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Newfoundland and Labrador Region

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POTENTIAL IMPACTS OF FINFISH AQUACULTURE ON HARD BOTTOM SUBSTRATES AND DEVELOPMENT OF A STANDARDIZED MONITORING PROTOCOL

Aquaculture cage on the South Coast of Newfoundland and Labrador (NL).

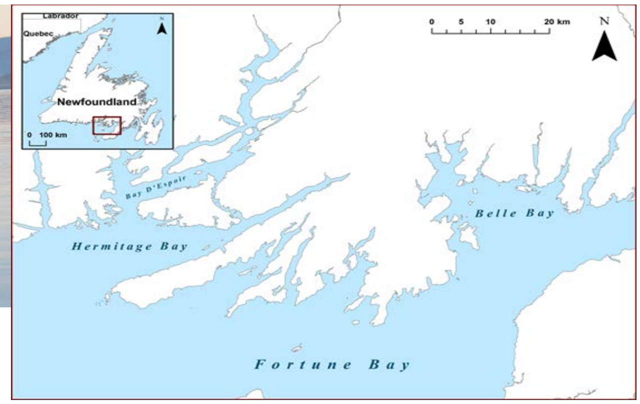

Figure 1. Map of the south coast of NL.

Context:

In the Newfoundland and Labrador (NL) Region, Fisheries and Oceans Canada's (DFO) Fisheries Protection Program (FPP) assesses potential impacts of finfish aquaculture operations on fish and fish habitat that support fisheries of value to Canadians. To assist in this assessment, the Newfoundland aquaculture industry has been responsible for conducting habitat monitoring of finfish aquaculture sites. However, past monitoring practices have presented challenges in the NL Region and consequently, DFO-FPP has recently implemented changes to its monitoring protocol by replacing redox and sulfide analysis with visual observations over hard substrates.

Fisheries and Oceans Canada's FPP is also responsible for reviewing new site applications and providing advice regarding siting and maximum production levels so as to minimize environmental impacts. The particular environmental conditions in the South Coast of Newfoundland (i.e. deep sites; low water currents; low water temperatures; hard bottom substrates) necessitate specific advice regarding the implications of site development and expansion in this Region. In an effort to deliver this advice, the following meeting objectives were developed: 1) Evaluate the standardized benthic monitoring protocol developed for assessing potential impacts of finfish aquaculture operations on hard bottom substrates; 2) Evaluate the applicability of the use of potential visual indicators (flocculent accumulation, off-gassing, Beggiatoa and/or Opportunistic Polychaete Complexes (OPC), etc.) to identify benthic impacts on various substrates; 3) Validate the use of DEPOMOD (a commercial model for predicting organic deposition under finfish aquaculture sites) as a tool for predicting the extent and severity of benthic changes associated with aquaculture operations within the NL Region); 4) Evaluate the characterization of the impacts of finfish aquaculture on hard bottom substrates in the NL Region, including changes in biodiversity, biophysical characteristics, and habitat functionality, and discuss the development of regional benthic monitoring thresholds of impact.

