Decision support and idea processing systems: challenges and opportunities for aquaculture research, management and education

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Abstract

Environmental Decision Support Systems (EDSS) and Idea Processing Systems (IPS) are now being developed to facilitate the collection, manipulation and analysis of a variety of kinds of environmental data in a variety of fields. EDSS/IPS’s typically consist of integrated hardware and software packages that facilitate operational decision making via user-friendly, visually interactive interfaces. To date, few EDSS/IPS applications for aquaculture have been developed. Therefore, the purpose of this paper is to address how EDSS/IPS technology may benefit aquaculture research, management, planning, knowledge generation and education. This paper discusses the functional units of an EDSS/IPS, the system’s life-cycle approach to system development, structured and semi-structured decision processes and decision support for aquaculture applications. It is the contention of this paper that computer systems development for aquaculture can be greatly improved by applying the EDSS/IPS technology to system’s analysis and design.

1 Introduction

Advances in computer technology have changed the way many things are done in society including the management of aquaculture facilities. Aquaculture, particularly in the developing world, is increasingly moving from extensive to semi-intensive and intensive operations and the increasing complexity of the production process demands better management in order to sustain high production. As management decisions have considerable effects on both the economics of production and on environmental pollution, decision making can be enhanced by increasing the access to and improving the handling and presentation of data. An efficient, cost-effective means of achieving this is the application of EDSS/IPS technology. The objectives of this paper is to (a) identify the decision-making and knowledge requirements for aquaculture professionals, (b) to compare and contrast existing EDSS/IPS systems, and (c) develop a comprehensive framework for the conceptual design of EDSS/IPS suitable for research and management of aquaculture facilities, and for education and training.
2 A Conceptual Framework For Applying EDSS/IPS Technology To Aquaculture

Decision Support Systems and Idea Processing Systems (DSS/IPS) are a class of computer-based information systems that provides interactive, user-friendly, decision support for managers and planners for solving structured and semi-structured problems Sprague[1]. EDSS/IPS are a sub-class of DSS/IPS that operates with environmental data to solve environmental problems. Computer scientists, eg. Guariso & Werthner[2], more rigorously define EDSS/IPS's as a class of DSS's that possess some or all of the following characteristics: (a) Dynamics. (Decisions are significantly affected by past phenomenon), (b) Spatial coverage. (Environmental data are collected from various geographical locations - the spatial component may be part of the modelling process), (c) Periodicity. (Environmental variables that are affected by seasonal variations), (d) Randomness (due to natural and experimental variation), and (e) Significant data requirement (particularly for spatially referenced data). Although these five characteristics do not exclusively define or are necessarily unique to EDSS/IPS, they are useful in distinguishing EDSS/IPS from other classes of information systems. The presence (or absence) of these characteristics and the relative importance of each characteristic in relation to others will depend on the application and decision requirements. In aquaculture, all these characteristics are operative and need to be accounted for in the design and construction of a suitable EDSS/IPS. EDSS/IPS’s are also distinguished from other environmental computer systems in their emphasis on assisting management decision processes in an environment where the decisions may be complex and/or fuzzy. The emphasis is on decision support rather than environmental control. EDSS/IPS's are not designed to replace human cognitive processes but to enhance them. To achieve this, it is imperative that two conditions are satisfied: The manager or planner must (a) have direct access to the data or information without the need to go through an intermediary (eg. a database administrator or programmer), and (b) have the ability to conduct “what-if” analyses and simulation. A strong feature of EDSS/IPS is management by perception. Consequently the user-machine interface must be designed in a manner which permits the user to remain in control and unstressed throughout the problem-solving process.

