Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2014/039

Newfoundland & Labrador Region

Use of remote video survey methodology in monitoring benthic impacts from finfish aquaculture on the south coast of Newfoundland (Canada)

G. Mabrouk, T. Bungay, D. Drover, and D. Hamoutene

Science Branch
Department of Fisheries and Oceans
PO Box 5667
St. John's NL Canada A1C 5X1

October 2014

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

© Her Majesty the Queen in Right of Canada, 2014
ISSN 1919-5044

Correct citation for this publication:

Mabrouk, G. Bungay, T., Drover D., and Hamoutene, D. 2014. Use of remote video survey methodology in monitoring benthic impacts from finfish aquaculture on the south coast of Newfoundland (Canada). DFO Can. Sci. Advis. Sec. Res. Doc. 2014/039. v + 15 p.

TABLE OF CONTENTS

ABSTRACT

Determining the extent of influence of finfish farms on surrounding habitats is very important for environmental monitoring. On the south coast of Newfoundland, Canada, aquaculture is expanding vastly in deeper areas where hard and patchy substrates are predominant. In this case, challenges in obtaining sediment grabs restrict the use of conventional performance-based standards such as free sulphide and redox potential. This work explores the use of remote video surveys as a primary tool to assess potential effects of deposition on the benthos. Two different camera systems were compared in relation to image quality, recording parameters, ease of species identification, and substrate categorization. The challenge of variability among observers was examined and discussed. This study has fed into establishing a standard of practice and a list of species for use by regulatory bodies and environmental companies. This study provides a dependable, cost effective, and efficient tool for the assessment of impacts of aquaculture activities in deep sites with hard and patchy substrates.

L’utilisation de l’imagerie vidéo pour la surveillance de l’effet des activités aquacoles sur les écosystèmes benthiques de la côte Sud de Terre Neuve

RÉSUMÉ

La détermination de l’effet des activités aquacoles sur les habitats benthiques est très importante pour une surveillance efficace de l’environnement marin. Sur la côte Sud de Terre Neuve, Canada, l’élevage de poissons s’est développé dans des zones marines qui maintenant incluent des zones profondes où les substrats sont souvent rocailleux et variés. Dans ce cas, l’utilisation de paramètres conventionnels tels que la mesure des sulfites et du potentiel réducteur des sédiments ne pourra se faire étant donné la difficulté d’obtenir des échantillons de substrat. La présente étude pose les bases de l’utilisation de l’imagerie vidéo pour documenter les changements benthiques. Deux cameras ont été comparées du point de vue de la qualité de l’image, des paramètres d’enregistrement des données ainsi que de la possibilité d’identifier le benthos et le substrat. La variabilité des analyses d’image entre observateurs est également discutée dans ce document. Les résultats de cette étude ont permis l’établissement d’une procédure détaillée pour l’utilisation de l’imagerie vidéo en plus d’un guide de reconnaissance des espèces observées jusqu'à présent. Le guide est aujourd’hui accessible aux organismes régulateurs et consultants en environnement. Les résultats de l’étude fourniront un outil fiable, économique et efficace pour l’évaluation de l’effet des activités aquacoles dans des régions de grande profondeur et où les substrats sont rocailleux et variés.

INTRODUCTION

In Newfoundland, Canada, the aquaculture industry has been growing on the south coast of the island. The number of aquaculture sites has increased and the location of these sites has expanded to different bays with different environmental conditions. This rapid expansion has triggered the need for the development of tools for an accurate assessment of the potential impact of these aquaculture sites on the habitat. These monitoring tools will not only be used from a regulatory point of view, but will also enable aquaculture companies to assess their management practices and ensure the sustainability of their operations.

Traditionally, habitat assessments requested by regulatory bodies in Newfoundland have been based on collecting primarily grab samples around the perimeter of farm cages, not more than two weeks prior or two weeks after initiation of fallow period and then 4-8 weeks before the fallow period ends. These bottom grab samples were sometimes supplemented by videos of the bottom (DFO 2011a). Currently, approximately 90 % of the finfish sites on the south coast occur in deeper areas and over hard and patchy substrates, varying from fine sand to medium pebbles to boulders and bedrock. Thus, it is not possible to apply conventional performance-based standards such as free sulphide and redox potential to assess benthic impacts because of the difficulty of obtaining bottom grab samples in these areas. This is in agreement with previous studies showing that communities of hard substratum habitats present a greater challenge than those with a soft substratum. This is due to the structural complexity of resident benthic communities (Leonard and Clark 1993) and the inherent problems of in situ sampling techniques (Shears 2007). Therefore, it was essential to find an alternative hard bottom monitoring technique for the south coast of Newfoundland and the use of video surveys presented itself as a possible reliable method.

Rapid survey methods such as those using remote videography, have been used to describe the pre-cage benthic environment and species assemblage, the sediment-water interface processes affecting particle deposition (e.g. pellet, feces), and post-cage changes to substrate and species assemblage and diversity (Crawford et al. 2001; Hargrave 2003; Sameoto et al. 2008). These surveys are now being used routinely in many countries to assess impacts of fish farms, and are considered to be a valuable monitoring tool (e.g. Chang and Thonney 1993; Heinig 1996). Video or photographic monitoring of hard bottom is a requirement of the Finfish Aquaculture Waste Control Regulation (FAWCR) in British Columbia (BC) and is outlined in the protocols for marine environmental monitoring (DFO 2011b). The videos are relatively easy to collect, affordable and provide a permanent record that can be retrieved at later dates for comparisons over time.

