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GIS and aquaculture: Assessment of soft-shell clam sites

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Abstract. The 1992 collapse of the northern cod fishery at Newfoundland, Canada and the subsequent closure of a majority of the inshore ground fishery has placed a focus on the development of aquaculture within the province. In May 1995 Innovative Fisheries Inc. of St. John's, Newfoundland, conducted field studies to evaluate the soft-shell clam (edible bivalve molluscs) resources on three sand flats near Burgeo, Newfoundland. GIS can be used to examine issues regarding the development and management of the soft-shell clam beds. GIS can also be applied to examine the issue of 'competing uses' for the proposed soft-shell clam aquaculture site. The information presented in this study indicates that GIS is an important tool for the aquaculture industry. These systems can be used to monitor, quantify and evaluate the soft-shell beds near Burgeo. Management issues such as water quality, resource sustainability as well as the economic viability of the clam resource can be assessed within a GIS environment. The results of the analysis in this study suggest potential problems with faecal coliform contamination from local cottages. Finally, data collection for aquaculture site assessment is required if a resource is to be managed effectively. GIS applications provide insights into the quality of the physical environment as well as the sustainability of a resource. However, it is the aquaculture operators who ultimately make the final decisions.

Keywords: Cod; Fisheries; GIS; Mollusc; *Mya arenaria*; Newfoundland.

Abbreviations: GCP = Ground control point; GPS = Global positioning system.

Introduction

In 1992 the Canadian government imposed a moratorium on the east coast cod fishery and subsequently closed a majority of the in-shore ground fishery. The closure of these fisheries has renewed efforts to develop aquaculture within the province of Newfoundland and Labrador. Aquaculture development is also encouraged by government policy and funding. Traditionally, commercial aquaculture within Newfoundland coastal areas was limited and included either cultured mussels or trout. Recently, salmon, scallop and cod farming have been attempted with limited success. Therefore, a majority of aquaculture farms are based on 'seeded' rather than naturally occurring resources. Given the government incentives to expand and diversify aquaculture, developers are also examining the potential of harvesting naturally occurring species such as the under-utilized soft-shell clams (*Mya arenaria*).

In May 1995 Innovative Fisheries Inc. of St. John's, Newfoundland, conducted field studies to evaluate the soft-shell clam resources on three sand flats near Burgeo, Newfoundland (Fig. 1). The field studies involved the collection of data within the study area on: (1) clam biology, (2) hydrology, (3) water quality and (4) land-use. This database will provide the information required for evaluating the economic viability and the management of the resource. These data also fulfil a requirement on government regulations for licensing aquaculture operations. The field data are spatial and the non-spatial attributes, relating to resource assessment and management issues, can be integrated, analysed and mapped using geographical information systems (GIS).

GIS and aquaculture

GIS has been used in aquaculture studies for at least 10 yr. Kapetsky et al. (1988) and Manjarrez & Ross (1995) used GIS to evaluate the suitability of coastal areas for fish farming activities. In these studies, the aquaculture potential of a coastal area was determined

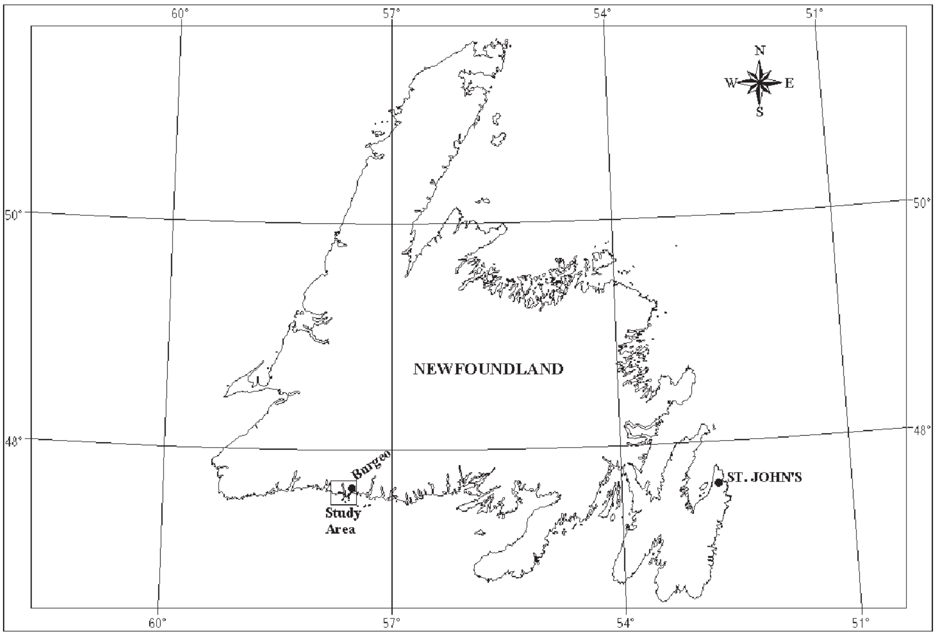


Fig. 1. Study area.

by factors such as bathymetry, water quality, exposure, land use and proximity to other facilities. Aquaculture management issues such as the multiple uses of estuarine waters, the impact of water quality on shellfish leases, aquaculture and habitat availability and conflict issues between aquaculture operations and marine waterfowl habitats have been addressed by Clarke (1990), Legault (1992) and Simms (1994), respectively.

The development of spatial databases for soft-shell aquaculture sites will permit the use of GIS as a decision support tool which can help both the aquaculture developers and the government regulator in assessing and managing the clam beds near Burgeo. The advantages of using a GIS as a part of the decision-making process are:

1. GIS provides the capability to integrate, scale, organize and manipulate spatial data from many different sources;
2. Data can be maintained, updated, extracted and mapped efficiently;
3. GIS permits quick and repeated testing of models which could be used to aid the decision-making process

These characteristics of a GIS can be used to examine issues regarding the development and management of the soft-shell clam beds. Development issues include water quality and avoidance of competing land uses. The primary management issue is the sustainability of the resource in the study area. This can be evaluated by the continual monitoring of the clam size distributions and water quality whereby the spatial databases can be updated for analysis and mapping in a GIS.

GIS can also be applied to examine the issue of 'competing uses' for the proposed soft-shell clam aquaculture site. In this situation the decision-makers can take an active part in structuring a possible solution to a problem. Since many resource management problems affect more than one group the decision-making process needs to incorporate the participation of the local inhabitants, aquaculture industry and the appropriate government agencies. Thus any issues regarding competing uses can be evaluated by mapping the various scenarios of conflicts or environmental impacts that a 'use' may have on the soft-shell clam environment.

Spatial data structures

A GIS should be capable of:

(1) creating digital abstracts of the real world;
(2) effectively handling of these data;
(3) providing new insights into the relationships of, or among, spatial variables; and
(4) creating summaries of these relationships (Berry 1993).