![Conceptual framework for EDSS/IPS design and factors influencing components of the EDSS/IPS.](image)

In the past decade there has been considerable debate as to what constitutes a DSS. Much of this debate was generated by computer professionals dealing with management information systems (MIS) for commercial and financial applications. There now appears to be a general consensus on DSS technology. However, the literature on EDSS/IPS is virtually non-existent. Therefore, in this paper, a conceptual model for EDSS/IPS is developed using generally agreed principles of DSS technology and illustrated on several examples in the aquaculture industry.
Figure 1 presents a conceptual model of an EDSS/IPS. Various components and functions are now discussed. EDSS/IPS consists of three components: a Dialogue Manager (DM), a Data-Base Management System (DBMS) and a Model-Based Management System (MBMS) (Pearson & Shim[3]). The interface between the manager and the machine is called the Dialogue Manager. The DM has the responsibility of translating the user requests into machine operable functions and returning the requested information in a user-friendly format. An important feature of the DM is the provision of user-controlled, human-directed dialogues that facilitate structured and semi-structured decision support. To achieve this human-machine synergy, the DM must interface directly with the data management system (DBMS) and the model management system (MBMS). The primary task of the DBMS is for the capture, retrieval and manipulation of environmental data and to translate user-requests obtained by the DM into a form that is tractable for use by the underlying models in the MBMS. The level of sophistication of the DBMS will depend on the application and user requirements for information and may range from a simple software program that sorts and extracts data from flat-files to high-powered database systems that handle operations on complex data models. Programs offering structured-query language support (SQL) appear to be popular in DBMS development.

The primary task of the MBMS is to provide analytical tools to augment the decision-making process. These tools might include statistical and graphical tools for data description, summary and analysis (eg. ANOVA, PCA, cluster analysis, linear and nonlinear regression, MDA, etc), simple mathematical and numerical techniques (eg., linear programming, dynamic programming, differential growth functions, nonlinear optimisation techniques, etc) and decision, idea processing and judgement simulation models (eg., analytic hierarchy process (AHP)). Depending on the nature of the decision process, the MBMS may be required to have considerable flexibility in order to handle qualitative as well as quantitative variables. If the EDSS/IPS includes decision, idea processing and judgement simulation then the user should be able to assign relative importance values to the various environmental parameters and management practices. The EDSS/IPS should then be able to provide an assessment of the potential success or otherwise of a certain management strategy. The outcomes of the modelling process are often expressed as probabilistic assessments associated with a set of user-specified criteria.

Each component of the EDSS/IPS (ie. the DM, MBMS, DBMS) to various degrees provides a set of capabilities to the operational manager or planner and improves the overall effectiveness of the decision making process. These components constitutes the core of the EDSS/IPS. Associated with the core are a set of functional units as indicated in figure 1. These functional units can be described in two broad dimensions; (1) task characteristics and (2) access patterns (Ariav & Ginzberg[4]). Task characteristics include: (a) task structure, (b) management level, and (c) decision phase. Access patterns include: (a) computer skill level and knowledge requirement of user, and (b) usage pattern and mode of operation. The task structure is concerned with the level of problem structure and definition required by the system to operate effectively. If all environmental parameters and decision variables are known and can be defined by equations or unambiguous statements, then the task is well structured. The decision models required to implement well-structured tasks are usually easy to implement in an EDSS/IPS, even though the decision or mathematical models might be complex. In semi-structured decision-making contexts, environmental parameters may be qualitative as well as quantitative. The decision environment may be loosely defined around desirable objectives or outcomes. Semi-structured environments often rely on heuristics as well as known scientific laws. The user generally is required to play a greater role in the decision process. Semi-structured tasks are generally more difficult to implement in an EDSS/IPS. The nature and style of modelling also depends on the task structure and decision phase. Semi-structured tasks rely more on “what-if” analysis, objective and goal generation, judgement simulation and probability assessments of outcomes. Well structured tasks rely more on traditional quantitative modelling practices such as operations research, numerical and statistical analysis.
The pattern of usage may also influence system design and operation. Environmental data is increasingly being generated from many different sources (eg. governmental, statutory and non-statutory bodies) and this is also true for aquaculture. Better management may result from increased accessibility to data from multiple external sources. Indeed future EDSS/IPS developments will, by necessity, need to integrate with distributed databases in order to improve environmental decision making. Another consideration of pattern of usage is the number of simultaneous users. Most EDSS/IPS are designed for single users. However, group-EDSS/IPS (multiple-simultaneous users) can also be important particularly for long-term, strategic environmental planning. The timeliness of information is another important factor. Technicians and operational managers are often required to make decisions daily or more frequently and are mainly concerned with control. Often rapid guesstimates are sufficient to arrive at appropriate actions for environmental control of aquaculture facilities. Accuracy can be sacrificed for speed. On the other hand, strategic management occurs on a longer time frame and there may be less requirement for timely information but more requirement for accuracy. Forecasting may be more important for strategic managers than control. The framework presented here is not only useful for systems design and implementation but can also be used for comparing and contrasting systems capabilities. This is illustrated in the next section.

