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Editor: **Nicola Ferrè**
Istituto Zooprofilattico Sperimentale delle Venezie
Viale dell'Università 10 - Legnaro (PD) - Italy

A framework for planning GIS projects in the aquatic animal health domain

This document has been developed through a collaborative effort and thanks to the contributions of a team of dedicated experts. We would like to acknowledge the invaluable input and expertise provided by:

- **Ferrè Nicola**, Istituto Zooprofilattico Sperimentale delle Venezie (IZSVe)
- **Otoniel Mardones Fernando**, Pontificia Universidad Católica de Chile (UC)
- **Posen Paulette**, Centre for Environment, Fisheries and Aquaculture Science (CEFAS)
- **Riuzzi Giorgia**, University of Padova (Unipd)
- **Sbettega Federica**, Istituto Zooprofilattico Sperimentale delle Venezie (IZSVe)
- **Tavornpanich Saraya**, Veterinary Institute of Norway (NVI)
- **Tizzani Paolo**, World Organisation of Animal Health (WOAH)
- **Conte Annamaria**, Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise (IZSAM)
- **Matteo Mazzucato**, Istituto Zooprofilattico Sperimentale delle Venezie (IZSVe)
- **Rodrigo Macario**, Istituto Zooprofilattico Sperimentale delle Venezie (IZSVe)
- **Marta Eichemberger Ummus**, Embrapa

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Introduction

Designing and developing Geographic Information Systems (GIS) projects to support aquatic animal health (AAH) activities can be challenging, particularly for individuals who are new to GIS or have limited expertise. A GIS consists of integrated computer hardware and software that store, manage, analyse, edit, output, and visualize geographic data. These challenges often lead to the adoption of unsuitable or unsustainable technological and organisational solutions. Additionally, the unique characteristics of aquatic environments and the specific geographic data requirements for AAH make it necessary to tailor the approach to GIS project planning.

Among other, GIS is a key component for spatial epidemiology, which is a sub-discipline of epidemiology that focuses on the study of the geographical distribution of diseases, health outcomes, and their determinants. It investigates the spatial patterns of diseases and other health-related events and the factors that influence their distribution and spread. Spatial epidemiology aims to identify disease clusters, determine risk factors, and inform public health interventions. By considering the spatial context of diseases, it helps identify at-risk populations, track the spread of diseases, and assess the impact of environmental and social factors on health outcomes.

Purpose and target users

The aim of this document is to provide a framework for developing GIS projects, specifically for AAH purposes including disease surveillance, risk analysis, outbreak investigation, etc. It can be used as a critical resource for establishing a structured and thoughtful approach to GIS project planning for AAH. By following this framework, users can navigate the complexities of GIS project development more effectively, reducing the risks of incomplete or unsustainable solutions.

The framework is intended for individuals with minimal experience of GIS applications, especially for AAH, but it also benefits those unfamiliar with GIS technologies, lacking exposure to GIS for AAH purposes, or needing guidance on data and features specific to aquatic environments. Experienced GIS technicians may also find it useful to compare this framework with their own applications, integrating suggested methodologies and standards, and evaluating the accuracy and completeness of their projects. Trainers and educators can use this document to strengthen their curricula, providing students with a valuable tool that offers practical and real-world insights.

Content and structure

This framework emphasises the importance of careful planning, reusing established GIS technologies, and adopting standards and best practices to ensure the project is robust and meets its goals. The GIS project planning approach outlined here is adapted from a standard information technology implementation process, but it is customised to address the distinct needs of AAH surveillance and disease response. Using an iterative and incremental methodology, the project is refined through successive steps, allowing for continuous improvement and increased precision at each step. The approach includes **five steps**: 1) conceptual design, 2) logical design, 3) development planning, 4) maintenance and 5) spatial risk communication; each one building upon the previous to deliver a well-rounded and fully integrated GIS solution.

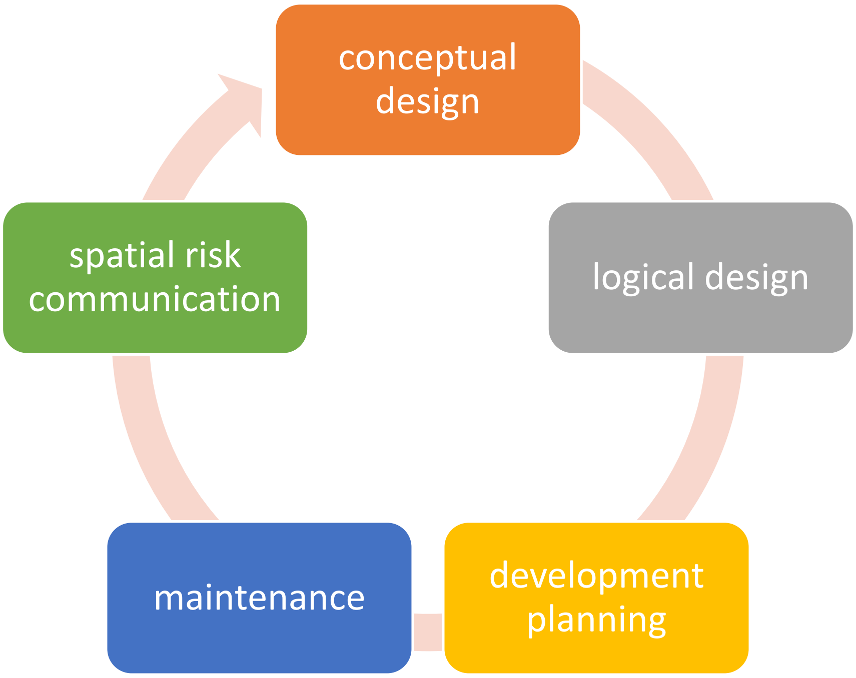


Fig. 1. *A visual representation of the five-step GIS project planning framework for AAH, designed as a sequential flowchart.*

Each step of this iterative methodology is described in detail in a dedicated Annex at the end of this document, providing practical guidance and examples to support its implementation.

Each step is presented as one or more propositions and following corollaries[1], offering main practical guidance and insights for GIS users. For more detailed instructions and guidelines related to the

[1] The framework was developed using a structured methodology based on propositions and corollaries. Propositions serve as foundational statements outlining key principles or assumptions that guide the framework's structure. Corollaries expand on these propositions, providing specific recommendations or actionable steps to implement the framework effectively. This approach ensures a logical and systematic progression from general concepts to practical applications, aligning with established methodologies in GIS planning and management (e.g., Tomlinson, 2007).

specific propositions and corollaries, the reader will be addressed to the relevant annexes at the end of this document.

How to use the framework

The proposed framework follows a step-by-step approach, guiding GIS technicians through each project step using propositions and targeted questions. This structured methodology ensures that each stage, from initial concept to maintenance and risk communication, is thoroughly addressed; thus, helping technicians build a sustainable, functional, and adaptable GIS solution tailored to AAH needs.

1. **Read and understand the framework**

   Objective: Ensuring a foundational understanding of the framework's structure, steps, and key concepts.

   Actions: Read through the document, focusing on the propositions and questions that highlight critical considerations at each project step. Pay special attention to the annexes, which offer practical examples and detailed descriptions of GIS concepts, technology, and project planning.

2. **Develop the information product**

   Objective: Defining the *information product* that fulfils the project's goals.

   Actions: In the Conceptual Design step, use the propositions and questions reported in the annexes to define the project's scope, objectives, stakeholders, and data requirements.

   Annex 1 provides sample information products, helping to visualise potential outputs and guide initial design choices. Annex 2 can be used when it becomes necessary to engage stakeholders early on by organising technology seminars (as suggested in Corollary 1.1) to ensure a shared understanding and gather any additional requirements about the envisaged GIS project.

   Output: Preliminary information product(s), designed to clearly describe the project output(s) to stakeholders.

3. **Design the GIS project for implementation**

   Objective: Translating high-level objectives into a logical and detailed project plan.

   Actions: Move into the Logical Design step to outline the technological solution to be developed. In particular, the focus should be on the data schema and the functions needed to handle and analyse the data. Use Annex 3 to explore GIS technologies relevant to aquatic environments. If needed, organise a list of reusable technologies (Corollary 2.1) to streamline the process. Ensure that the project design is specific to the functional aspect required, as recommended in Corollary 2.2.

Output: Development of the information product that shall include the data master plan.

4. **Prepare and execute the development plan**

Objective: Beginning the physical creation of the GIS components, from data collection to interface development.

Actions: In the Development Plan step, focus on selecting and organising the technologies to be included in the project. Proposition 3 recommends creating a GIS data plan, involving data acquisition, gap analysis, and data management protocols, for effective project execution. Refer to Annex 7 for detailed guidance on structuring a data plan. Eventually, include a pilot testing and collect user feedback to refine the system before full deployment. If advanced spatial analysis or specialised expertise is required, consider hiring externally sourced consultants as per Corollary 4.2.

Output: The GIS project and the data plan.

5. **Establish an ongoing data maintenance plan**

Objective: Ensuring the system remains accurate, functional, and relevant over time.

Actions: Once the GIS project is operational, move into the Maintenance step, implementing a plan to monitor system performance, update data, and incorporate new information. Proposition 5 emphasises the ongoing nature of GIS projects, requiring regular quality checks and updates to maintain output accuracy. Moreover, conduct regular quality assessments to verify data reliability, and update the data architecture to accommodate new information. In case of complex or large datasets, consider establishing a dedicated maintenance team or outsourcing specific tasks to keep the GIS solution up-to-date.

Output: The system maintenance program for both the data and the software used.

6. **Define a risk communication plan**

Objective: Ensure the clear and effective dissemination of spatially relevant risk information to target audiences.

Actions: In some projects, outputs may hold significant relevance for a range of stakeholders as they address specific risks and their geographic contexts. It becomes essential to implement tools and visualizations that allow stakeholders to explore and engage with the data effectively.

Output: Development of tools for spatial risk communication.

Conceptual Design

The conceptual design step establishes the foundation for the project by defining the overarching goals, objectives, and scope. In this step, key questions are addressed, such as the purpose of the GIS to support AAH and the expected outcomes. This stage is critical for aligning the project with the stakeholders' vision and ensuring that the GIS solution will effectively address the intended problem or research question and/or hypothesis.

Purpose: Defining the overall vision and scope of the project, clarifying what the project aims to achieve and identifying who will be involved.

Activities: Identify the project's goals and objectives and determine the stakeholders and their roles.

Proposition 1: Define scope and functions of the GIS project

At the outset of any GIS project, key features should be clearly defined, including the project scope, expected outputs, project duration (whether one-time or ongoing), target users and stakeholders, application environment (e.g., farmed, wild marine, freshwater, transitional waters), and the level of integration with other systems and datasets. The nature of the AAH issue—whether it involves active surveillance of emerging pathogens, monitoring endemic diseases, or managing outbreaks of highly infectious agents (e.g., IHNV) rather than chronic or parasitic infections (e.g., BKD)—should be explicitly considered. GIS serves as a critical tool for spatially analysing and visualising disease dynamics, enabling stakeholders to design targeted interventions based on geographic and epidemiological patterns.

This step establishes an initial description of the information product, outlining the specific spatial data and analyses required to meet the specific AAH objectives. It is part of the needs assessment activities, which bring together GIS technicians, epidemiologists, and other stakeholders to collaboratively explore and discuss project goals and expected outcomes, as well as disease-specific requirements. The result of this step is a summary description of the information product in a clear and accessible language. This ensures that stakeholders can understand, provide feedback, and approve or adjust the project's direction, fostering alignment between the GIS outputs and the specific demand in the relation to the specific AAH needs. Two examples of information products are provided in *Annex 1 - Preliminary Information Product*.

Corollary 1.1: If the GIS project includes complex functionalities, it is recommended to organize technology seminars during the needs assessment step

Organising technology seminars during the conceptual design step of a GIS project with complex functionalities is a strategic approach. These seminars help facilitate a thorough understanding of the project's requirements, ensuring that all stakeholders are aligned on the objectives and technical capabilities needed. They also provide an opportunity to explore different technological solutions, gather input from experts, and identify potential challenges early on. This proactive engagement can lead to more informed decision-making, ultimately enhancing the project's success and ensuring that the selected GIS tools and methods meet the project's demands.

A proposed agenda for a technology seminar is provided in *Annex 2 - Conducting a technology seminar*.

Logical Design

Building on the conceptual design, the logical design step involves translating high-level ideas into detailed plans. This step focuses on defining the data master plan, which includes data schemas, spatial relationships, and the database structure. It also involves establishing the functions and processes for data handling and identifying the types of data analyses needed to produce the desired outputs. The logical design serves as the system's blueprint, ensuring that all components are well-integrated and that the system can support the required outputs. The result of the Logical Design step is an enhanced version of the Information product, with a particular attention to the data aspects (see *Annex 3 - GIS Technical Specifications*).

