MACRO-LEVEL AGROECOLOGICAL SYSTEMS ANALYSIS AND SOCIOECONOMICS OF POND AQUACULTURE

Eighth Work Plan, Decision Support Systems Research (DSSR1D)
Final Report

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ABSTRACT

Recent work has been completed relating climatic and geographic factors to assess the suitability of particular agroecologic regions to aquaculture production. These studies were unable to compare the suitability of alternative land uses with aquacultural production. A study was therefore initiated to explore methods of generating terrestrial crop production estimates that: a) involve minimal use of complex simulation models and b) enable the use of biophysical input data likely to be available at the regional scale (e.g., monthly weather datasets). Such estimates are expected to assist regional-level decision makers to compare pond aquaculture with other types of farming systems. This work involved developing a framework to analyze and prioritize international development needs, and identifying and classifying indicators relating to sustainable development. Artificial neural networks were used to relate crop production to agricultural drivers. The Concurrent Decision-Making methodology appears to be a successful approach to facilitate stakeholder input into decision making and evaluation of alternatives intended to be used within group decision support tools. Development of a framework to assess international development needs and concomitant use of sustainable development indicators (SDI) should provide the target audience (i.e., international donor agencies, government organizations, and local groups) with a tool to examine where intervention would likely result in the greatest benefits. More specifically, such a tool can help to identify appropriate roles for aquaculture as well as other farming systems in disadvantaged communities.

INTRODUCTION

Our recent investigations that have focused on issues confronting regional-scale planners suggest the urgent need for tools that can facilitate holistic planning. In this context, personnel from Oregon State University have collaborated with the FAO to use models from the POND© software for regional-scale analysis. This has resulted in two detailed studies of inland aquaculture for Latin America (Kapetsky and Nath, 1997) and for Africa (Aguilar-Manjarrez and Nath, 1998). One of the limitations of both of these studies is that they provide only areal estimates of the suitability of land/water resources for inland (pond) aquaculture. No attempt was made to assess whether land/water resources are perhaps more *suitable* for other types of agriculture (e.g., terrestrial crop production and integrated farming systems).

Assessing alternate types of farming practices at the level of a strategic decision maker (e.g., policy planner) is not a trivial task because suitability of land/water resources for farming is a function of technical viability, availability of physical resources, and socioeconomic conditions, among other factors. From an analytical standpoint, simulation tools that relate biophysical and production variables can generate information which is useful for comparing farming systems in terms of technical viability. Currently available simulation models that can potentially be used for such analyses of terrestrial crop production are relatively complex (e.g., the DSSAT software; IBSNAT, 1994) and require daily weather data which is often unavailable. In this respect, the hierarchical structure of simulation models in the POND© software has provided a level of modeling (i.e., Level 1) that generates adequately accurate estimates of fish yield potential and associated resource needs for regional-scale analysis, as evidenced by their use in the studies cited above. One of the objectives of the current study was to explore methods of generating terrestrial crop production estimates that: a) involve minimal use of complex simulation models and b) enable the use of biophysical input data likely to be available at the regional scale (e.g., monthly weather datasets). Output from such methods is expected to assist regional-level decision makers to compare pond aquaculture with other types of farming systems.

Our recent work in the area of computer tools for holistic, regional-scale planning also suggests that the following areas merit attention: a) a framework to analyze and prioritize international development needs and b) identification and classification of indicators relating to sustainable development. Development of a framework to assess international development needs and concomitant use of sustainable development indicators (SDI) should provide the target audience (i.e., international donor agencies, government organizations, and local groups) with a tool to examine where intervention would likely result in the greatest benefits. More specifically, such a tool can help to identify appropriate roles for aquaculture as well as other farming systems in disadvantaged communities. Thus, additional objectives of the work reported herein were to develop a framework for assessing international development needs, and to arrive at appropriate indicators of sustainable development that can be used for planning purposes. Work conducted to date in these two areas (*Terrestrial Crop Performance Evaluation* and *Frameworks for Planning Sustainable Development*) is presented below.