The data structure used to store spatial data will determine how the data can be encoded, analysed and displayed. There are two basic data structures raster and vector. Vector data structures use discrete (*x*, *y* coordinates) points or line segments to represent spatial objects such as points, lines or polygons. Raster structures subdivides the area into a regular grid of cells (rows and columns), and these cells are used to represent point, lines or polygons (Berry 1993). The loca-

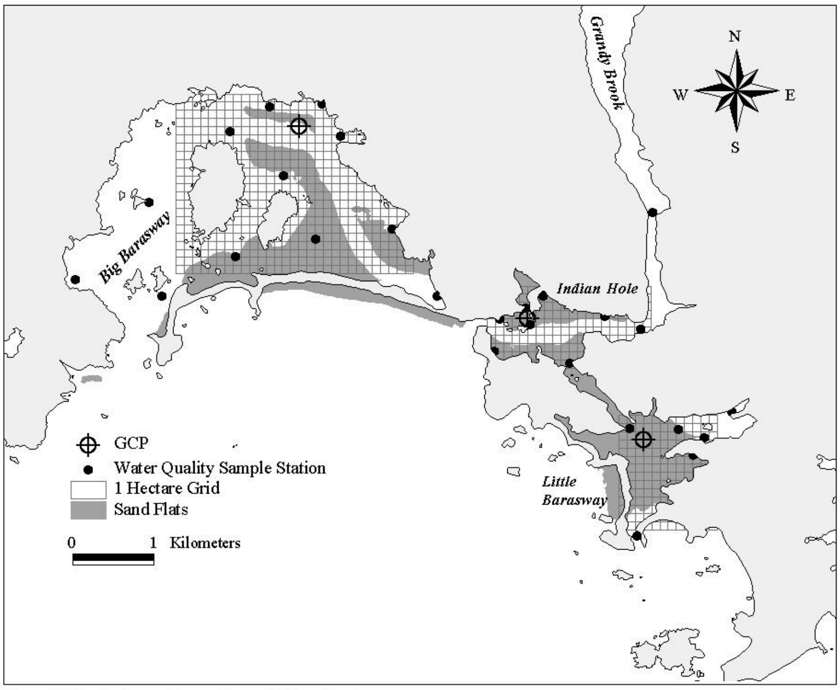


Fig. 2. Study area – survey data grids and points.

tion of vector objects are viewed as precise where each object is given an explicit *x* and *y* coordinate. The grid cells of a raster structure provide approximate or implied location of an object. For example, if the grid cells of a raster map is 25 m × 25 m then the location accuracy of an object is said to be ± 25 m.

A more important factor when selecting a vector or raster data structure is the implications on the encoding, storage, analysis and display. Generally, vector data structures are used for inventory, descriptive queries, spatial database management, and computer mapping. Raster structures are used for prescriptive analysis, spatial statistics and modelling (Berry 1993). GIS applications for aquaculture require both structures, and ideally the system used for analysis would provide the advantages of both vector and raster data structures. The Burgeo field data are stored initially as vector data and converted to raster as needed. In this study, vector and raster GIS capabilities are provided by ArcView$^{\text{TM}}$ 3.0 and its Spatial Analyst 1.0 module (Anon. 1996).

Data collection

The data used in this study can be divided into primary and ancillary databases. Primary data include all field data such as clam biology, hydrology, water quality and land use (Table 1). The 1 : 50 000 digital topographic maps and scanned aerial photographs are considered ancillary data.

The storage of any spatial data within a GIS requires that location of the objects be defined as either projection (metric *x* and *y*) or degree (latitude and longitude) coordinates, and the data are represented as points, lines or polygons. For this study, ground control points (GCP) were used to generate a 100 m × 100 m grid on the two estuaries – Indian Hole and Little Barasway – and the sand flats located in Big Barasway (Fig. 2). The GCP(s)

Table 1. Spatial and non-spatial data used in the Burgeo soft-shell clam study.

Data group	Spatial objects	Attributes (non-spatial)
Clam biology	Point	Length (mm); Width (mm); Weight (g)
100 m x 100 m grid	Polygon	Linked to all data by GEOCODE
Hydrology	Point and polygon	Water depth (m); Current speed and direction; Bottom substrate; Tidal data
Water quality	Point and polygon	Faecal coliform; Salinity; Temperature; Rainfall (24, 48, 78 h periods)
Land use	Point	Cottage locations (coded as non-pollution, potential or definite pollution source)
1 : 50 000 digital topographic map	Point, line and polygon	Coastline; Contours; Lakes; Rivers; Cultural features; Vegetation cover
Registered and edge-matched 1 : 12 500 area photographs (1989)	32 bit raster	Used for interpretation and visualisation of site characteristics.

are marked in the field with surveying poles. These grids are stored as polygons in an ArcView^{TM} vector shape file.

A unique numeric code, named GEOCODE, is used to link the non-spatial information database (e.g. water depth, bottom type) with the geo-referenced ha polygons. In addition, the unique code is also used for reference in the field. The map coordinates and the unique code of each ha grid centroid are stored as waypoints in a global positioning system (GPS). The GPS is used to locate the grids for data collection and harvesting. Therefore, because of the need to produce operational field maps, where the unique numbers must have a logical base for referencing in the field, an arbitrary number cannot be used for coding the grids. The numbers are based on the concept of a quadrant whereby NE, NW, SW and SE quadrants are assigned numeric values of 1, 2, 3 and 4 respectively. Thus, if a 1-ha grid is the first cell to the NE of the GCP it is given the code 111 which means that the cell is located in the NE and is the first row and column to the NE of the GCP. When the grid is located in the second row to the north of the GCP and 20 columns away from the GCP in the NE quadrant it would be code 1220. The first digit is the quadrant code while the following digits represent the rows and columns.

The soft-shell clam biology, water quality and land-use data are stored as points. The clam biology database represents clam samples taken at the centre of each grid. Individual clams were measured (length and width) and weight. For each clam, the data were stored as a single record in the point database. This meant that a single location has more than one record. However, the points represent a sampled area of ca. 0.25 m^2. However, before any descriptive analysis or mapping can be performed on this point data the information must be converted to densities or counts for each polygon in the 100 m × 100 m grid. The water quality points are permanent sample stations (Fig. 2) that will be used for environmental monitoring. These data are stored as x, y coordinates and as an ArcView^{TM} polygon vector shape file. Raster Thiessen polygons are formed by a proximal mapping function in Spatial Analyst 1.0 (Anon. 1996), and the shape of the polygon is determined by the distribution of the points. A polygon is formed around a point by constructing boundaries halfway between a point and its nearest neighbour. The result is a series of irregular shape polygons (converted to vector shape files) that can be used to map water quality within a vector data structure (Fig. 4, below). The reason for this approach is twofold; first there are some observations missing from the database that would make the point distribution too sparse for contouring by spatial interpolation algorithms. Second, if the database is transferred to a system without the capability to build Thiessen polygons or create a continuous surface by interpolation the existing polygons could be used for mapping water quality attributes.

A GIS approach to aquaculture site assessment

The data collected on clam biology, hydrology, land use and water quality as well as the inclusion of aerial photography and a digital topographic map provides the information required for an aquaculture site assessment. This evaluation should address issues on the suitability of the environment, potential competing land use and the sustainability of the soft-shell clam resource. A preliminary analysis of the field data will be given whereby a GIS approach is used to map and analyse the data in terms of (1) the physical site characteristics and land use; (2) water quality; (3) the soft-shell clam resource.

The clam resource will be evaluated in terms of spatial variability in the density of various size class distributions and population characteristics.

Site characteristics

The soft-shell clam inhabits bays and estuaries, intertidally and sub-tidally in water to depths of ca. 9 m (Newell & Hidu 1986). The potential aquaculture sites near Burgeo, Newfoundland, consists of two active estuaries (Indian Hole and Little Barasway), and one former estuary (Big Barasway) of the Grandy Brook (Fig. 3). The three sites are sheltered from prevailing southerly and westerly winds by sand and gravel spits. The sand flats for Big Barasway and Indian Hole (indicated by a solid white line on Fig. 3) are in fairly shallow water. The water depths at median tide in these two areas range from 0.30 to 2.16 m. Little Barasway has a delta forming (see Fig. 3) and the median tide depth ranges from 0.19 to 0.88 m. The substrate in Big and Little Barasway is predominantly sand while Indian Hole is more diverse with a combination of sand and weeds. All three areas have areas of 1 or 2 ha composed of mostly gravel or weed substrate.