Video surveys conducted in our study included optimizing the camera and data collection system. They also provided description of the substrate and the fauna and flora, with a focus on presence and percentages of indicator species of benthic impact mainly opportunistic polychaete complexes (OPC) and mat-forming bacteria (*Beggiatoa* spp). *Beggiatoa* spp. is a primary indicator of benthic change as it occurs at the interface of oxic and anoxic conditions and is typically associated with elevated sulphide levels (Preisler et al. 2007). The second potential indicator, OPC, is frequently observed in areas with organic enrichment and reduced conditions (Brooks 2001). In Newfoundland, a study on visual indicators used for compliance monitoring reports has revealed that performance-based indicators such as *Beggiatoa* spp. and OPC are valid biomarkers of aquaculture impact, and that they are present even on sites with hard bottoms. They can be used for regulatory purposes and correlate well with indicators of aquaculture activities such as flocculant presence, offgasing and sulphides (Hamoutene et al. 2013).

Sources of observer bias in underwater visual surveys have been previously discussed in the literature (Sale and Douglas 1981; DeMartini and Roberts 1982; Kimmel 1985; Mapstone and Ayling 1998; Ninio et al. 2003). In acknowledging that video monitoring of benthic impacts requires large amounts of fieldwork, completed over several years by multiple observers, it was essential to reduce biases among and within observers. This would allow that (spurious) patterns related to differences among observers can be distinguished from real spatial or temporal patterns in the environment.

The main objectives of this study are:

(1) to compare video camera systems for use in bottom sampling;

(2) to assess the level of variability among observers in analyzing videos; and

(3) to establish a preliminary list of local species as identified in still images extracted from videos.

Despite the fact that the list of species provided here will be evolving with further identification of species, it represents some of the main groups observed in the Newfoundland benthos. The work completed in this study fed into the development of an interim monitoring program currently in place and implemented by the Habitat Protection Division in the Department of Fisheries and Oceans (DFO), Canada and the aquaculture industry in Newfoundland.

METHODS

STUDY LOCATION

Over a three year period (2008-11), between June and October, video was collected at 19 sites on the south coast of Newfoundland with a total of 1030 sampling stations. Figure 1 shows the general area where sites are located and provides an example of two of the sampled sites. The sites consisted of finfish farms at various stages of production as well as two sites with no aquaculture activity used as references. For bathymetry data, Canadian Hydrographic Service bathymetry data of varying resolutions (2 m to 75 m) were interpolated by Inverse Weighted Distance to a 15 m resolution grid using ArcGIS Spatial Analyst Tools (ArcGIS Desktop 10.0, Environmental Systems Research Institute, Redlands, CA, USA).

DESCRIPTION OF THE VIDEO SYSTEMS

Two video systems were compared in terms of image quality. Camera A (SeaViewer, Tampa Bay, FL, USA) was set up at a 30^{o} angle to the bottom and was housed in an aluminum frame. One 25 watt high intensity discharge metal halide light was attached to the camera (battery powered) with no intensity control. This camera films in colour with a fixed focus at a resolution of 520 lines with a sensitivity of 0.05 ux. Camera B (Shark Marine, St. Catherines, Ontario, Canada) is also a color camera with fixed focus, a lower resolution than Camera A (380 lines) and a light sensitivity of 0.5 lux. Camera B was setup at a 90^{o} angle to the bottom and was housed in a stainless steel frame. One 150 watt halogen light was attached to the camera with low/high intensity control.

All cameras were connected to a deck box with monitor, global positioning system (GPS) overlay and recorder. An exterior quadrant grid of 0.50 m x 0.50 m and interior quadrant of 0.25 m x 0.25 m was added to the set up to provide a choice of standard areas for data collection and analysis (Figure 2).

VIDEO COLLECTION AND RECORDING

Video was collected at depths ranging from 15 m to 120 m. All video stations were geo-referenced with a GPS overlay and watermarked on the video with the date and time (Greenwich Mean Time [GMT]) the video was taken. Clarity of the water was rarely a challenge at these sites.

Initial video recording was started once the bottom became visible, after which the time (GMT), latitude and longitude of the sampling station was recorded. The camera cage was then lowered gently to the bottom and left there for 10 seconds. This period helped generate clear still images while retaining the video for the identification of benthic flora/fauna and determination of substrate type and flora/fauna percent coverage when applicable. The camera cage was then raised 0.2 m and dropped to potentially suspend the particles in the water and to help visualize and determine the substrate type. Once the water was clear, recording was stopped and the drop camera was raised again and taken to the next station (Figure 3).

COMPARISON OF THE CAMERA SYSTEMS

Images extracted from the videos recorded by the camera systems were compared by coding images according to quality as described in Table 1. Moreover, quality of videos was assessed by evaluating the number of useful frames according to the visibility scale (listed in Table 1), as well as estimates of the ratio of observations possible (i.e. usable frames) to the length of video to be analyzed.