This Science Advisory Report (SAR) is from the Regional Peer Review meeting that was held May 22-23, 2013 in St John's, NL. Participants included personnel from DFO, representatives from the Newfoundland and Labrador provincial government, the aquaculture industry, the Fish, Food and Allied Workers (FFAW) Union, the Miawpukek First Nation (MFN), and faculty and graduate students from Memorial University. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- Visual imaging can be used as an appropriate primary tool for assessing benthic changes on predominately hard bottom substrates in aquaculture areas of Newfoundland.
- Parameters for achieving good quality videos suitable for analysis were discussed. Factors included: resolution, added lighting and camera orientation. These methods can evolve with new technologies (camera systems, image processing software).
- Using standardized area measurement, such as a quadrant, with the visual imaging equipment is essential in achieving consistency in the spatial coverage of video surveys.
- Training observers to assess the videos as well as the use of the visual benthic identification guide are important elements in ensuring consistency and quality assessments.
- *Beggiatoa* and OPC appear to be acceptable indicators of organic deposition.
- *Beggiatoa* and OPC were not observed in reference sites and were found linked with aquaculture activities on a range of substrates.
- *Beggiatoa* and OPC were found to decrease with distance from cage.
- More sites need to be considered in order to validate DEPOMOD use to predict deposition from aquaculture farms in NL conditions.
- The characterization of benthic assemblages across the study area shows a patchy distribution (including patchy substrates). Relationships with depth, substrate type, and proximity to finfish cages were studied. Some benthic communities were very poor with little fauna/flora presence. Benthic hypoxic conditions may exist in some sites prior to aquaculture site set-up.
- Proper characterization of the spatial extent of areas of deposition necessitates the extension of sampling transects from cage edge beyond the current limit (50 m) to 120 m.
- *Beggiatoa* and OPC were still present on fallowed sites. After a one-year fallow period, results suggest a reduction of the spatial extent of benthic organic indicators (*Beggiatoa*, OPC) to the area below the cages. More research is needed to draw conclusions on the fallow period efficiency in contributing towards assimilation of deposits and a return to baseline conditions.
- The *Fisheries Act* amendments passed in 2012 create a fisheries protection program that will focus on the protection of fisheries and fish and fish habitat that support those fisheries. In the light of these changes, the findings of this work and its continuation will help inform the development of management thresholds.

INTRODUCTION

Traditionally, the habitat assessment of aquaculture sites requested by regulatory bodies in Newfoundland and Labrador have been based on collecting grab samples around the perimeter of farm cages, not more than two weeks prior or two weeks after initiation of the fallow period and then 4-8 weeks before the fallow period ends (at restocking). These bottom grab samples were sometimes supplemented by videos of the bottom. Currently, approximately 90 % of the finfish sites on the South Coast occur in areas deeper than 30 m and over hard and patchy substrates, varying from fine sand to medium pebbles to boulders and bedrock. Thus, often, it is not possible to apply conventional performance-based standards such as free sulfide and redox potential to assess benthic impacts because of the difficulty of obtaining bottom grab samples in these areas. On a sample of 23 aquaculture sites surveyed on the South Coast of NL, only 44.5 % of the grabs attempted resulted in usable samples (more than 5 cm of substrate) for sulfide and redox measurement. Therefore, it is essential to find an alternative monitoring technique and the use of video surveys presents itself as a possible reliable method. Video surveys are being used routinely in many countries and within Canada to assess impacts of fish farms, and are considered to be a valuable monitoring tool. Video monitoring of hard bottom substrates is required through DFO license conditions in BC under the Pacific Aquaculture Regulations, and protocols for this monitoring are appended to the license. Videos are relatively easy to collect, cost-effective and provide a permanent record that can be retrieved at any later date for comparisons over time.

The advice requested by DFO-FPP includes the establishment of standard operating procedures for video surveys in the NL Region. Videos would provide description of the substrate and the fauna and flora, with a focus on presence of indicator species of benthic change due to aquaculture, mainly OPC and mat-forming bacteria (*Beggiatoa* spp.) (as further discussed below). In acknowledging that video monitoring of benthic impacts requires analyses that might be completed by multiple observers, it was essential to reduce biases among and within observers. To complete the first objective of the peer review meeting, three main goals were set:

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.