The hills surrounding the potential sites are sparsely vegetated with exposed bedrock. Given the lack of vegetation cover and the distribution of lakes, streams and rivers in the region, there may be high freshwater run-off during sustained periods of rainfall. Since most of the cottages are a known pollution source the freshwater run-off may cause water quality problems (Fig. 3). There are also cottages located upstream on the Grandy Brook. The seaside and river cottages are usually occupied frequently from May to October. This coincides with the summer spawning and harvesting periods and could present a

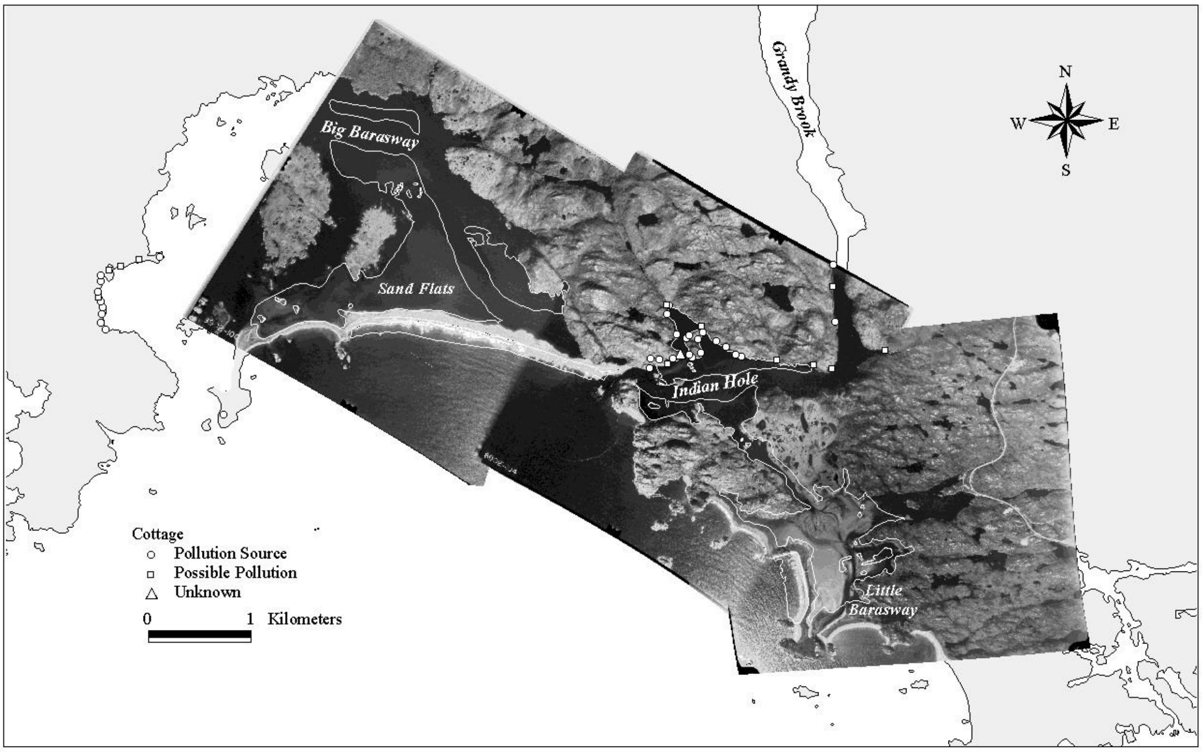


Fig. 3. Aquaculture site characteristics and cottage location.

potential contamination problem. Finally, field observations indicate that a majority of the sand flats in Big Barasway is subject to predation by gulls and seals while the areas in Indian Hole and Little Barasway appear to experience much less predation.

Water quality

The location of cottages in the study area (Fig. 3) introduces the possibility of contamination from faecal coliform. This may affect the commercial viability of a clam bed because there are government regulations that control the closing or opening of a contaminated area for harvesting clams. In Canada, if the faecal coliform density exceeds 13.99 MPN/100 ml, the area is closed to harvesting until the density falls below this value. During the field survey the water quality monitoring stations were sampled at regular intervals from May 28 to Sept. 13, 1995. During this period fecal coliform densities ranged from 1.9 to 920 MPN/100 ml. During a majority of the time the densities were at 1.9 MPN/100 ml, which is below the standard set by the Department of Fisheries and Oceans. However, during extended rainfall events (e.g. 52 mm over 72 h from Sept. 17 to 19, 1995) the fecal coliform densities range from 17 to 920 MPN/100 ml. This event is presented in Fig. 4.

Prior to the rainfall event the fecal coliform densities were at acceptable levels, however by Sept. 19, 1995 all areas were highly contaminated (Fig. 4). However, two days later (Sept. 21, 1995), most of Big Barasway had returned to acceptable levels except for an area in the

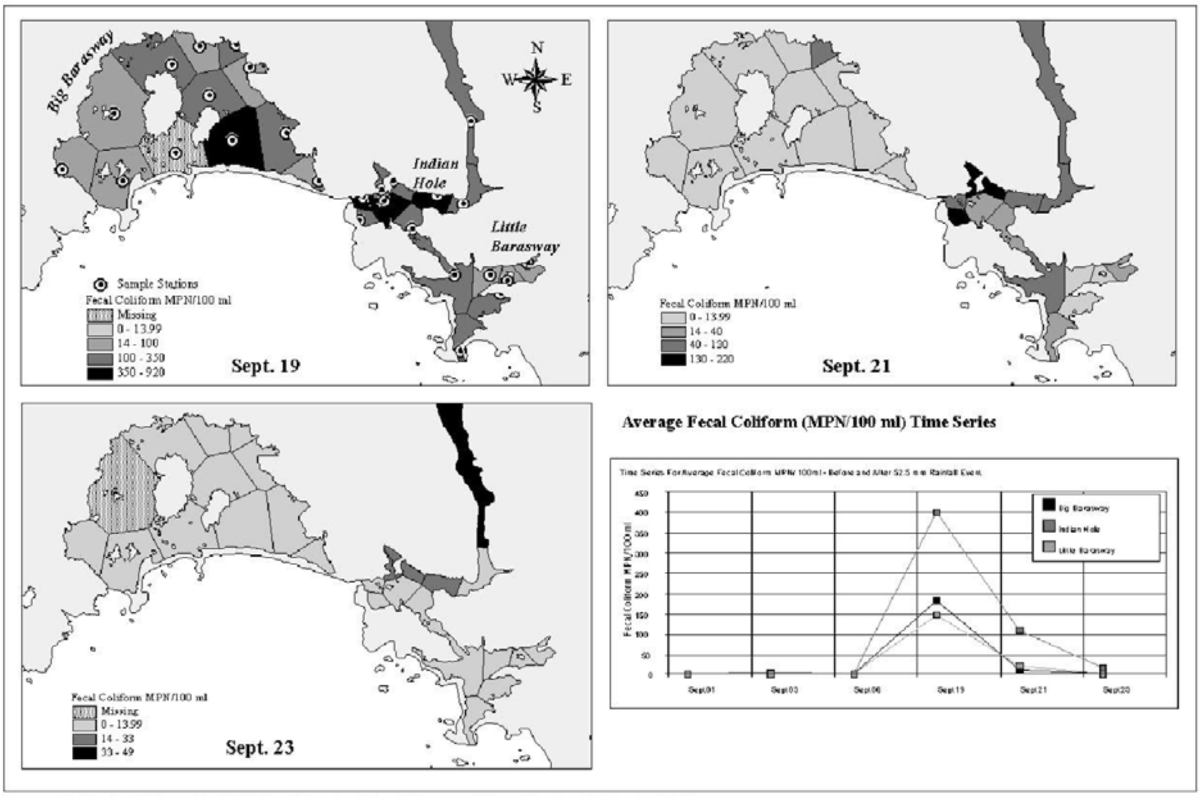


Fig. 4. Fecal coliform (MPN/100 ml) levels after 52 mm of rainfall (Sept. 19 - 23, 1995).

