

Introduction to Geographic Information Systems

David Miller, Chen Wang, Gillian Donaldson-Selby, Dave Miller,
Margaret M^cKeen
(James Hutton Institute),
Antje Gimble (Thünen Institute)

27 April 2018
(final edit 28 August 2018)

Abstract

This text is part of unit 5 in a Masters-level course in ‘Planning and Managing the Use of Space for Aquaculture’ made by the AquaSpace project. It supports a slide sequence that introduces Geographic Information Systems (GIS), which provide a framework for gathering, managing, and analyzing spatial data. They are used in relation to aquaculture for bringing together information on natural resources, protected areas and outputs of models. The data and examples are from the AquaSpace case study areas of Argyll and Bute, Scotland, UK, and south-east North Sea, Germany.

This document may be cited as:
Miller, D., Wang, C., Donaldson-Selby, G., Miller, D.G., McKeen, M. (2018) Introduction to Geographic Information Systems. AquaSpace project (H2020 no 633476), SAMS, Oban, Scotland, 8 pp.

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1 Study Guide

This text was written during the H2020 Aquaspace project (2015-2018, contract no. 633476) for a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture'. The course consists of a number of units; this unit introduces Geographic Information Systems (GIS). It includes definitions and descriptions of basic elements of GIS, clarification of distinctions to be made between commonly used but often misunderstood terms, and two examples of a small set of basic GIS functions, and two examples of GIS use as applied in the AquaSpace project. It is not a tutorial on the use of GIS.

The unit comprises a set of detailed slides, and the text that you are now reading, which provides a guide to the slides, plus additional reading and sources of information.

The learning outcomes for this unit are to be able to:

1. Explain why blah
2. Critically describe blah;
3. Select appropriate tools to investigate the issues.

2 Geographic Information Systems

GIS can be interpreted as having different meanings, usually relating to the key functions with which they are associated. A definition for GIS is provided in Slide 2 (a framework for gathering, managing, and analyzing spatial data), and two of the most significant uses, and thus topics with which GIS is synonymous (spatial analysis and cartography). Examples of the types of use of GIS in relation to aquaculture include bringing together information on natural resources, protected areas and model outputs, within which specific questions of relevance to aquaculture addressed using spatial analysis, and outputs by cartographic design and production (Slide 3).

2.1 Map Projections

It is critical to know that data used in a GIS are the projections of the Earth's surface onto a 2-dimensional surface. So, when setting up the GIS project it is important to identify what map projection is the most relevant to the geographic area of application, and the projection of any input data. There are many different ways this can be done, all of which involve the data being projected into 2-dimensions. Links are provided to further reading on the background to map projections on Slide 4.

2.2 Scale and Resolution

Knowing and understanding the concepts of scale and spatial resolution are very important in the successful use of GIS. Note the distinction between scale and spatial resolution, definitions of which are provided on Slide 5, and the difference between large and small scale in a cartographic (i.e. GIS) context and the common use of those terms in other disciplines.

3 Data

3.1 Data Structures

Data formats are the ways of encoding the data on the computer storage. There are numerous specific formats. Of those most widely used for vector data the Shapefile (originating from ESRI) is very common. Examples of the most common formats, and their suffixes, are shown in Slide 7.

Data held in a GIS are in different structures. These are: raster (e.g. satellite or aerial imagery), vector (e.g. roads, ownership boundaries), Triangular Irregular Network (often used to represent terrain), and object-based (i.e. structured to handle items as objects such as fields, buildings).

Examples of each of the four data structures are illustrated in Slides 8 and 9, each used as relevant to the context of applications in aquaculture.

- Raster – Imagery from observation methods (e.g. satellite, aerial photographs), derived (e.g. Digital

Elevation Models), scanned (e.g. maps for backdrops) (Slide 8).

- Points – To represent individual features too small for their aerial extent to be significant to the application (e.g. a point representing the centre of each fish cage, physical features such as telegraph poles) (Slide 8).
- Polygons – Features with an areal extent of significance in the context of the application (e.g. designated areas, land ownership, zones for permission for aquaculture) (Slide 9).
- Lines – to represent linear features such as cable routes, ferry routes, or physical features such as fences, walls, or roads (Slide 9).

3.2 Databases

GIS comprise databases of records of attributes of some form, linked to items in a geo-referenced data structure. The types and designs of such databases vary by GIS product. The most common structure is a relational database with associated tables or records, in which there are fields populated with data. These data are of individual features (e.g. on each fish cage, feeder unit, designated area).

In Slide 11, an example of such a table is shown for a dataset of fish cages in an area of the west coast of Scotland. These fields are populated with data such as the name of the aquaculture site, the number of fish cages in the site and, if they are located within a landscape designation of a National Scenic Area then the name is also recorded. The definition of the fields is also shown, along with the details of the type of field (e.g. text, number).

