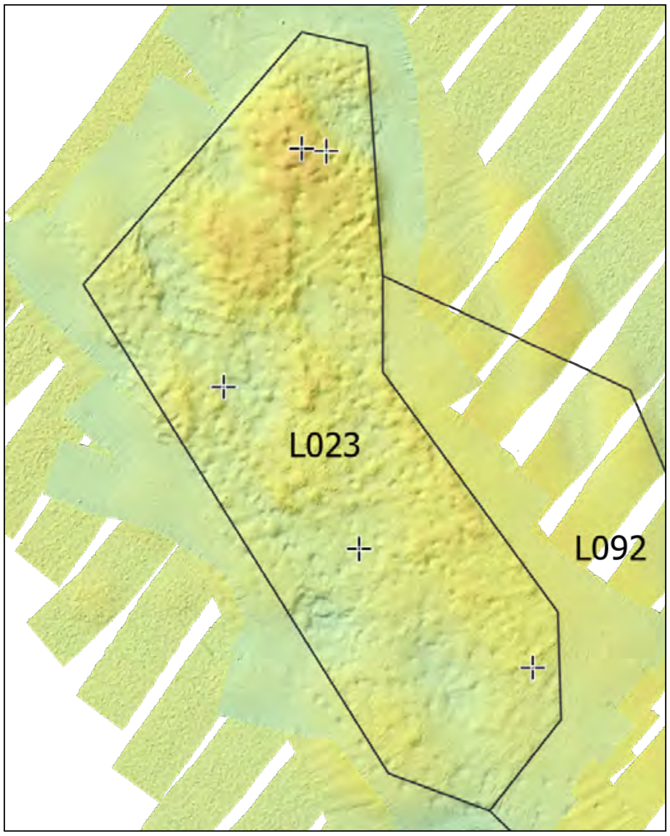

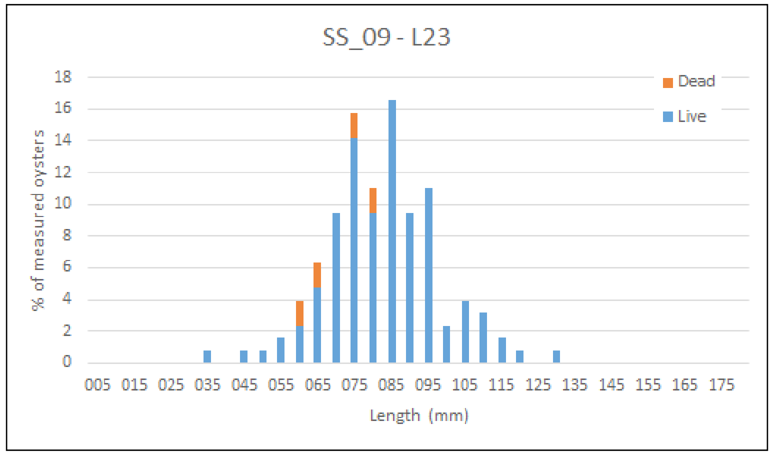

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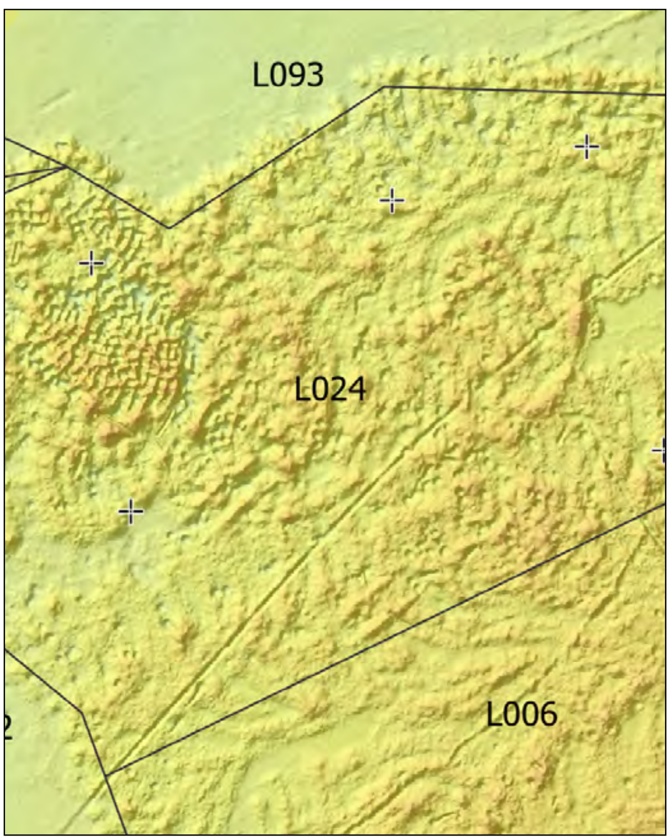

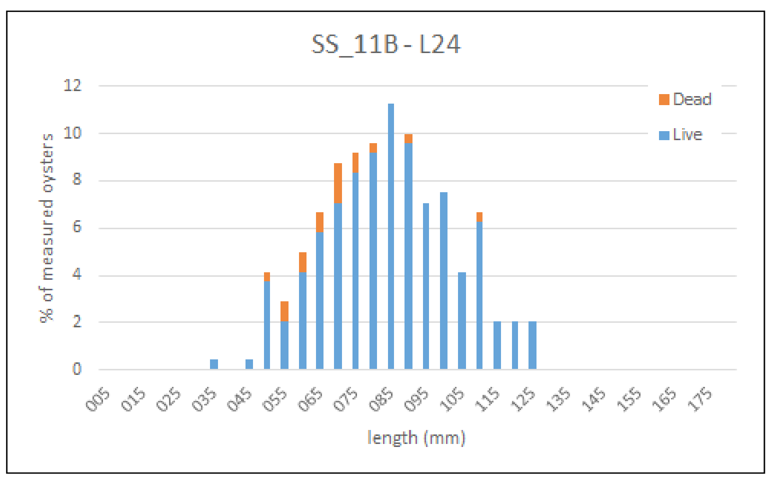

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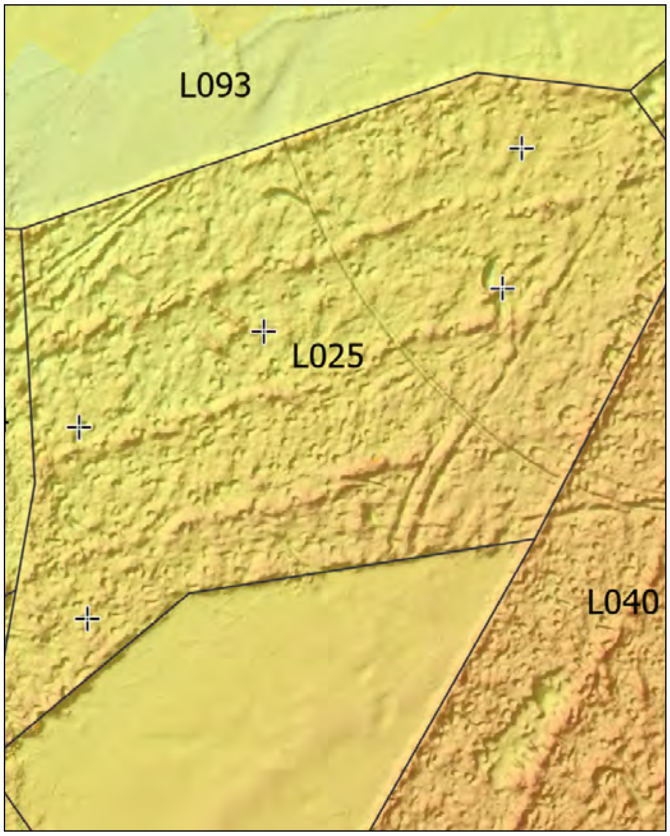

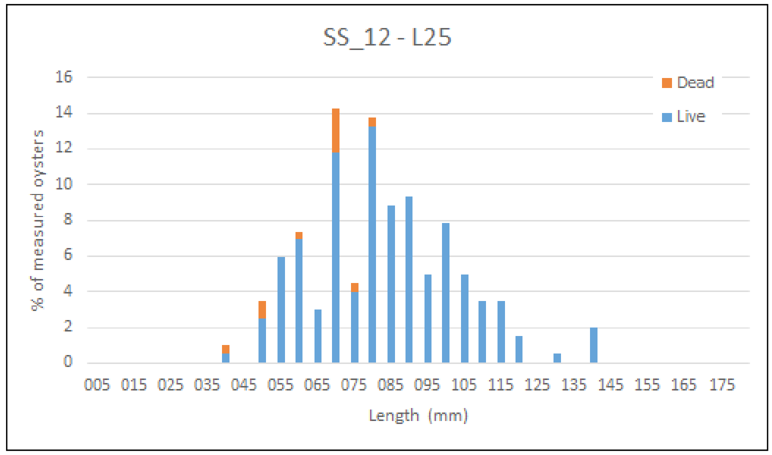

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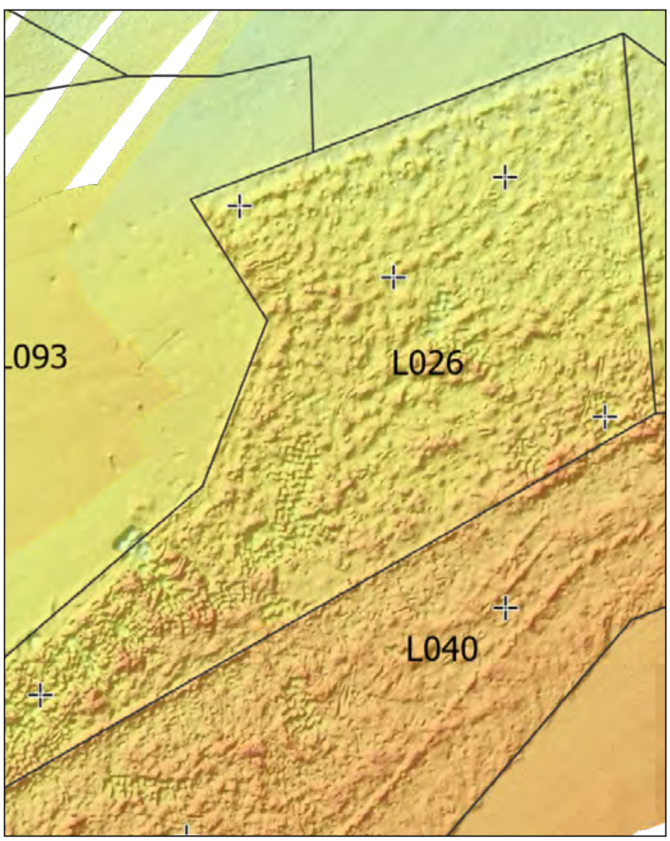

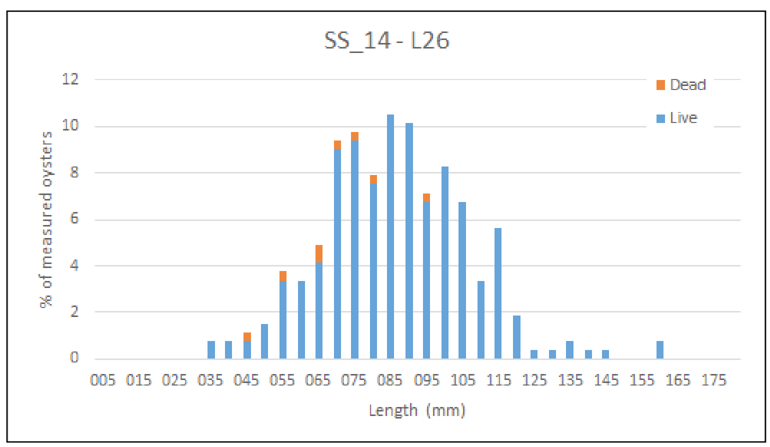

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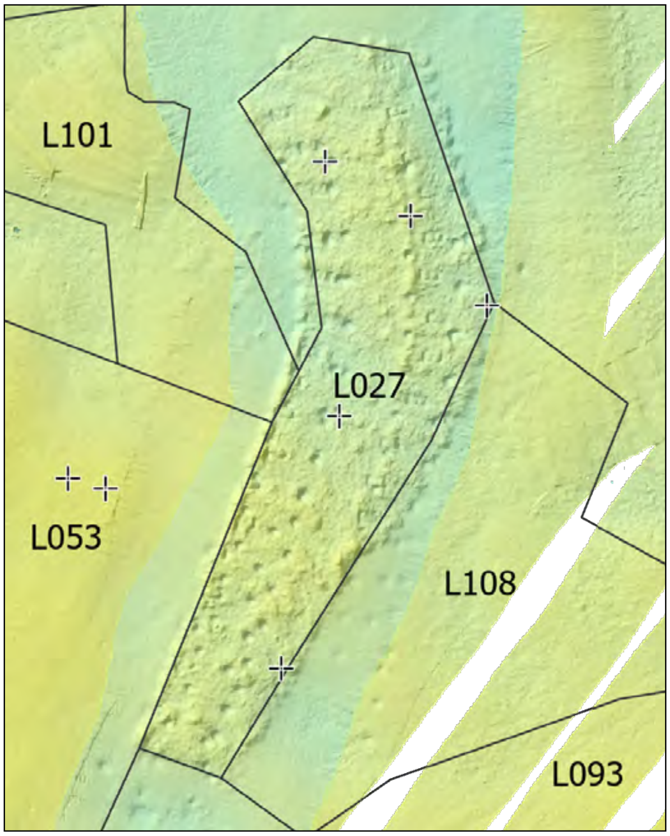

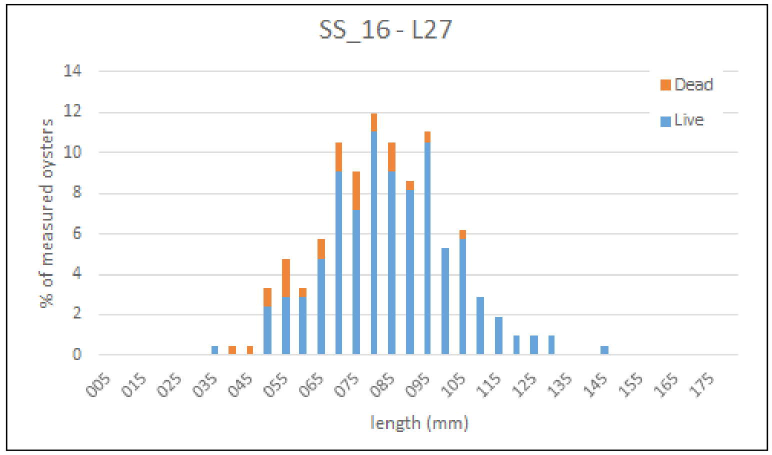

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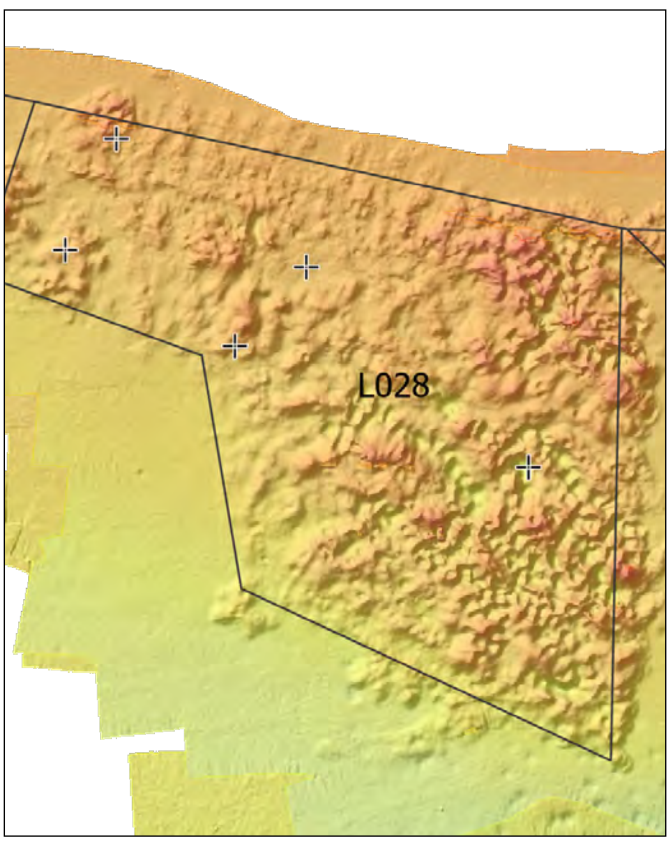

