A GUIDE TO THE DECISION SUPPORT SYSTEM FOR ENVIRONMENTAL ASSESSMENT OF MARINE FINFISH AQUACULTURE

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ABSTRACT

Doucette, L.I. and B.T. Hargrave. 2002. A Guide to the Decision Support System for Environmental Assessment of Marine Finfish Aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 2426: iv + 35 p.

The Marine Finfish Aquaculture Decision Support System (MFADSS) is designed to provide structured scientific advice to aid Habitat Managers in making decisions and to increase consistency in evaluating environmental data provided in marine finfish lease applications. The MFADSS requires input of lease site information and answers to two sets of questions to examine far field and site specific variables. Most of the required information is provided with a lease application. This guide explains how to compile the site and environmental data from a lease application and input the information into the MFADSS.

RÉSUMÉ

Doucette, L.I. and B.T. Hargrave. 2002. A Guide to the Decision Support System for Environmental Assessment of Marine Finfish Aquaculture. Rapp. tech. can. sci. halieut. aquat. 2426: iv + 35 p.

Le système de soutien décisionnel à l'aquaculture des poissons de mer (MFADSS) a pour but de donner des avis scientifiques structurés aux gestionnaires de l'habitat pour les aider à prendre des décisions et pour assurer une cohérence dans l'évaluation des données environnementales contenues dans les demandes de baux aquacoles. Le MFADSS nécessite la saisie de renseignements sur le site considéré et des réponses à deux séries de questions pour permettre l'examen des variables concernant le champ lointain et le site à proprement parler. La plupart des renseignements demandés sont contenus dans la demande de bail. Le présent guide explique comment réunir l'information sur le site et les données environnementales à partir d'une demande de bail et comment saisir ces renseignements dansle MFADSS.

INTRODUCTION

A decision support system (DSS) is a computer-based integrated approach for supporting management decisions. The DSS method has been widely used in diverse fields where a variety of information must be evaluated in making decisions. The approach has recently been proposed as a method for applying the precautionary principal to fisheries management decisions (Halliday et al. 2001). A web-based environmental assessment tool for freshwater aquaculture in the Great Lakes Basin is now available online (Brister and Kapuscinski 2002). Previous applications range from using a DSS as a medical diagnostic tool, to models for socioeconomic development, environmental impact assessment and water resource management (Hargrave 2002). A decision support system for marine finfish aquaculture intended to assist Department of Fisheries and Oceans (DFO) Habitat Managers in making siting decisions when evaluating finfish lease applications is described in Hargrave (2002). It provides a structured framework for providing scientific advice on aquaculture lease applications and, by applying a standard set of criteria, increases consistency in decision making. This report provides a more detailed description of how to input information into the Marine Finfish Aquaculture Decision Support System (MFADSS).

The MFADSS is based on a Traffic Light Method of scoring answers to questions that assess the state of environmental variables both near and distant from potential finfish aquaculture sites. It is intended to assist managers in compiling and assessing physical, chemical and biological information provided in site applications, allowing them to make informed, scientifically based decisions on environmental aspects of site assessments. It provides scientific input to siting decisions in a structured, uniform, and unbiased basis.

It must be emphasized that the MFADSS is intended to be used only as a screening tool. It provides a guide to assist in decision making rather than a system that provides an outcome that must be adhered to. Habitat Managers will still make the final decision on the acceptability or unacceptability of an individual application based on a broad range of criteria. However, the MFADSS serves to focus an assessor's attention on a set of potentially critical environmental variables that may be overlooked or not fully evaluated. Output from the system can be used as a warning of potential environmental problems and then managers can seek specific scientific recommendations on these issues. Managers are not obligated to use a decision rendered by the MFADSS. However, if an unacceptable rating is rendered for a site, and a decision is made to allow licensing to proceed, the decision would have to be justified with respect to variables identified as resulting in negative scores.

ACCESSING THE SYSTEM

The MFADSS is a web-based application that is currently accessible only through the Fisheries and Oceans (DFO) Intranet. The system administrator (contact Informatics Division or the Marine Environmental Sciences Division at Bedford Institute of Oceanography) must assign a user name and password for access to the Oracle-based system. Detailed instructions ("Marine Finfish Aquaculture Decision Support System

User Guide") will be provided by the system administrator after a new user name and password are assigned.

It is recommended that all information required to enter data into the MFADSS be assembled before accessing the system through the DFO Intranet. When input is completed and information is saved, scores are calculated and the input data is compiled in a unique database record within the MFADSS. If an application is re-entered (for example to alter some of the input information) an additional record is saved in the database. A database is thereby created for all users of the system. In its present configuration answers/data are required for all questions. If data are missing, the assessor must use their best judgement to substitute answers or estimated values based on knowledge of the lease area and other site applications. This would allow a temporary assessment of site suitability. A final assessment could only be completed when missing information is obtained. Changes that occur in variables as more recent information is provided by the proponent, such as mitigation measures that have been established or additional data for site variables (i.e. current speed, dissolved oxygen levels, Secchi depth, sediment geochemical variables, etc.), can be entered in the MFADSS as reassessments. Most importantly, if a site is monitored over time (for example in an environmental monitoring program) multiple entry of data for one site is possible for comparative purposes.

STRUCTURE OF THE MFADSS

The MFADSS consists of three sections (General Information, Ecosystem and Site Variables):

SECTION I: GENERAL INFORMATION

14 questions are used to record general lease site and species culture information (Fig. 1). A box for comments allows information to be added which an assessor considers relevant to the assessment.

SECTION II: ECOSYSTEM VARIABLES

This section consists of 10 questions used to determine the potential for impacts at the ecosystem (far field) level (Fig. 2). The questions are designed to examine the possible broad scale effects of fish farms and to indicate the potential for conflicts of ecosystem use where natural processes take precedence over potential interactions resulting from additional use. A net decision is created as a cumulative Ecosystem Index (EI) score.

Cumulative environmental effects of finfish farms are difficult to quantify (Hargrave 2002). Few simple, direct measures are available to measure broad scale effects such as eutrophication[1] or the creation of anoxic conditions[2]. In the case of some of the ecosystem variables, there may be a lack of supporting environmental data and quantitative numbers for calculating the distance of potential environmental impacts from farm sites. Since the purpose of the MFADSS is to serve as an expert screening tool, quantitative measures for all variables are not always required. Qualitative (yes/no) answers are often appropriate for describing effects of variables that act over broad spatial or temporal scales.

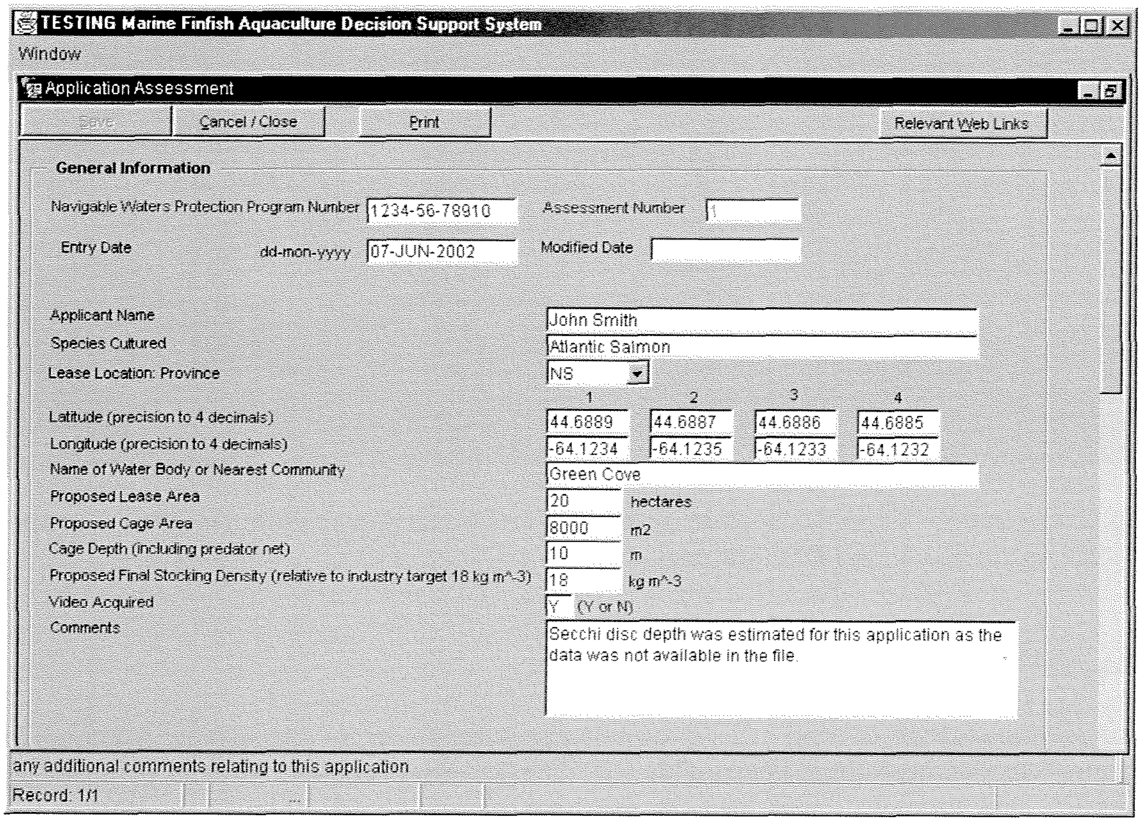


Fig. 1: General Information Section of the Marine Finfish Aquaculture Decision Support System viewed as a web page on the DFO Intranet.

[1]Eutrophication – The process by which an increase in the supply of dissolved nutrients results in higher rates of organic matter production by algae and macrophytes. Bacterial decomposition of organic matter from primary production can deplete the oxygen content of the water, resulting in stress or death of fish and other animals.

[2] Anoxic Conditions – The absence of dissolved oxygen in water or sediments. Oxygen may be depleted by fish respiration, oxygen consumption by particulate waste products in water and sediments, bacteria decomposition and chemical oxidation.