north; Indian Hole and Little Barasway remained highly contaminated. A survey of the water quality stations on Sept. 21 indicated that fecal coliform levels at Big and Little Barasway had returned to acceptable levels, while Indian Hole still had areas that were contaminated (Fig. 4). The time series graph in Fig. 4 suggests that the maximum contamination occurred on Sept. 19. Big and Little Barasway appear to flush completely within 5 days while Indian Hole may take longer because of contamination from upstream sources.

To date the long-term impact of fecal coliform contamination on clams is not known. Studies have demonstrated that clams can rid themselves of contaminates if they are exposed to clean seawater for approximately 48 hours. This process is only viable for marginally contaminated clams (Supan a& Cake 1982). Ongoing field surveys are examining the impacts of these type of run-off events on the clam beds. Furthermore, this is the first water quality study conducted on the estuaries and the residents were not aware of the fecal coliform contamination problem. Another solution to the problem is to present the information to the cottage owners and inform them of potential health risks, since the contamination affects the recreational use of these sand flats. This is a situation where the pollution can be controlled at the source.

Water characteristics such as salinity and temperature affect the growth, mortality and the production of the soft-shell clam. For example, clams need salinities of at least 5 parts per 1000 (ppt) to survive, but thrive in salinities from 25 to 35 ppt. Studies have demonstrated that, during excessive freshwater run-off clams may experience 90% mortality in areas where salinities reduced to less than 5 ppt (Newell & Hidu 1986). During the run-off event from Sept. 19 to 23, 1995 the salinities at Indian Hole and Little Barasway dropped below 5 ppt for several days, e.g. salinities ranged from 2 to 30 ppt, but returned to acceptable levels within 5 days (Fig. 5). The short-term impacts of low salinities on clam mortality have not been studied in this area. However, clams can survive low salinities if water temperatures are low (Allen & Garrett 1971). From Sept. 19 to 23, 1995 the water temperature ranged from 11 to 14.5 °C and there were no high clam mortalities recorded during this period.

When the water quality attributes fecal coliform and salinity are mapped as Thiessen polygons in Figs. 4 and 5 the maps reveal information about potential flushing rates and current dynamics. The maps provide the

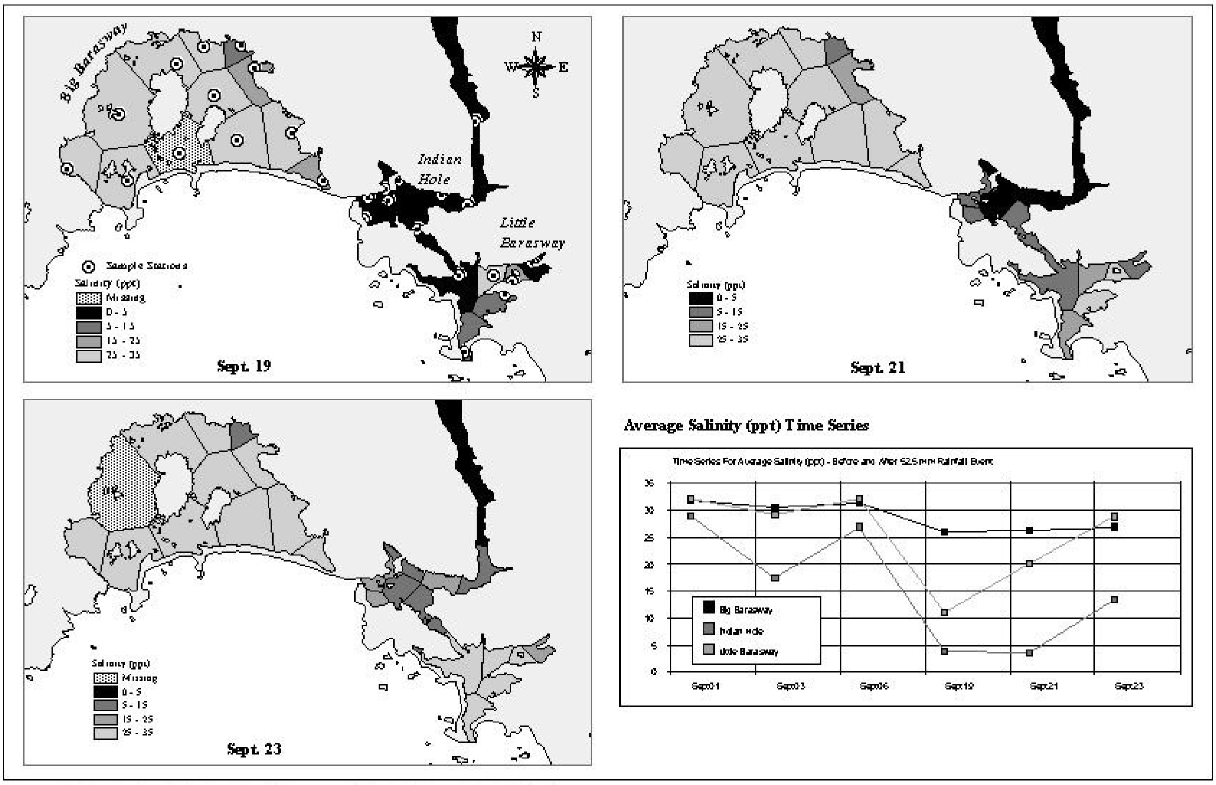


Fig. 5. Salinity (ppt) levels after 52 mm of rainfall (Sept. 19 - 23, 1995).

aquaculture operator with insights to possible problem areas. Given that Big Barasway flushes faster and did not record salinities below 5 ppt, this area could be seeded with clams from Indian Hole and Little Barasway.