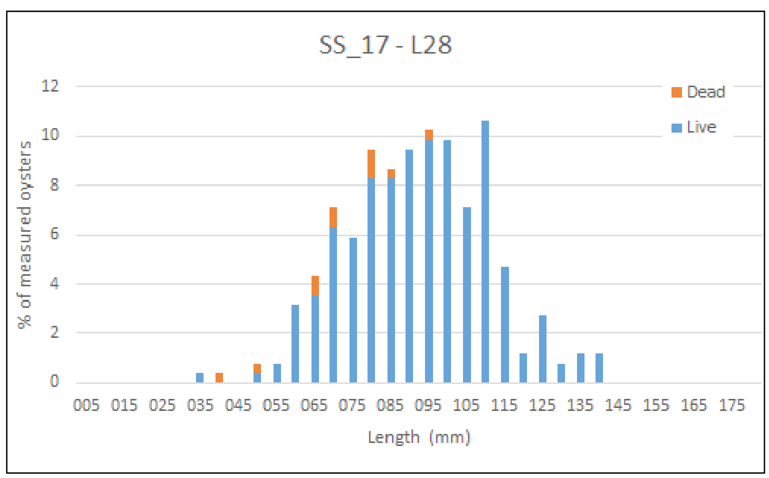

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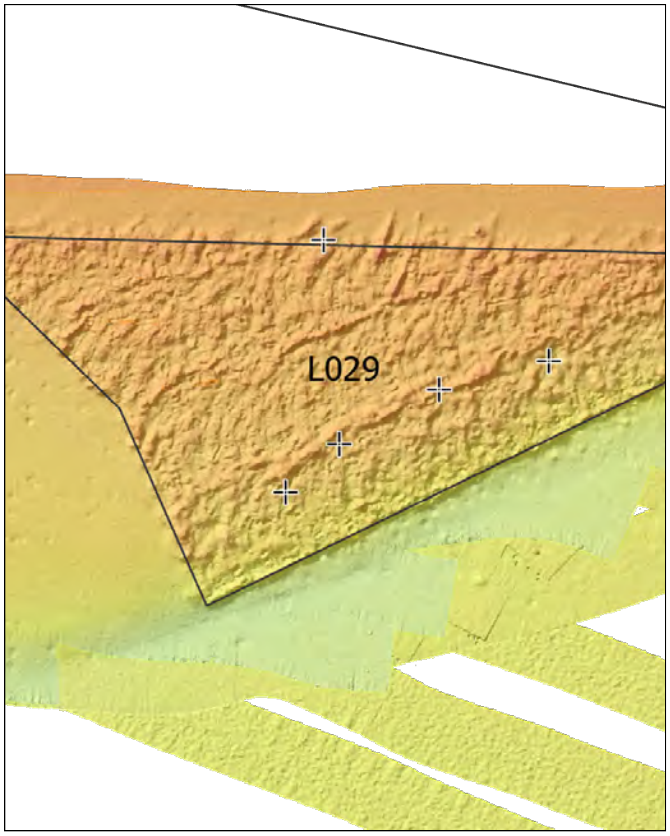

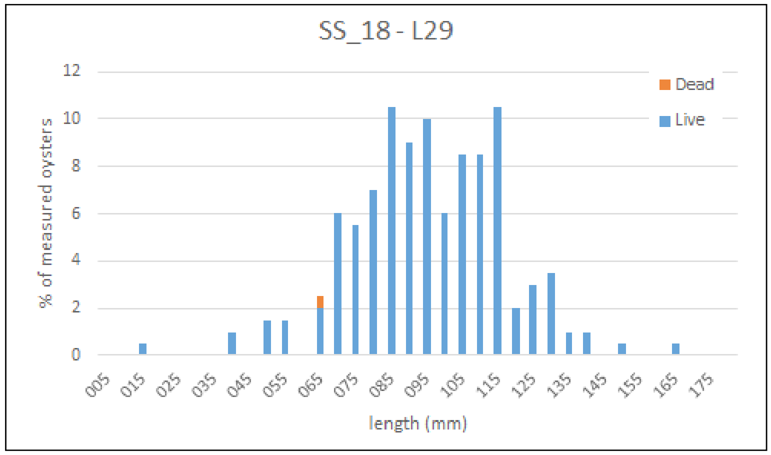

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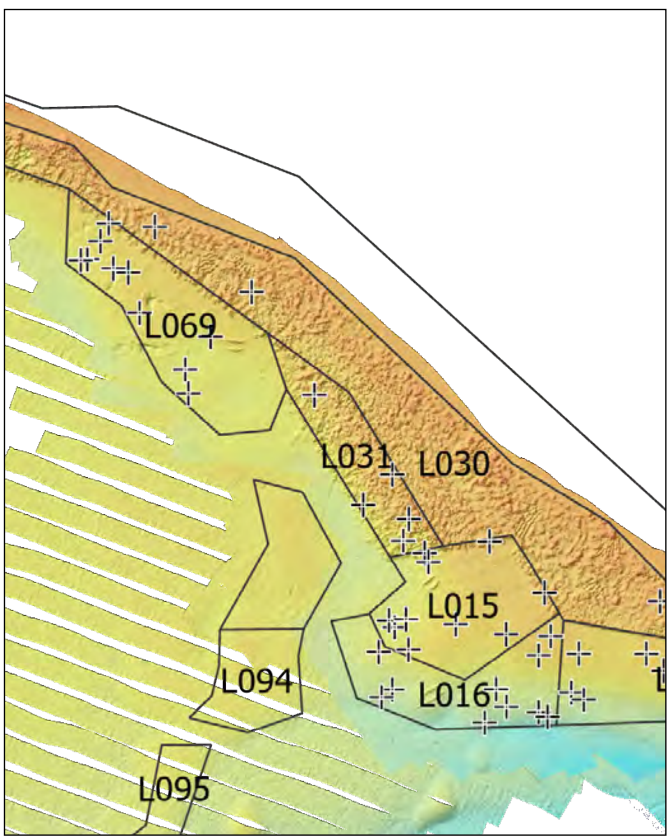

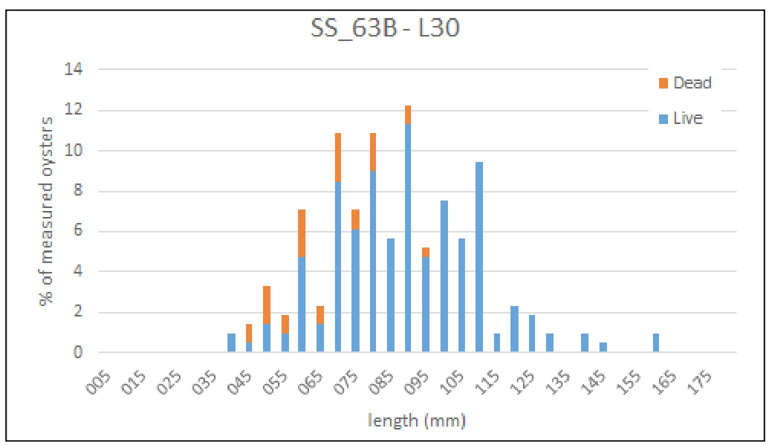

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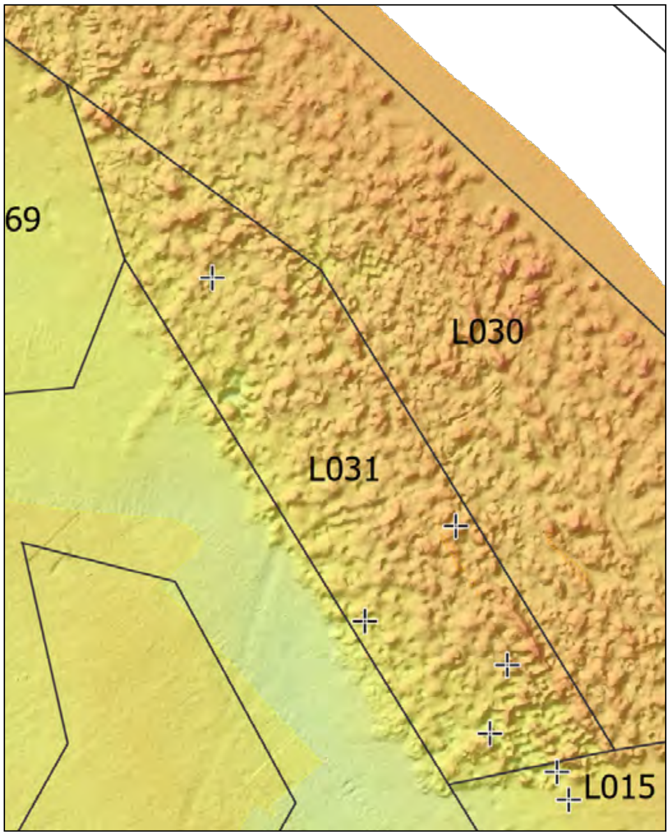

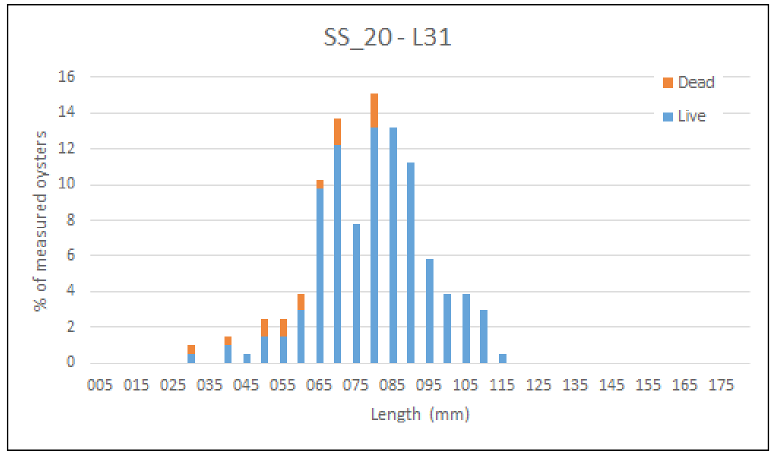

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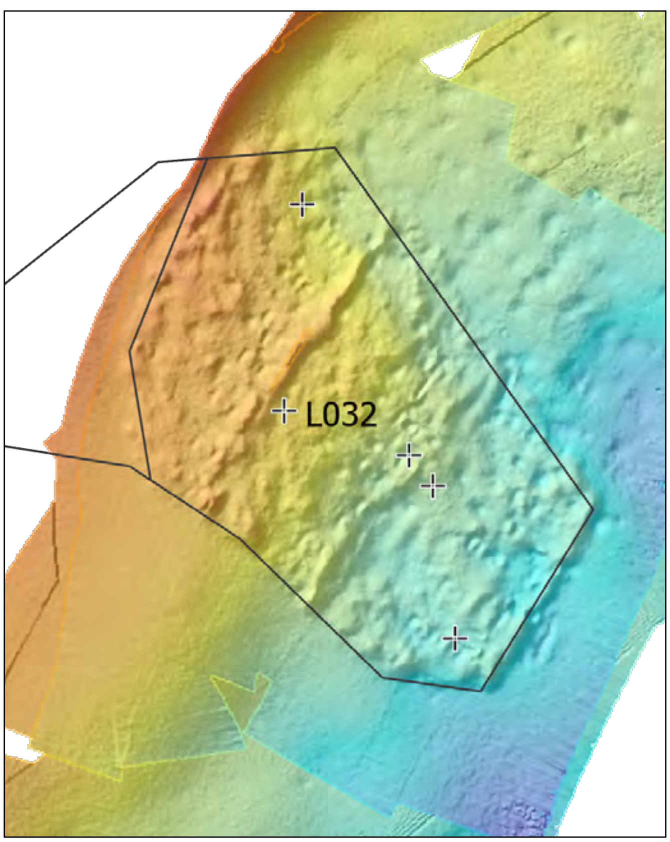

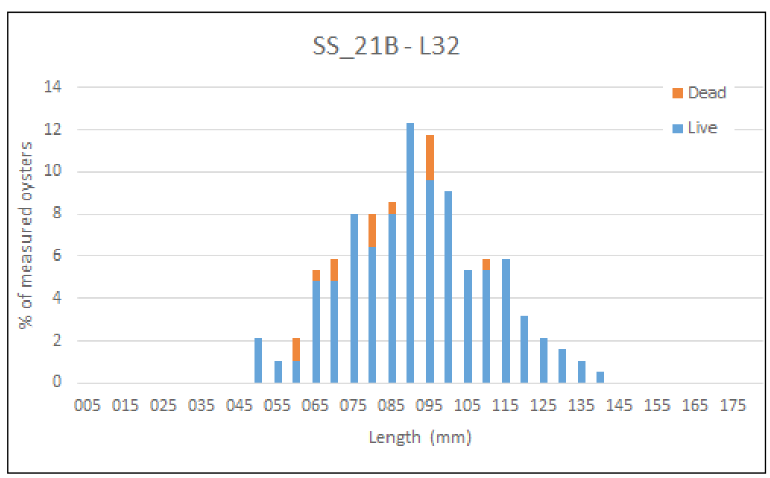

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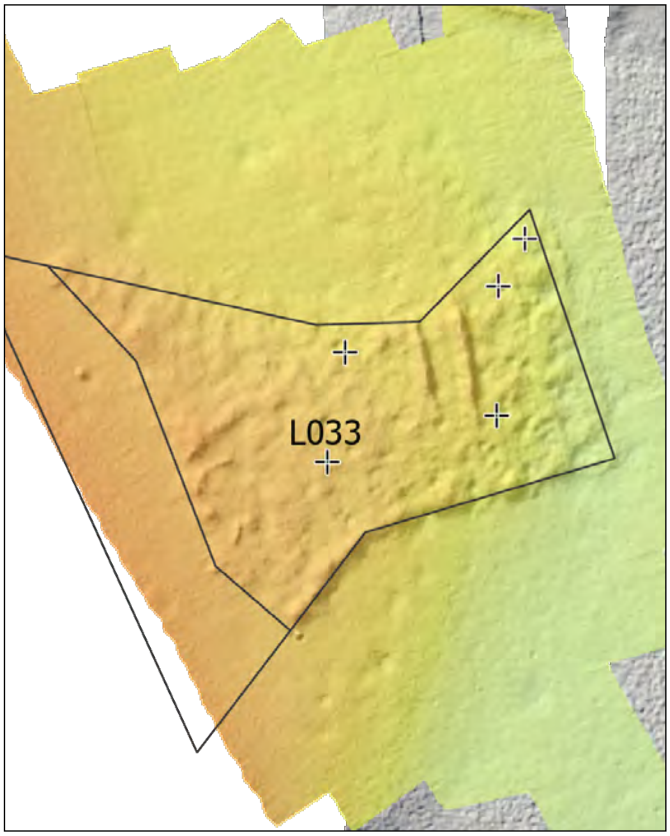

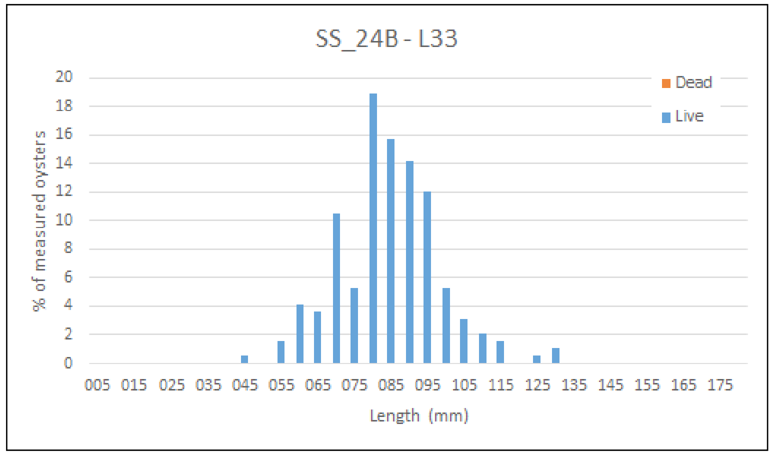

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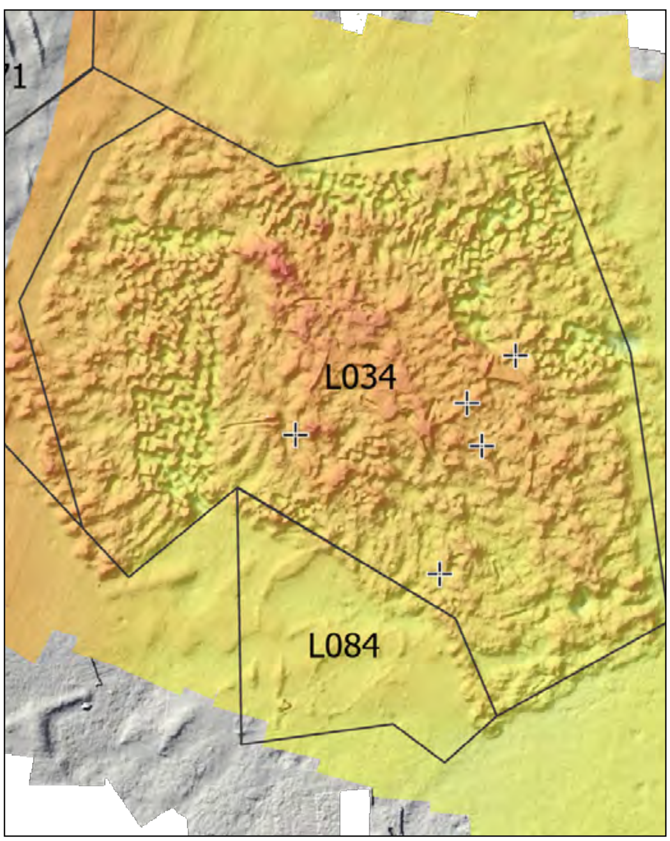