Table 1. Visibility scale used in video analysis.

Scale	Description to classify visibility in video systems
1	Poor (image out of focus, too far, or clouded by sediment. No identification or quantification possible)
2	Limited (organisms seen, but confidence in identification is low)
3	Average (some turbidity or color caste, but most large and/or common species can be recognized)
4	Excellent (lighting and color provide sharp images, especially if video is paused, and identification is possible with high confidence)
5	None (camera not on bottom, no light; this code is also used to mark beginning/end of set)

VIDEO ANALYSIS

Each video was analyzed a minimum of three times. The video collected was divided into individual frames, converted into digital formats and given appropriate file names. The video frames were analyzed by recording the variables listed in Table 2.

Table 2. Recorded parameters for video analysis.

Video name	Descriptive name including location and date
Operator(s)	Name of operator(s)
Length	Length/duration of video examined (minute)
Lat	Latitude
Lon	Longitude
TOC	Time of capture as recorded on video during survey (GMT)
Substrate	Value from 1 to 7 based on substrate categories: “flocculant”, bedrock, boulder, cobble, gravel, sand, mud
Offgassing	Yes/No for the presence of off gassing bubbles
Pellets	Yes/No for the presence of uneaten pellets
Coverage	For OPC, *Beggiatoa* spp., and mat-forming species percent coverage is recorded using Image J software
Species	Identify all biota to the lowest taxonomic class possible

At each station, dominant substrate types (flocculant, bedrock, boulder, cobble, gravel, sand, and mud) as well as each mat-forming species (coralline algae, seaweeds, kelps, bacterial mats, and OPC) were determined using Image J software (Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, Maryland, USA). Flocculent matter was recorded as a separate substrate class and visually differentiated from fine sediments due to its texture, its adherence to the camera grid, and the obvious sinking of the quadrants when laid on the bottom. Species identified and their abundances were recorded using common names or description of shapes. Encrusting species (e.g. sponges, coralline algae) were recorded as percent cover, while other species were recorded by abundance (Crawford et al. 2001).

OBSERVER VARIABILITY

To examine the variability among observers, three observers completed video analysis of a subset of two reference sites and two impacted sites consisting of 70 and 52 sampling stations, respectively. The first set of parameters considered was substrate type (flocculant, bedrock, boulder, cobble, gravel, sand, mud evaluated as percent cover), coralline algae (percent cover), and total species counts (epifauna abundance). These parameters were extracted after observers completed the video analyses of two reference sites (n = 32 and n = 38 stations in total). The second set of parameters consisted of *Beggiatoa* spp. and OPC, both measured as percent coverage, and were extracted only from images sampled at aquaculture sites (n = 25 and 27 stations). Both *Beggiatoa* spp. and OPC were either not or rarely present at reference sites.

Similarly, comparisons were conducted based on video analyses completed by one observer then repeated by that same observer after 7-14 days in a randomized manner (so stations were not always visualized in the same order). For substrate type, coralline algae cover and total number of species, the exercise was completed on one reference site (n = 38 stations). For

Beggiatoa spp. and OPC, the same impacted sites as cited earlier was analyzed twice by the same observers (n = 25 and 27 stations).

STATISTICAL ANALYSIS

After video analyses were concluded, parameters extracted from videos were compared between observers using analysis of variance with repeated measures (ANOVAR) (stations were considered as paired observations) using Sigma Plot software (Systat Software, Chicago, IL, USA). When data were not normally distributed, ANOVAR was performed on ranks (significance at $p < 0.05$). To compare data within observers (every observer compared to each other) paired t-tests were completed. When significant differences were found a coefficient of variation (CV) was calculated for every station (three observations when the three observers were compared and only two observations when observers were compared to themselves). A mean coefficient of variation was calculated using the CV of each station to illustrate the difference between observations.

RESULTS

IMAGE QUALITY COMPARISON BETWEEN CAMERA SYSTEMS

Results of the comparison between camera systems are summarized in Table 3. No statistical comparison was completed on these data considering there is one value per camera for the different parameters assessed. Data show that Camera B produces better quality images as evaluated by our observer. It also had the highest rate of usable frames as well as the highest percentages of good quality images.

Table 3. Image quality data for the camera systems.

Image quality data	**Camera A**	**Camera B**
Length of video analyzed	27 minutes	23 minutes
Number of usable frames per min	1.2	1.9
Number of usable frames to total number of frames attempted	0.39	0.76

*Usable frames are defined as corresponding to visibility codes 2 to 4.

Percentages of images according to quality	**Camera A**	**Camera B**
Code 1	49.38	11.29
Code 2	37.04	40.32
Code 3	3.70	38.71
Code 4	0.00	0.00
Code 5	9.88	9.68

VIDEO ANALYSIS

The species list as identified in the videos is provided in the photographic guide to benthic species of hard bottom communities in southwest Newfoundland (DFO 2013b). This table was produced through video analysis of 315 videos and photos. A sample image is provided in Figure 4.

OBSERVER VARIABILITY

Differences between observers

Some statistical differences ($p < 0.05$) in identifying substrate type, coralline algae coverage, as well as total abundance evaluations were found between observers (Table 4). The mean coefficients of variation were between 50.0 % and 66.7 %.