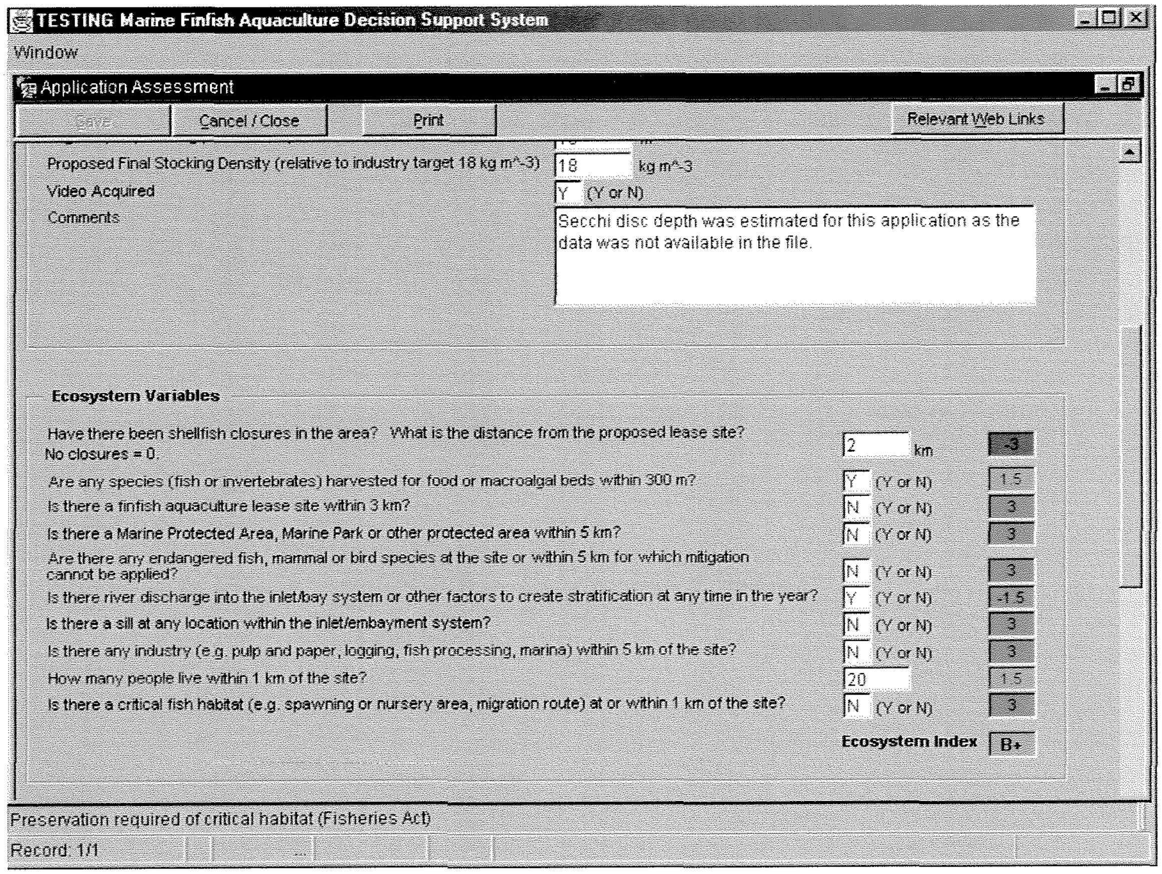


Fig. 2: Ecosystem Variables Section of the Marine Finfish Aquaculture Decision Support System as viewed on the DFO Intranet.

SECTION III: SITE VARIABLES

This section consists of a set of 12 questions structured to obtain site-specific information and to consider near field effects (Fig. 3). The questions consider effects of physical, chemical and biological variables (as measures of water and sediment quality) at the proposed lease site, to be used in calculations to assess environmental risks. A net decision is created as a cumulative Site Index (SI) score.

OVER-RIDING VARIABLES

In both the Ecosystem and Siting Sections there are two or three questions that have an over-riding (pre-emptive) effect on the cumulative score for the respective index. Input that results in a C score for an over-riding question, produces a C score for that index and an unacceptable net decision.

SCORING

Answers to each of the 22 questions in the ecosystem and siting sections produce positive to negative scores (A = +3, B+ = +1.5, B- = -1.5, C = -3). The arbitrary scale creates four separate ranking scores from acceptable (A) to unacceptable (C) with two intermediate scores for conditional acceptance. The broader range (-1.5 to +1.5) for the two intermediate scoring categories reflect uncertainty associated with conditions that are not clearly desirable or undesirable. By assigning a broader range of scores to intermediate values, the MFADSS can be used as a coarse screening tool for evaluating site suitability. Small changes in scores do not radically change cumulative scores unless values are near specified thresholds. This sensitivity is most critical at the transition from B- to C scores. The cumulative indices EI and SI are calculated and assessed as A, B+, B-, or C.

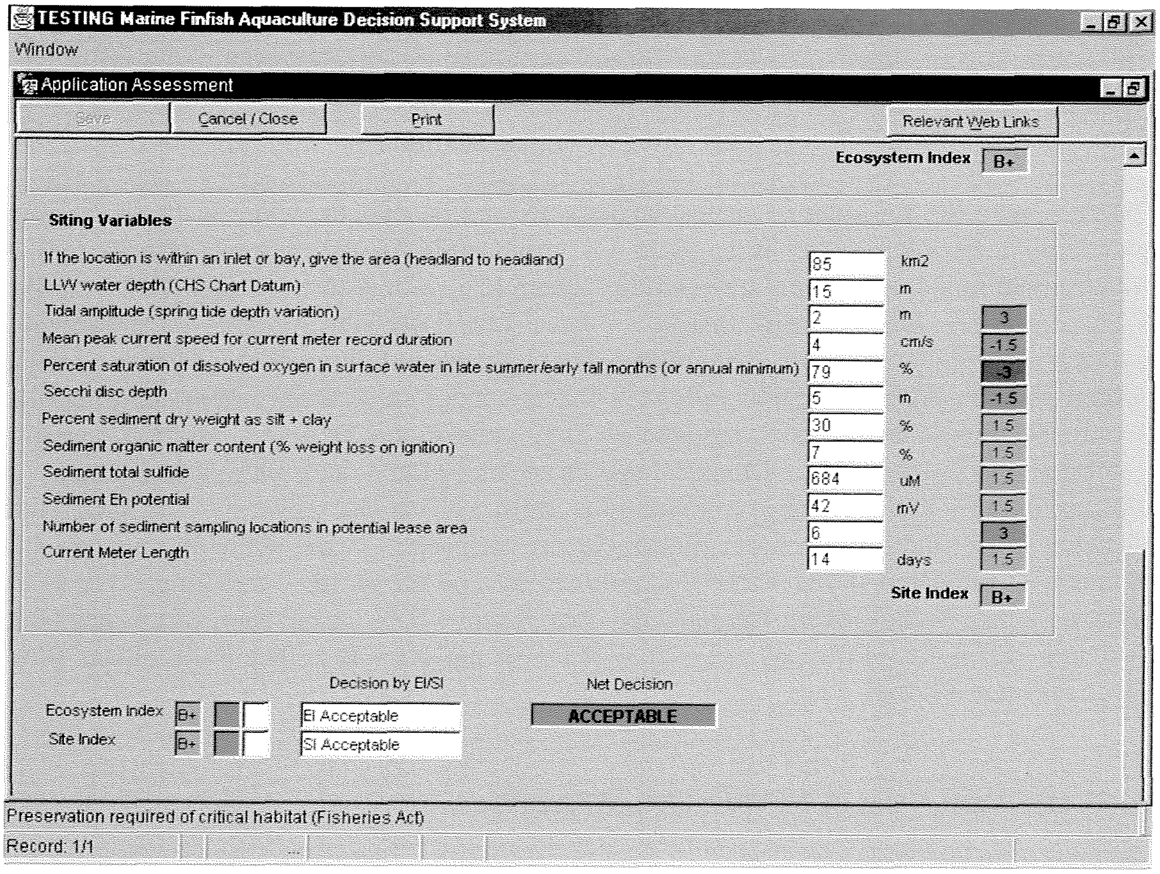


Fig. 3: Siting variables section of the Marine Finfish Aquaculture Decision Support System as viewed on the DFO Intranet.

Cumulative Ecosystem Index (EI): This value is the sum of numeric scores for ecosystem variable questions. If C is assigned for one of the three pre-emptive questions, EI = C. The maximum value for EI is 30 and the minimum is –25.5.

A = EI > 20
B+ = EI from 10 to 19
B- = EI from 5 to 9
C = EI < 4

Cumulative Site Index (SI): This value is the sum of numeric scores for site variable questions. If scores are C for one of the two over-riding questions, SI = C. If neither of these scores is C, the maximum value for SI from the site variable questions is 30 and the minimum is –27.

A = SI > 20
B+ = SI from 5 to 19
B- = SI from -10 to +4
C = SI < -10

The net decision based on EI and SI indices provides an overall decision (A = acceptable, B+ and B- = provisional acceptance (caution required), C = unacceptable) (Fig. 3).

Matrix for Combined Ecosystem and Site Index Scores:

To maximize the information in the separate EI and SI indices, while at the same time providing a blended score as a guide for advice, the four colour scoring system is transformed to a conventional three colour [green (G), yellow (Y), red (R)] Traffic Light. This simplifies the decision matrix to give clear decision points for acceptable, conditional and unacceptable. The intermediate light green colour (B+) closest to green is scored as 50% green and 50% yellow, while the more conditional intermediate orange score (B-) closest to red is designated as 50% yellow and 50% red. The GYR colour combinations for cumulative EI and SI scores are placed in a decision matrix to represent all possible EI and SI score combinations from GG to RR (Fig. 4). An acceptable decision is indicated if the colour matrix consists of green > 50%, while an unacceptable decision is indicated if red > 50%. Combined EI and SI scores containing B+ and B- indicate a provisional level of acceptance only if red = 25%. A decision of unacceptable is rendered if both yellow and red = 50% (EI = B- and SI = B-) since both indices show that caution is advised.

A GUIDE FOR COMPLETING THE MFADSS

GENERAL INFORMATION

1) *Navigable Waters Protection Program Number*

The NWPP number is used as a unique indentifying label for each application in the MFADSS and cannot be duplicated by two different users. Failure to enter a unique NWPP or other identification number could result in the loss of all data when an attempt is made to save the record. If a NWPP number for an application is not available or unknown, another suitable identifier (e.g. Habitat Management File number) could be used if it is confirmed that this number has not been used previously. Previous use can be determined by viewing the applications already present in the database, which are listed in order by their NWPP or other assigned numbers.

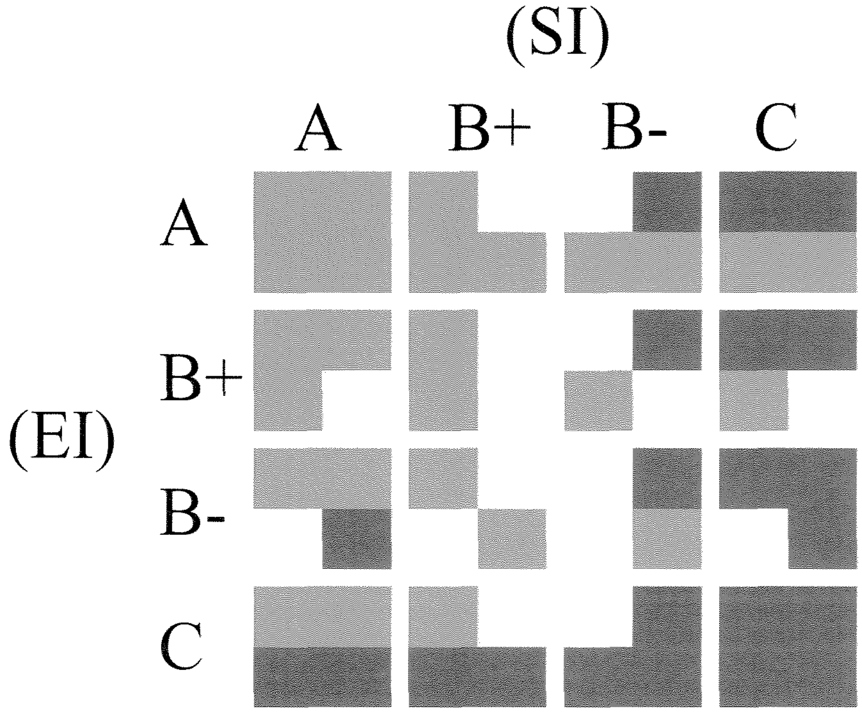


Fig. 4: Matrix for Combined Ecosystem and Site Index Scores.

