

1997

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El-Gayar, O. F. (1997). The use of information technology in aquaculture management. *Aquaculture Economics & Management*, 1(1-2), 109-128.

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Article in *Aquaculture Economics & Management* · March 1997

DOI: 10.1080/13657309709380207

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The Use of Information Technology in Aquaculture Management

By

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Abstract

The recent advances in information technology (IT) has profound impacts on all walks of life and aquaculture is no exception. The growing importance of aquaculture as an alternative source of protein has further emphasized the need to adapt and develop advanced IT for the better management of aquaculture facilities as well as the regional planning for aquaculture development.

It is the objective of this paper to review the use and potential prospects of IT in aquaculture management. The information technologies considered are instrumentation and process control, data management, computerized models, decision support systems, artificial intelligence and expert systems, image processing and pattern recognition, geographical information systems, and information centers and networks. The review include a brief introduction of each of the aforementioned technologies followed by a survey of their current application as well as potential use in aquaculture management.

Keywords: Aquaculture; Information technology; Instrumentation; Process control; Data management; Computerized models; Decision support systems; Artificial intelligence; Expert systems; Image processing; Pattern recognition; Geographical information systems; Computer networks.

1- Introduction

Information technology (IT) refers to the science of information handling and processing made possible by the convergence of the technologies of computing, microelectronics and telecommunications (Lynch 1991). The recent advances in IT has profound impacts on all walks of life. Indeed, we are now experiencing the information age. Currently, aquaculture is one of the fields which are looked upon as a potential application domain for advanced IT.

Aquaculture is the science and art of cultivating aquatic species. The significant importance of aquaculture stems from the fact that world wide demand for quality fish protein is increasing dramatically, while in the meantime, the natural fisheries are near their maximum sustainable yield (MSY) levels and are in the process of depletion. In addition, when fish are compared to other alternative sources of protein, e.g., terrestrial livestock, the following can be deduced:

Fish are non-competitive with human beings in their habitat and nutrition. (1)

Fish have better feed conversion ratios. (2)

Fish protein is of a better quality as it is associated with a low content of (3) calories, a low content of saturated fatty acids, and a high content of poly-
-3) which is a healthier diet with respect to its Ω unsaturated fatty acids (contribution to cancer, heart diseases, vascular diseases and rheumatic diseases.

The implications of such an increase in demand are twofold. First, aquaculture is moving from extensive to semi-intensive or intensive operations and the increasing complexity requires better management. Moreover, the decision making process is further complicated because of the dynamic and stochastic nature of the biological, physical and economic environments, thereby emphasizing the need for adapting advanced IT such as instrumentation and control, computerized data management, decision support systems, and expert systems for better management of aquacultural facilities.

Second, more sincere effort is dedicated towards aquaculture development as an alternative source of high quality cheap protein, particularly for developing countries where protein shortages already exist. Such effort is led by local governments as well as several international organizations that are involved in planning and financing aquaculture development in various regions of the world. The World Bank, the Food and Agriculture Organization of the United Nations, and the United States Agency for International Development are just a few examples of such organizations. However, and due to the wide range of issues involved in aquaculture development, the development and use of decision aids (such as decision support systems) as well as the application of new IT techniques (such as geographical information systems) for regional aquacultural development is inevitable.

This paper is written for the aquaculture practitioner at the farm level as well as the regional level. It seeks to review the use and potential of IT in aquaculture management. Specifically, the paper seeks to identify the potential benefits of the use of IT in aquaculture, the current status of IT in aquaculture, and the main obstacles for adoption. Information technologies are reviewed in sections 2 through 9 and include: instrumentation and process control, data management, computerized models, decision support systems, artificial intelligence and expert systems, image processing and pattern recognition, geographical information systems, and information centers and computer networks.

Finally, section 10 concludes the paper.

2- Instrumentation and process control

Instrumentation is the means of primary sensing of information used by the feedback loop of an automatically controlled system as well as by human operators of manually controlled systems (Zahradnik 1987). On the other hand, process control of systems traditionally refers to the art of monitoring the system visually and with analytical

measurement techniques for the purpose of providing manual control of the inputs to guide the system to the desired goal (Fridley 1987). However, nowadays, process control often refers to the use of instrumentation techniques for providing feedback information on the controlled system. Information can then be analyzed and appropriate actions initiated for controlling the system. In effect, process control is synonymous to the automatic control of an aquaculture production process.

From an aquaculture management perspective, instrumentation and process control can prove to be highly beneficial. In that regard, Zahradnik (1987) identifies two major applications where instrumentation can have the greatest potential in aquaculture. The first application area lies in environmental monitoring and control. The importance of which stems from the close correlation between the environmental conditions and factors affecting aquaculture production such as animal health, feed utilization, animal growth rates, stocking densities and waste management. Example of such environmental parameters include temperature, pH, salinity, dissolved oxygen, ammonia, nitrates, nitrites, suspended solids, turbidity, and water flow rates. The second application area lies in fish stock inventory assessment. The importance of which stems from the direct relation between fish stock quantities, feed efficiency, and disease control. Current stock inventory practice primarily involves stock sampling and mortality records. The use of visual sensors together with appropriate image processing and pattern recognition algorithms is particularly promising for adequately sensing fish biomass, a discussion of which is presented in section 7.

With regard to process control, Fridley (1987) identifies the potential benefits of the application of process control in aquaculture as:

- reducing cost, primarily realized by reducing time, effort and labor as well as optimizing resource use. For example, feeding can be matched closely with demand, thereby reducing losses due to unconsumed food.

- enhancing or extending management capabilities, primarily through allowing the operator to control factors that are impractical to control manually.
- facilitating production management and scheduling.
- improving reliability and safety of the operation.

Moreover, Balchen (1989) notes that the purpose of instrumentation and process

control in aquaculture is to improve:

- productivity, which depends upon continuous precise monitoring and control of environmental factors as noted earlier.
- product quality, which enhances profits and is determined by environmental factors as well as feed composition and the level of physical activities.
- product availability made possible by monitoring and controlling all pertinent parameters necessary to arrive at the optimal yield at the desired time to satisfy market demand.
- operation safety, attained by utilizing remotely operated actuators, thereby reducing the need for physical interaction between the operator and the process unit, particularly in hazardous situations.
- Environmental impact reduction, attained through monitoring and controlling aquacultural effluents in order to meet official regulations.

In general, there is a substantial literature on instrumentation and process control and the technology is well developed at the commercial level. However, the applications of the technology in aquaculture are few relative to manufacturing and agriculture. Table 1 lists some of the recent applications of instrumentation and process control in aquaculture.

To illustrate the application of instrumentation and process control in aquaculture, we present a few specific examples of such applications. With regard to instrumentation, Bjordal et al. (1987) describe a system for monitoring the behavior of salmon culture as

well as the environmental factors and different rearing conditions. The main objective of this work is to minimize the stress level of the fish by optimizing critical factors in order to avoid disease and to increase growth and quality of fish. Using appropriate sensors, environmental factors monitored are temperature, salinity, oxygen, current, tide, meteorological data, and light intensity. Sensors are interfaced to a computer where trend and historical analysis of stored data is performed. While such system is primarily for identifying the optimal levels of such environmental parameters and rearing conditions for salmon i.e., for research purposes. Once such levels and conditions are identified a similar system for the management of aquaculture facilities can be utilized for providing continuous monitoring of the parameters of concern and alarming the operator if any such parameters is out of its prescribed optimum range.

With regard to process control, Hansen (1987) presents a computer system for the control and monitoring of aquaculture plants. The system includes a special software module for handling different tasks such as data gathering, automatic control, alarming, logging, trend analysis, and reporting. With regard to monitoring and control, a software library is available for water quality, water distribution, heating systems, biomass, and feeding systems. The system is of a flexible configuration and can thus be adapted to the individual farm needs.

It should be noted, that the above examples are by no means exhaustive, they merely illustrate how computers can be used for monitoring and control in aquaculture facilities. However, in practice, the adoption of instrumentation and process control technology by fish farmers is hindered for a number of reasons:

- while it is easy to attach a number to the cost of adopting such a technology, it is not the case when trying to estimate the perceived benefits, thereby complicating the investment appraisal process.

farmers tend to distrust the use of the technology in favor of the more traditional approach of relying on visual observation and their own instinct and experience for aquaculture management. •

the harsh aquaculture production environment, particularly marine aquaculture, poses real challenges to the reliable operation of sensors and actuators. •

Nevertheless, the increasing awareness of fish farmers and the increasing availability of computer literate personnel would contribute towards the successful adoption of this technology. Also, the rapid technological progress is likely to produce sensors and equipment that would operate reliably in the harsh aquaculture environment at a reasonable cost.

3- Data Management

Aquaculture production is a complex undertaking involving a system of interwoven biological processes. The proper management of such system requires keeping track of a large amount of data. Moreover, and due to the dynamic nature of the production process and the high risk involved in making an inappropriate decision, the quality of the data and its timely availability are of prime importance. Data management thus becomes a vital task for aquaculture management.

While manual data management can be suitable for a small scale operation, the task quickly becomes difficult and complicated even for a modest farm size. In that regard, computers possess the processing power and storage capabilities necessary for performing virtually all data management activities such as storing, retrieving, analyzing and presenting data with ease. Moreover, recent advances in computer technology have made powerful computer hardware available at affordable prices with a large variety of ‘off the shelf’ software to choose from. Such software have matured with respect to capabilities and user friendliness to unprecedented levels not even predicted ten years ago.

The potential of computers in data management has spawned the interest of researchers and farmers alike. For example, Muench, Thomsen and Croissant (1986) of Island Science, Inc. present Pond Manager, a production data logging and decision management system for aquaculture. In this system, data are recorded manually and include environmental data such as air temperature, water temperature, salinity, pH, and dissolved oxygen, as well as information pertaining to feed, harvest, and stocking. Besides providing the basic data management routines for storing, retrieving, and reporting data, Pond Manager supports the management of various farm jobs by providing guidance to farm operators based on previously stored data. For example, feed scheduled per pond is printed on the next day's field data sheet, thereby guiding farm operators.