Table 4. Statistical differences between parameters identified by observers after video analyses of reference sites (substrate type and non-indicator species).

Parameter	Site 1 (n=32 stations)	Mean coefficient of variation	Site 2 (n=38 stations)	Mean coefficient of variation
Flocculant	p=0.065	N/A	p=0.986	N/A
Bedrock	N/A	N/A	p=0.278	N/A
Boulder	p=0.513	N/A	p=0.057	N/A
Cobble	p=0.383	N/A	p<0.001	66.7%
Gravel	p=0.030	30.2%	p=0.004	54.3
Sand	p=0.025	41.4	p=0.087	N/A
Mud	N/A	N/A	N/A	N/A
Coralline algae coverage	p=0.061	-	p<0.001	50.1%
Total abundance	p=0.427	-	p=0.027	53.0%

*N/A= not applicable

There were no statistical differences between observers for any of the benthic indicators species assessed (*Beggiatoa* spp. and OPC coverage) when evaluating videos from impacted sites (n = 25 and n = 27).

Difference within observers

Observer 1:

No differences were found in any of the substrate parameters and non-indicator species described above between video analyses completed for a reference site (n = 38 stations) at different times by observer 1.

Observer 2:

Some statistical differences were found in the coverage percentages evaluated by observer 2 for cobble and gravel (Table 5). A statistical difference was also recorded when comparing coralline algae percent coverage evaluated by observer 2 after two visualizations.

Table 5. Statistical differences between observations gathered by observer 2 after video analyses of one reference site (substrate type and non-indicator species).

Parameter	Paired t-test	Mean coefficient of variation
Cobble (n=38)	p=0.004	20.6%
Gravel (n=38)	p=0.039	17.7%
Coralline Algae (n=38)	p=0.051	27.3%

Observer 3:

A statistical difference in coralline algae coverage was found between the observations of observer 3 with a mean coefficient of variation of 26.6 % *(p* = 0.028). No differences in *Beggiatoa* spp. and OPC coverage from impacted sites (n = 52 stations in total) were found upon replicate observer review of videos from impacted sites.

DISCUSSION

Standardization of methods benefit long-term monitoring by maintaining continuity, precision of interpretation, and accountability. Adherence to these standards reduces the frequency of sampling errors that can cause difficulties in the analysis of observations and interpretation of findings. In study areas such as the ones described in this study, it is not possible to apply conventional performance-based standards such as free sulphide and redox potential to assess benthic impacts. It has become clear that an alternative tool needs to be used and that a visual sampling design with a defined and standardized sampling method needs to be developed. Visual surveys have been used successfully for the purpose of monitoring benthic changes in different regions all over the world (Chang and Thonney 1993; Heinig 1996; Crawford et al. 2001; Hargrave 2003; MacLeod et al 2004; Sameoto et al. 2008). In British Columbia, it was concluded that video imagery would be the most effective tool for hard substrate operational monitoring over the short term (Levings et al. 2002; Burd 2003; Emmett and Buchanan 2003). In Newfoundland, however, previous monitoring protocols required that videos be used as supplementary material only. No standard protocol was established, and guidance on the parameters to be extracted from these videos was never provided. Methodologies varied among different environmental companies and the videos obtained were mostly of poor quality and hard to interpret with no standardized data analysis and interpretation.

The collection of video imagery for hard bottom monitoring has been completed using a variety of instruments. British Columbia legislators have relied mainly on ROVs to collect video imagery

(Chang and Thonney 1993), while in other countries, such as Australia (Tasmania), regulators have relied primarily on self-contained underwater breathing apparatus (SCUBA) surveys (Macleod et al. 2004). In adapting visual monitoring methods, it is necessary to consider the challenges of the environment of the south coast of Newfoundland, such as the large variability in bathymetry and the presence of rock walls and boulders, as well as the patchiness of habitat and substrate (Bungay 2013). Aquaculture sites in Newfoundland often occur in deep waters exceeding 100 m, which precludes the use of divers to collect video imagery. Furthermore, the mooring systems used to anchor the aquaculture cages make it difficult to use ROVs around and under the cages directly. Similar problems were addressed by Wilding et al. (2012). These challenges led to the use of the drop video camera system for monitoring. It was also essential to find a balance between maintaining a reasonable distance from the bottom to avoid disturbing the substrate and damaging the camera system while achieving high quality images and accurate representation of the biota present.

In addressing issues of image quality, two affordable camera systems were compared and Camera B provided the best quality images allowing us also to identify the resolution and light requirements to be selected for monitoring purposes. Although Camera B had lower resolution and sensitivity to light, the cage design and, more importantly, the added lighting and camera angle resulted in creating a higher quality image. These results allow us to identify the minimum requirements needed for achieving good quality videos suitable for analysis. A standard of practice guide currently in use by environmental companies and regulatory bodies was developed to describe these requirements (DFO 2013a). These requirements help to address some of the identified inherent problems using drop cameras as already highlighted by Wilding et al. (2012). The patchy nature of the mega-benthos, the irregular ground, moorings, and drift/current speed can produce error but not necessarily bias. In addition to the camera itself, it was important to find a way to standardize the area examined and therefore quadrants were used to provide a tool for spatial consistency of the data to be collected for monitoring purposes. They also provide a scale to estimate size of organisms or to estimate spatial extent of coverage of mat-forming species. Another application highlighted by this study is the usage of the Image J software for the delineation of mat-forming flora and fauna as well as indicator presence.