TERRESTRIAL CROP PERFORMANCE EVALUATION

In this study we are investigating the use of artificial neural networks (ANN) to estimate crop yields (CY), water requirements (WR), fertilizer requirements (FR), and grow-out period or time to harvest (TH). These variables represent output analogous to predicted data from simulation models. ANN is a relatively recent artificial intelligence technique well suited for pattern recognition problems. A major advantage of ANN is the speed at which predictions are arrived at, typically several orders of magnitude faster than multiple simulation model runs.

Essentially, neural networks map input datasets (e.g., weather, soil, water, and management variables) to output data patterns (e.g., CY, WR, FR, and TH) such that if a "trained" ANN is presented with a new set of input data, it is able to accurately reproduce output variables. For evaluating crop performance by the use of ANN, one would ideally prefer to use measured input datasets together with output variables of interest from actual crop trials. Such data are difficult to come by—the alternate approach tested in this study was to use DSSAT (which has been extensively tested worldwide) as a means of generating synthetic output data with actual input weather, soil, and water datasets, together with likely management variable settings. Pilot runs have been made with DSSAT using soybeans as a test crop. The analysis used input datasets from locations in the state of Georgia.

As previously indicated, a primary objective of this effort is to reduce the amount of input data because in most real world instances, it is necessary to work with sparse datasets. Consequently, input datasets for training the ANNs were substantially reduced by summarizing the daily weather datasets (min/max temperature, precipitation, and solar radiation) used in DSSAT in the form of monthly means. An additional variable included in the monthly summaries is photoperiod (day length) because this parameter strongly influences physiological responses of the different crops, particularly soybean cultivars.

The approach of using monthly weather summaries is consistent with datasets that are typically used in regional-scale analysis by GIS (e.g., FAO, 1995). Other input variables used in the ANN included soil type, irrigation thresholds, photosensitivity coefficients, and planting dates. All of these inputs were used to train the ANN against desired outputs (i.e., CY, WR, FR, and TH) extracted from DSSATs summary output files. Preliminary results obtained using trained ANNs for a soybean cultivar planted either early or late in the season (Figure 1) suggest that predictions reasonably comparable to those obtained from DSSAT are possible, but with substantially reduced weather datasets. Relative errors were on average less than 10%. Following more extensive experimentation with several years of weather data, we plan to embed the trained neural networks in an expert system and apply it for estimating performance of different crops in a range of agroecological zones. Results from such analyses may be useful for regional decision makers to compare alternate farming systems, and to ultimately develop guidelines for land and water use management in different agroecological zones.

FRAMEWORKS FOR PLANNING SUSTAINABLE DEVELOPMENT

Strategic planning of development activities requires a systematic decision-making approach. One such approach, Concurrent Decision-Making methodology (CDM), intended to be used within group Decision Support System (DSS-decision tools for group meetings) has been outlined by Nath et al. (1998). The term "concurrent" indicates that all stakeholders present are actively involved in the phases of decision making.

Concurrent Decision-Making Methodology

CDM includes the following phases:

1. Identification and Selection of the Problem
2. Identification of Stakeholders
3. Problem Analysis
4. Goal Identification, Evaluation, and Specification
5. Generation of Solutions
6. Evaluation of Solutions
7. Selection of the Decision
8. Implementation and Monitoring

These phases are briefly described below. The decision phases are listed numerically suggesting the approach is constrained by the need to move from one phase to the next in a linear manner. In reality, however, the process is iterative and somewhat fluid in that one is encouraged to step back to any of the earlier phases (or steps within a given phase) as needed. However, skipping to a future phase is strongly discouraged.

<u>1. Identification and Selection of the Problem</u>
The first phase of the Concurrent Decision-Making methodology identifies and establishes problem objectives, which are stated in the form of a fairly general statement (e.g., degradation of the quality of life in a given region). This statement essentially provides some boundaries for the problem(s) to be addressed.