2) *Assessment Number*

The assessment number is the numeric counter for subsequent reassessments of the same application. Each time an application is reassessed the counter increases by one in the form of an extension to the identifier number. This occurs automatically and no data entry is required. Multiple reassessments for the same site are allowed and will be saved in the database.

3) *Entry Date*

The entry date for the application occurs automatically and user input is not required.

4) *Modified Date*

Entry date for a reassessment of the application. This is not required for a new application but it occurs automatically when an exisiting site is reassessed.

5) *Applicant Name*

The name of the person or company on the site application.

6) *Species Cultured*

The species being cultured is recorded to allow species-specific calculations (e.g. differences in growth efficiency between species) to be included for modeling purposes (e.g. oxygen consumption, waste production, or nutrient release).

7) *Lease Location: Province*

A record of the geographic location of a lease site by province allows regional differences (e.g. physical characteristics such as Secchi disc visibility or local government regulations) to be incorporated. The location also serves to categorize sites by province for ease in searching files.

8) Latitudes and Longitudes

Geo-referenced positions (as degree decimals) are required at either three or four corners of a potential lease area. If the specified lease site has only three sides, the fourth set of co-ordinates can be left blank. If the lease area has more than four corners then only four co-ordinates should be entered that are most representative of the total area (Fig. 5). The information allows a new location to be compared to previously approved leases and to determine proximity to existing farm sites.

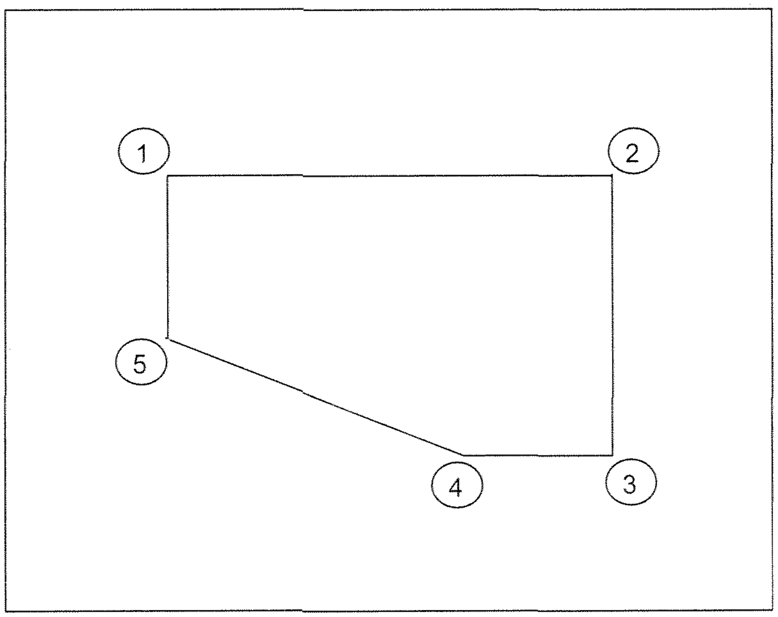


Fig. 5: The co-ordinates for corners 1, 2, 3 and 5 should be entered for a lease area of this shape.

The following examples describe the conversion of latitude and longitude to degree decimal format:

Example 1

If the co-ordinates of a lease are given in degrees, minutes, seconds they can be converted to degree decimal as follows:

NW corner given as: 45°12'06.8" N; 66°34'08.2" W

- Divide seconds by 60: 06.8 sec/ 60 = 0.1133
- Add seconds to minutes = 12.1133 minutes
- Divide minutes by 60: 12.1133 min/ 60 = 0.2019
- Add minutes to degrees = 45.2019 N
- North and east are positive, south and west are negative

The co-ordinates for the NW corner in degrees decimals are 45.2019; - 66.5689.

Example 2

If co-ordinates are given as minutes with decimals (Fig. 6) simply divide the minutes by 60 and add to the degrees.

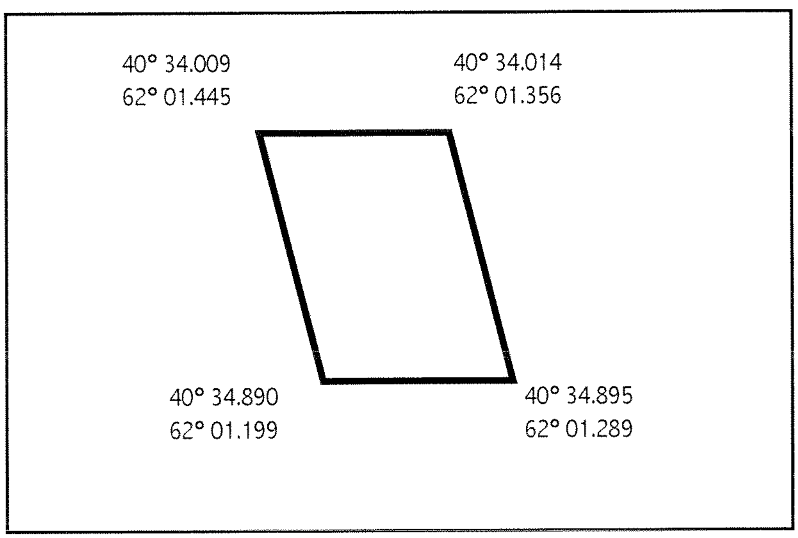


Fig. 6: An example of lease co-ordinates given as degrees and minutes with decimals. The NW corner becomes 40.5668, - 62.0241 when converted to degree decimal.

9) *Name of Water Body or Nearest Community*

The geographic or proper noun place name is used to identify the area where the lease is located. This is usually provided in the application. If it is not available, any appropriate place name for the geographic location can be used.

10) *Proposed Lease Area (hectares)*

The lease area gives the spatial scale with which farming operations will occur. This information is important for establishing navigable waters clearance distances. It may also be used for characterizing the region where site specific variables apply and for calculating near field waste loading rates within the lease boundary (1 hectare = 10^4 m^2).

11) Proposed Cage Area (m^2)

The number of cages times their surface area allows the total area of sediment under net pens to be calculated assuming no lateral movement of the pens. This value is used to determine the area of sediment subject to direct deposition of waste feed and feces under pens. For polar circle net-pens with a radius *r* this is calculated as a circular area under a cage ($A = \pi r^2$; Fig. 7).

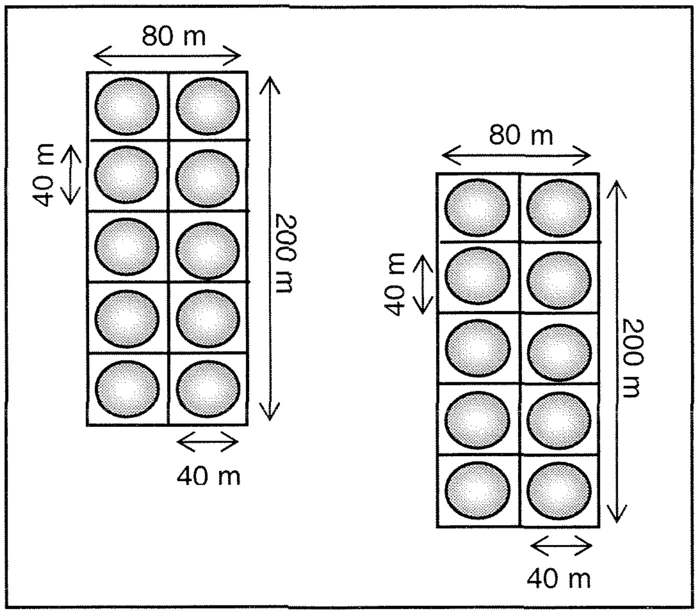


Fig. 7. The area under one net pen is multiplied by the number of net pens to determine the total area. For example, a 30 m diameter polar circle pen has an area of 707 m^2. The 20 pens in this example have a total area of 20 x 707 = 14 140 m^2.

12) Cage Depth (including predator net; m)

The cage depth below the water is used to calculate the total volume of water in all pens and the depth between the lowest net and the bottom. The cage depth (D) can be multiplied by the cage area (A) to calculate cage volume. This value can be used to confirm or calculate the proposed stocking density based on proposed numbers of fish to be cultured (see General Information, Question 13 below and Fig. 1). It is assumed that the total number of fish is equally divided among all cages, although in practice some cages are kept empty for transfer during grow-out. It is also assumed that fish utilize the total pen volume.

Cage depth is subtracted from total water column depth during a tidal cycle for MFADSS calculations. Depths < 5 m for > 50% of the time are considered to be insufficient to allow horizontal dispersion of particulate waste material. The measure of cage depth must include predator nets because these nets will also accumulate debris, macrofauna and macroalgae (Fig. 8). Accumulated debris can potentially reduce water flow, result in lower oxygen levels and greater deposition immediately below the cages.

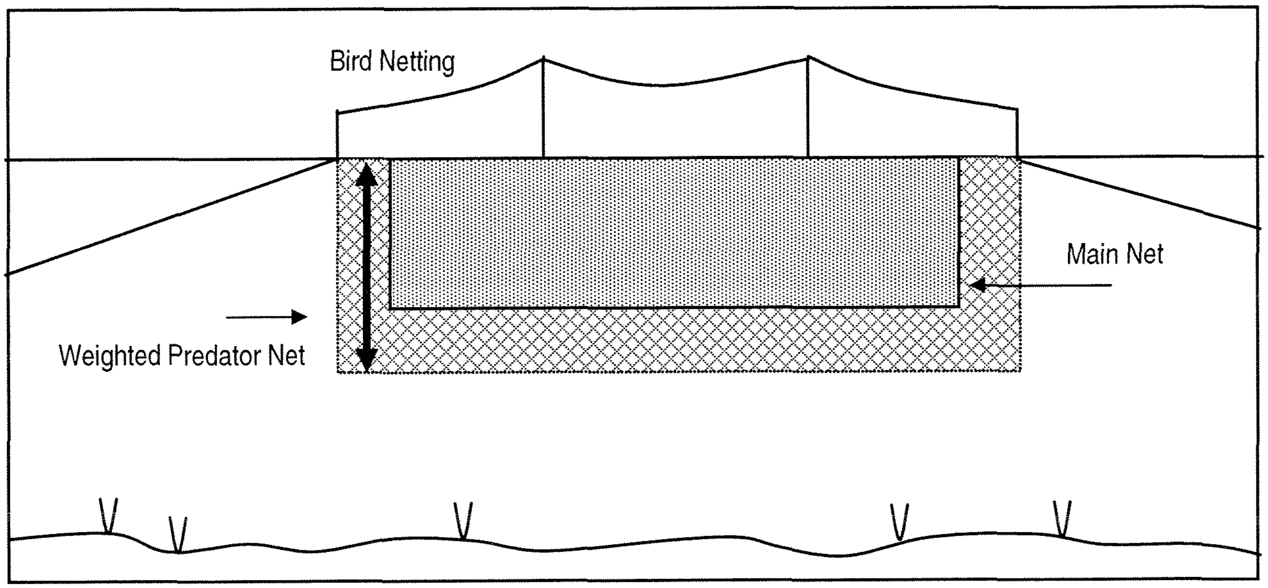


Fig. 8: The depth of the predator net is included in the determination of cage depth.