As another example, Varvarigos and Horne (1987) propose a microcomputer based data management system for aquaculture. Their system is primarily composed of a desktop microcomputer for centrally storing and analyzing farm data using a Lotus[®]1-2-3 worksheet, a pocket computer for directly recording field data, a printer and a modem for remote downloading of field data from the pocket computer to the desktop computer. Environmental and stock data are recorded in a standard form presenting the results in a daily, or weekly format, as required with all the computations performed by the computer.

Killcreas (1988), documents FISHY 2.0, a pond-oriented, menu-driven microcomputer program that is designed to allow fish farmers to accumulate and analyze data regarding fish production operations such as stocking, feeding, moving, mortality and harvest. Moreover, FISHY 2.0 is able to predict fish growth based on previously stored fish growth parameters. Fish growth estimates can then be used to compute probable harvest dates and weights. Another feature of FISHY 2.0 is the ability to automatically generate day-to-day records of events associated with the production operation. Such records can then be analyzed using RECORDS (Killcreas 1988) or using a spreadsheet such as LOTUS[®] 1-2-3.

It should be noted that the above examples of the application of computers to aquaculture data management is by no means exhaustive. Numerous systems are available or custom designed and are rarely reported in the literature. Moreover, the availability of powerful user-friendly, 'off the shelf', database and spreadsheet software packages make it possible for the individual fish farmer to effectively manage and analyze his own production data with minimal technical expertise.

Nevertheless, while sound data records are invaluable for proper decisions, computerization doesn't come without cost and thus a cost/benefit analysis is always warranted. In that regard, when appraising the investment, the computerized system should be capable of offering a return which at least breaks even with the investment and running costs. Typical capital expenditure include the necessary hardware and software. The hardware consists of a computer system with adequate storage capacity and a printer for printing reports. The software can either be purchased 'off the shelf', custom made or provided through an extension service. Operating expenditure is primarily composed of the operator's time required to enter and analyze the data. On the other hand, benefits are in the form of a more efficient and thus more profitable operation. In some cases, it would be difficult to quantify the potential benefits, however, as the scale of operation is increased, particularly through intensification, the adoption of computer database management can be more easily justified.

4- Computerized Models

In general, a model is a simplified representation of reality for the purpose of experimenting with alternative strategies (Leung 1986). In that regard, Cuenco (1989) provides the following reasons on "why is there a need to model aquacultural systems?"

- Modeling serves as a powerful tool for the formulation, examination and improvement of hypotheses and theories.

Models can make intelligent predictions about the consequences of various management strategies on the system. •

Modeling provides a working tool to conduct numerous "what if" experiments quickly and can evaluate the consequences of various hypotheses or management strategies of large and complex aquacultural systems which are seldom possible in their natural environment. •

Models serve as mechanisms to identify what is not known by organizing what is known within the framework of the models. •

Models facilitate the evaluation of complex interactions of aquacultural systems. •

Modeling accelerates the use of more quantitative and precise methods in aquaculture research. •

Models put together knowledge from theoretical, laboratory and field studies into a consistent whole so as to identify areas where knowledge is lacking, sparse or inconsistent. •

To summarize, model or modeling is used because of economy, availability, and information handling. It may cost less to derive knowledge from the model than the real world counterpart such as a large complex aquacultural system. The model may represent an aquacultural system which does not exist or cannot be easily manipulated. In addition, the model may provide a convenient medium to collect and/or transmit information.

In aquaculture, models are primarily numerical and thus computationally intensive.

In that regard, computers can provide the processing capabilities needed to make use of such models. Aquaculture models can be classified as biological, economic, bio-economic, and bio-physical (Leung 1993). Of particular relevance to aquaculture management are bio-economic models which are a mathematical description of an aquaculture enterprise relating its biological, physical, and economic elements for the purpose of assisting producers and decision makers in identifying optimal production system design and

operation management strategies (Leung 1993). The work by Allen et al. (1984) provides a comprehensive survey of aquacultural bio-economic models developed in the decade before 1984 (Table 2), while Leung (1993) reviews the modeling effort since 1984 (Table 3). Moreover, Leung (1993) indicates that while applications are few compared to agriculture, recent applications show that bio-economic modeling in aquaculture has followed if not paralleled the latest development in those for agriculture.

As an example of a modeling application in aquaculture at the farm level, Gempesaw, Lipton and Goggin (1993) present AQUASIM PC, a microcomputer based program for providing farm managers with an easy to use tool to help analyze aquaculture business decisions based on the manager's expectation of key production and market parameters. AQUASIM PC allows the manager to quantify uncertainty around production performance and prices, analyzes the effect of this uncertainty on financial performance, and associates probabilities to financial outcomes.

On the other hand, at the regional level, Sylvia and Anderson (1993) present a bio-economic model for developing information for private and public salmon aquaculture policy strategies when environmental issues are important. The two levels of analysis refer to the two actors - salmon producers and policy makers. While the producers are assumed to maximize profits, the public policy makers are faced with four policy objectives including revenue, benthic quality, profits, and tax revenues. The policy instruments in their study include the number of allowable sites and the effluent tax.

In practice, however, the issue of concern is how many of these models are available for the practicing fish farmer or decision maker. After all, to make use of such models requires a reasonable understanding of mathematics and the use of a computer to solve the often complex system of equations. Furthermore, the survey conducted by Varvarigos (1991) already indicates that IT is not a priority among fish farm managers. All of which boils down to the conclusion that although aquaculture models are systematically

developed by modelers from a multitude of disciplines and a large portion of such models would have a direct impact on aquaculture management, such models are underutilized by the practicing fish farmer.

The future, however, has a lot to offer. In fact, the recent technological developments in computer user interface accompanied with the adoption of decision support system technology provide the tools for modelers to bring their models to their ultimate users.

5- Decision Support Systems

In effect, decision support systems (DSS) technology can contribute towards making models available to the aquaculture practitioner by supporting the models with an appropriate user interface and a data base management system. By making such ever-increasing number of aquaculture models available to the aquaculture practitioner, decision support systems can significantly enhance the effectiveness of the decision making process, both at the farm level as well as at the regional level.

While there is no universally accepted definition of what constitutes a DSS, Sprague and Carlson (1982) give a definition that captures the key aspects of decision support systems. They define a DSS as an interactive computer-based system that helps decision makers utilize data and models to solve managerial problems. Furthermore, Sprague and Carlson (1982), propose a framework which regards a DSS to be composed primarily of three main components: a dialog component, a data base component and a modeling component as shown in Figure 1.

The dialog component is primarily concerned with handling the interface between the system components and the user. Typical capabilities of the dialog component include, the ability to handle a variety of dialog styles, to accommodate user actions with a variety of input devices, to present data in a variety of formats, to provide context sensitive on-line

help, to provide context sensitive error messages, and to allow the user to control processing in a flexible and easy manner.

The data management component is primarily concerned with all the data management activities. Typical capabilities of the data management component include, the ability to provide data maintenance and housekeeping tasks easily and quickly, to capture/extract data from a variety of sources, to portray logical data structures in user terms, and to handle personal and unofficial data so that users can experiment with alternatives based on their own judgments.

The modeling component is primarily concerned with the management of the model base. Typical capabilities of the model management component include, the ability to provide model maintenance and housekeeping tasks easily and quickly as well as the ability to provide interpretation to model results.

Decision support systems are already being used as decision aids to enhance the effectiveness of the decision making process in organizations in a variety of disciplines. Eom and Lee (1990) present a survey of the literature on the applications of DSS from 1971 through April 1988. A total of 203 DSS applications articles are compiled and classified according to 16 different application areas. In Table 4, the results of their survey is presented. This survey strongly indicates that decision support systems are increasingly applied in profit and non-profit organizations such as government, military, health care and education. Moreover, 73% of the articles were published in the last 8 years, but only 27% during the first 10 years (1971-1980) indicating that the number of DSS applications is increasing at an increasing rate. However, the number of DSS applications in aquaculture are relatively few.

In that respect, Ernst, Bolte and Nath (1993) developed a DSS for finfish aquaculture that is entirely concerned with operational level issues. This DSS consists of an integrated set of computerized tools, including mathematical programming and logical

algorithms, simulation models, expert systems and graphical user interface that provide applied and integrated expertise in fish genetics, biology and culture, aquatic chemistry, engineering and ecosystem processes.

On the other hand, at the regional level, El-Gayar, Leung and Rowland (1994) present the preliminary design of a prototype DSS that would aid the decision maker or the planner make choices regarding the planning and the development of the aquaculture industry for a given region. The system is composed of three main components: a model base containing all relevant models which are essentially multiple objective in nature, a data base containing all relevant data, and a dialog component providing a user interface to the other two primary components of the system. Based on the models and data stored in the model base and the data base respectively, the system would answer questions such as: what species to grow? what technology to use? and how much to grow of each species and/or technology?

In sum, the rapid increase in the number of models developed for aquaculture, together with their associated data requirements, emphasize the importance of developing DSS that pool models and data into one easy to use computer system suitable for practical (and not only research) applications either operational or strategic. The utilization of DSS technology would serve as a delivery system bringing aquaculture models from the esoteric world of the academia to the exoteric world of practical application.

6- Artificial Intelligence and Expert Systems

Artificial intelligence (AI) is a field at the intersection of computer science, cognitive psychology, logic, linguistics, and mathematics. Although there is no universal definition of AI or AI-based systems, however, one can loosely define AI as the field of study concerned with the development of tools and techniques for solving problems that are normally associated with human intelligence. In briefly presenting basic AI techniques

and application areas it is helpful to adopt a modified version of Nilsson's 'onion' model shown in Figure (2) and in which the basic AI techniques and tools are at the core and are surrounded by the main application areas of AI, sometimes considered as sub fields within AI. In the following paragraphs a brief description of each of the layers of the onion model is presented.