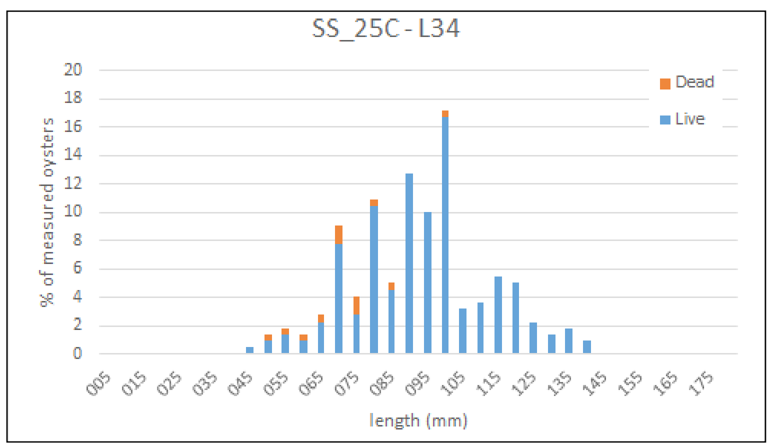

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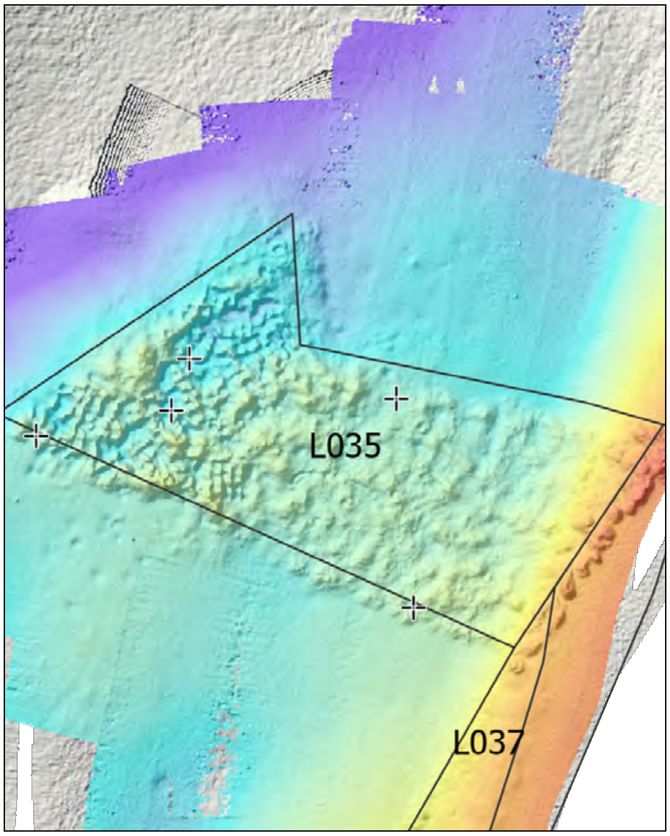

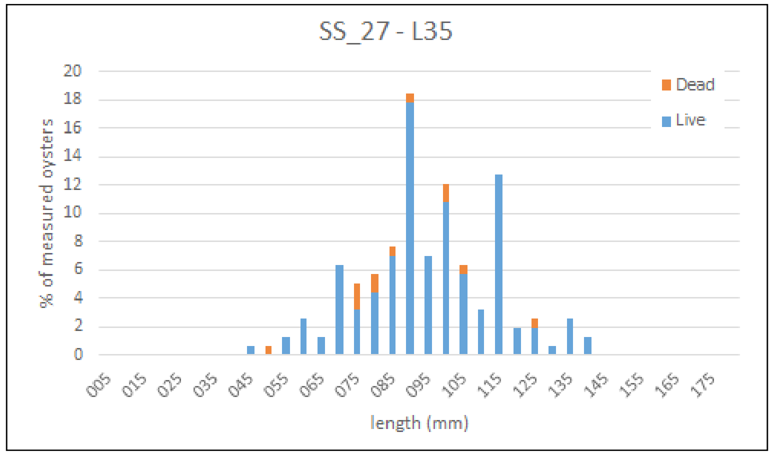

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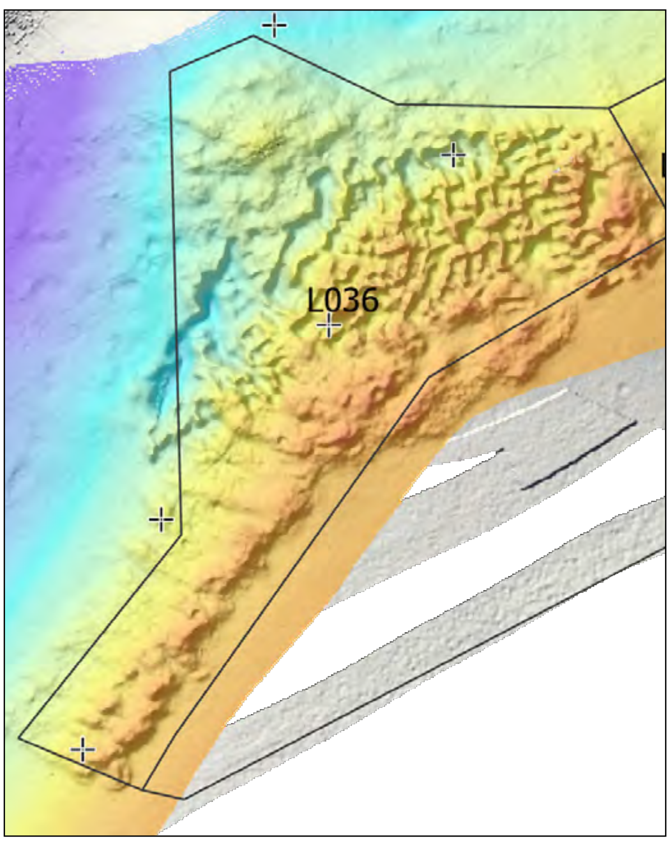

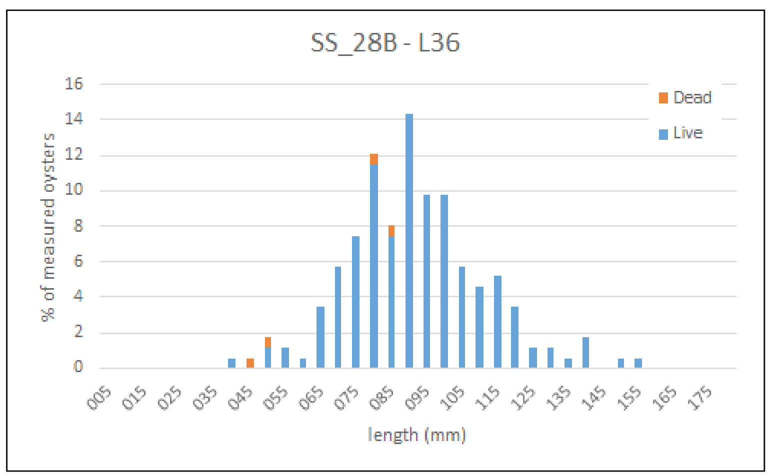

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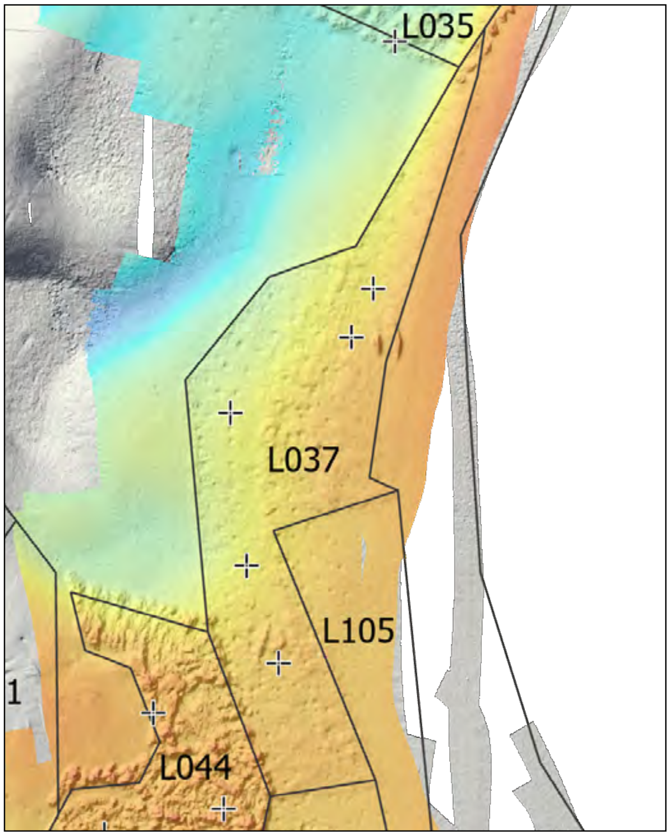

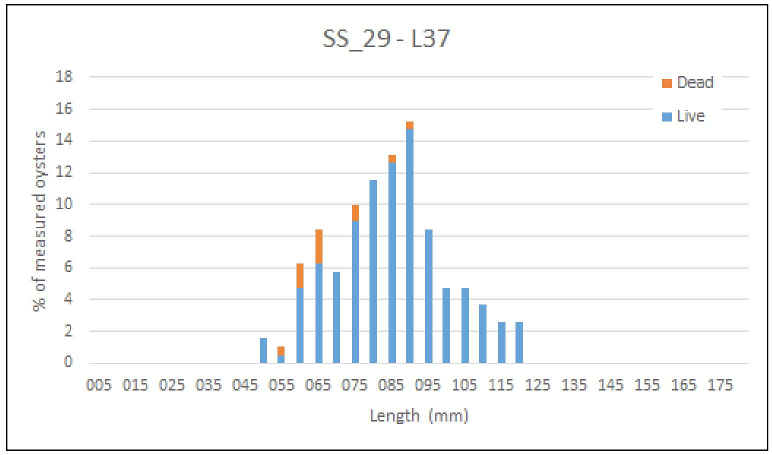

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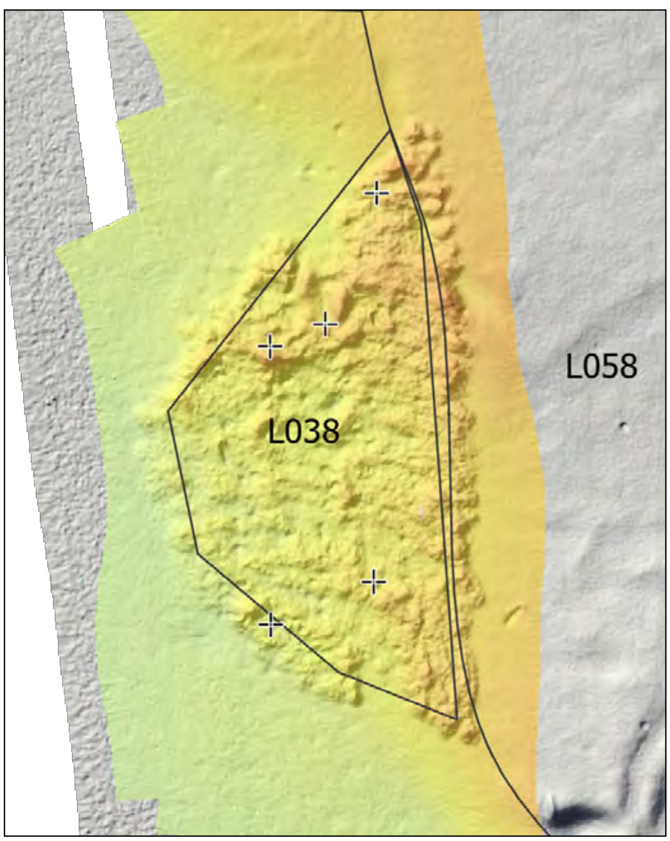

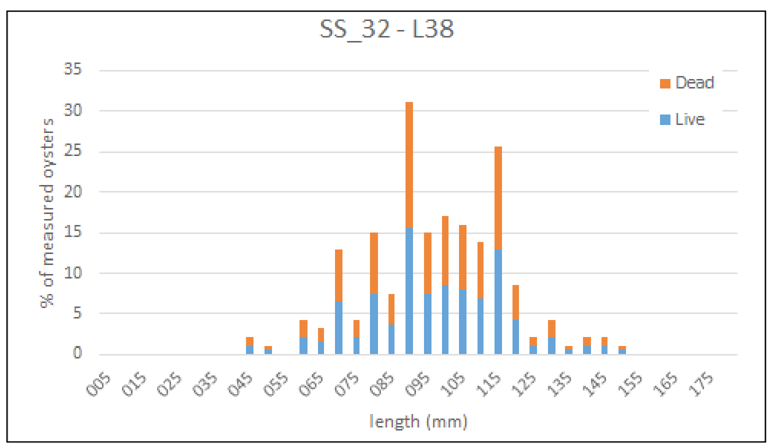

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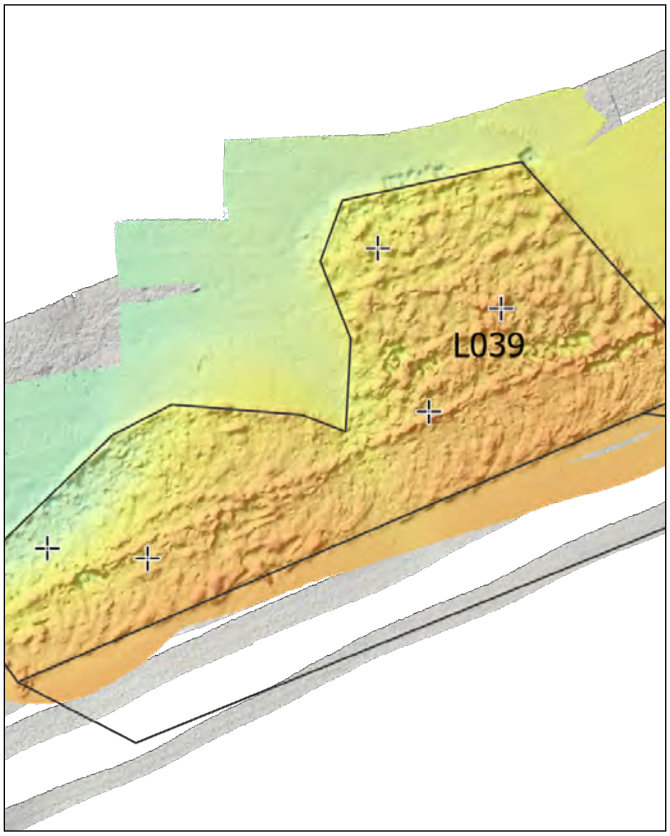

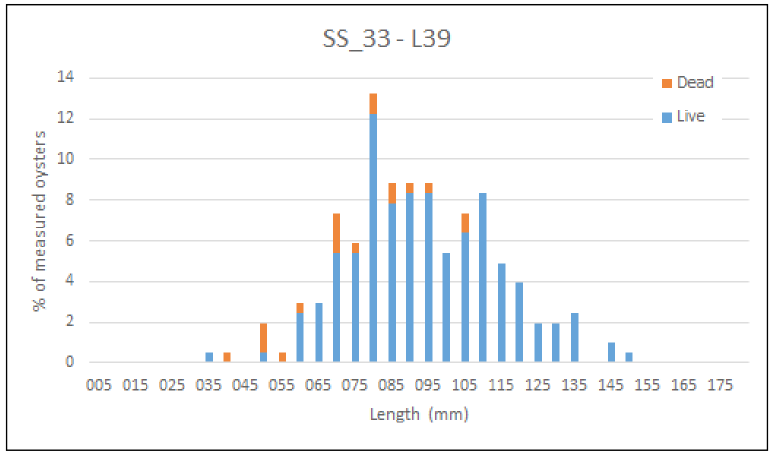

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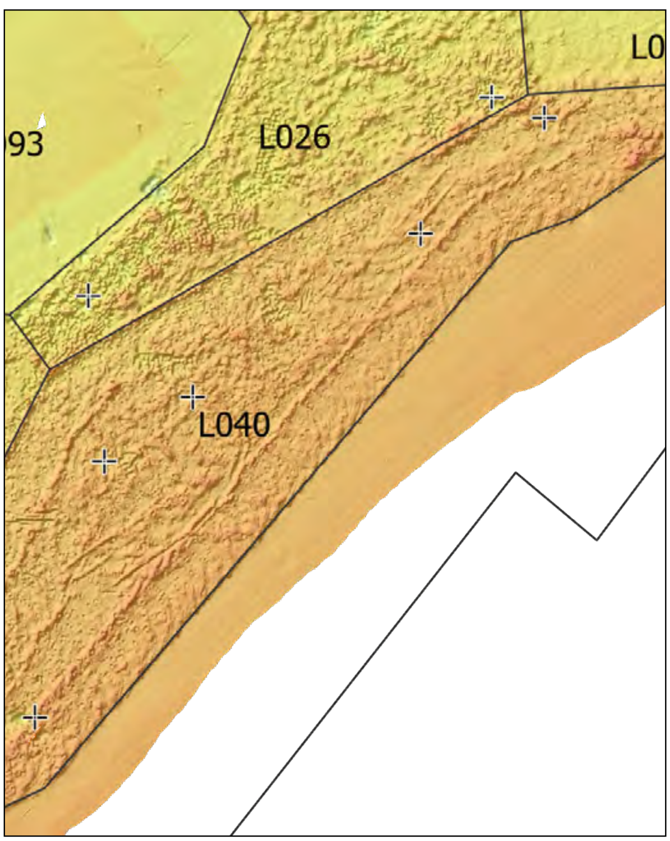