13) *Proposed Final Stocking Density (relative to industry target of 18 kg m^{-3})*

The stocking density is the average biomass (wet weight) of fish in all pens on a lease site. This value is used to determine feeding rates (using assumed food conversion ratios) and the amount of dissolved and particulate waste potentially released at the site. This value is usually provided in a lease application or can be calculated (see General Information, Question 12 above).

14) *Video Acquired*

Information (yes/no) regarding submission of a video is recorded in the MFADSS to confirm that a visual record of bottom conditions was obtained prior to occupation of a potential new lease site. This is often required by provincial licensing authories as part of a new site application. It provides a visual record of sedimentary features at a site that can be used to confirm requested site specific information on bottom type (sediment grain size), organic matter content and other sediment geochemical variables discussed below.

15) Comments

Text for any additional comments relating to the application can be entered in the Comments box. For example, since input into all fields in the MFADSS is required to complete the assessment, it may be necessary to use assumed or substituted values to provide answers to some of the questions. The Comments box can be used to indicate if assumed values were used due to missing data. Input into all fields in the MFADSS is required to complete the assessment (with the exception of the fourth pair of latitude/ longitude boxes).

ECOSYSTEM VARIABLES

1) *Have there been shellfish closures in the area? What is the distance (km) from the proposed lease site? No closures = 0*

Shellfish closure areas indicate organic (sewage) enrichment. This may be in the immediate area of a proposed lease site or in an adjacent area within the same general region. A linear distance measure is used to indicate proximity. The Canadian Federal Department of the Environment maintains a website of areas of shellfish closures: <www.ns.ec.gc.ca/epb/sfish/maps/class/html>.

Scoring:

A = no closure(s) (0), or closure(s) > 10 km away
B+ = closure(s) 5 to 10 km away
B- = closure(s) 3 to 4.9 km away
C = closure(s) < 3 km away

2) *Are there any species (fish or invertebrates) harvested for food or macroalgal beds within 300 m?*

A new farm site could potentially diminish or prevent harvesting of a traditional fishery. Wild and commercial intertidal shellfish beds should be a minimum distance away from a finfish aquaculture site. In the current version of the MFADSS, 300 m was assumed to provide a minimum distance to avoid negative impacts of material released from netpens. Productivity of macroalgal beds could be negatively impacted by increased water turbidity and fine particle sedimentation associated with finfish farm operations (e.g. fish fecal matter release and net cleaning activities). Macroalgal beds also offer habitat for juvenile fish and represent an integral part of the ecosystem that should be not be negatively affected.

Scoring:

No = A
Yes = B+

3) *Is there a finfish aquaculture lease site within 3 km? (over-riding variable)*

The cumulative effect of farms already approved in or adjacent to an inlet system within a threshold distance must be considered when making a decision to increase the number of licensed sites in a restricted area. In the present MFADSS a distance of 3 km between licensed sites is assumed to be required to minimize cumulative impacts. The value could be higher or lower depending on hydrographic conditions. The designation of this variable as over-riding indicates to the assessor that proximity of a new site to other existing licensed sites within the specified distance is a critical siting criterion.

Scoring:

Yes = C = over-riding variable ∴ EI = C and the site is Unacceptable
No = A

4) *Is there a Marine Protected Area, Marine Park, or other protected area within 5 km?*

Siting close to a protected area should be avoided to ensure a sufficient buffer area for environmental protection. As with other variables a linear distance is used to determine if sufficient separation exists between the proposed licensed farm site and a sensitive marine area designated for protection. A link to the DFO Oceans Program Activity website provides map-based information on Marine Protected Areas:
< www.dfo-mpo.gc.ca/CanOceans/Index.htm>.

Scoring:

Yes = B+
No = A

5) *Are there any endangered fish, mammal or bird species at the site or within 5 km for which mitigation cannot be applied? (over-riding variable)*

Aquaculture sites should not be located within 5 km of habitat utilized by any protected or endangered species unless mitigation measures can be applied to reduce potential harmful effects. In some cases more than 5 km may be required in order to ensure that large mammals are not affected. For example, acoustic deterrent devices are often used to protect cultured fish against predators. These devices can emit noise that interfers with predator behaviour over distances greater than 5 km. Use of alternative predator avoidance methods could be used to reduce potential harmful effects on an endangered species.

Endangered fish species are protected under legislation within the Department of Environment. A list of all endangered species is available from The Conservation Data Centre and the Committee on the Status of Endangered Wildlife in Canada. A link to their website is provided in the MFADSS: <www.cosewic.gc.ca>.

Scoring:

Yes = C = over-riding variable ∴ EI = C and the site is Unacceptable
No = A

6) *Is there river discharge into the inlet/bay system or other factors to create stratification at any time of the year?*

Stratification is due to the presence of a less dense surface layer of water that reduces water column mixing. Stratification is caused by freshwater inflow into a coastal area or increased temperatures during summer that create a warm surface layer above the thermocline (sharp temperature gradient) or halocline (sharp salinity gradient). Warm water is less dense than cold water and freshwater is less dense than seawater. A gravitationally stable water column is described as being stratified, consisting of layers of water with increasing density over depth. A strongly stratified water column is very stable with reduced mixing between deep and surface layers. This traps denser water below the surface layer where oxygen depletion and nutrient increases due to decomposition and the remineralization of settled particulate organic matter may occur.

Scoring:

Yes = B-
No = A

7) *Is there a sill at any location within the inlet/ embayment system?*

A sill is a submerged elevation separating two basins (Fig. 9). As with temperature and/or salinity stratification, a sill can restrict the exchange of deep water and reduce mixing within the surface layer. Depositional basins (deep areas behind sills) are usually sites where settled particulate material is retained and accumulated in bottom deposits. Sediments accumulated in areas behind sills are usually fine-grained with a high proportion of silt and clay size particles.

Uneven bottom topography may have the same effect as a sill in that fine grain sediments may be deposited in depressions. This increases the possibility of anoxic conditions in water and sediments and of negative environmental impacts due to oxygen depletion.

Scoring:

Yes = B-
No = A

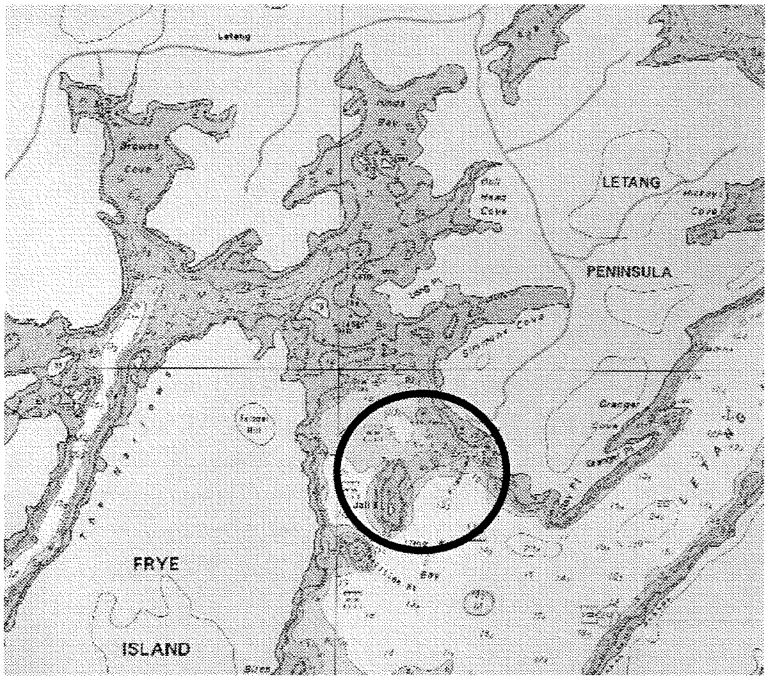


Fig. 9: A hydrographic chart of the Letang Inlet in SW New Brunswick. Depth contours show the presence of a sill that creates a depositional area in the inner bay. (Canadian Hydrographic Service Chart No. 4124)

8) *Is there any industry (e.g. pulp and paper, logging, fish processing, marina) within 5 km of the site?*

The presence of other industries with marine waste discharges already located within an inlet system could increase the cumulative effects on the ecosystem when aquaculture site development occurs.

Scoring:

Yes = B-
No = A

9) *How many people live within 1 km of the site?*

General population size can be used to scale the potential impacts of human land use. Any population greater than 500 is scored C. This takes into account not only sewage discharge but also other sources of urban discharges and run-off. Different methods of sewage treatment are not taken into consideration. A town of more than 500 people will have some negative effect on water quality in a bay regardless of the means of sewage treatment.

Scoring:

A = population < 10
B+ = population 10 to 49
B- = population 50 to 500
C = population > 500

10) *Is there a critical fish habitat (e.g. spawning or nursery area, migration route) at or within 1 km of the site? (over-riding variable)*

Spawning and nursery areas are considered to be essential for reproduction and to sustain local populations of juvenile and adult fish and invertebrates. In some areas new finfish aquaculture sites could have potential negative impacts on critical fish habitat due to increased water turbidity, sedimentation, release of chemicals, or the use of acoustic deterrent devices. Use of acoustic deterrent devices may cause avoidance of breeding areas by migrating species that move into an area for reproduction (e.g. wild Atlantic salmon migrating to home rivers to spawn).

Examples of critical spawning habitat:

• A river where wild Atlantic salmon spawn (salmon-bearing stream). Aquaculture sites should be located at least 1 km from the mouth of such a river.
• Lobster spawning habitat.
• Herring spawning areas that are designated as vital, major or important by DFO and provincial governments.

Scoring:

Yes = C = over-riding variable $\therefore$ EI = C and the site is Unacceptable
No = A

SITE VARIABLES

1) If the location is within an inlet or bay, give the area (headland to headland; km^2).