Purpose: Defining the technology and types of data needed to achieve the project's objectives.

Activities**:** Select appropriate GIS technologies, data models, and expected outputs.

Proposition 2: When developing a GIS project, it is important to select a set of technologies, prioritizing standard and widely accepted options whenever possible

When developing a GIS project, it is important to recognise that many necessary technologies may already be available. Therefore, the organisational model should prioritise reusing standard and existing datasets, helping to save time and resources by avoiding redundant efforts. The objective at this stage is to integrate the initial information product with a detailed description of the technologies to be used, in line with the expected outputs. GIS technologies that might be considered during the logical design step include spatial reference systems, temporal reference systems, spatial data structures, map layer portrayal, data collection methods, and data analysis methods. See Annex 3 - GIS Technical Specifications for a description of these technologies.

Corollary 2.1: Organising a technology inventory list for GIS projects

Maintaining a well-organised list of reusable technologies is essential for efficiency and consistency. By systematically cataloguing and maintaining these technologies, GIS professionals can streamline project workflows, reduce redundancy, and ensure high-quality outcomes. This cataloguing can be organised along several dimensions: standards, spatial data repositories (or Spatial Data Infrastructure, SDI), data from Earth observation satellites, and data already collected and maintained within the organisation. See *Annex 4 - GIS key features* for a brief description of these features.

Corollary 2.2: There is no one-size-fits-all solution in GIS; it is essential to define the specific type of GIS required to optimize outputs effectively

A GIS project is typically developed to address one or a combination of functional aspects, such as inventory, mapping, spatial operations, and spatial analysis. The inventory function focuses on storing and managing spatial data; mapping, which can be static or dynamic, allows users to visualise geographic data; spatial operations involve manipulating geographic data to perform tasks like drawing buffers or identifying zones; and spatial analysis uncovers patterns and trends, such as identifying disease clusters or modelling the spread of pathogens. For effective project management, it is recommended to concentrate on a single functional aspect to ensure consistency, simplify data updates, and align outputs with the project's objectives. See *Annex 5 - GIS functional aspects*.

Corollary 2.3: GIS technologies should be selected based on the available resources and project requirements

For complex spatial tasks, higher levels of GIS functionality are often essential, so the selection of GIS technologies should be based on the available resources. While basic tasks may only require a "simple" map as output, more complex tasks (e.g. intensive spatial data processing, in-depth geostatistical analysis) benefit from the capabilities of advanced GIS functions. For example, implementing a webGIS application, conducting geostatistical analyses, developing spatial models, using remote sensing data, or organising data in an enterprise DBMS, they all require specific resources and a strategic approach to GIS planning.

Creating a GIS strategic plan that outlines the long-term vision for GIS use, resource allocation, and staff training is a sustainable approach that prepares the organisation for future needs, including the integration and use of higher level of GIS functionality. Training should be aligned with task complexity levels to ensure team members are equipped to handle the GIS functions required for each task. Additionally, encouraging knowledge-sharing sessions, workshops, and certifications can build expertise in advanced spatial analysis, geostatistics, and remote sensing. See *Annex 6 - GIS strategic plan* for a suggested outline of a strategic plan content.

Development Plan

The development plan is where theoretical designs begin to take physical form. This step involves selecting software, hardware, and tools, as well as developing the actual GIS components, such as databases, interfaces, and applications. During development, data is collected, processed, and integrated into the system. Pilot testing and user feedback are crucial in this stage, helping to refine the system before full deployment. A well-structured implementation plan ensures that the GIS is developed efficiently, stays within budget, and meets set timelines.

Purpose: Defining the operational tasks and overseeing the actual execution and realisation of the project.

Activities: Develop detailed project plans, including data collection, data analysis, and workflows design.

Proposition 3: Acquiring geographic data is a critical component of any GIS project; therefore, having a well-organized GIS data plan is essential

A GIS data plan is crucial for organising and managing data within a GIS project. It begins with data identification, where the types of data to be used are defined, with a focus on reusing existing data. Then, a gap analysis is performed to identify any missing information, and strategies are developed to either integrate available data or create new datasets. Data architecture is then established to design an efficient storage structure, organise data into vector and raster formats, and decide whether to store data in files or a database. Data management processes ensure consistent data collection, maintenance, and updates. Regular quality checks are also essential to ensure accuracy and completeness, which are critical for reliable results. Finally, monitoring and evaluation assess the plan's effectiveness, with adjustments made as needed to enhance the project's success. For more details on addressing these elements refer to *Annex 7 - GIS data plan*.

Proposition 4: Spatial ability plays a crucial role in the design and development of a GIS project, as well as in assessing in-house expertise and determining the need for external expertise

The spatial ability of GIS technicians, along with the scope and nature of the GIS project, greatly influences the project performance. Essential skills can be acquired through education and training, by including specialised personnel on the team, or by obtaining externally sourced assistance. It is crucial to determine which activities and skills can be developed or managed in-house and which may require outside-sourced expertise. Core tasks should ideally be managed by organisational staff, while consultants can assist with complex tasks that require specialised GIS and epidemiology expertise. Notably, spatial ability becomes increasingly critical as task complexity rises. For more information on the GIS knowledge base refer to *Annex 8 - GIS knowledge base and in-house expertise*.

Corollary 4.1: Evaluating in-house GIS staff

In-house GIS expertise is crucial in AAH projects for managing tasks such as project coordination, data management, mapping, spatial analysis, and technical support. Assessing the specific GIS skills within a team allows project leaders to assign tasks that leverage individual strengths and identify areas where additional training may be beneficial, ensuring efficient workflow and improved project outcomes. A solid understanding of programming languages integrated with GIS software, such as Python for QGIS, is particularly important for in-house GIS technicians. These skills enable automation of repetitive tasks, customization of GIS tools, and advanced spatial analysis, significantly enhancing project efficiency and scalability. For instance, in an AAH project focused on monitoring disease spread among fish populations, a skilled in-house team can efficiently manage data collection and analysis. GIS technicians gather data from GPS devices on fishery boats and from remote-sensing sources, then clean and standardize this data to produce detailed maps that visualize disease hotspots. These maps aid in identifying areas requiring immediate intervention, while spatial analysis helps predict potential spread patterns based on environmental factors like water currents. Additionally, the team provides technical support to field staff, ensuring data is accurately recorded and maintained, which is essential for making informed, data-driven decisions in aquatic disease management. For a list of typical activities performed by in-house GIS staff see *Annex 8 - GIS knowledge base and in-house expertise*.

Corollary 4.2: Consider engaging external expertise

If in-house expertise is lacking GIS capabilities, it may be necessary to seek externally sourced specialists. Hiring external experts with strong GIS abilities can fill gaps in the project team, bringing advanced knowledge and perspectives that may not available in-house. This can significantly enhance the quality and efficiency of the project. External experts can provide specialised knowledge and techniques for complex spatial analyses or innovative GIS solutions. They can develop webGIS applications, perform spatial analysis on collected data, design the GIS project plan, train in-house technicians, and more.

Maintenance

Once the GIS system is operational, the maintenance step begins. Maintenance is essential for ensuring the long-term reliability and relevance of the system. It involves regular updates to data and software, monitoring system performance, resolving issues, and adapting the system to evolving user needs and technological advancements. A well-established maintenance plan ensures that the GIS remains functional, accurate, and up-to-date, providing sustained value to users.

Purpose**:** Defining the monitoring and improvement tasks.

Activities**:** Monitor the system's performance and address any issues that arise, perform regular updates and upgrades to the system components, and provide ongoing support and training to users.

Proposition 5: GIS projects do not end once they are put into operation; instead, they require ongoing activities such as quality control of results, system maintenance, and regular updates to incorporate new data as it becomes available

GIS projects are dynamic and evolving systems that outlive the design, development and deployment steps. Unlike traditional projects that may conclude upon completion, GIS projects enter a critical ongoing step once they are put into operation. This step involves continuous activities essential for maintaining the integrity, relevance, and effectiveness of the outputs produced.

One of the key ongoing activities in GIS projects is quality control. Since GIS outputs often inform crucial decisions, ensuring the accuracy and reliability of these results is paramount. This requires regular checks and validations to ensure that the data and processes used in the system produce consistent and correct results. Quality control is not a one-time task but an ongoing responsibility that safeguards the credibility of the GIS.

Software and functions maintenance is another critical aspect of the ongoing lifecycle of GIS projects. The technological environment in which a GIS operates is constantly changing; therefore, regular maintenance ensures that the system remains operational, efficient, and compatible with evolving situations. This maintenance is necessary to prevent system failures, improve performance, and incorporate new functionalities that might be required by users.

Additionally, GIS data is continually changing, and GIS projects must incorporate new data as it becomes available. This updating process ensures that the GIS reflect the most current state of the environment for which the project was created. See *Annex 9 - Organise the project maintenance* for more information.

Communication of the project outcomes

Communicating the project outcomes is a critical component of GIS planning aimed at effectively conveying geographically relevant information to stakeholders involved in AAH activities. It bridges the gap between the spatial analyses and actionable decision-making, ensuring that information is understood and utilised by diverse audiences, from public to policymakers.

Purpose**:** transforming spatial data into clear, accessible, and actionable insights, enabling informed decisions.

Activities**:** Develop tools such as WebGIS applications, dashboards, and story maps to visualise spatial information in a user-friendly way. Organise stakeholder-focused workshops or training sessions to ensure the proper interpretation and application of the communicated spatial information.

Proposition 6: When creating a map, the goal is to communicate a result, not merely to display the data that has been collected

A map filled with layers and colours is not necessarily effective for communication. It is key to identify the essential elements to be conveyed and translate them into a map that highlights the results in the study area. The goal is not to create a visually appealing map but to communicate the critical aspects clearly and effectively. For example, consider a GIS project monitoring disease outbreaks on aquaculture farms. A map showing every possible dataset—such as farm locations, water quality metrics, and transport routes—may overwhelm stakeholders. Instead, a focused map displaying only the disease hotspots and their proximity to water currents would be more effective in guiding biosecurity measures. Avoid finalising the first draft of a map; instead, create multiple versions of it emphasizing different data combinations and present them to target stakeholders, such as epidemiologists or health authorities. Collect feedback on readability and relevance to refine the map into a tool that effectively supports decision-making.

On the other hand, it is also important to know that final users need to be educated and told that the any map has its own limitations and that it is not possible to concentrate in map all the information they might expect from a spatial analysis.

Corollary 6.1: The role of symbology in enhancing map readability

A well-designed map symbology significantly improves the readability of results. Bertin's semiology book (Bertin, 1983) provides valuable guidance on how to represent layers based on the type of feature (point, line, or polygon) and the type of data (nominal, discrete, or continuous). However, readability is further enhanced by adopting standards or best practices in thematic representation.

When GIS technicians use consistent criteria to represent similar objects across different maps, it becomes easier for readers to interpret and understand the information. Familiarity with commonly used symbols reduces cognitive effort, as the reader recognises and associates the symbols with their meaning from prior maps. This consistency fosters better communication and ensures that maps are both effective and intuitive for different audiences.

Corollary 6.2: The importance of simplifying map content

An effective map focuses on simplicity by including only the most relevant elements needed to convey the message. Overloading a map with excessive details or unrelated data can obscure the key information and confuse the audience. To enhance communication, GIS technicians should prioritise clarity by reducing cluttering, while grouping similar elements and using a logical hierarchy to guide the viewer's attention. A streamlined map ensures that the audience can quickly grasp the main insights without being overwhelmed by unnecessary information. This approach is especially important in decision-making contexts, where clear and actionable visuals are essential.

Corollary 6.3: The potential of dashboards integrated with webGIS to support effective communication

Dashboards offer a powerful communication tool for decision-makers, particularly in the context of dynamic maps, tables of selected data, and information related to AMA or infected zones. Interactive graphs displaying trends from surveillance plans further enhance decision-making processes. These elements are all connected by an interactive map that aids decision-makers in interpreting data and analysing spatial relationships. By seamlessly integrating detailed data with visual representations, dashboards empower decision-makers to make informed decisions in a timely manner based on both the spatial context and the underlying data trends. The following is a list of good examples of dashboards:

- European Food Safety Authority (EFSA), https://www.efsa.europa.eu/en/microstrategy/salmonella-dashboard. Although they do not provide any dashboards specifically related to the AAH domain, they are useful for understanding the potential of the tool.
- University of California Davis, https://bioportal.ucdavis.edu/welcome/solutions.
- GeoWeb, SITE AQUICULTURA, https://mapas.cnpm.embrapa.br/apps/site_aquicultura/#/map.
- Barentswatch, https://www.barentswatch.no/fiskehelse/.