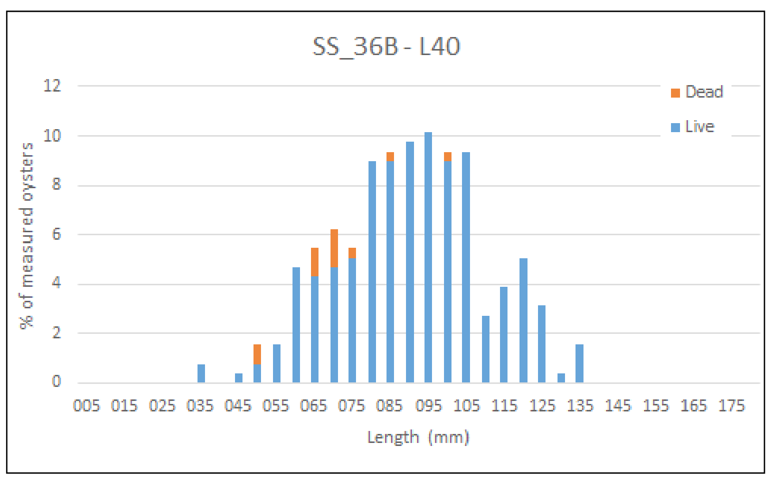

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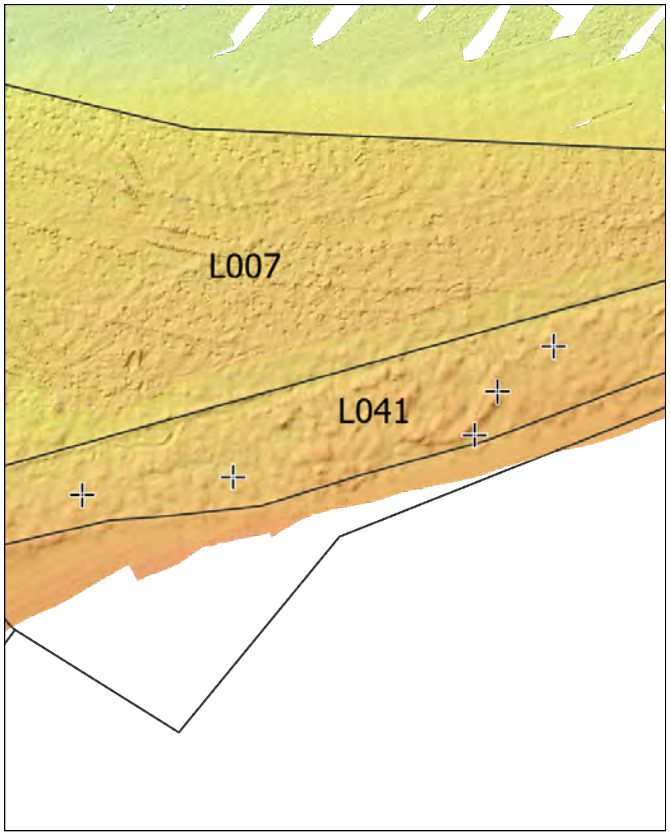

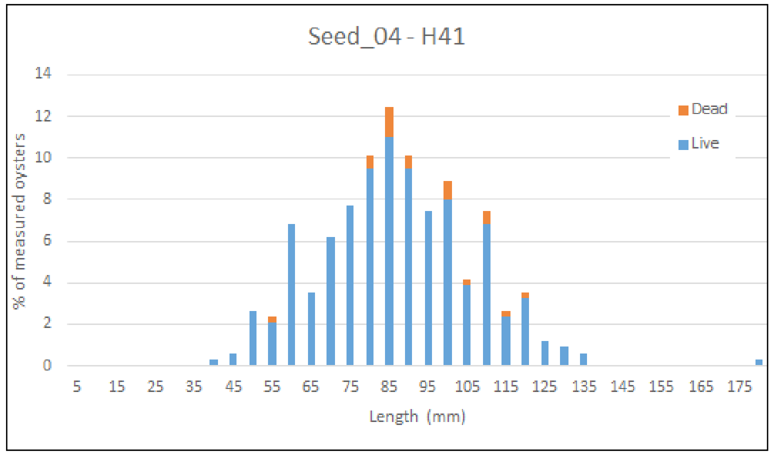

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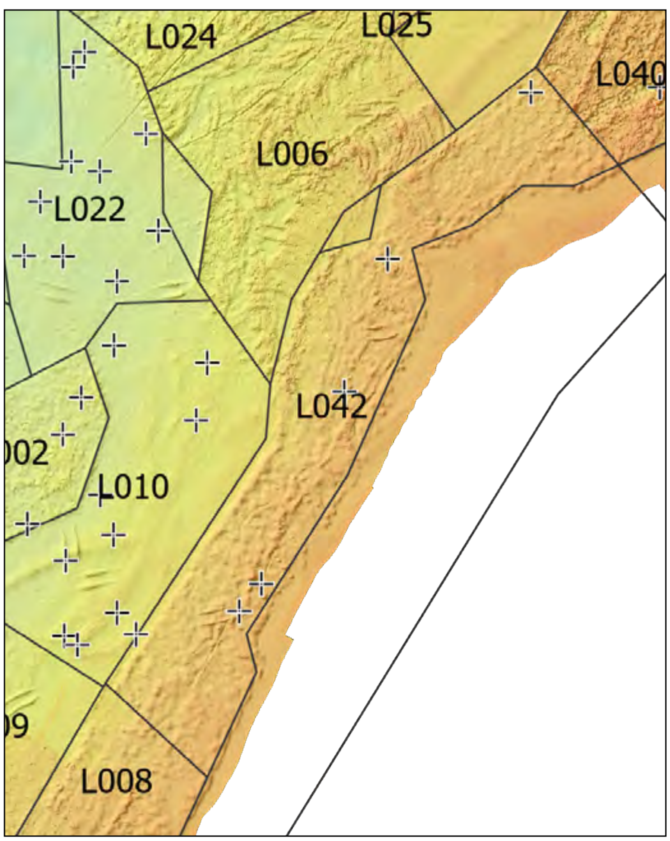

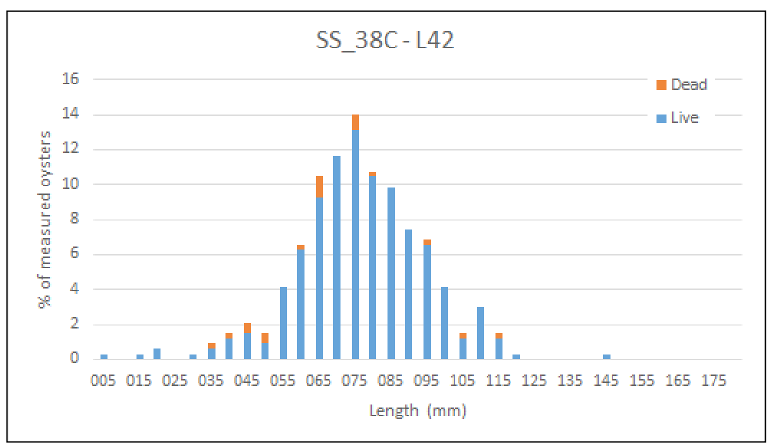

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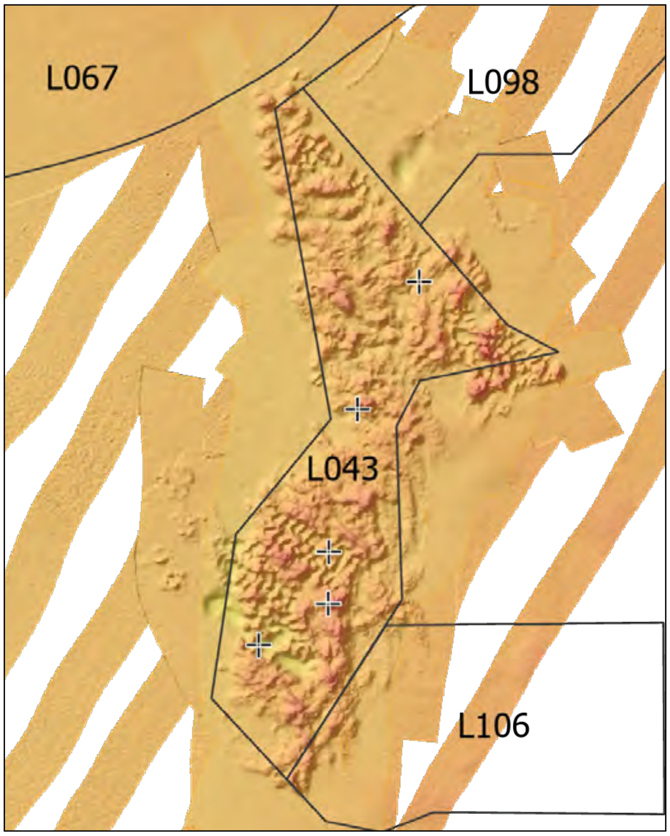

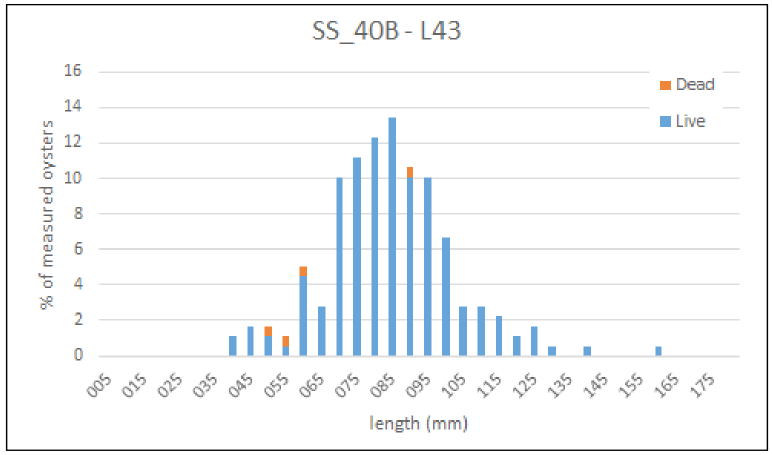

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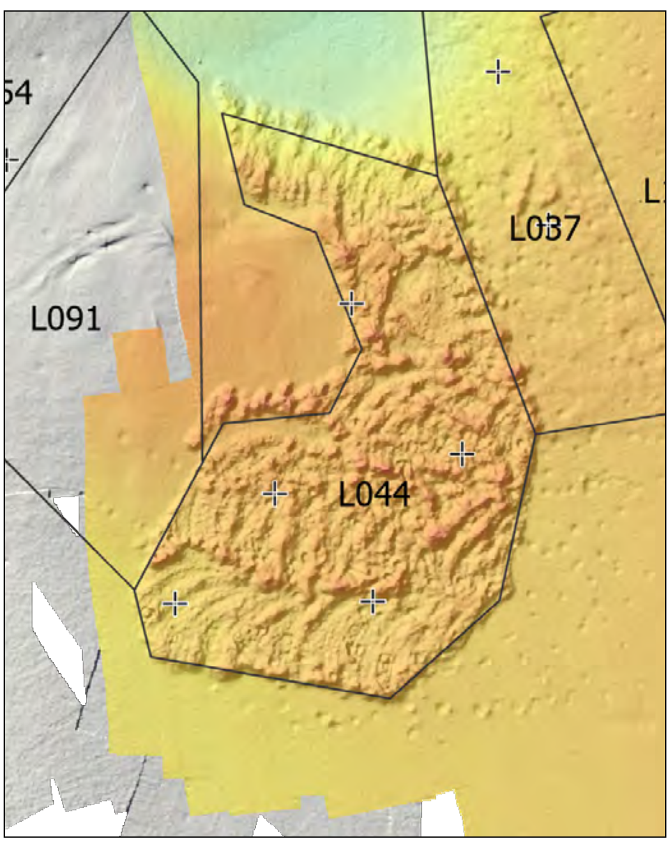

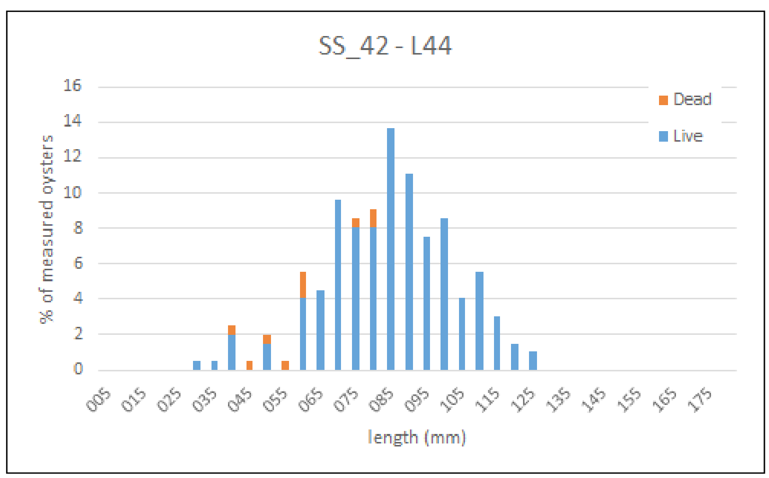

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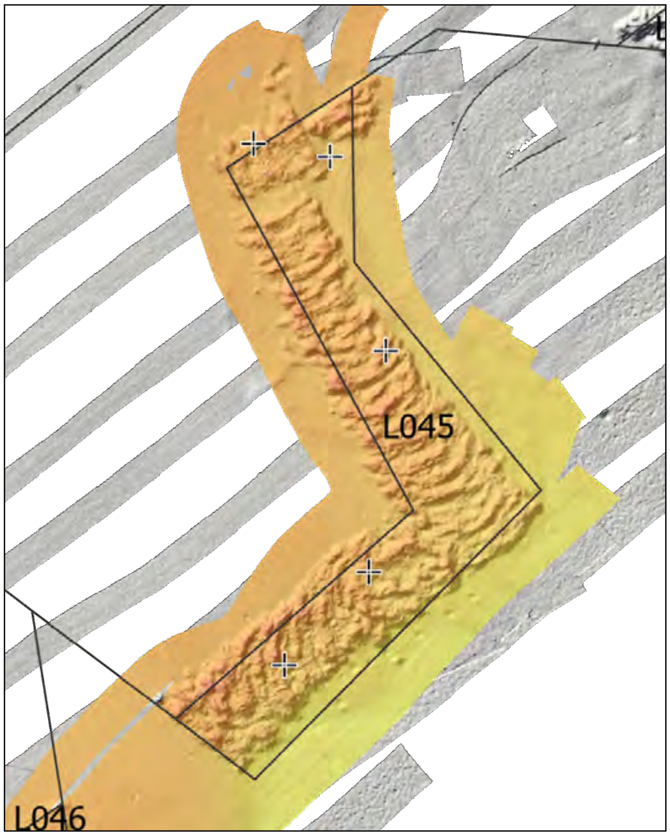

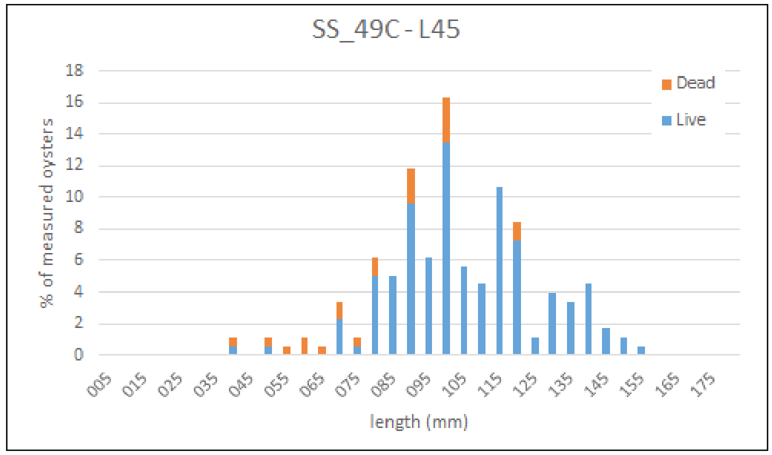

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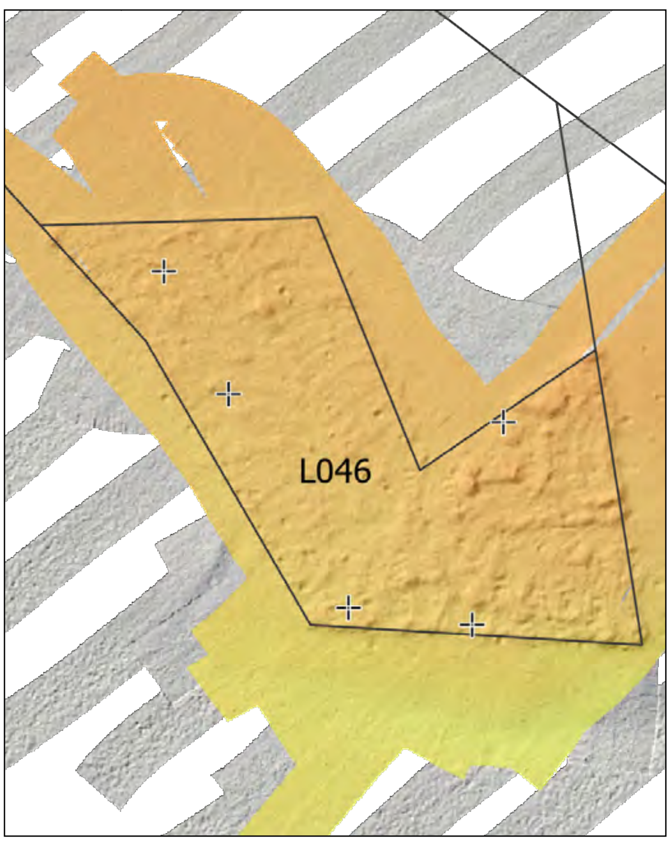