Knowledge representation is identified as a major AI constituent as it is realized that intelligent behavior is not so much due to reasoning methods as to a large stock of relevant and readily available knowledge. Several knowledge representation techniques have been developed for AI purposes, of which the most important are predicate logic, production rules, frames and semantic nets (Rauch-Hindin 1986; Schutzer 1986).

Reasoning and logic is one property that sets an AI system apart from more conventional programs. There are many different forms of reasoning: formal reasoning, procedural reasoning, reasoning by analogy, generalization and abstraction, default reasoning, and abduction. However, most current AI programs are based on the foundations of formal reasoning often referred to as resolution theorem proving. The forward and backward inference control strategies commonly found in rule-based expert systems are in fact special cases of the resolution principle (Schutzer 1986).

In AI, problems are often represented using a state-space approach in which problem solving is reduced to the process of merely searching for the goal state starting from some initial state. There are orderly search procedures that guarantee that all paths will be tried once, these are known as uninformed search methods and for AI problems they normally lead to a combinatorial explosion. Search is thus speeded up by using specific knowledge about the application area. Such informed search strategies are known as heuristic search. Examples of such strategies are the best-first and the branch and bound (Schutzer 1986).

As AI systems requirements differ from those of traditional programming, special languages and environments are needed to cater for these differences and thus facilitate and speed up AI systems development. The main AI languages are LISP and PROLOG (Schutzer 1986). However, in addition to languages, other integrated development environments are also used such as expert systems 'shells' for expert systems development (Rauch-Hindin 1986; Schutzer 1986).

Expert systems (ES), sometimes referred to as knowledge-based systems (KBS), have been a great success area for AI over the last 15 years. Expert systems are programs that use knowledge and inferential procedures to solve problems in specific problem domains. The source of the knowledge is primarily experimental human knowledge or expertise. ES are currently applied in a multitude of problem domains such as in decision support e.g., as a financial advisor, in troubleshooting and maintenance, in medical diagnosis, and in process control (Rauch-Hindin 1986; Schutzer 1986). ES are commonly developed using shells which are a collection of expert systems building tools that are designed to assist the developer by minimizing the amount of specialized knowledge, engineering and programming skills required to build an expert system. Several ES shells are commercially available in the market such as KEE by Intellicorp and EXSYS by EXSYS Inc. (Rauch-Hindin 1986; Schutzer 1986).

Natural language processing (NLP), is concerned with the understanding and generating of text. Applications of NLP are primarily in question-answering systems, in intelligent user interfaces to computer programs, in intelligent computer aided instruction and in system building tools (Rauch-Hindin 1986; Schutzer 1986).

Perception is a basic process of intelligence, it basically involves interpreting the raw signals we receive through our senses e.g., vision, hearing, and touch using the concepts and knowledge we have previously acquired and stored in our cognitive processor (Schutzer 1986). Machine perception is thus concerned with the development of techniques

that enable computers to understand and deal with information received through various sensors. Machine perception can be further divided into two broad fields: computer vision and speech understanding. Computer vision is concerned with developing techniques that enable computers to understand the output of 2-D and 3-D sensors i.e., visual information. Speech understanding, on the other hand, can be considered as an extension of NLP and is concerned with understanding spoken speech.

Planning can be defined as the design process for selecting and combining together individual actions into sequences to achieve goals. Some basic AI planning systems are now being developed that are independent of the application area (Schutzer 1986).

The process of learning has attracted the attention of researchers for a considerable amount of time. In AI, research into learning includes the desire not only to understand how people learn, but to provide computers with the ability to learn and to be taught rather than having to be programmed. It should be noted however that the practical application of such research is still in its infancy (Schutzer 1986).

With regard to aquaculture, AI applications are just emerging. In 1989, a workshop was held with the purpose of exploring the ways in which the considerable body of knowledge developed in this computer related discipline can be applied in fisheries and aquaculture management (Palmer 1989). A major outcome of this Workshop is the determination that there is a distinct need to examine the potential for knowledge-based systems application in fisheries science and aquaculture. The primary motivation of which is to take advantage of advances in computer sciences and apply these to the needs of fisheries sciences and aquaculture (Palmer 1989). The Workshop identified areas in aquaculture where the application of AI approaches is warranted. Table 5 present a list of such applications together with the associated AI approach. In the next paragraphs, a brief description of each such application is presented together with any relevant implementations.

Referring to the section on the use of computers for control and monitoring tasks, particularly in automating intensive systems, we say that the ever increasing complexity of such monitoring and control systems and the high risk involved in dealing with a stock of high economic value per unit mass indicate the need for timely intelligent decisions many of which cannot be performed by traditional process control software. Such applications are already emerging. In that regard, Padala (1990) presents the RIAX prototype system of Umecorp, Inc. that uses an ES to monitor and control a recirculating intensive aquaculture system. The Expert Controller (EC) module in RIAX uses rules based on an expert's knowledge and experience to deliver control strategies to system activators. The EC can also be programmed to send data to a computer simulation, run tests and examine the results to decide upon appropriate responses. Another application also involving the automation of recirculating aquaculture systems is proposed by Lee (1993). In this application the control system is interfaced to an ES shell in order to integrate management of the aquaculture and filtration systems. The author indicates that the technology results in the real-time monitoring and control of aquaculture systems analogous to that used by human managers.

The establishment of any aquaculture enterprise frequently involves the issue of site selection. The importance of this issue stems from the need to match the culture requirements of the species under consideration with those available on site in a manner that ensures growth and development of the cultured species. The problems involved with site selection are not due to the unavailability of information, but is due to the fact that the information available is not easily accessible and is usually not in a form that is immediately useful to the potential user (Palmer 1989). Knowledge-based systems, when coupled with a DSS and a geographical information system type database can assist in the accessibility of information, thereby aiding the selection process. Stokoe and Gray (1990) report the development of AQUASITE, a computer site assessment system utilizing an ES

shell. The system considers the full range of site assessment criteria and the main species of interest for aquaculture in the Atlantic region of Canada. Another closely related issue to site selection is environmental impact assessment. In that regard, Haakanson and Wallin (1991) address questions concerning the basic setup of an ES applied to environmental consequence analysis for natural aquatic ecosystems with particular emphasis on nutrient emissions from fish cage farms in coastal areas.

Disease diagnosis and treatment in aquaculture is another area where AI can be of assistance in aquaculture operation. In fact, AI applications in medicine, particularly in the diagnosis and treatment of diseases, already proved reasonably successful (Rauch-Hindin 1986) and there is no reason why that should not be the case in aquaculture. The availability of such disease diagnosis and treatment systems can provide adequate diagnostic and treatment capabilities to on-farm operators in a timely manner thereby contributing to the overall success of the aquaculture operation. Bossu, Mantoni and Saroglia (1989) present an ES for the diagnosis and the relative therapeutic treatment of sea bass (*D. labrax*) reared in thermal effluents. The system utilizes a data base containing data derived from eight years of observations at the experimental station of Torre Valdaliga (Rome, Italy), thereby making it possible to date back to cases of disease already verified, to the environmental factors possibly associated with them, and to the therapeutic treatment used in their effects. The assessment of the impact of non-indigenous species is another application where AI can prove beneficial particularly, when current thinking leads to the conclusion that without the introduction of non-indigenous species, commercial aquaculture will not grow into a major industry (Palmer 1989). Unfortunately, up to our knowledge, no actual applications are reported in the literature.

Another application areas for AI in aquaculture are in production, processing and handling of aquaculture products. Examples include examining fish eggs in an incubator and determining which oyster on a conveyor belt has the desired orientation. Such

applications, however, are still investigated using traditional image processing and pattern recognition techniques as described in section 7.

The measurement of physical properties such as size, shape and hardness of aquatic products is particularly important for the design of processing equipment. AI can assist in providing appropriate techniques for the analysis and interpretation of information acquired through a variety of technologies including, but not limited to, computer-based acoustics, optical, chemical and mechanical methods.

Computer-aided design of aquaculture facilities is another application where AI can prove beneficial. Several computer-aided systems design are reported in the literature, however, their use of AI techniques is not obvious.

Finally, training aids and education would be quite valuable for providing managers of aquaculture facilities expertise based on the experience of others (Palmer 1989). In that regard, intelligent computer-assisted learning and instruction can provide an inexpensive means of refining management skills in an environment that avoids the costly ramifications of error (Palmer 1989). Unfortunately, no such system is reported in the literature. However, on the education side, Hanfman, Bielawaki and Lemand (1989) present REGIS, a regional information system for African aquaculture. REGIS merges hypermedia and expert systems into a useful easy-to-access information retrieval system that focuses on African aquaculture. The ES component acts as an advisor on both small and commercial scale aquaculture ventures in a particular region.

In summary, AI has a lot to offer to aquaculture in general and aquaculture management in particular, both on the farm-level and on a regulatory level. Unfortunately, current applications are few as compared to business and manufacturing. However, with the continuous advancement in computer hardware and software, the future of AI in aquaculture is indeed promising.

7- Image Processing and Pattern Recognition

Image processing (IP) is primarily concerned with the development of computer algorithms for the processing of digital images so that the result is more suitable than the original image for subsequent processing and use. For example, smoothing algorithms are used for reducing noise and other spurious effects that may be present in an image as a result of sampling, transmission or disturbance in the environment during image acquisition. Another example is image enhancement algorithms that are used to compensate for effects such as shadows and 'hot spot' reflectance that may result in an acquired image in response to improper illumination.

On the other hand, pattern recognition (PR) is primarily concerned with extracting features regarding the content of an image and then recognizing the different components of the image. Several recognition approaches are proposed in the literature ranging from the use of statistical techniques to the utilization of AI concepts and techniques. For the sake of clarity, AI-based pattern recognition systems are reviewed in section 6 as machine perception or more specifically computer vision where the aim is of image understanding and not mere recognition.

