Review Paper

Application of Expert Systems in Fisheries Sector – A Review

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Abstract

The concept for expert system development comes from the subject domain of Artificial Intelligence (AI). Expert system is a computer programme that uses available information and inference to suggest solutions to problems in a particular discipline emulating the logic and reasoning process using artificial intelligence technology. The present paper discusses the expert systems, its advantages and disadvantages and its application in the fisheries sector. A total of 91 expert systems developed in the field of fisheries are reviewed by grouping the expert systems under six categories viz., fish identification, fisheries management, aquaculture management, fish disease diagnosis and health management, fisheries information management and fish product marketing. Expert system could play a lead role for knowledge updation and transfer of technology in fisheries where the research extension linkage is poor, manpower and funds available are inadequate for extension service.

Keywords: Expert system, decision support system, information technology, fisheries, aquaculture.

Introduction

World fisheries have grown dramatically in the last 50 years. From a production of few million tonnes in the early 1950s, fisheries production in 2006 was reported to have risen to 143.6 million tones[1]. This clearly indicates that fisheries sector continues to grow more rapidly than any other animal food-producing sectors. Demand for fisheries products continues to increase to meet the needs of consumers, reflecting recognition of the dietary benefits of fish and shellfish in both developed and developing countries. The oceans of the world have a finite supply of environmental goods and services available to support human activities and needs[2].

In this era of computer revolution, relevant expertise is need of the hour. Information of the required technical advice always has the potential of improving efficiency in all spheres of fisheries development and Information Technology (IT) has a major role to play in this development. One of the branches of IT, Expert systems, has drawn the interest of researchers and professionals in different fields in the recent years. Expert systems currently find success in areas such as science and engineering, finance, medicine, transportation and communications[3]. Expert systems have also found its application in the field of agriculture including fisheries sector. Almost every field currently has a special interest group for expert systems technology. This widespread interest in expert system technology is due to the ability of the expert systems to solve practical and real-world problems.

This paper provides an overview of this technology and the expert systems developed in fisheries. The expert systems developed in the field of fisheries over a period of about last 25 years are reviewed.

Experts and Expert Systems

'Experts' are Subject Matter Specialists who have the knowledge and skill to solve specific type of problems[4]. Experts' skill usually comes from extensive experience and detailed specialized knowledge of the problems they handle. Unavailability and scarcity of expert in a particular field and if available, inaccessibility for common people, and expensive consultation charges are the major problems in accessing a human expert. Besides, repetitive kind of job might discourage the expert and affect his efficiency. Further, limitation of memory and processing inability of all the essential knowledge required in the process of decision-making is considered to be the obstacle faced by human experts. Due to continuous research and development, new knowledge in enormous amount is being added in every discipline and thus more relevant and accurate advice can be taken from a human expert if his own knowledge is updated which is not an easy task. Human experts are bounded by limitations and it is quite difficult for a human expert to consider all the essential factors while taking a decision. Something is always escaped and remains unattended. Thus some tool or assistance is needed even for an expert to update his knowledge and get help in decision making process.

A computer-based expert system seeks to capture enough of the human specialist's knowledge so that it will solve the problem directly as well. Expert systems are basically computer programs that either recommend or make decisions for people, based on knowledge collected from experts in the field[5].

Typically, the problem areas are complex enough such that a simpler traditional algorithm is insufficient to provide the proper solution. Indeed, the foundation of a successful expert system depends on a series of technical procedures and development that may be designed by certain technicians and related experts. As such, expert systems do not typically provide a definitive answer, but provide a probabilistic recommendation.

Expert system is defined as an interactive computer programme that uses available information and inference to suggest solutions to problems in a particular discipline emulating the logic and reasoning process using artificial intelligence technology[4], with built-in knowledgeable pool and solutions on different subjects[6], performs on par with highly skilled experts[7], and is a simulation of a consultation process between an expert of a particular field and a non expert[8].

An expert system differs from a conventional computer program[4]. The conventional program is algorithmic in nature and will not entail subjective information, whereas, the expert system tends to behave as human experts in decision making and is highly interactive. It has the ability to capture human decision making expertise and represent this expertise as a series of rules and facts. The management policies that have to be adopted under practical situations can conveniently be incorporated in an expert system.

Advantages and limitations of expert systems

Expert systems have both advantages and limitations as listed in the table 1 [4]. Despite the fact that expert systems have several limitations, they have been widely successful and proved their value in a number of important applications by being able to analyze many practical problems that lie within defined parameters.

Table 1
Advantages and limitations of Expert Systems

Advantages	Limitations
1. Permanent and not dependent on its use	1. Lacks creativity and commonsense
2. Rapid and easy transfer of knowledge between expert systems	2. Non-adaptable without human intervention
3. Easy to document the knowledge	3. Lacks sensory input of the problem
4. Relatively inexpensive	4. Narrow focus

Expert systems in fisheries sector

Expert systems are rapidly becoming an integral part of applications in a number of domains ranging from traditional manufacturing processes to applications in outer space[9]. Expert systems have been shown to improve traditional approaches by as much as an order of magnitude. There are number of areas, including fisheries and aquaculture, in which the return on investment in an expert system can be tremendous. Expert

systems are tools for fisheries and aquaculture management since they can provide the site-specific, integrated and interpreted advice that fishers, farmers and extension agents need to more efficiently manage fisheries and aquaculture concerns. However, the development of expert systems for fisheries sector is fairly recent, and the use of these systems in commercial venture is rare to date[10, 11]. This paper provides the bibliography on different expert systems developed in the field of fisheries. To have better understanding in the subject, 91 expert systems developed in the field of fisheries have been grouped under six categories as summarized in the table 2.

Table 2
Categories of Expert Systems developed in Fisheries

Sl. No.	Category	No. of Expert Systems reviewed
1	Fish identification	4
2	Fisheries management	24
3	Aquaculture management	26
4	Fish Disease diagnosis and health management	30
5	Fisheries information management	2
6	Fish product marketing	5
	TOTAL	**91**

Fish identification

The taxonomic identification of fishes is a time-consuming process and making errors is indispensable for those who are not specialists. Automated species identification provides a good option to the burden of routine fish taxonomic identification, however, automated species identification based on morphological characteristics has not been widely employed in any discipline of the biology[12]. Four expert systems developed for taxonomic identification of fish are discussed in this section.