3.3 Data and Information

Spatial data are available from public and private sector sources. In line with the Aarhus Convention (1998), there is an obligation on public authorities to provide access to environmental data relevant to decision-making. An example of the provision of spatial is that of Scotland, which provides access to data on thematic topics (e.g. aquaculture, soils, waters) through Scotland's Environment Web (SEWeb). Data on natural

heritage features and designated areas are available for download from the Scottish Natural Heritage Natural Spaces WWW site.

In Slide 12, WWW sites can be accessed through the embedded hyperlinks, to enable the exploration of Scotland's Aquaculture Map, and downloading spatial data for use in the GIS from the Scottish Natural Heritage WWW site.

3.4 Data: Key Questions

The data used must be appropriate to the requirements of the tasks to be undertaken. It is essential to ensure that the relevant factors are taken into account (e.g. dataset content, scale, resolution, date of publication) as well as availability and cost. A checklist of key questions regarding data is presented in Slide 10.

4 GIS Software

There are numerous software packages which have functionality for entering, creating and handling geographic data, spatial analysis for various specialist applications, and the production of maps or other forms of graphical and tabular outputs.

Different GIS software packages have strengths in some functions compared to others (e.g. raster data handling compared to vector data handling). A few key points are highlighted in Slide 13. Some packages are Open Source (e.g. QGIS, GRASS) and others commercial (e.g. ArcGIS, MapInfo). Licencing and costs of GIS packages vary considerably depending upon national and institutional (e.g. academic) arrangements. Examples of functions and applications with GIS, shown in this Module, using ArcGIS, presented in Slides 14 to 31.

4.1 Functions

Examples of selected basic functions provided by GIS and shown in Slides 14 to 17, applied in the Scottish Case Study area.

i) Displaying multiple datasets - Graphical overlay:

- (a) enables features to be superimposed on each other, such as features of interest on top of a

basemap to provide geographical context;

(b) the user can modify the order of the datasets, and thus what features in one datasets are visible on top of another dataset;

(c) the location of features can be interpreted with respect to one another. For example, a view of fish cages or aquaculture developments (in red) which are within or outside areas designated as National Scenic Areas (shown in blue in the right hand image).

ii) Analysis and interpretation of spatial relationships between factors such as their querying and measuring.

Observation and measurements always require to be considered in relation to their context. Two examples of on-screen queries are shown in Slide 15.

Left image: On-screen query of the spatial database of an individual fish cage in an aquaculture site. The window view of the database entries is shown on the right of the image.

Right image: Measurement of the direct distance within a scene. The example is the distance between the nearest fish cage from the jetty (178.88 m). A lesson from this example is that the precision with which the answer is reported is irrespective of the accuracy of the position of the data items, and their dimensions. i.e. The precision of the distance reported is too high. A key message from this example is the reporting of results obtained from GIS functions should be commensurate with the accuracy of the data to ensure no mistaken interpretation of the accuracy of outputs.

iii) Displaying multiple datasets – Topological overlay:

(a) enables the combination of features in two or more datasets with each other;

(b) share the 'identity' of features;

(c) in the example shown, if a fish cage is within a National Scenic Area, the details of such an area are added to the database tables of the fish cage.

4.2 Example of basic functions: Buffer

(i) Derives the area within a specified distance from selected of groups of features of interest.

(ii) The distance of the buffer can be modified by the user to a specific purpose.

(iii) Output file is a dataset of the shape generated by the buffer function.

4.3 Feature selection

The selection of features is a frequently used function in GIS. This can be done by:

(i) On-screen, pointing at an individual, or group, of features which also highlights those selected in the associated table;

(ii) Select entries in the table, which will also highlight the associated spatial feature on-screen;

(iii) Select by attributes using criteria, highlighting entries in the table and the spatial feature on-screen;

(iv) Combining, as a union, the boundaries and attributes of two input datasets of polygons, producing a single output dataset comprising the details of both inputs.

In the example on Slide 19, the datasets of the National Scenic Areas and the candidate Special Areas of Conservation have been combined. Areas which are in both designations have been selected, and one of those highlighted, north of Oban, UK.

5 Example GIS Analysis: AquaSpace Tool

5.1 Introduction

The AquaSpace tool is a Geographic Information System -based spatial planning tool that enables a spatially explicit and integrated assessment of indicators reflecting the economic, environmental, inter-sectorial and socio-cultural risk and opportunities for proposed aquaculture systems. Details are provided in unit 6, and described in Gimpel *et al.*, 2018.

The tool takes account of:

- (i) Opportunities relating to socio-economic assessments of the added value of an activity, food security or expected revenues;
- (ii) Risks relating to an evaluation of combined environmental effects of the planned activity and the additional pressure contributed by a new aquaculture activity to the overall human pressures in a management area.