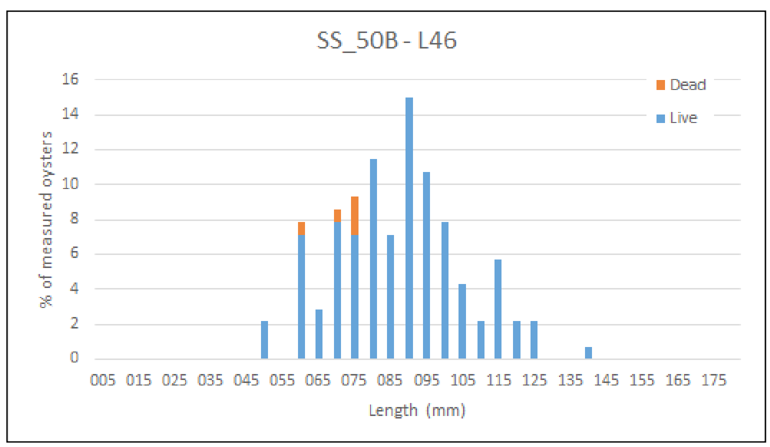

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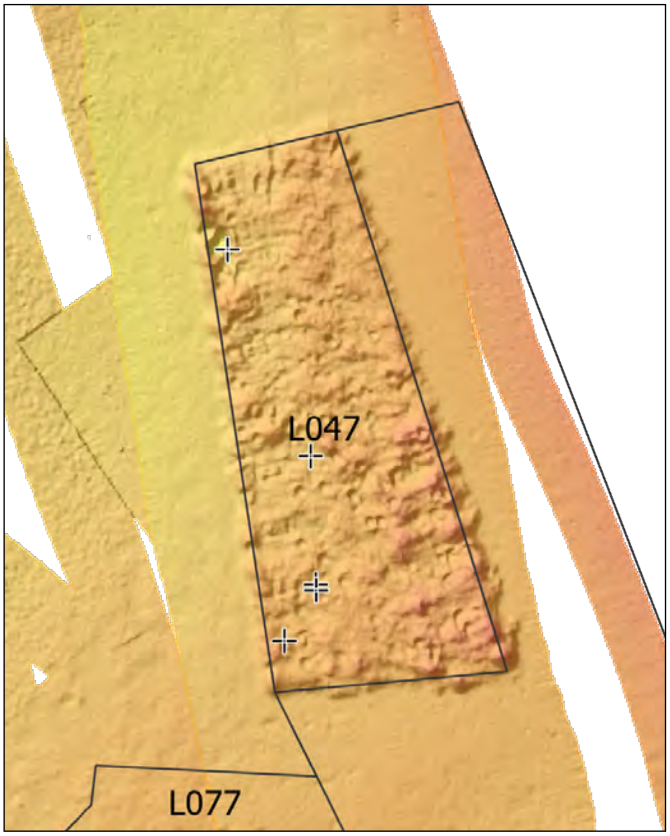

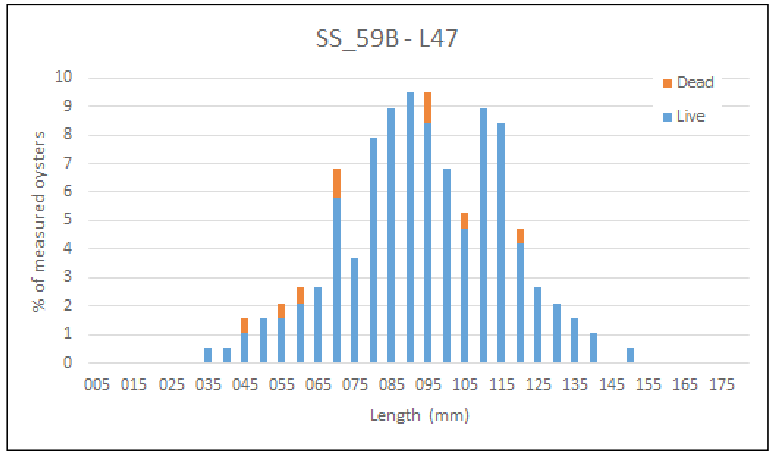

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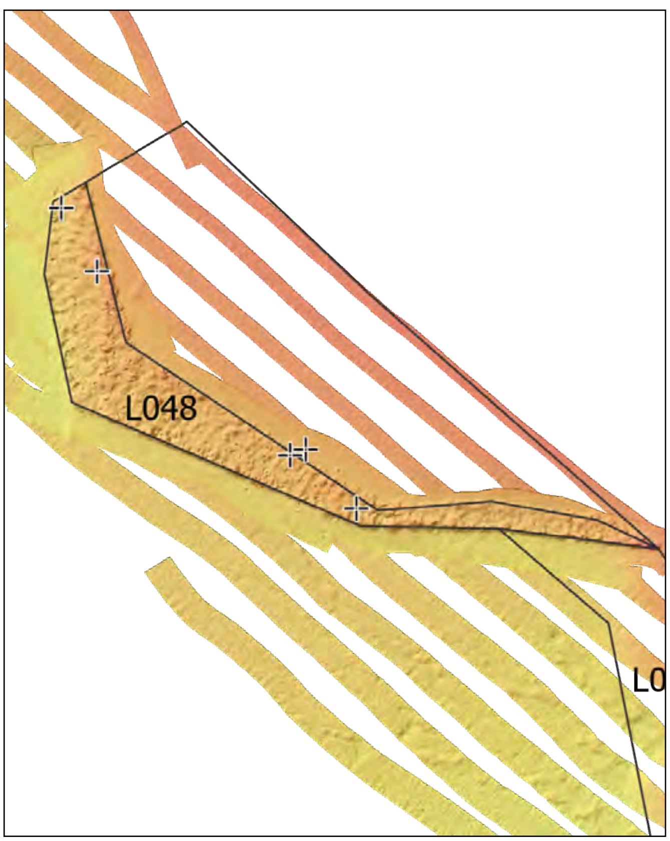

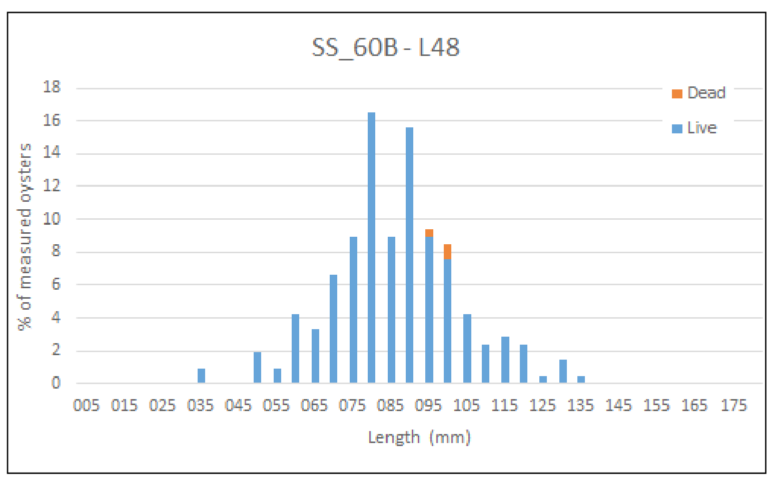

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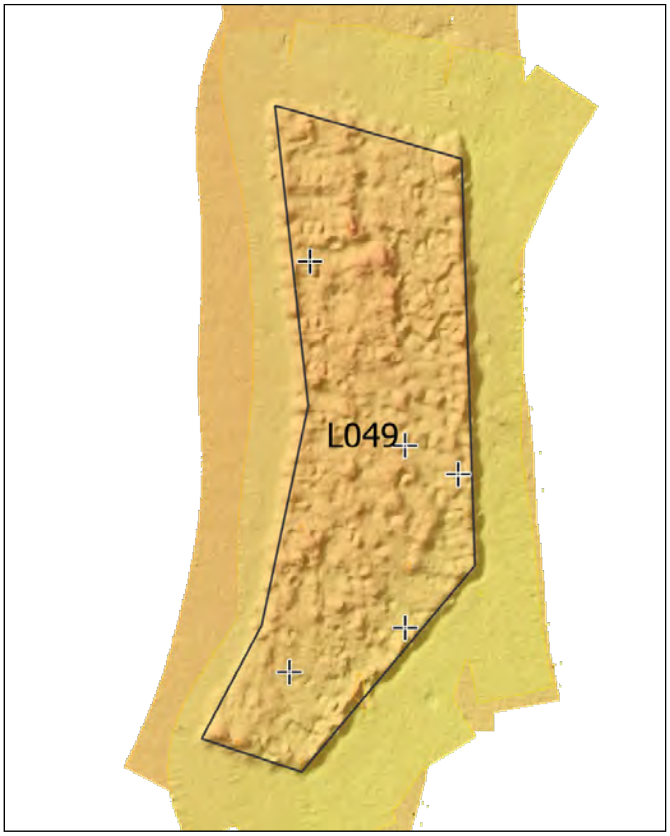

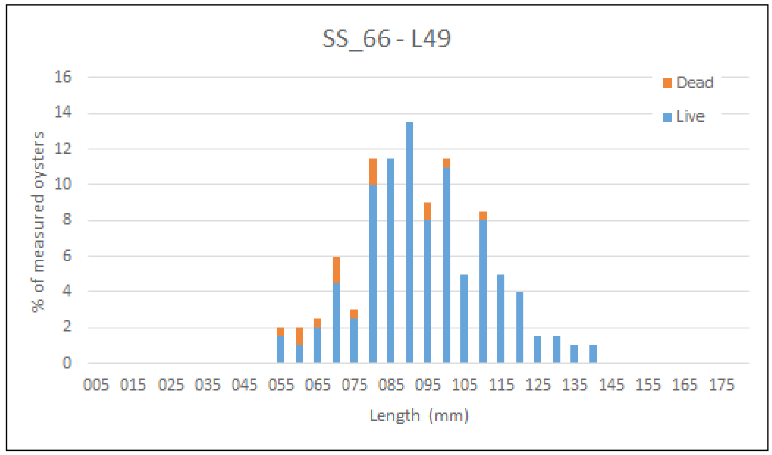

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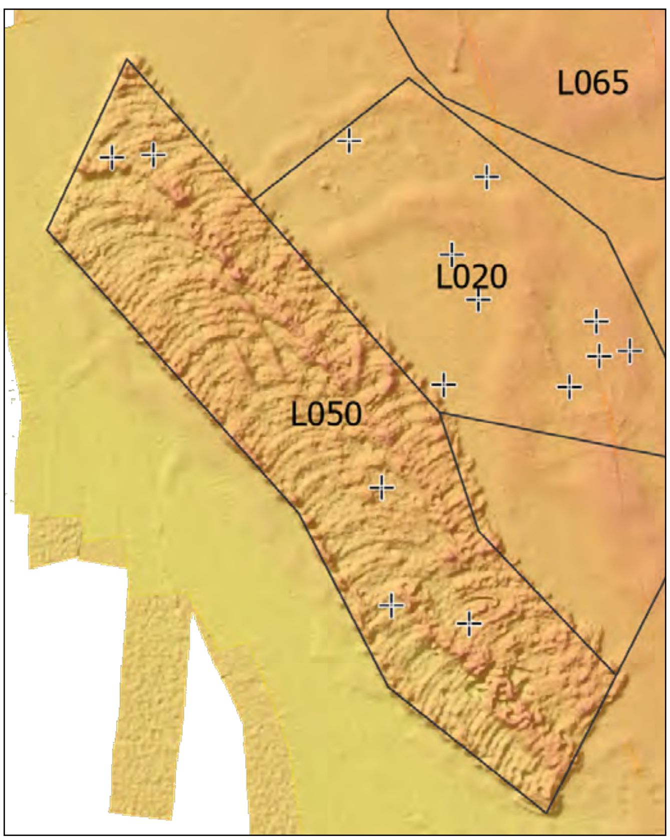

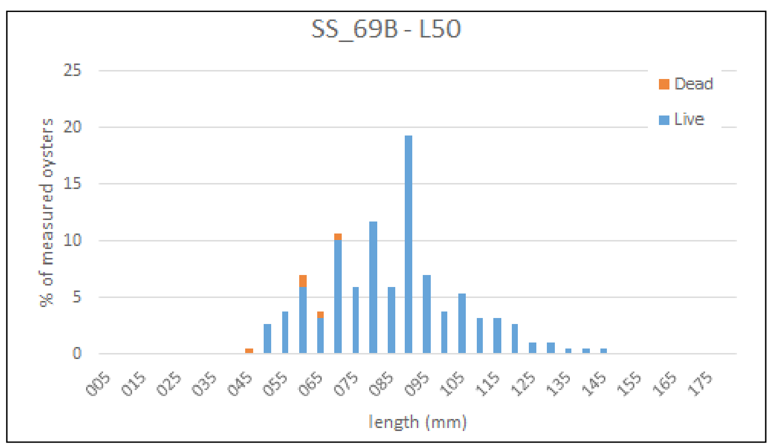

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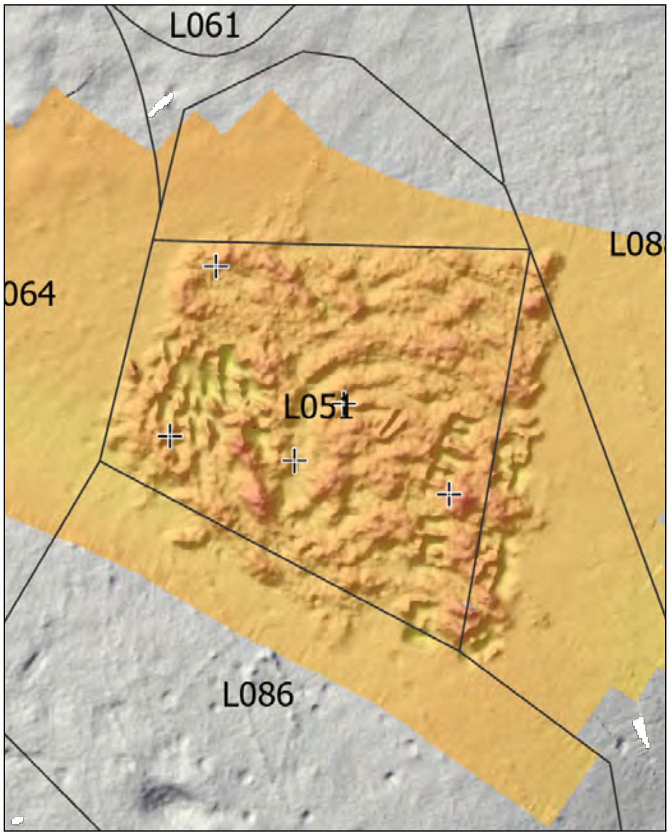