<u>2. Identification of Stakeholders</u>
The second phase involves identification of stakeholders because diverse individuals and groups are potentially

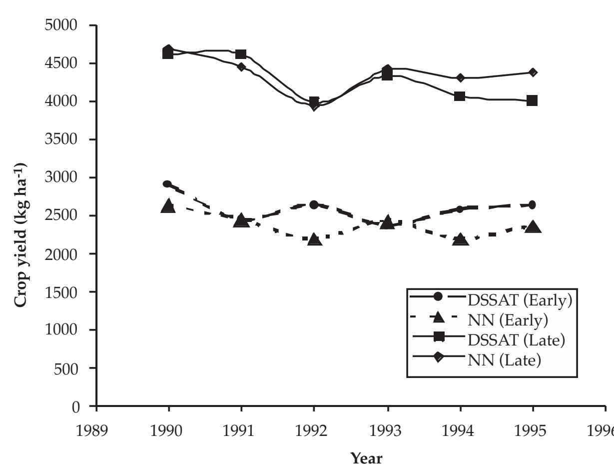

Figure 1. Preliminary results comparing crop yields for soybean from the DSSAT software and trained neural networks (NN) for the years 1990-1995. Early and late, respectively, refer to early and late planting dates for the crop as determined by DSSAT.

impacted by the selected problem or have an interest in seeing a solution to the problem. Each stakeholder may have a specific perspective, but all stakeholders share an identical (higher-level) goal that is represented in the objective statement of the problem.

3. Problem Analysis
This phase involves identification of causal factors, which affect the selected system in such a way that if they are changed, the state of the system will also change. Problem analysis can be systematically approached by adopting a hierarchical structure, with causal factor groups defined and listed at higher (more abstract) levels and sub-factors identified and listed within an appropriate group at lower (less abstract) levels. Direct and indirect relationships among factors/sub-factors should also be identified, because they provide a means for prioritizing intervention efforts. This phase involves considerable use of data and knowledge available for the system, as well as brainstorming among representative stakeholders and experts to ensure a full appreciation of complex and often conflicting factors and sub-factors.

This phase will also involve examination of the current state of the causal factors. At this stage, it is typically necessary to identify measurement units (metrics) for the factors. Note that metrics are usually assigned at the sub-factor level rather than at the factor group level, because the former is less abstract and can therefore be more precisely defined.

4. Goal Identification, Evaluation and Specification
This phase will involve identification of appropriate causal factors/sub-factors in the system that need to be changed in order to address the problems identified in Phase 3 above. The identified causal factors/sub-factors constitute goals, which have the following properties:

- a direction (e.g., increase, decrease, hold constant);
- a numerical value;
- a time frame within which the desired change is to occur;
- an assigned priority; and
- a higher-level context within which the goal resides.

An important step in this phase of CDM is to assign appropriate target values or desired future conditions (DFCs) for the first three of the above properties. It may not always be possible to specify a numerical value and time frame for a goal at the level of a factor group because, as previously indicated, this level is more abstract. However, as part of DFC specifications, sub-factors will always be assigned a desired direction of change in addition to a numerical value and a time frame.

Specifying priorities provides stakeholders with an objective means of weighing different goals and is a critical part of multi-objective decision making. It also provides stakeholders with a more objective basis of understanding the importance each of them assigns to different goals.

With regard to the context of a goal, it is necessary for stakeholders to realize that goals are essentially a means of achieving a higher end. Thus, meeting the DFC for a certain sub-factor is a means of achieving a higher-level goal (specified for the associated factor group). This hierarchical scheme extends all the way up to individual and/or organizational levels.