This dimension provides an area enclosed within a defined shoreline perimeter for making calculations of tidal exchange volumes and for determining loading rates of dissolved and particulate matter additions from waste discharges.

The exact surface area of the inlet or bay does not need to be calculated. Simple shapes may be used to estimate the surface area from headland to headland. The most appropriate shape should be drawn and surface area calculated based on the scale of the map.

Example 1

A rectangle is used to calculate the area of Gabarus Bay (Fig. 10).

Scale 1 cm = 0.63 km
Rectangle = A = l x w
A = 11.2 cm x 9.0 cm = 7.1 km x 5.7 km
Calculated Area = 40.5 km^2; Actual Area (HW) = 42.6 km^2 (Gregory et al. 1993)

Note: This calculation was based on the original map (Gregory et al. 1993). The map in the figure may not be to scale. Results may vary depending on how the rectangle is drawn. The calculation of the surface area of the bay serves only as an approximation.

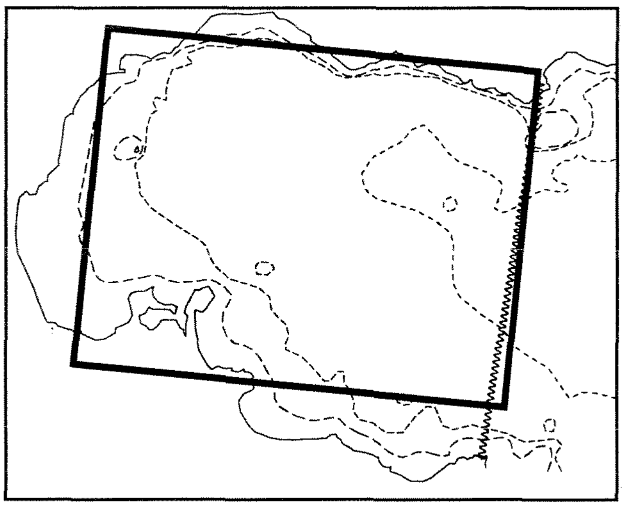


Fig. 10: A rectangle was used to estimate the area of Gabarus Bay. Irregular lines join headlands. The estimated area (40.5 km^2) is similar to the actual area (42.6 km^2) determined by Gregory et al. (1993).

Example 2

Isosceles triangles are used to calculate the areas of Indian and Wine Harbours (Fig. 11).

Scale 1 cm = 0.57 km
Isosceles Triangle: A = ab/2 (a = base, b = height)

Indian Harbour: A = (5.9 cm x 10.4 cm)/ 2 = (3.4 km x 5.9 km)/2
Calculated Area = 10.0 km^2; Actual Area (HW) = 11.3 km^2 (Gregory et al. 1993)

Wine Harbour: A = (4.0 cm x 6.0 cm)/ 2 = (2.3 km x 3.4 km)/2
Calculated Area = 3.9 km^2; Actual Area (HW) = 4.1 km^2 (Gregory et al. 1993)

Note: These calculations were based on the original map (Gregory et al. 1993). The map in the figure may not be to scale.

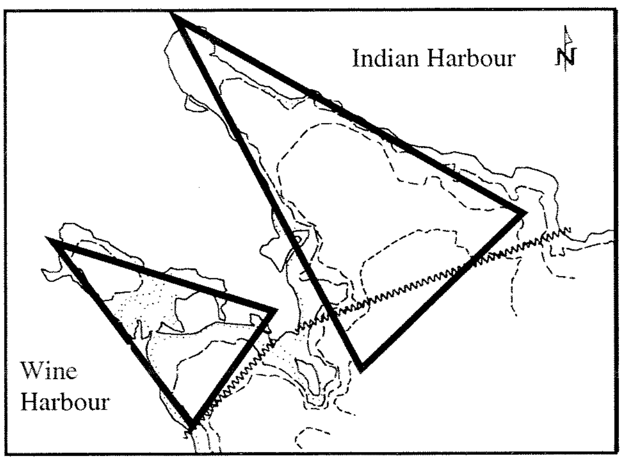


Fig. 11: Isosceles triangles were used to estimate the area of Indian Harbour and Wine Harbour. Irregular lines join headlands for each harbour. The estimated areas are similar to actual areas determined by Gregory et al. (1993).

Scoring:

No score is directly applied to the estimate for headland to headland area.

2) *LLW depth (Lower Low Water; CHS Chart Datum; m)*

Values for lower low water (LLW) depth can be obtained from published maximum/ minimum tide heights (Canadian Hydrographic Service) or directly from hydrographic charts. The mean depth of the proposed lease area should be used (Fig. 12). No score is applied to this value. The number entered for LLW is used with the values entered for Cage Depth and Tidal Amplitude to determine the minimum distance between the net and the bottom at various times over a tidal cycle (see Site Variables, Question 3 below and Fig. 3).

Scoring: No score is directly applied to LLW depth.

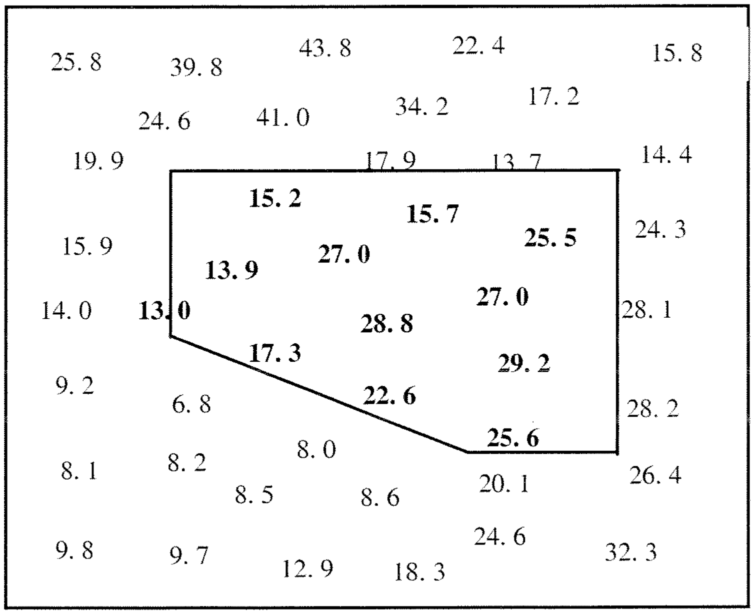


Fig. 12: If the mean LLW depth is not given in the lease application it can be determined from a hydrographic chart by calculating the mean of the depths within the proposed lease area. Mean LLW depth in this example is 21.7 m.

3) *Tidal amplitude (spring tide depth variation; m) (over-riding variable)*

The tidal amplitude is used with the values entered for Cage Depth and LLW depth to determine the percentage of time that depth under net pens is < 5 m (Fig. 13). DFO Pacific Region requires at least 10 m of clearance between the net pens and the bottom. However, in other areas in Canada (i.e. the Maritimes) water depths are too shallow to permit this ideal water depth. The distance used in the present MFADSS is considered a minimum clearance to ensure that nets remain far enough above the bottom to reduce deposition of particulate waste directly under pens. The Canadian Tide tables can be accessed at <www.lau.chs-shc.dfo-mpo.gc.ca/marees/produits/accueil.htm>.

Scoring:

A = depth < 5 m for < 10% of time
B+ = depth < 5 m for 10 to 29.9% of time

B- = depth < 5 m for 30 to 50% of time
C = depth < 5 m for > 50% of time = over-riding variable ∴ SI = C and the site is Unacceptable

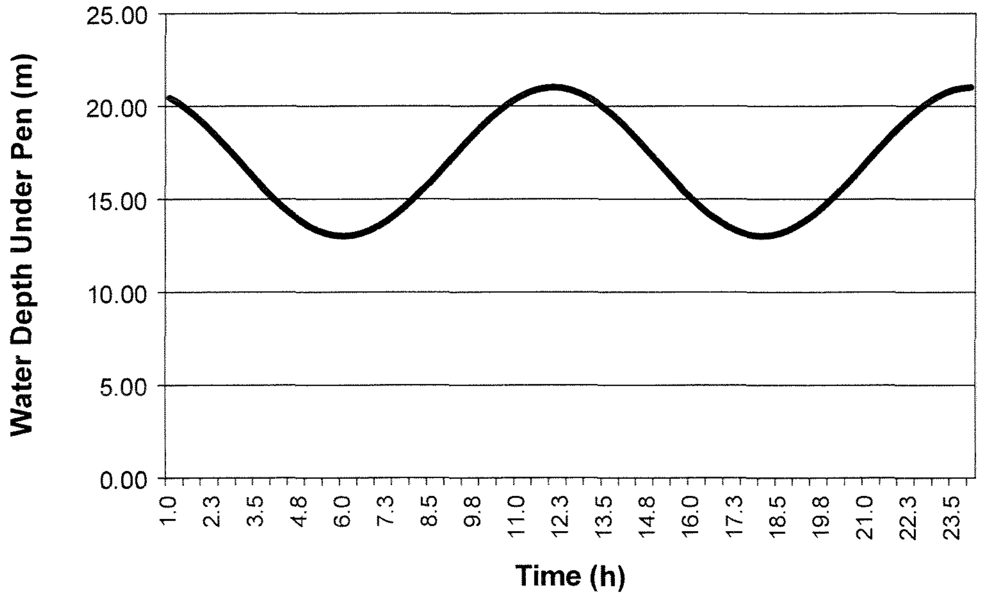


Fig. 13: A sine curve is used to calculate variations in water depth (m) under a pen through a 24 hour tidal cycle.

4) *Mean peak current speed for current meter record duration (cm s^{-1}) (over-riding variable)*

This is the mean maximum current speed over several consecutive tidal cycles. A sine curve is used to describe changes in current velocity over time during a tidal cycle (Fig. 14). The percentage of time that the current speed is less than 2 cm s^{-1} is calculated.

Current velocity may be reported in a site application in several ways. Typically it is presented as either a chart (Fig. 15) or in a table (Table 1). Current speed recorded hourly over the recommended time period of at least 29 days could results in tables that are many pages in length. The mean peak current speed should be taken from the maximum speed that is reported in the table over several tidal cycles.

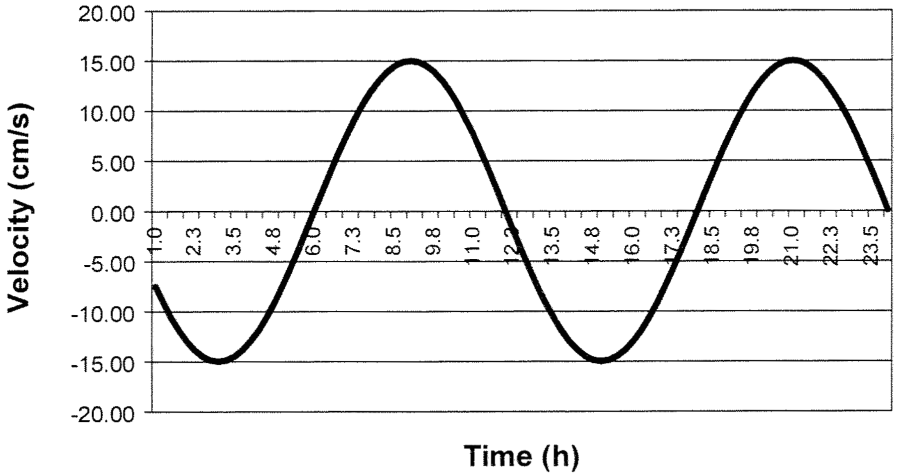


Fig. 14: A sine curve is used to calculate variations in current velocity (cm s^{-1}) through a 24 hour tidal cycle.

