Nearshore Habitat Mapping in Atlantic Canada: Early Results with High Frequency Side-scan Sonar, Drop and Towed Cameras

H. Vandermeulen

Fisheries and Oceans Canada
Science Branch, Maritimes Region
St. Andrew's Biological Station
531 Brandy Cove Road
St. Andrew's, N.B.
E5B 2L9

2014

Canadian Technical Report of Fisheries and Aquatic Sciences 3092

Fisheries and Oceans Canada / Pêches et Océans Canada

Canada

Canadian Technical Report of
Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1 - 456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457 - 714 were issued as Department of the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des
sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais que ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les scences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon regional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 3092

2014

NEARSHORE HABITAT MAPPING IN ATLANTIC CANADA: EARLY RESULTS WITH HIGH FREQUENCY SIDE-SCAN SONAR, DROP AND TOWED CAMERAS

by

H. Vandermeulen

Fisheries and Oceans Canada
Science Branch, Maritimes Region
St. Andrew's Biological Station
531 Brandy Cove Road
St. Andrew's, N.B.
E5B 2L9

E-mail: herb.vandermeulen@dfo-mpo.gc.ca

This is the three hundred and thirteenth Technical Report
of the St. Andrews Biological Station.

Cat. No. Fs 97-6/3092E-PDF ISBN 978-1-100-23933-0 ISSN 1488-5379

Correct citation for this publication:

Vandermeulen, H. 2014. Nearshore habitat mapping in Atlantic Canada: Early results with high frequency side-scan sonar, drop and towed cameras. Can. Tech. Rep. Fish. Aquat. Sci. 3092: vi + 16 p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Vandermeulen, H. 2014. Nearshore habitat mapping in Atlantic Canada: Early results with high frequency side-scan sonar, drop and towed cameras. Can. Tech. Rep. Fish. Aquat. Sci. 3092: vi + 16 p.

Important aspects of benthic habitat structure occur at the sub-meter scale in the nearshore. A ‘first generation’ of equipment and methods was utilized to map this zone at the appropriate scale. The approach was to use a small twin engine vessel equipped with an inexpensive high frequency side-scan sonar ground-truthed by a drop camera or SCUBA, and a transponder positioned towed camera. The geographic positioning accuracy and very shallow (to 1 m) operating capability are novel aspects of the equipment and its application. Example results are presented for a variety of nearshore marine habitats in Atlantic Canada.

RÉSUMÉ

Vandermeulen, H. 2014. Cartographie des habitats côtiers au Canada atlantique : Résultats préliminaires obtenus à l'aide d'un sonar à balayage latéral haute fréquence et de caméras sous-marines et remorquées. Can. Tech. Rep. Fish. Aquat. Sci. 3092: vi + 16 p.

Des aspects importants de la structure de l'habitat benthique sont observés à l'échelle submétrique près du littoral. Une « première génération » d'équipement et de méthodes a été utilisée pour cartographier cette zone à l'échelle appropriée. L'approche consistait à utiliser un petit navire biturbine équipé d'un sonar à balayage latéral haute fréquence peu coûteux vérifié au sol par une caméra sous-marine ou par plongée, et d'une caméra remorquée positionnée par transpondeur. La précision du positionnement géographique et une capacité opérationnelle en eaux très peu profondes (jusqu'à 1 m) sont les aspects novateurs de l'équipement et de son application. Des exemples de résultats sont présentés pour divers habitats marins côtiers du Canada atlantique.

INTRODUCTION

Nearshore studies (<30 m and particularly <10 m depth) to map benthic habitat have emulated deep-water equipment with inexpensive substitutions in pressure casings with shallow depth ratings (e.g. Stevens and Connolly 2005; Collier and Humber 2007; Griffith et al. 2010; Stolt et al. 2011). Very often, however, these nearshore efforts lack accurate geographic positioning. GPS is often used instead of full dGPS (e.g. Kaeser and Litts 2008; Gonzalez-Socoloske et al. 2009) which creates an accuracy difference of meters versus centimeters. Nearshore studies also rarely consider the position of towed equipment behind the vessel, using layback calculations at most (e.g. Hewitt et al. 2004; Stevens and Connolly 2005; Collier and Humber 2007; Stolt et al. 2011).

Transponders are almost never attached to towed gear in shallow water situations. It can be argued that towed equipment will usually be very close to a vessel's GPS antenna in shallow water, and the difference in position is not significant. However, the author has frequently experienced towed gear slewing 10 m or more behind a vessel due to waves and current in waters as shallow as 5 m.

The marine nearshore of eastern Canada is a patchy and dynamic environment. Important aspects of benthic habitat structure and function occur at the sub-meter scale in this zone. Equipment and methods to map the nearshore must be appropriate for that scale.

Mapping results from a relatively inexpensive high precision (sub-meter) system are described here for the placement of nearshore bottom features to a geographic accuracy of approximately 2 m. Capital costs were kept low by using off the shelf components designed with modest depth ratings.

2.0 MATERIALS AND METHODS

2.1 Side-scan and Drop Camera

Details of equipment specifications and manufacture are found in Vandermeulen (2007). A sturdy 6.7 m long 'Cape Sable' style inshore vessel (high sharp bow, low flat stern, 46 cm draft) was fitted with 50 hp twin outboard engines and large low pitch propellers for controlled towing at slow speeds in shallow water. All electronics were placed in the wheelhouse and powered by a deep cycle battery / gel power pack system (12 V DC and 120 V AC outputs). A stern davit for deploying equipment was mounted with a dGPS antenna (Trimble® DSM™ 132 with beacon correction). A 'break-away' arm was mounted on a pivot at the base of the davit post to deploy equipment in the water. The arm extended vertically just below keel depth and moved equipment out of harm's way if an underwater obstacle was struck.

A dual high frequency (330 or 800 kHz) Imagenex (Port Coquitlam, British Columbia) SportScan side-scan was fixed to the base of the arm such that the transducers were located directly below the dGPS antenna. The side-scan was typically run at 800 kHz and 8 dB gain with a 30 m swath width to provide the best possible image detail.