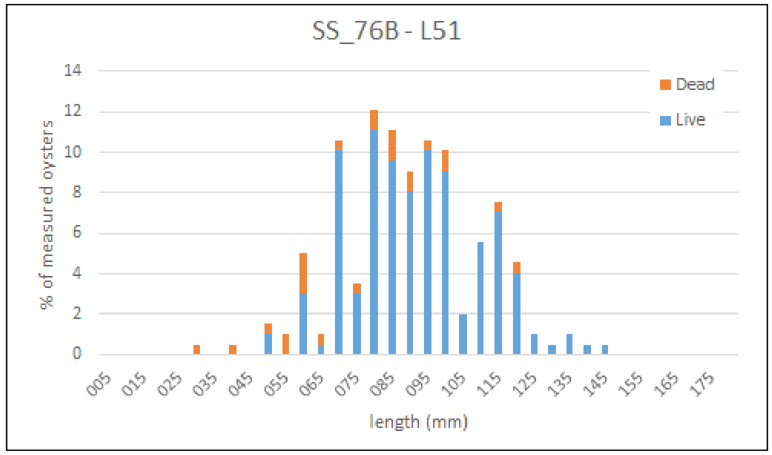

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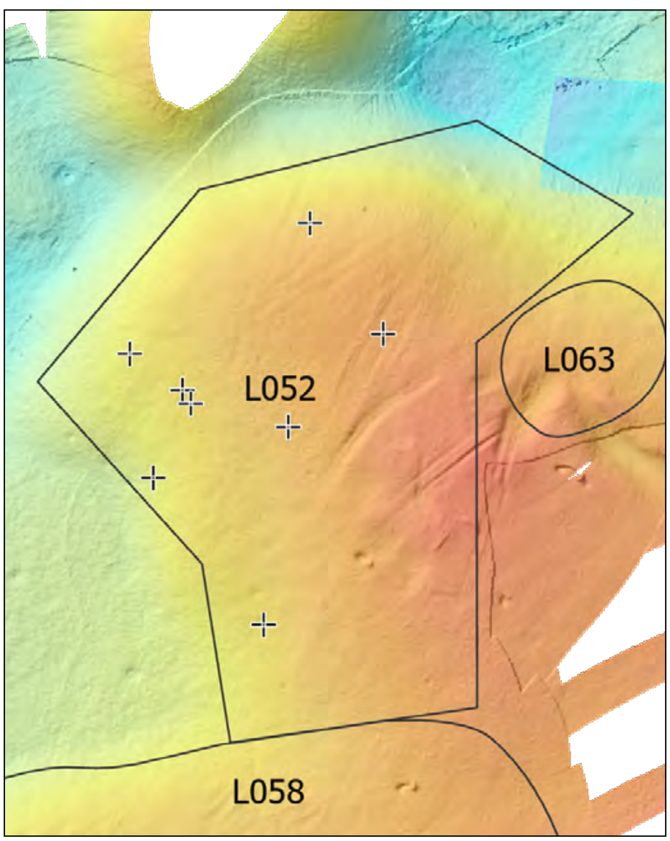

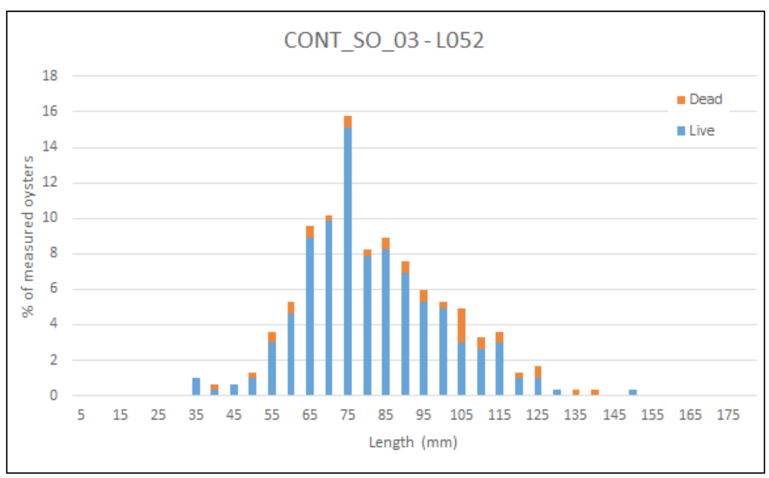

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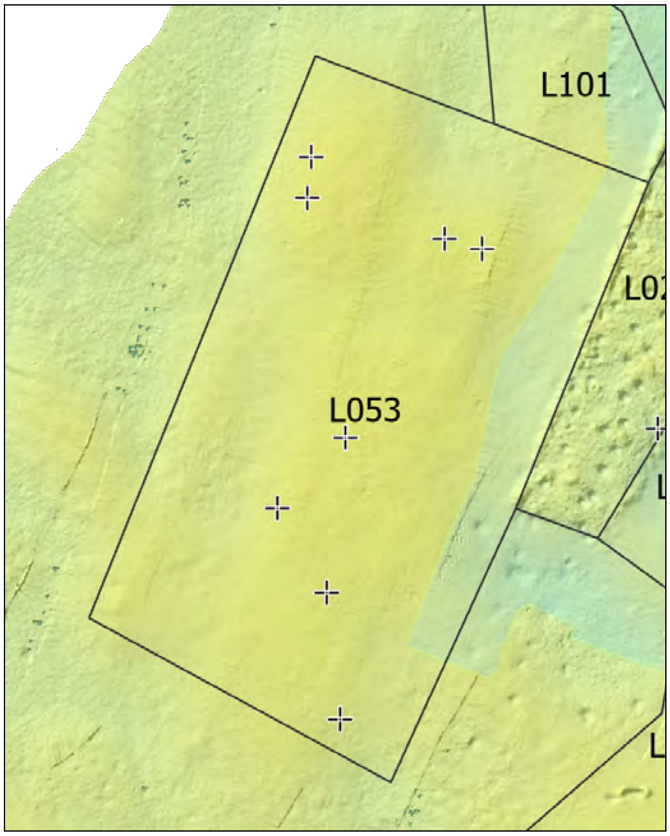

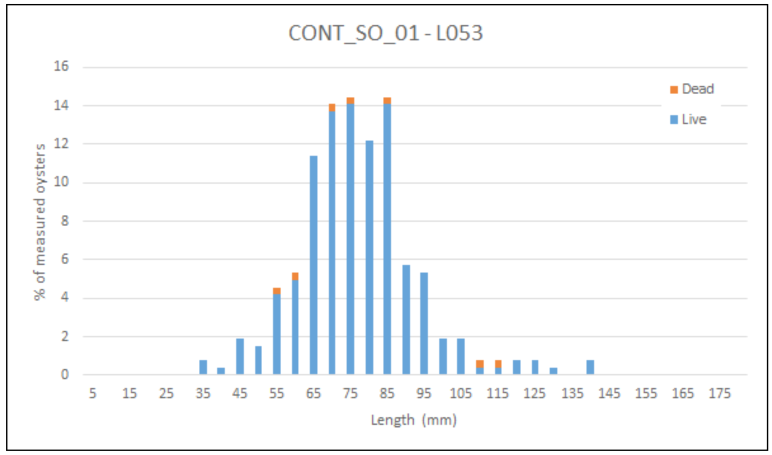

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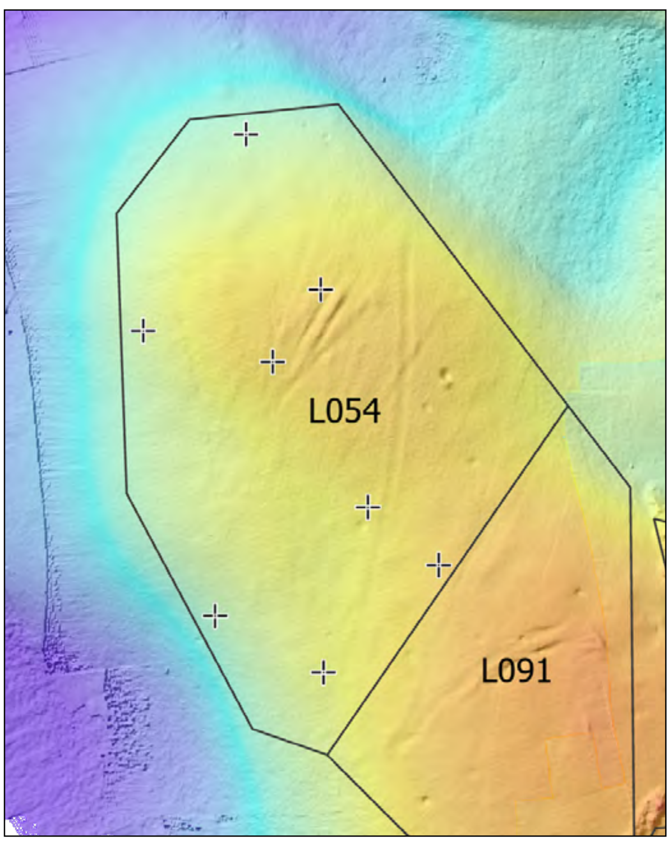

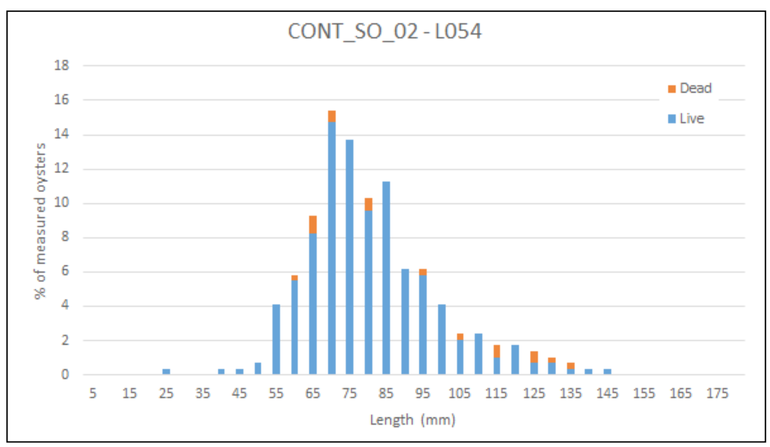

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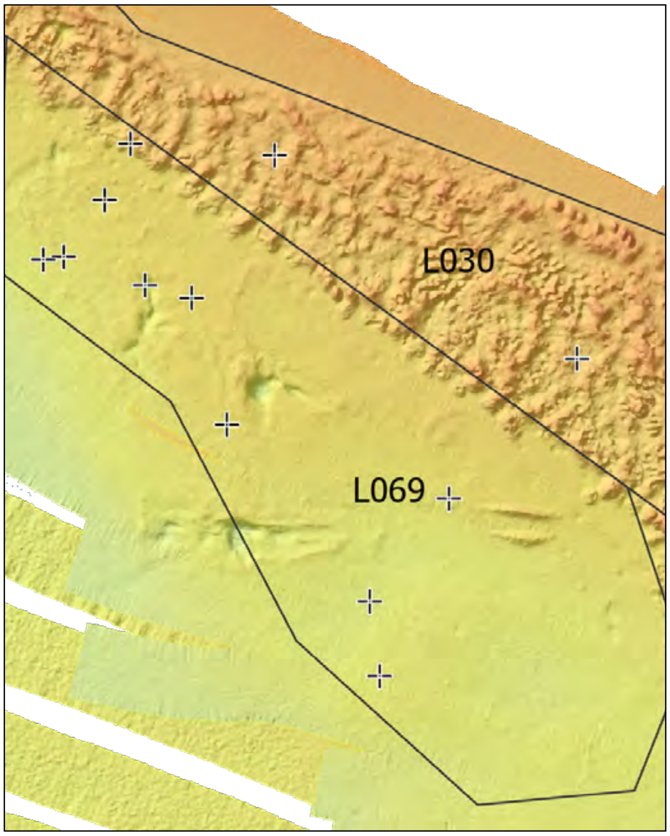

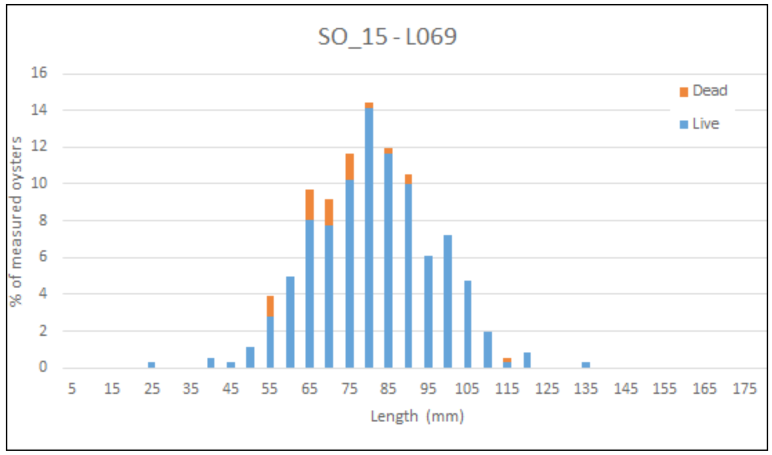

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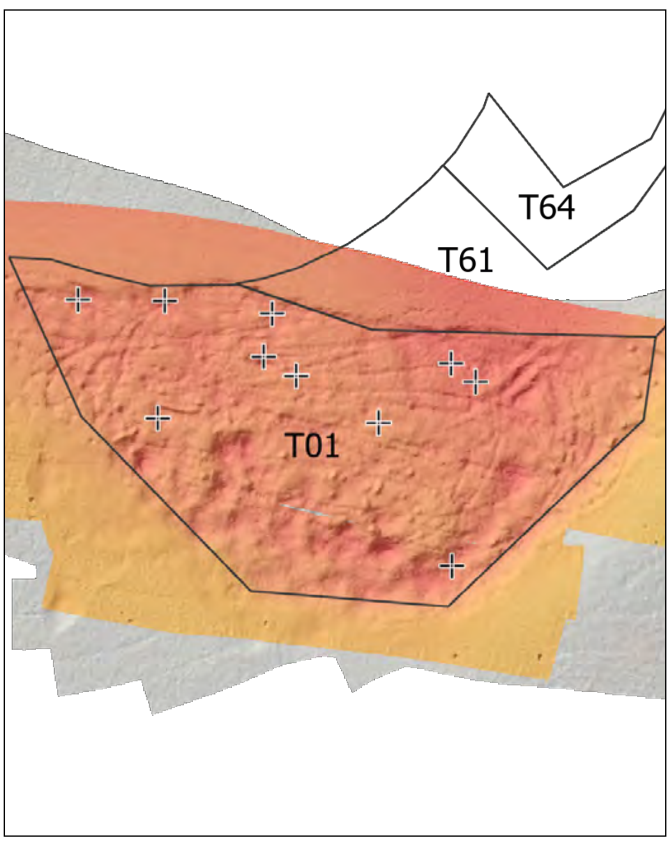

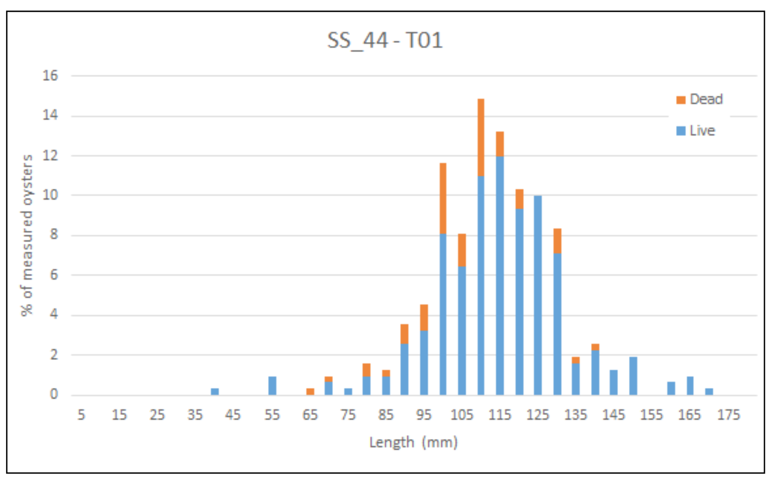

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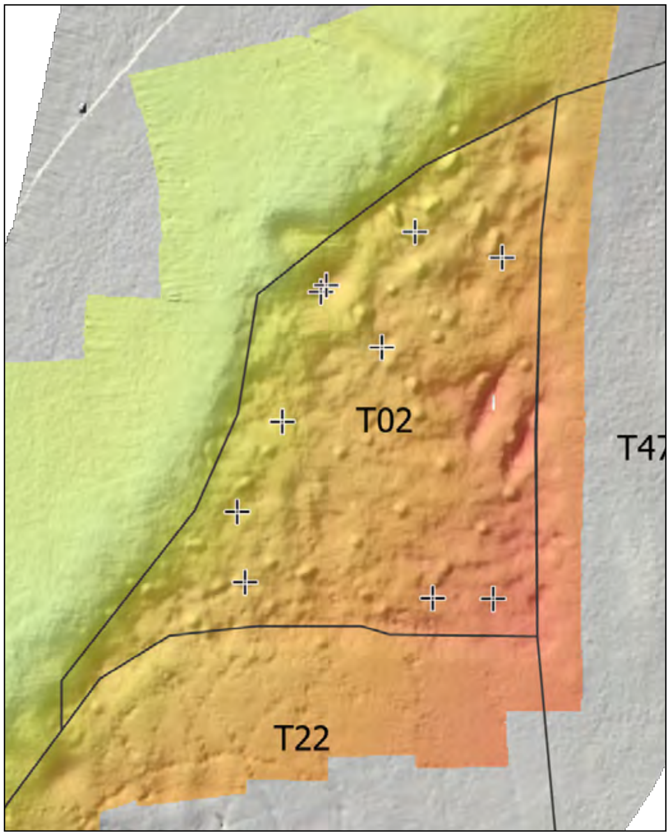