The most important challenge in analyzing the videos collected is the inherent observers' variability which was addressed in this study. Sources of observer bias in underwater visual surveys have been previously discussed in the literature (Sale and Douglas 1981; DeMartini and Roberts 1982; Kimmel 1985; Sanderson and Solonsky 1986; Thresher and Gunn 1986; Greene and Alevizon 1989; Bortone et al. 1991; Samoilys 1992; Mapstone and Ayling 1998). One of the main sources of error as highlighted by our results seems to reside in the distinction between some of the substrate classes selected for this study. This suggests the necessity of limiting the categories in order to get a more consistent evaluation by observers. Possible categories of substrate classification could be modified from previous classification schemes. These classes would include bedrock (continuous solid rock), coarse (boulders greater than 250 mm and rubble ranging from 130-250 mm), medium (cobble ranging from 30-130 mm, and gravel ranging from 2 -30 mm), and fines (sands ranging from 0.06 -2.00 mm and mud/silt/clay less than 0.06 mm) as modified from the Wentworth-Udden scale (Wentworth 1922). Overall, most of the differences between observers (or sets of observations from the same observers) were found when evaluating substrate types and coralline algae coverage in reference sites with variation coefficients between 17 % and 66 %. The coralline algae often appear in bright colors, commonly red or pink, and sometimes rendered the evaluation of percent coverage using manual tracing challenging. Importantly, no differences were found when evaluating the presence of indicators of benthic impact (i.e. *Beggiatoa* spp. or OPC) as these species play an important role in regulatory assessments.

In conclusion, the videography method used in this study presents itself as a dependable, cost effective, and an efficient tool for evaluating habitat on aquaculture lease areas. The relative ease of video collection and access to areas under and around the cages, despite complicated mooring systems, were important aspects for ease of implementation by environmental companies. In addition, our results suggest that there is minimal observer variability and therefore we recommend providing a detailed instructional manual and adequate training to observers to reduce the margin of error. This work will aid regulating bodies as well as environmental monitoring companies in Newfoundland in the monitoring of benthic changes from aquaculture farms on hard bottom habitats. A comprehensive guide of standard of practice for use of camera is developed (DFO 2013a). In addition, a photographic guide to benthic species of hard bottom communities on the south coast of Newfoundland has also been developed (DFO 2013b). Both could be used by environmental companies when conducting their assessments.

ACKNOWLEDGEMENTS

This study was supported by the Aquaculture Collaborative Research and Development Program (ACRDP), Fisheries and Oceans Canada.

REFERENCES CITED

Bortone, S.A., Martin, T., & Bundrick, C. M. 1991. Visual census of reef fish assemblages: a comparison of slate, audio, and video recording devices. Northeast Gulf Sci., 12(1), 17-23.

Brooks, K. M. 2001. An evaluation of the relationship between salmon farm biomass, organic inputs to sediments, physiochemical changes associated with those inputs and the infaunal response –with emphasis on total sediment sulphides, total volatile solids and oxidation reduction potential as surrogate endpoints for biological monitoring. Technical Advisory Group, Ministry of Environment, Lands and Parks, Port Townsend, Washington, USA, 210 pp.

Bungay, T.R. 2013. Assessment of the influence of finfish aquaculture on hard bottom habitats in a boreal sub-arctic marine environment. Thesis (M.Sc.) Memorial University of Newfoundland, St. John's, Newfoundland, Canada.

Burd, A.B. 2003. Boulder Patch kelp model: draft report. Technical report, Department of Marine Sciences, University of Georgia, St Athens, GA, USA.

Chang, B. D., and Thonney, J.P. 1993. Overview and environmental status of the New Brunswick salmon culture industry. Bull. Aquac. Assoc. Can., 92(3), 61-63.

Crawford, C., Mitchell, I., and MacLeod, C. 2001. Video assessment of environmental impacts of salmon farms. ICES J. Mar. Sci., 58(2), 445-452.

DeMartini, E.E., and Roberts, D. 1982. An empirical test of biases in the rapid visual technique for species-time censuses of reef fish assemblages. Mar. Biol., 70, 129-134.

DFO 2013a. Standard operating procedures (SOP) for underwater video camera system.

DFO 2013b. A photographic guide to benthic species of hard bottom communities in Southwest Newfoundland.

DFO 2011a. Finfish aquaculture: Farm monitoring report for fish habitat. Marine Environment and Habitat Management Division, Newfoundland and Labrador Region, St. John's, NL, Canada.

DFO 2011b. Potential impacts of waste deposition from finfish aquaculture and other industrial operations on hard seabeds. Habitat Protection Division, Newfoundland and Labrador Region, St. John's, NL, Canada, 54 pp.

Emmett, B., and Buchanan, S. 2003. Review of information on habitat use by nearshore benthic fish and invertebrates in the vicinity of finfish aquaculture sites in British Columbia. Archipelago Marine Research Ltd. Victoria, BC, Canada.