Conclusions

Developing a GIS project for AAH purposes requires careful planning, from the conceptual design to the maintenance step. By following a structured, iterative approach—comprising the conceptual, logical, development, and maintenance steps—projects are more likely to meet user needs, optimise resource use, and ensure sustainable outcomes. As aquatic environments pose unique challenges, it is necessary to make thoughtful decisions regarding technology, data management, and team expertise. Ensuring data quality, integrating appropriate technologies, and continuously monitoring system performance will keep GIS projects reliable and adaptable over time.

Final Recommendations

It is crucial to invest time in planning each step of the GIS project, with particular emphasis on defining the project's scope, selecting the right technologies, and ensuring a well-organised collaboration for data management among GIS technicians, stakeholders, and externally sourced experts (if necessary), thus enhancing the project's success. Ongoing maintenance, including regular updates and quality control, should be incorporated as an integral part of the project's lifecycle to ensure its long-term effectiveness. By adopting a strategic, adaptive approach, the GIS project can continue to deliver valuable insights for disease surveillance and response in the AAH domain.

Annex 1 - Preliminary Information Product

An information product in a GIS project for the aquatic environment is a specially designed output that serves as a key decision-support tool. This product could be a map, report, data visualisation, or interactive dashboard, all crafted to convey essential information to inform stakeholders about a specific need or request. For instance, it may show disease risk zones, spatial buffers for disease surveillance or control, or farm distributions in a way that is tailored to the needs of stakeholders, such as researchers, epidemiologists, or policymakers.

Defining this information product at the very start of project development is crucial, as it sets a clear scope for the project.

Below is a series of questions useful for creating the set of information needed to define the information product. For each question, an explanation and one or more practical examples are also provided.

- **What is the purpose of the GIS project you intend to develop?**
  The following components should be considered when defining the purposes of a GIS project:
  - <u>*Project objectives*</u>*. Clearly define objectives and specific issues to be addressed. Example: i) Mapping the spatial distribution of pathogens. The project aims to map the location of pathogens identified during the monitoring plan. ii) Identifying fish farms within infected zones. The project aims to enhance early detection and response by providing stakeholders with the farm location relative to disease-infected or risk areas, thus supporting informed decision-making for disease prevention and control.*
  - <u>*Deliverables*</u>*. Identify the expected outputs. Example: maps, tables, spatial analysis, web applications, other GIS products.*
  - <u>*Geographical Extent*</u>*. Specify the geographical extent of the project. This is essential for determining the appropriate spatial resolution of geographic features and understanding the scale at which GIS analyses will be conducted. Example: a large-scale project (e.g., 1:10.000, 1:25.000) might focus on specific features such as a river basin, a lake, or a lagoon, while a small-scale project (e.g., 1:1,00.000, 1:25.000.000) could encompass broader areas, such as an entire river network of a country or region (e.g., the Danube Basin) or a sea (e.g., the Mediterranean Sea).*

- **Identify and specify any potential limitations or restrictions related to the development of the project**

Outline any limitations regarding budget, time, technology, and data availability. Example: i) the project will utilise open-source GIS tools (e.g., QGIS) and leverage existing datasets where possible, ii) the project timeline is set at four months, requiring efficient planning and execution to ensure mapping and data collection are completed within this period.

- **Will it be a one-time project or an ongoing program?**
  <u>One-time project</u>. *Designed for a specific short-term purpose, these GIS projects are typically not maintained or updated once their output is produced. Example: (i) creating a map of the spatial distribution of fish farms monitored for a specific pathogen in the current year, (ii) generating a list of farms within the infected zones to be included in a regulation prohibiting the movement of fish from those farms, (iii) producing maps of salmon fish farm spatial distribution for a conference poster.*
  <u>Ongoing program</u>. *A GIS project that supports long-term activities. This type of project involves ongoing maintenance of data, outputs, and the project infrastructure. A typical example of an ongoing project is the GIS system dedicated to the inventory of fish farms, requiring: (i) continuous data updates through regular updating procedure to ensure accuracy and relevance, (ii) system monitoring and security, including data backup and access control, and (iii) organisation of collected data to facilitate easy and effective reuse by other GIS projects. Another ongoing project is the implementation of a webGIS dedicated to presenting information from a surveillance program. For this type of project, information technologies, laboratory results, fish farm locations, area data, and environmental data must be carefully organised according to a model that ensures the data is accurate and consistent.*

- **In which environment will the project be applied?**
  The aquatic environment should be classified as marine, freshwater or transitional water. Each environment has unique characteristics, which need specific background maps, GIS functions, geographic data representations, and data collection methods. For example, the distance between two points can be the seaway distance in marine environments rather than network distance in freshwater environments.

- **Who are the project stakeholders?**
  Projects should always begin with a clear request from a stakeholder who specifies both the type of output desired and its intended use. Projects lacking clear stakeholder identification and defined output risk being unused, leading to resource waste. Example: if stakeholders require a webGIS to present geographic data supporting disease response for a given pathogen, assessing

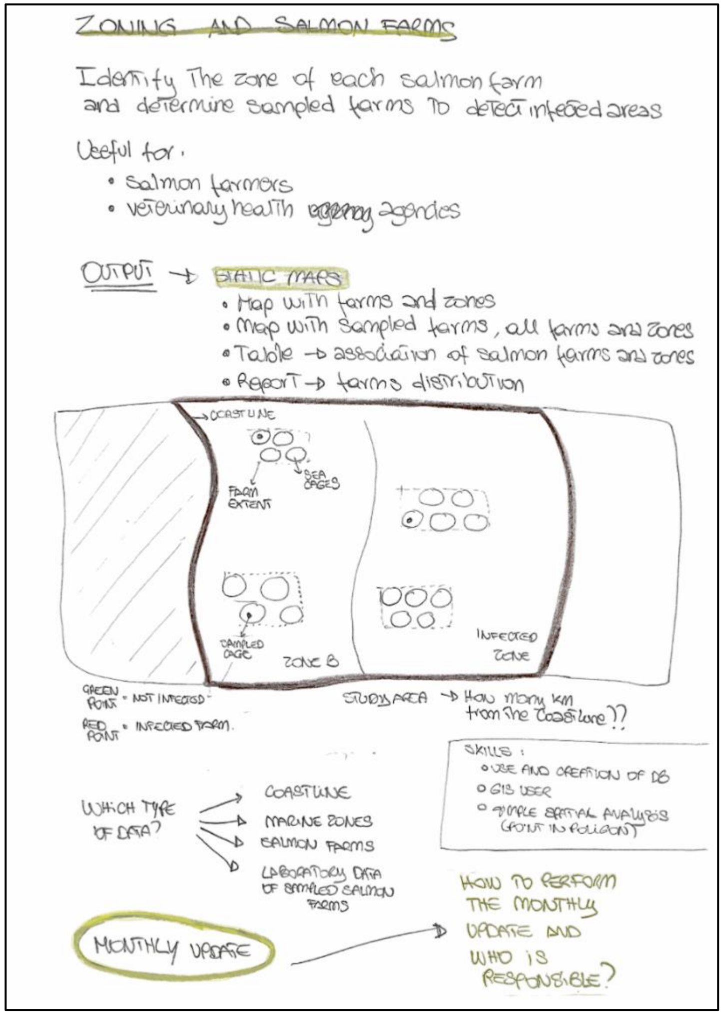
stakeholders' needs is crucial. This assessment must be included in the system's definition, design, and implementation.

- **How do the end-users interact with the GIS?**
  Specifying how end-users interact with the project output is fundamental to design the GIS project. During the purpose specification step, output types are identified (e.g., map, table). At this step, a more precise specification of each identified output should be defined. Example: i) for a map, specify the geospatial data and its representation; ii) for a table, detail the information presented. For instance, if stakeholders need a GIS to identify farms within infected zones, the output could be a PDF map identifying the farm by code, a list of farms per zone, or a webGIS where users can explore zones and farm information interactively.

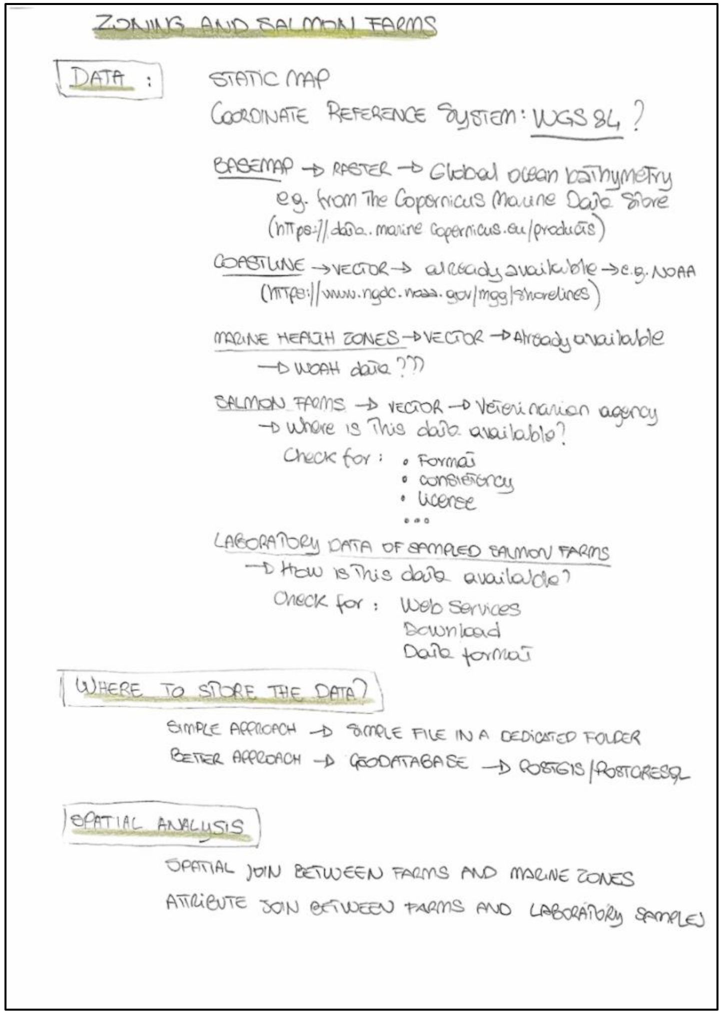
- **What skills will be needed to implement the GIS project?**
  Depending on the project complexity, necessary skills for development must be identified at this stage, including those requiring outside-sourced assistance. Typically, the in-house GIS technician outlines the necessary resources for project development. This in-house approach offers advantages: tailored solutions for specific organisational needs and easier integration with existing systems and processes. If the organisation lacks a GIS technician capable of defining the necessary resources, an external expert can provide specialised knowledge, establish workflows and potentially reduce costs by avoiding the need to hire and train in-house staff.

An information product often takes the form of a diagram, frequently a hand-drawn sketch, as it is collaboratively "constructed" with the stakeholder. Below are two examples of information products.

a



b



An information product should ideally include the following elements (i) **title**: a clear and concise name for the product, (ii) **description**: A brief explanation of what the product is and its context, (iii) **objectives**: the specific goals the product is intended to achieve, (iv) **outputs**: the expected results, including key characteristics of the product, (v) **input data type**: the type of data required to generate the outputs, and (vi) **update frequency**: how often the output needs to be updated to remain relevant.

1. *Example of Information Product. This example is presented in a raw, handwritten format, as its primary purpose is to quickly capture and sketch the information obtained during informal interviews. The use of simple language and graphical elements allows interviewees to "visualize" their input, enabling them to review and refine the content. This approach minimizes misunderstandings and ensures that the captured information aligns with their intentions. Panel (a) refers to a marine environment, while Panel (b) represents a freshwater environment. Both figures share the same structure, derived from the questions outlined in Annex 1.*

Annex 2 - Conducting a technology seminar

Conducting a technology seminar is necessary to build this foundational knowledge. This seminar will introduce GIS technology to stakeholders, highlighting its relevance and potential for monitoring and managing AAH. Through this seminar, participants will learn about the capabilities of GIS, share their perspectives on the types of GIS projects they envision, and discuss essential functionalities and desired outputs. A technology seminar can be adapted based on the organiser's experience, the participants, and available time. A simplified seminar should consider the following elements:

1. Introduction to GIS. Provide participants with a basic understanding of GIS and its terminology. Present an example of a draft or information product from a previous GIS project, emphasising the importance of making these tools accessible to all participants.
2. Project planning approach. Outline the GIS project planning process (referring to *Annex 10 - GIS fundamental aspects* as needed). Discuss the purpose of the GIS project and clarify the type of contributions expected from participants.
3. Thematic Presentations. Whenever possible, include presentations by participants with specific or relevant expertise. These participants could share case studies, research findings, or demonstrate technical applications related to the proposed GIS project.
4. Participant engagement. Structuring the seminar to promote active engagement is crucial. The organiser should invite participants to ask questions, share experiences, and join discussions to clarify concepts and spark new ideas. An example of fostering engagement could be organising a hands-on activity where participants work in small groups on a simple GIS mapping task. For instance, provide each group with a basic dataset related to AAH (e.g., farm distribution), and have them use a GIS tool to plot the data, showing spatial patterns in farm distribution. As they work, encourage participants to discuss questions like: i) "What trends or patterns do you see in the data?"; ii) "How might these patterns impact AAH?" iii) "What additional data would be useful to enhance this map's accuracy?". After the activity, each group presents their map and shares their observations. GIS technicians facilitate the activity by asking follow-up questions, inviting comments from others, and linking findings to practical GIS applications.
5. Information product composition. Collaboratively develop an information product, encouraging participants to contribute and focus particularly on defining the project outputs. Ensure that the proposed outputs are reviewed and approved by participants.

