Title: USE OF A GIS-BASED PARTICULATE WASTE DISTRIBUTION MODEL AS A TOOL TO AID MARINE FISH CAGE SITE SELECTION

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http://www.aquaculture.stir.ac.uk/GISAP/Projects/Oscar.htm
http://www.aquaculture.stir.ac.uk/GISAP/Projects/Wastes.htm

Application Tools: GIS

Main Issues Addressed: Environmental impacts of aquaculture

The general problem, or aim of the study, and the contribution of GIS, remote sensing and/or mapping to the solving the problem: Once a preliminary assessment of the potential suitability of a region for developing marine fish cage aquaculture has been determined, areas selected as the most suitable will benefit from a further study to quantify the dispersive nature of a particular site, and therefore aiding the final decision by assisting in predicting possible environmental impacts and also help regulators to establish the maximum desirable production at a site to support sustainable development of the industry.

Modelling of input and distribution of wastes and discharges is a cost-effective tool that can assist in the prediction of the dispersive potential of a site. In this study an improved version of an existing predictive particulate waste distribution model for marine cage fish farming, which uses Geographic Information Systems (GIS) combined with a spreadsheet, is presented.

Main Environments: Marine

Culture System: Cages

Organism Divisions: Marine fishes

Genera and Species: Any marine fish from which data to estimate a mass balance is known and water current flow and direction data can be measured.

Target country: All coastal countries.

Target Audience: Managers and regulators involved in site selection, establishment of the maximum desirable production at a site, estimation of the maximum number of farmed tonnage and number of cages at a site, environmental impact assessment, design of monitoring programmes and farm management.

Duration study and year begun: The model has been developed over various years. First studies date from 1984, where since research has been continually been carried out until nowadays. This study was part of a Ph.D. thesis which took 3 years.

Personnel involved: The model has been developed with the participation of many researchers, mainly from the environment and GISAP group within the Institute of Aquaculture.

USE OF A GIS-BASED PARTICULATE WASTE DISTRIBUTION MODEL AS A TOOL TO AID MARINE FISH CAGE SITE SELECTION.

Introduction

Cage aquaculture, as with any other economic activity which uses natural resources, depends upon inputs (e.g. water, feed) and attendant processes (e.g. capacity of the environment to degrade wastes) to produce a final product for consumers (e.g. fish) in an environmentally responsible manner. This utilisation of environmental resource may have social, economic and environmental benefits such as provision of food, employment, increase of income, improved nutrition and health, decreased pressure on natural stocks (Beveridge, 1996). On the other hand, interactions with the environment can also generate negative impacts. Wastes, which are generated by the farming activity and released into the environment, may have a negative effect on natural resources decreasing their quality and quantity. Of all the wastes released by marine fish farming to the environment, particulate organic waste in the form of uneaten feed and faeces are usually the most significant fraction (Beveridge, 1996). This material, which generally settles on the seabed near to the cages, provides a net input of organic carbon and nitrogen to the sediments which can cause major changes in benthic community composition and productivity, and may exceed the environment's capacity to bioprocess this material (Gowen and Bradbury, 1987; Gowen *et al*., 1988; Findlay and Watling, 1994; Hargrave, 1994; GESAMP, 1996). Moreover, environmental deterioration due to high organic matter concentrations in the sediments may affect the health of farmed fishes and hence profitability (Beveridge, 1996; GESAMP, 1991b).

Impacts of wastes on the environment, due to an intensive aquaculture, has lead to a negative perception of aquaculture by the public. In addition, the increasing number of marine farms threatens to bring competition between fish farmers and other users and potential users of coastal space, such as the tourism industry. Therefore, to ensure a sustainable development of the aquaculture industry, there is a need to allocate suitable locations for aquaculture (i.e. controlled site selection) to resolve conflicting demands for coastal space, avoid undesirable impact on the environment, as well as ensuring profitability (Kapetsky *et al*., 1987; GESAMP, 1991a; GESAMP, 1997).

Once a preliminary assessment of the suitability of a region for developing marine fish cage aquaculture has been determined - based on criteria such as: water quality requirements (temperature, suspended solids, sewage discharges, etc.), physical parameters of the environment (waves, currents, bathymetry, etc.), infrastructure to support the industry (roads, airports, ports, etc.), and other uses of the coastal space (tourism, fisheries, nautical sports, etc.) - areas selected as the most suitable will benefit from a further study to quantify the dispersive nature of a particular site assist in predicting environmental impacts and help governmental regulators to establish an environmentally responsible level of production. Estimation of input and distribution of waste from fish cages can be achieved in a cost-effective manner using quantitative spatial modelling.