Mapping and analysis of soft-shell clams

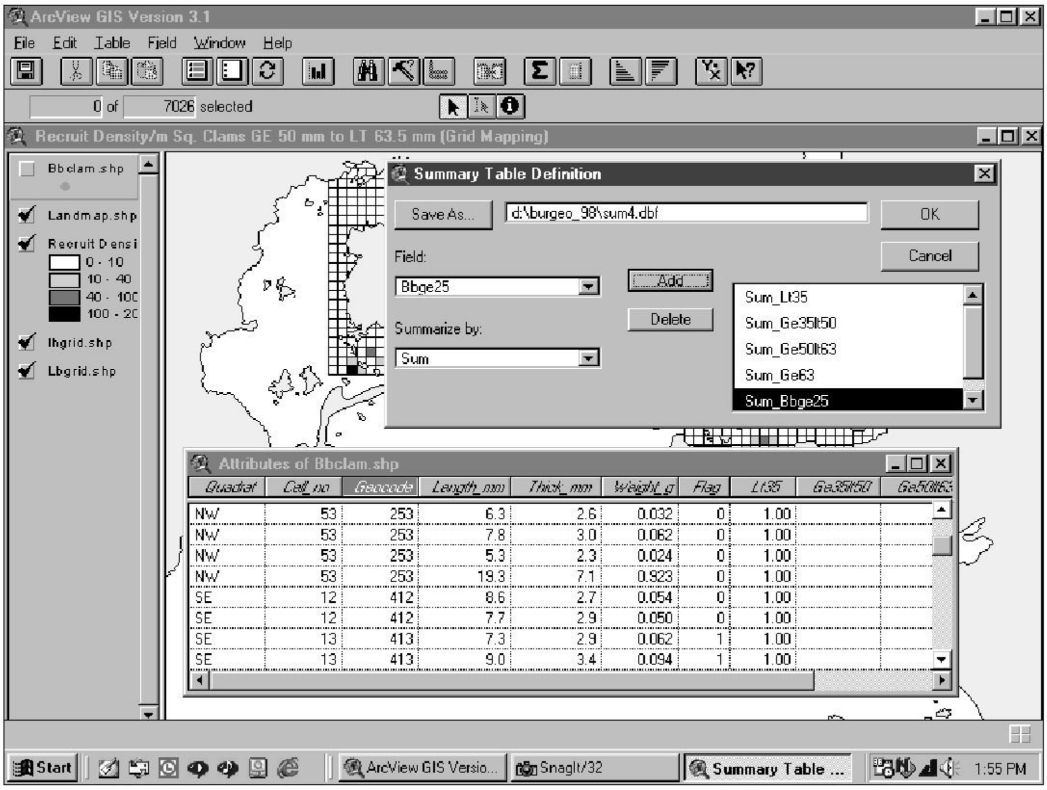
GIS is a tool that is capable of quantifying and visualizing the characteristics of the natural clam resource. The clam biology database is used to examine the spatial density of the resource, estimate the market biomass, and develop a potential harvesting plan. These issues are addressed by descriptive and prescriptive queries within ArcView^{TM} and the Spatial Analysis module (Anon. 1996).

Preparation of the clam biology data for analysis included the calculation of clam densities as well as an estimate of the total biomass for each area. The attribute clam length was subdivided into four classes:

1. Juvenile: length < 35 mm;
2. Pre-recruits: length ≥ 35 and < 50 mm;
3. Recruits - length ≥ 50 mm and < 63.5 mm;
4. Brooding Stock – length ≥ 63.5 mm.

A Query Summarize function in ArcView^{TM} (Fig. 6) was used to summarize by GEOCODE, the total number of clams for each size class. Thus each 100 m × 100 m grid in the recruit group represents the market clam population. The procedure for calculating clam densities involved the addition of the four clam size class fields (attributes) to the clam biology point databases. For each record a value of 1 was assigned to a size class attribute if the clam length value was within the specified class interval otherwise the value was set to 0. The study area is assigned a total count for each clam size class. Given that the sampling occurs in a 0.25 m^2 plot at the centre of each grid, the density for each size class was calculated as: *n*/area, where *n* is the total number of clams in a grid. An estimate of the market clam biomass was calculated using the ArcView^{TM} Query Builder and Field Calculator. A market biomass is calculated by estimating the total number of clams in a 1-ha grid. The estimation of the biomass is based on several assumptions:

1. The clam densities are homogeneous within a 100 m × 100 m grid;
2. It takes 1500 recruit size clams to make a bushel;
3. One bushel of recruit size clams weights ca. 27 kg



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Save As... d:\burgeo_98\sum4.dbf

Field: Bbge25

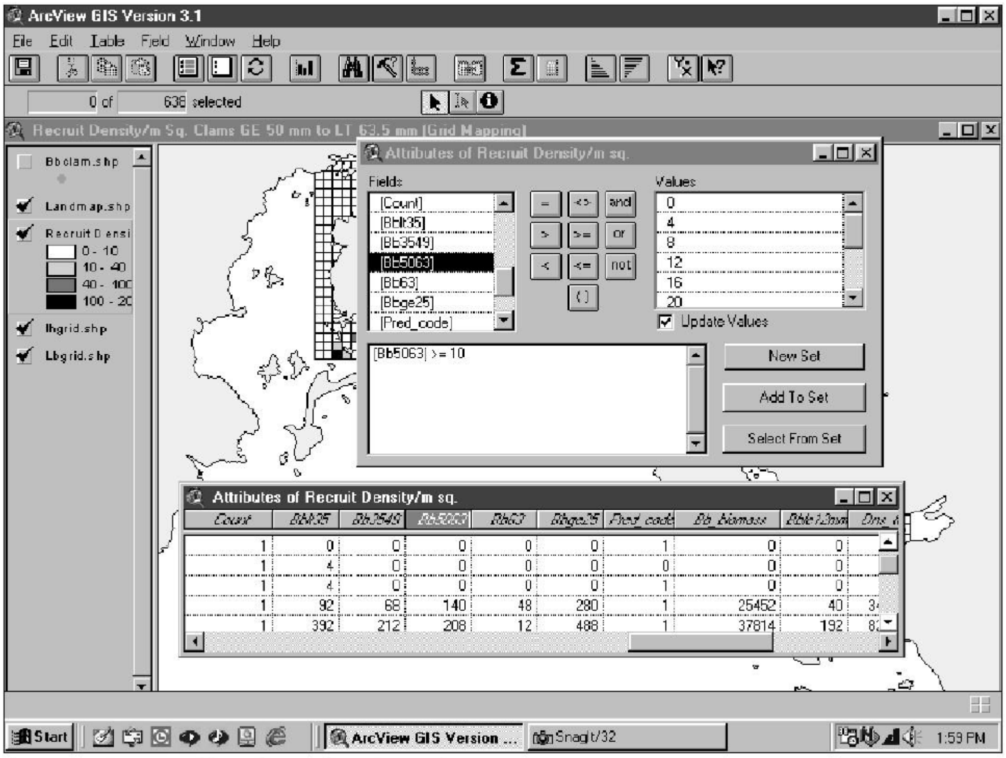
Summarize by: Sum

- Sum_Lt35
- Sum_Ge35lt50
- Sum_Ge50lt63
- Sum_Ge63
- Sum_Bbge25

Attributes of Bbclam.shp

Quadrat	Cell_no	Geocode	Length_mm	Thick_mm	Weight_g	Flag	Lt35	Ge35lt50	Ge50lt6
NW	53	253	6.3	2.6	0.032	0	1.00		
NW	53	253	7.8	3.0	0.062	0	1.00		
NW	53	253	5.3	2.3	0.024	0	1.00		
NW	53	253	19.3	7.1	0.923	0	1.00		
SE	12	412	8.6	2.7	0.054	0	1.00		
SE	12	412	7.7	2.9	0.050	0	1.00		
SE	13	413	7.3	2.9	0.062	1	1.00		
SE	13	413	9.0	3.4	0.094	1	1.00		

Fig. 6. ArcView Descriptive Query summary.



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Fields:

- [Count]
- [Bblt35]
- [Bb3549]
- [Bb5063]
- [Bb63]
- [Bbge25]
- [Pred_code]

Values:

- 0
- 4
- 8
- 12
- 16
- 20

☑ Update Values

[Bb5063] >= 10

Attributes of Recruit Density/m sq.

Count	Bblt35	Bb3549	Bb5063	Bb63	Bbge25	Pred_code	Bb_biomass	Bble12mm	Dns_
1	0	0	0	0	0	1	0	0	
1	4	0	0	0	0	0	0	0	
1	4	0	0	0	0	1	0	0	
1	92	68	140	48	280	1	25452	40	3
1	392	212	208	12	488	1	37814	192	8

Fig. 7. ArcView Query Builder “Select recruit density GE 10.m^{-2}”.