In aquaculture, the application of image processing and pattern recognition techniques are emerging. Table 6 presents a list of such application. In the next paragraphs a brief description of a few examples of such applications is presented.

Petrell, Neufeld and Savage (1993) present an inexpensive Non-invasive Fish Enumeration (NIFE) pattern recognition system. The system does not require artificial lighting or manipulation of the fish. The system is primarily composed of three underwater video cameras that are integrated with a microcomputer-based image analysis system to capture fish images in a marine sea cage. The initial results indicate that the system is able to count the fish within commercial sized sea cages within 5% of the actual count. As the system was still under development as of 1993, the authors neither provided any estimate

on the cost of such system nor its potential success in a commercial aquaculture production setting.

As another example, Foster et al. (1993) present an algorithm for food pellet detection and counting. The system is composed of a microcomputer-based image processing system linked to an under water camera and a video tape recorder. Such application is particularly important in aquaculture management as it allows to reduce food wastage and to ensure that the fish receive the correct dosage of drugs. Unfortunately, improvements are still needed to allow the system to determine the pellet count more accurately.

So and Wheaton (1993) present a computer vision control system to sense, locate and sever the oyster *Crassostrea Virginica* hinge. The overall efficiency varies from 14.2% to 38.7% which may not yet be suitable for commercial applications.

In effect, current applications of IP and PR in aquaculture are new and their commercial viability is still in question. However, services such as non-invasively determining fish biomass, food management, algae count in live food production and image analysis of remote sensing data that IP and PR can provide for aquaculture management, are of particular importance. In that regard, future development of computer technology as well as IP and PR algorithms would certainly make their commercial applications in aquaculture a reality.

8- Geographical Information Systems

Geographical information systems (GIS) can be considered as a collection of integrated computer hardware and software for the purposes of inputting, storing, manipulating, and presenting geographical data as shown in Figure 3 (Meaden and Kapetsky 1991).

In aquaculture, the applications of GIS is proliferating at an unprecedented pace particularly in the field of planning for aquaculture development. In that regard, the need

and importance of GIS application in aquaculture can be summarized as follows:

- there is an urgent need to secure and optimize suitable aquaculture sites (Meaden and Kapetsky 1991).
- the voluminous amount of data to be considered, including, water, land, human resources, and economic data.
- the need for a systematic approach to data acquisition and analysis that is able to cope with a wide range of source data types and origins (Ross, Mendoza and Beveridge 1993).

GIS are already utilized in the planning for aquaculture development. Table 7 presents a list of such applications. As an example of such studies, Kapetsky, McGregor and Nanne (1987), in one of the earliest studies on the use of GIS in aquaculture, assess the capabilities of a GIS and satellite remote sensing to rapidly provide synoptic information to plan for aquaculture development. The region of concern is the Gulf of Nicoya on the Pacific coast of Costa Rica. Utilizing remote sensing data, GIS is used to evaluate locations for three aquaculture development opportunities: inter-tidal, sub-tidal and suspended culture; extensive culture of shrimp and fish in solar salt ponds; and semi-intensive shrimp culture outside of mangrove areas. The criteria for evaluation included salinity, infrastructure and water quality for all culture types. The results indicate that opportunities exist for aquaculture development. However, further ground and water investigations are needed to verify the suitability of individual areas identified before development programs can be planned in detail. The authors then conclude that GIS and satellite remote sensing technologies can be combined to provide a variety of information useful for planning for aquaculture development. However, while this approach is technologically feasible, it can be relatively expensive to implement, particularly in the

context of developing countries. The authors thus suggest that to improve its cost effectiveness, time and expenses for the development of a central GIS facility can be shared

with other departments of the government that are likely to benefit from its services.

As a recent example of GIS applications in aquaculture, Ross, Mendoza and Beveridge (1993), assess the potential of GIS for site selection in coastal aquaculture using as an example salmonid cage culture development in Scotland. The criteria for evaluation included bathymetry, current, shelter, and water quality. The results suggest that a total of 1.26 ha. (6.4% of the total area) are suitable for cage culture. The authors then conclude that the GIS approach to site selection has the potential to give useful results, the reliability of which depends on the accuracy of the source data. The total cost of the GIS approach is about \$9000; \$90 for software, \$1000 for skilled labor and \$7910 for hardware. This is compared to a manual analysis and processing cost of \$2000. However, the authors note that the cost differences is derived from the initial purchase of the required hardware and will reduce rapidly with each subsequent use of the GIS. Moreover, manual assessment produces results which may be biased by subjective personal assumptions and not based on actual bio-technological limitations thereby further justifying the adoption of GIS technology.

In effect, several perceived benefits have promoted the quick expansion of GIS applications in aquaculture. Most important of which include: the ease to analyze different scenarios by varying the initial assumptions and criteria, the possibility to accommodate data from widely differing spatial sources such as field work data, remote sensing imagery and secondary maps, the efficient access to a huge volume of data thereby improving the quality of decisions, and the cost effectiveness realized on the farm level by optimizing its location and on the public level by optimizing resource allocation.

On the other hand, problems do exist with the proper applications of GIS in aquaculture. Most important of which include: the difficulty in quantitatively assessing the

perceived benefits of a particular GIS application for comparison with the projected cost, the extremely slow process of digitizing maps which in turn translates to cost overhead, the potential errors encountered in utilizing much of the poor quality existing hard copies of graphical and tabular data, the shortage of GIS skilled personnel, and the lack of user-friendly interfaces to many existing systems. For a comprehensive review of GIS in aquaculture, we recommend Meaden and Kapetsky (1991).

9- Information centers and computer networks

The ability of computers to store and retrieve large amounts of information in an organized fashion, coupled with the advent of high speed reliable communication systems form the foundations for information centers and computer networks. In aquaculture, Swann, Jensen and Einstein (1995) illustrate the use of the Aquaculture Network Information Center (AquaNIC). AquaNIC contains a wide variety of information that can be either viewed on the user's computer monitor, downloaded via modem, or a copy sent to the user's electronic mail (e-mail) address. Moreover, AquaNIC allows the user to link to other aquaculture databases on the Internet, thereby acting as a gateway to the world's electronic resources in aquaculture.

Benn and Kuhns (1995), introduce FISHNET, a special interest group forum on CompuServe, a commercial, but widely used computer network. In their presentation, the authors demonstrated how the forum's message board can be used for information exchange, toured the various libraries, and demonstrated how to access and acquire information from them. They also demonstrated the live conferencing abilities of the forum.

Another information resource is the Delaware's Aquaculture Resource Center, established in October 1991 by the Delaware Sea Grant Marine Advisory Service (Ewart 1995). The center's collection provides public access to more than 1200 titles including

bibliographies, books, catalogs, extension fact sheets, periodicals, state aquaculture plans, technical reports and videos. Moreover, the center provides access to AquaNIC and other on-line information resources. During its years of operation, the center is proving to be an effective means for organizing and disseminating technical, economic and legal/regulatory information primarily at the state and local levels (Ewart 1995).

Another application is a Compact Disk Read Only Memory (CD-ROM) based electronic information system developed by the Institute for Food and Agricultural Sciences, University of Florida, and is known as the Florida Agricultural Information Retrieval System (FAIRS). FAIRS is a multi-disciplinary, hypermedia (i.e., utilizing different forms of information such as text, images, sound and video clips) database system providing extension personnel and their related industry with a rapid diverse desktop library (Lazur 1995). FAIRS contains over 2,000 agricultural extension publications, building plans and several plant selection programs. The system also offers a special publishing program that allows for existing or new publications, tables, graphs and photographs to be incorporated into electronic handbooks on compact discs. Lazur (1995) notes that FAIRS has greatly increased the counties extension offices' abilities to provide diverse information to their users.

The large volume of diversified aquaculture information made available by the merger of computer database and networking capabilities is invaluable to aquaculture farmers, planners and researchers alike. However, accessing such information involves several issues:

- the acquisition of the necessary hardware represented by a computer system, a modem to interface the computer to the telephone line and a printer to print the desired information.
- the acquisition of appropriate communication software that is responsible for initiating and controlling a communication session.

the acquaintance with some networking and communication terminology necessary for •
setting up the modem and the communication software. •

the existence of a suitable information source and the information required to access •
that source. Such information can be in the form of Internet commands such as •
TELNET and FTP accompanied by the necessary login information such as a user •
identification and password information. •

for information sources only accessible through the Internet, access to an Internet •
gateway is required. For individual fish farmers, Internet gateway access can be •
available through extension services, local universities or from commercial providers. •

For the planner, much of these issues are normally resolved by the information
technology support unit in his/her organization. However, for the individual fish farmer,
the situation is quite different. In fact, without the availability of extension services for
providing the necessary technical support for the initial set-up and ideally, for providing
an Internet gateway access, setting up a computer system for on-line information access
can become a costly and time consuming operation.

Moreover, and as with any farm investment, proper investment appraisal in which
cost is weighted against potential benefit is warranted. Costs include capital expenditure
on the necessary hardware and software, and operating expenditure primarily in the form
of communication costs and a monthly fee for the commercial Internet gateway provider
or the commercial network such as CompuServe or Prodigy. On the other hand, benefits
are primarily in the form of readily available technical and market information, the value
of which is often hard to quantify.

10- Concluding remarks

While advanced information technologies hold great promise for aquaculture
management at the farm as well as the regional level, IT potential in aquaculture has not

been realized yet. Even for mature and commercially available technologies such as instrumentation and process control, there are relatively few applications compared to agriculture and manufacturing. Obstacles for adoption are mainly attributed to the difficulty in perceiving and quantifying the potential benefits as well as the tendency to distrust new technologies. In fact, the result of a survey conducted in 1987 and reported by Varvarigos (1991) concerning production planning and the management of information on 293 salmon and trout farms in the United Kingdom, indicates that IT is not a priority among fish farm managers. In effect, microcomputers were used mainly for accounting and word processing. Computerization when rejected was primarily on grounds of excessive costs and time requirements. Moreover, besides the cost factor in utilizing IT in aquaculture, fish farmers and planners in countries that do not produce the necessary hardware and software may face additional problems regarding the acquisition and maintenance of the necessary equipment (Lester, Perkins and Wang 1987).