6. <u>Exploring Opportunities</u>. Discuss the opportunities provided by the GIS project. Analyse the information product to identify potential inefficiencies, gaps, or areas for improvement, such as enhanced data management or automation or tasks automation.

A seminar structured around these elements provides a comprehensive, interactive introduction to GIS, fostering understanding, engagement, and collaboration among stakeholders. However, careful planning, skilled facilitation, and a manageable scope are essential to balancing the depth and breadth of the seminar's content, ensuring that all participants benefit, regardless of their experience level.

Annex 3 - GIS Technical Specifications

The following technical specifications are essential for further developing the information product developed during the Conceptual Design step:

- Coordinate systems. Use EPSG codes as Spatial Reference System Identifiers (SRIDs) and EPSG definition data for identifying coordinate reference systems (https://epsg.io/). For example, the EPSG code 4326 represents the WGS84, the world geodetic system used in GPS.
- Temporal data. Time-related information is often required, and using standard format is advisable, specifically the Gregorian calendar and the "YYYY-MM-DD" or "YYYYMMDD" format.
    - [YYYY] Indicates a four-digit year, (0000 - 9999).
    - [MM] Represents a two-digit month (01 - 12).
    - [DD] Represents a two-digit day (01 - 31).

  For instance, "27 June 1968" may be represented as "1968-06-27" (extended) or "19680627" (basic).
- Spatial data type. Spatial data types determine how geographical information is encoded and stored. In the section "**Spatial data type**" there is a brief description of the most used spatial data type.
- Map layer portrayal. Maps, the principal output of GIS, should be clear and readable. Using established styles and symbols ensures visual consistency and effective communication. For instance, an infected zone might be represented with a wine red (#B2182B) at 70% transparency, outlined in solid wine red (#B2182B) with a 2-pixels stroke width.

  However, **ISO 19117:2012 Geographic Information - Portrayal** is the existing standard dedicated to represent layers. The standard provides a conceptual schema for mapping geospatial features as symbols and creating portrayal catalogues. It allows for the flexible visualisation of features across various GIS applications, enabling datasets to be portrayed uniquely without altering the original data. This separation is beneficial in aquatic GIS, where symbols for different marine features need specific representations on maps, such as for ecosystems or bathymetric data, to support data-driven decision-making.
- Data collection method. Two methods can be identified:
    - **Primary (or direct)**. This method implies reaching the location of interest physically, to capture both the accurate spatial coordinates and the detailed attributes that define the feature. For instance, when georeferencing a fish farm in the sea, the surveyor would use a GPS device to pinpoint the exact coordinates of the farm's location, while simultaneously

recording attributes such as the type of aquaculture, species present, and environmental conditions like water temperature or salinity. This direct method ensures high positional and thematic accuracy by integrating both spatial data and the relevant context of the location. However, it also requires considerable resources, particularly when surveying remote or challenging locations such as offshore fish farms, where logistical coordination and specialised equipment are essential for accurate data collection. In this case, the GPS device records the coordinates, while a dedicated attribute list (either on paper or via a digital interface in a GIS) captures the additional information. This combination of accurate spatial data and comprehensive attribute details is crucial for managing and analysing aquatic health in a geographically specific context.

- **Secondary (or indirect)**. Location information is calculated by digitising from maps or remotely sensed images. This method provides only the location information without the associated attributes that characterise the feature. For example, georeferencing a fish farm in the sea using remotely sensed imagery may be challenging if the farm's cages are not visible in the image or if multiple farms are located near each other, making it difficult to distinguish between them. In such cases, the spatial accuracy of the coordinates may be low, and it becomes impossible to reliably identify and differentiate features. This method typically uses platforms like Google Earth, Bing Maps, or ArcGIS Earth to identify geographic locations and derive coordinates. While it offers a quick way to gather location information, it does not capture the attribute data, such as the species farmed or environmental conditions. These attributes must be collected through other methods, such as on-site surveys or telephone interviews. Moreover, the success of this approach is heavily dependent on the accuracy of the underlying maps or images, as any positional inaccuracies in the imagery will directly affect the precision of the collected data.

The choice between direct and indirect methods for data collection in GIS projects largely depends on several factors, including the available resources, the number of features to be collected, their ongoing maintenance, the required level of accuracy, and the time constraints for completing data collection. Direct methods, such as on-site surveys using GPS devices, offer higher accuracy and detailed attribute data but require significant resources and time, particularly for remote or complex locations. Indirect methods, like heads-up digitising from maps or satellite images, are more cost-effective and quicker but provide only location data with lower spatial accuracy and no attribute information, necessitating additional data collection methods.

Ultimately, the decision should align with project objectives and resource availability, ensuring a balance between accuracy, efficiency, and feasibility.

- Data analysis. In the AAH domain, GIS supports a wide range of data analysis techniques that help monitor, predict, and manage health-related challenges. Below are the most common data analysis methods used in this field:
    - *Proximity Analysis*: Measuring distances between features to analyze spatial relationships. Specifically, this analysis evaluates the closeness or distance between different spatial features or layers. It helps identify areas where features are near each other, which is essential for understanding relationships between locations, such as potential risks or interactions. For instance, proximity analysis can be used to assess the distance between fish farms and wild fish habitats, helping to identify zones where there may be increased risks of disease transmission between wild and farmed fish populations
    - *Buffer Analysis:* Creating zones around specific features (e.g., fish farms, waste discharge points) is a GIS process used to evaluate their spatial relationships with surrounding elements. This method, known as buffer analysis, involves generating a zone (buffer) around a spatial feature at a specified distance. The buffer zone is then used to analyse interactions between the feature and other elements within or outside the defined area.

      For example, to assess environmental conditions around a fish farm, you can use buffer analysis to create a 5-kilometer radius zone around the farm. This buffer helps identify nearby farms, water bodies, or environmental features that could influence disease spread. Such analysis might reveal farms sharing the same water sources or critical habitats within the buffer zone, supporting effective monitoring and intervention planning.
    - *Overlay Analysis:* Combining multiple spatial layers, such as fish farm locations, water quality data, and wild fish habitats, to identify areas of overlap and interaction. This analysis is based on the process of stacking and combining multiple spatial layers. This technique facilitates the integration of diverse datasets to examine how various factors interact spatially. For instance, overlaying the layer of fish farm locations with aquatic management areas allows GIS to identify which areas contain fish farms
    - *Temporal analysis*: Tracking changes over time by integrating spatial and temporal data. It involves studying patterns, trends, and changes within a dataset across different time periods to understand the dynamics of spatial phenomena. For instance, by analysing the progression of disease outbreaks in fish farms over several months or years, GIS can help identify patterns in disease spread, seasonal variations, and the effectiveness of disease management strategies.

- *Geostatical Analysis*: in GIS it refers to the use of statistical techniques to model, predict, and analyse continuous data. Typical geostatistical methods is the kriging and the spatial autocorrelation, they are used to interpolate values in unmeasured location based on sampled data points, providing insights into spatial variability and trends. For example geostatistical analysis can be used to predict temperature, across a lake or river where only a few measurements have been taken. Using kriging, GIS can estimate the values at unsampled locations, creating a continuous map of water temperature.
- *Interpolation*: is a method used to estimate unknown values at unmeasured locations based on the known values of surrounding points. It creates a continuous surface by "predicting" data values for areas where direct measurements are unavailable.

  The differences between interpolation and geostatistical analysis lies in their complexity: interpolation uses simpler mathematical techniques like inverse distance weighting to estimate values between known data points and it assumes that the value at an unknown location is influenced directly by the surrounding known values, without considering spatial dependencies in the dataset; geostatistical analysis is a more advanced form of interpolation that incorporates statistical models to account for spatial relationships and variability. For example the kriging not only consider the distance between points but also the patterns and trends in the data (spatial autocorrelation), and it provides also a measure of uncertainty for the estimates. In summary, while both methods aim to estimate unknown values, interpolation is simpler and more direct, while geostatistical analysis is more robust and suitable for complex spatial datasets with underlying patterns or uncertainties.
- *Hotspot Analysis*: Identifying areas with high concentrations of a particular feature or activity. These areas are considered "hot spots" because they exhibit a significantly higher occurrence or intensity of a specific event compared to surrounding areas. Hot spot analysis can be used to identify regions with a high prevalence of disease outbreaks in fish farms. For instance, by analysing the spatial distribution of disease cases across multiple farms, GIS can pinpoint areas where outbreaks are most frequent.

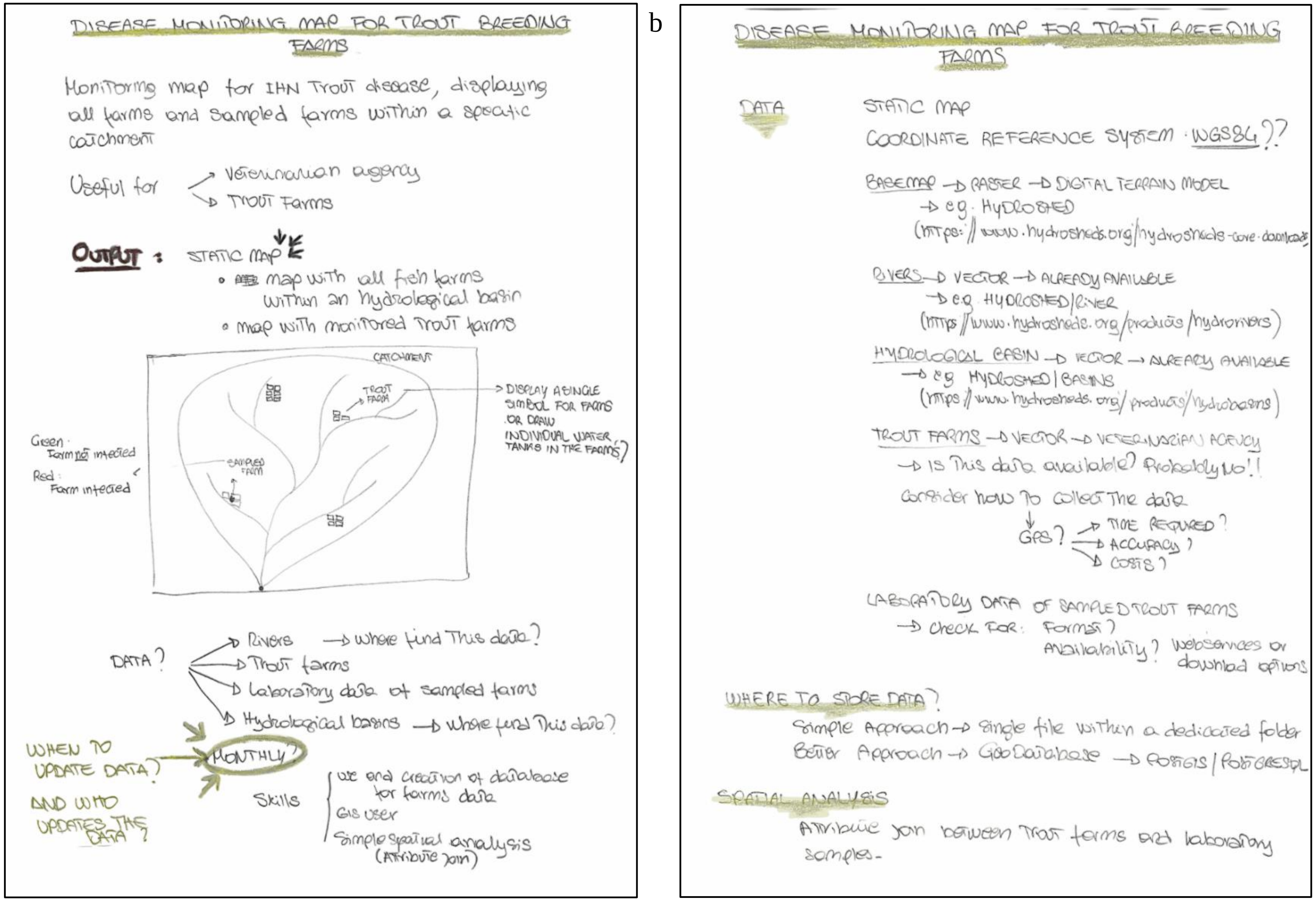
In the bibliography, you will find references useful for data analysis.