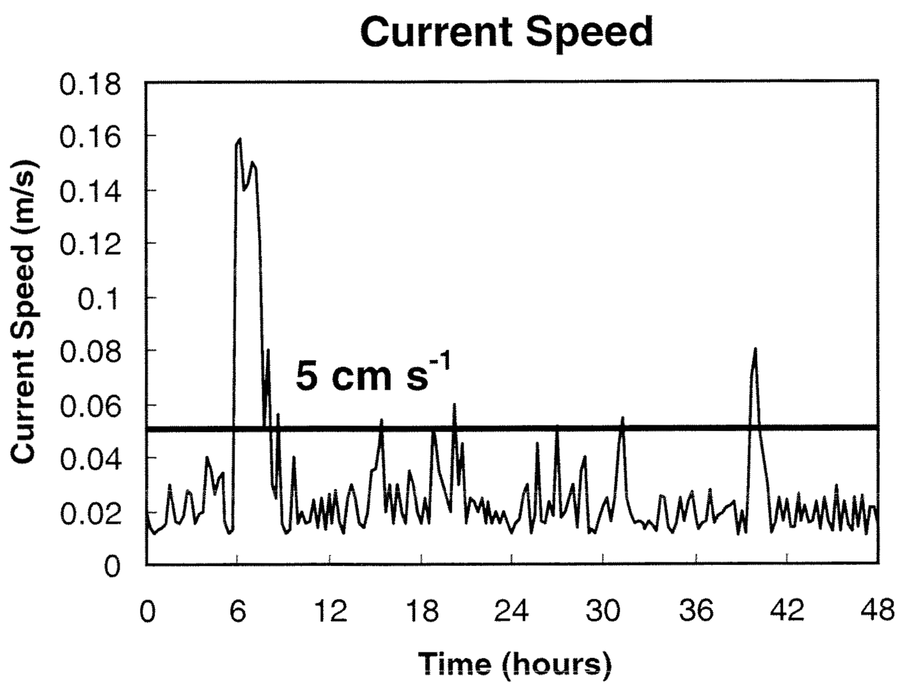


Fig. 15: Mean peak current speed can be determined when current speed is reported over time by choosing maximum current speeds that are repeated several times. In this figure the duration of the current record is only 48 hours. This makes it difficult to determine why there is a large peak in velocity between 6 and 9 hours. Is it due to tides or high winds? Is it a regular occurrence or an anomaly? The average peak current velocity of 5 cm s^{-1} may be a low estimate. However without a longer current record we must estimated the current speed conservatively. A record length > 7 days is preferable.

Table 1: A 24-hour current velocity record. The mean peak current velocity would lie between the Maximum Speed (31 cm s^{-1}) and the Mean Velocity (12.0 cm s^{-1}). The length of the record is very short (1 day) and three peaks occur in the velocity record. From these three time periods a mean peak current speed of 22.7 cm s^{-1} can be calculated. This is > 14.9 cm s^{-1} and therefore a score of "A" would be assigned. Note: The minimum *reported* current speed is 2 cm s^{-1}, however current meters are not accurate at velocities < 2 cm s^{-1}. Therefore the minimum reported current velocity is likely not the *actual* minimum current velocity

Time of Day	Speed (cm s^{-1})	Direction (degrees)
1200	6	165
1330	3	140
1500	8	175
1630	15	340
1800	28	325
1930	16	325
2100	8	300
2230	2	120
2400	8	150
0130	31	180
0300	25	190
0430	5	215
0600	9	310
0730	11	310
0900	2	340
1030	21	180
1200	6	170

Minimum Speed: 2.0 cm s^{-1}
Maximum Speed: 31.0 cm s^{-1}
Mean Velocity: 12.0 cm s^{-1}
Mean Direction: 231°

X = 22.7 cm s^{-1}

Scoring:

A = current velocity < 2 cm s^{-1} < 10% of the time; corresponding range = entered value > 14.9 cm s^{-1}

B+ = current velocity < 2 cm s^{-1} 10 to 19.9% of the time; corresponding range = entered value 5.3 to 14.9 cm s^{-1}

B- = current velocity < 2 cm s^{-1} 20 to 40% of the time; corresponding range = entered value 3.3 to 5.2 cm s^{-1}

C = current velocity < 2 cm s^{-1} > 40% of the time; corresponding range = entered value < 3.3 cm s^{-1}

5) *Percent saturation of dissolved oxygen in surface water in late summer/ early fall months (or annual minimum)*

Depth profiles for percent saturation of dissolved oxygen in the water column may be measured at various locations (for example at each corner of a potential lease site) over a given depth profile (Table 2). If dissolved oxygen falls to < 6.4 mg l^{-1} (approximately 78 % saturation at typical late summer maximum temperatures in temperate east coast waters) fish such as Atlantic salmon will be stressed (Davis 1975). Good husbandry requires reduced feeding levels at these times to account for lower rates of food intake associated with stress from oxygen limitation. Oxygen consuming processes such as microbial respiration of naturally occurring organic matter also creates seasonal minima of dissolved oxygen in surface or deep water at some locations in both eastern and western coastal regions in Canada. If the proposed lease area is in such a region, additional oxygen depletion through direct consumption by fish and increased water column and sediment respiration could reduce oxygen to stressful levels. The minimum dissolved oxygen concentration is a critical variable not only for the cultured species but also the ecosystem as a whole.

If the oxygen levels are reported for a temporal period other than late summer/ early fall the data should be considered cautiously. Oxygen concentrations in late summer/ early fall will typically be lower than at other times of the year. Therefore, if data collected in December show low oxygen concentrations (i.e. 80 to 85%) they will be even lower (i.e. < 80%) and unacceptable during the warmer summer period.

Scoring:

A = > 90 %
B+ = 85.1 to 90 %
B- = 80 to 85 %
C = < 80 %

6) *Secchi disc depth (m)*

An extinction coefficient describes the exponential reduction in light with increasing depth due to selective absorption and scattering by water and dissolved and particulate matter in suspension. The extinction coefficient can be approximated from a Secchi disc reading: the depth at which a 30 cm diameter white disc disappears from sight under calm conditions during the day. For any given coastal area it should be possible to find published data for characteristic values of Secchi disc depth if this was not requested or provided in the site application. This variable could also be assigned an expected range that could change seasonally for a specific region. A typical value for Secchi disc depth in clear coastal waters is > 9 m. Water with increasing turbidity due to suspended particulate matter (SPM) is undesirable for salmon aquaculture. High SPM levels indicate the potential for increased bacterial biomass and respiration in the water column, which may lead to increased rates of oxygen consumption.

Table 2: An example of a dissolved oxygen data table for water column measurements as reported in a finfish aquaculture lease application. An average value for percent saturation of dissolved oxygen can be calculated as the mean of data over all depths.

Location	Date	Time	Depth (m)	Temp (° C)	Salinity (ppt)	DO (% sat)	DO (mg L^{-1})
Shore of Transect (150 m)	04/08/00	1120	0	8.9	33.53	127.3	11.87
Northwest Corner	04/08/00	1140	0	12.0	32.81	105.5	9.88
			2	12.3	32.82	85.4	7.95
			4	12.4	32.73	81.0	7.52
			6	12.4	32.74	80.4	7.46
			8	12.4	32.72	80.5	7.48
			10	12.4	32.71	80.3	7.45
Northeast Corner	04/08/00	1204	0	12.5	32.76	87.7	8.12
			2	12.5	32.81	83.5	7.71
			4	12.6	32.78	83.7	7.65
			6	12.6	32.78	86.6	7.99
			8	12.6	32.74	82.3	7.6
			10	12.6	32.75	82.7	7.63
			12	12.6	32.75	82.9	7.65
Southeast Corner	04/08/00	1219	0	12.2	28.33	83.5	8.00
			2	12.3	32.33	83.4	7.79
			4	12.3	32.90	82.0	7.62
			6	12.3	33.06	83.6	7.76
			8	12.4	33.00	83.6	7.75
			10	12.5	32.93	84.0	7.78
Southwest Corner	04/08/00	1240	0	12.2	32.76	87.5	8.15
			2	12.4	32.77	82.8	7.69
			4	12.4	32.77	82.3	7.63
			6	12.5	32.72	82.3	7.63
			8	12.5	32.70	79.1	7.33
			10	12.5	32.71	83.5	7.73
			12	12.5	32.73	81.5	7.55
			14	12.5	32.71	83.9	7.76

Scoring:

A => 8 m
B+ = 6.1 to 8 m
B- = 4 to 6 m
C =< 4 m

7) *Percent sediment dry weight as silt + clay*

A simple classification of bottom sediment grain size may be reported as proportions of clay (< 2 μm), silt (2 to 50 μm) and sand (50 to 2000 μm). The proportions of sediment weight in various size categories can be used to infer current velocity near the seabed (Table 3). Areas of high current velocity will have greater resuspension, preventing accumulation of fine-grained material (silt/ clay) and hence coarser (higher proportion of sand to clay/silt) grained deposits.

Scoring:

A =< 5 % silt + clay
B+ = 5 to 49.9 % silt + clay
B- = 50 to 90% silt + clay
C => 90 % silt + clay

8) *Sediment organic matter content (% weight loss on ignition)*

Percent of sediment dry weight lost on ignition is a convenient measure of total organic matter (OM). This value is inversely related to sediment grain size, although in certain coastal areas terrigenous inputs (e.g. wood fibre, coal fragments) may alter the expected inverse relationship. Fine-grained deposits have a higher surface area and contain more OM g^{-1} than more coarse-grained sediments. Generally, unenriched (non-eutrophic) coastal sediment with varying proportions of silt, clay and fine sand contains < 5% organic matter (Fig. 16). Fine-grained sediments with high OM indicate depositional environments where resuspension is minimized and current speeds are low. A C score indicates high levels of OM beyond the range of values normally found in coastal sediments receiving organic matter from natural sources.

In some applications "Total Organic Carbon" is erroneously reported when what was actually measured was "Organic Matter" (Table 4). Determination of organic carbon is more costly than gravimetric determinations of organic matter since elemental analysis requires a dedicated analyzer. Organic Matter is measured by combustion of pre-weighed sediment in a muffle furnace at 550 °C for four hours to determine the percent weight loss. Measures of organic matter by combustion are much less expensive than elemental analysis. If methods used to measure organic matter (carbon) are not reported in an application, then it may be assumed that Organic Matter was measured rather than Total Organic Carbon.