To help alleviate obstacles to IT adoption, extension services can play an important role in demonstrating the benefits of IT to farmers as well as in providing the necessary technical support.

To conclude, while the result of the survey by Varvarigos (1991) is somewhat disappointing, the steady decline in computer hardware prices together with its increasing functionality and the availability of flexible, user friendly and powerful software would definitely contribute toward encouraging more fish farmers to adopt information technology, changing the situation in the years to come.

References

- Adams, C. M., W.L. Griffin, J.P. Nichols, and R.W. Bricks (1980a). Bioengineering-economic model for shrimp mariculture system. TAMU-SG-80-203, Texas A&M University, 118 pp.
- Adams, C. M., W.L. Griffin, J.P. Nichols, and R.W. Bricks (1980b). Applications of a bioeconomic engineering model for shrimp mariculture systems. *Southern J. Agr. Econ.* 12:135-41.
- Ali, C.Q., L.G. Ross and M.C.M. Beveridge (1991). Microcomputer spreadsheets for the implementation of geographic information systems in aquaculture: A case study on carp in Pakistan. *Aquaculture* 92:199-205.
- Allen, P.G. and W.E. Johnston (1976). Research direction and economic feasibility: an example of systems analysis for lobster aquaculture. *Aquaculture* 9:155-80.
- Allen, P.G., L.W. Botsford, A.M. Schuur, and W.E. Johnson (1984). *Bioeconomics of Aquaculture*. Elsevier Science Publishers, New York.
- Alsagoff, K.S.A., H.A. Clonts, and C.M. Jolly (1990). An integrated poultry, multi-species aquaculture for Malaysian rice farmers: A mixed integer programming approach. *Agricultural Systems* 32:207-31.
- Azizan, Z. (1983). Using simulation methods to determine the optimal harvesting period for the cultured Malaysian freshwater prawns. *Macrobrachium rosenbergii*. Masters Thesis, University of Illinois, 196 pp.
- Bacon, J.R., C.M. Gempe II, I. Supitaningsih and J. Hankins (1993). Risk management through integrating aquaculture with agriculture, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 99-111.
- Bala, B.K. and M.A. Satter (1989). System dynamic simulation and optimization of aquacultural systems. *Aquacultural Engineering* 8:381-91.
- Balchen, J.G. (1989). Instrumentation, information and control systems in aquaculture, in *Instrumentation in Aquaculture* (Ed.) J.A. Wyban and E. Antill, Honolulu: The Oceanic Institute, pp. 1-11.
- Benn, J.R. and J.F. Kuhns (1995). FISHNET and Compuserve: Two stops on the Aquaculturist's information superhighway), in *Book of Abstracts, Aquaculture '95, February 1-4, 1995*, San Diego: The World Aquaculture Society, p. 61.
- Bevan, D.J. and D.L. Kramer (1988). A control system for the long term maintenance of hyponic water. *Aquaculture* 71:165-169.
- Bjordal A., S. Floen, J.E. Fosseidengen, B. Totland, J.T. Ovredal, A. Ferno and I. Huse (1987). Monitoring biological and environmental parameters in aquaculture, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 151-155.

- Bjorndal, T. (1988). Optimal harvesting of farmed fish. *Marine Resource Economics* 5:139-59.
- Bossu, T., M. Mantoni and M. Saroglia (1989). Expert system for sanitary control in intensive fish culture: The case of sea bass reared in thermal effluents, in *Aquaculture Europe 89 - Short Communications and Abstracts of Review Papers, Films/Slideshows and Poster Paper* (Ed.) R. Billard and N. De Pauw, Belgium: European Aquaculture Society, pp. 39-40.
- Botsford, L.W., H.E. Rauch and R.A. Shleser (1974). Optimal temperature control of a lobster plant. *IEEE Trans. Automatic Control* AC-19:541-3.
- Botsford, L.W., H.E. Rauch, A.A. Schuur and R.A. Schleser (1975). An economically optimum aquaculture facility. *Proc. World Maric. Soc.* 6:407-20.
- Botsford, L.W. (1977). Current economic status of lobster culture research. *Proc. World Maricult. Soc.* 8:723-39.
- Botsford, L.W., J.C. Van Olst, J.M. Carlberg and T.W. Gossard (1977). The use of mathematical modeling and simulation to evaluate aquaculture as a beneficial use of thermal effluent. *Proc. 1977 Summer Computer Simulation Conference*, Chicago, 18-20 July 1977, pp. 405-10.
- Boyle, W.A., A. Asgeirsson and G.M. Pigott (1993). Advances in the development of a computer vision fish biomass measurement procedure for use in aquaculture, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 382-392.
- Brown, L.M., I. Gargantini, D.J. Brown, H.J. Atkinson, J. Govindarajan and G.C. Vanlerberghe (1989). Computer-based image analysis for the automated counting and morphological description of microalgae in culture. *Journal of Applied Phycology* 1(3):211-225.
- Cacho, O.J., H. Kinnucan and U. Hatch (1991). Optimal control of fish growth. *American Journal of Agricultural Economics* 73:174-83.
- Cacho, O.J., U. Hatch and H. Kinnucan (1990). Bioeconomic analysis of fish growth: effects of dietary protein and ration size. *Aquaculture* 88:223-38.
- Callaghan, S.S. (1975). A dynamic model of a proposed heated finishing plant for oysters. M.S. thesis, University of Massachusetts, 112 pp.
- Chen, S.S. and F.W. Wheaton (1989). Oyster hinge line detection using image processing. *Aquacultural Engineering* 8(5):307-327.
- Cuenco, M.L. (1989). Aquaculture systems modeling: an introduction with emphasis on warmwater aquaculture. *ICLARM Studies and Reviews* 19, 46 pp.
- Dartez, J. (1989). Continuous dissolved oxygen monitoring and control systems for aquaculture, in *Instrumentation in Aquaculture* (Ed.) J.A. Wyban and E. Antill, Honolulu: The Oceanic Institute, pp. 45-53.

- Ebeling, J.E. and T.M. Losordo (1989). Continuous environmental monitoring systems for aquaculture, in *Instrumentation in Aquaculture* (Ed.) J.A. Wyban and E. Antill, Honolulu: The Oceanic Institute, pp. 54-70.
- El-Gayar, O.F. and P.S. Leung (1994). A risk programming model for brackish water polyculture: a case study in Egypt. Paper presented at the 25th Conference of the World Aquaculture Society, Jan. 1994, New Orleans.
- El-Gayar, O.F., P.S. Leung and L. Rowland (1994). An aquacultural development decision support system (ADDSS): a preliminary design. Paper presented at the 25th Conference of the World Aquaculture Society, Jan. 1994, New Orleans.
- Emanuel, W. R. and R.J. Mulholland (1975). Energy based dynamic model for Lago Pond, Ga. *IEEE Trans. Automatic Control* AC-20:98-101.
- Engle, C. R. and G. Pounds (1993). Economics of single- and multiple-batch production regimes for catfish, in *Aquaculture: Models and Economics* (Ed.) U. Hatch and H. Kinnucan, Boulder: Westview Press, pp. 75-89.
- Engle, C. R. and U. Hatch (1988). Economic assessment of alternative aquaculture aeration strategies. *Journal of the World Aquaculture Society* 19: 85-96.
- Eom, H.B. and S.M. Lee (1990). A survey of decision support systems applications (1971-April 1988) *Interfaces* 20:65-79.
- Ernst, D.H., J.P. Bolte and S.S. Nath (1993). A decision support system for finfish aquaculture, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 568-580.
- Ewart, J.W. (1995). Delaware's Aquaculture Resource Center), in *Book of Abstracts, Aquaculture '95, February 1-4, 1995*, San Diego: The World Aquaculture Society, p. 108.
- Fenaux, R., G. Malara and H. Clautre (1985). A turbidostat driven and controlled by microcomputer. *Aquaculture* 48:91-95.
- Foster, M., M.R. Ito, R. Petrell and R. Wang (1993). Detection and counting of uneaten food pellets in a sea cage using image analysis, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 393-402.
- Fridley, R.B. (1987). Modeling, identification and control of aquacultural processes and facilities, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY: Pergamon Press, pp. 17-24.
- Gates, J. M., C.R. MacDonald, and B.J. Pollard (1980a). Salmon culture in water reuse system: an economic analysis. University of Rhode Island Marine Technical Report, 78, 52.
- Gates, J.M., C.R. MacDonald, and B.J. Pollard (1980b). A dynamic linear programming model of fish culture in water reuse systems. Rhode Island Agricultural Experiment Station Contribution No. 1892: 20.