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(Robert 1981).

The biomass estimate for each grid is calculated as:

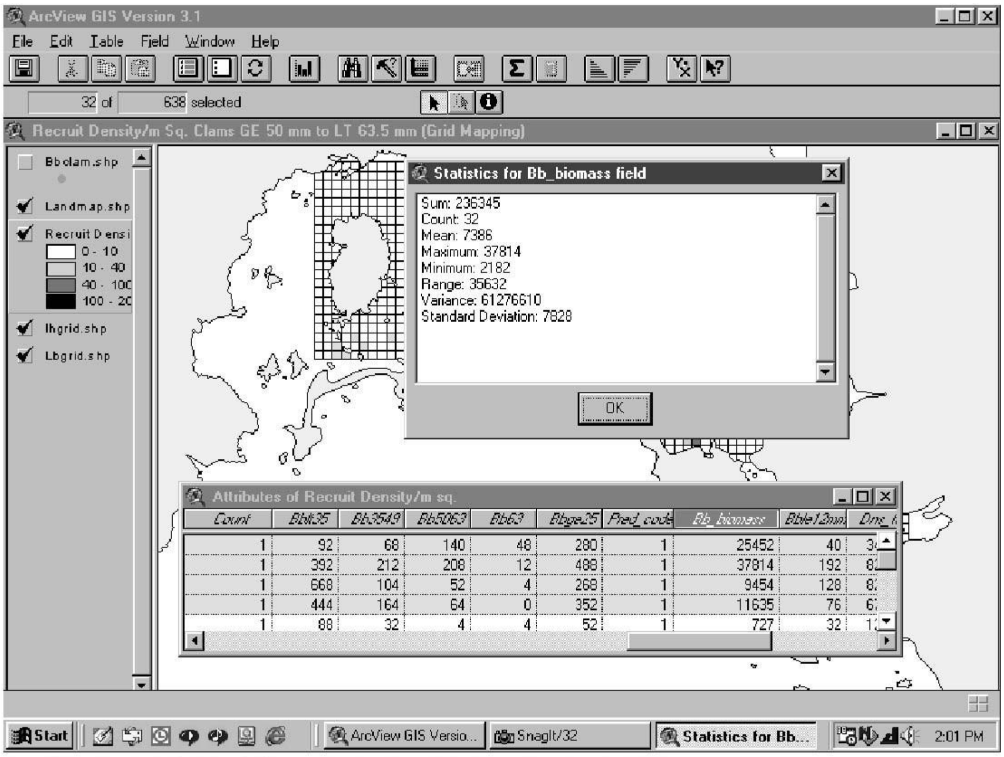
$$(\text{clam density.m}^{-2} * \text{grid area}) / 1500) * 27 \qquad (1)$$

The result is a clam shell weight in kg for each 100 m × 100 m grid. A grid is economically viable only if the recruit clam density is ≥ 10 m^2. These criteria can be used with the ArcView^{TM} Query Builder (Fig. 7) to select grids for the biomass calculation. After the grids are selected a Field Statistics function can be used to calculate the biomass. For example, Fig. 8 illustrates how the biomass was calculated for Big Barasway. Note that the sum value, in the Statistics for BB_biomass field, is 236 345 kg. This number represents the predicted biomass for Big Barasway.

The 100 m × 100 m grids are used for descriptive analysis such as the calculation of densities. The polygons can also be used for mapping attributes. Fig. 9 A illustrates the use of the grids to map the distribution of mature clams densities/m^2 (e.g. clams ≥ 25 mm). Mature clam densities of 161 to 269.m^{-2} are acceptable for good growth while higher densities can impede growth because of competition for food and space (Newell & Hidu 1986).

From an aquaculture management perspective areas with excessive mature clam densities, depending on the size class distribution, need to be culled or harvested. Thus mapping of the mature clam densities can identify areas that require culling or harvesting as well as areas of low densities that require seeding. A possible solution to the excessive density problem is to move the culled juvenile or pre-recruit clams to areas of low densities.

Mapping clam densities with vector polygon data will reveal trends, but if the data are to be used in any prescriptive analysis the spatial data must be converted to a raster format. The visualization and analysis of clam densities in a GIS can be applied to a raster version of the original grid. However, the clam density distribution is a continuous spatial variable and should be mapped as a continuous surface where possible. Continuous surfaces are created in a raster GIS by using spatial interpolation algorithms. ArcView^{TM} Spatial Analyst provides an inverse distance squared (IDW) and a spline interpolation routine. The process of converting the clam density data from polygon to point coordinates for interpolation involved several steps. Firstly, stratified random samples of coordinates were generated for each of the three areas. The sampling density ensured that 25 m spacing occurred between the points. Secondly, a point-in-polygon procedure



Sum: 236345
Count: 32
Mean: 7386
Maximum: 37814
Minimum: 2182
Range: 35632
Variance: 61276610
Standard Deviation: 7828

Count	Bblt35	Bb3549	Bb5063	Bb63	Bbge25	Pred_code	Bb_biomass	Bble12m	Dns_
1	92	68	140	48	280	1	25452	40	3
1	392	212	208	12	488	1	37814	192	8
1	668	104	52	4	268	1	9454	128	8
1	444	164	64	0	352	1	11635	76	6
1	88	32	4	4	52	1	727	32	1

Fig. 8. ArcView Field Statistics for biomass based on query: “Select recruit clam density ≥ 10.m^{-2}”.

