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Recommendation Domains for Pond Aquaculture

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WorldFish CENTER

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ABBREVIATIONS

AGRAQUA	Agro-ecological Analysis for Aquaculture
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development, Germany)
BN	Bayesian networks
BNSS	Bayesian Network Support Software
DVD-ROM	digital versatile disk – read-only memory
D-leaf	data leaf
E-leaf	expert leaf
GeNIe	Graphical Network Interface
GIS	geographic information systems
HH	households
IdriSP	IDRISI™ Support Program
MCE	multi-criteria evaluation
NGO	nongovernmental organization
PWAP	pond water availability period
SAQUA	Suitability Analysis and Query for Aquaculture
TGP	thermal growth period

INTRODUCTION

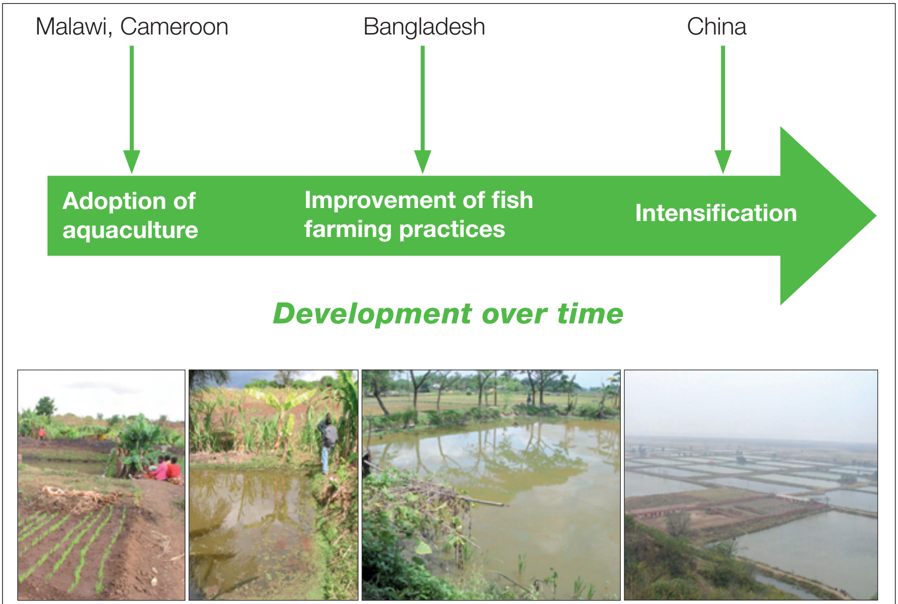
Raising fish for food, or aquaculture, is a long tradition spanning many centuries in some countries. In others, it was introduced only relatively recently. In either case, aquaculture development is rapidly gaining prominence in many countries that face reduced supply from capture fisheries for various reasons such as overfishing, natural resource degradation from environmental pollution and climate change. In many developing countries, freshwater aquaculture plays an increasingly important role in smallholder farming systems toward improving the availability of affordable animal protein for household consumption, diversifying production, reducing risk and supplementing household income. Recent decades have seen increased research efforts in aquaculture to develop various technologies that are viable for newly entrant farmers and also help small-scale farmers to evolve and expand their production toward greater market orientation. Unfortunately, though, smallholder-oriented aquaculture technologies have been successfully disseminated beyond the demonstration phase to larger numbers of poor rural farmers in only a few countries. Even in these countries, such as Bangladesh, more rapid development is required to keep up with the growth in demand for fish.

The number of farmers who can potentially benefit from aquaculture research and extension is very large, and governmental and nongovernmental efforts to promote various aquaculture technologies continue. However, the benefits from these efforts have yet to be realized. An informed basis for recommending particular aquaculture practices and technologies would improve the chances of their successful and sustained adoption. Central to this recommendation is the ability to (1) identify where and under what conditions various types of aquaculture would be feasible and (2) recognize what constraints need to be overcome. These are challenges faced by planners, managers, extension workers and researchers concerned with aquaculture development.

RECOMMENDATION DOMAINS FOR FRESHWATER POND AQUACULTURE: A research project

To address these challenges, a 3-year research project, titled "Determination of High-Potential Aquaculture Development Areas and Impact in Africa and Asia", was carried out to develop and supply the tools for integrative analysis to support informed decision-making on promoting and scaling out target technologies for pond aquaculture. The project was piloted in four countries: Cameroon and Malawi in Africa, and Bangladesh and China in Asia. These countries occupy various stages along the spectrum of aquaculture development (see Figure 1), thereby allowing researchers to test the applicability and usefulness of the decision-support tools under differing sets of circumstances.

Figure 1. The four case study countries occupy different stages in the developmental spectrum of aquaculture adoption and intensification.



Homestead fish ponds Malawi Cameroon | **Improved intensive fish pond in Bangladesh** | **Intensive fish ponds in China**

The project was funded by the Federal Ministry for Economic Cooperation and Development, Germany (BMZ by its German abbreviation) and coordinated by the WorldFish Center with participation from the University of Kassel and the University of Hohenheim in Germany, and national partner institutions including the Institut de Recherche Agricole pour le Développement in Cameroon, Fisheries Department in Malawi, Department of Fisheries in Bangladesh, and Chinese Academy of Fishery Sciences.

This report summarizes the findings of the project and is accompanied by a DVD-ROM containing the main project outputs, including the various software modules for geographic information systems (GIS) and Bayesian (or belief) network modeling developed over the course of the project. The DVD-ROM also contains sample datasets and the compiled knowledge base.

PROJECT SUMMARY

OBJECTIVE AND EXPECTED OUTPUTS

The main project objective is to determine recommendation domains for promoting the development of freshwater pond aquaculture aimed at improving household food security and the livelihoods of smallholder farmers. Recommendation domains are places and sets of conditions for which a particular target aquaculture technology is considered feasible and therefore good to promote. Target technologies may range from low-input systems integrated into the other farming activities of rural households to enhance their food security to more intensive systems requiring external inputs and aiming to supplement household income from the sale of surplus fish.

The main outputs of the project are:

1. an integrated knowledge base of freshwater pond aquaculture systems and practices, as well as the driving factors for their adoption and continued development; and
2. an analysis and decision-support package that can be used to (a) identify places and situations in which freshwater aquaculture is feasible; and (b) elucidate the nature of constraints requiring appropriate interventions to realize the potential of the target areas.

These outputs constitute a knowledge-based system for making informed decisions on promoting particular aquaculture technologies to benefit small-scale farmers. The domains identified at the national level or below help aquaculture planners, managers and extension workers focus aquaculture development efforts on the most promising areas and situations and, in less-suited areas, to identify the kinds of interventions that are needed to overcome the limitations encountered.

TARGET USERS

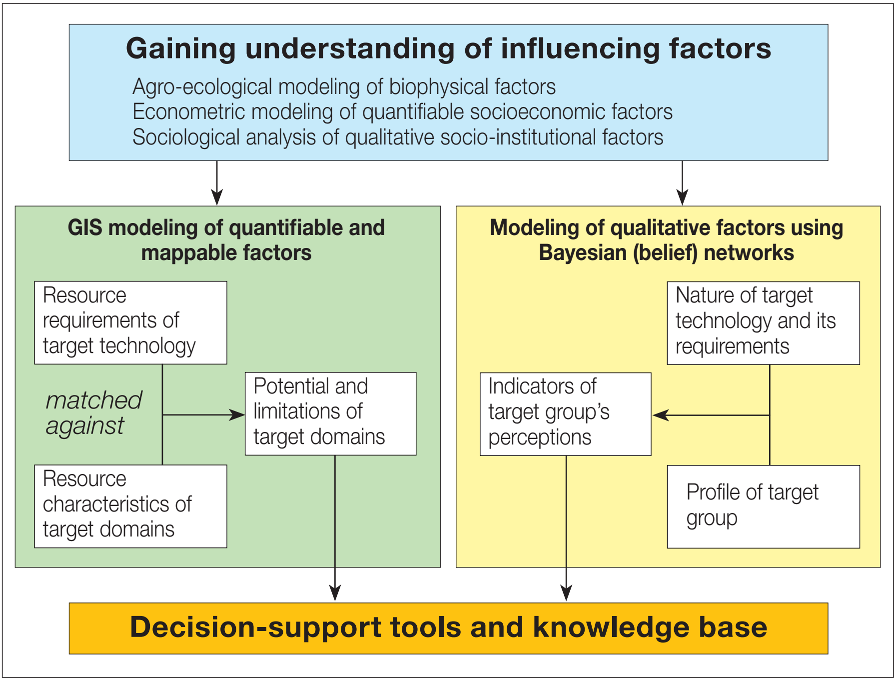
The project outputs are for stakeholders concerned with promoting freshwater aquaculture for sustenance and income generation among small-scale farmers. These stakeholders include:

1. policy planners who have influence on national investments and on research, development and extension policies and legislation;
2. decision makers in national, regional and local governments and in development funding agencies;
3. aquaculture extension workers in regional and local governments and nongovernmental organizations (NGOs); and
4. researchers in aquaculture systems, farming systems, rural livelihoods, and rural resource and land use planning.