Greene, L.E., and Alevizon, W.E. 1989. Comparative accuracies of visual assessment methods for coral reef fishes. Bull. Mar. Sci., 44(2), 899-912.

Hamoutene, D., Mabrouk, G., Sheppard, L., MacSween, C., Coughlan, E., and Grant, C. 2013. Validating the use of *Beggiatoa* sp. and opportunistic polychaete worm complex (OPC) as indicators of benthic habitat condition at finfish aquaculture sites in Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci., 3028, vii: 18pp.

Hargrave, B.T. 2003. A scientific review of the potential environmental effects of aquaculture in aquatic ecosystems: far-field environmental effects of marine finfish aquaculture. Can. Tech. Rep. Fish. Aquat. Sci., 2450, 131 pp.

Heinig, C.S. 1996. The Maine Department of Marine Resource's Finfish Aquaculture Monitoring Program (FAMP) 1992-1995. Joint Standing Committee on Marine Resources Second Session of the 117th Maine State Legislature, Maine Department of Marine Resources, Augusta, Maine, USA.

Kimmel, J.J. 1985. A new species-time method for visual assessments of fishes and its comparison with established methods. Environ. Biol. Fishes, 12(1), 23-32.

Leonard, G.H., and Clark R.P. 1993. Point quadrat versus video transect estimates of the cover of benthic red algae. Mar. Ecol. Prog. Ser., 101, 203-208.

Levings, C.D., Helfield, J.M., Stucchi, D.J., and Sutherland, T.F. 2002. A perspective on the use of performance based standards to assist in fish habitat management on the seafloor near salmon net pen operations in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc., 2002/075. 59 pp.

MacLeod, C., Crawford, C., and Moltschaniwskyj, N.A. 2004. Assessment of long-term change in sediment condition after organic enrichment: defining recovery. Mar. Pollut. Bull., 49(1-2), 79-88.

Mapstone, B.D., and Ayling, A.M. 1998. An investigation of optimum methods and unit sizes for the visual estimation of abundances of some coral reef organisms, research publication No. 47, Great Barrier Reef Marine Park Authority, Townsville, Australia, 70 pp.

Ninio, R., Delean, S., Osborne, K., and Sweatman, H. 2003. Estimating cover of benthic organisms from underwater video images: variability associated with multiple observers. Mar. Ecol. Prog. Ser., 265, 107-116.

Preisler, A., de Beer, D., Lichtschlag, A., Lavik, G., Boetius, A., and Jørgensen, B.B. 2007. Biological and chemical sulfide oxidation in a *Beggiatoa* inhabited marine sediment. International Soc. Microbial Ecol., 1, 341-353.

Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, 1997-2012.

Sale, P.F., and Douglas, W.A. 1981. Precision and accuracy of visual census technique for fish assemblages on coral patch reefs. Environ. Biol. Fishes, 6, 333-339.

Sameoto, J.A., Lawton, P., and Strong, M.B. 2008. An approach to the development of a relational database and GIS applicable scheme for the analysis of video-based surveys of applicable scheme for the analysis of video-based surveys of benthic habitats. Can. Tech. Rep. Fish. Aquat. Sci, 2818, 34 pp.

Samoilys, M. 1992. Review of the underwater visual census method developed by the QDPI/ACIAR project: Visual assessment of reef fish stocks. Conference and Workshop Series QC92006, Department of Primary Industries, Brisbane, Australia.

Sanderson,S.L., and Solonsky, A.C. 1986. Comparison of a rapid visual and a strip transect technique for censusing reef fish assemblages. Bull. Mar. Sci., 39(1), 119-129.

Shears, N.T. 2007. Shallow subtidal reef communities at the Poor Knights Islands Marine Reserve after eight years of no-take protection, Northland Conservancy Report, Department of Conservation, Wellington, New Zealand, 48 pp.

Thresher, R.E., and Gunn, J.S. 1986. Comparative analysis of visual census techniques for highly mobile, reef-associated piscivores (Carangidae). Environ. Biol. Fishes, 17, 93-116.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. J. Geol., 30(5), 377-392.

Wilding, T., Cromey, C., Nickell, T., and Hughes, D. 2012. Salmon farming impacts on muddy-sediment mega-benthic assemblages on the west coast of Scotland. Aquac. Environ. Interact., 2, 145-156.