The output of the Logical Design step

The Logical Design step builds upon the initial information product by refining the data and identifying the appropriate analysis methods. During this step, the focus is on enhancing the information associated with the GIS Technologies described above.

a

b



The enhanced information product is essential for detailing input data specifications. For base maps, it should indicate potential sources for acquisition. For specific data, the source, format, and expected quality must be clearly defined. Additionally, the method of data storage—whether in databases, files, or other systems—should be specified. It is crucial that all data-related specifications align with the existing data plan within the organization. If new requirements or sources are identified, the data plan should be updated accordingly to ensure consistency and efficiency.

Fig. 2. *Example of an enhanced information product. Similar to the preliminary version shown in Panel (a) and Panel (b), the enhanced information product is also created in a quick, handwritten style. At this stage, the focus shifts to elaborating on the input data, its storage, and the type of data analysis required. Panel (a) represents the information product for marine environments, while Panel (b) corresponds to freshwater environments.*

Spatial data type

Identifying the spatial data type is crucial in a GIS project, as it determines how data is stored, analysed, and visualised. Vector data is ideal for discrete features like points (e.g., monitoring sites), lines (e.g., rivers), and polygons (e.g., farms), while raster data is better suited for continuous information like satellite imagery of salinity or algae distribution. Choosing the right type ensures accurate representation of real-world phenomena and supports precise analyses.

Standard data formats, such as shapefiles, GeoJSON, and GeoTIFF, are essential for compatibility, data sharing, and long-term preservation. While shapefiles are simple and widely used, more advanced formats like GeoPackage (robust storage for vector and raster data) offer greater flexibility but may require additional expertise. The choice of data type and format should balance the project's spatial needs with the team's technical capabilities, ensuring both accuracy and operational feasibility. Below are examples of commonly used spatial data types.

Raster data.

- **GeoTIFF**. A geospatial data format that extends the standard TIFF (Tagged Image File Format) by embedding geographic metadata. This metadata includes information such as the coordinate system, projection, and georeferencing, which allows the image to be accurately placed on a map. GeoTIFF is widely used to store and share satellite imagery, elevation data for terrain analysis, scanned map, and remote sensing data.
- **JPEG2000**. An advanced image compression standard designed to improve upon the original JPEG, especially for large, high-resolution images. JPEG2000 uses wavelet-based compression, allowing for both lossless and lossy compression within the same file. This flexibility is valuable for GIS applications as it enables the storage of high-quality images without losing critical detail. Additionally, JPEG2000 allows for rapid access to multiple resolution levels, enabling users to zoom in and out without needing separate files for each resolution. This feature is particularly advantageous for GIS applications where users may need to view a broad area, such as aquaculture area, while also focusing on specific sites for detailed inspection.

Vector data.

- **ESRI Shapefile**. The ESRI Shapefile is a widely used geospatial vector data format developed by Esri. It is commonly used in GIS to represent the geometry and attributes of spatial features and can store points, lines, and polygons, making it suitable for various types of spatial data, such as monitoring sites, rivers, fish farms, and zones. A detailed description of the SHP file format can be found here.

- **Comma Separated Values (CSV) and Tab Separated files (TSV)**. CSV and TSV files are plain text formats for storing tabular data. Each line represents a row of data, with fields separated by commas (in CSV) or tabs (in TSV). These formats are widely used for data exchange in spreadsheet applications (MS Excel) and simple databases.
- **Geographic Markup Language (GML)**. GML is an XML-based format for encoding geographic information, developed by the Open Geospatial Consortium (OGC) as an international standard. It enables the storage, transport, and sharing of geographic data across different systems and applications. GML is widely supported by GIS software.

  This example of CSV file represents aquaculture data, with two farms represented as points. **Keyhole Markup Language (KML)**. KML is an XML-based format for visualising geographic data, mainly used with Earth browsers like Google Earth, Google Maps. It supports data visualisation and can be viewed with various GIS software.
- **GeoJSON**. GeoJSON is a format based on JavaScript Object Notation (JSON) for encoding geographic data. It's popular for web mapping and data sharing due to its simplicity and compatibility with web technologies. GeoJSONIt is often used to exchange geographic data between servers and web applications.

Vector and raster data.

- **GeoPackage**. GeoPackage is an open, standards-based format for storing and exchanging geospatial data. Developed by the Open Geospatial Consortium (OGC), it serves as a lightweight, efficient, and alternative to more complex geospatial data formats. A GeoPackage file, with a .gpkg extension, is a SQLite database that can store multiple geospatial data types, including vector data (like points, lines, and polygons), raster data (such as satellite imagery), and associated attribute data.

Annex 4 - GIS key features

In GIS projects it is essential to consider several key features that streamline the planning and development processes. These features include standards, spatial data repositories, and earth observation satellites, all of which play critical roles in ensuring the GIS project is efficient, scalable, and reliable.

Creating a catalogue of these features is crucial for accelerating the GIS project planning step. By organising and standardising key components—such as terminologies, data schemas, and functionalities—project planners can avoid redundancy and ensure that all stakeholders are aligned. This catalogue serves as a valuable resource, helping identify existing data sources, and enabling the reuse of data in multiple contexts. For instance, spatial data repositories and satellite services provide essential geospatial information for aquatic health monitoring. Accessing these resources allows GIS projects to be developed more efficiently, reducing time and resources while maximising project impact and success.

The key GIS feature to consider include:

- <u>Standards</u>. GIS planners use standards to harmonise terminologies, organise data schema, and define project functionalities. An example is the feature concept dictionary developed by the Aquae Strength project, which provides structured definitions and semantics for the following spatial objects:

  Specific AAH geographic entities. These include spatial data crucial for developing GIS projects in the AAH domain, covering various spatial objects related to fish populations (e.g., fish farms, wild fish distribution), epidemiologically significant events (e.g., outbreaks, sampling collections) or other epidemiological information (e.g., infected areas, disease-free areas). GIS technicians are responsible for organising, collecting, maintaining, and utilising this type of data within GIS projects.

  Basic hydrographic elements. These represent real-world phenomena used to contextualise and characterise the aquatic spatial environment in GIS projects. This background spatial information (i.e., geographical names and shapes) ensures consistent positional accuracy for specific aquaculture animal health geographic entities. This type of data can be sourced from local or international spatial data repositories, such as Diva portal (https://diva-gis.org).

  The AAH FCD, for instance, defines spatial object types for GIS projects focused on aquaculture animal health, specifically fish disease monitoring and response. While it supports standardised representations of disease events and management areas, it doesn't cover all aquatic GIS applications, such as those related to water quality or wild animals (Link to the FCD).

- Spatial data repositories. They provide geospatial data that can be downloaded or accessed via web service directly through GIS software. The Aquae Strength project offers practical examples on how to access and utilise data from these spatial repositories, which are particularly useful in the domain of AAH. This guidance is provided in the document entitled *Spatial data repository for aquaculture animal health*, aimed at assisting AAH professionals in accessing a free catalogue of downloadable data sources. This document includes a section on repositories or Spatial Data Infrastructures (SDI), offering guidance for accessing and using data within a GIS software. Featured resources include Diva-GIS, Geofabrik, Marine Regions, HDMA database, Merit Hydro, Aquastat, and Hydroshed. Each repository entry is accompanied by detailed instructions for downloading datasets, enabling users to efficiently import data for use in GIS. (Link to the Spatial Data Repository).
- Earth observation satellites. Satellites equipped with specific sensors collect valuable data about Earth's surface. For example, the Copernicus Marine Environment Monitoring Service (https://marine.copernicus.eu/access-data) offers regular, systematic information on the physical state and dynamics of the ocean and marine ecosystems, including currents, temperature, wind, salinity, and sea level. The Aquae strength project also provides examples of how to access and utilise some of Copernicus Marine Environment Monitoring Service in the AAH domain (Link to the Earth observation satellites).

Annex 5 - GIS functional aspects

A GIS project is typically developed to perform one or more of the following functional aspects:

- Inventory. Inventory functions in GIS involve storing and managing spatial information, often used for cataloguing spatial data related to fish farms, specific areas, and zones. This function is generally established once to serve as a resource for data management in various projects. A well-organised GIS inventory is essential for efficient management of resources for facilitating data and functionality reuse across projects.
- Mapping. Mapping in GIS is the process of displaying geographic data. The maps produced can be either static or dynamic (interactive), with significant differences in their format, functionality, and application:
  - *Static maps*. These maps are printed on paper or saved as image files (e.g., JPEG, PNG). Users cannot interact with these maps, as the view, scale, and content are fixed). Additionally, information displayed on static maps does not change once created, so any updates require a new version of the map.
  - *Dynamic maps*. These maps are displayed on electronic devices (e.g., web applications, GIS software, or mobile apps), allowing users to interact with the map by zooming, panning, clicking on features, and toggling data layers. Data in dynamic maps can be updated in real-time or periodically, ensuring that the map reflects the most current information.

  Examples of mapping applications include maps showing the spatial distribution of fish farms, the extent of an Aquaculture Management Area, and visualisation of data derived from a surveillance plan.
- Spatial operation. Spatial operations involve tools and techniques for analysing and manipulating geographic data. In AAH, spatial operation might include: drawing buffers around fish farms affected by a particular pathogen, identifying fish farms within infected zones, checking for intersections between infected zones and AMAs, identifying river basin where wild fish were captured, calculating seaway distance between fish farms.
- Spatial analysis. Spatial analysis is the process of examining spatial data to uncover patterns, relationships, and trends using analytical techniques. Examples of spatial analysis in AAH include: identifying clusters of disease (e.g., hot spot analysis), characterising the spatial distribution of epidemiological measures within zones using geostatistical indicators (e.g., mean, median, standard deviation), estimating epidemiological values for unsampled locations through spatial

interpolation techniques (e.g., Kriging, IDW), modelling possible disease spread, defining densely populated fish areas.

To maintain management simple, it is recommended that GIS projects focus on only one of these functional aspects at a time. This approach streamlines layer handling and ensures consistent outputs over time. GIS projects that attempt to address multiple functional aspects may face challenges with data updates and risk producing outputs that are misaligned with the project's objectives.

Annex 6 - GIS strategic plan

A strategic plan for a GIS project in the AAH domain should provide a clear and structured framework for leveraging geospatial technologies to monitor, manage, and respond to health threats in aquatic environments. The plan should outline the key objectives, methodologies, and resources required for successful implementation. It should address data needs, technological requirements, stakeholder engagement, and potential challenges, aiming to enhance decision-making, strengthen surveillance, and improve disease management.

The structure of the GIS strategic plan can follow a general framework typical of any strategic plan but should be tailored to the specific needs of a GIS aquatic project. The proposed index might include the following sections:

1. **Vision and mission**: defines the long-term purpose and overarching goals of the GIS within the organisation, providing direction and defining aspirations for its implementation.
   Example vision: "*to establish GIS applications to support disease surveillance and response*".
   Example mission: "*to use geospatial technologies to monitor animal health conditions, facilitate data-driven decision-making, and promote collaboration among stakeholders*".
2. **Strategic goals and objectives**: outlines specific, measurable goals and objectives that align with the project's vision and mission. Example can be: "*Develop a GIS tool to map disease outbreaks*", or "*Map 90% of fish farms in the region within two years*".
3. **Stakeholder engagement and partnerships**: identifies key stakeholders (e.g. government agencies, trade association, research institutions) and outlines strategies to involve them in the project (e.g. identify data needs and ensure the GIS project meets diverse stakeholder requirements).
4. **Alignment with organisation's policies**: ensures the GIS project aligns with the organization's internal policies, operational standards, and broader frameworks established by relevant regulatory national bodies or international organizations, such as WOAH or FAO.
5. **SWOT analysis**: analyses the project's strengths, weaknesses, opportunities, and threats to anticipate challenges and leverage advantages.
6. **Technology strategy**: defines the technological tools, platforms, and infrastructure required to implement and sustain the GIS project.
7. **Data strategy**: Outlines how data will be collected, managed, shared, and maintained to support the GIS project. For instance, to develop a centralised data repository to store fish farm locations and disease outbreak data.

8. **Risk management strategy**: identifies potential risks to the project and proposes strategies to mitigate them.
9. **Implementation and operational plan**: details the step-by-step process for implementing the GIS project, including Gantt chart, milestones, and assigned responsibilities.
10. **Performance metrics and evaluation**: defines criteria and methods to measure the success and impact of the GIS project.
11. **Additional elements**: covers any supplementary aspects, such as training programs, knowledge-sharing platforms, or future expansion plans, communication strategy, resource allocation, etc.