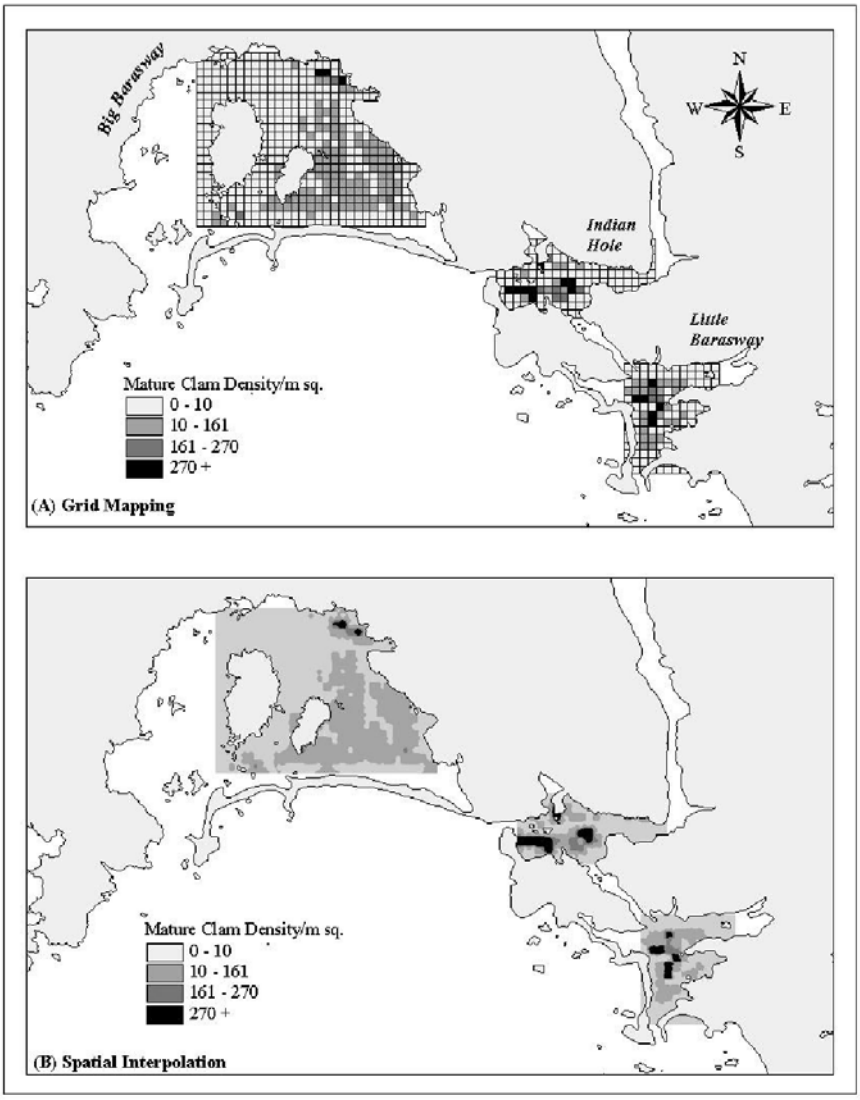


Fig. 9. Comparison of (**A**) Grid mapping and (**B**) Interpolation mapping – Mature clam density.m^{-2}.

was used to attach the grid density size class data to the points database. An inverse distance squared algorithm was used to create continuous surfaces for all clam size density classes. Fig. 9B illustrates the interpolation result for mature clam density. A comparison of Fig. 9A, B indicates that some spatial averaging occurs, (e.g. the maximum density is reduced from 488 to 473.m^{-2}). However, the interpolation preserves the original trends in the data. Fig. 9 B indicates that, in some areas, there is a need to cull the mature clam population, especially at Indian Hole.

According to Newell & Hidu (1986) the expected spatial distribution of clams in an area ranges from highly dispersed in the juvenile size class to a highly aggregated pattern in the recruit and brooding classes. Mapping the size class densities as continuous surfaces indicates that a similar pattern occurs in Big Barasway (Fig. 10) and to a lesser degree in Indian Hole and Little Barasway. Fig. 11 confirms the increasing spatial aggregation from juvenile to brooding stock classes whereby an inverse relationship exists between the larger clam size classes and percent area occupied. For example, in Big Barasway juvenile clams (> 35 mm) are found in 95% of the surveyed area while brooding stock clams (≥ 63.5 m) are found in only 17% of the area.

Fig. 11 also presents information on the clam population characteristics. In Big Barasway there is a large decrease in clam density from the juvenile to pre-recruit class (Fig. 11B). The average density drops from a high of 124.m^{-2} for the juvenile class to 30.m^{-2} for the pre-recruit class. There is also a dramatic change in densities at Indian Hole where the average density drops from 125.m^{-2} for the pre-recruit class to 53.m^{-2} for the recruit class. Little Barasway shows a more gradual change

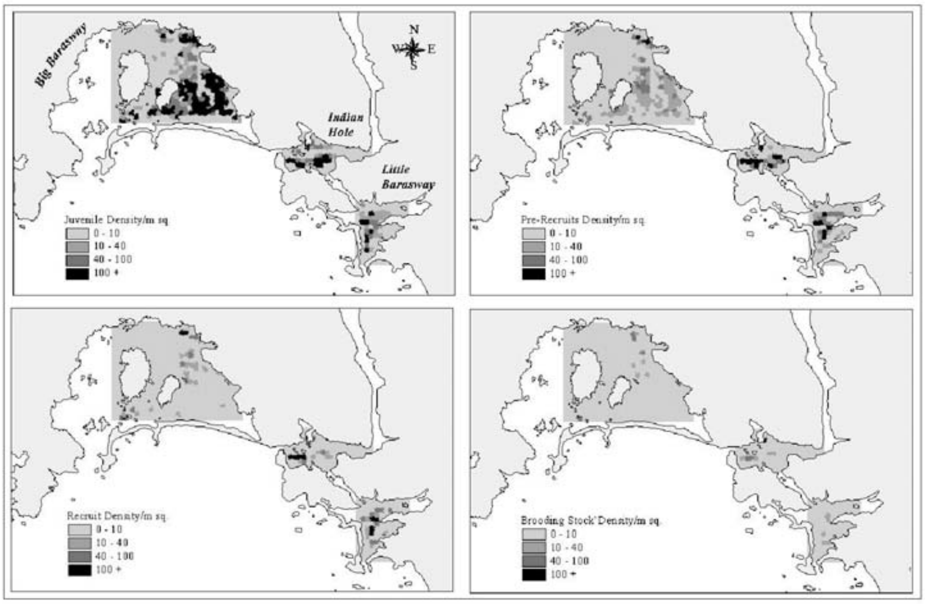


Fig. 10. Clam density.m^{-2} by class size.

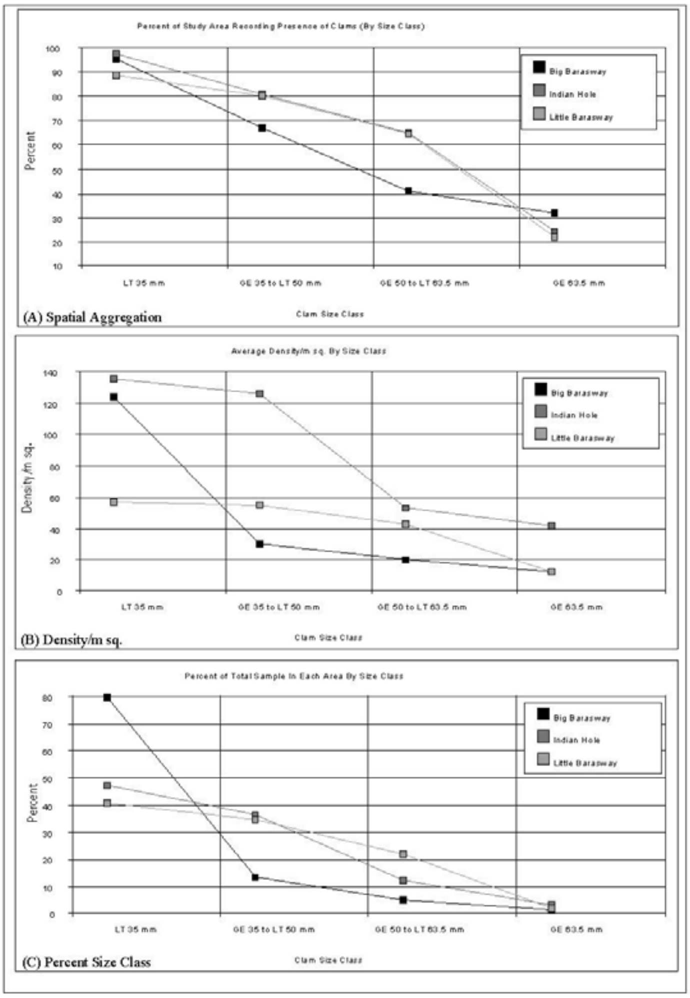


Fig. 11. A. Spatial aggregation; **B.** Density; **C.** Percent size class trends.

where the average densities are 57, 55, 43.m^{-2} for the juvenile, pre-recruit and recruit classes respectively. Indian Hole has the highest densities in all classes while Big Barasway has the second highest juvenile density but the lowest densities in all other classes. The frequency size class information presented in Fig. 11 (C) indicates that 80% of the sampled clam population in Big Barasway is juvenile and the recruit population accounts for only 10% of the sampled data. The trends at Indian Hole and Little Barasway are similar. The juvenile classes at these locations account for 47 and 42 percent of the clams sampled, however, Little Barasway has a higher percentage of recruits (23%) than Indian Hole with 14%. Although Indian Hole has a higher density of clams.m^{-2} Little Barasway has the highest percentage of recruit clams suggesting a possible higher survival rate for clams at this location. The low percentages associated with the larger clams at Big Barasway needs further study in order to understand the dramatic changes in the observed densities. Although the area appears to be experiencing high predation, an analysis of the data did not reveal any correlation between the presence or absence of predators and the size class distribution.