An additional step in this phase is to evaluate the assigned DFCs in relation to the current state of the causal factors (i.e., calculating the distance between the current and desired future states). This can provide a basis to judge whether assigned DFCs are realistic and if they need to be re-specified. Thus, evaluation and specification of goals occurs in an iterative rather than a sequential manner.

5. Generation of Solutions
This is a brainstorming and creative phase to generate as many concept solutions/decisions as possible with little judgment as to their suitability for the problem. During this phase, it may be necessary to conduct preliminary "what-if" scenarios (e.g., using models and/or other knowledge-based systems) to explore and understand relationships among causal factors and how they may change in response to different intervention schemes.

6. Evaluation of Solutions
In this phase the concept solutions are combined and reduced to a reasonable number, which can be fully explored and subjected to multi-objective optimization analysis, if necessary. It may be necessary to revisit causal factors that were previously identified that may create conflicts among participants.

7. Selection of the Decision
In this phase the focus returns to the individual(s) as the decision maker. It is expected that stakeholders will use both the objective information provided by the above phases as well as their intuition/experience to arrive at a reasoned decision.

8. Implementation and Monitoring
In the final phase of CDM, the decision is committed to action(s), but must be accompanied by appropriate implementation measures and monitoring schemes agreed to by the stakeholders. Often determinations of a detailed procedure of actions, responsibilities of individuals, and timelines are needed, activities that will use knowledge gained from the above phases. Implementation and monitoring schemes are required to continually evaluate consequences of the decisions against DFCs and to acquire new data and knowledge for use in the future. This phase is particularly important for strategic planning activities that are designed to be fully adaptive (responsive) from the outset.

Sustainable Development Indicators

A number of international development organizations (CSD, 1996) have been involved in an integrated effort to develop a framework for sustainable development indicators (SDI). This framework is primarily intended for use in decision making at the national level (CSD, 1996). Because it is to be used as a guide for all the member countries of the UN, the framework is understandably very comprehensive and provides an exhaustive list of development indicators (approximately 130) with associated descriptions. These indicators are categorized within a number of broad categories that address social, economic, environmental, and institutional issues. Within each of these categories, a number of thematic areas are addressed. Thus, social issues that are addressed include:

- combatting poverty;
- demographic dynamics and sustainability;
- promoting education, public awareness, and training; and
- protecting and promoting human health.

Table 1. Examples of higher-, intermediate-, and operational-level goals identified for two of the seven security areas recognized by CARE within an overall mission of sustainable improvement of livelihood security (adapted from CARE, 1998). Operational-level goals have not been assigned specific target levels in these examples because the framework is intended to be a generic one to be adapted by decision-makers in specific locations. In other words, targets for operational goals are site-specific.

Higher-Level Goals	Intermediate-Level Goals	Operational-Level Goals
1. Increase in % of families with nutritional and food security	1.1. Increase in % of families with better access to food	1.1.1. % of families with a target number of meals per day 1.1.2. % of families according to quality (e.g., protein, energy, and micro-nutrients) of meals consumed 1.1.3. % of families according to number of months per year that are scarce in food
	1.2. Increase in % of children with adequate nutrition and growth trends	1.2.1. % of children under 2 years old with less than two standard deviations (weight/height, height/age, weight/age) 1.2.2. % of children under two years old with adequate growth trends
	1.3. Increase in % of families with availability and diversity of food	1.3.1. % of families with higher yields than the regional average for basic crops 1.3.2. % of families implementing more than two non-traditional crops[1] 1.3.3. % of families with agricultural products cultivated in an improved family garden[2]
2. Increase in % of population with environmental security	2.1. Increase in % of population using sustainable practices and appropriate management of natural resources	2.1.1. Increase in % of watersheds under sustainable management 2.1.2. Increase in % of land area under sustainable management 2.1.3. Increase in % of forest area under sustainable management

[1] Farmed fish is often a non-traditional crop that provides diversity in food choices and has substantial nutritional value.
[2] Family gardens for subsistence farmers also increases food diversity, potentially provides better overall nutrition and has other indirect benefits (e.g., increased opportunities for women to both improve family conditions and sell/barter extra produce).