- Gempesaw II, C. M., F.F. Wirth, J.R. Bacon, and L. Munasinghe (1993). Economics of vertical integration in hybrid striped bass aquaculture, in *Aquaculture: Models and Economics* (Ed.) U. Hatch and H. Kinnucan, Boulder:Westview Press, pp. 91-105.
- Gempesaw, C.M., D. Lipton and S. Goggin (1993). AQUASIM PC ver. 1.7 User's Manual. The Extension Service of the USDA and the University of Maryland Sea Grant Extension Program.
- Griffin, W.L., J.S. Hanson, R.W. Brick and M.A. Johns (1981). Bioeconomic modeling with stochastic elements in shrimp culture. *J. World Maric. Soc.* 12:94-103.
- Griffin, W.L., L.A. Jensen and C.M. Adams (1983). A generalized budget simulation model for aquaculture. TAMU-SG-83-202, Texas A&M University, 131 pp.
- Griffin, W.L., W.E. Grant, R.W. Brick, and J.S. Hanson (1984). A bioeconomic model of shrimp maricultural systems in the USA. *Ecological Modeling* 25:47-68.
- Haakanson, L. and M. Wallin (1991). Use of econometric analysis to establish load diagrams for nutrients in coastal areas, in *Marine Aquaculture and the Environment* (Ed.) T. Maekinen, pp. 9-23.
- Hanfman, D., L. Bielawski and R. Lewand (1989). REGIS: REGIONAL Information System for African Aquaculture, full version, 5 1/4-inch disk.
- Hansen, E. (1987). Computer aided control and monitoring of aquaculture plants, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 187-192.
- Hanson, H.M. (1992). A flexible temperature and environmental controller. *Progress in Fish Culture* 54(2):130-131.
- Hanson, J.S., W.L. Griffin, J.W. Richardson and C.J. Nixon (1985). Economic feasibility of shrimp farming in Texas: an investment analysis for semi-intensive pond grow-out. *Journal of the World Mariculture Society* 16:129-150.
- Hatch, U. and J. Atwood, (1988). A risk programming model for farm-raised catfish. *Aquaculture* 70:219-30.
- Hatch, U., S. Sindelar, D. Rouse, and H. Perez (1987). Demonstrating the use of risk programming for aquacultural farm management: the case of penaeid shrimp in Panama. *Journal of World Aquaculture Society* 18:260-69.
- Hatch, U., J. Atwood, and J. Segar (1989). An application of safety-first probability limits in a discrete stochastic farm management programming model. *Southern Journal of Agriculture Economics*, 18:65-72.
- Hochman, E., P.S. Leung, L.W. Rowland and J.A. Wyban (1990). Optimal scheduling in shrimp mariculture: a stochastic growing inventory problem. *American Journal of Agricultural Economics* 72:382-93.
- Johnson, F.C. (1974). Hatch--a model for fish hatchery analysis. U.S. National Bureau of Standards, Washington, D.C. Report NBSIR 74-521, 51 pp.

- Johnston, W.E. and L.W. Botsford, (1981). Systems analysis for lobster aquaculture. *Proc. World Symp. on Aquaculture in Heated Effluents and Recirculation Systems*, Stavanger 28-30 May 1980, Berlin, Vol. II, pp. 455-464.
- Jorgensen, L. (1987). An automated system for incubation of pelagic fish eggs, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 211-213.
- Kapetsky, J.M, L. McGregor and H. Nanne (1987). *A geographical information systems and satellite remote sensing to plan for aquaculture development: a FAO - UNEP/GRID cooperative study in Costa Rica*. FAO Fisheries Technical Paper No. 287, FAO, Rome, Italy.
- Kapetsky, J.M., J.M. Hill and L.D. Worthy (1988). A geographical information system for catfish farming development. *Aquaculture* 68:311-320.
- Kapetsky, J.M. (1989). *Malaysia - A Geographical Information System for Aquaculture Development in Johor State*. FAO, Rome, Italy.
- Kapetsky, J.M., J.M. Hill, L.D. Worthy and D.L. Evans (1990). Assessing potential for aquaculture development with a geographical information system. *Journal of the World Aquaculture Society* 21(4): 241-249.
- Kapetsky, J.M., U.N. Wijkstrom, N. MacPherson, M.M.J. Vincke, E. Ataman and F. Caponera (1991). *Where are the best opportunities for fish farming in Ghana? The Ghana geographical information system as a decision making tool for fish farming development*. FAO Field Technical Paper No. 5, FAO, Rome, Italy.
- Karp, L., A. Sadeh and W.L. Griffin (1986). Cycles in agricultural production: The case of aquaculture. *American Journal of Agricultural Economics* 68:553-561.
- Killcreas, W.E. (1988). *FISHY 2.0 User's Guide*. Agricultural Economics Department, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.
- Krom, M.D., S. Grayer and A. Davidson (1985). An automated method of ammonia determination for use in mariculture. *Aquaculture* 44:153-160.
- LaFranchi, C. (1992). Optimal selection of species and harvest scheduling for cultured shrimp. Department of Agricultural and Resource Economics, University of Hawaii, Master Thesis, 66 pp.
- Lazur, A.M. (1995). Information transfer through use of CD-ROM technology, in *Book of Abstracts, Aquaculture '95, February 1-4, 1995*, San Diego: The World Aquaculture Society, p. 160
- Lee, P.G. (1993). Computer automation for recirculating aquaculture systems, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 61-70.
- Lester, L.J., S. Perkins and B.T. Wong (1987). Microcomputer use in aquaculture genetics. *NAGA* 10(2):9-10.

- Leung, P.S. (1986). Application of systems modeling in aquaculture. *Aquacultural Engineering* 5(2-4):171-182.
- Leung, P.S. and L.W. Rowland, (1989). Financial analysis of shrimp production: an electronic spreadsheet model. *Computers and Electronics in Agriculture* 3:287-304.
- Leung, P.S. and Y.C. Shang, (1989). Modeling prawn production management system: a dynamic Markov decision approach. *Agricultural Systems* 29:5-20.
- Leung, P.S. (1993). Bio-economic Modeling in Aquaculture After Two decades, in *Proceedings of the International Symposium on Socioeconomics of Aquaculture* (Ed.) Y.C. Shang, P.S. Leung, C.S. Lee, M.S. Su and I.C. Liao, Taiwan: Taiwan Fisheries Research Institute, pp. 115-137.
- Leung P.S., Y.C. Shang, and X. Tian, (1994). Optimal harvest age for giant clam *Tridacna derasa*: an economic analysis. *Journal of Applied Aquaculture* 4:49-64.
- Lipschultz, F. and G.E. Krantz (1980). Production optimization and economic analysis of an oyster (*Crassostrea virginica*) hatchery on the Chesapeake Bay, Maryland, USA. *Proc. World Maricul. Soc.* 11:580-91.
- Logan, S.H. and K. Shigekawa (1986). Commercial production of sturgeon: the economic dimensions of size and product mix. Giannini Research Report No. 335, University of California, 69 pp.
- Logan, S.H. and W.E. Johnston (1993). A replacement model for rainbow trout broodstock under photoperiod control, in *Aquaculture: Models and Economics* (Ed.) U. Hatch and H. Kinnucan, Boulder: Westview Press, pp. 107-122
- Losordo, T.M., R.H. Piedrahita and J.M. Ebeling (1988). An automated water quality data acquisition system for use in aquaculture ponds. *Aquacultural Engineering* 7(4): 265-278.
- Lynch, D.B. (1991). *Concise Dictionary of Computing and Information Technology*. London: Chartwell-Bratt.
- Lyon, P.R., H.G. Arthurs, D. Hancock and J. Mullins (1993). Data acquisition system for monitoring saturation levels of dissolved gases in fresh water aquaculture, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 81-88.
- Malara, G. and A. Sciandra (1991). A multiparameter phytoplankton culture system driven by microcomputer. *Journal of Applied Phycology* 3(3):235-241.
- McNown, W. and A. Seireg (1983). Computer aided optimum design and control of staged aquaculture systems. *J. World Maricul. Soc.* 14:417-433.
- Meaden, G.J. and J.M. Kapetsky. (1991). *Geographical information systems and remote sensing in inland fisheries and aquaculture*. FAO Fisheries Technical Paper No. 318, FAO, Rome, Italy.
- Moller, B. and K.I. Dahl-Madsen (1987). Continuous monitoring respiration in production scale trout culture, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY: Pergamon Press, pp. 133-136

- Muench, K.A., R.D. Thomsen and R.D. Croissant (1986). Computers in aquaculture. *Aquacultural Engineering* 5(2-4):199-217.
- Munasinghe, L., C.M. Gempesaw II, J.R. Bacon, W.W. Lussier and L. Konwar (1993). AMACS: A user friendly Windows-based aquaculture monitoring and controlling software, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 71-80.
- Naiberg, A., J. Petrell, C.R. Savage and T.P. Neufeld (1993). A non-invasive fish size assessment method for tanks and sea cages using stereo video, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 372-381.
- O'Connor, B.D.S., J. Costelloe, B.F. Keegan and D.C. Rhoads (1989). The use of REMOTS super technology in monitoring coastal enrichment resulting from mariculture. *Marine Pollution Bulletin* 20(8):384-390.
- Oiestad, V. (1987). Automatic feeding and harvesting of juvenile atlantic cod (*Gadus morhua* L.) in a pond, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 199-203.
- Padala, A. (1991). *Expert systems for aquaculture*. UMECORP notes.
- Palmer, J.D. (1989). *Application of Artificial Intelligence and Knowledge-Based systems Techniques to Fisheries and Aquaculture*. Fairfax:Virginia Sea Grant College Program.
- Petrell, R.J., T.P. Neufeld and C.R. Savage (1993). A video method for non-invasively counting fish in sea cages, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 352-361.
- Piedrahita, R.H., J.M. Ebeling and T.M. Losordo (1987). Use of data acquisition systems in aquaculture, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 259-262.
- Plaia, W.C. (1987). A computerized environmental monitoring and control system for use in aquaculture. *Aquacultural Engineering* 6(1): 27-37.
- Poxton, M.G. and G.T. Goldsworthy (1987). The remote estimation of weight and growth in turbot using image analysis, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 163-170.
- Rauch, H.E., L.W. Botsford and R.A. Shleser (1975). Economic optimization of an aquaculture facility. *IEEE Transactions on Automatic Control* AC-20:310-19.
- Rauch-Hindin, W.B. (1986). *Artificial intelligence in business, science and industry*. Englewood Cliffs, New Jersey:Prentice-Hall, Inc.
- Roegner, G.C. (1988). Use of image analysis in determination of growth and mortality rates of newly settled *Crassostrea virginica*. *Journal of Shellfish Research* 7(1):190.
- Ross, L.G., E.A. Mendoza and M.C.M. Beveridge (1993). The application of geographical information systems to site selection for coastal aquaculture: An example based on salmonid cage culture. *Aquaculture* 112:165-178.