3 EDSS/IPS’s For Aquaculture:

3.1 Aquaculture Research and Monitoring System (ARMS)

ARMS was one of the first EDSS/IPS developed for aquaculture. It was developed by the Aquaculture Research Group at Deakin University in 1991 (Bourke, Stagnitti & Mitchell[5, 6]). ARMS is a flexible software system that aids in the collection, monitoring and analysis of aquaculture experiments. It was specifically designed to capture and analyse physio-chemical and biological data generated in the research on culture of freshwater crustaceans. ARMS has implemented many features of a EDSS/IPS including a capacity for semi-structured decision support and what-if analysis. A key-feature of ARMS is a probabilistic estimate of specific experimental outcomes using Saaty’s[7] Analytic Hierarchy Process (AHP) for simultaneously evaluating qualitative and quantitative variables. ARMS may be used to examine the validity of the assumptions used in past aquaculture experiments and, more importantly, to simulate new experiments before actual implementation. It also has a demonstration capacity that may be used to train other managers, planners or students. The design of ARMS stresses modular independence and thus the decision process and database management are not necessarily coupled to the experimental data and maybe modified to suit the requirements of other organisations or applications.

ARMS interfaces to WQMS, a water quality management system that provides on-line monitoring of real-time data on pond temperature, conductivity, pH and dissolved oxygen (see figure 2). Using ARMS, the user can also store and retrieve textual descriptions of each pond experiment in flat files and match these descriptions to various previously stored historical data sets. It provides a range of statistical and graphical functions, and allows decision modelling. The MBMS of ARMS is a simple engine that interfaces into a number of existing commercial packages (Minitab, Microsoft Excel and Microsoft Word) to provide basic statistical support, spreadsheet functions and word processing requirements. ARMS uses a menu-driven, graphical front-end program written in Borland’s Turbo Pascal 4.0. Many of ARMS functions have been implemented using Borland’s Turbo Toolboxes. ARMS uses a hierarchical file structure to store information and is managed by routines written in Turbo Pascal. It operates under DOS. ARMS contains nearly 8000 lines of code and consists of three major components: a Statistical Summaries Module, a Decision Support and Judgement Simulation
Module, and a Display and Calculation Module (see figure 2). These modules are briefly described below.