IDEXSYS, an identification expert system was developed for identifying fish larvae of Northeast Atlantic[13]. In IDEXSYS, morphometric measurements in combination with discriminate analysis were used to identify and separate stocks. This expert system guided the user very fast to the most probable species at a convincing success rate.

Another expert system was developed based on the content-based image recovery which could provide statistical clues for assisting taxonomists to identify new species or subspecies[14]. This expert system had a learning component that can identify representative body shape characters of known species of fish based on digitized landmarks.

An automated taxonomic identification system named as IPez assists taxonomists in identification of fishes based on its morphological characters[15]. Besides helping in the taxonomic identification of fishes in short time with minimal errors, this expert system allowed determining of the main morphometric

characters that have promoted divergence among closely related species.

Whale Watcher Expert System, an online system for the identification of whales was developed by the Ministry of Fisheries and Oceans, Canada[16]. The Whale Watcher Expert System produces pictures, movies and sounds to support its communication with the user.

Fisheries Management

For developing the strategies for effective fisheries management and planning, consideration of long-term viability of fish population is essential. Although the information on fishery resources exists, it is mostly in scattered form and is not available in a consolidated form. For the proper utilization, equitable distribution and optimal management of fishery resources the most needed are an inventory of resources, present day utilization levels and future utilization possibilities. Expert system has been realized as an important tool for fisheries management and are developed to efficiently manage the fishery resources. This section reviews 24 expert systems developed for fisheries management.

CANOFISH (CANOnical FISHery Management Expert System) demonstrated the strength, necessity and utility of an expert system for fishery management[17]. This system provided information on management of multispecies fishery resources. The expert system PISCES controls the introduction of exotic fish species into the waters in Southern Africa[18].

An expert system was designed to provide annual catch quotas of the northern anchovy, _Engraulis mordax_, optimize sampling effort in time and space, and provide an environmental description for recruitment prediction[19]. The system also provides advice on measurements for optimization of the sampling effort.

Another expert system provides prediction on the fishing conditions of Japanese anchovy _Engraulis japonicus_ off the coast of Kanagawa Prefecture[20]. In this expert system, a total of 28 variables including egg abundance, catch of larvae, Kuroshio path, etc., were considered for making forecast of the fishing conditions.

An expert system for use in fishery stock assessment and management described four levels of support to scientists and managers to increase fish productivity by providing the technical explanations, managing and cataloging the repetitive processes, guiding the low-level decisions, and contributing directly to the strategic and policy decisions[21].

For management of Tuna fisheries, an expert system was developed by integrating the expert system with Remote sensing[22]. The system makes use of environmental remotely sensed data and behaviour of tuna for providing the information on tuna fisheries management.

MRAG Ltd. developed two fisheries management expert systems viz, ProTuna and ProFish[23]. ProTuna expert system was intended for the management of tuna fisheries which draws up a list of recommended management plan of action and delivers appropriate advice. ProFish expert system was a more generalized fisheries management expert system not specializing in any one species and provided a broader range of advice on fishery characteristics, policy environment, current management measures and management objectives concerning the most likely resource species in the target area. Another expert system was developed to analyze and recommend the relationship of fish and its environment for optimal fisheries management[24].

FDES, Fishway Design Expert System recommends the most suitable fishway type for given design conditions[25]. This expert system provides recommendations on the basis of fishways hydraulics, fish passage performance, and cost requirements, as Fishways contribute to the sustainable development of water resource projects by providing a path for fish migrations.

An expert system was developed to recommend a suitable design of fish vessel[26]. The system incorporates knowledge bases derived from existing vessel series, government regulations, fishing vessel replacement rules, and classification society rules with design software such as resistance and stability algorithms. Besides recommending the suitable fish vessel design, the system also reasons out the constraints involved in various designs of fishing vessel.

FISHMAP, a sampling expert system for fish stock assessment was developed by the Center for Marine Science, Environment and Technology, University of Maryland[27]. FISHMAP enables the user to evaluate potential environmental, anthropogenic, and fishing influences on stock abundance and thus aids in taking appropriate management actions. Another expert system for fish stock prediction developed at the University of Skoevde can use complex relations between environmental information, fish stocks, migration of fish and conventional data used in Virtual Population Analysis to estimate the fish stock size[28].

The LCSS (Lamprey Control Selection System) expert system assists in developing an environmentally and economically efficient sea lamprey control strategy in Great Lakes[29]. LCSS assists in long and short term management of sea lamprey populations.

An expert system approach was successful in relating recruitment of South African anchovy, _Engraulis capensis_ to wind and sea surface temperature, and environmental and biological indices[30]. The system proved to have great potential in supporting the future management of the South African anchovy fishery in the dynamic environment of the Benguela Current.

SimerFish, an expert system for management of marine biological natural resources, evaluates and predicts the marine fish stocks and determines the allowable quotas[31]. This expert system could forecast population abundance and biomass, possible total allowable catch, determine the quota allocation to subjects of fishery, based on various criteria.

CLUPEX provides measures for management of herring (*Clupea harengus*) fisheries. It captures and integrates scientific and local knowledge in the form of heuristic rules. Using input on biotic and abiotic environmental conditions, CLUPEX uses the rules to provide quantitative and qualitative predictions on the structure, dynamics and mesoscale distribution of shoals of migratory adult herring during different stages of their annual life cycle[32].

An expert system was developed to identify the probable fishing ground for anchovy (*Engraulis ringens*) in the northern zone of Chile[33]. The probable fishing ground model in this expert system is supported by past evidence of the spatial and temporal distribution of anchovy, and by the optimum ranges of sea surface temperature, thermal gradients and chlorophyll recorded in fishing zones. The probable fishing ground charts are calculated with remote sensed satellite data and a decision support analysis using GIS.

Another expert system integrates life history and ecological characteristics of marine fishes to estimate their vulnerability to fishing to help biologist overcome the risk using conventional methods, which is difficult for the majority of fish species, as the population data normally required by such methods are unavailable. This system describes the known relationship between biological characteristics and vulnerability of marine fishes from published literature, and could be used as a decision support tool in fishery management and marine conservation planning[34].