APPROACH AND FRAMEWORK

The project adopted a framework, depicted in Figure 2, that integrates the various multidisciplinary components into a knowledge-based analytical and decision-support system to provide an informed basis for recommending particular aquaculture practices and technologies. An important first step in the research was to gain an understanding of the main factors influencing the potential for successfully adopting the target aquaculture technology. This then serves as the basis for using the GIS and Bayesian network modeling techniques developed by the project to analyze the data collected on these influencing factors. The resulting decision-support toolkit can help various target users identify both the locations and the conditions suitable for smallholder freshwater pond aquaculture, as well as the aquaculture systems and technologies suited to these locations. This process is explained in further detail below.

Figure 2. Framework for developing and using decision-support tools for determining recommendation domains for freshwater pond aquaculture.



THE KNOWLEDGE BASE

An important first step in the research was to gain understanding of the main factors influencing the potential and successful adoption of the target aquaculture technologies. As the driving factors may be biophysical, socioeconomic and institutional in nature, this was done through gathering and consolidating a diverse body of knowledge. The relative importance of these factors may vary for different countries and specific target technologies.

Biophysical factors are relatively universal in nature and were identified by searching the literature and consulting with experts. Among the important factors are climate (e.g., whether temperature and water conditions are conducive for producing the target species), terrain and soil (e.g., the ease or difficulty of constructing ponds and their ability to retain water).

Socioeconomic and institutional factors tend to be more country- and context-specific. Case studies in each of the four countries were compiled to determine the status and development of aquaculture and to understand the driving factors for the adoption and diffusion of aquaculture innovations. Information was gathered through a literature review, socioeconomic surveys and consultation with experts. The wealth of information collected from these case studies was compiled and consolidated as monographs profiling aquaculture development in the four countries. The monographs are included on the accompanying DVD-ROM.

THE DECISION-SUPPORT TOOLKIT

The core activities of the project were to develop tools for:

1. analyzing available data to develop indicators for the driving factors influencing aquaculture potential and adoption, which in turn are used for
2. determining recommendation domains (both spatial and non-spatial) for freshwater pond aquaculture.

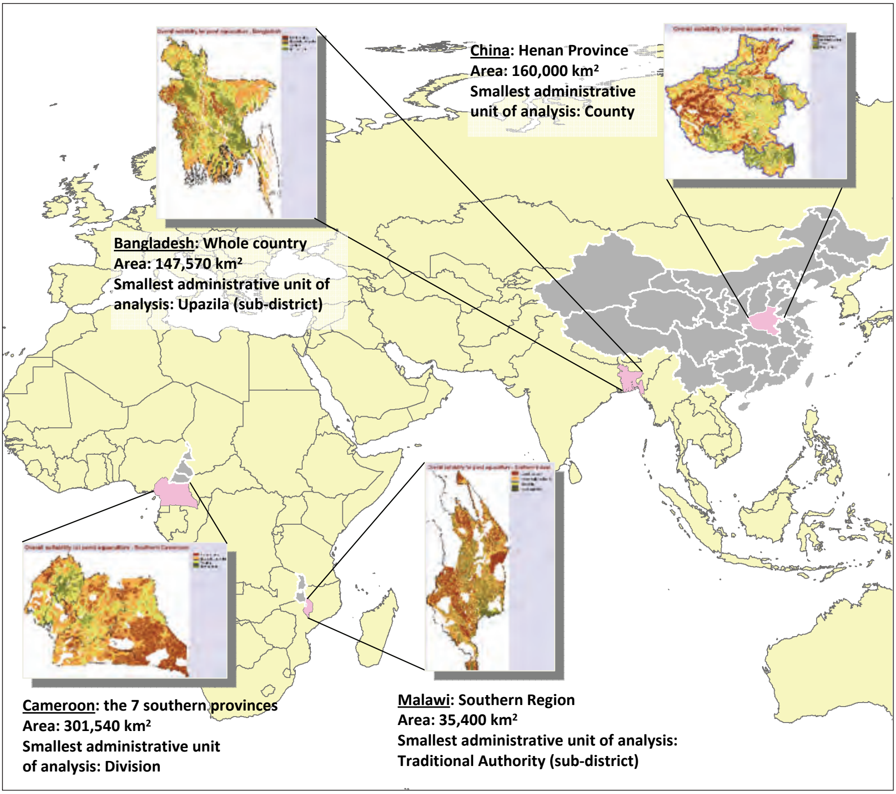
Two main sets of tools were developed, as described below.

GIS MODELING

One tool set identifies and maps areas of differing aquaculture potential as spatial domains. The potential for aquaculture is influenced by several biophysical and socioeconomic factors that vary over space, and GIS techniques lend themselves well to analyzing and mapping aquaculture potential or suitability based on a variety of these factors.

The GIS modeling tools were applied to selected regions in the four countries (see Figure 3).

Figure 3. The project sites in Bangladesh, Cameroon, China and Malawi.

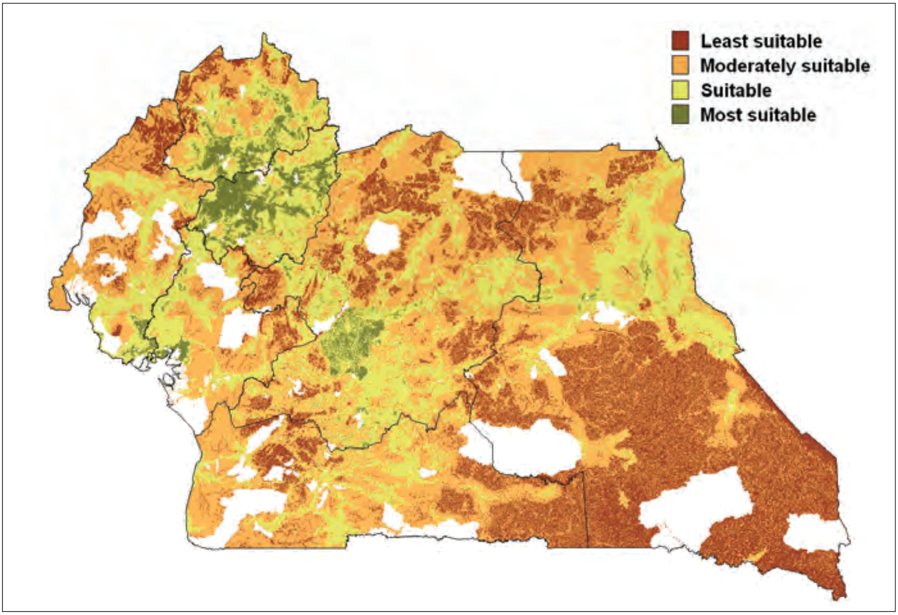


GIS modeling tools can be used to answer practical questions asked by policymakers, aquaculture planners and managers, and extensionists, such as the following:

1. Where, and how extensive, are areas of high potential for the target aquaculture technology? (illustrated by Figure 4)
2. What are the main limiting factors constraining less-suited areas? (Figure 5)
3. Where does a particular constraining factor (e.g., poor access to inputs) occur within the less-suited areas? (Figure 6)

Figure 4 is an example of the output from GIS modeling of the potential, or suitability, of freshwater pond aquaculture for southern Cameroon, taking into consideration a variety of factors, both biophysical (water availability and terrain conditions) and socioeconomic (input availability and access to markets and demand centers for fish products).

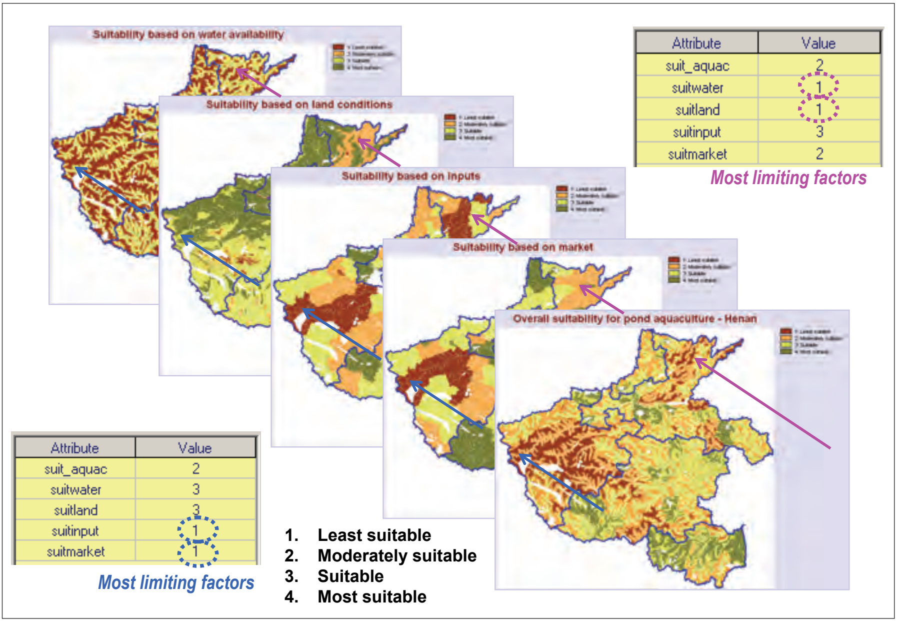
Figure 4. Map of southern Cameroon showing overall suitability for freshwater pond aquaculture (areas under conservation and forest protection, and therefore not available for aquaculture development, were excluded from analysis and are shown in white).