Although numerous biological and geochemical variables have been used to assess benthic condition near aquaculture sites, none of these indicators have been fully assessed on hard and patchy substrates. Two impact indicators, *Beggiatoa spp*. and OPC, used on soft substrates may have utility on hard substrates because they are conspicuous members of the benthic fauna and are known to occur near finfish sites and areas of enrichment on hard substrates. *Beggiatoa* forms bacterial mats and occurs at the interface of oxic and anoxic conditions and is typically associated with elevated sulfide levels, and it has been frequently observed under or adjacent to finfish farms sited on hard seabeds in BC (Emmett et al. 2008). Moreover, several studies have found that local benthic organic enrichment under fish cages can be detected by the presence of bacterial mats. The second potential indicator, OPC, is frequently observed in areas with organic enrichment and reduced conditions. In NL, a study of monitoring reports (at cage edge) has revealed that *Beggiatoa* and OPC are valid visual indicators of benthic change due to aquaculture and had the strongest response to operational activity (baseline, production level, fallowing) and water-depth and, substrate type to a lesser degree. They correlate with indicators of aquaculture activities such as flocculent presence, offgasing and sulfides at NL aquaculture sites (Hamoutene et al. 2013). *Beggiatoa* mats are observed independent of sampling dates and prove useful for monitoring environmental impacts associated with net pens. Using percent-cover of bacterial mats instead of merely absence or presence has been considered and *Beggiatoa* coverage thresholds are now used in some jurisdictions, such as BC (Emmett et al. 2008) and Maine (Wilson et al. 2009). The data analyzed to achieve the second objective of this meeting include information collected in the field by DFO staff as well as extracted from industry monitoring reports. Data were analyzed to reveal trends across sites in relation to distance from cage and evaluate variability within stations located in the same direction.

A variety of modeling methods for investigating the dispersal of aquaculture waste around finfish farms are available the most common of which is DEPOMOD (Cromey et al. 2002; Chamberlain et al. 2005). Initially developed in Scotland, DEPOMOD has since been tested for use in BC and is utilized by various regulatory agencies and stakeholders worldwide. DEPOMOD, a particle tracking model, is used to predict deposition of carbon (flux in g $C/m^2/d$) onto the seabed as influenced by bathymetry, currents, particle settling rate (feces and feed), cage position, feeding rate and feed waste. As part of objective three of this meeting, a study to validate the use of DEPOMOD in the NL region was completed in order to predict carbon deposition underneath and in the vicinity of fish farms. The verification of the model output was performed by comparing observed carbon deposition at the bottom with values computed from the model. The former was estimated using data from sediment traps installed around two aquaculture sites.

Hard-bottom habitats are typically colonized by sessile invertebrates such as sponges, cnidarians, ascidians, and bryozoans, responsible for most of the diversity and biomass. Whether the grouping of fauna is taxonomic or locomotory, there is an inherent patchiness to hard bottom communities. There have been no comprehensive surveys of the benthic communities around aquaculture sites of NL and little is known about the effect of deposition on predominant assemblages. Objective four of the meeting involved:

1. the characterization of deep benthic boreal/sub-arctic assemblages around salmonid cage sites on the South Coast of NL and their spatial distribution;
2. the identification of factors influencing the distribution of benthic assemblages around cage sites and the link to *Beggiatoa* and OPC presence; and
3. the determination of spatial extent of indicator presence around some finfish sites in NL in an attempt to evaluate footprints.

The particular environmental conditions in the South Coast of Newfoundland (i.e. low water currents; low water temperatures; naturally low dissolved oxygen at depth; hard bottom substrates) necessitate specific advice regarding the implications of site development and expansion in the region. Fisheries and Oceans Canada’s-FPP will use this advice to inform decisions on siting and stocking and determine whether additional or a reduction in mitigation measures and/or best management practices are required to minimize adverse effects of aquaculture operations on fish and fish habitat. This advice would then result in more regulatory certainty for DFO and the aquaculture industry in the NL region, and provide the fishing industry and general public with more confidence that any potential environmental impacts of aquaculture operations are being properly managed. The *Fisheries Act* amendments passed in 2012 create a fisheries protection program that will focus on the protection of fisheries and fish and fish habitat that support those fisheries. In light of these changes, the findings of this work and its continuation will help inform the development of management thresholds once management objectives have been set.

ANALYSIS

Objective 1

The standardization of methods benefits 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. Aquaculture sites in Newfoundland often occur in deep waters (between 30 m and 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. These facts led to the use of a drop video camera system in the NL monitoring program.

Standard operating procedures for video monitoring using a drop camera have now been established and described in the guide currently being used (DFO 2013a). Our findings show that the design of a frame around the drop camera and most importantly the added lighting and camera angle resulted in creating higher quality images. It was also 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 collected for monitoring purposes. They also provide a scale to estimate size of organisms or the 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 species (coralline algae) as well as indicator presence (*Beggiatoa*, OPC).