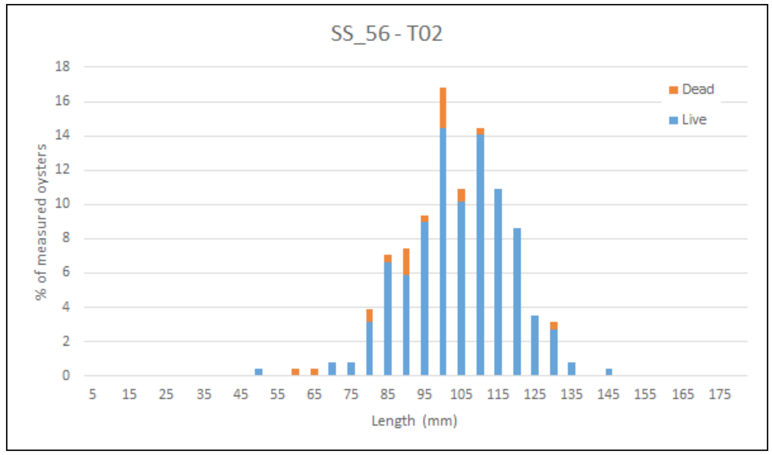

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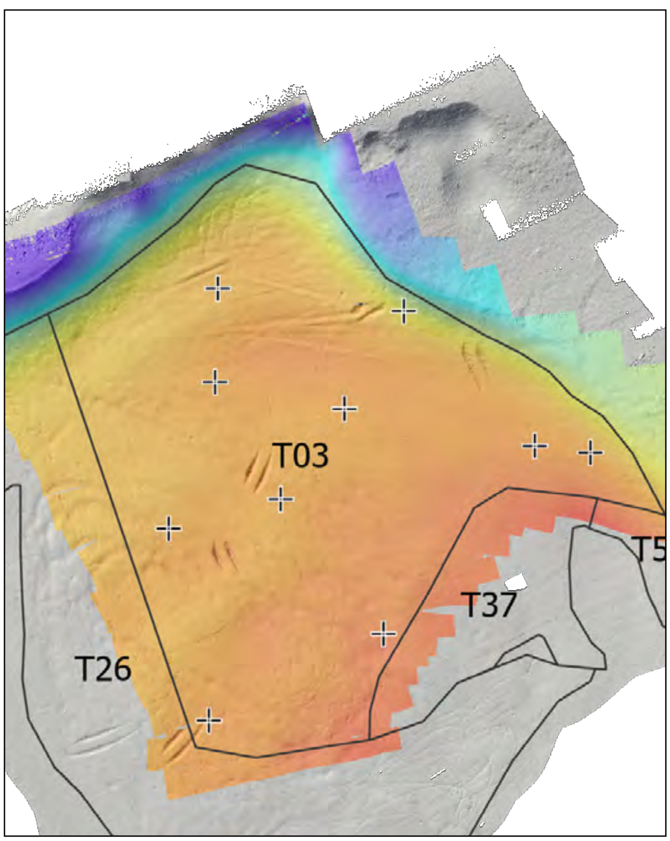

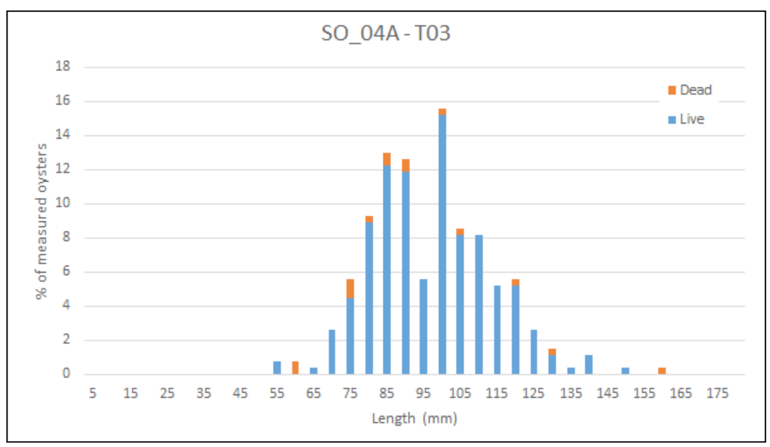

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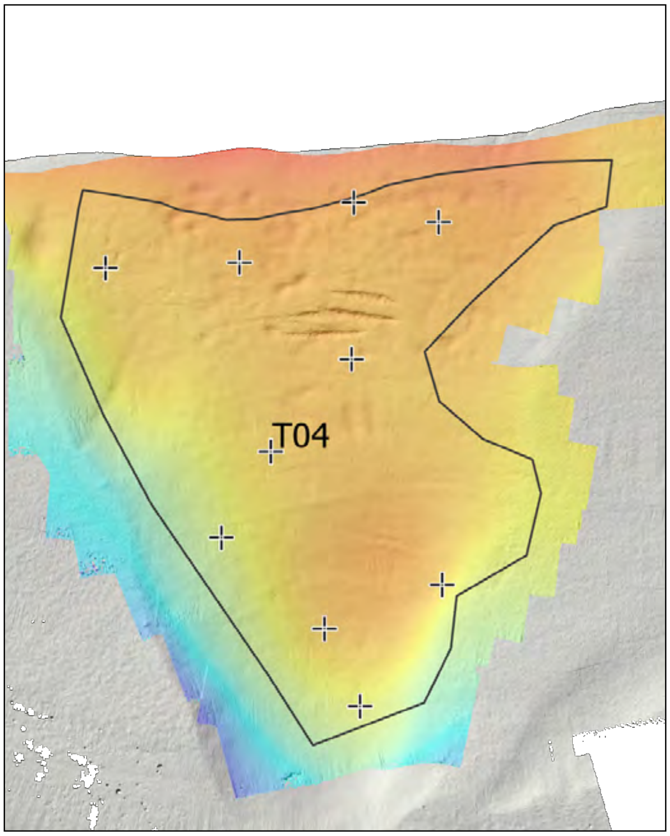

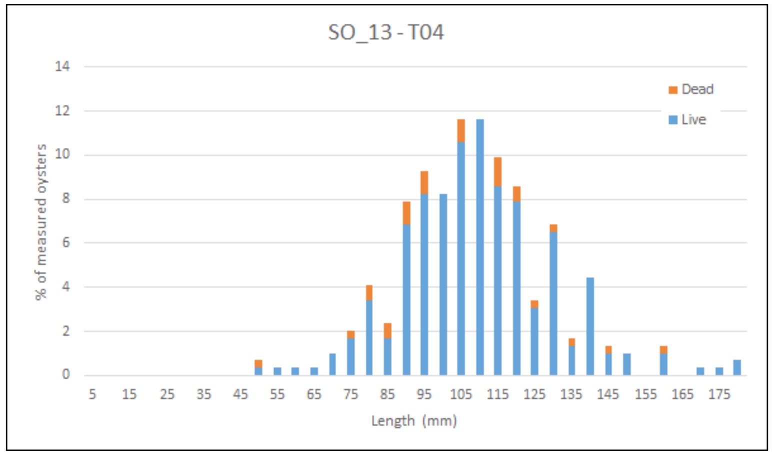

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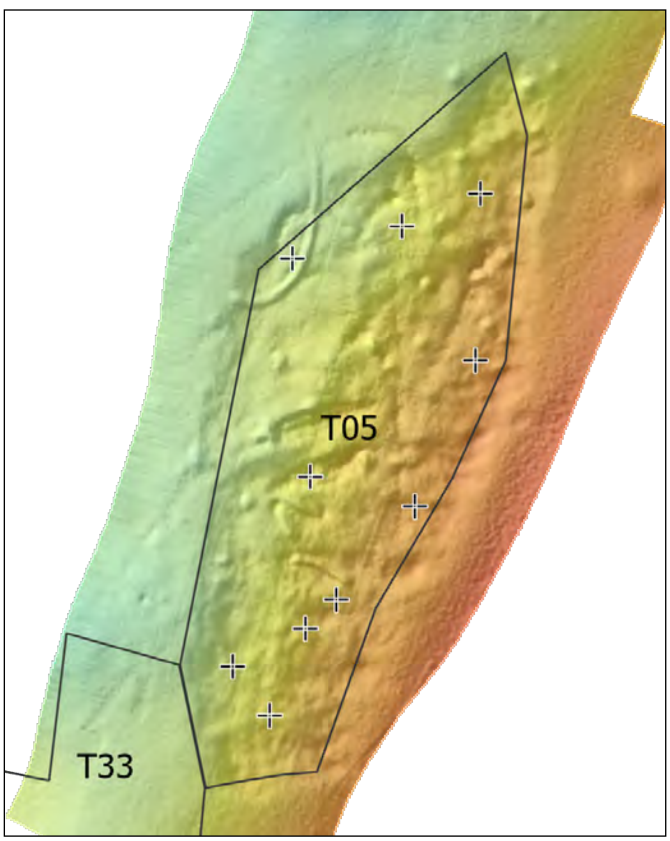
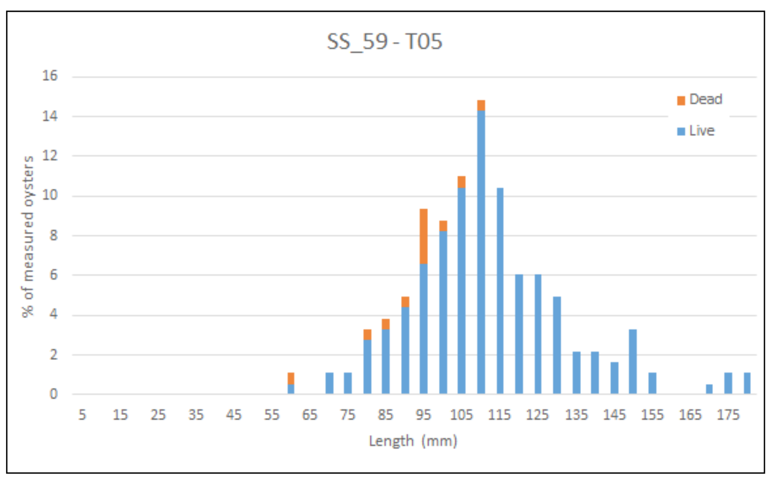
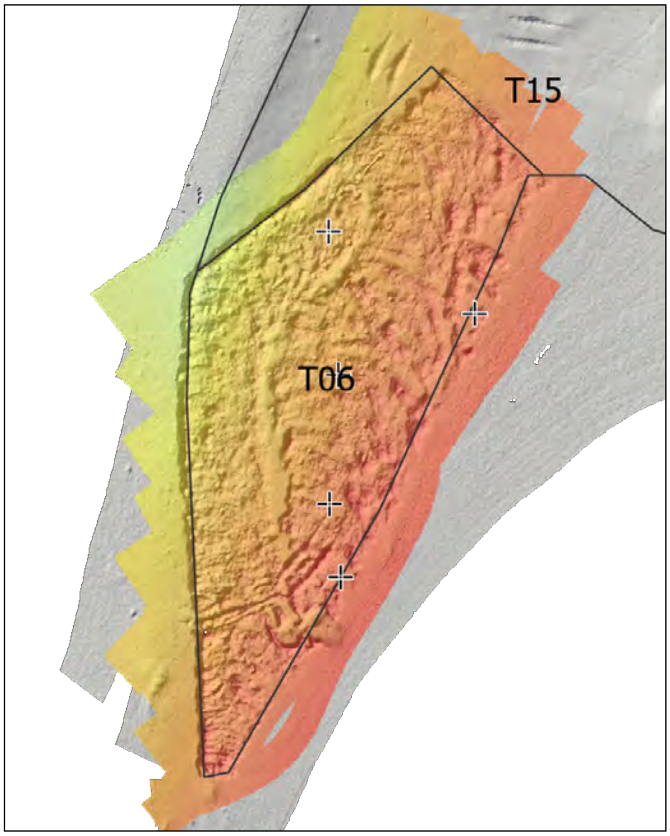
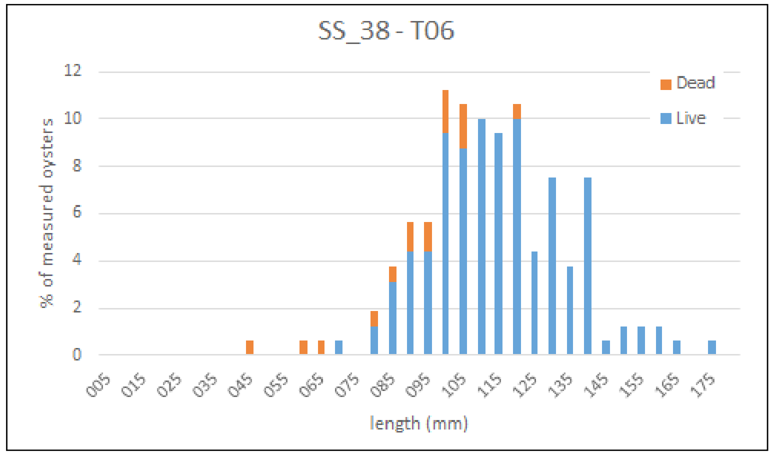




Reef T06





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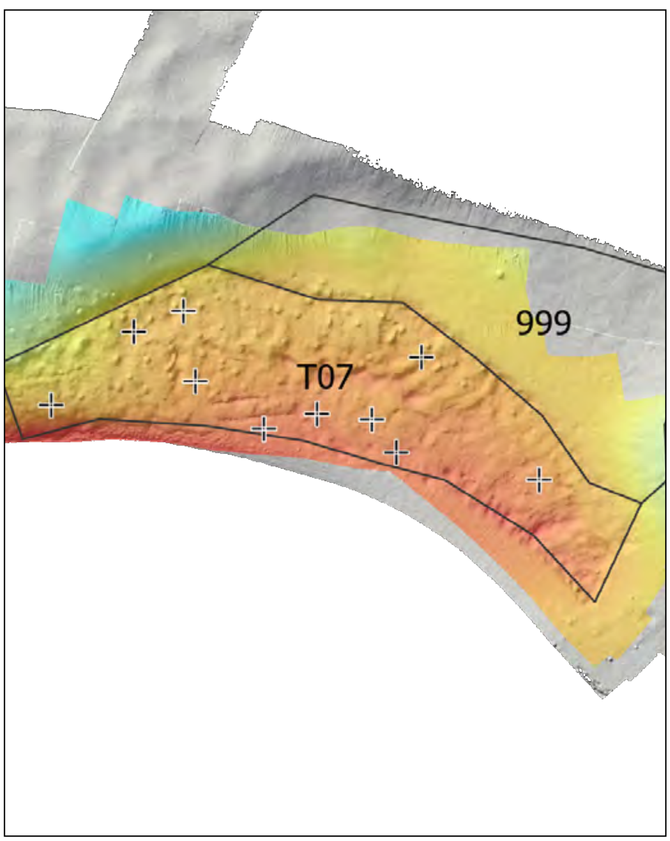

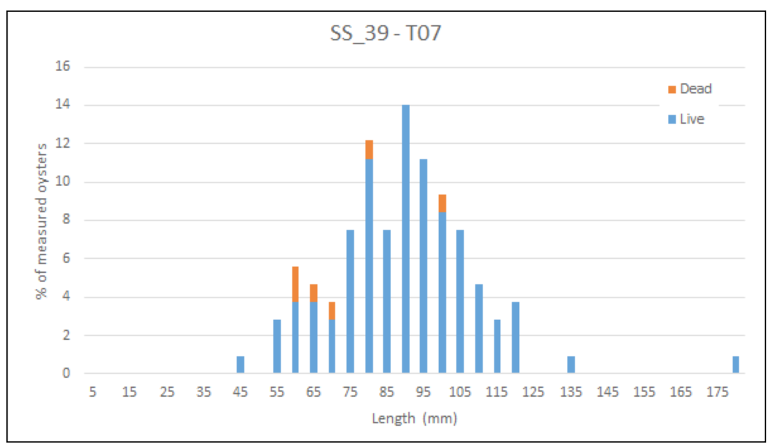

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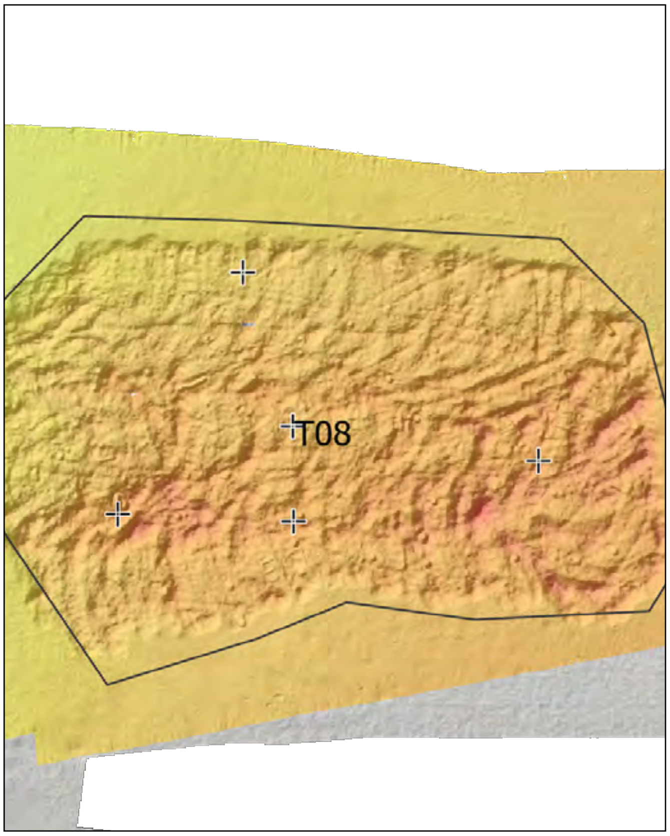