Vessel speed was approximately 2-3 knots, and it was possible to survey in water as shallow as 1 m, and as deep as 10 m (the acoustic 'shadow' directly below the side-scan would become too large in deeper water). Side-scan data was post processed with a mosaic software package (SonarWeb Pro side-scan mosaic software, Chesapeake Technology Inc., Mountain View, California) to generate GeoTIFF images that were embedded into ArcGIS projects with hydrographic chart background layers.

A simple drop camera system was developed to ground-truth the side-scan imagery. An inexpensive 12 volt color camera in a plastic housing was placed in a folding tripod. Twin lasers mounted on the tripod provided a 10cm scale along the line of sight, which was a vertically downwards view. Video clips taken with the camera covered a bottom area of 50 X 75 cm.

Once the vessel was on target (using a navigation computer at the helm) the extended tripod was lowered over the side via the davit and the engines were reversed just prior to the tripod hitting bottom, to ensure vertical cable alignment. Therefore, the camera was directly under the dGPS antenna when video clips were collected. The operational depth for this system was the same as for the side-scan; 1 to ~10 m. It became too unwieldy to ensure vertical cable alignment in waters >10 m depth.

Position data from the dGPS was sent to a video overlay and added to the video stream from the camera, the output was recorded on a miniDV camera. In this manner, each frame of video included true geographic position of the camera plus time and date stamp. The miniDV tape format is digital, and the tapes were post processed into short clips (approximately 15s per camera drop) in AVI format to provide moderate resolution data (720 X 480). The AVI files were embedded as georeferenced clickable points in the same ArcGIS projects as the side-scan images.

2.2 Towed Camera

A more complicated towed camera system was developed for stand-alone habitat classification work. The video camera was a moderately priced unit designed for underwater work (model SV-16, Shark Marine, Burlington, Ontario). It was attached to a depressor wing along with the 10 cm laser scale and a transponder from a TrackLink 1500LC acoustic positioning system (LinkQuest Inc., San Diego, California). The camera and lasers were protected by a stainless steel cage bolted to the underside of the wing. The camera view was forward, covering approximately 1 to 2m width with a slight downwards angle. The TrackLink transceiver was mounted to the breakaway arm (i.e. the transceiver was directly under the dGPS antenna during camera tows). The transceiver positioning beam was 3º, which is quite adequate in the shallow waters where the camera was deployed (1 to >10 m, depth limited by the length of our cable at 30 m – not the pressure rating of the transponder or camera). Tow speeds were typically one or two knots.

The towed camera wing was deployed by looping its support cable (Kevlar® strength layer plus internal wires for power and video feed back to the wheelhouse) over a custom made plastic clutch block (30.5 cm diameter) which spun clockwise to allow the cable and wing to be pulled into the boat, but locked on counter-clockwise spin as the cable was played out and over the side. The locking action of the clutch block held the wing in position as it was towed, relieving most of the strain on the operator holding the cable (i.e. there was no powered slip-ring winch). The wing was lowered via the cable slipping over the plastic surface of the locked block. There was just enough friction to slip the cable out as required and then to hold it in place for the tow. The operator made slight angle changes to the cable relative to the clutch block on the davit to control the level of friction and ‘hold’.

The heart of the towed camera system was a transceiver notebook computer equipped with multiple COM ports via PCMCIA cards. Position data from the dGPS was sent to the transceiver computer along with digital compass and transceiver data feeds. The transceiver computer then calculated true camera geographic position and sent that data to the video overlay for insertion into the video stream, as well as to a file that recorded the camera track and depth over time. The overlay output was recorded on a miniDV recording consul. A separate feed from the consul went to a video monitor so the camera operator could view the camera output in real time and pull on the cable to raise or lower the wing for appropriate height off bottom and to avoid obstacles.

As per the drop camera, the miniDV tapes recorded with the towed camera were post processed into clips. However, the towed camera AVI clips were longer (~ 10 minutes each). The AVI files were embedded as georeferenced clickable points along the camera tow line which was itself overlain in the same ArcGIS project as the side-scan images.

2.3 Study Area

Our side-scan and camera systems were tested at a number of sites representing a range of nearshore habitats from Atlantic Canada (Fig. 1). The first site, St. Andrews, is in the Bay of Fundy where the tidal range is over 7 m. The harbour bottom is composed of rocky outcrops in the shallows, grading to gravel at the low tide mark with sand in the subtidal. The rockweed *Ascophyllum nodosum* (L.) Le Jol., dominates the rocky intertidal. Deeper waters contain much lower densities of macrophytes, and a mix of red and brown algae predominate.

Sambro is on the Atlantic coast of Nova Scotia and the tidal range is approximately 2 m. Rocky outcrops dominate the intertidal, rapidly turning to sand / silt in deeper waters. Rockweed is common in the intertidal, with a mix of brown / red algae down to about 9 m, where *Desmarestia* J.V. Lamour. can become common.

River Denys Basin is a protected, shallow enclosed bay in the rural western area of the Bras d’Or Lakes, Cape Breton. The basin is atidal, and most of the shore is gently sloping sand / mud which continues at depth. Macrophyte cover is sparse, although some extensive eelgrass (*Zostera marina* L.) meadows can be found nearshore.

Wrights Cove is a highly urban / industrial inlet off of Halifax harbour. The cove has a rocky / gravel shoreline (~ 2 m tides) grading to sand / mud at depth. Rockweed occurs in the intertidal, with very little macrophyte cover in the subtidal. Navy Island

Cove occurs as a shallow inlet off the south end of Wrights Cove. Navy Island Cove is less developed than Wrights, and it supports a salt marsh.

McNabs Island rests at the mouth of Halifax harbour. The island has a variety of nearshore habitats, ranging from exposed steeply sloping gravel shores with abundant algal cover from intertidal to deep subtidal (where *Agarum clathratum* Dumort. is dominant) to shallow sandy bays with dense eelgrass beds.