Although southern Cameroon is generally climatically suited for pond aquaculture (given its warm tropical climate with ample rainfall), the distinct geographical pattern showing the more densely-populated and western part as being generally more suited than the more remote eastern part suggests the strong influence of socioeconomic factors, including infrastructure support, on aquaculture potential.

For aquaculture planning and management, it is important to know the nature of the constraints faced in less-suited areas so that the appropriate interventions can be made to overcome them. The same rating of “moderately suitable” at two locations may reflect different sets of limitations. For example, Figure 5 shows two locations in Henan province of China that are rated as “moderately suitable” (with a rank of 2), where the most limiting factors are biophysical in nature (water and land constraints) at one location but socioeconomic in nature (input and market constraints) at the other. The kinds of interventions needed to overcome the constraints are necessarily different at these two locations.

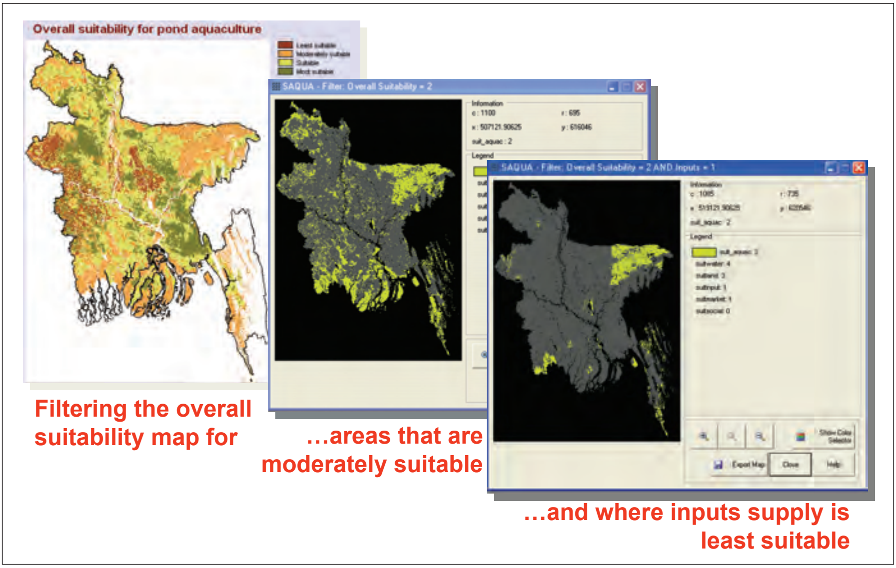
Figure 5. Querying the map of aquaculture suitability for Henan Province in China reveals that different factors limit potential at two locations rated as moderately suitable.



Such a decision-support tool comes in handy for aquaculture support and extension personnel to identify specific constraints in order to focus on relevant aspects of services that are needed most in their areas of operation.

Conversely the question may be asked: Within areas identified as moderately suitable, where is there need for interventions to overcome constraints of access to such inputs as feed and seed? Figure 6 illustrates use of the map filtering function of the GIS decision-support tool to pick out moderately-suited areas that face constraints of input supply. This helps identify priority target areas for a specific intervention (in this case improving the availability and distribution of pond inputs) to help raise the potential in these areas for aquaculture production.

Figure 6. Querying the map of aquaculture suitability for Bangladesh to find out where a certain constraint (e.g., inputs supply) occurs in moderately suitable areas.



The GIS modeling tools developed in this project may be used repeatedly at the national scale or below for varied investigations, as illustrated above. This allows the construction of suitability maps for a number of different scenarios or for anticipated changes in conditions – if, for example, a particular constraining factor is overcome (e.g., improved road infrastructure enhances access to markets), or climate change trends reduce rainfall or aggravate the uncertainty of water supply.

BAYESIAN NETWORK MODELING

The use of GIS requires quantifiable data that are comprehensively mapped over the area of interest. Many factors that determine whether a particular aquaculture technology is sustainably adopted – particularly social, cultural and institutional factors – are not readily quantifiable, let alone mapped. In many situations these "soft" factors have an overriding influence on technology adoption yet are excluded from GIS analysis and modeling.

GIS modeling is therefore complemented in the project with another set of modeling tools based on Bayesian networks (BN), which can incorporate factors of a qualitative nature that influence farmers' perceptions about a particular aquaculture technology. The outcome of the modeling is a reading of the probability of farmers' positive versus negative perception of the target technology, which indicates the likelihood that they will adopt it.

Figure 7. Regionalized probabilities that Bangladeshi farmers look favorably upon improved extensive polyculture of fish in ponds.

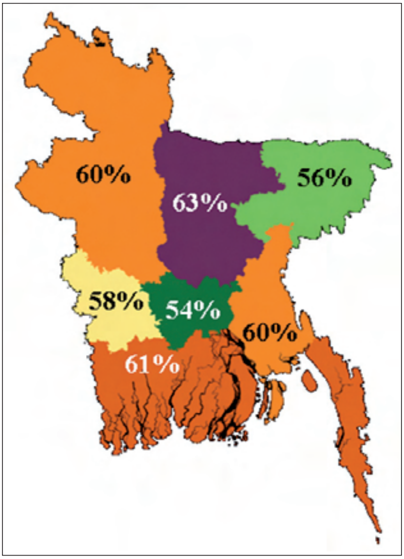


Figure 7 shows the result of such analysis conducted by constructing BN models for the different regions of Bangladesh. The most positive perception (63%) occurs where freshwater pond aquaculture is most widespread and developed, while the least (54% and 56%) occurs in regions with low-lying, flood-prone depressions.

While most of the factors influencing farmers' perceptions of a particular aquaculture technology cannot be readily mapped, the result from BN modeling conducted by constructing BN models for the different regions can be mapped, as shown in Figure 7 for Bangladesh. A mapped result obtained from BN modeling can be included as an input into the GIS modeling, or among the layers of maps for querying the limitations encountered at less-suited areas (as illustrated in Figure 6).

In summary, the development and combined application of GIS and BN modeling provides a suite of analytical tools that can assist policymakers, aquaculture planners and managers, extension workers, and researchers to make strategic assessments about aquaculture potential and identify interventions needed to promote target aquaculture technologies.

METHODOLOGIES AND PRODUCTS DEVELOPED

A suite of research methodologies, analytical models and decision-support tools were developed in the course of the project. Research was conducted in two main phases:

1. gaining understanding to generate the knowledge base; and
2. developing the analytical and decision-support tools to determine recommendation domains for freshwater pond aquaculture.

GAINING UNDERSTANDING AND BUILDING THE KNOWLEDGE BASE

A variety of approaches and methodologies have been adopted and developed for systematically determining a wide range of factors that influence the suitability or feasibility of a particular aquaculture technology for adoption by target fish farmers. While biophysical factors (e.g., water availability and temperature requirements) tend to be relatively universal, estimating these factors requires an understanding and modeling of the underpinning agro-ecological processes and the comprehensive collection of relevant quantitative environmental data. Different approaches and methods are used for determining and analyzing quantitative (or "hard") and qualitative (or "soft") socioeconomic factors. The analyses and products that have been developed by the project are included in the accompanying DVD-ROM and are described below.

AGRO-ECOLOGICAL MODELING OF BIOPHYSICAL FACTORS

Several key biophysical factors affect fish production in ponds, including when and how long the water temperature is conducive for fish growth (i.e., the thermal growth period) and when and how long there is sufficient water in the pond for fish culture (the pond water availability period). If the duration of both periods is sufficiently long, farmers will be able to harvest larger-size fish or raise fish in multiple cycles.