5.2 Interface

The AquaSpace tool is an Add-in to the ArcGIS software package. An overview of the tool interface is shown in Slide 15. It includes:

- (i) The table of contents (left);
- (ii) The AquaSpace toolbar (top, highlighted in yellow);
- (iii) The ArcGIS catalog window (right), showing the AquaSpace Geodatabase (GDB);
- (iv) The AquaSpace siting tool (highlighted in yellow at the bottom right) is available from the AquaSpace toolbar and facilitates the site selection.

5.3 Conceptual overview

A conceptual overview of the AquaSpace tool is shown in Slide 21.

The *users input* (right side of slide) defines the study area (e.g. country), the port from which aquaculture business should be transacted, the culture species, the corresponding culture system, the compilation of constraining, conflicting or synergistic human uses and the aquaculture locations to be tested.

Following the general input data (e.g. management area or culture system to be assessed), inter-sectorial, environmental, economic and socio-cultural data are processed and outputs produced in graphic and tabular forms, and exportable to tailored report formats (for more details see Gimpel et al., 2018 AquaSpace Tool, D3.3).

5.4 Outputs

One output from the AquaSpace Tool (Slide 22) is a map of cumulative assessments of blue mussel for set scenarios, for a case-specific

port of Hörnum/Sylt in north-west Germany, areas of constraint, synergy and conflict, management boundaries, areas of aquaculture production.

Outputs created in the GIS-based tool can be exported and presented in graphical forms other than maps. The graph in Slide 23 is a representation of a spatially explicit performance of inter-sectorial, environmental, economic and socio-cultural indicators for 15 different aquaculture planning scenarios with *M. edulis*. It shows potential trade-offs between the AquaSpace Tool indicators by comparing data normalised in application of a z-transformation. The graph enables an interpretation of the relative levels of indicators for each of four categories: Socio-cultural, inter-sectorial, environmental, and Economic.

6 Cartography

One of the most significant outputs of which a GIS is capable is a cartographic product (or map). The functionality of the relevant GIS tools will support the design and the production of maps. Note that a map has certain requirements such as title, scale, north arrow, legend, copyright statement, locational details, examples of which are shown in Slide 25.

Generally, the software will have a process for producing a product which comprises all of the requirements of a map and is suitable for printing as a chosen size of document (e.g. A0, A3, A4). The standard printing resolution is 300 dpi (dots per inch).

7 Visibility Analysis

Visibility Analysis enables the calculation of what is visible from where (theoretically), assuming a clear view (i.e. no mist, low cloud). Factors which are taken into account are the height of the observer and the target, the curvature of the Earth, and atmospheric distortion.

Typically, the outputs of such analysis are maps which show the visibility of features in terms of the number of features which are visible from where (i.e. every point in the area

of interest), and the extent of the area of such views. Generally, such datasets can be queried on-screen to inspect the visibility (in terms of these metrics) of features from specific locations. An illustration of the variables which can be set is shown in Slide 26.

8 Example Application: Seascapes and Aquaculture

8.1 Introduction

The contribution of aquaculture to, and its potential impact on, the character of seascapes (i.e. coastal landscapes) can be positive (i.e. consistent with the physical and cultural features), and negative (i.e. degrade visual amenity).

The Strategic Guidelines for the sustainable development of EU aquaculture (European Commission, 2013) provides an overarching context. The EU Environmental Impact Assessment regulations and guidelines provide a framework for its implementation in EU Member States.
<http://ec.europa.eu/environment/eia/eia-legalcontext.htm>

An assessment of the potential visual and landscape impacts of aquaculture are a requirement of the Environmental Impact Assessment (EIA) of a proposed development.

The implementation of European, national and regional policies, regulations and guidance varies by country. However, visual and landscape issues are a key element of EIAs. Typically, such assessments comprise visual (using forms of visualisation) and landscapes (e.g. with respect to the character of the landscape). Within the latter, a key requirement is answering the questions of what (e.g. aquaculture sites) can be seen from where (e.g. view points, population centres – referred to as ‘visual receptors’), and how much can be seen (e.g. the number of fish cages)?

The assessment of cumulative visual impacts of aquaculture developments addresses similar questions but with respect to the number of aquaculture sites, the places and sequence in

which they might be viewed, and their combined impacts on visual receptors.

Government agencies (e.g. Scottish Natural Heritage, Scotland, UK) provide guidelines on specific elements of EIAs (e.g. Visualisations for Aquaculture, SNH, 2018).

The AquaSpace Visibility Analysis Toolset, implemented in GIS, is directed towards answering such questions.

8.2 Methods

The location of each fish cage in the Argyll and Bute case study area was digitised using the relevant GIS tools and checked with data from Marine Scotland on aquaculture sites, from the Scotland’s Aquaculture Map WWW site:

(<http://aquaculture.scotland.gov.uk/map/map.a.spx>)

The spatial database of fish cages was expanded to include details of the aquaculture development, and some information about heights of the structures, and a default of 1m for the cage (4 m if the centre supports are included).