New London Bay is a broad estuary receiving inputs from several watersheds. Agricultural impacts include elevated nutrient concentrations in rivers and streams in the area, and the head of the estuary suffers from hypereutrophic conditions. The estuary is shallow with a sand / gravel bottom largely overrun with *Ulva* L. mats (both live and rotting) during the summer months.

3.0 RESULTS

3.1 Side-scan and Drop Camera

The side-scan has proved to be very useful for discerning soft versus hard bottoms, and three dimensional bottom features. The GeoTIFF images were produced so that soft bottoms with low acoustic reflectivity were indicated as dark brown, while acoustically reflective hard surfaces (e.g. rocks, pilings, debris) were light brown to yellow. The hardness contrast is illustrated in Fig. 2 (left panel) where large (3 to 5 m diameter) piles of shell show up as bright circular domes against an otherwise featureless soft mud bottom. Even though this site is only about 2m deep, the water was too murky to identify the piles visually and drop camera images were not useful. The shell piles were verified by SCUBA observations. The piles were consistent in size and shape with piles of oyster shell (bioherms) discovered recently in deeper (~ 5 to 8 m) portions of the basin (G. Bugden, pers. comm.).

Figure 2 (right panel) is an example of the side-scan's ability to define three dimensional bottom structure. Steep sided 'pits' or trenches were observed in an otherwise smooth hard packed sand bottom in 2 to 3 m of water. Later observations by snorkelling in the area determined that the trenches were about 2 m deep and flat bottomed. The sides of the trenches were highly unusual in that they were composed of tightly intertwined dead branches and tree trunks forming a solid and near vertical wall. The trenches may represent erosional features formed after a relict forest was inundated by the sea and covered by sand as the Bras d'Or Lakes developed after the last glaciation (J. Shaw, pers. comm.).

An experimental deployment of Reef Balls™ (hollow cement artificial reef units approximately 1 m diameter) at McNabs Island provided an interesting target for the side-scan (Fig. 3). The left panel of the figure shows two rows of the spherical units, one row longer than the other, on a sandy flat bottom at about 5 m depth. The right side of that panel also indicates patches of eelgrass on a sandy / gravel bottom right near shore (~ 1m depth). The eelgrass shows up as 'clouds' with an acoustic shadow distal to the center line of the side-scan swath indicating the edge of the eelgrass patch (ground-truthed by drop camera and SCUBA). Eelgrass is highly acoustically reflective (bright in the images), due to the presence of air chambers (lacunae) in the leaves. Indeed, a dense eelgrass bed can resemble hard sand in the GeoTIFFs, which reinforces the need for ground-truthing via the drop camera. The right panel of Fig. 3 was taken in Wreck Cove on McNabs Island, through a dense eelgrass bed. The abrupt change in acoustic reflectivity (bright to dark in the GeoTIFF) represents the edge of the eelgrass bed at about 3m depth. The drop camera confirmed the presence of eelgrass and 'bare' bottom types in both locations in Fig. 3.

Figure 4 (top panel) indicates the complex bottom topography of the mid-section of Navy Island Cove due to natural cobble / rock reefs and large solitary boulders (some over 1m diameter). The relatively featureless bottom of Cook Head (Fig. 4 bottom panel) is contrasted by the orderly placement of piles of cobble (bright patches) to artificially enhance topography and attract benthic organisms to this site. The flat sand/mud bottom at Cook Head was confirmed by drop camera video clips.

Overall, the side-scan imagery was useful to describe bottom features at all sites. However, it was exacting work to ground truth the imagery with drop camera or SCUBA based observations. The vessel had to return to the side-scan track and it took considerable skill at the helm to position on target via the navigation computer for the ground truthing observations. Also, the acoustic shadow formed in the center line of the side-scan imagery in deeper waters proved frustrating for mapping purposes.

3.2 Towed Camera

Much larger areas could be covered with the towed camera versus the side-scan / drop camera over a similar time span. It was also possible to quantify bottom type information recorded by the towed camera. Table 1 provides an example of the analysis of video clips taken in New London Bay. The bay was overrun with *Ulva* mats due to eutrophication and only a few patches of eelgrass remained. The camera was towed along the mid-line of the main channels of the upper bay. Each ten minute segment of video was observed and time stamp and positional data recorded over short time intervals or when the bottom type or cover changed. In this example, the cover was uniformly 'sparse' *Ulva* with a patch of eelgrass. Figure 5 illustrates the three point abundance scale created to classify the presence of *Ulva* in the bay. All video clips were viewed and coded as in Table 1, with the resulting map shown in Fig. 6.

A similar analysis was applied to the abundance of sea cucumbers (*Cucumaria frondosa* Gunnerus) off St. Andrews. A trawl fishery for sea cucumber exists in the area, and a trawler had worked the bottom just prior to running towed camera transects perpendicular to the trawl tracks. A three point scale of sea cucumber abundance was created, along with evidence of fishing via trawl marks (Fig. 7). The resulting maps are shown in Fig. 8.

The towed camera system afforded a 'one pass' method to obtain information on bottom features in nearshore areas. By replacing side-scan transects with towed camera transects in a survey, a field team need only be deployed to a site once (i.e.

no further ground truthing required). However, the towed camera only had a 1 to 2m width of view, while the sidescan provided information over a 30m swath. The towed camera system was also much more expensive than the side-scan / drop camera equipment due to the transceiver / transponder hardware.

DISCUSSION

Focussing upon the true geographic placement of gear is important for shallow benthic surveys. More accurate maps are created as a result. We attained geographic accuracy for our surveys in three ways, side-scan fixed to dGPS antenna position; drop camera aligned to dGPS antenna position while recording; and an accurate transponder / transceiver positioning system for the towed camera.