A decision support system for fisheries policy and management decisions on optimal harvesting plan for the fishing industry was developed and applied to the real situation in the Northeastern U.S[35]. A simulation optimization is built in the system to assist the authorities in planning for a fleet of vessels in terms of time and location of fishing, as well as amount and target species to be fished.

A knowledge based expert system for prediction of fishing ground for pelagic fish in the coastal area of Central and South Sulawesi was developed by using a series of satellite data of sea surface temperature, sea surface chlorophyll-*a* and turbidity[36]. With these parameters, the system understands the temporal and seasonal variability of the marine environment of the study area, and identifies the oceanographic phenomena, i.e. upwelling, front or eddy. To generate spatial configuration of fishing ground prediction map, GIS model was integrated with the result of Knowledge-Based Expert System.

A Fisheries Management Decision Support System was developed for management of the Northeastern US multi species fishery[37]. This system determines the optimal fishing plans, in terms of the amount of fish to be caught from each species at each sub-area and at each time period, utilizing the data provided by the user. To provide the best management advice, this system integrates multiple sources of information, including stock status, spatial distribution, catch per unit effort, and environmental and economic factors collected from fishery independent research surveys as well as fishery dependent observations.

STRAT-TECH, Inc. developed an expert system called Fishing Expert that provides fishing tips for bass (smallmouth and largemouth), trout (brook, brown, and rainbow trout), musky, walleye, northern pike, crappie, and bluegill[38]. The expert system advices are based on weather, time of year (e.g. spring, summer, and fall), type of water (e.g. lake, river, or stream), wind, spawning conditions, high / low pressure systems, day or night fishing, etc. The techniques and tips given are unique for the fish specified by the user.

Aquaculture Management

Aquaculture, from a backyard farming operation has developed into a commercial farming enterprise, and is considered as an alternative source of protein. Due to on-farm and off-farm exigencies aquaculture production practices are constantly getting improved/ modified to deal with the emerging scenarios. The change in aquaculture scenario has emphasized the need to adapt and develop expert systems for the better management of aquaculture facilities. 26 Expert systems developed in aquaculture for performing various tasks have been reviewed in this section.

An expert system was developed for monitoring the sanitary condition of Sea bass, *Dicentrachus labrax* reared in thermal effluents[39]. This expert system was used to monitor mortality rates and effects on the thermal plant, and also single out causes of mortality and environmental and technological risk factors.

AQUASITE, a computer site assessment tool assists farmers and policy makers in selection of ideal site for undertaking marine coastal aquaculture[40]. This expert system considers the full range of site assessment criteria and the main species of interest for mariculture in the Atlantic Region of Canada.

SCHUBERT AUDIT evaluates the ability of trout farms to breed fish of defined quality for consumption and restocking[41]. This expert system has been developed from a methodology under use in the industry and the quality audit to comply with laws on the management of fish farms.

UMECORP developed Recirculating Intensive Aquaculture eXpert (RIAX), an expert system to monitor and control culture of *Tilapia mozambique* in an intensive aquaculture system[42].

RIAX guides inexperienced operators through important maintenance and emergency procedures, besides delivering predictive advice about complex problems. Forecasting biological, chemical and mechanical events before they occur gives operators and system managers' ample warning to deal with spurious or large scale events.

'Crystal' expert system monitors and controls the water quality in aquaculture farm[43]. The system stores rule base, fed with real time measured data to ensuring the health of the fish. By building sensor knowledge into the expert system, the novice user could specify the needed sensors, or build them to drawings supplied by the system.

An expert system was developed for dealing with complexities in sustainable integrated mariculture systems[44]. This expert system provides information on many area of integrated mariculture, which includes spreading of overheads, waste reduction and leveraging of factors such as feed, power, expertise, management resources, capitalized assets and transportation systems. Besides these, the expert system also provides decision support on site selection, species selection, system design and operation control.

DESTA (Decision Support Tool for Aquaculture) allows a novice computer user to enter data for the environmental assessment of a new aquaculture pond or site through a visually interactive dialogue session[45]. This tool is a valuable decision support tool for assisting anyone engaged in the selection and development of sites for aquaculture.

FIsheries Nutriology Expert System (FINES) studies the aquaculture farming way by building a fish farming dynamic model[46]. This expert system provides a quasi-optimal farming way as the factors of growth phase physiology condition and environment change. FINES also automatically design the compound feed and diagnose nutritive disease as per the inputs of the user.

An expert system was used to reproduce expert evaluations of data from investigations of the benthic impact of a fish farm in the Red Sea[47"]. This expert system was used to study the geochemical profiles of a farm as it provided the valuable data on the benthic impacts of fish farming, as the interpretation of these data was a complex process requiring scientific sophistication and understanding of benthic processes.

A user-friendly expert system was developed as a generic reference relating to TEechnological and MAnagement (TEMA) aspects of shrimp, *Litopenaeus vannamei* farming practices[48]. This expert system provides assistance to confirm, complement or modify the information that users of the expert system have of semi-intensive and intensive technologies for grow-out, and management practices for controlling pond water quality, productivity and feeding of *L. vannamei.*

ADDSS (Aquacultural Development Decision Support System) aids the decision maker/ planner in making choices regarding the planning and development of the aquaculture industry in a given region[49]. This system is composed of three main components: a model base containing all relevant models which are essentially multiple objectives in nature, a database containing all relevant data, and a dialog component providing a user interface to the other two components of the system. ADDSS was successfully demonstrated in Northern Egypt to plan aquaculture development and demonstrate it as a viable industry for supplying cheap and good quality protein, balancing the foreign exchange deficits, improving the standard of living, and creating employment opportunities.

AquaFarm, a simulation and decision support system aids in design and management planning of finfish and crustacean aquaculture facilities[50]. AquaFarm has its use in aquaculture production facilities of any design and management intensity, for brood fish maturation, egg incubation, grow out of finfish or crustaceans in cage, single pass, serial reuse, water recirculation, or solar-algae pond systems. The user has total control over all facility and management specifications, including site climate and water supplies, components and configurations of fish culture systems, fish and facility management strategies, unit costs of budget items, and production species.