APPENDIX I - FIGURES

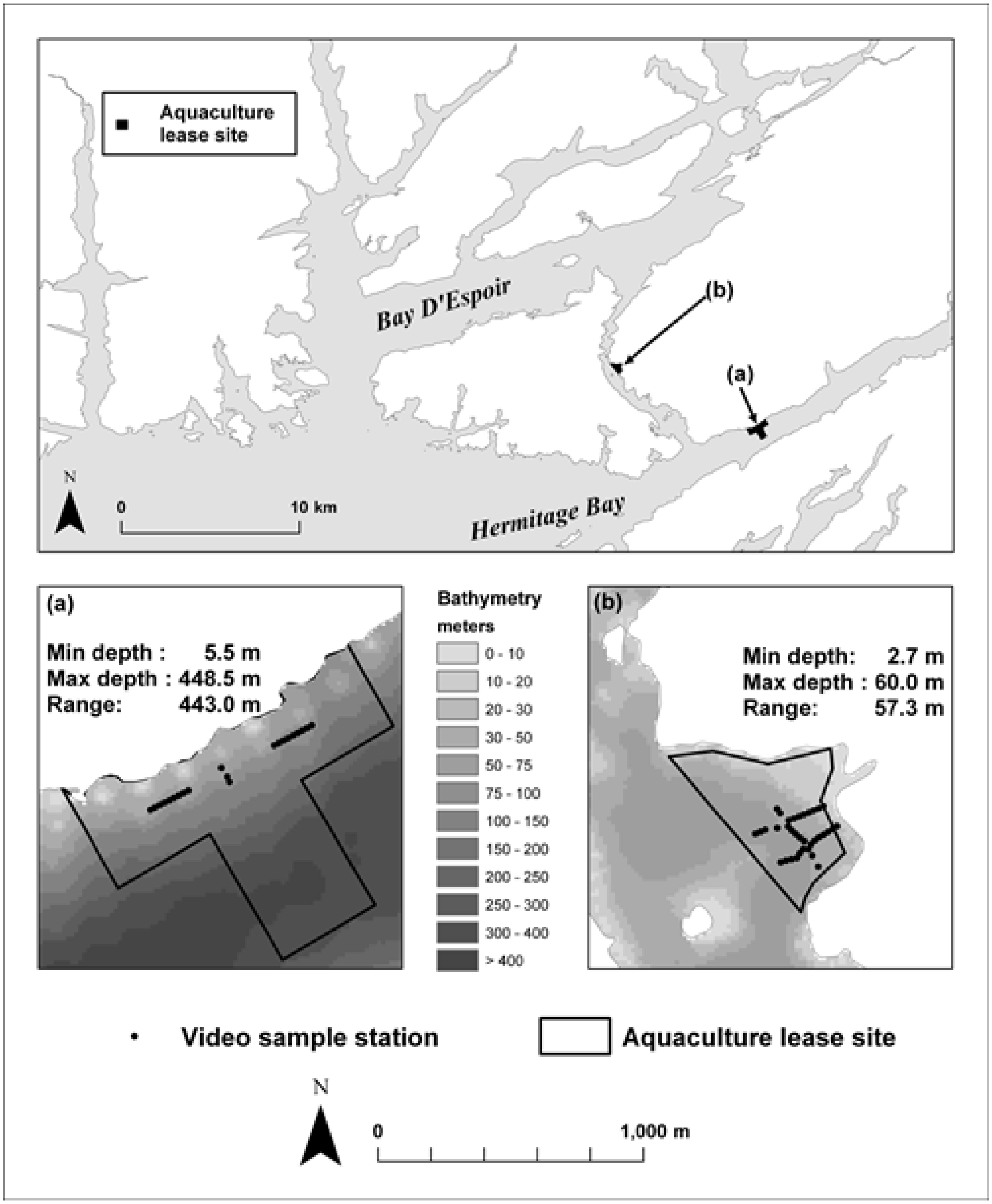

Figure 1. Example of two aquaculture leases, site (a) and site (b) on the south coast of Newfoundland (locations of sampling stations.)

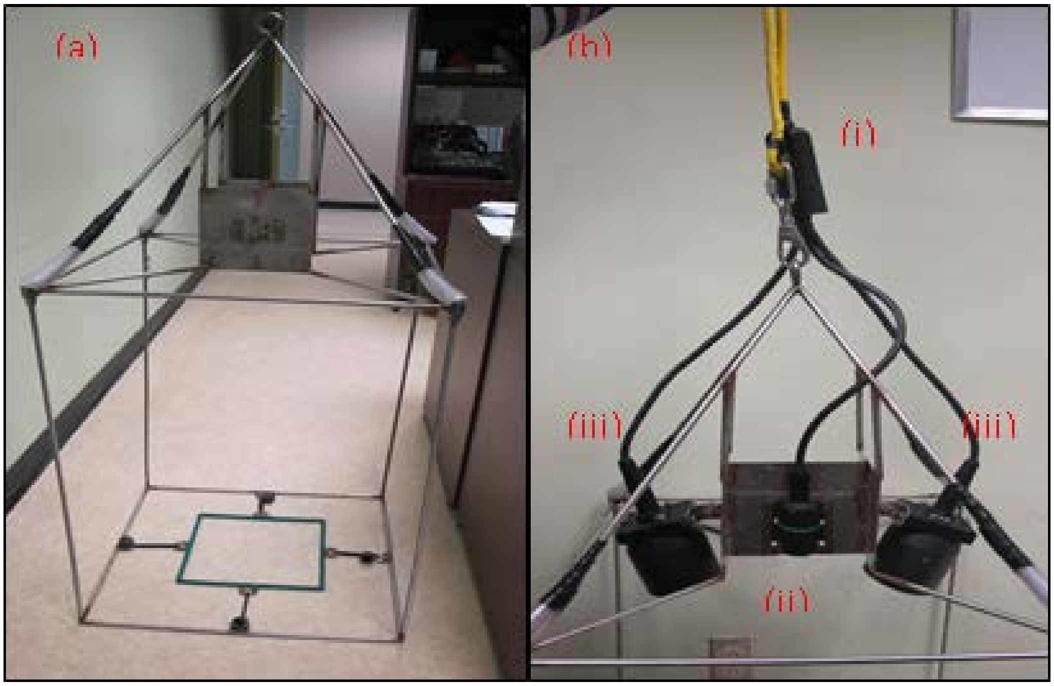

Figure 2. Bare camera frame with quadrants.