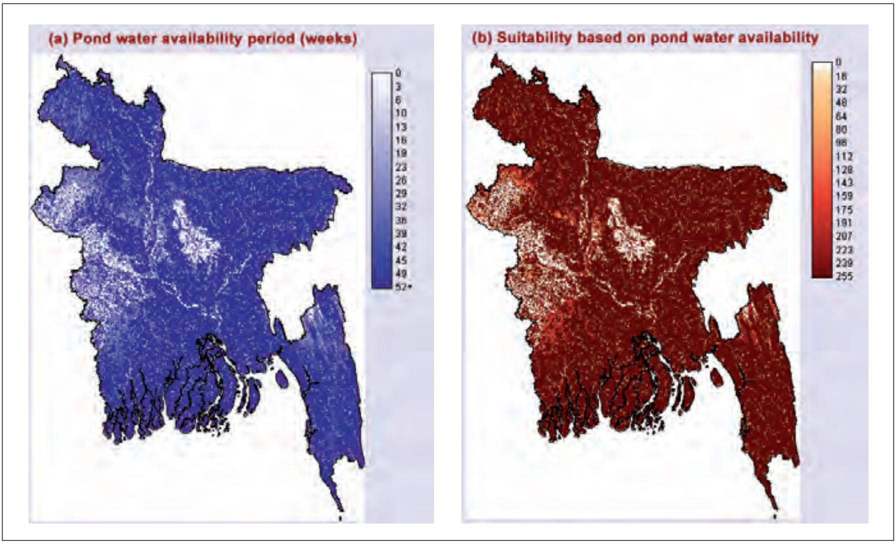
Estimation and mapping of the relevant biophysical indicators for assessing suitability for pond aquaculture, such as the duration of water availability for fish ponds, involves complex modeling of environmental processes that require separate modeling and programming tasks. The project developed models and programs packaged within the Agro-ecological Analysis for Aquaculture (AGRAQUA) freeware for estimating the following biophysical indicators relevant for pond fish culture:

1. The thermal growth period (TGP) is the length of time when the water temperature stays between the lower and upper critical thresholds for fish growth. These thresholds are specific to fish species. Historical air temperature data are used for estimating water temperature in the pond, which is then plotted over time (in intervals of weeks, 10-day periods [dekads] or months) to determine the TGP.
2. The pond water availability period (PWAP) is the continuous time period when there is sufficient water depth in the pond to raise fish. Filling a pond using natural sources of water involves a number of biophysical processes. Water enters the pond from direct rainfall, surface water flow from higher ground, seepage through the soil and rising of the ground water table. Water is lost from the pond through evaporation, overflow and seepage out of the pond and loss to a deeper groundwater table. The net amount of water retained in a pond of particular dimensions, at any instance, is determined by the balance between the gains and losses due to these processes. The water budgeting approach was adopted to develop a mathematical model that computes the level of water in the pond at fixed time intervals (every week, 10 days or month) throughout the year. Modeling the PWAP requires historical climatic and groundwater data and also knowledge of the topography, and soil properties at each place and in its surroundings. Submodels are also developed to estimate evaporation of water from the pond surface and surface water runoff – two important sources of water loss and gain.
3. Fish yield estimates (FYE) within a certain growth period are based on the van Bertalanffy model, which simulates the biophysical growth process by which a fish increases its body mass or weight depending on the surrounding water temperature and the amount of food it consumes. The growth duration is determined by the TGP and the PWAP. Certain growth parameters that are specific to fish species are also needed as inputs for the model. The fish growth models developed also take into account the feeding regimes for the key nutrients – nitrogen and phosphorus.

The three estimations above can be done at particular points or locations, or over an area of interest if the input data are available in mapped form. An area of interest may be a country, or a region or province within a country, depending on the resolution, or level of detail, of the mapped data. As many of the input biophysical data required for modeling are collected at sample points (especially climatic, hydrological and groundwater data), GIS techniques are used to interpolate the point-based data to generate input maps. Each input map is represented as a grid of cells, and calculations are done for every cell to estimate the indicator of interest, that is the TGP, PWAP or FYE.

Figure 8 shows the resulting PWAP map (a) on the left, which serves as an indicator of water availability for pond culture. Places where the PWAP is too short to raise fish to acceptable size would be rated as unsuitable for aquaculture from the viewpoint of water availability, unless interventions to irrigate the ponds were introduced. On the other hand, places with perennial water supply for ponds and therefore the ability to support more than one fish crop would be considered highly suitable. Map (b) in Figure 8, which is derived from map (a) by rating the suitability for pond aquaculture based on water availability, is used as an input indicator map in the GIS modeling of overall suitability for pond aquaculture (as described in a later section on "Mapping aquaculture potential").

Figure 8. Maps of Bangladesh showing (a) pond water availability period (PWAP); and (b) suitability rating for pond aquaculture based on expert-specified PWAP thresholds (on a scale of 0 to 255, from least to most suitable).



SOCIOECONOMIC ANALYSIS OF ADOPTION AND DIFFUSION FACTORS

Two approaches were undertaken for analyzing the wide range of socioeconomic factors and their influence on the adoption and diffusion of target aquaculture technologies:

1. An econometric-based approach was used to analyze data that are quantifiable, whereby regression equations representing the mathematical relationship between adoption and its driving factors were solved using data from household surveys. Statistical regression analysis determines the nature and strength of influence of each determinant factor (e.g., farm size, managerial capacity and access to inputs). Quantifiable indicators were identified for the significant determinant factors, such as the number of livestock and agricultural crops if by-products are used as feed, or access to markets as measured by the actual distance or the travel time based on average travel speed along the traversed road (depending on its type or condition). Indicators that can be mapped are included in the GIS modeling, together with biophysical factors, to determine spatial domains for the target technology.
2. A qualitative, situation-specific approach was adopted to understand the process of adoption and diffusion of the target aquaculture technology from the farmers' point of view. The approach is based on the force-field concept whereby human behavior is considered as a movement in the psychological field, and is a function of the person and his/her subjectively-perceived environment. A person aiming at a certain target mobilizes his/her personal power to attain it. The motive to move toward the target is perceived as the driving force. The route that is pursued to reach the target can be obstructed by barriers, perceived as inhibiting forces. The behavioral outcome is a result of the psychological field of forces in which inhibiting and driving forces are present in a state of equilibrium or disequilibrium with varying degrees of tension between them. The configuration and effect of forces is situation-specific, that is, the same force can be a driving force in one situation and an inhibiting force in another. Oral history interviews with farmers and semi-structured interviews following an interview guide with farmers and experts served as the basis for data collection to identify the perceived driving and inhibiting forces that influence the adoption decision. The understanding thus gained was used to select and group factors according to their causal relationships and construct a first generic version of the BN model described in a later section on "Analyzing farmers' perceptions towards target aquaculture technologies".

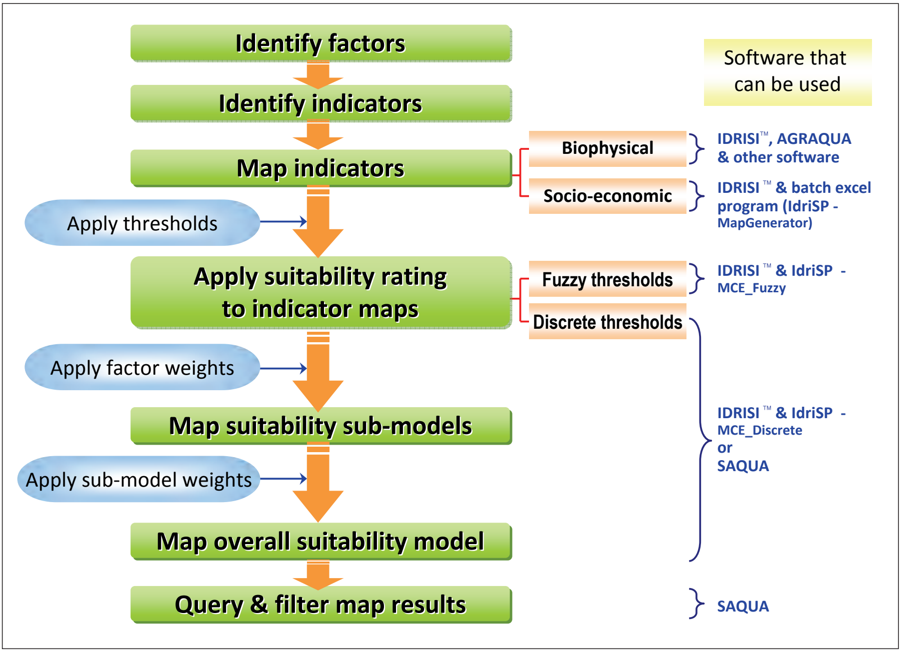
DEVELOPMENT AND USE OF THE DECISION-SUPPORT TOOLKIT FOR DETERMINING RECOMMENDATION DOMAINS FOR FRESHWATER POND AQUACULTURE

The project used a combination of available software supplemented with programs developed in-house to customize the GIS and BN modeling tools for determining recommendation domains for freshwater pond aquaculture. Work included the development of user-friendly interfaces to facilitate stakeholder use. The programs developed in-house are packaged into a decision-support toolkit and offered as freeware in the accompanying DVD-ROM. Examples of how the tools are used are described below.

MAPPING AQUACULTURE POTENTIAL

The flow chart in Figure 9 shows the main steps in the GIS analysis and modeling of aquaculture suitability.