All acoustically obtained benthic habitat data needs to be ground-truthed. Our side-scan, for example, can ‘confuse’ hard packed sand with dense, continuous eelgrass. For this reason, all of our side-scan imagery was compared to drop camera or SCUBA observations.

The method of equipment deployment and the shallow draft of the support vessel allowed benthic surveys in just one meter of water. Shallow operational capability is very important in atidal or low tide range areas where it may be necessary to cover many hectares of bay / estuary in turbid waters only 1 – 4 m deep.

A ‘next generation’ of equipment and methodology has been developed by our laboratory following the ‘first generation’ described in this paper. A new towfish was developed which fused sidescan and video capabilities (Vandermeulen 2011a), followed by the addition of an echosounder (Vandermeulen 2011b). A studio quality high definition video system is presently our newest update to the towfish.

ACKNOWLEDGMENTS

The Atlantic Canada base map data for Fig. 1 is courtesy of DMTI Spatial Inc., ESRI GIS & Mapping Software. The shoreline base map data for New London Bay (Fig. 6) is courtesy of the Department of Environment, Energy & Forestry, Land Resource Modelling Section, Prince Edward Island. Sean Steller assisted in the field and with data analysis.

REFERENCES

Collier, J.S., and S.R. Humber. 2007. Time-lapse side-scan sonar imaging of bleached coral reefs: A case study from the Seychelles. Remote Sens. Environ. 108: 339-356.

Gonzalez-Socoloske, D., Olivera-Gomez, L.D., and R.E. Ford. 2009. Detection of free-ranging West Indian manatees *Trichechus manatus* using side-scan sonar. Endanger. Species Res. 8: 249-257.

Griffith, D.W., Peery, C.A., Daigle, W.R., Keefer, M.L., and N. Wright. 2010. Development of a multipurpose telemetry and habitat survey instrument platform for small boats. Mar. Coast. Fish. Dyn. Manag. Ecosys. Sci. 2: 299-303.

Hewitt, J.E., Thrush, S.F., Legendre, P., Funnell, G.A., Ellis, J., and M. Morrison. 2004. Mapping of marine soft-sediment communities: Integrated sampling for ecological interpretation. Ecol. Appl. 14: 1203-1216.

Kaeser, A.J., and T.L. Litts. 2008. An assessment of deadhead logs and large woody debris using side scan sonar and field surveys in streams of southwest Georgia. Fisheries 33: 589-597.

Stevens, T., and R.M. Connolly. 2005. Local-scale mapping of benthic habitats to assess representation in a marine protected area. Mar. Freshwater Res. 56: 111-123.

Stolt, M., Bradley, M., Turenne, J., Payne, M., Scherer, E., Cicchetti, G., Shumchenia, E., Guarinello, M., King, J., Boothroyd, J., Oakley, B., Thornber, C., and P. August. 2011. Mapping shallow coastal ecosystems: A case study of a Rhode Island Lagoon. J. Coastal Res. 27: 1-15.

Vandermeulen, H. 2007. Drop and towed camera systems for ground-truthing high frequency sidescan in shallow waters. Can. Tech. Rep. Fish. Aquat. Sci. 2687: v + 17 p.

Vandermeulen, H. 2011a. Mapping the nearshore using a unique towfish. Can. Tech. Rep. Fish. Aquat. Sci. 2959: v+ 18p.

Vandermeulen, H. 2011b. An echosounder system ground-truthed by towfish data: A method to map larger nearshore areas. Can. Tech. Rep. Fish. Aquat. Sci. 2958: v+ 21p.

Table 1: Video analysis method. Digital video segments examined for *Ulva* abundance (in this example all segments indicate ‘A’ or sparse *Ulva*) and the presence / absence of eelgrass (*Zostera*). Each TrackLink generated time stamp on the video corresponds to unique camera coordinates, so a map of *Ulva* and eelgrass can be made.

Video Segment	Time	Latitude	Longitude	*Ulva*	Eelgrass
1	12:34:54	46,27.716658	-63,27.631403	A	no
	12:36:01	46,27.704459	-63,27.648414	A	no
2	12:42:29	46,27.617459	-63,27.730594	A	no
3	12:52:38	46,27.494440	-63,27.927924	A	no
	12:55:37	46,27.445523	-63,27.952996	A	yes
	12:58:25	46,27.396631	-63,27.913226	A	yes
	13:00:08	46,27.367700	-63,27.857828	A	no
4	13:02:34	46,27.328258	-63,27.789530	A	no
5	13:05:19	46,27.318877	-63,27.724861	A	no