ARMS provides simple on-screen graphing and descriptive statistics. However, the major statistical analyses are executed in Minitab. By choosing the Statistical Module option in the ARMS menu, ARMS will reformat the requested data into a file which is input directly into Minitab. The user then has a number of specially written Minitab macros available to perform regularly requested operations on the data (e.g. regressions, correlations and ANOVA) or can use the full range of generic functions offered by Minitab. Minitab was chosen as the base module for statistical calculations not only because it is easy to use and very efficient, but also covers a wide range of desired analyses required for all current applications in aquaculture operations. It is also inexpensive and has good support and upgrade paths. Graphical displays can be generated in two ways - directly within ARMS or via MS Excel. The on-screen graphs are low resolution but quick to generate and contain cubic spline smoothing. They are useful for on-line monitoring and demonstration purposes. High resolution graphs for use in reports can be generated in MS Excel by custom-made macros. Other macros perform frequently required database operations and mathematical calculations. As with Minitab, ARMS reformats the selected data and directly transfers it into an Excel spreadsheet. When in Excel, the user also has the flexibility of developing their own personal macros by modifying those provided or using generic functions.
Conducting individual experiments, particularly those which might continue for a year or more, is a very costly enterprise. Therefore, ARMS has implemented a decision support tool that allows the user to make decisions about planned experiments by assigning importance values to a number of qualitative and quantitative variables. This approach has been used successfully in other environmental studies (eg. see Itami & Stagnitti[8]). The underlying decision model used in ARMS is AHP and was developed by Saaty[7]. AHP is a multicriteria, multiobjective decision model that uses a hierarchical or network structure to represent the decision problem and then develops priorities for alternatives based on judgements made by the decision maker. The operation of AHP basically involves the creation of a decision hierarchy by decomposing the decision problem into levels consisting of interrelated decision elements. ARMS has implemented the decision problem as a three-level hierarchy in which the top level of the hierarchy contains the most macroscopic decision objective; ie. the aquaculture experiment. The next level of the hierarchy contains detailed attributes of the experiment (eg., stocking density, substrate, pond temperature, etc) and the third level of the hierarchy contains desired experimental outcomes such as survival rate, production failure and biomass increase. The user inputs relative importance ratings and pairwise comparisons to all variables at the various levels of the decision tree. These importance ratings and pairwise comparisons provide the user with a basis for assessing the utility of the judgements made in setting up the experiment. This method can rapidly produce a scenario of "predicted" outcomes without the need to individually conduct each experiment. The set of conditions which leads to the "best-case" scenario can then be implemented at less risk and cost.

3.2 Decision Support For Pond Aquaculture (POND)

POND is a recent EDSS/IPS developed for the management of an entire aquaculture pond facility including species/facility customisation for particular aquaculture operations, economic and biomass forecasting, operational lot management, water quality and sediment management, and estimation of feed and fertiliser requirements. The main focus of POND is to provide a view of the pond dynamics at both the individual pond level as well as the facility level (Nath, Bolte & Ernst[9]). It is being developed by the Biosystems Analysis Group in the Department of Bioresource Engineering at Oregon State University and is supported by the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSPP) funded in part by the U.S. Agency for International Development. POND grew around an earlier decision tool called PONDCLASS which provided analytical tools for fertilisation and liming requirements for aquaculture ponds. POND now encompasses four general functional areas: (a) estimation of fertilisation and liming requirements for individual ponds, (b) pond simulation models, (c) economic analysis, and (d) parameter estimation (see figure 3).

The fertilisation recommendation schedules are based on linear programming models developed earlier by PONDCLASS and tested on several sites in Asia and Honduras. The objective of this module is to provide the least-cost combination of fertilisers that meet nutrient requirements of a pond. The simulation modules of POND are a collection of analytical, deterministic formulae that address various pond dynamics. These formulae are expressed in terms of ordinary differential equations and are solved numerically. The simulation capability of POND is powerful and can be used to perform what-if analysis. POND's simulation models are organised into a 3-level hierarchy as shown in figure 3. Level 1 models are concerned with predicting fish growth based on a simple view of the pond including water and heat sources and sinks, fertiliser application, feed, pond temperature and volume. Level 2 models includes prediction of phytoplankton, zooplankton and nutrient dynamics (nitrogen, phosphorus and total carbon). Level 3 models incorporate the functionality of the first two levels and includes additional capabilities for simulating bacterial kinetics and detailed water quality and sediment dynamics where relevant for certain culture practices. User-specified feeding and fertilisation schedules are matched with predicted nutrient mass balances to estimate nutrient consumption and production rates.
POND includes economic forecasting in the form of enterprise budgets. The user inputs various interest rates and income sources and when the simulation is complete, POND generates a report of costs based on an areal, unit of production, and facility basis. This module permits the user to quickly generate income/cost strategies based on various facility configurations. The parameter estimation module is used to calibrate best-fit model parameters for different species, locations or management strategies. The calibration process permits the user to adjust model parameters based on their experience or by matching actual growth data of other species. The functional modules of POND might be thought of as the MBMS of the system. The dialogue manager of POND is windows-based and very flexible. Graphical displays of information are easily generated in a variety of formats. The DBMS is simple but adequate for retrieving ASCII data stored in flat files. The purpose of the DBMS is to supply information for the simulation models. The databases (files) in POND are managed by a consistent dialogue interface that allows the user to browse, add, delete, copy and save records. A free download of the software and user manual is available at the following internet address: http://biosys.bre.orst.edu/pond/pond.htm.