Below are three examples of indexes derived from some strategic plans. They are merely examples that can serve as inspiration for drafting your own strategic plan.

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Fig. ***5*** *Index of a Strategic Plan for establishing a* ***new*** *GIS service. This example of strategic plan begins with an introduction and a review of GIS in aquaculture, showcasing its potential and successful applications. An organization needs review identifies challenges, while GIS strategic themes and goals outline the service's mission, vision, and objectives. The plan evaluates existing tools in the analysis of current GIS solutions, covering software, hardware, and data inventories, and identifies gaps in the Gap analysis section. Administrative solutions detail operational models, training, and maintenance strategies to ensure sustainability. Proposed GIS projects include creating a fish farm WebGIS Site, developing an outbreak data management system, and establishing a GIS data catalogue. These initiatives aim to modernize GIS operations, improve decision-making, and foster collaboration for sustainable*

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Fig. ***6*** *Index of a Strategic Plan for* ***upgrading*** *the GIS service. This example of strategic plan begins with a program overview highlights the benefits of a GIS service, emphasizing its role in decision-making, efficiency, and transparency, while the guiding principles ensure alignment with organizational values. GIS program goals are defined and tied to the organisation's strategic plan, illustrating their broader relevance.*

A review of the GIS history tracks the system's evolution through three phases: launch, initial applications, and expansion. The current state section evaluates the system's workload, governance, and resources, providing a baseline for improvement.

The organizational evaluation includes a SWOT analysis to assess strengths, weaknesses, opportunities, and threats, along with key challenges the GIS service faces. The strategic opportunities analysis focuses on gathering organizational needs, valuing potential projects, and identifying common solutions to address gaps.

The strategic plan implementation outlines the priorities for upgrading the GIS service, governance strategies, and budget considerations, providing a clear roadmap for execution.

1. Project Identification

1.1 Call for proposals
- Project Title
- Project Acronym
- Project Code
- Date of Approval
- Priority / Measure
- Lead Beneficiary (official name in English, Country, level of Nuts II - III or equivalent)
- Project Length
- Total Budget
- Partnership

1.2 Project Summary

2. Project Description

2.1 Project background and the problems and/or challenges to be addressed
2.2 Project Objectives (general and specific)
2.3 Coherence of the project
2.3.1 Coherence of the project with the Programme's strategy
2.3.2 Coherence of the project with the relevant EU policies and horizontal issues
2.3.3 Coherence of the project with public national and subnational strategies
2.4 Added value of the cross-border cooperation in this project
2.5 Methodology approach
2.6 Expected results and outputs
2.7 Sustainability and long last effects of the project
2.8 Level of cross-border cooperation (Joint Development / Join Staffing / Joint Implementation / Join Financing)
2.8.1 How the project will realize one/more of the previous joint cooperation system
2.9 Project management

3. Beneficiary list

3.1 Beneficiary role
- Institution (Institution name in national original language, Institution name in English language, Legal status, "de minimis" condition)
- Address (Street, Number, Postal code, City, Country, NUTS II - III o equiv.)
- Legal representative / Authorized Person (Name/surname, Function)
- Contact person (Name/surname, Function, Street, Number, Postal code, City, Ph. Num., Fax, E-mail)
- Beneficiary financial details (IBAN Code, Swift Code, CUP Code, Total budget, EU co-financing, National co-financing, Additional public/private funding (where required))

3.2 Beneficiary organization (human resources, equipment, budget, other important information)
3.3 Description of previous (and current) experiences in CBC and international projects
3.4 Contribution of the Beneficiary to the project
3.5 Competences, capacity and know how of the Beneficiary in implementing project activities and results

4. Work package

- WP
- Title
- Responsible beneficiary

4.1 Actions (ACT, Starting month, Ending month, Total amount €, Description, Role of each beneficiary, Location)
4.2 Qualitative and quantitative descriptions of the outputs (Date of delivery, Description, Beneficiary/ies, Target value) - Total amount
4.3 Qualitative and quantitative descriptions of the results (Date of delivery, Description, Beneficiary/ies, Target value) - Total amount

5. Total project budget

5.1 Total project budget per WP
5.1.1 Total project budget per costs category
5.2 Table of co-financing sources per Beneficiary
5.3 Total budget overview per budget lines and per WP
5.4 Total spending forecast per WP and per period
5.5 Beneficiaries' budgets per budget lines and per WP
5.6 Beneficiaries' spending forecast per WP and per period

6. Timeplan

*Fig. **7** Index of a Strategic Plan for a GIS project.*
This example outlines a framework for developing and implementing a geospatial information system tailored to organizational needs. It begins by identifying the project's origin, such as a call for proposals or partnerships, and its title. The plan describes the project's background, objectives, and added value, emphasizing improved data management, decision-making, and stakeholder engagement.
Key beneficiaries include government agencies, aquaculture producers, and policymakers. The plan details work packages comprising actions, outputs, milestones, and results, supported by a comprehensive budget overview and a time plan to ensure timely and efficient implementation. This strategic plan serves as a roadmap to maximize the impact of GIS technology on organizational goals.

Annex 7 - GIS data plan

To ensure a GIS project is effective and well-structured, establishing a comprehensive data plan is essential. In the context of AAH, a data plan organises and defines the types of data required, identifies potential gaps, and sets up a clear framework for data storage and retrieval. Key components of a GIS data plan include:

- Data identification: In the Logical Design step, the types of data to be used in the GIS project are identified and defined. In the following step, these data types are described in detail through a preliminary physical data schema. For instance, while the Logical Design step may identify a need for data on farms, this step provides a detailed description of the data structure for farms, such as:

  `Farm Name`: Name of the aquatic farm.

  `Latitude` and `Longitude`: Coordinates of the farm location.

  `Species`: Type of species cultivated on the farm.

  `Capacity`: Maximum production capacity of the farm in tonnes.

- Gap analysis: Once the data needed is specified in the data identification step, the next step is to verify whether this data is already available. To streamline this process, it is beneficial to maintain an organised catalogue of available data and technologies, as outlined in *Annex 4 - GIS Key Features*. Perform a gap analysis by comparing the available data against the identified data. If the analysis reveals missing information, develop a specific strategy to address these gaps. For essential hydrographic elements, data integration can be challenging, as existing datasets may not be customizable or up-to-date. Often, available datasets are used as they are, with minimal modification. For specialised geographic entities related to AAH, such as farm locations or disease monitoring zones, missing data presents two main options:
  - *Creating a new dataset from scratch*: this approach involves clearly defining the entities you want to represent (e.g., farms, sampling points), selecting the appropriate geometry type (e.g., point, polygon), and specifying the attributes required to characterise each feature (such as farm name, species, and capacity).
  - *Integrating missing data into an existing dataset*: to enrich an existing dataset, consider using data joins. This method links each geographic object to a unique code, which connects to a table of additional attributes. This non-geographic table can hold detailed information without needing to modify the original geographic features directly.

- Data management: Once the data to be used in the project has been established, it's essential to organise it in a way that aligns with the project's objectives. If the project is a one-time effort, the data should be extracted and arranged in specific structures. For instance, if data files are used (e.g., ESRI Shapefiles for vector data), a possible structure for organisation is:

  `/gis_data/` (Root directory for GIS data)

  `/vector_data/` (Vector data storage)

  `/raster_data/` (Raster data storage)

  `/attribute/` (Tabular data)

  `/backups/` (Scheduled backups of databases and files)

  However, if the project is ongoing, it's necessary to determine how the data will be used and whether it should be filtered according to specific criteria. Examples of this could include applying a temporal filter (e.g., data from the past month), a geographic filter (e.g., a particular watershed or sea area), or an attribute filter (e.g., a specific species). Additionally, it's important to consider how the data will be updated. For instance, if a dedicated GIS project exists to keep farm data up-to-date, that project and its associated procedures should be used to ensure data is kept up-to-date effectively.

  To facilitate the development of a data plan for a GIS project, a series of questions and considerations have been outlined. The answers to these questions aim to address the elements outlined previously:

- **What data do you need for your project?**
  It is essential to establish the dataset required for the GIS project. For each data type identified in the logical design step, the attributes necessary to achieve the intended outputs should be specified. At this stage of the project planning, there is no need to focus on whether the data is currently available or on the cost of acquiring it, as these concerns will be addressed in the next steps. The goal is to list everything that is desired, and the feasibility of obtaining the data will be assessed later. For example, you may specify that farms should be represented geographically as multipolygons, even though acquiring this data might be costly.

- **Determine if the existing "specific AAH geographic entities" data is sufficient or if new data collection is necessary.**
  Before starting the project, you should verify the data you already have. To streamline this process, ensure you have an organised catalogue of the available data and technologies, as outlined in Annex 4 - GIS Key Features. *If this catalogue has not yet been organised, focus on two key data*

types: the registry of aquaculture sites and surveillance data. Assess the completeness of these data in terms of geographic coverage and their temporal accuracy to ensure they are suitable for project needs.

- **Are there spatial data repositories (Geoportals) to be accessed for acquiring "basic hydrographic elements" data?**
  Explore the national and international spatial data repositories that may supply the needed "Basic hydrographic elements" data. Use the suggestion provided in [Annex 4 - GIS key features]() *to develop your own technology catalogue to be used for GIS projects. However, when creating your technology catalogue, consider that local organisations may have geographic and environmental data that is useful for GIS projects related to AAH.*
  In acquiring basic hydrographic elements, attention should be given to the reference system, the update frequency of acquired data, and the accuracy of the information. Remember: more detailed data is not always the best option; it depends on the scale of use and the purpose for which it is intended. If the acquired map is only used as a background, sometimes a simpler map that facilitates readability is better than a highly detailed one that makes it difficult to highlight the relevant data.
- **When defining a new GIS data schema, consider the intended use and attributes needed for the outputs.**
  When defining a new GIS data schema, consider the attributes of the geographic object from the perspectives of map visualisation, data analysis, and geostatistical or mathematical model development.
  - *For Map visualisation, define attributes relevant to the project's purpose to avoid excessive data collection.*
  - *For Data analysis, consider different types of attributes (i.e., levels of measurement), which could be:*
    - *Nominal: Names that cannot be ranked or measured (e.g., monitoring site ID), but do not support arithmetic;*
    - *Ordinal: Rank or orders that cannot undergo arithmetic operations (e.g., ranking aquaculture management areas by biosecurity measures);*
    - *Ratio: It is used to represent values with precision and proportionality, such as the number of fish in a farm.*
  - *For Geostatistical or mathematical models, consider factors that influence animal populations' health and disease spread, including:*

- *Animal demographics (e.g., species, age, animal movement).*
- *Farm management practices (e.g., production amount, feeding practices, housing conditions, biosecurity measures).*
- *Pathogen factors and surveillance (e.g., pathogen type and characteristics, laboratory test results, sample collection dates).*
- *Temporal factors (e.g., dates of sample collection, dates of laboratory test results).*

- **What should you do if some attributes that are needed for your project are not present in the available feature schema?**

  A geospatial feature refers to any real-world entity that can be represented in geographical space, typically including both spatial (e.g., coordinates) and attribute (e.g., fish farm name) information. Geospatial features can range from simple points representing locations to complex entities like rivers and basins. However, not all data needs to be included in the attribute section of a feature; some data can be incorporated through a join operation.

  The join operation is the process of combining information from two different datasets based on a common attribute or spatial location. This operation allows for the integration of data sources, thereby enhancing analysis and visualisation capabilities in GIS. There are two main types of join operations in GIS:

  - *Attribute Join: combining data based on a common attribute field, (e.g., joining a laboratory test result dataset with a fish farm dataset based on the farm ID).*

    Fish Farms Dataset *(the latitude and longitude coordinates have been omitted for space reasons):*

Farm ID	Farm Name	Species	Capacity (tons/year)
F001	Blue Sea Farms	Atlantic Salmon	100
F002	Ocean Fresh Farms	Tilapia	150
F003	Coastal Waters	Trout	50

    Laboratory Test Results Dataset:

Farm ID	Test Date	Test Result	Disease Detected
F001	2024-05-01	Negative	No
F002	2024-05-03	Positive	Yes
F003	2024-05-05	Negative	No

    Join Operation **(**perform an attribute join based on the Farm ID**)***:*

Farm ID	Farm Name	Species	Capacity (tons/year)	Test Date	Test Result	Disease Detected
F001	Blue Sea Farms	Atlantic Salmon	100	2024-05-01	Negative	No
F002	Ocean Fresh Farms	Tilapia	150	2024-05-03	Positive	Yes
F003	Coastal Waters	Trout	50	2024-05-05	Negative	No

    This join allows users to link the laboratory test results with the relevant fish farms, providing a comprehensive dataset for monitoring surveillance progress.