Table 3: A typical table of sediment geochemical measurements provided in a finfish aquaculture lease application. To determine the percent sediment dry weight as silt + clay calculate the mean of the silt/ clay fraction given in the Grain Size (%) column. If sampling is not possible in certain areas because of rock ledges (arrow) simply calculate the mean of the samples that were obtained.

Location	Lat/Long	Depth (m)	Sulfide (µM)	Redox Potential (mV)	Total Organic Matter (%)	**Grain Size (%)**	Sediment Description	Comments
Transect: 150 m from Center	45.5033 -65.8101	22.3	228	Water: 247 Inter: 175 2 cm: 46 4 cm 78	6.72	**Gravel: 84.9** **Sand: 14.7** **Silt/Clay: 0.37**	8 to 10 cm of sand with rocks, ledge underneath	
Center	45.5028 -65.8028	36.3	27.8	Water: 290 Inter: 273 2 cm: 221 4 cm: 218	2.71	**Gravel: 37.2** **Sand: 62.0** **Silt/Clay: 0.72**	8 to 10 cm of sand with rocks, ledge underneath	
East Corner	45.5039 -65.8034	36.4	NA	NA	NA	**NA**	**Rock ledge**	**Unable to obtain core**
South Corner	45.5019 -65.8050	15.2	NA	NA	NA	**NA**	**Rock ledge**	**Unable to obtain core**
West Corner	45.5040 -65.8101	19.8	5.9	Water: 300 Inter: 294 2 cm: 275 4 cm: 290	2.01	**Gravel: 27.2** **Sand: 72.8** **Silt/Clay: 0.06**	4 to 7 m deep patches of sand, some rock ledges	Broken shells in sediment
North Corner	45.5054 -65.8113	17.1	209	Water: 243 Inter: 235 2 cm: 214 4 cm: 148	4.04	**Gravel: 71.9** **Sand: 27.0** **Silt/Clay: 1.07**	8 to 10 cm of sand with rocks, ledge underneath	

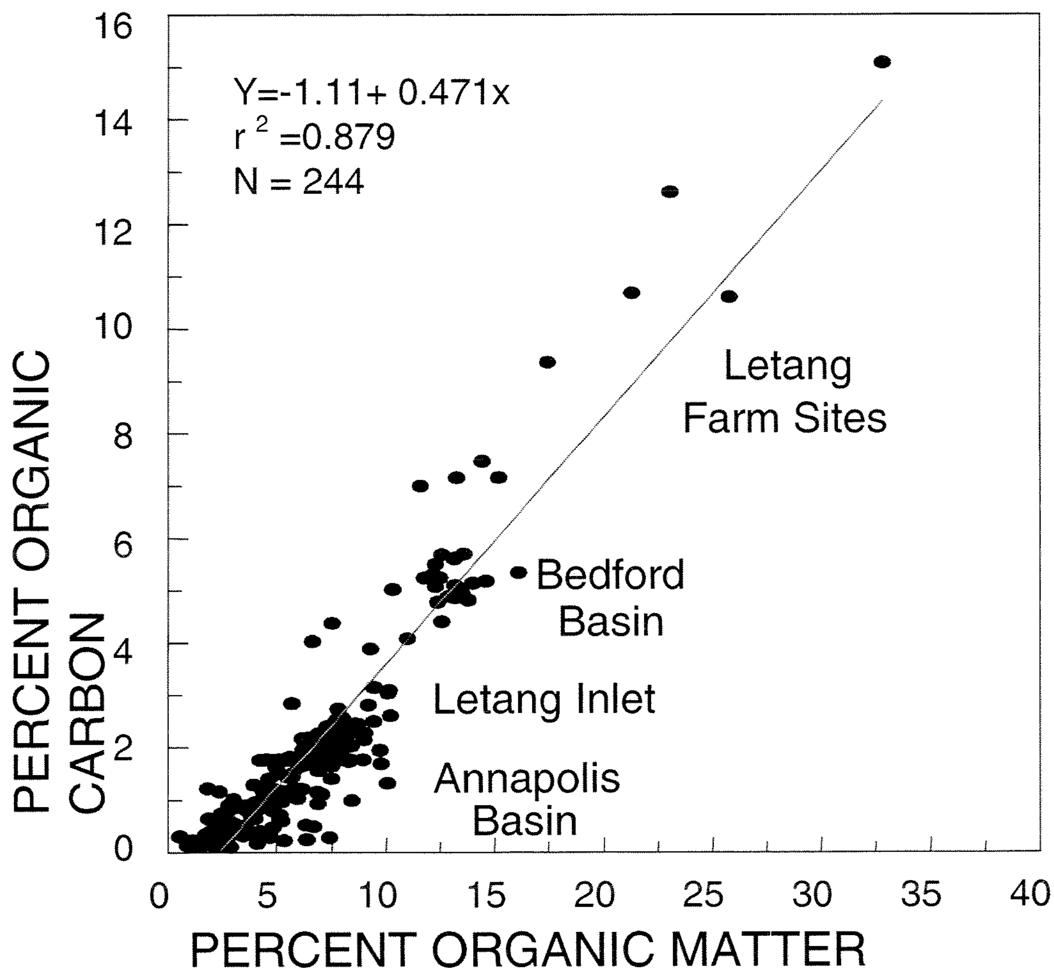


Fig. 16: Percent organic matter in sediment is measured by combusting material in an ashing oven or muffle furnace at 550 °C. Sediment organic carbon is measured with an elemental analyzer. Percent organic matter refers to all organic material (lipids, carbohydrates and proteins) in the sediment and will generally be two to four times greater than the percentage of organic carbon.

Table 4: A typical table of geochemical variables in sediments provided in a finfish aquaculture lease application. The column labelled Total Organic Carbon is probably in error. It should be headed "Organic Matter". The mean of the samples (n=4) would be reported for Organic Matter (%) in surface sediments at this site.

Location	Lat/Long	Depth (m)	Sulfide (μM)	Redox Potential (mV)	**Total Organic ~~Carbon~~ Matter (%)**	Grain Size (%)	Sediment Description	Comments
Transect: 150 m from Center	45.5033 -65.8101	22.3	228	Water: 247 Inter: 175 2 cm: 46 4 cm 78	**6.72**	Gravel: 84.9 Sand: 14.7 Silt/Clay: 0.37	8 to 10 cm of sand with rocks, ledge underneath	
Center	45.5028 -65.8028	36.3	27.8	Water: 290 Inter: 273 2 cm: 221 4 cm: 218	**2.71**	Gravel: 37.2 Sand: 62.0 Silt/Clay: 0.72	8 to 10 cm of sand with rocks, ledge underneath	
East Corner	45.5039 -65.8034	36.4	NA	NA	**NA**	NA	**Rock ledge**	**Unable to obtain core**
South Corner	45.5019 -65.8050	15.2	NA	NA	**NA**	NA	**Rock ledge**	**Unable to obtain core**
West Corner	45.5040 -65.8101	19.8	5.9	Water: 300 Inter: 294 2 cm: 275 4 cm: 290	**2.01**	Gravel: 27.2 Sand: 72.8 Silt/Clay: 0.06	4 to 7 m deep patches of sand, some rock ledges	Broken shells in sediment
North Corner	45.5054 -65.8113	17.1	209	Water: 243 Inter: 235 2 cm: 214 4 cm: 148	**4.04**	Gravel: 71.9 Sand: 27.0 Silt/Clay: 1.07	8 to 10 cm of sand with rocks, ledge underneath	

Scoring:

A = < 6 %
B+ = 6 to 9.9 %
B- = 10 to 15 %
C = > 15 %

9) *Sediment total sulfide (μM)*

All marine sediments contain both micro- and macro-organisms that require oxygen for survival. However, in some areas of high organic matter supply, rates of oxygen consumption may exceed rates of supply through diffusion and advective exchange with surface water. Oxygen is then depleted from sediment pore water below a specific depth determined by relative rates of supply and consumption. In certain cases, the sediment may be anoxic even at the sediment-water interface.

Aerobic and anaerobic organisms may live at the oxic/anoxic interface, but at deeper depths in sediments where complete anoxic conditions occur only anaerobic taxa are found. Bacteria such as sulfate reducers utilize $SO_4^{=}$ as a hydrogen acceptor in anaerobic sediments and H_2S (rotten egg smelling gas) is produced as an inorganic metabolic by-product. This diffuses upwards to form a substrate for chemosynthetic bacteria at the anoxic/oxic interface. In anoxic pore water, H_2S may be precipitated as FeS (black sediment) or dissociate into H^+ + HS^- (Fig 17). The rate of sulfate reduction and accumulation of reduced forms of $S^=$ are related to the rate of organic matter supply and sediment accumulation.

Free sulfide ions ($S^=$) can be measured in freshly collected sediments using a silver/sulfide (Ag/S) combination electrode. Total sulfide concentration (μM) in the surface layer (0 to 2 cm depth) are used in the MFADSS to quantify anoxic conditions (Table 5) (Wildish et al. 1999). A score of C indicates high $S^=$ levels beyond the range of values normally found in coastal sediments receiving organic matter from natural sources.

Scoring:

A = $S^=$ < 300 μM
B+ = $S^=$ 301 to 1299 μM
B- = $S^=$ 1300 to 5999 μM
C = $S^=$ > 6000 μM

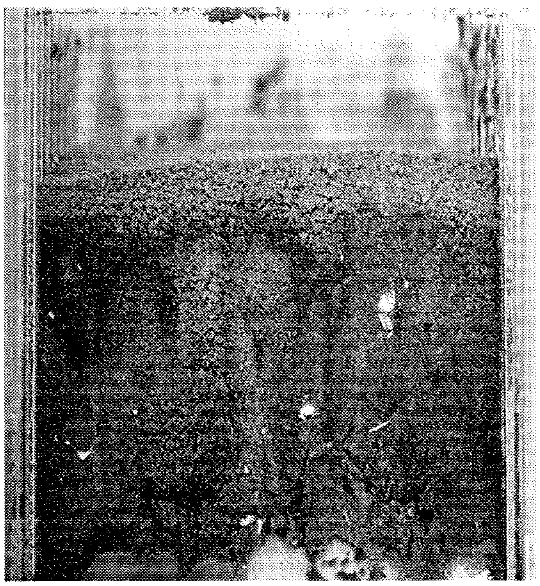
10) *Sediment Eh (redox) potential (mV)*

A platinum electrode is used to measure the Eh (redox) potential of marine sediments. When corrected to the normal hydrogen electrode (NHE), based on the reference electrode potential, Eh_{NHE} provides a measure of electron activity as the potential between the reference and Pt electrodes. In contrast, pH is a measure of proton (H^+)

activity. Eh_{NHE} potentials in marine sediments from surface to subsurface depths usually vary between -300 and + 300 mV. Oxygenated surface layers should have positive (> 0 mV) potentials and as oxygen is depleted with sediment depth, or in surface layers under conditions of high organic matter input, Eh_{NHE} potentials decrease (< 0 mV; Table 5). In anaerobic sediments where sulfate reduction occurs, Eh_{NHE} potentials decrease logarithmically as sulfide concentrations increase (Fig. 18). Changes in Eh_{NHE} potentials in combination with $S^{=}$ measurements can be used to determine the presence/absence of oxygen in the sediment (Wildish et al. 1999). A general relationship between Eh and pH has been used in a similar manner to classify benthic enrichment associated with finfish cage aquaculture in Norway (Anon. 2000).