Aquaculture management and GIS

GIS can be used to manage and organize operations at an aquaculture site. The harvest plan presented in this contribution is an example that demonstrates how a GIS can be used to help aquaculture operators map and evaluate their proposed activities. Through GIS the operator can identify and map the areas to cull or harvest as well as evaluate the expected yield along a proposed harvest path. These applications can be called prescriptive because the results of the analysis can be used as rules or guidelines for harvesting clams.

The use of a GIS to develop aquaculture operation scenarios requires the definition of criterion or rules for a particular activity. In this study the following rules are used to identify areas for harvesting or culling:

1. The density of recruit clams must be greater than or equal to 10.m^{-2}.
2. When the density of mature clams exceed 269.m^{-2} the area must be culled.

The Map Query tool in ArcView™ Spatial Analyst is used to define areas where the mature clam density is greater than 269.m^{-2} and where recruit densities are $\geq$ 10.m^{-2}. The result of this analysis is two binary maps where 0 and 1 indicates that the condition is false and true respectively. The Map Calculator tool in Spatial Analyst is used to combine the maps to identify areas of no harvesting, harvesting only as well as sites where both culling and harvesting is required. The binary maps are used to calculate the harvest plan map where:

[Map of harvest areas] + ([Map of cull areas]* 2). (2)

This expression will produce a map with four values, (1) the no harvest, (2) harvest only, (3) cull only and (4) combined cull and harvest areas; they will be coded 0, 1, 2 and 3, respectively. The harvest plan map produced by this analysis is presented in Fig. 12 and the harvest only or cull and harvest areas are easily identified. A profile analysis was performed at Indian Hole on the estimated metric ton/ha map. A proposed harvest track was digitized on the Harvest Map and a profile was generated (Fig. 12). The profile result indicates a low expected yield of about 1 metric ton/ha at the start and a high of 26 tons/ha is available at about 300 m from the start. However, at about 1 km from the start the expected yield drops to 0 tons/ha. The area where the expected yield drops to zero is at the beginning of a no harvesting zone. These areas may consist of either juvenile or pre-recruit clam beds that should not be disturbed. Thus the harvest plan map could be improved by adding other layers such as maps that identify areas that maybe important for juvenile or pre-recruit clams. The profile analysis can also be used to evaluate proposed harvesting tracks and select only those tracks that offer the highest yield/ha.

The calculation of harvesting area and the expected yield/ha provides an estimate of the total market biomass for all three areas. Big Barasway has the highest market biomass at 236 metric tons followed Indian Hole and Little Barasway with 223 and 216 metric tons, respectively (Fig. 12). An examination of the average yields/ha indicates that Indian Hole is the most productive at 13.94 metric tons/ha followed closely by Little Barasway at 11.37 tons/ha. Finally, Big Barasway is the least productive area at 7.37 tons/ha.

Conclusion

The information presented in this study indicates that GIS is an important tool for the aquaculture industry. These systems can be used to monitor, quantify and evaluate the soft-shell beds near Burgeo. Management issues such as water quality, resource sustainability as well as the economic viability of the clam resource can be assessed within a GIS environment. The results of the analysis in this study suggest potential problems with faecal coliform contamination from local cottages. Furthermore, at Big Barasway the relatively low counts and densities at the recruit and brooding size classes raise questions about clam mortality. This trend is also supported by the fact that the Big Barasway average yield/ha is approximately half of the average yield calculated

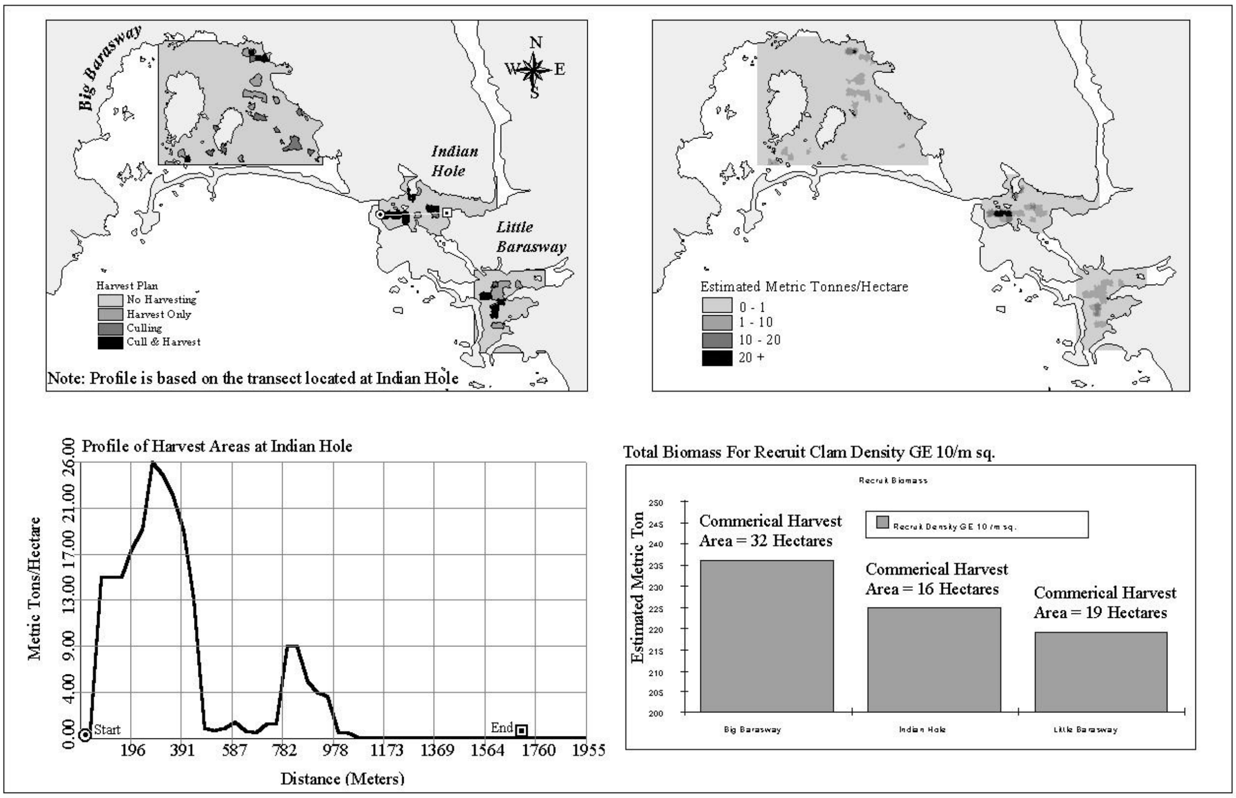


Fig. 12. Harvest plan for aquaculture sites.

for Indian Hole although the area is twice as large (Fig. 12).

Finally, data collection for aquaculture site assessment is required if a resource is to be managed effectively. GIS applications provide insights into the quality of the physical environment as well as the sustainability of a resource. However, the aquaculture operators will ultimately make the final decisions.

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