  - *Spatial Join: combining data based on spatial relationships, (e.g., determining which farms fall within a zone).*

Fish Farms dataset:

Farm ID	*Farm Name*	*Latitude*	*Longitude*
F001	*Blue Sea Farms*	*34.0522*	*-118.2437*
F002	*Ocean Fresh Farms*	*36.7783*	*-119.4179*
F003	*Coastal Waters*	*37.7749*	*-122.4194*

Zone dataset *(representing a disease control zone as a polygon):*

Zone ID	*Zone Name*	*Geometry (polygon)*
Z001	*herpesviruses*	*[Polygon data]*

Spatial Join *(perform a spatial join to determine which fish farms fall within the disease zone):*

Farm ID	*Farm Name*	*Latitude*	*Longitude*	*Zone ID*	*Zone Name*
F001	*Blue Sea Farms*	*34.0522*	*-118.2437*	*Z001*	*herpesviruses*
F002	*Ocean Fresh Farms*	*36.7783*	*-119.4179*	*NULL*	*NULL*
F003	*Coastal Waters*	*37.7749*	*-122.4194*	*NULL*	*NULL*

This join helps users determine which farms are located within the disease control zone, enriching your analysis with spatial context.

- **Establish a data collection method.**

  GIS data capture methods refer to the techniques and processes used to collect geographical data and input it into a GIS for analysis, visualisation and storage. Each GIS data capture method has its strengths and limitations, depending on factors like accuracy requirements, scale of data collection, budget, and available technology. The effective selection and integration of these methods are crucial for generating accurate and reliable spatial data for GIS applications. See Annex 3 - GIS Technical Specifications for a brief description of the principal data capture methods.

  It is crucial to have a well-planned data collection method that takes into account three key factors: ***cost***, ***time***, *and* ***accuracy****. First, the cost of data collection should be assessed to ensure that the process remains within budget constraints. Secondly, the time required for data collection should be considered to avoid delays in project timelines. Finally, accuracy is paramount, including both the geographical details of the geographic data (such as the resolution of spatial coordinates) and the attributes used to characterise the data (such as the completeness and precision of the information collected). Balancing these three factors is essential for a successful data collection campaign, as it ensures the data collected is not only reliable but also feasible to gather within the available resources.*

- **Quality is a crucial consideration. Always incorporate data quality checks into the data capture and maintenance protocol.**

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- **Quality is a crucial consideration. Always incorporate data quality checks into the data capture and maintenance protocol.**

  Once data is collected, it must be quality-checked. This step involves several critical activities to ensure the data is accurate, up-to-date, and useful for creating maps, conducting spatial data analysis, and developing geostatistical or mathematical models. The data quality check consists of the following components:

  - *Data Cleaning. Identification and correction of errors in the collected data (e.g. missing values, correcting typo errors, standardising data formats).*
  - *Data Updating. Incorporation of new data and updating existing data, which is crucial for dynamic datasets like laboratory test results or animal movement.*
  - *Data Validation: Verification of data integrity and accuracy through on-site survey or cross-checking with other data sources, to ensure the data meets predefined standards and criteria.*
  - *Data Backup and Recovery. Implementation of backup strategies to protect data against loss or corruption.*

Annex 8: GIS Knowledge Base and In-House Expertise

Spatial ability is a critical skill for GIS technicians, directly influencing the quality and effectiveness of GIS projects, particularly in complex domains like AAH. This expertise encompasses understanding spatial relationships, programming, database management, and spatial analysis. Strong spatial abilities enable technicians to design GIS solutions that accurately model real-world relationships, supporting robust, data-driven decisions. For example, in a GIS project focused on managing disease outbreaks in aquaculture, technicians with strong spatial skills can analyse geographic factors influencing pathogen spread, such as proximity to water currents and environmental conditions.

Key Skills for GIS Technicians

1. **Spatial Relationships**:
   Understanding how geographic features interact is fundamental for GIS. This includes analysing proximity, connectivity, and dependencies between features like fish farms and water zones. For AAH, this ensures accurate mapping and insightful spatial analysis.
2. **Programming**:
   Programming skills allow technicians to automate processes and create custom GIS solutions. For example, using Python to automate repetitive tasks, such as calculating seaway distances or analysing fish farm buffers, improves efficiency and scalability.
3. **Database Management**:
   Effective GIS requires managing spatial and attribute data in databases. This includes tasks like querying, updating, and organizing data for representation through maps or charts, ensuring data consistency and accessibility.
4. **Spatial Analysis**:
   Spatial analysis, including techniques like kriging and spatial autocorrelation, uncovers patterns in data. For example, identifying clusters of disease outbreaks among fish farms allows targeted interventions to mitigate risks.
5. **Hydrodynamic Modelling**:
   Hydrodynamic modellers are essential in GIS projects for AAH and aquaculture, providing critical inputs on water dynamics such as flow patterns, currents, and dispersion of pollutants or pathogens. In freshwater environments, they play a key role in predicting disease spread in rivers and lakes, assessing the impact of water flow on fish habitats, and managing nutrient

accumulation in reservoirs or ponds. Their expertise supports GIS analyses by predicting disease spread between farms, identifying nutrient accumulation zones, and assessing site suitability based on water circulation.

Recommended GIS Training Resources

GIS professionals can enhance their skills with courses tailored to AAH and environmental applications:

- **Introduction to Spatial Analysis in GIS (Esri Academy)**: Covers spatial patterns analysis, essential for understanding aquatic disease dynamics.
- **Applied Spatial Data Analysis with R (University of Washington)**: Teaches spatial analysis using R for complex workflows in aquatic epidemiology.
- **Spatial Epidemiology and Outbreak Detection (Johns Hopkins University)**: Focuses on disease tracking and spatial data analysis in aquatic environments.

Python for QGIS

Python has become an essential tool for GIS technicians, particularly for those working with QGIS. Its flexibility and power allow users to automate tasks, customize workflows, and extend QGIS functionality, making it a valuable skill for managing complex GIS projects. Learning Python enables GIS technicians to handle large datasets, perform advanced spatial analysis, and create dynamic visualizations more efficiently. For those in AAH, mastering Python for QGIS can greatly enhance the ability to integrate environmental models, automate repetitive processes, and manage spatial data effectively.

To build a strong Python knowledge base for QGIS, the following courses are highly recommended:

- **Python Foundation for Spatial Analysis**:
  This course introduces Python programming concepts with a focus on spatial analysis, offering foundational skills for integrating Python into GIS workflows.
  [https://spatialthoughts.com/courses/python-foundation-for-spatial-analysis/]
- **Mapping and Data Visualization with Python**:
  Covers the creation of professional maps and visualizations using Python, helping users communicate complex spatial data effectively.
  [https://spatialthoughts.com/courses/python-dataviz/]
- **PyQGIS Masterclass – Customizing QGIS with Python**:

Focuses on leveraging Python to customize QGIS, enabling users to develop tailored solutions and automate processes within the software.
[https://spatialthoughts.com/courses/customizing-qgis-with-python/]

These courses are freely available on YouTube for those who do not require a certification, providing accessible resources for GIS technicians aiming to advance their Python and QGIS expertise.

In-House GIS Expertise

The expertise of in-house GIS staff is crucial for the success of GIS projects. Evaluating and developing these skills ensures projects are well-executed and sustainable. Common activities managed by in-house GIS teams include:

- **Project Management**: Planning, resource allocation, and documenting processes to maintain transparency and reproducibility.
- **Data Collection and Management**: Acquiring, cleaning, and standardizing spatial data from diverse sources, such as satellite imagery and field surveys.
- **Map Production and Visualization**: Designing and creating maps for reports and presentations tailored to stakeholders.
- **Spatial Analysis**: Performing tasks like buffering, overlay analysis, and spatial queries to derive actionable insights.
- **Technical Support**: Maintaining GIS systems, resolving technical issues, and providing user support to ensure optimal functionality.

By combining robust spatial skills with targeted training and leveraging in-house expertise, organizations can build and sustain effective GIS solutions, maximizing their impact in AAH.

Annex 9 - Organising the project maintenance

Effective GIS project maintenance involves the following key activities:

- Project administration. GIS project administration is crucial for ensuring quality and consistency in outcomes. The primary goal is to keep the system functional, relevant, and responsive to changing needs. This involves continuous monitoring of system performance, tracking project outputs, and gathering user feedback to support ongoing improvements and integration.
- Data administration and updates with new available datasets. Data is the backbone of any GIS project, and maintaining its accuracy is paramount. As new data becomes available or existing data changes, it must be seamlessly incorporated into the GIS. Data administration should be part of the GIS data management plan, which should be regularly updated to incorporate new resources. Additionally, a reliable data backup plan is critical to safeguard against data loss or system failure. Regular backups of essential data and configurations ensure the GIS can be quickly restored in case of an unexpected failure.
- Output reuse. Organising GIS maintenance to maximise the reuse of outputs enhances the system’s overall value and impact. This task ensures that GIS data and outputs are accessible, understandable, and applicable across other GIS projects. Key elements include:
    a. Standardising data formats, symbols, and classification systems used in the GIS project.
    b. Providing outputs in multiple formats to meet varied user needs, making information adaptable for various uses, from formal reports to public presentations.
    c. Organising comprehensive documentation and metadata. Metadata is essential for conveying the data's origin, accuracy, scale, and limitations, helping users understand the context and reliability of GIS outputs. Detailed documentation on data processing, analysis, and visualisation supports future projects by allowing GIS technicians to replicate or build upon previous work.
    d. Making sure there are no copyright or other limitations to use of the source data, which would limit the reuse or sharing of outputs.
- User support and training. Ongoing user support is essential for a functional GIS system. Users may face challenges or require additional training to use the GIS effectively. Maintenance involves providing continuous user support, promptly resolving issues, and offering training sessions to ensure users can effectively leverage the GIS system to its full potential.

Annex 10 - GIS fundamental aspects

GIS projects are grounded in both functional and fundamental aspects that collectively determine their effectiveness and impact. Various definitions and classifications of these aspects exist, shaped by the specific domain and the perspectives of the experts who develop them. For the application of GIS in the domain of AAH, a tailored set of functions and fundamental aspects has been defined. These definitions, along with their content and reference bibliography, are based on the extensive experience of experts in GIS for AAH who contributed to this document. The references and their associated scientific contributions are presented below.

GIS functional view

As GIS is a technology that acquires and stores geographic and other related attribute data for processing, analysing, synthesising and visualising spatial information (Maguire, 1991), it enables both simple and complex operations, depending on the type of data, analyses to be performed, and required outputs (Maguire and Dangermond, 1991; Walter, 2020). Three functional aspects of GIS can be identified: *mapping* (e.g., inventory, data querying), *spatial operation* (e.g., overlaying, buffering, exploratory spatial data analysis), and *spatial analysis* (e.g., modelling, decision making). These must be combined and optimised when planning a GIS project (Chan and Williamson, 1997).

GIS technology view

There is no one-size-fits-all solution for GIS projects (Bossler et al., 2010). As with any technological application, the key factor to GIS success is how it is applied to solve an organisation's business problems (Somers, 1998). Goodhouse and Thompson proposed the Technology-to-Performance Chain (TPC) model to describe the relationship between technology and results. According to this model, technology performance depends on its utilisation and the fit between that technology and the tasks it supports (Goodhouse and Thompson, 1995). In the GIS body of knowledge defined by DiBiase et al. (2007), the technological component plays a crucial role in planning a GIS application. Having substantial competence in available GIS technologies, understanding how to use them, recognising their potential and limitations, and knowing the resources necessary to exploit them is paramount.

Spatial thinking

Developing GIS projects requires expertise in spatial data organisation, capture and manipulation (Fang et al., 2014). Key concepts such as location, scale, representation, and spatial relationships must be understood to define the framework used to produce the required outputs (Sinton, 2015). These spatial thinking skills are part of the common knowledge developed within the Information Community (IC) involved in developing GIS projects. ICs are composed of individuals who share a common understanding of their domain, including definitions, vocabularies, and common technology (Open Geospatial Consortium, Inc.).

GIS for AAH

Pathogen transmission between aquatic animals differs significantly from that between terrestrial animals. Water, serves as a medium that facilitates the spread of pathogens and transmission within a population (Corsin et al., 2009). Without GIS, the dynamics in marine areas and the creatures and resources we utilise from oceans and waterways would remain largely unknown (Kaymaz and Yabanh, 2017). However, GIS, remote sensing, and mapping are not as commonly used in aquaculture as in other disciplines such as water resources. A possible explanation for this limitation is the lack of awareness about the capabilities of GIS tools among administrators and managers, as well as limited access to experienced practitioners, especially in developing countries (Kapetsky and Aguilar-Manjarrez, 2007). Furthermore, the application of GIS in spatial epidemiology has shown significant potential to identify risk factors for disease outbreaks, such as herpesvirus in oysters or White Spot Disease in shrimps, and to enhance management of aquatic resources (Munieza et al., 2017; Pernet et al., 2018). Spatial epidemiological approaches continue to play a vital role in understanding disease transmission dynamics in aquatic environments (Walker & Winton, 2010; Lafferty et al., 2015) or describing mortality patterns in marine mammals strandings (Alvarado-Rybak et al., 2020).