One important challenge in analyzing the videos collected is the inherent observers' variability. Our results suggest that there is minimal to no observer variability and therefore we recommend providing a detailed instructional manual and adequate training to observers to reduce the margin of error. The main deliverables addressing this objective are:

1. a comprehensive guide of standard of practice for video camera usage (DFO 2013a); and
2. a photographic guide to benthic species of hard bottom communities on the South Coast of Newfoundland (DFO 2013b).

Both documents can be used by environmental companies when conducting their assessments.

Objective 2

Results from our studies as well as data extracted from industry monitoring reports were examined to evaluate the applicability of using *Beggiatoa* and OPC as indicators of benthic change due to finfish aquaculture operations. Data were analyzed to reveal trends across sites in relation to distance from cage (as a proxy for decreasing deposition) and evaluate variability within stations located in the same direction. Sites with different conditions and sampling times (depth, substrate, production, etc.) were grouped (baseline group, Part 1 or Part 2) in order to identify dominant trends, independent of specific site conditions, and to ensure that indicators such as *Beggiatoa* and OPC responded to aquaculture operations presence throughout the year. The first set of data analyzed pertains to monitoring reports completed at cage edge; *Beggiatoa* and OPC presence were then noted with no assessment of coverage. Changes to the habitat monitoring protocols were implemented in June of 2011 with protocols changing from cage edge sampling to transect sampling (3 transects around the cage array). In addition, a better quantification of OPC and *Beggiatoa* presence was completed through the evaluation of percent coverage using a reference frame and Image J software. Counts/abundances of fauna and flora were also recorded in order to better evaluate epibiota richness. The second set of data analyzed and discussed is collected according to this latest protocol.

When using data extracted from monitoring reports, our observations averaged at the site level revealed that *Beggiatoa* and OPC were not found in reference sites and are acceptable visual indicators of the effects of aquaculture operations on the benthos. Decision tree analyses revealed that *Beggiato*a and OPC had the strongest response to operational activity (baseline, production level, fallowing) and to a lesser degree to water-depth and substrate type. *Beggiatoa* and OPC correlate well with other variables monitored, such as, flocculent presence, offgasing and sulfides (Hamoutene et al. 2013). However, our recent results suggest that *Beggiatoa* coverage does not increase linearly with suplhides level (Hamoutene 2014). *Beggiatoa* and

OPC were found to decrease with distance from cage though exhibiting patchy distributions. Despite this patchiness, average differences in indicators coverage between stations along transects in the same direction were less than 10 %. When transforming data in dummy variables (presence/absence) we found the same trends. Presence/absence of indicators could eventually be used as a potential trigger to inform of benthic organic enrichment at finfish aquaculture sites considering some of the variability observed in coverage values. Recent findings suggest the existence of an upper limit in sulfide concentrations where conditions are no longer suitable for *Beggiatoa* development. Information on *Beggiatoa* coverage should be considered in the light of other evidence gathered through video imaging, such as benthic richness and diversity, as well as the presence of other indicators (polychaetes, flocculent, offgasing, etc.) (Hamoutene 2014).

Our results suggest that benthic hypoxic conditions (as per sulfide and redox measurements) may exist in some sites prior to aquaculture activities. Sediments in Newfoundland coastal waters are often rich in organic matter and are seasonally (temperature < 0°C) or always cold (-1.8 to < 5°C) influencing sulfate reduction rates. Additionally, inner basins of some bays and fjords protected from waves may naturally experience seasonal hypoxia that will influence sediment-water exchange processes (Anderson et al. 2005).

In our assessment, we noted the following limitations in data collection when evaluating *Beggiatoa* and OPC:

1. *Beggiatoa* (white mats) will cover/colonize all surfaces not allowing us to properly identify the substrates below and in some cases to observe presence of OPC deeper in the sediment/flocculent, thereby underestimating OPC presence;
2. we were not able to take into account the thickness of bacterial mats in video data; and
3. it was difficult to discriminate between low and intermediate impact areas. Quantitative data from video recordings can detect major organic enrichment but are not as sensitive as benthic infaunal data to lower levels of disturbance (Crawford et al. 2001).