POND, a decision support system analyses pond aquaculture facilities by the use of a combination of simulation models and enterprise budgeting[51]. POND provides the ability to simulate pond dynamics and fish growth for warm water pond aquaculture facilities, and to compute enterprise budgets relating various cost and returns from a particular facility to determine short and long term profitability.

An expert system was developed to optimize the denitrification rates and eliminate discharge of toxic by products, i.e., NO_2^-, NO, N_2O or H_2S in commercial aquaculture system to improve the production capacity[52]. This expert system maintains Nitrate-nitrogen concentration <5 ppm while avoiding any increase in NO_2^- or H_2S concentrations. Similarly, another expert system for water quality evaluation of aquaculture pond was developed which could inspect the factors of water quality in the aquaculture pond, analyse the water quality and evaluate them, and then diagnose the environment of the aquaculture water[53]. The expert system also provides feasible suggestions for the effective water quality management.

CADS_TOOL (Cage Aquaculture Decision Support Tool) assists the cage aquaculture managers to optimize their choice of sites for placement of cages[54]. This system covers four essential activities starting from classifying a site, selecting the best site from several site alternatives, calculating a sustainable holding density from a chosen site, and finally performing an economic appraisal of a site.

An expert system was developed to improve shellfish production on mussel rafts in Maine[55]. This expert system combines computer based methodologies for determining tidally driven flows, wave heights, flow through shellfish raft systems and consumption of food by the shellfish to optimize the production cycles on shell fish rafts.

An internet-based expert system was developed for management of freshwater fish farming operation[56]. The installed measurement system that measures water temperature, pH and oxygen dissolved in water and the expert system that supervises and controls the fish production process are connected via the internet for communication. Access to the on-site measurement equipment via internet enables better supervision, planning and better utilization of production resources, which results in increased quality of fish, increased fish growth and bigger profits.

An expert system helps farm managers in decision making in infrastructure planning and management of nitrogen-rich water in aquaculture farm[57]. The expert system provides improved strategies for the optimisation and control of bioprocesses involved in nitrogen removal by phyto-treatment pond.

A feeding expert system was developed for indoor intensive culture of South Flounder by analyzing the feed fed and impact of various factors on feeding[58]. This expert system assists in effective feed management and better supervision of the culture system through Personal Digital Assistant (PDA).

An Israeli company has developed SmartFish Expert System (SES), an expert system for aquaculture that provides fish growers with web-based farm management and analysis through global aquaculture database system; SmartFeed (SF), an optimal feeding system; and Smart Control (SC) offering tailored turnkey projects for aquaculture sites[59].

Apart from its use in prime aquaculture activities, expert systems have also found its application in licensing the aquaculture activities. A decision support system for marine finfish aquaculture, MFADSS (Marine Finfish Aquaculture Decision Support System) aids the Department officials in decision making for evaluating finfish lease applications[60]. MFADSS provides scientific advice on aquaculture lease applications by applying a standard set of criteria which increases consistency in decision making. Another decision support system was developed for regularizing the licensing for finfish aquaculture activities[61]. Similarly, a decision support system was also developed for licensing to undertake freshwater cage aquaculture[62].

Fish Disease diagnosis and health management

The expert system technology has been most widely applied in the field of medical diagnosis. Similarly, it has also found its way into disease diagnosis and health management in the fields of agriculture, animal sciences and fisheries. The Fish health management is a crucial part of aquaculture. The development of expert systems in fish health management has shown an increased use of information technology to support aquaculture information systems research and development. Thirty (30) expert systems developed in fish disease diagnosis and health management are presented in table 3 in chronological order. Different parameters like visible symptoms, water quality, image of the diseased fish, microscopic image, etc. have been employed by various expert systems for diagnosing the fish disease.

Table 3
Expert Systems developed in Fish disease diagnosis and health management

Sl. No.	Expert System	Description/ Method of disease diagnosis
1	AQUADOC – for diagnosis of various fish diseases[63]	External systems, histopathological symptoms and confirmatory test
2	SALMEX – to diagnose diseases of farmed salmonid fishes in seawater[64]	Behaviour signs, external signs and internal symptoms
3	SEDIP – for diagnosing diseases in freshwater and seawater fish[65]	External and internal symptoms
4	Fish Doctor – diagnosis of various fish disease[66]	Behaviour signs and external signs
5	FINES – for diagnosis of nutritive diseases of farm fish[46]	Diagnose nutritive disease of farmed fish
6	Expert system for diagnosis of various fish diseases[67]	Behaviour signs and external signs
7	Fish-Vet – PC based expert system for diagnosis of various fish disease[68]	Behaviour signs and external signs
8	Fish disease diagnosis expert system[69]	Web based disease diagnosis
9	Fish-Expert – web based fish disease diagnosis for freshwater fishes[70]	Behaviour signs, external signs and internal symptoms, water quality examination and microscopic examination
10	HAMES – for diagnosis and treatment of farmed tilapia diseases[71]	Observations and selected water parameters to diagnose the diseases of farmed tilapia

11	Fish disease diagnosis expert system[72]	Reasoning system for diagnosis of various fish disease with description and solution
12	T-vet – web based tele-diagnosis of fresh water fish diseases[3]	Tele-diagnosis with farmers (synchronous) and off-line diagnosis (asynchronous) enabling farmers to send multimedia information such as text, images and graphics to receive diagnosis
13	Expert system for fish disease diagnosis based on ontology[73]	Diagnosis based on ontology
14	Expert system for fish disease diagnosis based on image retrieval[74]	Diagnosis based on image retrieval
15	SEDPA – expert system for Eel disease diagnosis[75]	Primary data – symptoms and eel pathologies and secondary data – historic data of physical, chemical, biological and yield
16	AWQEE-DSS –water quality evaluation and early warning for fish disease [76]	Evaluation and early warning on water quality parameters with management measures
17	Crab-Expert –crab disease diagnosis[77]	Tele-diagnosis and treatment services to farmers with access to internet
18	H-vet – tele-diagnosis of fish disease[78]	Call centre oriented hybrid disease diagnosis and consulting system
19	Expert system for fish disease diagnosis based on fuzzy inference model[79]	Fuzzy inference model through a set fish disease diagnostic cases
20	Expert system for fish disease diagnosis based on image processing of pathogen's microscopic image[80]	Disease diagnosis through image processing from the microscopic image and sending a message about diagnosed disease and treatment to fish farmers on their mobile
21	Expert system for fish disease diagnosis[81]	Case-based reasoning: two step case retrieve model
22	Call centre based expert system for fish disease diagnosis[82]	Automation of fish diagnostic process based on call centre via telephone
23	Expert system for diagnosis of various fish diseases[83]	Tele diagnosis of fish disease
24	EWS-FDWQ – fish disease warning based on water quality[84]	Fish disease diagnosis based on water quality
25	ES-FDD – fish disease diagnosis based on disease data and image[85]	Fish disease data and images
26	Expert system for fish disease diagnosis using SMS (Short Message Service)[86]	Automation of fish diagnostic process through SMS from mobile phones
27	AquaSDS –fish disease diagnosis based on fuzzy logic decisions[87]	Intelligent agents based diagnosis method
28	Expert system for identification of diseases of farmed flounder[88]	Early warning index through Expert survey method
29	Expert system for fish disease diagnosis based on rough set and classifier fusion[89]	Diagnosis by combination of rough set theory and classifier fusion using data from reduction fish disease diagnosis case database
30	Two stage fish disease diagnosis expert system[90]	Clinical signs and Microscopic images