3.3 Decision Support Tool For Rating Soil and Water Information For Aquaculture Pond Location (DESTA)

DESTA is a decision support tool for rating soil and water characteristics for new aquaculture facilities. It was recently developed by Stagnitti[10]. The software is based on a conceptual framework developed earlier by Hajek & Boyd[11]. The user of DESTA is requested to enter values for some 50 environmental parameters that potentially effect the development or operation of new ponds (see figure 4). DESTA produces limitation ratings for each environmental variable supplied by the user. User responses are classed into slight, moderate or severe limitation ratings. Slight ratings indicate that in-situ soils or water supplies have properties favourable to the
design, construction, operational management and/or maintenance of the aquaculture facility. Moderate ratings indicate that the environmental parameter has properties that require attention. The degree of limitation can be reduced only by special planning, design, management or maintenance. Severe limitations indicate one or more properties of the soil or water supplies are likely to produce a significant effect on the successful operation of the pond or facility. In this case, significant cost and effort are required to overcome severe limitations. Severe limitations consequently may force a potential site to become economically non-viable. User inputs are required in three main sections: (a) soil limitation ratings for excavated ponds, or soil limitation ratings for pond embankments, dikes and levees, (b) source-water limitations, and (c) watershed features and water availability (see figure 4).

Soil Limitation Ratings

Excavated Ponds

Raised Embankments, Levees & Dikes

- depth to sulfidic layer
- organic layer thickness
- exchangeable acidity
- lime requirement
- soil pH
- clay content
- slope of terrain
- water table depth
- flood frequency
- % of small/large stones
- organic matter content
- depth to bedrock
- soil engineering class
- shrink-swell potential
- erodibility

Source-Water Quality Limitations

- brackish/freshwater
- TDS
- salinity
- pH
- alkalinity
- hardness
- secchi disk visibility
- mineral activity
- turbidity
- DO
- gas bubble pressure
- iron content
- orthophosphate content
- carbon dioxide
- COD
- ammonia content
- nitrite content
- hydrogen sulfide content
- chlorine content
- toxic materials

Water Availability & Watershed Limitations

- water budget
- inflow rate
- pumping head
- rainfall seasonality
- vegetative cover
- runoff/pond volume ratio

DESTA Probability Assessment

Figure 4: DESTA system overview.

DESTA provides a tabular report, grading all environmental variables into limitation classes and provided that sufficient information has been entered by the user, DESTA will make a probability estimate of the potential success of a new venture. If very few severe or moderate limitations in the environmental parameters are found, then a high probability assessment will result. If there is insufficient information supplied by the user, then DESTA will report only the limitation ratings for specified environmental parameters and no probability assessment is made. At this stage, the user cannot not adjust the importance ratings on the environmental parameters, nor can s/he adjust the ranges of values which determine which limitation class a particular environmental parameter value might lie in. However, DESTA will be modified soon to permit this. A beta 1 version of DESTA is freely available at the following internet site: http://www.cm.deakin.edu.au/~frankst/.
4 Systems Comparison and Classification

A conceptual model of a generic EDSS/IPS was developed earlier in this paper. The knowledge and decision requirements for aquaculture were outlined as well. The conceptual model for EDSS/IPS development and the decision environment for aquaculture can serve as invaluable tools for potential designers of new decision support systems for aquaculture. The framework outlined in this paper is also useful for comparing and contrasting existing systems’ functionality. Three specific EDSS/IPS for aquaculture have been discussed. Using the criteria developed in section 2, a summary of their capabilities is presented in Table 1.