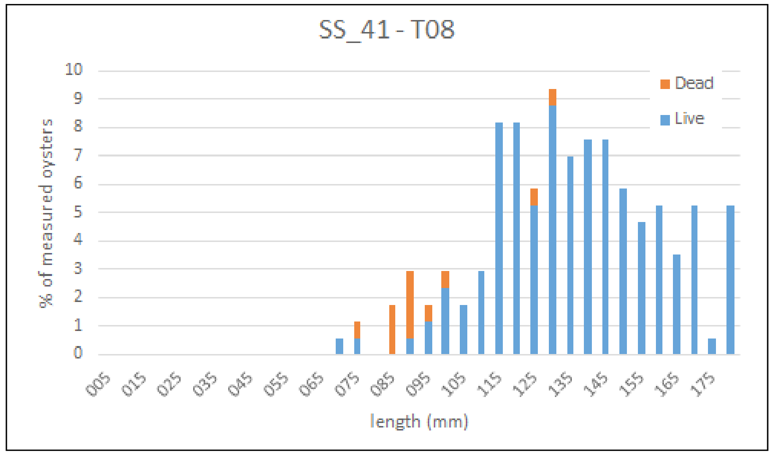

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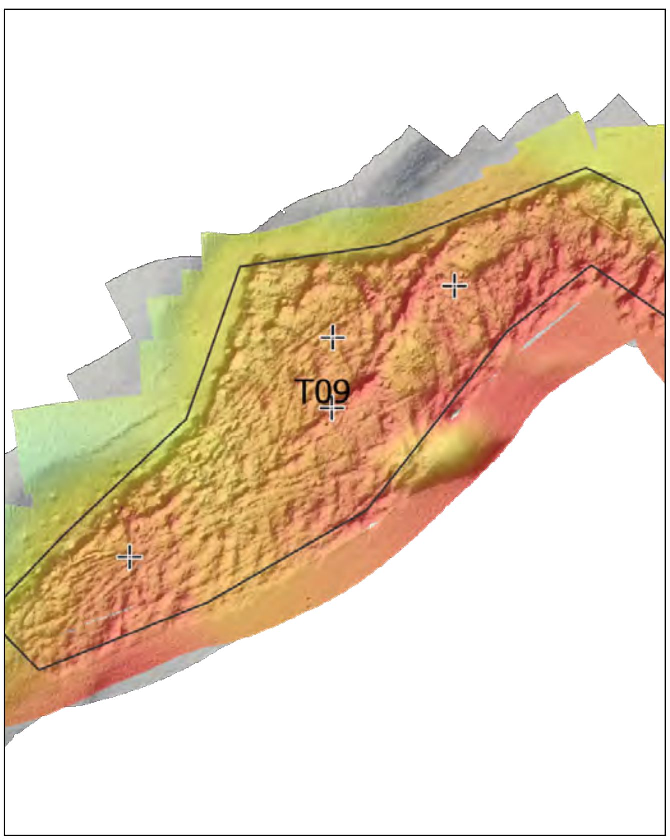

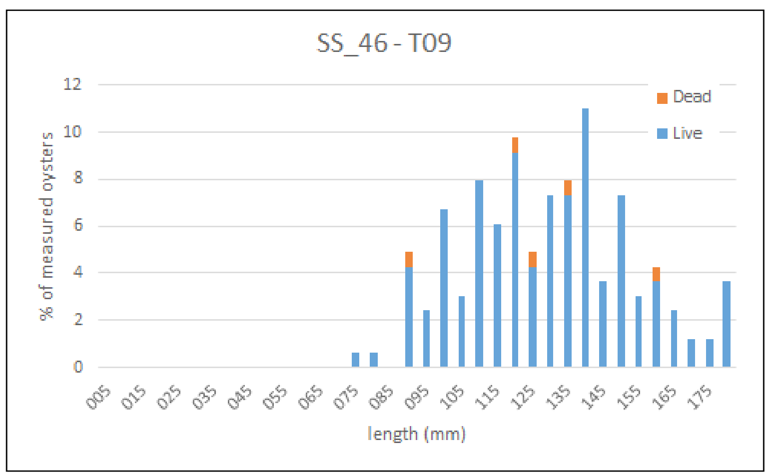

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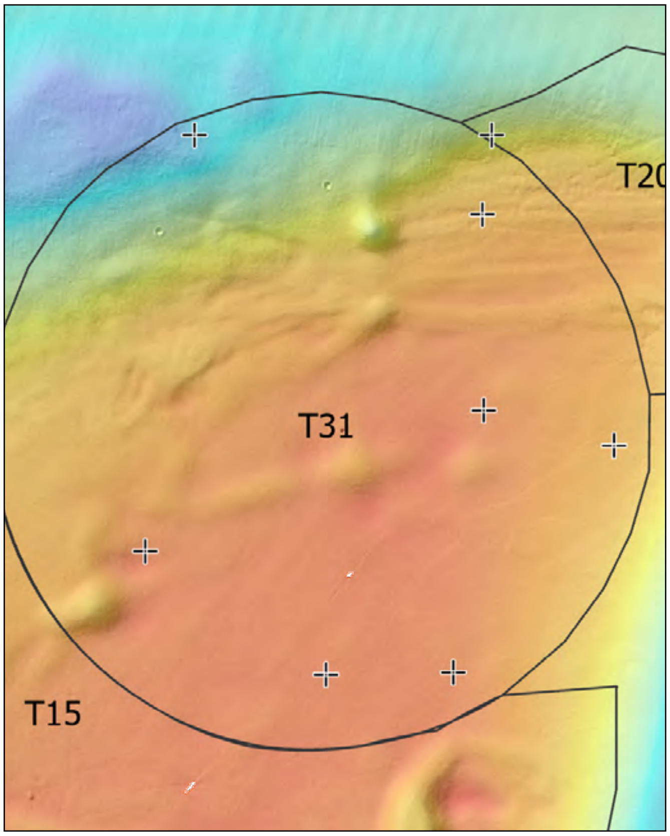

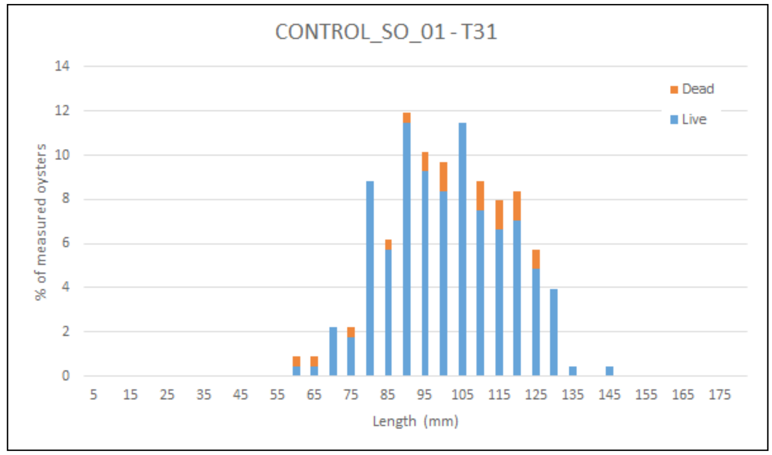

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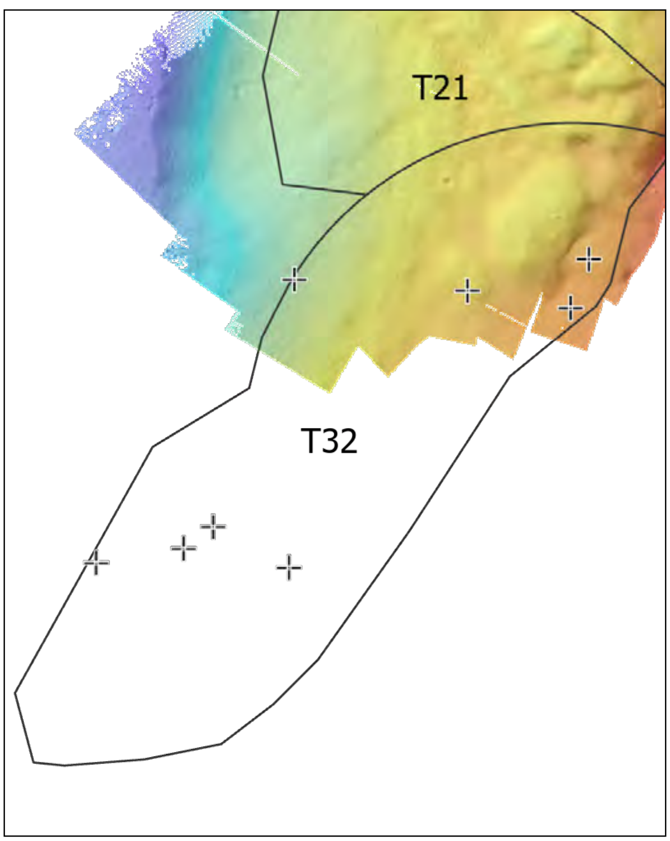
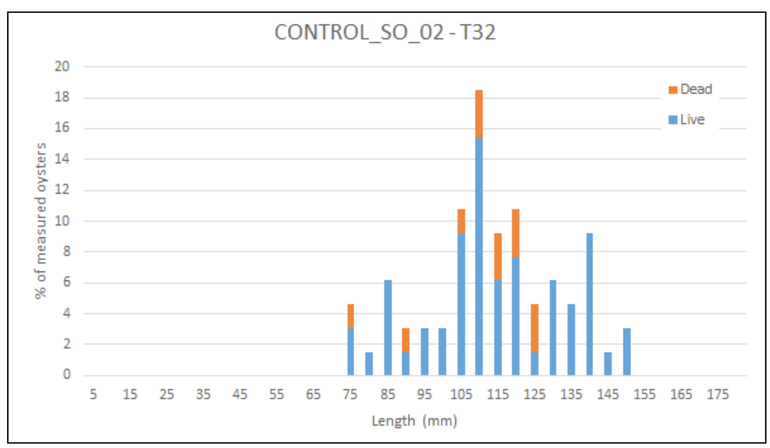
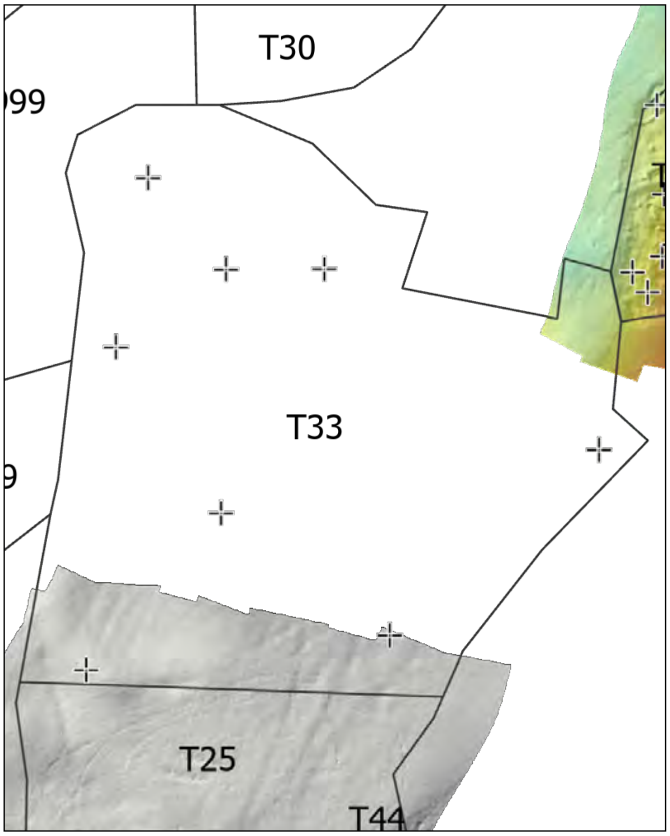
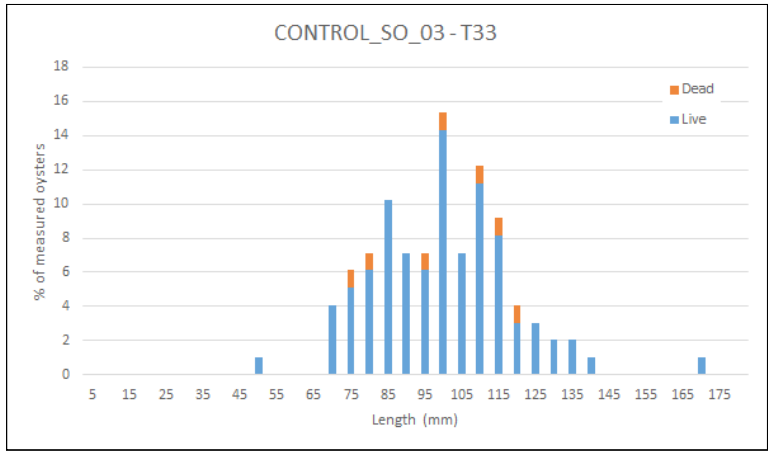




Sonar images not produced annually on all sentinel reefs.

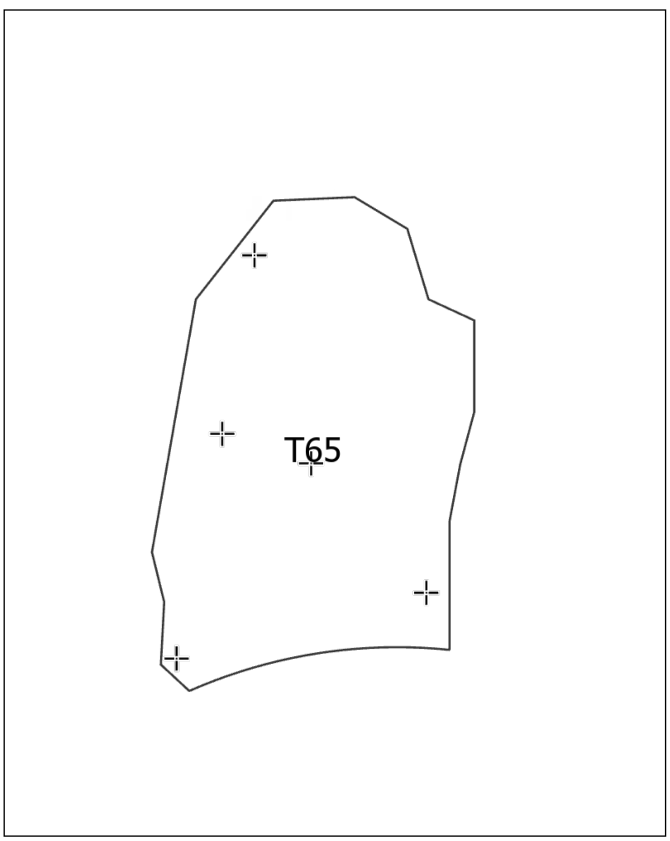
Reef T33

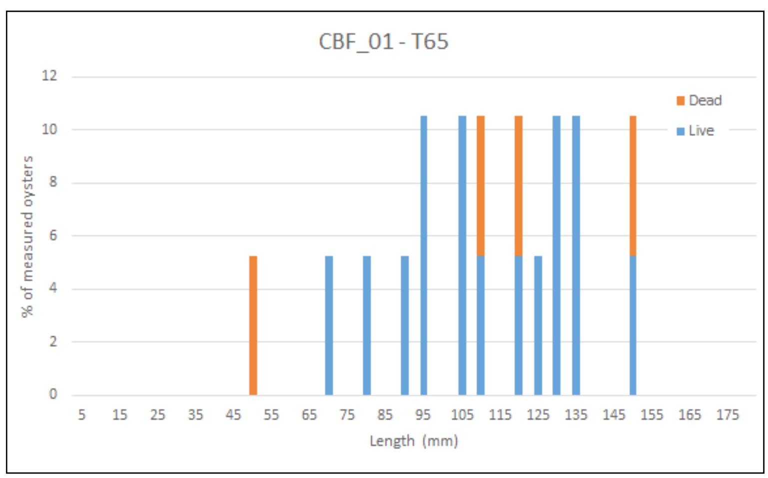




Sonar images not produced annually on all sentinel reefs.

Reef T65





Oyster gardening reef—no sonar image produced in 2019.

Funding for the data collection and analysis in this report was provided by the NOAA Chesapeake Bay Office and the U.S. Army Corps of Engineers' Baltimore District.

This report is available online at https://www.chesapeakebay.net/who/publications-archive/maryland_and_virginia_oyster_restoration_interagency_teams

Cover photo: Oyster survey work. Photo: Oyster Recovery Partnership.

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Data on biological metrics (oyster density, oyster biomass, presence of multiple year classes, shell budget)

- Ward Slacum, wslacum@oysterrecovery.org

Placing substrate to form a reef in Harris Creek. Photo: NOAA Chesapeake Bay Office.