Fisheries information management

The National Agricultural Library's Aquaculture Information Center had developed an expert-system based advisor called AQUAREF for supporting reference-related to aquaculture information inquiries[91]. It is an automated system developed for storage and access on mircrocomputers. This expert system was developed to help improve access to basic resource tools and information in aquaculture in U.S. Another expert system, REGIS (Regional Information System for African aquaculture) provides information on aquaculture of the Sub-Saharan Africa region in an easy-to-use form for administrators[92]. It presents a descriptive summary of African aquaculture, covering areas such as consumption and production statistics, extension, training, credit programmes, associations, government policy and legislation, and development projects.

Fish product Marketing

Experts systems have found its application in forecasting of future market prospects for various products. It has also been applied in the field of fish market forecasting.

STRATEX (STRATegic decision making system for EXport firms), a knowledge based system aids in decision making in trade of fish and fisheries products by supporting the choice of

market segments and export trade of raw and manufactured fish products in Norway[93].

APPFSS (Aquatic Products Price Forecasting Support System) was developed by China Agricultural University to provide decision aids to price forecasting to avoid market imbalance[94]. This expert system combines models, data, expert knowledge and a user interface and support participants of aquaculture industry to predict market price and related information.

By using a Case Based Reasoning (CBR) approach, an expert system was developed forecasting the price of aquatic products and constructs a forecasting system which can automatically collect internet data on aquatic product prices[95]. The system could effectively analyze and forecast the aquatic product prices using source data from dedicated web sites. Expert systems have also been developed to predict the fishery market in Jiangxi Province in China[96], to forecast Danish ex-vessel seafood prices[97], and to forecast aquatic products price based on agent[98].

Conclusion

Expert system technology is a promising area of information technology having its applications in varied sectors including fisheries. Expert systems are not only the means to apply subject matter specialist's knowledge to a particular problem area but are also potentially powerful learning resources to help the novice end users of the expert system to develop their own expertise. Combined knowledge of multiple human experts gives the system more breadth that a single person is likely to achieve. Expert systems are used to capture the knowledge of human experts to either assist the expert or use them in those situations where the expert is not available. The application of expert systems in fisheries has gradually increased over the years, and is expected to expand further in the near future. This review of expert systems developed in the fisheries sector in past, provide an insight into the types of applications which can be expected in future.

Acknowledgement

References

1. FAO, The State of World Fisheries and Aquaculture (SOFIA) 2008, Food and Agriculture Organization, United Nations, Rome, 176 **(2009)**

2. FAO, The State of the World Fisheries and Aquaculture (SOFIA) 2006, Food and Agriculture Organization, United Nations, Rome, 162pp **(2007)**

3. Duan Y., Fub Z. and Lib D., Towards developing and using web-based tele-diagnosis in aquaculture, *Expert Systems with Applications*, **25**, 247–254 **(2003)**

4. Waterman D. A., A Guide to Expert Systems, Addison-Wesley, Reading, MA **(1986)**

5. Smith S., Verification and validation of rule-based expert system, CRC Press, Boca Raton **(1993)**

6. Maher M. L., Expert Systems for Structural Design, *Journal of Computing in Civil Engineering*, **1** (4), 270-283 **(1987)**

7. Minkarah I. and Ahmad I., Expert Systems as construction management tools, *Journal of management in engineering*, **5 (2)**, 155-163 **(1989)**

8. Wijesudera A. and Harris F.C., Using expert systems in construction, *Construction Computing*, July, 1986 **(1986)**

9. Durkin J., Expert Systems in the Sciences, *The Ohio Journal of Science*, **90 (5)**, 171-179 **(1990)**

10. Lee P. G., A review of automated control systems for aquaculture and design criteria for their implementation, *Aquaculture Engineering*, **14**, 205–227 **(1995)**

11. Malone R. and DeLosReyes Jr. A. A., Categories of recirculating aquaculture systems, In: Advances in Aquacultural Engineering, *Northeast Regional Agricultural Engineering Service*, Cornell, NY, NRAES-105, 197–208 **(1997)**

12. Gaston K. J. and O'Neill M. A., Automated species identification – why not? Philosophical Transactions of the Royal Society of London, Series B 359, 655–667 **(2004)**

13. Froese R. and Schofer W., Computer-aided identification of fish larvae, ICES Copenhagen (Denmark) 10 pp **(1987)**

14. Chen Y., Bar H. L. and Teng F., A content-based image retrieval system for fish taxonomy, *In: Proceedings of the 7th ACM SIGMM International Workshop on Multimedia Information Retrieval* (Hilton, Singapore, November 10-11, 2005) MIR '05 ACM, New York **(2005)**

15. Guisande C., Manjarrés-Hernández A., Pelayo-Villamil P., Granado-Lorencio C., Riveiro I., Acũna A., Prieto-Piraquive E., Janeiro E., Matías J. M., Patti C., Patti B., Mazzola S., Jiménez S., Duque V. and Salmerón F., IPez: An expert system for the taxonomic identification of fishes based on machine learning techniques, *Fisheries Research*, **102**, 240–247 **(2010)**