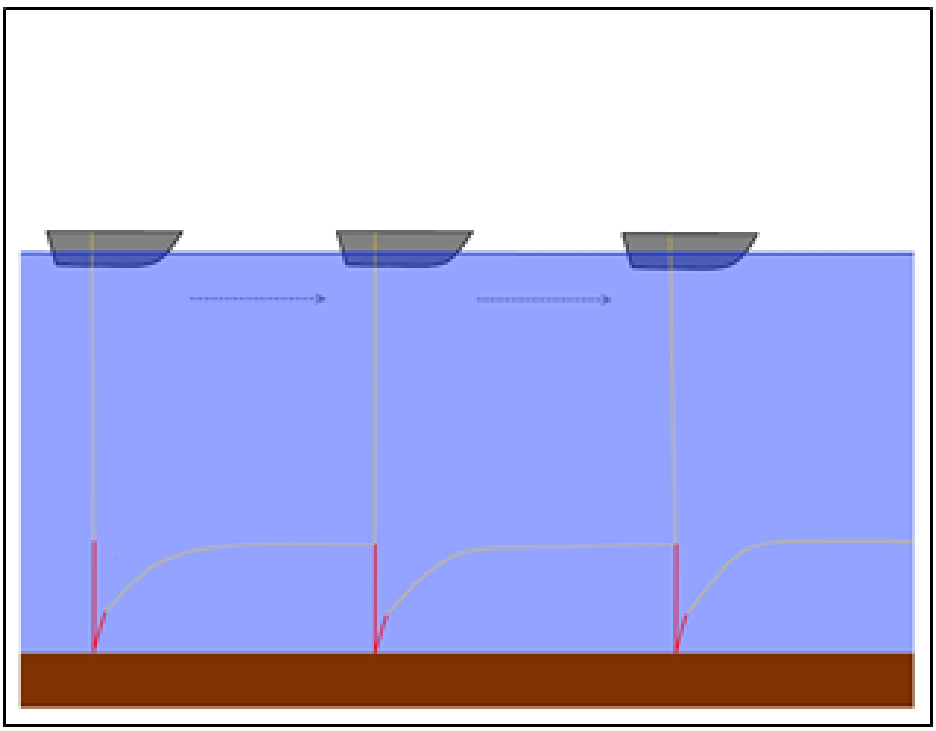

Figure 3. Drop transects methodology. Yellow shows the movement of underwater camera setup transitioning to red when the camera is on.

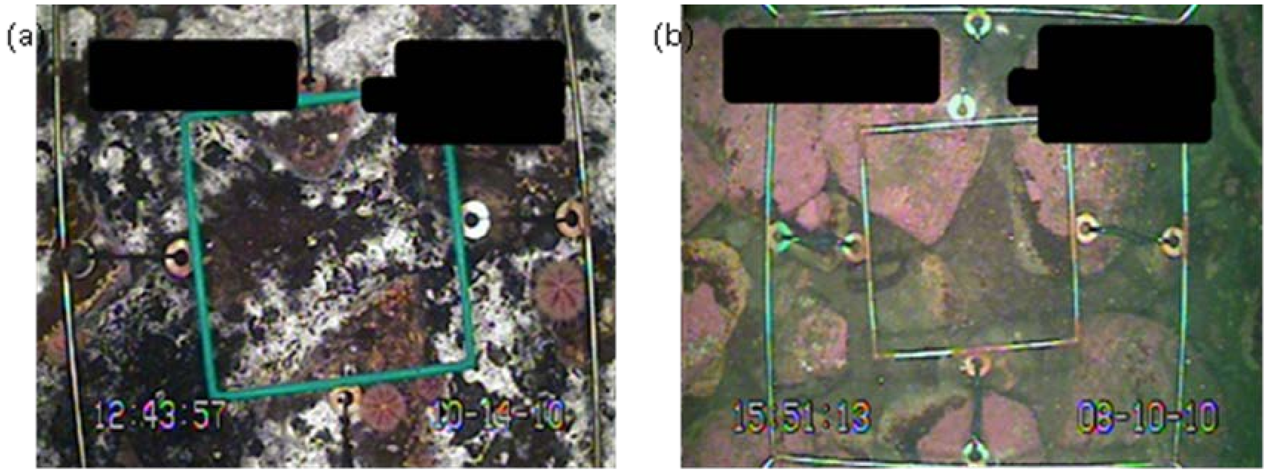

Figure 4. Sample photos of encrusting species taken from drop transects; (a) photo of *Beggiatoa* spp. covering a cobble, sand, and mud bottom, (b) photo of Coralline algae (Lithothamnion) on top of boulders, cobble, and sand.