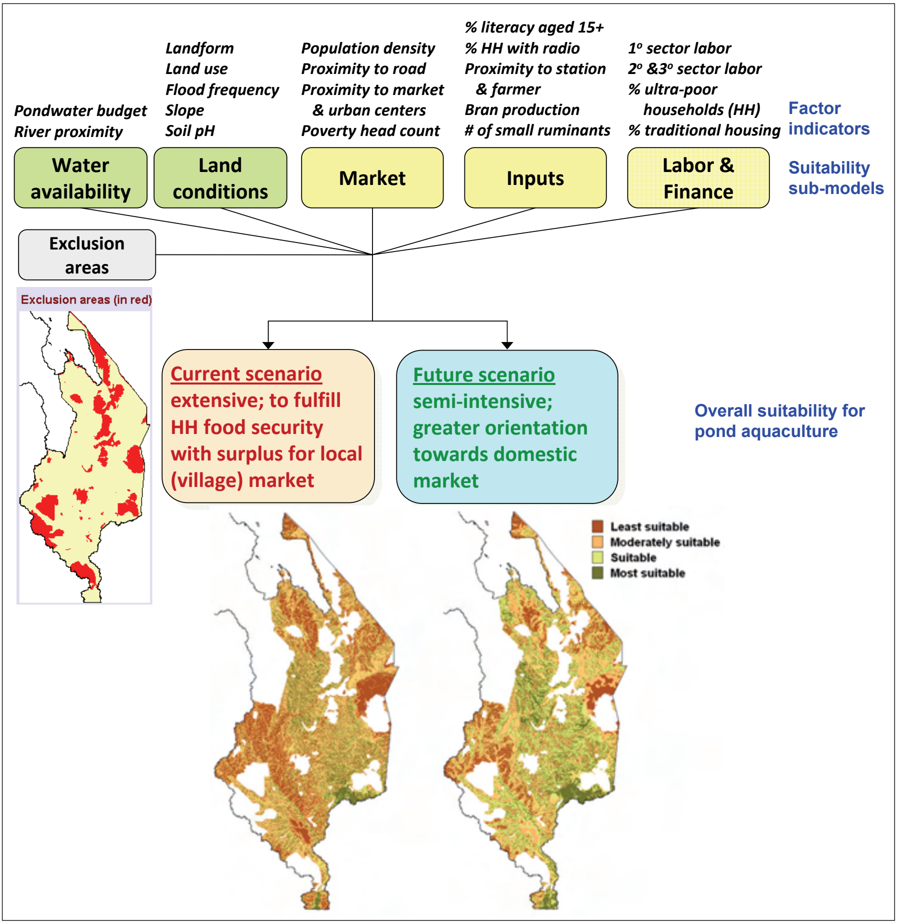
Figure 9. Flow chart of GIS modeling steps and software applied for analysis.



The GIS analysis starts with identifying the factors that influence the potential for a particular aquaculture technology. For example, the target technology in Malawi is low-input polyculture of various indigenous tilapia species in integrated agriculture-aquaculture systems that are commonly practiced by smallholder farmers. The factors identified may be biophysical or socioeconomic in nature: for example, water availability, land conditions, market conditions, and the availability of inputs and knowledge. A relevant indicator for each factor is selected, quantified and mapped. An indicator for water availability, for example, is the duration of sufficient water supply from natural sources to enable fish culture in the pond. For each indicator, local experts are consulted to set thresholds for different suitability levels (least suitable, moderately suitable, suitable, and most suitable).

The overall potential for the target aquaculture technology is determined by the combined suitability ratings of all factors considered. Some factors may be viewed as more important and therefore would carry more weight than others, with local experts consulted in assigning the factor weights. The multi-criteria evaluation (MCE) technique, which is a weighted linear combination of the input indicator maps, is applied to evaluate aquaculture potential. Because of the multiplicity of factors influencing aquaculture suitability, GIS modeling is carried out in two stages. First, sub-models are developed around groupings of factors (Figure 10) for easier and more logical weighting of these factors. In the second stage, the resulting maps from the sub-models are weighted and combined to produce the overall suitability map.

Figure 10. Overall suitability for pond aquaculture for the Southern Region of Malawi.



The modeling can be done repeatedly for different sets of underlying assumptions about the relative importance of selected driving factors and how each factor influences the potential of the target aquaculture technology. Figure 10 shows suitability maps for fish pond culture in southern Malawi for current and future scenarios of aquaculture development.

For the convenience of target users, the project developed the Suitability Analysis and Query for Aquaculture (SAQUA) software, which allows for GIS modeling of aquaculture suitability and for querying multiple map layers, such as the overall suitability map and its component input maps (the last step of the flow chart in Figure 9).

The first feature, for GIS modeling, enables the MCE technique to be used for mapping aquaculture suitability independently of licensed, commercial GIS software. For users opting to do the GIS modeling using the IDRISI™[1] software, the project also developed an Excel-based batch-control program called the IDRISI™ Support Program (IdriSP) to automate the modeling process. IdriSP includes a MapGenerator program that automates the generation of thematic maps of socioeconomic indicators by linking a base map of administrative boundaries with a table containing values of the socioeconomic attributes reported by the corresponding administrative units.

The second feature, for querying multiple map layers, contains two map-querying tools to guide aquaculture management. Figure 5 illustrates the use of the drill-down query function to find out which of the input maps pose limitations at a particular location. Figure 6 shows the use of the filtering function to identify less-suitable areas that face a particular limiting factor and therefore need a particular intervention. Both tools help to identify opportunities for interventions and shed light on the nature of the most effective intervention.

[1] IDRISI™ is the trademark of Clark Labs, Clark University, Worcester, MA 01610-1477 USA

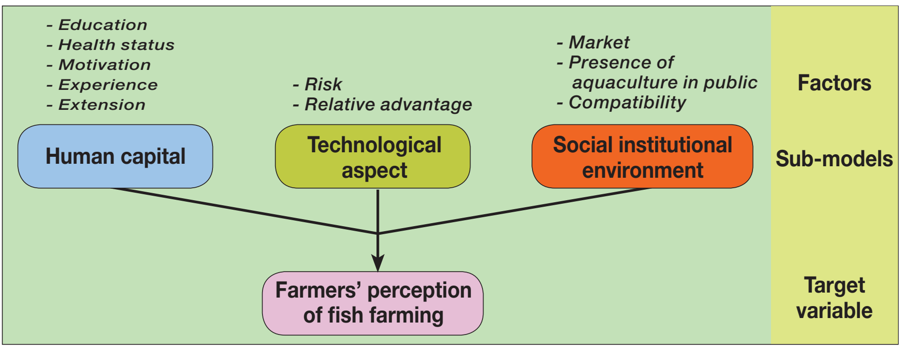
ANALYZING FARMERS' PERCEPTIONS TOWARDS TARGET AQUACULTURE TECHNOLOGIES

Field investigations and stakeholder consultations conducted by the project concerning driving and inhibiting factors for sustainable aquaculture reveal that social and institutional factors are important determinants of the sustainable adoption of fish farming. Yet these factors are often omitted from GIS-based analysis of aquaculture suitability because they cannot be conveniently mapped. Hence, an alternative approach using BN modeling was used to capture the causal interdependencies of driving and inhibiting factors, as perceived by farmers, that influence their likelihood of adopting a particular aquaculture technology.

Developing a BN model starts with identifying the objective or target variable, which in this case is a probabilistic statement regarding farmers' perception of a particular aquaculture technology. There can be a multitude of factors that influence farmers' perception, which may be broadly grouped into the following categories (Figure 11):

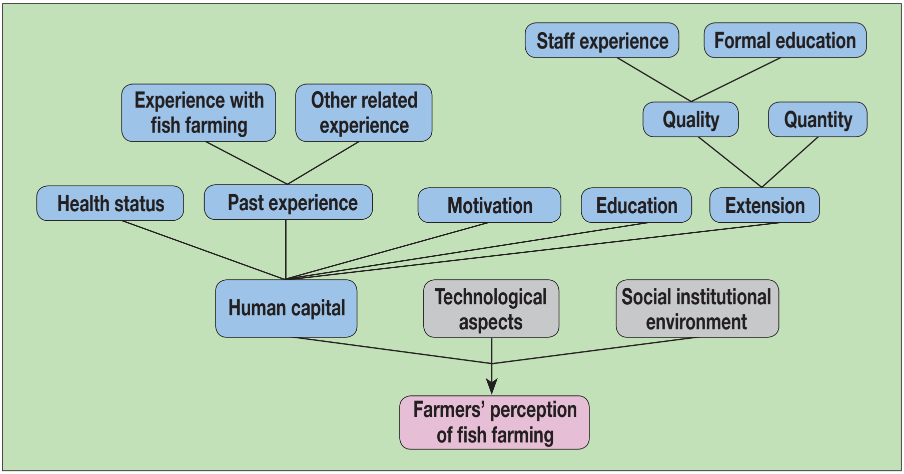
1. the human capital that farmers have at their disposal, as well as their personal preferences and individual motivations;
2. such characteristics of the technology as how well it suits the immediate physical environment (including risks) and its relative advantage in relation with farmers' existing livelihood activities; and
3. the enabling social and institutional support that is available and accessible to improve the chances of farmers' sustainable adoption.

Figure 11. The three main groupings of factors influencing farmers' perception of fish farming.



Using a hierarchical modeling approach, each of the three main groupings of factors that constitute the basic BN model can be structured as a sub-model consisting of influencing factors. Experts are consulted on identifying these country-specific factors and their causal dependencies within each sub-model (Figure 12).

Figure 12. The human capital sub-model of the Bayesian network model for Malawi.