- Rusch, K.A. and R.F. Malone (1989). Development of an automated continuous algal culture production system, in *Instrumentation in Aquaculture* (Ed.) J.A. Wyban and E. Antill, Honolulu: The Oceanic Institute, pp. 71-83.
- Rusch, K.A. and R.F. Malone (1993). A microcomputer control and monitoring strategy applied to aquaculture, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 53-60.
- Sadeh, A. (1986). Value of information in production processes: the case of aquaculture. Dissertation, Texas A&M University.
- Sanno, J.O. (1987). Alfa-log: A computerized registering, control, and alarm system for aquaculture, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 205-210.
- Schutzer, D. (1986). *Artificial intelligence, an application oriented approach*. New York:Van Nostrand Reinhold Company.
- Schuur, A.M., P.G. Allen and L.W. Botsford, (1974). An analysis of three facilities for the commercial production of *Homarus americanus*. American Society of Agricultural Engineers, Winter Meeting Paper No. 74-5517, 19 pp.
- Shaftel, T.L. and B.M. Wilson (1990). A mixed-integer linear programming decision model for aquaculture. *Managerial and Decision Economics* 11:31-38.
- So, J.D. and F.W. Wheaton (1993). Computer vision control system for an oyster hinge breaker, in *Techniques for Modern Aquaculture* (Ed.) J. K. Wang, St. Joseph, Minnesota: American Society of Agricultural Engineers, pp. 382-392.
- Sparre, P. (1976). A Markovian decision process applied to optimization of production planning in fish farming. *Meddr Danm. Fisk. - og Havunders.* 7:111-97.
- Sprague, R.H. and E.D. Carlson (1982). *Building Effective Decision Support Systems*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc..
- Springborn, R.R., A.L. Jensen, W.Y.B. Chang, and C. Engle (1992). Optimum harvest time in aquaculture: an application of economic principles to a Nile tilapia, *Oreochromis niloticus*, growth model. *Aquaculture and Fisheries Management* 23:639-47.
- Srekk, H.O., H. Kryvi and S. Elvestad (1992). Nation-wide assessment of the suitability of the Norwegian coastal zone and rivers for aquaculture (LENKA), in *Aquaculture and the Environment* (Ed.) N. de Pauw and J. Joyce, European Aquaculture Society Special Publication 16, pp. 413-440.
- Stokoe, P.K. and A.G. Gray (1990). AQUASITE: A computer site assessment system for marine coastal aquaculture, in *Proceedings of the Aquaculture Association of Canada Conference*, pp. 94-96.
- Swann L., G. Jensen and M. Einstein (1995). Using the aquaculture network information center (Aqua-NIC), in *Book of Abstracts, Aquaculture '95, February 1-4, 1995*, San Diego: The World Aquaculture Society, p. 222.

- Syed, A.L.A. (1985). A mixed integer programming approach for integrating poultry with multispecies aquaculture on Malaysian rice farms. Ph.D. thesis, Auburn University, Auburn, Alabama, 166 pp.
- Sylvia, G. and J.L. Anderson (1993). An economic policy model for net-pen salmon farming, in *Aquaculture: Models and Economics* (Ed.) U. Hatch and H. Kinnucan, Boulder:Westview Press, pp. 17-38.
- Talpaz, H. and Y. Tsur (1982). Optimizing aquaculture management of a single-species with fish population. *Agricultural Systems* 9:127-142.
- Tian, X. (1993). Optimal aquafarm structure and size: a case study of shrimp mariculture. Department of Agricultural and Resource Economics, University of Hawaii, Dissertation, 179 pp.
- Tisdell, C. A., L. Tacconi, J.R. Barker, and J.S. Lucas (1993). Economics of ocean culture of giant clams, *Tridacna gigas*: internal rate of return analysis. *Aquaculture* 110:13-26.
- Tsur, Y. and E. Hochman (1986). Economic aspects of the management of algal production. *CRC Handbook of Microalgal Mass Culture*, CRC Press Boca Raton, pp. 473-83.
- Vandermeulen, H. (1991). A simple microcomputer-based data acquisition system for monitoring pH shifts. *Journal of Applied Phycology* 3(4):373-374.
- Varvarigos, P.(1991). Production planning and the management of information on fish farms: results of a UL survey. *Aquaculture and Fisheries Management* 22:217-227.
- Varvarigos, P. and M.T. Horne (1987). An inexpensive microcomputer based data record-keeping system for the individual fish farm, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 263-272.
- Wang, J. (1988). The microcomputer control system of aquaculture aerating devices. *Fish. Mach. Instrum. -Yuye-Jixie-Yiqi* (5):6-8.
- Warming, M. (1987). Oxygen control in aquaculture plant, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 193-197.
- Wu, R.S.S. (1989). Biological and economic factors in the selection of cultured fish species and the development of a bio-economic model. *AQUACOP IFREMER Actes de Colloque*, 9:437-444.
- Zahradnik, J.W. (1987). Status and perspectives in the instrumentation of aquacultural facilities, in *Automation and Data Processing in Aquaculture* (Ed.) J.G. Balchen, NY:Pergamon Press, pp. 23-29.

Table 1: Instrumentation and process control applications in aquaculture.

Principal Applications	Author(s)
Environmental monitoring and control	Bevan and Kramer (1987); Bjordal (1987); Plaia (1987); Ebeling and Losordo (1989); Hanson (1992);
Water quality data acquisition systems	Fenaux et al. (1985); Krom et al. (1985); Moller and Dahl-Madsen (1987); Piedrahita, Ebeling and Losordo(1987); Losordo, Piedrahita and Ebeling (1988); Vandermeulen (1991)
Dissolved oxygen monitoring and control	Warming (1987); Dartez (1989); Lyon et al. (1993)
Automated continuous algal production system	Rusch and Malone (1989); Malara and Sciandra (1991)
Monitoring and control of aquaculture plants	Hansen (1987); Sanno (1987); Munasinge et al. (1993); Rusch and Malone (1993)
Automation and control	Jorgensen (1987); Oiestad (1987); Wang (1988)

Table 2: List of Bio-economic Models in the First Decade :1974 to 1983

Principal Applications	Model
Schedule of release dates and choice of stocks in hatchery	Johnson (1974)
Optimal temperature for lobster culture	Botsford, Rauch and Shleser (1974)
Optimal culture systems: stacked tray, raceway and silo	Schuur, Allen and Botsford (1974); Botsford et al. (1975)
Optimal schedule of fertilizer application	Emanuel and Mulholland (1975)
Evaluating indirect heating from electric generating station thermal effluent	Callaghan (1975)
Design and operation of an aquaculture facility	Rauch, Botsford and Shleser (1975)
Optimal stocking, feeding and harvesting decisions	Sparre (1976)
Defining areas in which research success would have high potential rewards	Allen and Johnston (1976); Johnston and Botsford (1981)
Choice of heat sources	Botsford (1977); Botsford et al. (1977)
Optimal fish culture decisions in a water re-use system and financial feasibility analysis	Gates, MacDonald and Pollard (1980a, b)
Combination of purchases and culture activities that minimized total culture cost	Lipschultz and Krantz (1980)
Financial feasibility of shrimp growout operation	Adams et al. (1980a,b)
Directing future research needs	Griffin et al. (1981)
Optimal harvesting strategy	Talpaz and Tsur (1982)
A generalized budget simulation system	Griffin, Jensen and Adams (1983)
Optimal aquacultural plant design	McNown and Seireg (1983)
Optimal Harvesting	Azizan (1983)
Cost of producing the Japanese clam	van Hemelryck (as described in Allen et al. 1984)

Table 3: List of Bio-economic Models in the Past Decade :1984 to 1993

Principal Applications	Model
Directing future research	Griffin et al. (1984)
Comparison of different culture systems	Syed (1985)
Financial performance of shrimp farms	Hanson et al. (1985)
Optimal management (harvesting policy) of algal biomass	Tsur and Hochman (1986)
Optimal stocking and harvesting	Karp, Sadeh and Griffin (1986)
Size and product mix of commercial sturgeon production	Logan and Shigekawa (1986)
Value of information in production process	Sadeh (1986)
Evaluating production choices	Hatch et al. (1987)
Assessing risk-income tradeoffs for alternative production activities	Hatch and Atwood (1988)
Aeration strategy	Engle and Hatch (1988)
Optimal harvesting of farmed fish	Bjorndal (1988)
Evaluating candidate species for mariculture	Wu (1989)
Optimal stocking and harvesting strategies	Leung and Shang (1989)
Financial evaluation of alternative design and operation	Leung and Rowland (1989)
Assessing risk-income tradeoffs for alternative production activities	Hatch, Atwood and Segar (1989)
Optimal harvest schedule	Hochman et al. (1990)
Optimal operation and management	Bala and Satter (1990)
Synchronizing broiler and fish growth cycles for organic fertilization of fish ponds	Alsagoff, Clonts and Jolly (1990)
Production scheduling and strategic planning w.r.t. technological changes	Shaftel and Wilson (1990)
Cost-effective feeding regimes for pond-reared fish	Cacho, Hatch and Kinnucan (1990); Cacho, Kinnucan and Hatch (1991);
Optimum harvest time	Springborn et al.(1992)
Optimal species selection and harvest schedule	LaFranchi (1992)
Optimal aquafarm structure and size	Tian (1993)
Optimal length of harvest cycle	Tisdell et al. (1993)
Optimizing public and private net-pen salmon aquaculture strategies	Sylvia and Anderson (1993)
Optimal production management strategies - single-batch vs. multiple batch	Engle and Pounds (1993)
Economics of vertical integration in striped bass aquaculture	Gempesaw II et al.(1993)
Optimum replacement of broodstock for rainbow trout	Logan and Johnston (1993)
Evaluating economic benefits of incorporating a small scale trout enterprise with a grain and broiler farm	Bacon et al. (1993)
Optimal harvest (rotation) age	Leung, Shang and Tian (1994)
Choices of species	El-Gayar and Leung (1993)

Table 4: Major DSS application areas and the number of articles published in the field during the period from 1971 to April 1988 as reported by Eom and Lee (1990).