GIS planning

GIS projects vary in complexity, ranging from small and simple (involving limited software, data, and users), to large and complex projects (involving numerous datasets, applications, users and complex systems and databases) (Somers, 2002). Regardless of complexity, developing a GIS project requires substantial expertise in GIS functionalities, GIS technologies, and spatial thinking (Campbell and Masser, 1995). For a GIS project to be successful, all these components must be carefully coordinated and integrated (Luaces et al., 2004).

Glossary

- *Aquaculture Management Areas (AMA)*: Defined regions where aquaculture activities are planned and managed.
- *Aquatic animal health (AAH):* The branch of veterinary science focused on the health, welfare, and diseases of aquatic organisms such as fish, shellfish, and marine mammals.
- *Attribute Join:* it is a GIS operation that combines data from two different tables based on a common field (called key). This allows GIS technicians to link "where" things are (e.g. fish farms) with additional descriptive information so "what" they are about (e.g. number of restocked fishes, biosecurity data).

  Imagine you have shape file with the locations of fish farms (spatial data) and a separate table providing fish farm details, such as the species farmed, the production capacity, and recent health inspections. Using the farm unique identifier (farmID) as attribute join, you can link the spatial data of the fish farms with the descriptive table by matching the farmID in both datasets. This process enriches the map, allowing you to visualize not only the location but also key information about each farm.
- *Biosecurity*: Practices designed to prevent the introduction and spread of harmful organisms in aquatic systems.
- *Continuous data*: this type of data represents variables that change gradually and seamlessly over space or time, without discrete boundaries or interruptions. In GIS, this type of data is used for raster data.
- *Coordinate Reference System (CRS):* it is a framework used to define how spatial data is mapped onto the earth's surface and to precisely measure locations on the surface of Earth as coordinates. For a practical explanation of why we need a CRS refers to: https://docs.qgis.org/3.34/en/docs/gentle_gis_introduction/coordinate_reference_systems.html.
- *Data Gap Analysis:* it is the process of identifying missing data required to achieve specific goals. This helps determine what additional data needs to be collected or improved. For example suppose you have to plan a GIS project to monitor disease outbreaks in a given area. With the data gap analysis, you might find that while you have spatial data on fish farms, you lack critical information about species breaded, critical biosecurity measures, or disease history data. Identifying these gaps allows you to organise specific data collection to fill in the missing data.
- *Data master plan*: A data master plan is a comprehensive document that outlines the strategy for managing, organizing, and utilizing data within an organisation. It acts as a blueprint that specifies

the types of data available, their sources, formats, quality standards, storage methods, and workflows for data acquisition, processing, and analysis. By detailing data sources and formats, the plan facilitates the data identification in the GIS project planning steps. Moreover, the data master plan is instrumental in optimizing resource allocation, as it helps prioritize data collection and processing tasks, ensuring efficient use of time, budget, and human resources. Finally, a well-defined data master plan enhances the reusability of datasets by documenting those that can support multiple GIS applications. This approach reduces redundancy, saves resources for future projects, and ensures that the data collected remains valuable beyond the scope of the initial project.

- *Data schema:* is the structure or blueprint that defines how data is organized, stored, and related within a GIS. For example, in a GIS database for monitoring fish diseases, a data schema might define tables for storing information about fish farms (e.g., location, species, capacity), disease outbreaks (e.g., pathogen type, date, affected farms), and biosecurity conditions (e.g., water source management, stock management). The schema specifies how these tables are related, such as linking outbreaks to specific farms and environmental factors.
- *Discrete data*: this type of data represents distinct, separate values or categories that do not flow continuously across space. Discrete data used to describe specific locations, boundaries, or classifications (e.g. fish farms, water bodies). Discrete data is typically represented using vector formats (points, lines, polygons).
- *Dynamic Mapping:* it refers to the interactive maps in a webGIS environment that allow users to explore (e.g. zoom, identifying the spatial object), query, and analyse spatial data in real time. Unlike static maps (e.g. map in PDF), dynamic maps are connected to datasets and therefore enabling data updates. A classic example is a webGIS application for monitoring disease outbreaks. Dynamic mapping allows users to view the current status of fish farms, including disease situations. Users can click on a specific farm to see its health history, zoom in to analyse nearby fish farms, or filter the map to show only farms reporting diseases in the last 30 days. As new data about outbreaks becomes available, the map updates automatically, ensuring the information remains current.
- *Epidemiological Models*: Computational representations of disease dynamics used to predict and control outbreaks.
- *Geocoding*: it is the process of converting textual location data, such as addresses or place names, into geographic coordinates (latitude and longitude) that can be used as spatial data. For example

in a freshwater aquaculture project, geocoding can be used to map fish farms using their postal addresses.

- *Geographic Information System (GIS):* A system combining hardware, software, and data for capturing, managing, analysing, and displaying spatially referenced data.
- *GPS*: it is a satellite-based navigation system that provides precise location, velocity, and time data to a receiver anywhere on Earth. In aquaculture, GPS can be used to collect the exact location of fish farms situated in the open sea. For instance, when mapping marine aquaculture facilities, technicians use a GPS device aboard a boat to record the coordinates of each farm's anchor points, or where a sample has been collected.
- *Heat Map*: it is a visual representation of data density in an area. By means of colour gradients we can indicate the concentration and dispersion of a specific phenomenon. With warmer colours (e.g. red) often representing higher densities or intensities, and cooler colours (e.g., green) indicating lower levels. For example a typical heat map can is used to show areas with the highest number of disease outbreaks in fish farms. This allows stakeholders to focus surveillance or mitigation efforts in areas with the most significant issues.
- *Incremental:* A process in which a project is developed manageable segments or increments. Each increment represents a complete subset of the project's overall functionality, adding progressively to the final product.
- *Information product:* Refers to the output or deliverable created from a GIS project or analysis. These products are typically designed to convey specific geographic information, patterns, or insights to meet the needs of decision-makers, stakeholders, or the generic users. GIS technician: A professional responsible for the development, maintenance, and management of GIS projects. Key responsibilities typically include: data collection and management, GIS analysis, project maintenance, map creation, and technical support.
- *Interpolation*: is a method used to estimate unknown values at unmeasured locations based on the known values of surrounding points. It creates a continuous surface by “predicting” data values for areas where direct measurements are unavailable.

  The differences between interpolation and geostatistical analysis lies in their complexity: interpolation uses simpler mathematical techniques like inverse distance weighting to estimate values between known data points and it assumes that the value at an unknown location is influenced directly by the surrounding known values, without considering spatial dependencies in the dataset; geostatistical analysis is a more advanced form of interpolation that incorporates statistical models to account for spatial relationships and variability. For example the kriging not only consider the distance between points but also the patterns and trends in the data (spatial autocorrelation), and it provides also a measure of uncertainty for the estimates. In summary, while both methods aim to estimate unknown values, interpolation is simpler and more direct, while geostatistical analysis is more robust and suitable for complex spatial datasets with underlying patterns or uncertainties.

- *Iterative*: A cyclical process of planning, developing, and refining a project through repeated cycles. Each iteration involves revisiting and revising the project's components, progressively enhancing and expanding them with more detail and accuracy.
- *Map layer*: a map layer is a group of point, line, or polygon features that represent a specific type of real-world entity in a GIS. Each layer is dedicated to a particular dataset, such as farms, rivers, or administrative boundaries, and these layers are stacked together in a GIS to create a complete map.
- *Metadata*: Information about data that describes its source, accuracy, format, and other relevant details.
- *Pathogen Dynamics*: The study of the behaviour, spread, and control of disease-causing organisms in aquatic environments.
- *Raster Data*: it is a type of spatial data representation in GIS that uses a grid of cells to store information about a geographic area. Each cell in the grid holds a single value, such as temperature, or dissolved oxygen. Raster data is commonly used for continuous data. For example raster data can be used to map water temperature across a large lake or coastal area. Each cell represents the temperature at a specific location.
- *Spatial Analysis*: Methods used to examine spatial data for patterns, relationships, and trends.
- *Spatial Autocorrelation*: refers to the degree to which data values are similar or different across nearby locations. In other words, it measures how much the value at one location is related to values at neighbouring locations. For example, suppose you’re monitoring disease outbreaks in fish farms located within a lake. Spatial autocorrelation helps identify whether areas with high disease incidence are clustered together. For instance, if one fish farm has a high number of sick fish, nearby farms are likely to have similar disease patterns. By understanding this, you can focus surveillance and interventions on specific regions with high spatial autocorrelation, leading to more effective disease control.
- *Spatial database*: a spatial database is a specialised type of database that is designed to handle spatial data (data that represents objects, features, or phenomena tied to a specific geographic location or area). This includes point, line, polygon, and raster data. It is used in GIS applications.

Spatial databases allow for the storage, query, manipulation, and analysis of spatial data, supporting operations such as proximity searches, spatial relationships, and geospatial analysis.

- *Spatial data/geospatial data*: it refers to data representing features with attributes that can be geographically located on the Earth's surface. This includes information about the position, shape, and relationships of features. Practically, spatial data not only shows where things are but also provides details about them.
- *Spatial Data Infrastructure (SDI)*: refers to the framework necessary for spatial data sharing, discovery, access, and management. It includes policies, standards, technologies, and human resources that facilitate the organization, integration, and dissemination of geospatial information. An example is DIVAGIS.
- *Spatial Epidemiology*: A sub-discipline of epidemiology that studies the geographical distribution of health outcomes and their determinants.
- *Spatial Join*: it is a GIS operation used to combine two datasets based on their spatial relationships. It connects attributes from one dataset with another based on their geographic proximity or shared spatial characteristics. For example, if you need to associate to the farms the information of the aquatic area management they are within, a spatial join can combine farms data (such as name, species, capacity) with data from areas (such as area identifier, area health status). By doing so, you can link specific fish farm information to areas characteristics and analyse surveillance or intervention strategies according to the integrated data.
- *Spatial Query*: it is a GIS function used to retrieve information based on geographic or spatial characteristics. It allows users to filter and manipulate spatial data based on location, distance, or other spatial relationships. For example, if you need to monitor the spread of diseases among fish farms, a spatial query can be used to identify the farms within a certain distance from a known outbreak: you could filter all farms within a 10 km radius of a disease hotspot, helping to prioritise areas for disease surveillance or intervention.
- *Temporal data:* Data representing features that have assigned time attributes, the values of which may change with time.
- *Topology*: it refers to the creation of spatial relationships between features. It focuses on spatial constraints such as adjacency, connectivity, and containment. For example, topology can be used to understand disease transmission routes between freshwater fish farms by analysing how fish farms are connected through waterways. Additionally, topology can constrain the containment of a fish farm within a specific sea area by ensuring that the farm's boundaries do not overlap with nearby protected or restricted zones.

- *Vector Data*: it is a type of spatial data that represents geographic features using points, lines, and polygons. These features are defined by their location (coordinates) and attributes, making vector data ideal for representing discrete objects such as farms, aquatic management areas, infected zones, rivers, etc.
- *webGIS:* Refers to GIS technology delivered through web-based platforms. It enables users to access, interact with, and analyse spatial data via the internet using standard web browsers.
- *Workflow Automation*: it refers to the use of automated processes to perform repeated operations or functions within a GIS project. These workflows streamline data management and analysis by reducing manual intervention and ensuring consistency. For example, workflow automation can be used to set up to regularly monitor fish farms, track disease outbreaks, and assess environmental conditions.
- *Zonal Statistics*: it refers to the process of calculating summary statistics for raster data within specific zones defined by vector features such as polygons or regions. These statistics provide insights into the distribution of data within each zone, such as average values, sum, standard deviation, or counts. For example, a zonal statistics operation can calculate the average water temperature, pollutant concentration, or pH level across multiple fish farms, helping to understand how environmental factors impact AAH within defined zones.

Acronyms

AAH: Aquatic animal health

AMA: Aquaculture Management Area

CRS: Coordinate Reference System

CSV: Comma-Separated Values

DBSM: Database Management System

DEM: Digital Elevation Model

EPSG: European Petroleum Survey Group (standard for coordinate reference systems)

FAO: Food and Agriculture Organization

GeoTIFF: Georeferenced Tagged Image File Format

GIS: Geographic Information System

GML: Geographic Markup Language

IDW: Inverse Distance Weighting

ISO: International Organization for Standardization

KML: Keyhole Markup Language

OGC: Open Geospatial Consortium

RDBMS: Relational Database Management System

SDI: Spatial Data Infrastructure

SRS: Spatial Reference System

WGS84: World Geodetic System 1984

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