We used the GeNIe[2] software to create a graphical model depicting the influencing variables and their causal dependencies. In the resulting graph, the factors are represented as nodes that are linked according to their dependencies in a chain of parent-child causal relationships. Figure 13 illustrates how these dependencies are graphically represented. At each node, the factor assumes a particular state or outcome; for example, the state of extension staff experience is perceived to be 80% good, 15% moderate and 5% poor. The probability values for the outcomes can be based on expert judgment, thus enabling unquantifiable factors to be included in the BN. Where quantitative data are available for a particular factor, experts are consulted on classifying the quantified measure into probabilities.

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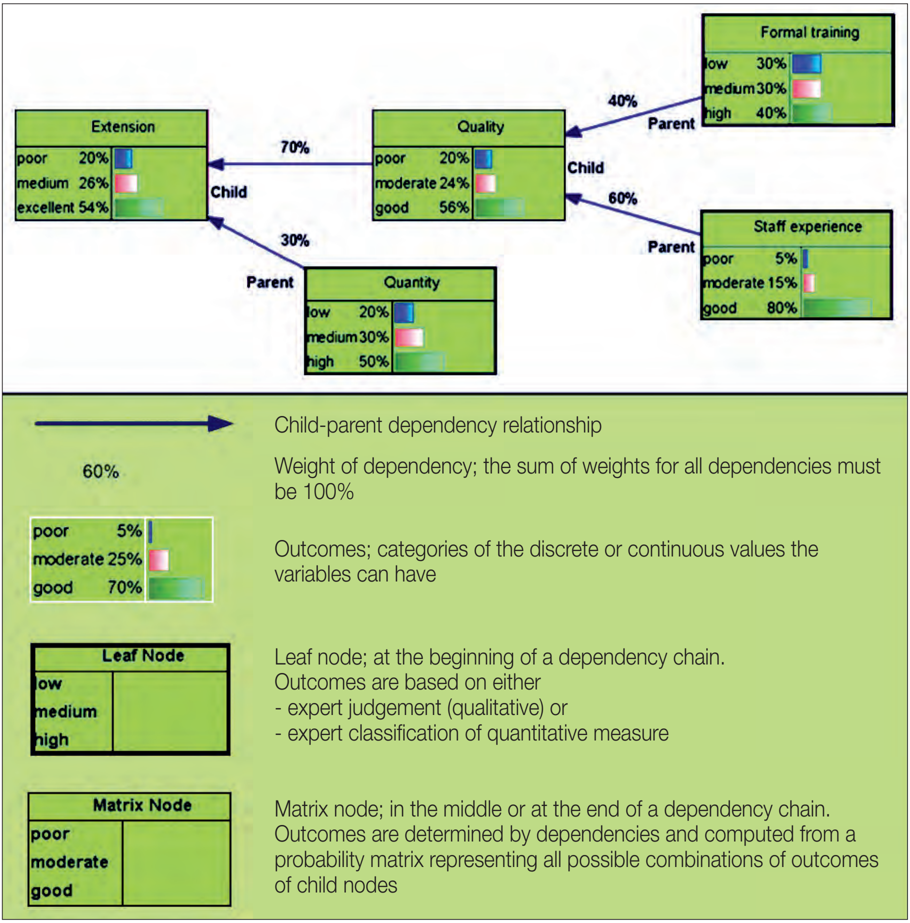
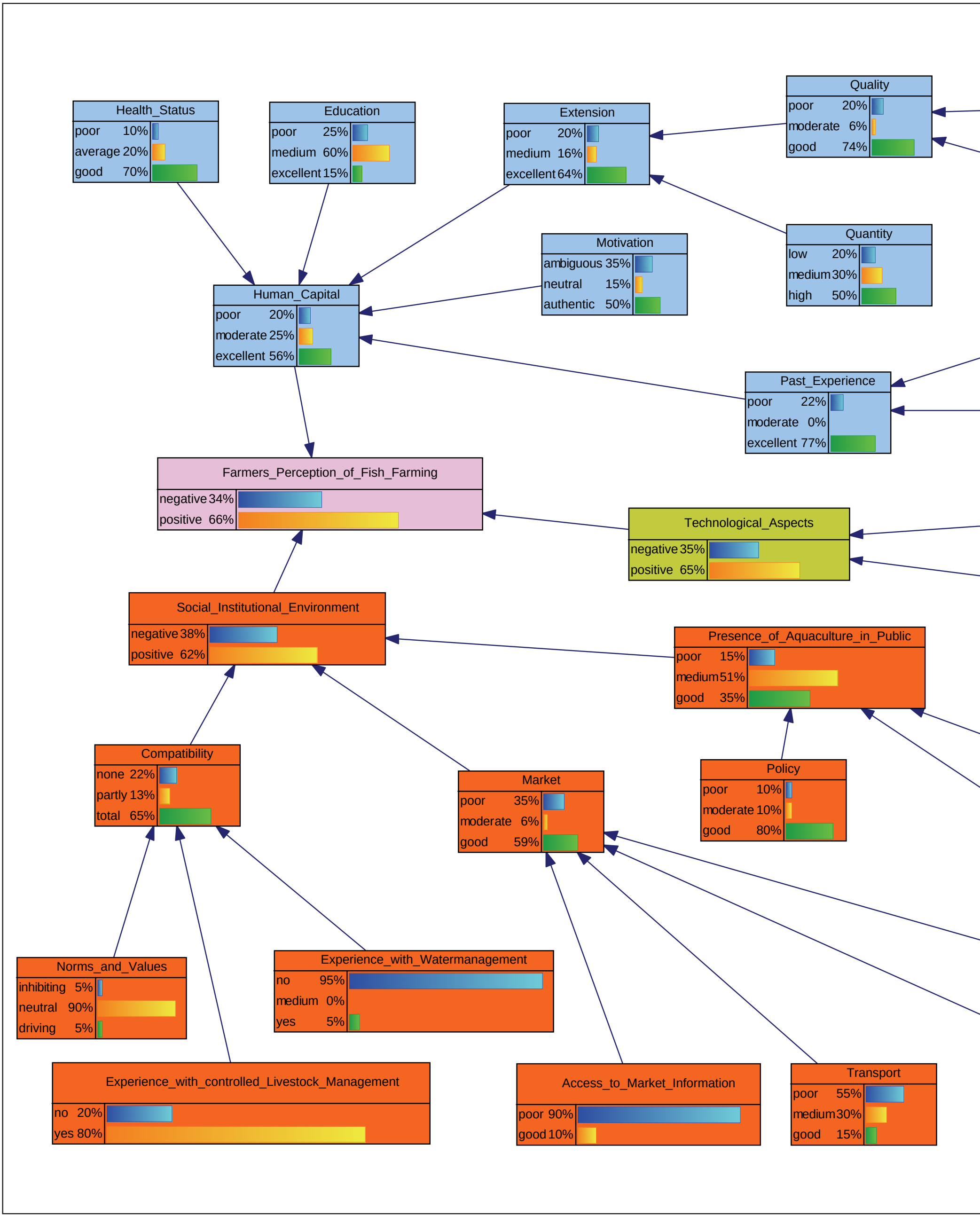
[2] GeNIe is the acronym for Graphical Network Interface, a freeware of the University of Pittsburgh included in the accompanying DVD-ROM.

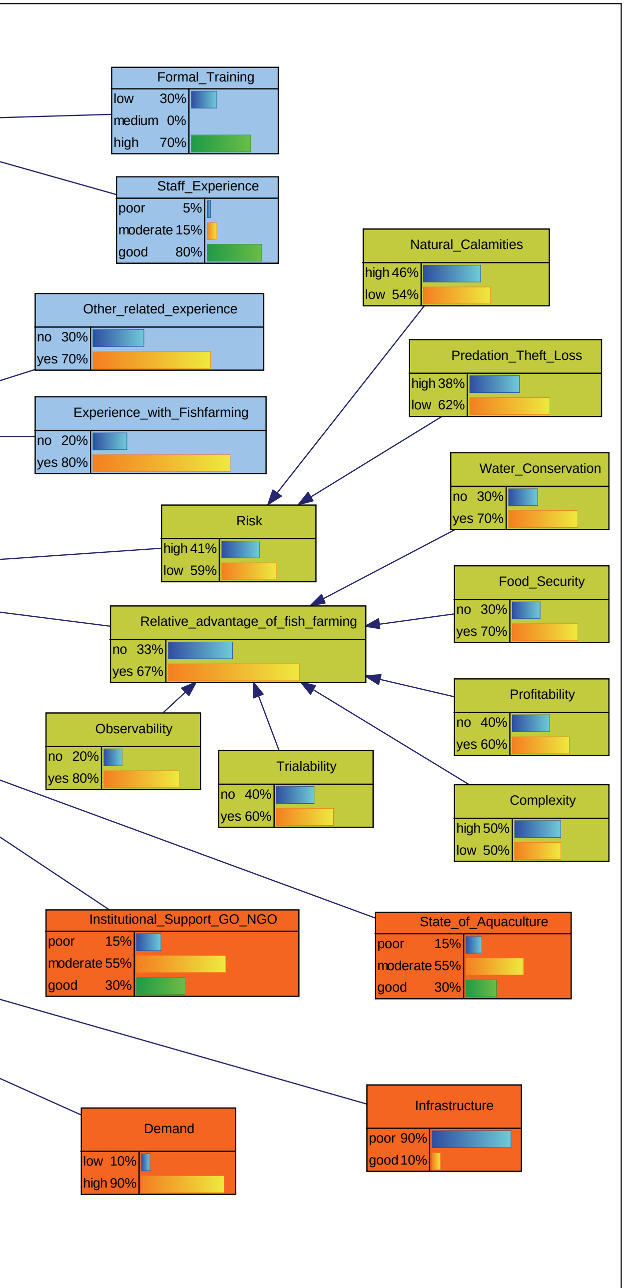
Figure 13. Uncertain knowledge (expressed as probabilities) is propagated along a dependency chain, from parent nodes via child nodes towards the main variable of a Bayesian network.