Similarly, environmental issues addressed include:
- protecting freshwater resources;
- protecting ocean resources; and
- promoting sustainable agriculture and rural development.

The above two lists constitute a very small subset of those documented in the SDI framework (CSD, 1996) but serve to illustrate the range of issues addressed. Further, the SDI framework uses a systems approach organized around the following concepts:

1. *Driving Force Indicators*: These represent human activities, processes, and patterns that influence sustainable development;
2. *State Indicators*: These indicate the (current) "state" of sustainable development; and
3. *Response Indicators*: These indicate policy options and other strategies that reflect attempts to change state indicators such that they move towards a more sustainable state.

For example, with respect to promoting sustainable agriculture and rural development, representative indicators identified by CSD (1996) are as follows:

- *Driving Force Indicators*: a) Use of agricultural pesticides; b) use of fertilizers; c) irrigation percent of arable land; and d) energy use in agriculture.
- *State Indicators*: a) Arable land per capita; and b) area affected by salinization and waterlogging.
- *Response Indicators*: a) Agricultural education.

It may be argued that these indicators are somewhat simplistic and even incomplete in some regards, but as stressed in the CSD document, the SDI framework is a work in progress. It is intended to provide a forum where the issues can be discussed and indicators can be expanded or reduced and modified according to the needs and priorities of individual countries/ organizations.

A second argument that can be made against the SDI framework is that it is far too detailed for practical decision making, particularly within individual organizations or small groups of organizations dealing with aspects of social, economic, environmental, and institutional issues (such as those affiliated with the PD/A CRSP). Moreover, it does not lend itself well to an analytical framework for implementation in a decision support system.

Consultations with representatives of CARE, the non-governmental international development organization based in Atlanta, suggest that the strategic planning framework they use is more appropriate for the above situations. This framework is being put into place for Honduras (CARE, 1998) and also approaches sustainable development ("adequate quality of life for all the members of the present generation, leaving the same or better options for future generations") in a systems manner. The framework recognizes social, economic, and ecological sub-systems and focuses on sustainable improvement of livelihood security as an overall mission.

Within the mission of livelihood security, certain higher-level goals can be defined. These goals seek to increase the percentage of the population that has:

1. Nutritional and food security;
2. Health security;
3. Educational security;
4. Participation in civil society deliberations;
5. Housing security;
6. Economic security; and
7. Environmental security.

Within each of the above security areas, CARE has identified intermediate- and operational-level goals. Examples of these for food and environmental security are provided in Table 1. Clearly, the SDI framework developed by CARE is conceptually very compatible with the CDM process described above, particularly with regard to a hierarchical goal structure where higher-level goals are more abstract and lower-level ones more operational in the sense that DFCs can be developed for them.

The next phase in this project should focus primarily on implementation of the above SDI framework in a regional-scale DSS, together with an expert system for estimating crop performance (based on the neural network approach previously discussed) and other knowledge-based tools (e.g., models). We will also integrate GIS functionality into the regional-scale DSS primarily for the purpose of data manipulation, visualization, and analysis. It is expected that the overall tool will be used to explore alternate land/water use strategies in relation to different crops (including fish farming) for the inland regions of Honduras.

ANTICIPATED BENEFITS

The study has two primary benefits to the aquaculture community. First, the identification of geographic sites which show potential for successful aquaculture development is critical in determining how to allocate development resources and identifying opportunities for economic development in a biologically suitable manner. The work accomplished under this study identifies such areas based on important biological parameters. Further, the development of datasets and methodologies supporting this analysis are general and can be applied to other areas and development opportunities. Second, the incorporation of more explicit analysis of land use decisionmaking and alternative uses for particular land forms and resources will allow planners and policymakers to more successfully identify areas where compatible land use patterns can be implemented.

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