This study describes the development of specific Geographic Information Systems (GIS) spatial modelling techniques for particulate waste distribution based on a pre-existing model (Telfer, 1995; Walls, 1996; Perez-Martinez, 1997), which use a complex application of distribution equations developed by Gowen *et al.* (1989). The success of GIS for modelling purposes stems from its capacity for fast image generation and manipulation, the flexibility to run alternative scenarios, statistical analysis of the image and generation of sophisticated output which helps visual and quantitative interpretation of results. This model has been previously validated using field data and fish production information (Perez *et al*., 2002).

Model development

There are three main stages to this model: 1) quantification of the waste material (uneaten feed and faeces) using mass balance techniques; 2) calculation of the distribution of the waste components using Gowen's formulas (Gowen *et al*., 1989); and 3) calculation and generation of the final distribution diagrams. The first two submodels are run in a spreadsheet and the third is carried out using the GIS software IDRISI32. The final output from the model is a quantitative contour map showing the distribution of particulate organic carbon deposited on the seabed.

1) Mass balance

The quantities of waste released to the environment, particulate organic carbon in form of uneaten feed and faecal material, are calculated using a mass balance model (Figure 1). The expected fish production during a set period of time is multiplied by the expected food conversion ratio (FCR) for that period. In the present model, the percentage of water in the feed is assumed to be 8% (Findlay, 1994) while that of carbon in the feed is assumed to be 46% (Penczak *et al.*, 1982). From the feed given to the fish, 90% is consumed and the remaining 10% is lost as uneaten feed (Hargrave, 1994). It is assumed here that 50% of the consumed carbon is respired (Gowen *et al*., 1988) and that 14% is incorporated into body tissues (Chen, 2000), although it is important to bear in mind that mass balance quantities for organic carbon flux for cage production vary from author to author (e.g. Gowen *et al.*, 1989; Silvert, 1994; Telfer, 1995; Hevia *et al.*, 1996). Carbon in faecal material is calculated as the difference between carbon consumed and carbon used for respiration and growth.

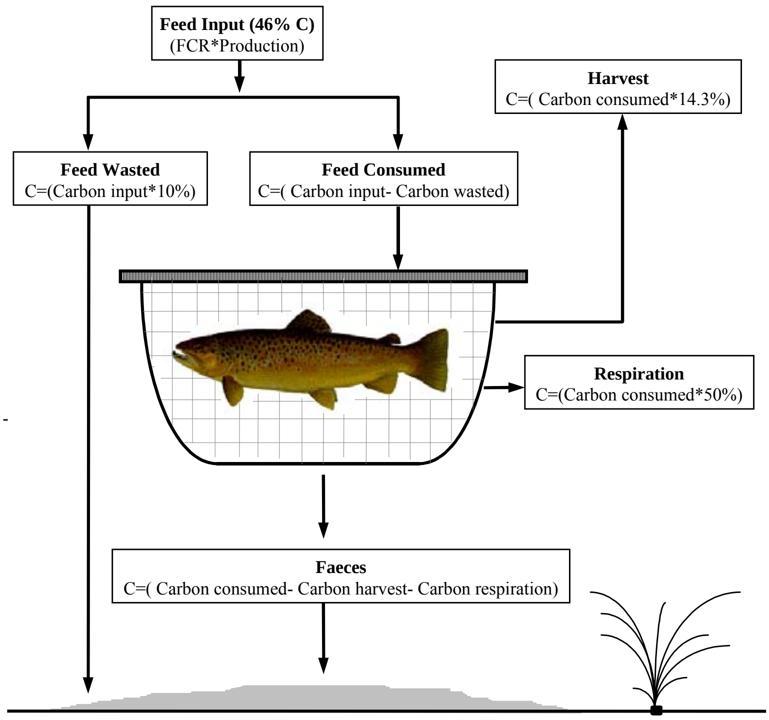

Figure 1 Mass balance used to calculate carbon wasted from uneaten feed and faecal material in fish net-pen culture.

2) Distribution equation

For modelling purposes, the farm is located in the middle of a 500 by 500 cell array where each cell representing 1 m^2 and X and Y are their coordinates. The horizontal distribution of a particle (X and Y components for each cage of the farm) is calculated using the equations of Gowen *et al*., (1989) (Eq. 1 and 2). The depth under the cage (d), the current speed (V), current direction (θ), settling velocity (u) and position of each cage (x, y) are site specific measured quantities. Current speed and direction are measured for a defined period of time using current meters. Because wastes fall more or less vertically through the cage (Inoue, 1972), the source of distribution was assumed to be from the depth corresponding to the bottom of cage. The same equation is used to calculate the distribution of both uneaten feed and faeces, but different settling velocities are assigned to each; 0.128 m s^{-1} and 0.04 m s^{-1} respectively (Warrer-Hansen, 1982; Chen *et al*., 1999).