16. http://www.aiinc.ca/demos/whale.html accessed on 21.01.2010 **(2013)**

17. Golden B. L. and Rothschild B. J., A microcomputer based Decision Support System for multispecies fishery management, Technical Report No. 1, The University of Maryland **(1987)**

18. Purchase H., De Moore I. and Bruton M. N., PISCES - an expert system for the control of the introduction of exotic fish species into southern Africa, *In: International Conference on alternative life history styles of fishes and other organisms*, Grahanmtown, South Africa, June, 1987 **(1987)**

19. Ryan J. D. and Smith P.E., An expert system for fisheries management, *In: Oceans 85 Proceedings: Ocean Engineering and the Environment,* 2, 1114-1117 **(1985)**

20. Aoki I., Inagaki T., Mitani I. and Ishii T., A prototype expert system for predicting fishing conditions of anchovy off the coast of Kanagawa prefecture, *Bulletin of the Japanese Society for scientific fisheries*, **55 (10)**, 1777-83 **(1989)**

21. Stagg C.M., The expert support system as a tool in fishery stock assessment and management, *In: Proceedings of the NATO Advanced Study Institute on Operations Research and management in fishing* (Ed. A. Guionares Rodrigues), Povoa de Varzim, Portugal, 299-314 **(1990)**

22. Stretta J. M., Petit N. and Simier M., Integration of aerospatial remote sensing into the data base associated with an expert system for the tuna fishery, *In: French Contributions in the French-Japanese Symposium: Remote sensing in Marine Biology, Fishery Resources, Oceanography*, (Eds. M. Petit and J.M. Stretta) Bulletin Institute Oceanographique, Monaco, **6**, 199-207 **(1990)**

23. MRAG Ltd., Fisheries management expert systems. *Research reports on the developments of Protuna and Profish*. MRAG Ltd., 23 **(1991)**

24. Fuchs F., An expert system for analyzing relationships between fish and the environment, International Council for the Exploration of the Sea, Copenhagen, Denmark, Internation Council for Exploration of the Sea, C.M. 1991/D:5, 6 **(1991)**

25. Bender M., Katopodis C. Simonovic S. P., A prototype expert system for fishway design, *Environmental Monitoring and Assessment*, **23**, 115-127 **(1992)**

26. Calisal S. M., Mikkelsen J., McGreer D., Akinturk A. and Havens W., Fishing vessel design and constraint reasoning system, *In: Design of Marine and offshore Structures* (Eds. T.K.S. Murthy and J.A Alaez), Elsevier/ Applied Science (UK), 183-199 **(1992)**

27. Rothschild, Brian J., Development of a sampling expert system:"FISHMAP". Solomons, MD, University of Maryland Center for Environmental and Estuarine Studies. Chesapeake Biological Laboratory, 162pp. *(Reference Series,90-090) (UMCEESCCBL 90-090)* **(1990)**

28. HS-IDA, HS – IDA – Examensarbeten - Sammanfattningar (DVP96), http://www.ida.his.se /ida/ Examensarbeten /DVP/DVP96/xjobbDVP-DVP96.chtml# 2 **(1996)** accessed on 21.01.2010 **(2010)**

29. LCSS, Integrated management of sea lamprey: 1986–1996, http://www.essa.com / services / aquatic / tenyears.html accessed on 15.09.2009 **(2009)**

30. Korrûbel J. L., Bloomer S. F., Cochrane K. L., Hutchings L. and Field J. G., Forecasting in South African pelagic fisheries management: the use of expert and decision support systems, *South African Journal of Marine Science*, **19 (1)**, 415-423 **(1998)**

31. Sazonova L., Osipov G. and Godovnikov M., Intelligent system for fish stock prediction and allowable catch evaluation, *Environmental Modelling & Software*, **14**, 391–399 **(1999)**

32. Mackinson S., An adaptive fuzzy expert system for predicting structure, dynamics and distribution of herring shoals, *Ecological Modelling*, **126**,155-178 **(2000)**

33. Nieto K., Yánez E., Silva C. and Barbieri M. A., Probable fishing grounds for anchovy in northern Chile using an expert system, *International Geoscience and Remote Sensing Symposium*, IGARSS '01. **Vol. 7**, 2985-2987 **(2001)**

34. Cheung W. W. L., Pitcher T. J. and Pauly D. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing, *Biological Conservation*, **124**, 97–111 **(2005)**

35. Truong T. H., Rothschild B. J. and Azadivar F. Decision support system for fisheries management, *In: Proceedings of the 37th conference on winter simulation*, Orlando, Florida, 2107-2111 **(2005)**

36. Sadly M., Hendiarti N., Sachoemar S. I. and Faisal Y., Fishing Ground Prediction Using a Knowledge-based Expert System Geographical Information System Model in the South and Central Sulawesi Coastal Waters of Indonesia, *International Journal of Remote Sensing*, **30 (24)**, 6429-6440 **(2009)**

37. Azadivar F., Truong T. and Jiao Y., A decision support system for fisheries management using operations research and systems science approach, *Expert Systems with Applications*, **36 (2)**, 2971-2978 **(2009)**

38. http://www.st-tech.com/fishing/fishing.aspx accessed on 13.01.2010 **(2010)**

39. Bossu T., Mantoni M. and Saroglia M., 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, Slide shows and Poster papers*, presented at the International Aquaculture Conference held in Bordeaux, France, 2-4th October, 1989, 39-40 **(1989)**

40. Stokoe P. K. and Gray A. G., AQUASITE: a computer site assessment system for marine coastal aquaculture, *Bull. Aquacul. Assoc. Canada*, **90 (4)**, 94-96 **(1990)**

41. Rallet F., Garnerin P. and Tuffery G., Schubert audit: Expert system for assistancea in the quality audit of farms producing trout for consumption and restocking, First operational mock-up, *Bulletin Fracois Peche et Pisceculture*, **316**, 1-14 **(1990)**

42. Padala A. and Zilber S., Expert Systems and their use in Aquaculture, *In: Rotifer and Microalgae Culture Systems*, Proceedings of a U.S. – Asia Workshop, Honolulu, HI **(1991)**

43. Harris D. D., Zhang F. and Sydenham P. H., Application of an expert system to monitoring and control in aquaculture, *Knowledge-Based Systems*, **4 (3)**, 165-171 **(1991)**