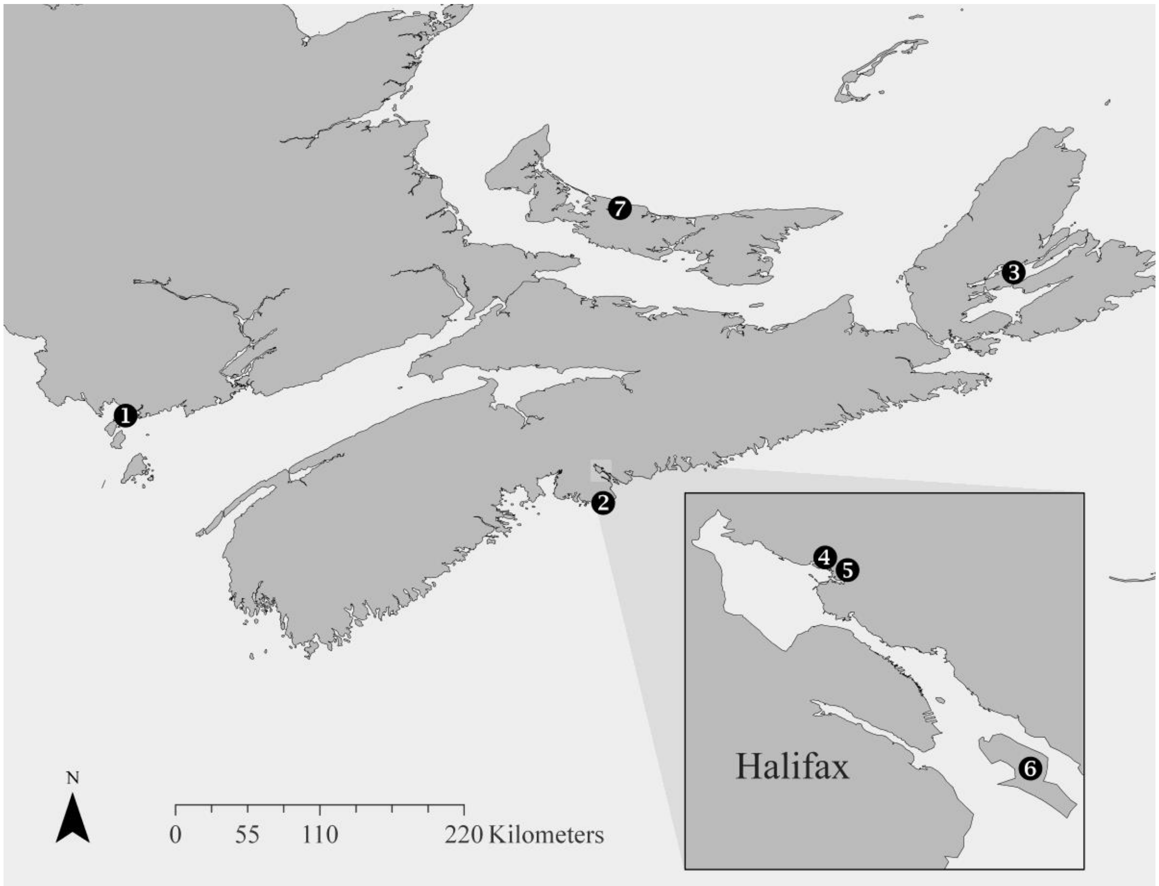

Figure 1: Location of field sites in Atlantic Canada. 1) St. Andrews harbour (New Brunswick); 2) Sambro harbour (Nova Scotia); 3) River Denys Basin (Cape Breton, Nova Scotia); 4) Wrights Cove (Halifax, Nova Scotia); 5) Navy Island Cove (Halifax, Nova Scotia); 6) McNabs Island (Halifax, Nova Scotia); 7) New London Bay (Prince Edward Island).

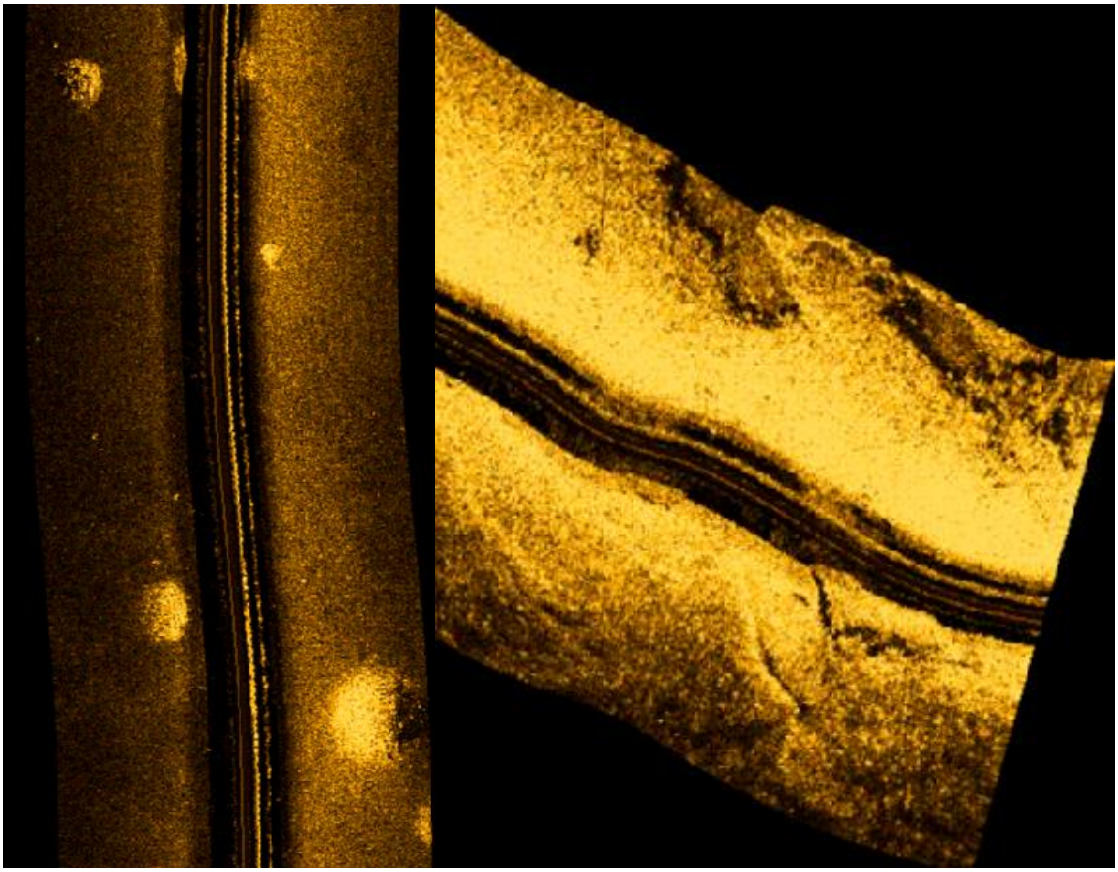

Figure 2: Side-scan images from River Denys Basin (30 m swath). Left panel, oyster bioherms (bright piles of material) on an otherwise featureless soft bottom. Right panel, 'trenches' (dark indented patches on top swath) in a smooth hard packed sand bottom.