Eq. 1 $$X = \frac{d * V\sin\theta}{u} + x$$

Eq. 2 $$Y = \frac{d * V\cos\theta}{u} + y$$

3) Geographical Information Systems (GIS)

The carbon deposition co-ordinates calculated with Gowen's formula (Gowen *et al*., 1989) and their associated carbon values are imported into IDRISI32 GIS software where interpolation of values of nutrients between grid squares generates a complete surface. This technique enables detailed contour maps to be drawn with limited hydrographic datasets. However, the nature of the interpolation process means that the calculated quantities of sediment carbon are over-estimated and require correction.

Most models assume a single point as the source of carbon output from a cage (feed and faeces), usually the cage centre. To eliminate this assumption, predicted carbon values allocated on the seabed are spread over an area equal to the cage area by applying a filter within IDRISI32 (Figure2).

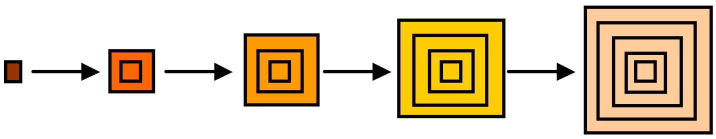

Figure 2 Consecutive filtering technique to spread carbon into an area similar to the cage area.

Variations in initial distribution of waste and post-deposition changes in carbon are considered by using a second filtering technique within IDRISI32, which redistributes the amount of carbon from each cell into the eight surrounding cells by a predetermined percentage, which differs between the relatively dense feed and lighter faeces. Each cell represents $1 m^2$, hence the final area affected from each of the initial cells is $9 m^2$ (Figure 3).

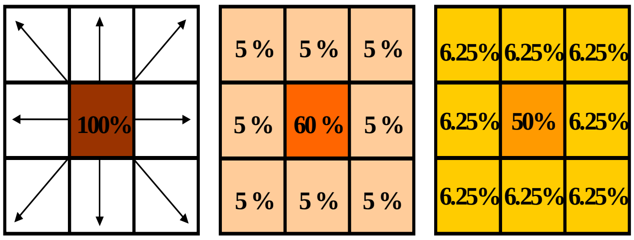

Figure 3 Sequence of steps involved in “carbon spreading”. (a) The original cell as predicted from Gowen’s equations; (b) spread of carbon from uneaten feed to surrounding cells; (c) spread of faecal carbon to the surrounding cells.

Finally, it is necessary to correct the carbon quantities in the resultant image, which are over-estimated due to the interpolation process. Interpolation generates additional data between a set of known values. However, it does not reduce the original carbon concentrations to compensate for this, which means that the model assumes that there is considerably more carbon entering the sediment than there really is. The correction is achieved by multiplying the resultant output by a correction factor (CF), which is calculated by dividing the total predicted waste carbon from the mass balance (feed and faeces) by the total carbon in the resultant image.

$$CF = \frac{\text{Total predicted waste carbon (kg)}}{\text{Waste carbon in the image (kg)}}$$

Results

Output from the model is in the form of a contour plot of organic carbon (g C m^{-2}), showing distribution of the particulate organic carbon material as deposited on the seabed. Figure 4 and Figure 5 show two examples of the model output run using data from a salmon cage farm in the west coast of Scotland (Perez *et al*., 2002) and for a seabass cage farm in the east of Spain (Kernick, 2000), respectively.

