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The usage of visual indicators in regulatory monitoring at hard-bottom finfish aquaculture sites in Newfoundland (Canada)

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ABSTRACT

Finfish aquaculture can be installed over hard and patchy substrates where grab sampling is challenging and use of video can be an appropriate tool to document benthic changes. Video monitoring can show visual indicators of enrichment, namely flocculent matter, *Beggiatoa*-like mats, and opportunistic polychaete complexes (OPC). We examined factors influencing presence of indicators using 52 video monitoring reports collected in Newfoundland, Canada. The main driving factor was distance to cage, with indicators showing a higher probability of occurrence within 10 m from cages due to low current velocities. Indicators were less prevalent on sites dominated by hard substrates while OPC in particular were restricted to depths >35 m. *Beggiatoa*-like bacteria covered a larger surface than the two other indicators; however, our results suggest the necessity of amalgamating information related to all the indicators (including bare stations that could indicate anoxia) to establish a more accurate evaluation of aquaculture impact.

1. Introduction

In certain regions, such as in some Norwegian counties (Taranger et al., 2014), in British Columbia, Canada (Abo et al., 2013) and Newfoundland, Canada (Anderson et al., 2005; Hamoutene, 2014; Hamoutene et al., 2013, 2014, 2015), finfish aquaculture sites are installed over hard substrates where grab sampling to assess benthic habitat changes due to organic enrichment can be challenging. In particular, local Newfoundland (NL) conditions have dictated the use of visual approaches for documenting benthic changes resulting from aquaculture instead of sulfide/redox sampling (DFO, 2012; Mabrouk et al., 2014). However, and despite the development of adapted protocols (Mabrouk et al., 2014), additional work is required to identify lower levels of disturbance (Hamoutene et al., 2015) and determine thresholds for use in regulatory regimes (DFO, 2014). For instance, the Norwegian mandatory monitoring program for organic loading assessment is built on a quantitative evaluation that is limited in its efficacy to soft sediment habitats (Taranger et al., 2014). Further knowledge should be developed to better understand the interaction of organic and nutrient waste release on different habitat types including hard bottom habitats, and coastal sandy habitats, (Taranger et al., 2014).

In NL, along the South Coast of the island, most salmonid farms occur in deep bays or fjords (>30 m) where substrates consist of bedrock, rock or cobble with patches of soft sediments (Anderson et al., 2005; Hamoutene, 2014; Hamoutene et al., 2013, 2015). Benthic video surveys of the South Coast revealed a patchy distribution of benthic organisms (identifiable at a high taxonomic level) characterized by low natural abundances and richness (Hamoutene et al., 2015). These low natural total abundances can adversely affect the performance of several ecological indices (e.g. Borja and Muxika, 2005; Keeley et al., 2012) rendering challenging the quantification of benthic changes. In a recent NL study, correlations of abundances and richness of enumerable organisms with distance from cage were weak, and stations close to cages were not always statistically different from stations further away or at the reference sites (Hamoutene et al., 2015). These findings confirmed that benthic video surveys at sites dominated by hard substrates are less sensitive than infaunal data at detecting lower levels of disturbance, and that relative densities of enumerable epibenthic organisms can be similar at affected and unaffected stations (Crawford et al., 2001; Hamoutene et al., 2015). In addition, the classification of the ecological status of rocky substrata remains challenging since major groups such as algae and invertebrates co-vary, both naturally and with the alteration of environmental conditions (Diez et al., 2012). This is likely due to the patchiness of invertebrate taxa (Branch, 1985), and the fact that the degrees of alteration of groups such as macroalgae are not always taken into account when using common ecological indices (Diez et al., 2012).

Despite these limitations, video monitoring can show evidence of organic matter enrichment at aquaculture sites through the presence of *Beggiatoa* spp.-like bacterial mats, opportunistic polychaete complexes (OPC), and flocculent matter, (Hamoutene et al., 2015), hereafter referred to as 'visual indicators'. *Beggiatoa*-like mats and OPC are both indicators of organic enrichment (IOE); their presence reflects a stage of

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enrichment described as sub-hypoxic as per sulfide regimes (Brooks, 2001) through the Pearson–Rosenberg model (Pearson and Rosenberg, 1978). Extreme abundances of one, or a few, opportunistic taxa are a useful feature for elucidating effects as the peak provides an important reference point along the enrichment gradient (Pearson and Rosenberg, 1978; Keeley et al., 2012). Flocculent matter, consisting of a viscous mixture of decomposing pellets, microbes, fish feces, dorvilleid mucus and sedimented organic matter (Salvo et al., 2015a), can also be observed in benthic video surveys at aquaculture sites. Flocculent matter is not indicative of a particular stage of organic enrichment, but provides a characterization of the zone of deposition beneath cages. Flocculent matter often co-occurs with IOE and represents a drastic change of substrate for benthic fauna and flora, especially on hard substrates.