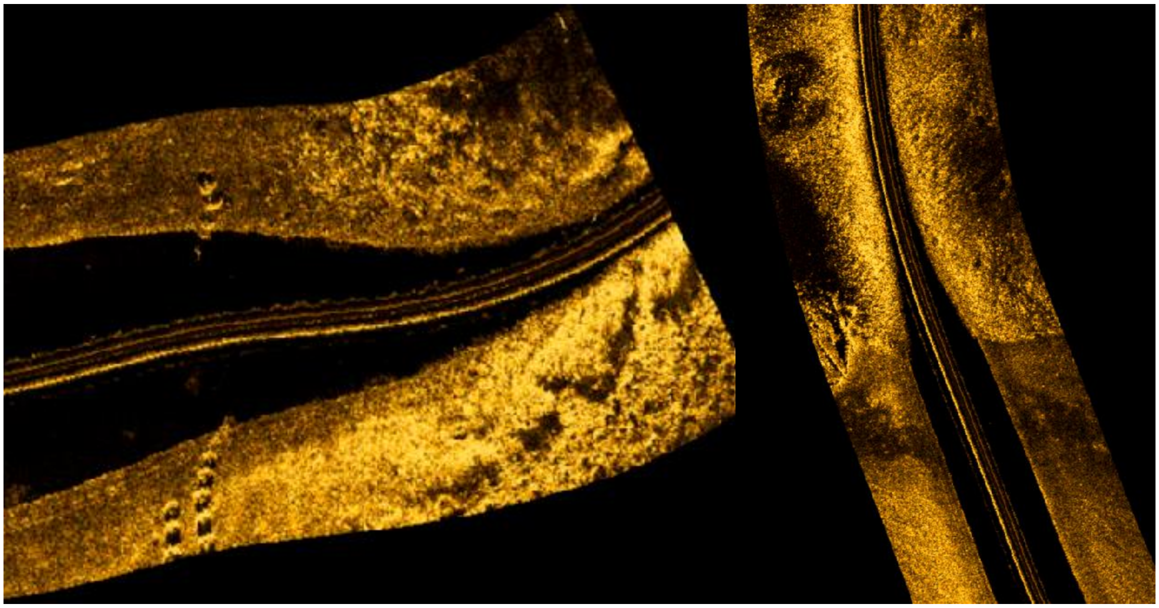

Figure 3: Side-scan images from McNabs Island (30 m swath). Left panel, Reef Balls™ (on left in deeper water) and *Zostera* patches (lower right). Right panel, *Zostera* bed (top half) with abrupt transition to muddy sand (bottom half).

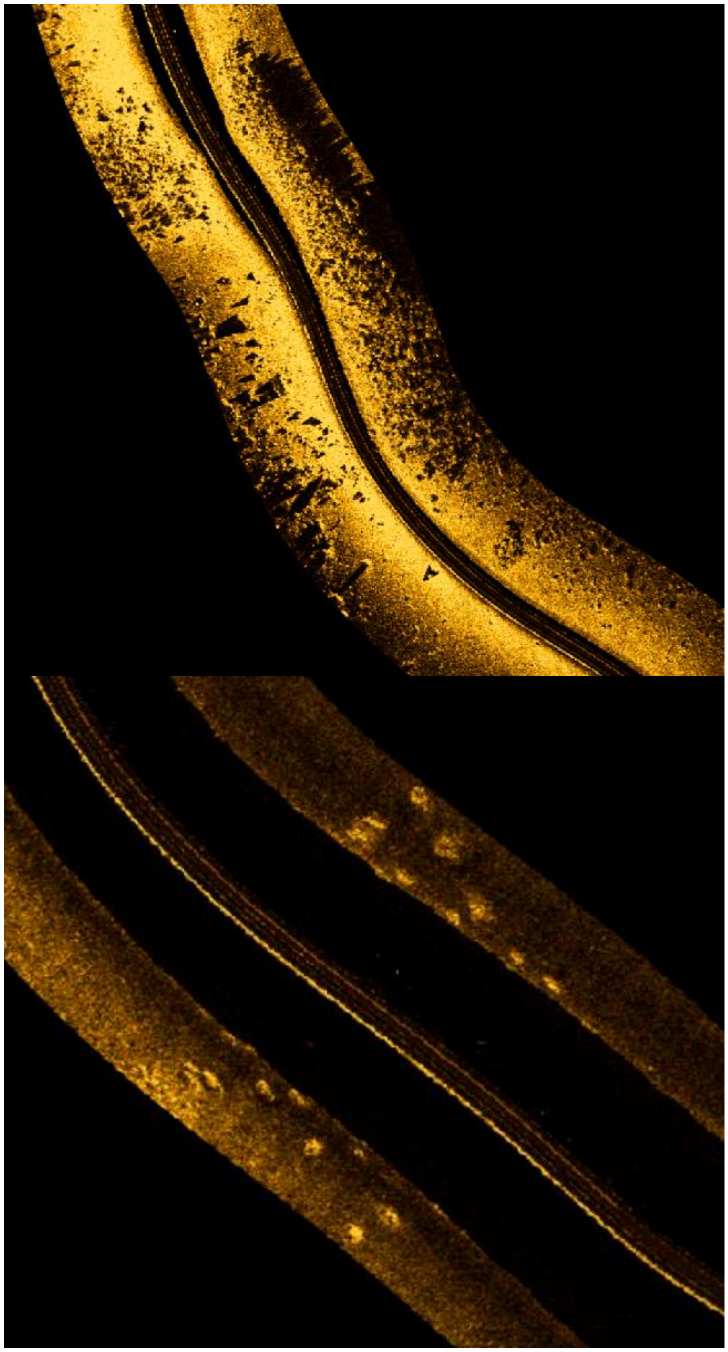

Figure 4: Top: Navy Island Cove - a hard sandy / gravel bottom in shallow water (~2 m), note rock reef on right side and large solitary boulders on the left (30 m swath width). Bottom: Cook Head (Sambro harbour) cobble reef piles on a silty / sand bottom.