The crucial part of the BN modeling is defining, for each matrix node, its corresponding probability matrix that represents all possible combinations of outcomes of its parent nodes. This matrix may be manually filled by the expert or mathematically computed based on the outcomes of the parent nodes and expert-assigned weights for all the dependencies. Based on these settings, the underlying Bayesian mathematics computes the propagation of these probabilities through the network of causal dependencies, resulting in the final probabilistic outcomes for the model objective, in this case the likelihood that farmers are positive in their perception towards a target technology (Figure 14).

Figure 14. The Bayesian network graph for Malawi.

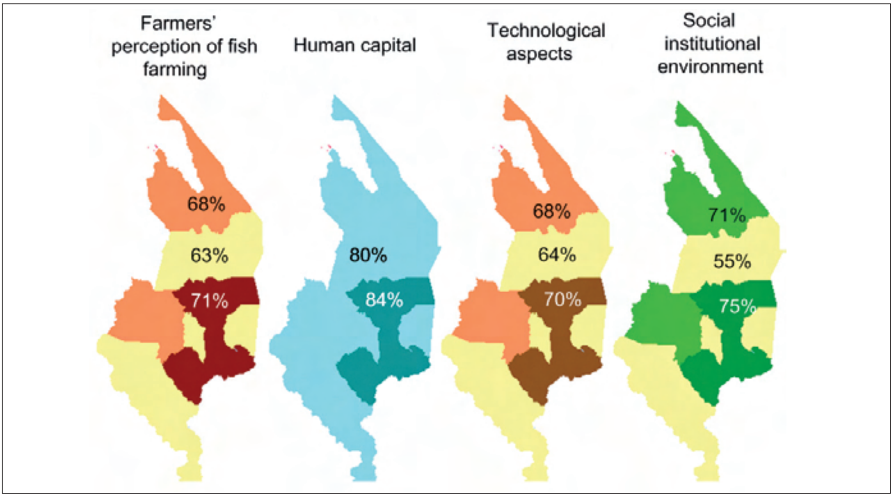




BN modeling requires expert knowledge to set parameters for the model, i.e., to set the probability values for outcomes of the leaf nodes as well as to construct the probability matrices of the matrix nodes. Using the constructed BN model, setting parameters may be done for the whole country or, separately, for defined regions or zones. With regionalized parameters, the outcomes can be mapped (see Figure 15 for the Southern Region of Malawi where the regionalized modeling was done for three zones, each zone comprising several traditional authorities, or sub-districts). The mapped outputs from BN modeling can be used as inputs in the GIS modeling of aquaculture potential. This enables factors that influence farmers' decisions about technology adoption, which are normally not quantifiable and therefore omitted, to be included in the GIS analysis and modeling of aquaculture potential.

For the convenience of target users, the project developed Bayesian Network Support Software (BNSS), which contains user-friendly interfaces with the GeNIe software to facilitate the various steps of the BN modeling, particularly for setting regionalized parameters for the model. One interface converts the graphical model generated in GeNIe into a tabular, hierarchical listing of factors and possible outcomes, so that the user can enter columns of model parameters (i.e., outcomes for leaf nodes and weights for dependencies) by region. The filled tables are then used to drive Bayesian computations in GeNIe to generate outcomes by region.

Figure 15. Regionalized probabilities of farmers in the Southern Region of Malawi with a positive perception of fish farming as the final outcome of the Bayesian network modeling, and the corresponding outcomes (% positive) of the sub-models.



Another interface provides the option of automatically computing the combinatorial probability matrix for each matrix node, based on outcomes of its parent nodes and the weights of its dependencies as assigned by experts. This may be a welcome tool (especially in the absence of expert input) with which the user fills in probability matrices of high dimensions, which can become unwieldy for manual entry. For example, three parent nodes, each with three outcomes, result in a child node, also with three outcomes, yielding a combinatorial probability matrix of 3 rows and 3^3 (= 27) columns, or 81 cells.

A third interface helps the user assign outcome values (as probabilities) to a leaf node when quantitative data are available for the proxy variable of its associated factor,[3] e.g., the number of extension agents by region (which may be normalized by fish farmer population or total fish pond area) as a proxy for

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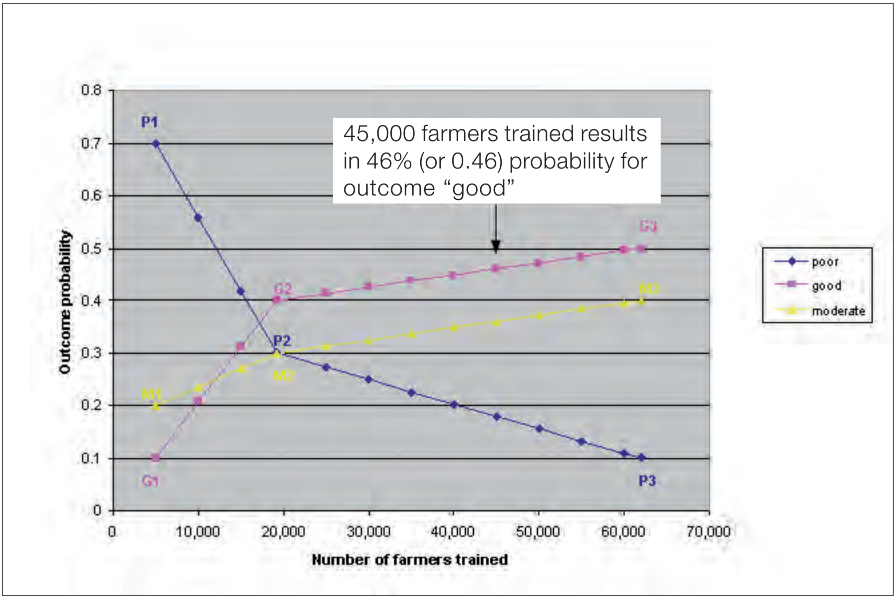
3 Such a leaf node, where the variable is quantifiable, is termed a "D-leaf" (short for "data leaf"), as opposed to an "E-leaf" (short for "expert leaf"), which refers to a leaf node for which no quantified data are available and for which the outcomes must therefore be assigned by experts.

the factor “extension quantity” (Figure 13). Quantitative data for this variable may be obtainable for the smallest administrative unit available (e.g., sub-district) and can be used to compute region-or zone-based estimates as well as the overall average. An expert consulted to translate the quantitative data into probabilistic outcomes may feel less comfortable in doing so for several regions than for the entire area. The interface has a mapping function for the regionalized estimation of outcomes for the particular leaf node, based on expert-assigned outcomes for the entire area (Figure 16).

Figure 16. The mapping function shows assumed dependencies between the number of farmers trained and the outcomes for the variable “extension quantity”.



In the example shown in Figure 16 for the Southern Region of Malawi, the number of farmers who received training in aquaculture management is used as a proxy indicator for the leaf node “extension quantity”. Data at the sub-district level obtained from the Fisheries Department show that the minimum, average and maximum numbers of farmers trained over a fixed period are 4,935, 19,218 and 62,016. Experts are of the opinion that, for the Southern Region as a whole, the probabilities for extension quantity are 40% for the “good” outcome, 30% for “moderate” and 30% for “poor”. These values appear in Figure 16 as the three points G2, M2 and P2, corresponding to the number of farmers trained on average in all sub-districts. It is assumed that a high number of trained farmers will yield a high probability of the good outcome (the magenta line). Expert consultation associated the maximum number of farmers trained in a sub-district with a 50% probability of extension quantity being good (point G3), while the minimum number of farmers trained was associated with a 10% probability (point G1). For a zone where the number of farmers trained (averaged over sub-districts within the zone) is 45,000, the corresponding probability of extension quality being good is 0.46, or 46%, based on simple linear interpolation as indicated in Figure 16. Similarly, with expert inputs, the mapping functions for outcomes “moderate” and “poor” may be constructed (the yellow and dark blue lines, respectively) and used for reading off the corresponding probabilities for that zone.