Table 1: Systems comparisons using the conceptual framework in figure 1.

<table>
<thead>
<tr>
<th>System</th>
<th>POND</th>
<th>ARMS</th>
<th>DESTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1. Task structure</td>
<td>Structured</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Semi-Structured</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Unstructured</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>A2. Management-level supported</td>
<td>Technicians</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Pond managers</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Executive/Financial/Administrative</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>A3. Decision phase supported</td>
<td>Identify &amp; define problems</td>
<td>Limited</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Identify opportunities and outcomes</td>
<td>Limited</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>What-if scenarios</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Probabilistic assessment of outcomes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Generates summaries and reports</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Generates graphical and tabular summaries</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Support for strategic decision making</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td></td>
<td>Support for tactical decision making</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>B1. Database management</td>
<td>Interacts with database/s</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Database/s exclusive to EDSS/IPS</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Distributive databases</td>
<td>No</td>
<td>No</td>
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<tr>
<td></td>
<td>DBMS queries and other functions</td>
<td>Simple</td>
<td>Simple</td>
</tr>
<tr>
<td></td>
<td>Extraction of data from several sources</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>B2. Model management</td>
<td>Quantitative modelling &amp; statistical analysis</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Decision analysis &amp; modelling</td>
<td>Limited</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Models interact with DBMS</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Simulation &amp; Forecasting</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>B3. User Interface/Dialogue Management</td>
<td>Command line/Power-user</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Interactive/Menu-driven</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>On-line help</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>C1. Required expertise level of user</td>
<td>Computer skills (High, Moderate Low)</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Quantitative skills (High, Moderate Low)</td>
<td>Moderate</td>
<td>Low</td>
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<tr>
<td></td>
<td>Discipline knowledge level (aquaculture)</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>C2. Usage pattern and operation</td>
<td>Single direct use</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Group DSS</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Links to external CBIS’s</td>
<td>No</td>
<td>Limited</td>
</tr>
<tr>
<td>Implementation</td>
<td>Operating system</td>
<td>Windows 3.1</td>
<td>DOS 4.0</td>
</tr>
<tr>
<td></td>
<td>Minimum platform</td>
<td>386 IBM</td>
<td>286 IBM</td>
</tr>
<tr>
<td></td>
<td>Minimum storage requirements (Mb)</td>
<td>1.5</td>
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<tr>
<td></td>
<td>Minimum memory requirements (Mb)</td>
<td>4</td>
<td>2</td>
</tr>
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</table>

Conclusion

We have introduced a framework for the application of EDSS/IPS technology in aquaculture and have shown that it may contribute to improved design and management of environmental data and models. Using this framework several current EDSS/IPS's developed for the aquaculture industry have been contrasted and reviewed. Common features of these systems are powerful information
processing and modeling routines that are supported by user-friendly, visually-interactive interfaces or dialogue managers. Using advanced simulation modules, prediction tools and decision analysis, EDSS/IPS’s for aquaculture significantly reduce the time currently spent by managers, planners and researchers in manipulating data and enhances the quality of experimental reports. The ability to anticipate experimental outcomes by calibrating or simulating various management or production practices without the need to physically conduct the experiment is extremely cost and time effective and reduces the risk of production failure and poor economic performance. Indeed the costs associated with development of EDSS/IPS’s are likely to be minuscule in comparison to the costs of constructing an aquaculture facility. EDSS/IPS’s are therefore an important innovation to aquaculture. The challenge for future EDSS/IPS development is the need to better integrate with on-line distributed data sources such as satellite imagery and weather data.

References