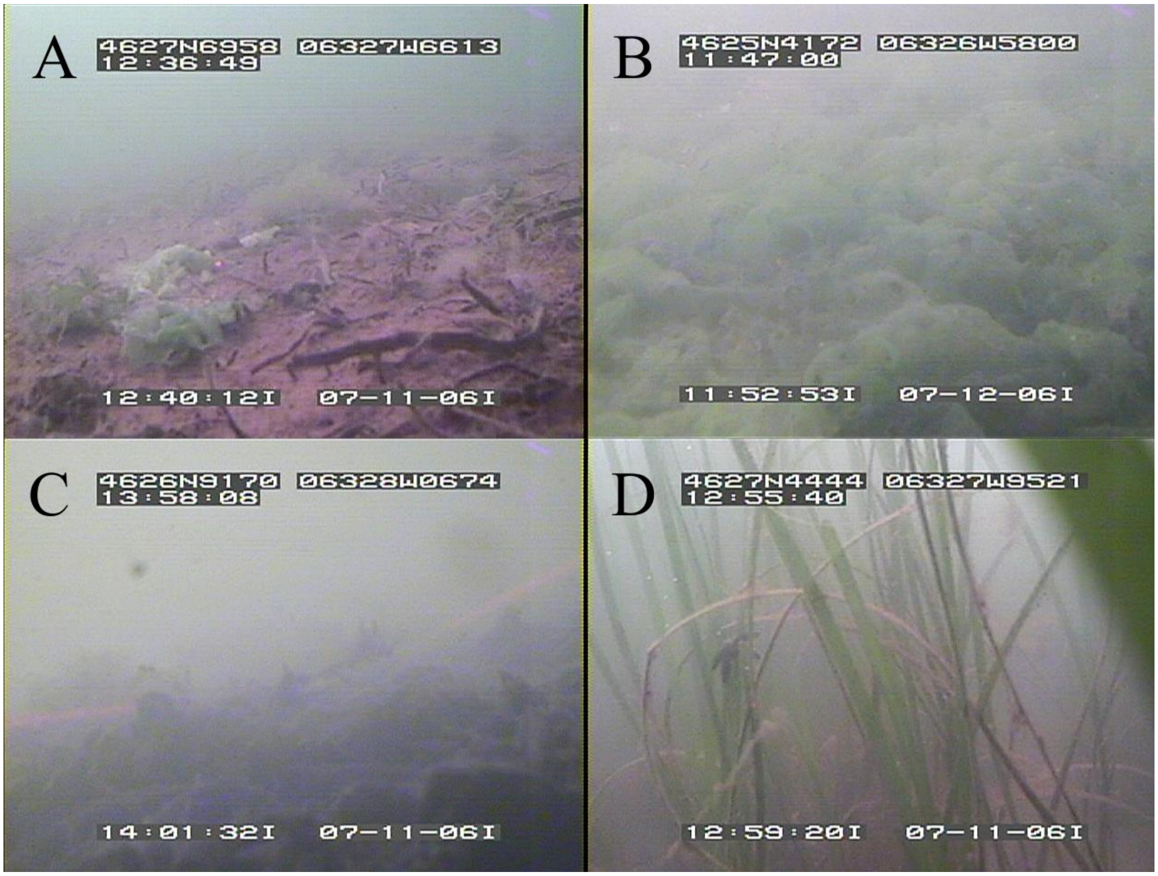

Figure 5: Three point *Ulva* scale for southern section of New London Bay (Stanley Bridge area) where (A) is sparse green *Ulva*, (B) abundant green *Ulva*, (C) deteriorating *Ulva* mat, and (D) eelgrass bed. Note positional, time and date stamp data in each frame of video.