A related dataset of all feed stations was compiled in the same way, with basic information on the heights of those structures where available, and defaults where individual details were not available (5 m).

In the database of fish cages and feeder stations, the viewing distances were set to 15 km (to accommodate potential cumulative visual impact issues. Viewing distances selected can reflect local topography (e.g. 2 km where there is restricted, short, views; 7 km to 10 km for more open or longer views). Viewer height is set to 2m. For more details, see guidance from Scottish Natural Heritage (2018).

The visibility calculations were run in ArcGIS and the outputs datasets (grid raster files) were created of: (i) the number of fish cages, (ii) the number of feeder stations, and (iii) the number of aquaculture sites. These datasets can be viewed in the GIS, presented in different ways, such as colouring according to different schemes, to illustrate the visibility of a development (yes/no) or number of cages.

Examples of the input datasets and outputs are shown in Slide 27.

8.3 Outputs of analysis

Outputs from the analysis of visibility of fish cages in the Argyll and Bute area are shown in Slide 28.

In the left map, the aquaculture sites are shown for the Argyll and Bute case study area, and the geographic distribution of the visibility of the number of fish cages.

The visibility of aquaculture sites (e.g. fish cages) require interpretation with respect to visual receptors (e.g. viewpoints) or assessments of the characteristics of landscapes. The right map shows the visibility of fish cages with respect to landscape character assessment areas, in the northern part of Argyll and Bute. The Landscape Character Assessment (LCA) unit shown is one in which the assessment refers to aquaculture and the potential for the landscape to be sensitive to such developments.

8.4 Interpretation of visibility of fish cages:

In Slide 29, the map shows outputs from GIS visibility analysis overlaid on data which represents contexts (e.g. Landscape Character Assessment areas, existing land uses), for an area of north Argyll. Key findings of the interpretation of the landscape impacts of aquaculture are:

- (i) Landscape Character Assessment provides an important context for considering aquaculture and its development. Characteristics of significance include the topographic scale and openness of the landscapes/seascapes, and sense of place.
- (ii) Positive associations are of aquaculture with good stewardship of natural resources (i.e. fish) and adds to the visual complexity of scenes.
- (iii) Negative associations are with disturbance of coherent views and reducing the naturalness of the scene.

Note that aquaculture is only one of the uses of land and sea which is changing, so perceptions of change and the contribution of aquaculture are complex.

8.5 Findings

The outputs of visibility data provide the geographic contexts and some of the evidence for interpretation of the interactions between aquaculture and seascapes. These are combined with outputs from public engagement using visualisation tools (Masters Module 9).

The findings brought together from these two toolsets are listed in Slide 30, noting the positive and negative contributions made to seascapes by aquaculture.

9 Emerging Uses for GIS

The use of GIS and related tools is increasing rapidly. Examples include citizen science and public collection of environmental data, web-mapping services on desktop and mobile devices, and means of enabling public participation in planning. Some such functions are facilitated by Apps on mobile devices from which summaries are produced, including maps and some forms of spatial analysis. An example of the provision of information on aquaculture developments in Scotland, using web-based mapping, is shown in Slide 32.

10 Further Study

Extensive reading on the general topic of Geographic Information Systems is available online. References to a few well respected, authoritative books are provided (Slide 33). In particular the books by Heywood et al. (2011) now in its 4th Edition, and Tomlinson (2013) in its 5th Edition.

High quality online resources which explain the principles of key GIS functions are available at the ESRI WWW site, as is online support for use of the ArcGIS tools, a link to which is provided in Slide 33. Such resources include video tutorials (e.g. University of Toronto, on YouTube), links to which are provided on Slide 34.

The AquaSpace project has developed a set of GIS-based tools: Aquaculture Planning Decisions Support Systems; AquaSpace Tool (Arc GIS add-in); Bluefarm 2 (QGIS add-in); SISAQUA (GIS Web tool derived from AkavaVIS); Visibility Analysis (in ArcGIS). Further information can be found in the

ToolBox page on the AquaSpace web site at www.aquaspace-h2020.eu. More details of the AquaSpace Tool are available in unit 6 and of Visibility analysis in unit 9.

11 Self Assessment Questions

Not yet available

12 Acknowledgements

Acknowledgements are due to individuals and organisations for the provision of materials for this Module. The contents have been created using materials supplied from different sources, as noted below:

- (i) James Hutton Institute, UK.
- (ii) Thünen Institute, Germany.
- (iii) Map images use data from Ordnance Survey under licence to James Hutton Institute.
- (iv) Selected graphical images from ESRI.
- (v) Links are provided to videos of the use of GIS, by Don Boyes, University of Toronto.

13 References

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