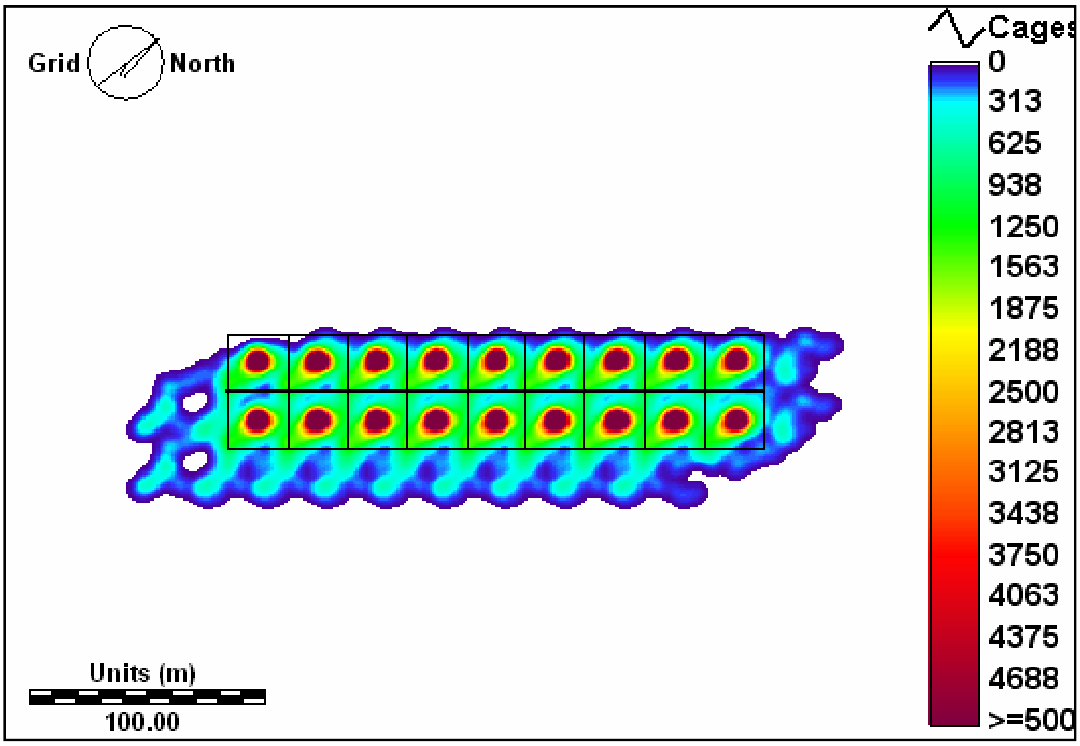

Figure 4 Contour model for a salmon cage farm site on the west coast of Scotland showing distribution of organic waste ca … ass of 172.5 t …

Figure 5 Contour model for a seabass farm site on the east cost of Spain showing distribution of organic waste carbon input (g C/m^2) to the sediment over a 2-months simulation period with a maximum standing biomass of 0.33 tonnes fish and a feed input of 0.64 tonnes.

The output from Figure 4 shows the distribution of the cages in the farm, which comprised 18 cages located in two rows of 9. The mean depth under the cages was 15 m. From the mass balance calculations 35.4 tonnes of carbon were wasted, 10.3 tonnes and 25.0 tonnes due to uneaten feed and faeces respectively. The carbon was distributed mainly in NE and SW directions. The highest concentrations were located under the cage, reaching values of 12 kg C m^{-2}. The concentration of carbon decreased as the distance from the cage increased.

Figure 5 shows a farm distribution of 6 cages located in two rows of 3. In this site the mean depth was 3 m. The mass balance calculations predicted 0.1 tonnes of carbon wasted, 0.06 tonnes and 0.05 tonnes due to uneaten feed and faeces respectively. The dispersion was restricted within the close proximity of the cage system, approximately 5-10 m. Carbon was distributed mainly underneath of the cages, reaching concentration as high as 2.5 kg C m^{-2}.

Discussion

Models are built upon assumptions based on both knowledge of the process involved and personal judgement of their importance, their relation to each other and with the environment. Because assumptions carry an inherent risk of inaccuracy, it is desirable both to reduce their use to a minimum and to identify their impact on overall predictions in order to understand and interpret model outputs. A possible sources of inaccuracy in the present model is the assumption that all particulate carbon waste from the fish cages settles on the seabed, where none is degraded or consumed by invertebrates and wild fish. Although it is likely that this will vary with location, the present GIS model considers post-deposition movement of carbon, and has eliminated some assumptions from previously used modelling techniques. Although at present the model has only been developed for particulate carbon, the distribution of any other solid or particulate-bound material from fish farms, such as N, P or in-feed chemotherapeutants, can also be modelled, providing that accurate data on inputs are available.

The model presented has been developed, over various years in the Institute of Aquaculture, with the participation of many researchers. Latest developments are making improvements by fully integrating it into the GIS system (Brooker, 2002; Institute of Aquaculture, unpublished data). The latest version of the model calculates positions of cages within a digital map of the coastline, then models waste dispersion from the site using variable bathymetry, variable settling velocities and a random point source. The variable bathymetry allows local features such as shorelines and depth to be taken into account in the modelling process. A GUI (Graphical User Interface), created using the Borland Delphi^{TM} development tool, makes data entry possible through simple dialogue boxes, e.g. production data, settling velocities, cage positions, hydrographic datafiles, bathymetry and coastal structures. Using the “Applications Programming Interface” provided with the IDRISI32 software, it has been possible to create a seamless interaction between the model calculations and the GIS. However, more work on waste dispersion modelling and on integration of coastal management information is required.

The particulate waste distribution models described here, are useful for final selection of the most suitable sites for marine cage farming. Moreover, they can help regulators to establish the maximum desirable production at a site to remain within the capacity of the environment to support nutrient inputs. Other applications of the model are for environmental management and rapid generation of “*what if?*” scenarios for hypothetical levels of fish production. An environmental management plan should include and Environmental Impact Assessment which incorporates a quantitative prediction of significant impacts and a monitoring programme design (GESAMP, 1996). Numerical models, such as described here, have the potential to generate quantitative predictions, and are therefore a useful tool in quantifying impacts of cage aquaculture wastes.

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