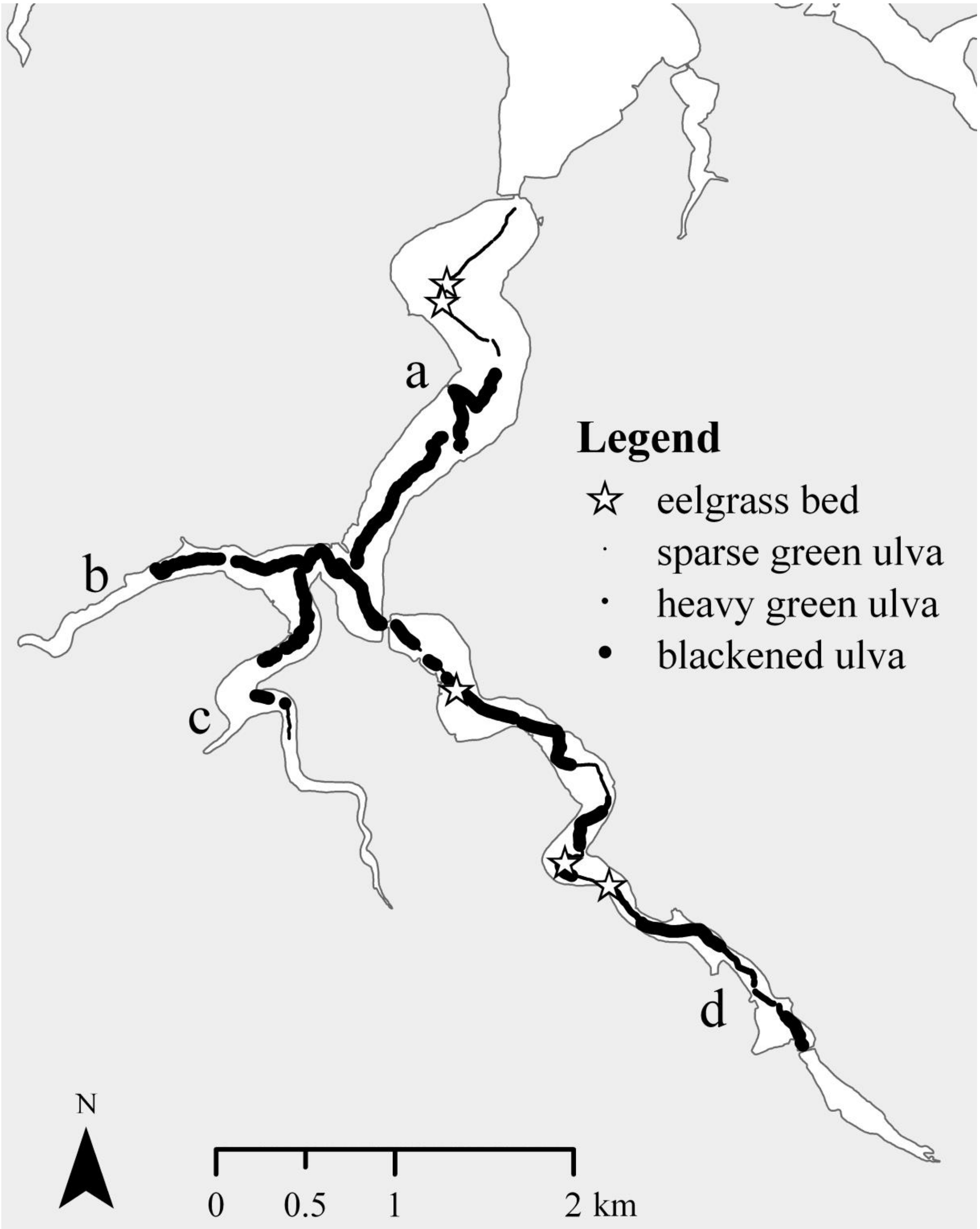

Figure 6: Stanley Bridge (New London Bay) – map of the three point *Ulva* scale plus eelgrass patches.

Figure 7: Sea cucumber abundance (St. Andrews) where (A) is few, (B) many and (C) high density. The sea cucumbers are the dark, sausage shaped objects. (D) bare striated sand in foreground constituting a trawl mark.

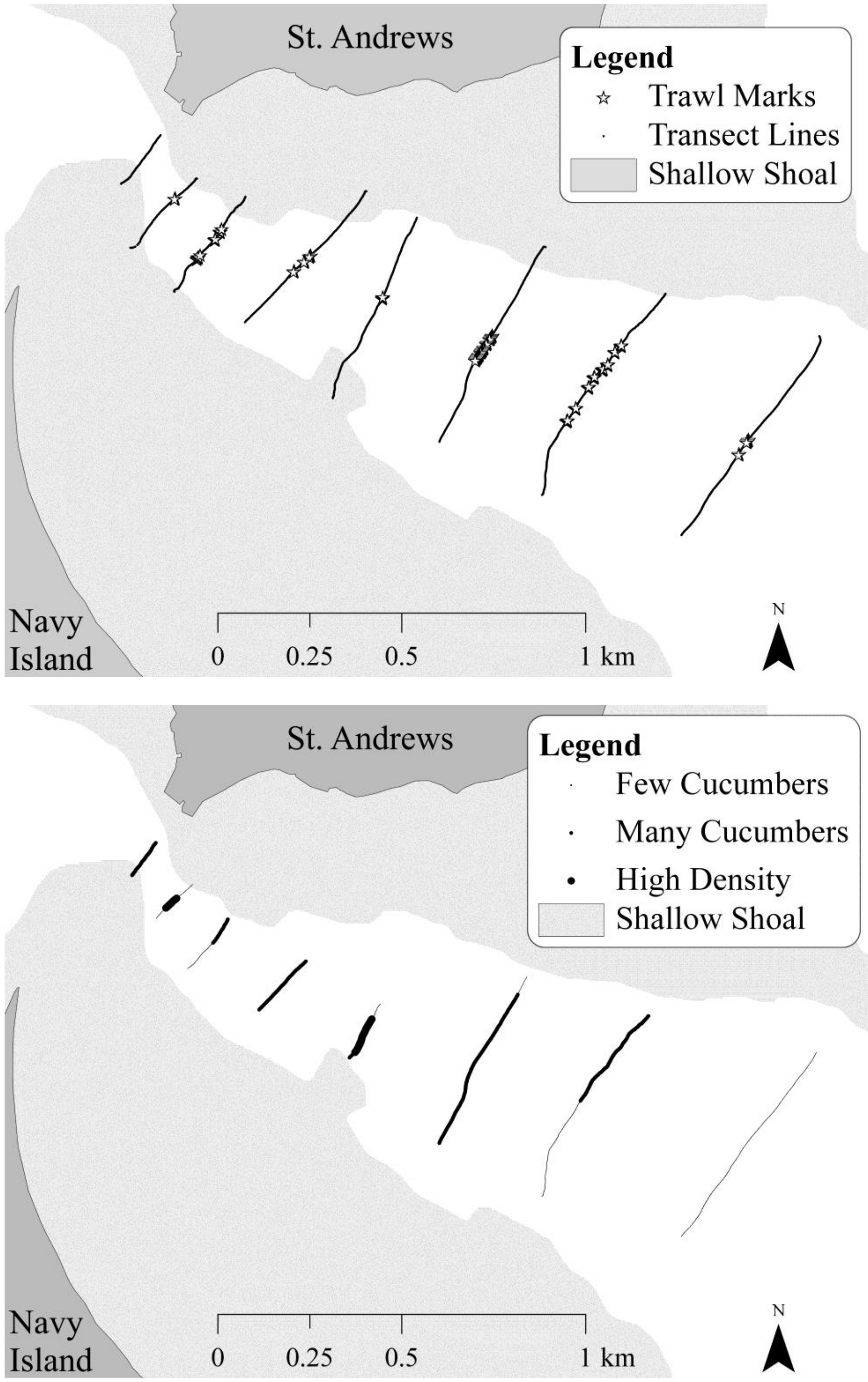

Figure 8: Top: St. Andrews camera transect lines and trawl marks. Bottom: sea cucumber abundance along the transects