44. Neish I. C. and Ask E. I., Expert systems in sustainable integrated mariculture, *In: Sustainable Aquaculture 1995 Proceedings, Pacific Congress on Marine Science and Technology*, PACON International, Hawaii, 271-280 **(1995)**

45. Stagnitti F. and Austin C., DESTA: a software tool for selecting sites for new aquaculture facilities, *Aquaculture Engineering*, **18**, 79-93 **(1998)**

46. Ni R., Huang N., Qu W. and Wang X., Studies on fisheries nutriology expert systems based on neural network. *Journal of Zhejiang College of Fisheries/Zhejiang Shuichan Xueyuan Xuebao*, **17 (4)**, 274-280 **(1998)**

47. Baptist M. J., Silvert W., Krost P., Angel D. L.**,** Assessing Benthic Impacts of Fish Farming with an Expert System Based on Neural Networks, *Bulletin of the Canadian Society for Theoretical Biology,* **(1998)**

48. Hernandez-Llamas A. and Villarreal-Colmenares H., TEMA: A software reference to shrimp *Litopenaeus vannamei* farming practices, *Aquaculture Economics & Management*, **3 (3)**, 267-280 **(1999)**

49. El-Gayar O. F. and Leung P. S., ADDSS: a tool for regional aquaculture development, *Aquacultural Engineering*, **23**, 181–202 **(2000)**

50. Ernst D. H., Bolte J. P. and Nath S., AquaFarm: simulation and decision support for aquaculture facility design and management planning, *Aquacultural Engineering*, **23**, 121–179 **(2000)**

51. Bolte J., Nath S. and Ernst D. Development of decision support tools for aquaculture: the POND experience, *Aquacultural Engineering*, **23**, 103–119 **(2000)**

52. Lee P. G., Lea R. N., Dohmann E., Prebilsky W., Turk P. E., Ying H. and Whitson J. L., Denitrification in aquaculture systems: an example of a fuzzy logic control problem, *Aquacultural Engineering*, **23**, 37–59 **(2000)**

53. Wang R. M, He Y. Y., and Fu Z. T., Evaluation of the water quality of aquaculture pond expert system, *In: AFITA 2002: Asian agricultural information technology & management, Proceedings of the Third Asian Conference for Information Technology in Agriculture*, Beijing, China, 26-28 October, 2002 **(2002)**

54. Halide H., Stigebrandt A., Rehbein M. and McKinnon A. D., Developing a decision support system for sustainable cage aquaculture, *Environmental Modelling & Software*, **24**, 694–702 **(2009**)

55. Newell C. and Richardson J., An expert system for the optimization of shellfish raft culture. *Journal of Shellfish Research*, **22 (1)**, 347 **(2003)**

56. Petrinec K., Petrinec Z., Kovacic Z. and Zupan B., Experimental Validation of an Internet-based Expert System for the Fresh-water Fish-Farming Industry, *In: Proceedings of the IEEE International Conference on Computational Cybernetics* (ICCC 2003), Siofok, Hungary, August 29-31, 2003 **(2003)**

57. Vezzulli L., Bartoli M., Nizzoli D., Naldi M., Fanciulli G., Viaroli P. and Fabiano M., A simple tool to help decision making in infrastructure planning and management of phytotreatment ponds for the treatment of nitrogen-rich water, *Water SA* **32 (4)**, 606–610 **(2006)**

58. Xu L., Yu C., Xing B. and Li D., A PDA-Based Feeding Expert System For Indoor intensive Culturing of Southern Flounder In china, *Computer and Computing Technologies in Agriculture II*, **1**, 725-733 **(2009)**

59. http://www.bit.or.at/ik/ec-bsshow8.php?ref1=MAI smartfish & vQuelle=ecaustria.at&cc= accessed on 10.01.2009 **(2009)**

60. Hargrave B., A traffic light decision system for marine finfish aquaculture siting, *Ocean & Coastal Management*, **45**, 215-235 **(2002)**

61. Silvert W., Decision support systems for aquaculture licensing, *Journal of Applied Ichthyology*, **10**, 307–311 **(1994)**

62. Moccia R. D. and Reid G. K., Aquaculture sustainability: developing concepts of a decision support tool for licensing freshwater cage aquaculture in Ontario, In: AAC Special Publication No. 12, 106-114 **(2007)**

63. Watson I., AQUADOC: an expert system to aid in the study of fish diseases, Unpublished M.Sc. Thesis, University of Essex **(1986)**

64. Steinebach C. and Pereira C., SALMEX: An Intelligent Knowledge Based System for the Diagnosis of Salmonid Fish Diseases, *In: Jaakkola, H. and Linnainmaa, S. (Eds.): 2ⁿᵈ Scandinavian Conference on Artificial Intelligence 1989, Proceedings of the 2nd SCAI*, Tampere, Finland, June 12-15, 1989. Frontiers in Artificial Intelligence and Applications, Volume 4, IOS Press 1989, Amsterdam, The Netherlands, 431-442 **(1989)**

65. Bogatu D., Bumbaru S., Oprea L., Trofimov L., Novac C. and Metaxa I., Expert system for ichthyopathological diagnosis, *Aquaculture*, **129 (1-4)**, 437 **(1995)**

66. Wang C., Huang S. and Ji R., Fish disease diagnosis system - 'Fish doctor', The transaction of Jimei University, 1997 **(3)** (in Chinese) **(1997)**

67. Ding W., Li W. and Li Ma, Diagnosis of fish disease and design of fish disease expert system, *In: International Symposium on Intelligent Agricultural Information Technology (ISIAIT),* 183–187 **(2000)**

68. Zeldis D. and Prescott S., Fish disease diagnosis program – problems and some solutions, *Aquacultural Engineering*, **23**, 3–11 **(2000)**

69. Zheng Y., Study on expert system of fish diagnosis based-on internet, Unpublished Master's thesis of China Agriculture University **(2001)**

70. Li D., Fu Z. and Duan Y., Fish-Expert: a web-based expert system for fish disease diagnosis, *Expert Systems with Applications*, **23**, 311–320 **(2002)**