Objective 3

Organic particles released during farm operations are transported, dispersed and potentially degraded as they sink toward the bottom. Effects on the benthic ecosystems depend upon the rate at which the material settles and the ability of ecosystems to assimilate the added flux of organics. This objective encompassed the evaluation of the applicability of the aquaculture waste deposition model, DEPOMOD, in understanding and predicting the pattern and amount of particle deposition from marine finfish cage sites on the South Coast of Newfoundland. In order to assess the surface area of deposition underneath and in the vicinity of fish farms, currents at different depths were recorded at locations near aquaculture farms. The current velocity time series, together with the bathymetry of the area and the feed input data, were considered in order to run DEPOMOD. Observed carbon deposition at the bottom was estimated using data from sediment traps installed around the sites (deployed approximately 2 m above seabed).

Sensitivity analyses on the model parameters and DEPOMOD output were not comparable with results obtained with common model parameters used in recent analyses in other regions. These findings suggest that additional analyses on more sites are needed in order to use the model under Newfoundland conditions and establish its general applicability in predicting carbon deposition. Factors associated with the sediment trap type, deployment duration, depth above seabed, and the type of buffered solution used as a preservative need further consideration for future DEPOMOD assessments.

Objective 4

As stated previously, there have been no comprehensive surveys of the benthic communities around finfish aquaculture sites of NL and little is known about the effect of deposition on predominant assemblages. The current approach is not site specific and was selected in order to establish cause and effect relationships between main benthic community features and aquaculture activities by documenting changes across sites. Aquaculture sites with a similar length of production had different production levels and are operated by different aquaculture companies (different stocking densities and feeding strategies) precluding the association of a level of production with a specific benthic change.

The sites investigated in this study covered a wide range of depths with basins, steep rock walls, and large expanses of low-sloped areas revealing a mosaic of substrate types. Although fine and medium sediments were sometimes dominant, bedrock was present at most sites. The benthic assemblages identified across the study sites showed a patchy distribution, with some relationships with depth, substrate type, and the proximity of finfish cages. Within the current video sampling scheme (i.e. documentation of epifauna only), some NL sites exhibit bare environments with no fauna/flora or very low abundances. Benthic communities showed evidence of change due to aquaculture waste deposition through a decrease in abundance and diversity. The study was unsuccessful in characterizing an intermediate zone with moderate to light benthic changes using video data.

Beggiatoa presence on aquaculture sites was found in areas encompassing OPC and flocculent presence. On the other hand, OPC could be absent (or not visible) in sites in operation suggesting the role of other factors (season, depth, etc.) requiring further investigation. As stated above, the data also highlight the patchiness of indicators (*Beggiatoa* and OPC), a fact that should be taken into account in the design of regulatory regimes. The presence of indicators was observed at average distances ~ 70 m from cage edges suggesting the need to extend sampling transects to at least 120 m (50 m in today's regulatory protocol) with stations separated by 20 to 30 m to better delineate the spatial extent of deposits.

Some stations located in the fallowed sites exhibited *Beggiatoa* and OPC while others had no indicators and no flora and fauna. The spatial extent of indicators showed a reduction of the footprint to the area below the cage after fallow. Nonetheless, considering the grouping of data from different sites and disparities in length of fallow periods more research is needed to draw conclusions on the fallow period efficiency in contributing towards assimilation of deposits.

As already stated above, our findings highlight the fact that information on indicator's coverage or presence/absence should always be considered in light of other evidence gathered through video imaging, such as benthic richness and diversity. For example, stations with no *Beggiatoa* and where no other epifauna can be observed might suggest a high level of enrichment though absence of *Beggiatoa* at reference sites implies no aquaculture impact.

Sources of Uncertainty

- In establishing sampling protocols to assess fauna/flora abundance in low-diversity and patchy hard-bottom seafloors with varying water-depths, the sampling design, number of stations per transect or grid, sample replication, camera distance off seafloor (boulders) need to be further investigated.
- There is uncertainty associated with deploying sediment traps on sloped seabeds in inshore areas for DEPOMOD. Trap type, deployment height, deployment duration, and sample preservation influence the sample collection.