Application area	Number of applications
1. Corporate functional management	133
1.1 Accounting/auditing	4
1.2 Finance	19
1.3 Human resources management	10
1.4 International business	5
1.5 Information systems	10
1.6 Marketing/Transportation/Logistics	44
1.7 Production and operation management	27
1.8 Strategic management	14
2. Agriculture	3
3. Education	7
4. Government	6
5. Hospital and health care	10
6. Military	7
7. Natural resources	12
8. Urban and community planning	6
9. Miscellaneous	19
Total	203

Table 5 : AI approaches for aquaculture applications (Palmer 1989).

AI approach	Aquaculture application
Intelligent control	Monitoring and control of intensive aquaculture systems.
Knowledge-Based Decision Support Systems	Aquaculture site selection. Aquatic organism disease diagnosis and treatment. Aquaculture system design. Environmental impact assessment for aquaculture.
Deep model	Non-indigenous species introduction assessment.
Machine perception and classification	Machine perception and classification in aquaculture production and processing. Physical properties measurement of aquatic products.
Computer-assisted processing	Computer integrated processing of aquatic products.
Intelligent computer-assisted learning and instruction	Training aids in aquaculture. Educational programs for aquaculture.

Table 6 : Application of image processing and pattern recognition in aquaculture.

Principal Applications	Model
Fish biomass measurement	Boyle, Asgeisson and Pigott (1993)
Fish counting	Petrell, Neufeld and Savage (1993)
Size assessment	Naiberg et al. (1993)
Production and processing of aquatic products	Chen and Wheaton (1988); So and Wheaton (1993);
Detecting and counting uneaten food pellets	Foster et al. (1993)
Weight and growth estimation	Poxton and Golgsworthy (1987)
Counting of microalgae in culture	Brown et al. (1989)
Determination of growth and mortality rates	Roegner (1988)
In remote sensing applications	O'Connor et al. (1989)

Table 7 : GIS applications in aquaculture.

Principal Applications	Author(s)
Catfish farming development in Louisiana, U.S.A.	Kapetsky, Hill and Worthy (1988); Kapetsky et al. (1990)
Aquaculture development in Costa Rica	Kapetsky, McGregor and Nanne (1987)
Aquaculture development in Johor state, Malaysia.	Kapetsky (1989)
Fish farming opportunities in Ghana	Kapetsky et al. (1991)
Assessment of the potential for salmonid cage culture in Scotland.	Ross, Mendoza and Beveridge (1993)
Assessing the potential for carp culture in Pakistan.	Ali, Ross and Beveridge (1991)
Assessment of the suitability of the Norwegian coastal zone and rivers for aquaculture.	Srekk, Kryvi and Elvestad (1992)

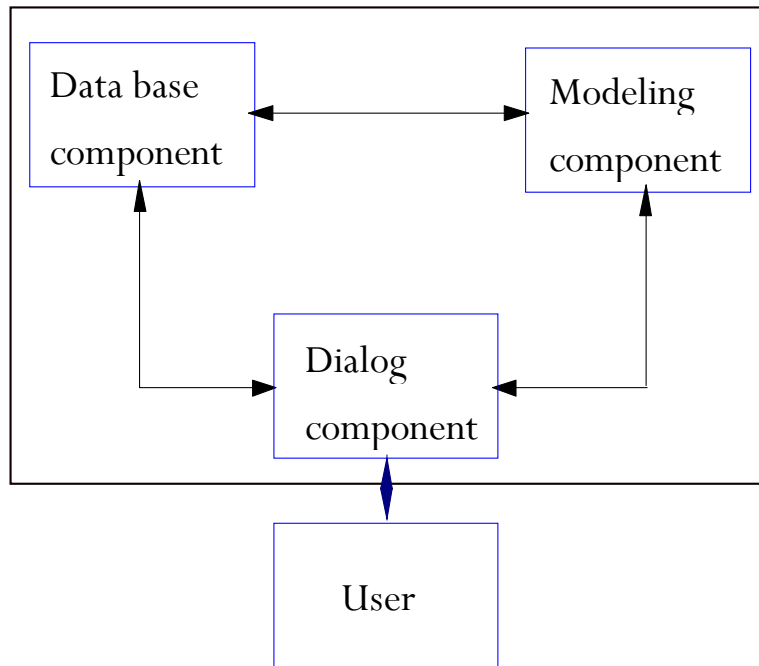


Figure 1 : DSS framework (adapted from Sprague and Carlson, 1982).

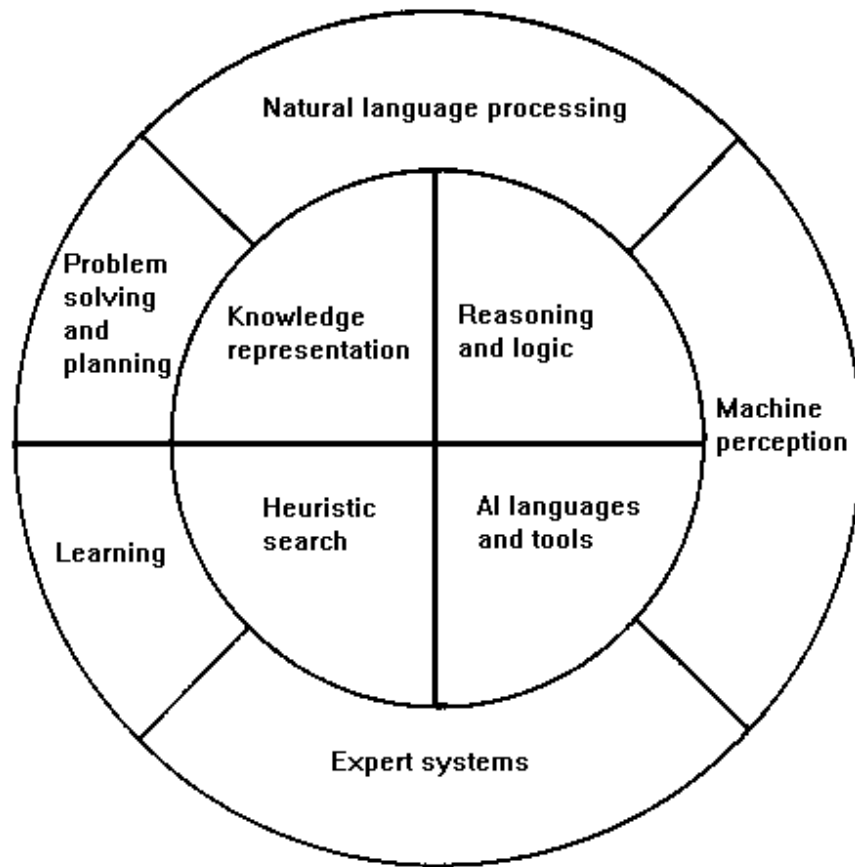


Figure 2 : Nilsson's Onion model (modified).

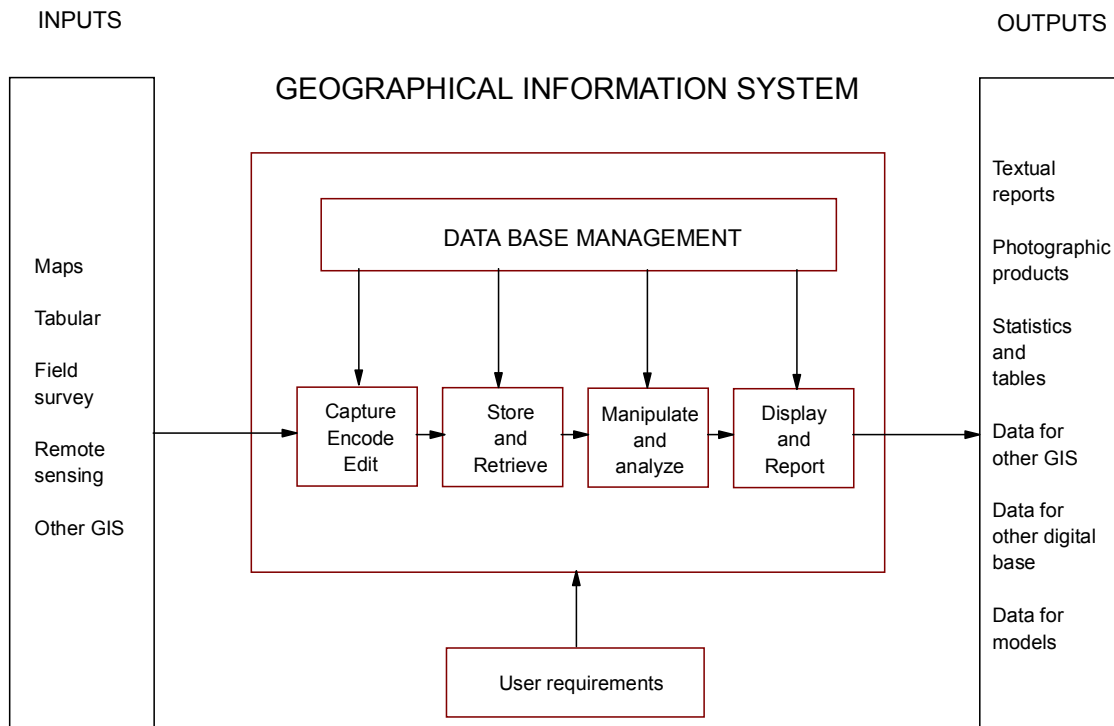


Figure 3 : Systems Diagram to illustrate GIS (Meaden and Kapetsky, 1991).