Finally, a fourth interface within BNSS tabulates the computed, regionalized outcomes of the target variable into an Excel-based format that allows direct linkage with the corresponding digital map of regions or zones. The Excel-based MapGenerator program, which is packaged within IdriSP, uses this output table of the regionalized BN model outcomes to generate the maps in Figure 15.

For the convenience of users interested in trying out BN modeling, the accompanying DVD-ROM contains:

1. the necessary software (the GeNIe freeware of the University of Pittsburgh and the BNSS developed in-house);
2. examples of the country-specific BN models constructed in GeNIe and the corresponding BNSS interface files;
3. country-specific data files that contain regionalized proxy indicators for the D-leaves of the BNs; and
4. tutorial guides on the BN modeling application developed by the project.

In conclusion, the BN modeling tools developed by the project as part of the decision-support toolkit can be used to:

1. represent uncertain knowledge (often associated with human perceptions) expressed as probabilities;
2. facilitate stakeholder participation through visual representation of cause-effect relationships;
3. support the integration of qualitative data for E-leaves and quantitative data for D-leaves as proxy indicators of influencing factors; and
4. help explain and analyze complex systems of a qualitative nature by finding the variables with the most impact and evaluating different scenarios based on varying assumptions.

POSSIBILITIES AND BENEFITS OF USING THE DECISION-SUPPORT TOOLKIT

The development and combined application of GIS and BN modeling provides a suite of analytical tools that can inform and assist policymakers, aquaculture planners and managers, extension workers, and researchers in making strategic assessments and identifying interventions needed to promote target aquaculture technologies. The approach, methodologies and tools developed in this project can be further used in several ways. For example, the analysis that has been piloted for the southern parts of Cameroon and Malawi can be extended to cover the whole of both countries and also be applied to other countries. On the other hand, using the tools to conduct more in-depth analysis for specific zones or regions within a country can help identify potential for, and constraints to, scaling out pilot aquaculture promotion efforts conducted in development "hot spots" to achieve more widespread impacts.

As illustrated by the case of Malawi, the analysis can be done not only for the status quo of aquaculture in the country but also for future scenarios assuming more advanced stages in aquaculture development. Likewise, the tools can be used to analyze the consequences to aquaculture potential if prevailing conditions change – if, for example, trends of climate change affect rainfall patterns in such a way that water availability for fish ponds is reduced or made more uncertain. The techniques and tools developed can be applied to support decisions on planning and managing aquaculture systems other than pond culture, as well as to other sectors to determine recommendation domains for livestock and crop production.

REQUIREMENTS FOR USING THE DECISION-SUPPORT TOOLKIT

The effective application of a decision-support tool requires relevant and appropriate knowledge and data. The decision-support tools developed in this project are scale neutral; that is, the purpose of the analysis and availability of data determine the resolution at which the tools are applied and results achieved. Depending on the breadth and depth of knowledge available, the analysis and answers may apply to different levels: continental, regional, national or sub-national. More detailed scales of analysis can be conducted only if data are available at the corresponding resolution. It is often the lack or insufficiency of data that constrains the use of these tools. In practice, these tools, particularly GIS modeling, are more commonly used for regional-scale assessment, planning and management than for specific siting of fish ponds. Nonetheless, the broader-scale assessment helps aquaculture planners and extension workers to focus on particular geographical areas of high potential where more detailed, on-the-ground investigations are necessarily conducted for selecting pond sites.

These decision-support tools are most effectively applied if the parties concerned assume complementary roles in the chain of tasks by which they first generate the knowledge base used to operate the tools and then interpret and assess the results (see Table 1). Sustained use of such decision-support tools requires that institutions ensure that the required skill sets and expertise are either available, acquired or outsourced.

Table 1. Users, roles, knowledge and skills required, and recommended software			
Target user	**Role**	**Knowledge & skills required**	**Recommended software**
Aquaculture extensionist, planner, decision maker	Provide expert knowledge for inputs into geographic information system (GIS) and Bayesian network (BN) modeling	Awareness of the utility of the GIS and BN modeling tools as applied to determine recommendation domains	
	Exploratory GIS modeling and interpretation of outputs		SAQUA
Aquaculture researcher	Provide expert knowledge for inputs into GIS and BN modeling	Understanding of basic GIS and BN principles relevant to the modeling applications for determining recommendation domains	
	Carry out GIS modeling and query map results		IDRISI ™ (with IdriSP), or SAQUA
	Carry out BN modeling		GeNIe and BNSS
GIS analyst or GIS-trained aquaculture researcher	Generate GIS data sets in cooperation with subject specialists and aquaculture experts	Working knowledge of GIS software and its application to generating biophysical and socioeconomic data analysis and mapping	Commercial GIS software e.g., IDRISI™, ArcView™, ArcGIS™ or AGRAQUA
	Customize batch programs for automating GIS modeling tasks	Working knowledge of IDRISI Kilimanjaro or Andes software and understanding of the multi-criteria evaluation technique	IDRISI ™ (with IdriSP)
Computer analyst or BN-trained aquaculture researcher	Develop or modify the BN model structure for evaluating farmers' perceptions of aquaculture technology	Working knowledge of BN modeling and GeNIe	GeNIe and BNSS

AGRAQUA = Agro-ecological Analysis for Aquaculture, BNSS = Bayesian Network Support Software, GeNIe = Graphical Network Interface, IdriSP = Idrisi Support Program, SAQUA = Suitability Analysis and Query for Aquaculture.

Note: ArcGIS ™ & ArcView ™ are trademarks of the Environmental Systems and Research Institute, Redlands, California. IDRISI ™ is a trademark of Clark Labs, Clark University, Worcester, Massachusetts.

ANNOTATED LIST OF CONTENTS OF DVD-ROM

The main outputs of the project are offered on the accompanying DVD-ROM. The contents of this DVD-ROM (listed in Table 2) can also be downloaded from www.worldfishcenter.org/RDproject/

Table 2. Contents of the Recommendation Domains Project DVD-ROM

	Items	Description
1	**Digital version of this booklet accompanying the DVD-ROM**	
2	**Public domain software, with user guides and manuals**	All the software programs provided run in the Windows operating environments XP or higher and require .NET Framework installed.
2.1	AGRAQUA	Contains programs for modeling and mapping: 1. thermal growth period for fish growth; 2. pond water availability period, which is when water from rainfall, surface runoff and groundwater sources is accumulated to a sufficient depth for raising fish; and 3. fish yield estimation for simulating fish growth and estimating yield.
2.2	SAQUA	Contains programs for carrying out: 1. GIS modeling of aquaculture suitability using the multi-criteria evaluation technique, and 2. drill-down and filtering functions to query the suitability map and input layers.
2.3	IdriSP	An Excel-based batch-control program for carrying out GIS modeling for aquaculture suitability in IDRISI™ (Kilimanjaro and Andes versions).
2.4	The Bayesian network (BN) modeling tools & data files GeNIe freeware BNSS	This suite of software programs and data files allows users to create new BN models or adapt existing models. GeNIe provides a graphical click-and-drop interface that enables users to construct models and diagnose causal relationships. BNSS is a user-friendly interface for entering and changing probability values and for automatically computing conditional probability matrices.
3	**Documented sample data sets for four countries**	This contains indicator maps of selected biophysical and socioeconomic factors for GIS modeling, with the following geographical coverage:
3.1	Bangladesh	Entire country, except the coastal area and the southeastern Chittagong Hill Tract
3.2	Cameroon	Seven provinces of southern Cameroon
3.3	Malawi	Southern Region of Malawi
3.4	China	Henan Province

4	**Case study reports**	These are country profiles of freshwater aquaculture development, with emphasis on understanding factors influencing the adoption and intensification of aquaculture technologies.
4.1	Bangladesh	
4.2	Cameroon	
4.3	Malawi	
4.4	China (Henan)	
5	**Stakeholder evaluation report**	Stakeholder assessments of the relevance and usefulness of the project outputs.
6	**Publication lists**	
6.1	Papers and books, etc., published and to be published	
6.2	Presentations and posters	
6.3	Theses	

MEMBERS OF THE PROJECT TEAM

Besides the intellectual challenge of innovating integrative approaches, methods and tools to meet the project objectives, implementing a project that is multidisciplinary and covers diverse countries in Africa and Asia constituted a challenge that called for cohesiveness among the team of researchers and the support of institutions spanning several countries. This project was fortunate to have benefited from the dedicated work of the research team members and support staff mentioned below:

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  - Institut Recherche Agricole pour le Développement of Cameroon, as the focal national partner, and Institut National de Cartographic for supplying data;
  - Chinese Academy of Fishery Sciences, as the focal national partner, and the Henan Fisheries Bureau for facilitating research activities in the province; and
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This publication introduces the methods and results of a research project that has developed a set of decision-support tools to identify places and sets of conditions for which a particular target aquaculture technology is considered feasible and therefore good to promote. The tools also identify the nature of constraints to aquaculture development and thereby shed light on appropriate interventions to realize the potential of the target areas. The project results will be useful for policy planners and decision makers in national, regional and local governments and development funding agencies, aquaculture extension workers in regional and local governments, and researchers in aquaculture systems and rural livelihoods.

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