- There are knowledge gaps in the biology of OPC, in particular, the understanding of seasonal effects, role in remediation processes, and natural life cycle.
- There is uncertainty regarding the presence and biology of different *Beggiatoa* species.
- There are knowledge gaps regarding observations of *Beggiatoa* and OPC and other fauna/flora at greater distances from cage edge (far-field effects).
- Research is needed to quantify percent cover of *Beggiatoa* and OPC in relation to depositional flux and water depth in order to establish an impact threshold for regulatory purposes (according to objectives set by regulators).
- More research is needed on fallow periods as a management tool due to the depauperate nature of some benthic environments and the persistent presence of indicators in others (at cage edge mostly).

CONCLUSIONS AND ADVICE

The use of a drop video camera for monitoring is recommended in NL conditions considering that aquaculture sites often occur in deep waters precluding the use of divers and that mooring systems of aquaculture cages make it difficult to use ROVs around cages. Standard operating procedures have been established and described in the guide currently being used. Our findings show that adding lighting and adjusting the camera angle resulted in a higher quality image. The area examined at every camera drop was standardized using quadrants to provide a tool for spatial consistency of the data collected. Quadrants provide a scale to estimate size of organisms and the spatial 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 species (coralline algae) as well as indicator presence (*Beggiatoa*, OPC). Our results suggest that there is minimal to no observer variability and therefore we recommend providing a detailed instructional manual and adequate training to observers to reduce the margin of error.

The sites investigated in this study (South Coast of NL) covered a wide range of depths with basins, steep rock walls, and large expanses of low-sloped areas revealing a mosaic of substrate types. Although fine and medium sediments were sometimes dominant, bedrock was present at most sites. Some sites exhibited bare environments with no fauna/flora or very low abundances under the current sampling scheme (i.e. epifauna). In addition, our results suggest that benthic hypoxic conditions (as per sulfide and redox measurements) may exist in some sites prior to aquaculture activities. Benthic communities showed evidence of change due to aquaculture waste deposition through a decrease in abundance and diversity. Our Decision Tree Analyses revealed that the status of the finfish site (baseline, production, fallow) had the strongest influence on the presence of *Beggiatoa* and OPC. *Beggiatoa* and OPC also respond to depth and substrate type at a lower hierarchical level in the decision tree. Thus, *Beggiatoa* and OPC are acceptable indicators of the effects of aquaculture operations on the benthos. Their presence/absence correlate with other assessed variables, such as, flocculent presence, offgasing and sulfides. However, results suggest that *Beggiatoa* coverage does not increase linearly with sulfides level (Hamoutene 2014). *Beggiatoa* and OPC were found to decrease with distance from cage (used as a proxy for decreasing deposition) though exhibiting patchy distributions. Presence of indicators was observed at average distances ~ 70 m from cages suggesting the need to extend sampling transects to at least 120 m (50 m in regulatory protocol) with stations separated by 20 to 30 m to properly delineate deposition areas.

More research is needed on fallow periods as required by regulators in the NL Region as a management tool in light of the depauperate nature of some benthic environments and the persistent presence of indicators in others. Regulators will need to set measurable objectives in order to understand where fallow period requirements fit in order to achieve these objectives.

OTHER CONSIDERATIONS

- Validate DEPOMOD as tool for predicting deposition under NL conditions and determine the relationship between depositional flux and alterations to benthic fauna and flora. Factors associated with the sediment trap type, deployment duration, depth above seabed, and preservative type need further consideration for future DEPOMOD assessments.
- In light of the recent changes to the *Fisheries Act*, the development of regional benthic monitoring thresholds of impact and the role of the fallow period need to be further discussed once regulators have set measurable objectives to achieve.

SOURCES OF INFORMATION

This Science Advisory Report is from the Regional Peer Review meeting that was held May 22-23, 2013 in St John's, NL: Potential impacts of finfish aquaculture on hard bottom substrates and development of a standardized monitoring protocol. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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