71. Brock J. A., Itoga S. Y. and Coleman D., Hawaii Aquaculture Module Expert System, Center for Tropical and Subtropical Aquaculture, Oceanic Inst., Waimanalo (Hawaii) **(2002)**

72. Wen J., A reasoning system for fish disease diagnosis, Unpublished M.Sc Thesis, China Agricultural University, Beijing (in Chinese) **(2003)**

73. Guo Y., An ontology based fish disease knowledge acquisition and diagnosis reasoning integrating system, Unpublished PhD thesis, China Agriculture University, Beijing **(2004)**

74. Lou D., Chen M. and Ye J., Study on a fish disease case reasoning system based on image retrieval, *New Zealand Journal of Agricultural Research*, **50**, 887-893 **(2007)**

75. Gutiérrez-Estrada J. C., Sanz E. D. P., Lo´pez-Luque R. and Pulido-Calvo I., SEDPA, an expert system for disease diagnosis in eel rearing systems, *Aquacultural Engineering*, **33**, 110–125 **(2005)**

76. Wang R., Chen D. and Fu Z., AWQEE-DSS: A Decision Support System for Aquaculture Water Quality Evaluation and Early-warning, In: International Conference on Computational Intelligence and Security, 959-962 **(2006)**

77. Yuan H., Yang Y. and Chen Y., Crab-Expert: a Web-Based ES for Crab Farming, In: Proceedings of ICARCV '06. 9th International Conference on Control, Automation, Robotics and Vision, 2006 **(2006)**

78. Li D., Zhu D. and Fu Z., A hybrid tele-diagnosis system on fish disease, In: Proceedings of the 5th WSEAS International Conference on Applied Computer Science, Hangzhou, China, April 16-18, pp194-199 **(2006)**

79. Wen J., Li D., Zhu W. and Fu Z., A new method for fish-disease diagnostic problem solving based on parsimonious covering theory and fuzzy inference model, In: IFIP, International Federation for Information Processing, (Ed.

Brammer, M.), Artificial Intelligence in Theory and Practice, **217**, 455-464 **(2006)**

80. Jeong-Seon P, Myung-Joo O. and Soonhee H., Fish Disease Diagnosis System Based on Image Processing of Pathogens' Microscopic Images, In: Frontiers in the Convergence of Bioscience and Information Technologies, 2007, 878-883 **(2007)**

81. Zhu W. and Li D., A CBR system for fish disease diagnosis, *Computer and computing Technologies in Agriculture*, **2**, 1453-1457 **(2008)**

82. Zhang J. and Li D., A call centre oriented consultant system for fish disease diagnosis in China, IFIP International Federation for Information Processing, Volume 259. *Computer and computing Technologies in Agriculture*, **2**, 1447-1451 **(2008)**

83. Yuan H., Xie L., Chen M., He Q. and Chen Y., An expert system for fish disease tele-diagnosis based on 3I fuzzy reasoning mechanism, *In: 7th World Congress on Intelligent Control and Automation*, WCICA 2008, 2121-2125 **(2008)**

84. Nan L., Ruimei W., Jian Z., Zetian F. and XiaoShuan Z., Developing a knowledge-based early warning system for fish disease/health via water quality management, *Expert Systems with Applications*, **36**, 6500–6511 **(2009)**

85. Xiaoshuan Z., Zetian F., Wengui C., Dong T. and Jian Z., Applying evolutionary prototyping model in developing FIDSS: An intelligent decision support system for fish disease/health management, *Expert Systems with Applications*, **36**, 3901–3913 **(2009)**

86. Wang G. and Li D., A Fish Disease Diagnosis Expert System Using Short Message Service, *In: International Conference on Communications and Mobile Computing*, 299-303 **(2009)**

87. Novac-Ududec C., A Model for an Intelligent Support Decision System in Aquaculture, MPRA Paper No. 13065. http://mpra.ub.uni-muenchen.de/ 13065/ **(2009)**

88. Xing B., Li D., Wang J., Duan Q. and Wen J., An early warning system for flounder disease, *In: (Eds.) Li, D. and Chunjiang, Z. IFIP International Federation for Information Processing*, Volume 294, Computer and computing Technologies in Agriculture II, **2**, 1011-1018 **(2009)**

89. Yuan-hong W. and Jun L., A New Method for Fish Disease Diagnosis System Based on Rough Set and Classifier Fusion, In: Artificial Intelligence and Computational Intelligence, International Conference on*, **2**, 24-27, 2009 International Conference on Artificial Intelligence and Computational Intelligence, Shanghai, China **(2009)**

90. Han C.M., Lee S.W., Han S. and Park J.S., Two-Stage Fish Disease Diagnosis System Based on Clinical Signs and Microscopic Images, Computational Science and Its

Applications - ICCSA 2011, Lecture Notes in Computer Science, **6783**, 635-647 (**2011**)

91. Hanfman D., AQUAREF: An expert advisory system for reference support, *The Reference Librarian*, **23**, 113-133 **(1989)**

92. Freeman, R. R. and Haufman D. T., REGIS: a prototype regional information system for African aquaculture, *In: International Association of Marine Science Libraries and Information Centres*. Conference, 15th, 1989 at St George, Bermuda, 55-64 **(1990)**

93. Borch O. J. and Hartvigsen G. Knowledge-based systems for strategic market planning in small firms, *Decision Support Systems*, **7(2)**, 145-157 **(1991)**

94. Xiaoshuan Z., Tao H., Revell B. and Zetian F., A forecasting support system for aquatic products price in China, *Expert Systems with Applications*, **28 (1)**, 119-126 **(2005)**

95. Yuan H., Chen Y. and Ju J., A CBR based predication method for web aquatic products prices, *In: International conference on intelligent systems and knowledge engineering, Atlantic Press, Paris, p186,* **(2007)**

96. Liangen X. and Xiaoyong L., The trend forecasting of fishery market in Jiangxi Province, *Agricultural Economic of Jiangxi*, **2,** 23 (in Chinese) **(2000)**

97. Nielson M., Forecasts of Danish ex-vessel seafood prices. http://www.sam.sdu.dk/ime/EAFE2000/Papers/MaxNiel.pdf **(2000)**

98. Xiaoshuan Z., Design the forecasting support system based on agent for aquatics product price, *Computer Engineering*, **8**, 134–136 **(2004)**