Scoring:

A = > + 100 mV
B+ = 0.1 to + 100 mV
B- = 0 to - 100 mV
C = < -100 mV



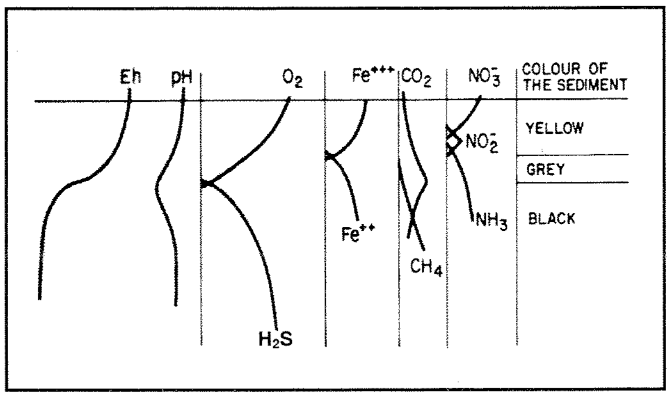


Fig. 17: The chemical zonation of sediments is visible in colour variations depending on the presence of iron or manganese. Oxidized sediments appear light brown to yellow (surface), the oxic/anoxic interface appears grey, and anoxic (FeS) sediments are black. Oxygen (O_2) is replaced by hydrogen sulfide (H_2S) gas with increasing depth and the redox potential (Eh) decreases with depth. This depth-related diagram of changes in geochemical variables with sediment depth (right) is from Fenchel (1969).

Table 5: A table of geochemical sediment measurements provides redox potential and sulfide concentration data. The mean of sulfide concentration (µM) and redox potential (mV) are calculated for all samples collected. If data is provided for more than one depth, use the mean of the sediment-water interface layer for an input value to the MFADSS.

Location	Lat/Long	Depth (m)	**Sulfide (µM)**	**Redox Potential (mV)**	Total Organic Matter (%)	Grain Size (%)	Sediment Description	Comments
Transect: 150 m from Center	45.5033 -65.8101	22.3	**228**	**Water: 247 Inter: 175 2 cm: 46 4 cm 78**	6.72	Gravel: 84.9 Sand: 14.7 Silt/Clay: 0.37	8 to 10 cm of sand with rocks, ledge underneath	
Center	45.5028 -65.8028	36.3	**27.8**	**Water: 290 Inter: 273 2 cm: 221 4 cm: 218**	2.71	Gravel: 37.2 Sand: 62.0 Silt/Clay: 0.72	8 to 10 cm of sand with rocks, ledge underneath	
East Corner	45.5039 -65.8034	36.4	**NA**	**NA**	NA	NA	**Rock ledge**	**Unable to obtain core**
South Corner	45.5019 -65.8050	15.2	**NA**	**NA**	NA	NA	**Rock ledge**	**Unable to obtain core**
West Corner	45.5040 -65.8101	19.8	**5.9**	**Water: 300 Inter: 294 2 cm: 275 4 cm: 290**	2.01	Gravel: 27.2 Sand: 72.8 Silt/Clay: 0.06	4 to 7 m deep patches of sand, some rock ledges	Broken shells in sediment
North Corner	45.5054 -65.8113	17.1	**209**	**Water: 243 Inter: 235 2 cm: 214 4 cm: 148**	4.04	Gravel: 71.9 Sand: 27.0 Silt/Clay: 1.07	8 to 10 cm of sand with rocks, ledge underneath	

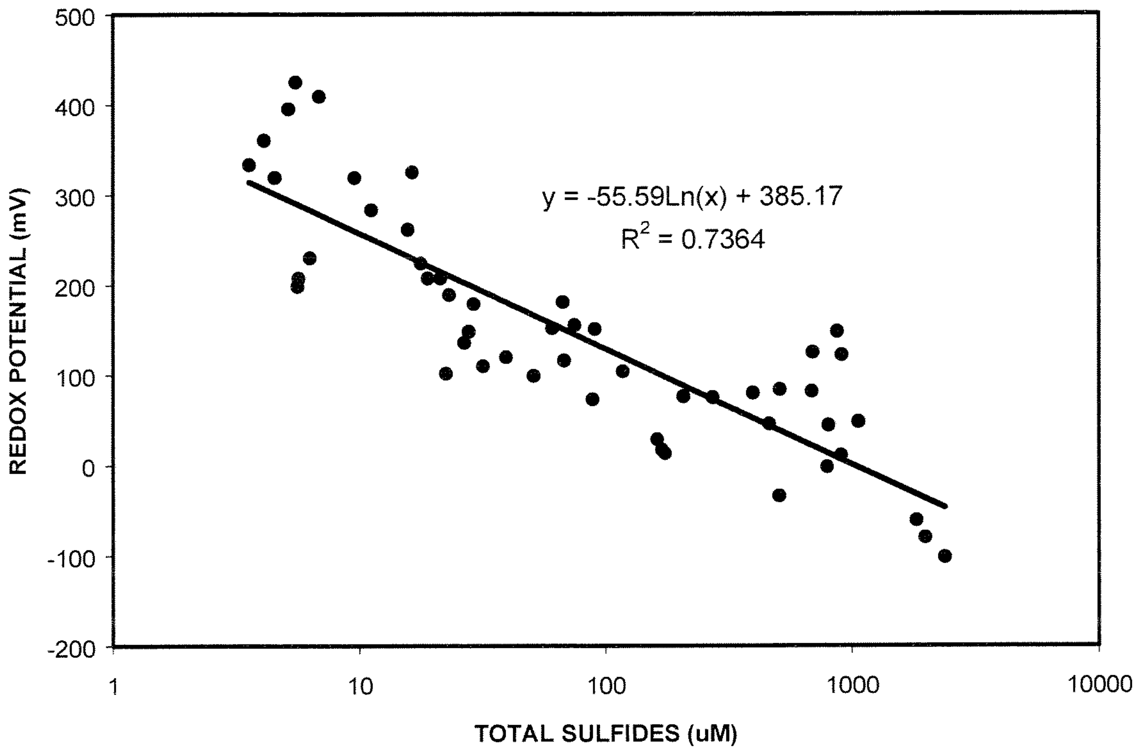


Fig. 18: In anaerobic sediments where sulfate reduction occurs, Eh_{NHE} potentials decrease logarithmically with increasing total sulfide concentrations. Thus, high sulfide levels ($\geq$ 1000 µM) are characteristic of hypoxic or anoxic sediments when Eh_{NHE} potentials are < +100 mV. In oxic sediments low sulfide concentrations (< 500 µM) should be associated with high Eh_{NHE} potentials (> + 100 mV). If this general relationship does not appear in the data, measurements reported for one of the variables may be suspect.

11) *Number of sediment sampling locations in potential lease area*

This variable is related to the quality of sediment observations. For statistical comparisons and determination of variability in data collected in different areas at different times, a minimum number of observations (n) is required. For example, if n < 3 for sulfide and Eh determinations in sediments, only a mean and range of values can be reported. Since there is no measure of variance, no statistical comparisons (spatial or temporal) are possible between the proposed farm and reference sites. It is recommended that a minimum of n = 5 sediment samples be collected at both a proposed lease site and a reference location (> 500 m distant) to calculate mean and variance values. Additional sampling could be requested if the number of observations reported was small (i.e. n < 5).

Scoring:

A = n ≥ 5
B+ = n = 4
B- = n= 3
C = n = 1 or 2

12) *Current meter (deployment) length (days)*

Variability in current velocity observed at a site will be determined by the length of the period of observation. Short periods of measurement (e.g. a few hours) will be affected by tidal conditions at the time of observations. An accurate description of major tidal variations requires a minimum 45 day record to observe both lunar and solar frequencies. Longer periods of observations also increase the likelihood for observations of variability due to episodic wind and climatic events. Since 29 day or longer current meter records are required to differentiate spring and neap tidal variations, > 29 days is the minimum required to accurately determine the proportion of time currents < 2 cm s^{-1} occur. A current meter record of this length will help to resolve fluctuations that are caused by high winds and storm surges and to determine the proportion of time that the current is < 2 cm s^{-1}. A longer record of current measurements could be requested if the duration for observations reported was too short (i.e. < 2 days).

Scoring:

A = ≥ 29 days
B+ = 7 to 28.99 days
B- = 2 to 6.99 days
C = < 2 days

FREQUENTLY ASKED QUESTIONS

1) *What values do you enter into the MFADSS if the proposed lease site is located on a rock bottom and hence no geochemical measurements are reported?*

If the proposed aquaculture site is located on rock substrate then it is in a high energy, erosional area. The current velocity should be high and very little sediment would be deposited at the site. This can be verified by examination of a video if this has been obtained from the site. The assumed data for these variables should be reported in the Comments box under General Information. The location would be scored "A" for geochemical variables if the following assumed values were assigned:

Percent Sediment Dry Weight as Silt + Clay = < 5 %
Sediment Organic Matter Content = < 5%
Sediment Total Sulfide = < 300 µM
Sediment Eh Potential = > + 100 mV

2) *If samples are not collected from one or more points at the lease site (i.e. due to the presence of a rock ledge) do you estimate the geochemical measurements for these points as in question 1 (above)?*

Whenever possible the mean value for input into the MFADSS should be determined from the data provided. If benthic geochemical data is available for at least three of the sampling points then the mean should be determined using the information supplied. It is possible that even a high-energy area, such as a rock ledge, could accumulate organic matter if sufficient organic waste collects in the sediment at other points under the cages. In some cases, it may be necessary to request additional sampling.

3) *How is variability handled for input data? For example, what should be done if geochemical measurements from one corner of the proposed lease site are very different from the other sampling points (e.g. redox potentials are much lower and sulfide concentrations are higher)?*

Anomalous data should not be ignored. If there are relatively few measurements and one value is very different from other measurements, the anomalous value should not be included in calculations of a mean. Low redox potentials and high sulfide concentrations are signs of the presence of increased organic matter in surface sediments. An effort should be made to determine the source of the organic matter. River outflow or the presence of an aquaculture site at that location in the past are two possible causes of increased organic matter. It may be necessary to adjust the location of the proposed lease site to avoid such areas. Variability in any measured variable associated with site specific observations should be reported in the Comments box under site information. This variability is critical for a full evaluation of environmental conditions in all near field variables and it must be considered in designing an environmental monitoring program for the site.

REFERENCES

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