Since 2011, the NL monitoring program requires that video collection at aquaculture sites be completed at 10 m intervals along 50 m transects extending from each corner of the cage array, with each sampling point referred to as a station. The spatial coverage of IOE can be evaluated at each station by analyzing images extracted from videos of the seafloor. Previous studies have revealed that within-station percent coverage of *Beggiatoa*-like mats and OPC decreased with increasing distance from finfish cages, but with considerable patchiness in distribution (Hamoutene et al., 2014). Furthermore, sulfide and redox values associated with bacterial coverage measured on soft sediment patches showed significant differences only when comparing absence and presence of bacteria and not between different levels of coverage (Hamoutene, 2014). These findings suggest that the documentation of the presence/absence of IOE at sampling stations might be a cost and time efficient substitute to percent coverage determinations, especially within a regulatory framework. Mapping the incidence of visual indicators at an aquaculture site is also indicative of the footprint of sub-hypoxic conditions and might be useful in follow-up surveys (Hamoutene et al., 2015). However, organic enrichment can lead to oxygen depletion/anoxia resulting in the absence of *Beggiatoa* spp. (Brooks et al., 2004; Hamoutene, 2014), and likely affecting OPC presence (Salvo et al., 2015a). Thus, the absence of IOE needs to be interpreted with caution and requires further understanding before predicting recovery or potential azoic conditions (Hamoutene et al., 2015). The ecological characteristics underpinning the progression from peak of opportunists (IOE) to azoic conditions associated with extreme enrichment are not well known and as a result are often simply represented by a categorical shift (e.g. Simboura and Zenetos, 2002; Keeley et al., 2012). Indicators can also have biases with regard to site and/or region-specific characteristics highlighting the importance of selecting indicators that are regionally validated (Keeley et al., 2012). The proper interpretation of IOE presence/absence in the context of aquaculture production or fallowing periods requires a better understanding of distribution limits of IOE and their relationships to environmental factors such as depth, substrate type, and ocean current regimes in the region of interest.

In this study, we examine the potential factors influencing IOE and flocculent matter presence/absence using an extensive dataset extracted from 52 video monitoring reports collected between 2009 and 2013 (34 sites). The objectives of our study are: 1) to examine the relationships between the presence of visual indicators and environmental conditions (depth, substrate type, time of year) and document co-occurrences between the three visual indicators; 2) to test for relationships between visual indicators and environmental and production related farm-specific variables (biomass at stocking, distance from cage, length of production cycles, ocean current regimes, depth, substrate type); and 3) to compare the footprint of each indicator at the end of a production cycle and after a one year fallowing period using presence/absence data collected at stations. We discuss the potential application of these footprints to aquaculture regulatory regimes and to track recovery processes, and bring novel information on monitoring of aquaculture effects on hard-bottom substrates.

2. Materials and methods

2.1. The study area

The study area (Fig. 1) is located on the continental shelf of the South Coast of Newfoundland, Canada and is characterized by complex bathymetry with deep basins, shallow sills and numerous side bays and inlets. The vertical structure of the water in the area is stratified with warmer and fresher water at the surface from spring to fall, particularly in the Bay d'Espoir fjord where a large quantity of freshwater is discharged from a power generation dam (MSRL, 1980). In Fortune Bay, natural runoff occurring at the head (Belle Bay), for the most part, stratifies the water column, with strength gradually diminishing in the Fortune Bay basin, away from the head (de Young, 1983). Temperature and salinity profiles from 2009 to 2013 (results not shown) indicate that the water column in the area is essentially a 2–3 layer system from spring to fall featuring a heated and freshened seasonal surface layer and the intrusion of deep water below 150 m depth in the deepest basins. The thickness of the surface layer varies both in space and time and is found to be generally within the 5–20 m range. The dynamics associated with such topographic and water structure characteristics are likely to be similar to that of other mid-latitude fjords which typically present complex layered currents (e.g., Inall and Gillibrand, 2010).

2.2. The monitoring program

In NL, a salmon production cycle is generally completed after 2.5 to more than 3 years, with smolts stocked in cages when weighing 60–100 g and adults harvested between 3 and 4.5 kg. Aquaculture sites vary in area, number of cages and stocked biomass and are located within three main regions: Fortune Bay–Belle Bay, Connaigre Peninsula and Hermitage Bay–Bay d'Espoir (Fig. 1). The most recent monitoring program requires that video should be collected within two weeks of harvest (referred to as Part1) and four to eight weeks before the end of a fallow period (referred to as Part2). Video is also required prior to aquaculture stocking (baseline reports) and for licensing purposes. Fallow periods of one year have been implemented for fish health reasons but have varied in length according to bay management requirements. Monitoring is conducted by consultants and reports are generated as part of the regulatory process. Prior to 2011, underwater videos were collected at the four corners of the cage array (Hamoutene et al., 2013); after 2011, video monitoring was completed along transects extending from the cage edge at each corner of the cage array. Transect sampling follows a tiered approach with underwater video completed at 10 m intervals as per GPS positioning (10–15 m error according to depth) starting at the cage edge (0 m) and continuing for a maximum of 50 m (Fig. 2). Each sampling point is referred to as a station. Sampling is often discontinued after 30 m from cage edge if no IOE are detected. Also, no sampling is done at stations >100 m in depth due to camera limitations (cable length, camera resolution, lighting). All sampling and reporting were completed by a single environmental company. Monitoring reports were selected on the basis of consistency in documenting the presence/absence of IOE and overall site description. Video footage is recorded using a custom built underwater video camera mounted to an aluminum frame with a quadrate of 50 cm × 50 cm at a 90° angle, pointing vertically at the seafloor and coupled to a GPS recorder (DFO, 2012; Mabrouk et al., 2014). Video frames showing a clear image of the cage resting flat on the bottom are selected, extracted and converted into image files (.jpeg,. png) for analyses. Image J software is used to determine percent coverage of sediment type, *Beggiatoa*-like mats and polychaetes (OPC) within the 25 cm^2 quadrate.

2.3. Video analyses and database preparation

The monitoring reports include the following information for each station: GPS coordinates, depth, predominant substrate type, a list of