PN-ABA-907
XN-ABA-907-A

AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON D C 20523

DATE: 9/30/88

MEMORANDUM

TO: AID/PPC/CDIE/DI, room 209 SA-18

FROM: AID/SCI, Victoria Ose

SUBJECT: Transmittal of AID/SCI Progress Report(s)

Attached for permanent retention/proper disposition is the following:

AID/SCI Progress Report No. 2. A - 36

PR - 1 Jan - 30 June 84

PR - 1 Jan - 30 June 85

PR - 1 July - 31 Dec 85

Attachment

+ FINAL recvd 9/29/88

+ 2 other? reports

PN-ABA-907

2 A-36

Strengthening of South East Asian

Aquaculture Institutions

A Progress Report

1 January - 30 June 1984

Grant Number DAN-5543-G-SS-2103-00

by

James S. Diana
School of Natural Resources
The University of Michigan
Ann Arbor, MI 48109-1115

I. Summary

Substantial progress on this grant has occurred since December 1983. The major efforts include:

(1) Revision of workshop document

(2) Initiation of experimental work

(3) Improvement of computer models and development of a model for walking catfish

(4) Site review in Bangkok with Kenneth Osborn, USAID.

Each of these areas are detailed below

II. Workshop Document

The workshop document has been substantially revised, and final completion of the document as a University of Michigan special publication should occur by December 1984. Also, the document will be circulated to publishers for possible printing and wider distribution. Revisions in the documents are based on several peer reviews, comments from workshop participants, work on site between myself and the Kasetsart University faculty, and an extensive review by Karl Lagler.

III. Experimental Work

As part of the workshop document, several experiments were planned for completion at Kasetsart University. These five projects were proposed formally by each investigator (see Appendix ___ for their proposals), reviewed by J. Diana and K. Lin, then enacted by each P.I. Progress to date on these projects was reviewed by me during July 1984, and summaries of the progress follow:

A. Developing feed for Pangasius (W. Chuapoehuk)

A market survey was conducted, and a value of catfish flesh of 11 baht/kg was determined. To allow for a profitable operation, feed developed could not cost over 6 baht/kg, considering conversion efficiency of Pangasius (1.4 kg feed: 1 kg fish) and value of the fish. A poultry feed was then adapted for fish with 14% protein and about 1300 k cal 1g, for 5 baht per kilo. A second feed (swine) was also adapted, 18% protein, about 1400 kcal per g, cost 7 baht/kilo. These feeds will be tested beginning August 21 utilizing Pangasius in 1/8-acre ponds, and the flesh quality of fish from normal marketing procedures and from the developed diets will be compared.

B. Water Quality in Clarias Culture (W. Tarnchalanukit)

Water quality will be monitored in recirculating concrete ponds stocked with Clarias. Due to poor seed availability, experiments were not begun until August. Three densities of fish will be stocked (each replicated), and water quality measured. In July, fry for stocking had reached 2.5 cm, and by mid-August they should have reached 5 cm and the experiments were to be begun then.

C. Seed Production in Ophiocephalus (U. Na Nakorn)

This project involves both development of methodologies for artificial propagation, and also feeding techniques for young fish. By mid-July, several fish had been injected, stripped of eggs, and fertilized, but the success rate was less than 10%. Problems with identifying the sex of fish, as well as maturation stage, make this an uncertain process, and only about 50% of the females injected have produced viable eggs. Much additional work is needed on this phase.

Early feeds tested were either Moina, pellets, raw fish, or clam flesh. Moina produced the best survival (90%), followed by clams (65%) a wet "pellet" paste (60%), raw fish (40%), and powder (10%). Future plans are to test specifically the differences between Moina and the pellet paste, since these produced good survival and differ considerably in ease of delivery.

D. Predator Control in Puntius Ponds (P. Suraniranat)

This experiment has been most successful of all. The predators of interest are backswimmers (insects), and control methods are establishing a surface film to block their ability to surface and breathe. Several oils and pesticides were tested, and the most cost-effective treatment was about 2 cc of diesel oil per m^2 of water surface. The dosing rate was determined by lab bioassays, and this dosing rate was lowest of five chemicals tested. Also, diesel oil was cheapest per liter of all chemicals tested.

One experiment has been completed in the field, while the second run is in progress. The design includes one control pond (no treatment), two ponds treated at bioassay dosing rate, and two ponds at twice the dosing rate. Each pond was stocked with 3,000 larval fish per m^2. After four weeks, total fry production was:

Control	95,000 fry
1x dosing	270,000 fry
2x dosing	377,000 fry

A replicate of the above is now being run, and a report on the work is being written.

E. Oxyeleotris Seed Production (M. Boonbrahm)

This project is to raise sand goby fry to a stockable size. Artificial injections have been attempted to stimulate breeding, and were only successful in late July. Slates put into breeding ponds were more successful. Feeding regimes of natural rotifers for two weeks, followed by Daphnia, for four weeks, then finally by pellets will be used to raise fry. Feeding rates, success, etc. will be measured.

IV. Computer Models

A computer model on Clarias production was developed, bringing the total number of models to five. This should be the last new model developed, although all will be further reviewed and refined.

The models, and a computer, were given to KU faculty during my site visit in July, and faculty were encouraged to take courses on microcomputer use. I hope this will stimulate someone to begin using these models in teaching and developing them further.

V. Site Review

J. Diana, K. Osborne, and the K.U. faculty met in July in Bangkok and reviewed progress to date and future plans for this grant. The progress reviewed has been included in this and previous progress reports.

VI. Appendix - Research Proposals

A. Project Title

Practical feed for catfish Pangasius sutchi

Leader

Wiang Chuapoehuk

Rationale

Culture of catfish, Pangasius sutchi, has long been practiced in Thailand. In general, this catfish has been fed kitchen waste mixed with parts of aquatic weeds and rice bran. This nutritionally incomplete feed mixture is not only wasteful, as it is not in a form of which fish can utilize, but also often causes the pollution of water and consequently low quality of fish flesh. Low quality flesh leads to low marketing price and demand, thus hampering the widespread of culture of this fish. This study is therefore designed to remove the foregoing problem by using the alternative practical feed.

Objective

The proposed study is aimed to improve marketing price of this catfish through feeding it with an artificial practical feed.

Work Program

To attain the foregoing objective, the following work programs will be included.

Surveys of Fish Marketing Price

Marketing price of this catfish in the whole country will be surveyed and analyzed for mean value. This mean value of marketing price will be considered for practical feed formulation.

Feed Formulation and Preparation

A low cost but high quality practical feed will be made of inexpensive potential feed ingredients readily available in the country. The feed will be prepared as a dry, sinking pellet form.

Testing of the Feed

The prepared feed will be tested with this catfish in earthen ponds for growth and survival estimates.

Evaluation of the Feed

Besides growth and survival estimates, cost-benefit efficiency will be evaluated. Acceptability of fish flesh will also be made through an organsleptic test method.

B. Title

Water Quality in Recirculating Clarius batrachus Culture Ponds

Leader

Wit Tarnchalanukit

Rationale

Clarias culture in Thailand has been practiced for more than 30 years. There is only one cultured freshwater species of Clarias which can obtain the highest production per unit water surface area and income. Approximately 1,800 rais are used for culturing Clarias, with annual yields of about 12,000 tons in Thailand.

Since the fish farmers have fed mainly trash fish to Clarias, water pollution and disease problems usually occurred, and sometimes resulted in mass mortality. Besides, inbreeding and genetics, and poor management are also major limiting factors to Clarias production.

An initiation on using of circular concrete pond for culturing Clarias with water recirculating system at the Department of Aquaculture, Faculty of Fisheries, demonstrate an increase of Clarias production and shorter culturing period but it faces disease problem due to poor water quality.

Gradual increase of water pollution in pond shows little effect on Clarias health but sudden change of water quality will affect Clarias quite seriously. It is commonly believed that deterioration of either they physical or chemical properties of water will be causative to Clarias infectious diseases. No data has been reported concerning the critical levels of both factors. Therefore, determination of water quality in Clarias ponds has to be done in order to know the specific level that weaken fish resistance to disease infection.

Objectives

To deter:ine the physico-chemical properties of water in recirculating Clarias culture ponds with various stocking densities in relation to growth, survival and frequency of occurrence of infection diseases.

Procedure/Methodology

Ten circular concrete ponds will be used to stock 4 - 5 cm length Clarias, and the experiment will consist of five treatments with two replications each. Stocking number of the young Clarias in treatment 1 - 3 will be 3,000, 5,000, and 7,000 per replication, respectively. A commercially available floating pellet with 30% protein content will be used for the first 60 days and a 25% for the last 60 days of culturing period. Feeding rate will be about 7% on the average of fish body weight per four time-day.

Physico-chemical properties of the source water and the water in rearing pond will be determined at one-week intervals throughout the experimental period. Water characteristics to be determined are as follows:

Temperature	DO
Turbidity	BOD
pH	Carbon dioxide
NH_3	Alkalinity
H_2S	Hardness

Growth rate of fish and frequency of occurrence of infectious diseases will be measured and observed. Survival rate of fish will be estimated at the end of the experiment.

C. Seed Production for Snakehead Fish

Introduction

Snakehead fish, Ophiocephalus striatus, is a fresh-water fish whose flesh is a favorite among Thai people. Its marketing demand is great all year round. Therefore, it is being widely cultured especially in the Central Plain of Thailand. In 1980, the culture production from the entire country was about 3,883 tons, with a market value of more than 95 million baht. All fingerlings used for culturing are collected from natural waters. But due to water pollution problem and decrease in spawning ground, fingerling collection becomes unpredictable and cannot fulfill the demand of farmers.

In order to solve the shortage of fingerling supply of this fish, a research program will be conducted at Aquaculture Department, Faculty of fisheries, Kasetsart University to find out the best practices for seed production.

Objectives

Specific objectives of the proposed study are:

(1) to find the effective hormone substance used to induce successful spawning of snakehead fish,

(2) to find the effective dosage, number and time of injection of that hormone,

(3) to find an appropriate method of egg incubation, nursing of fry and culturing of fingerling of snakehead fish.

Project Leader: Mrs. Uthairat Na Nakorn
Aquaculture Department
Faculty of Fisheries, Kasetsart University

Study Scheme

The activities that will be included in this research program are as follows:

(1) to document biology, feeding and spawning habits and requirements for spawning, with special reference to those in Thailand.

(2) preparation of brood fish

- collection from natural habitats
- rearing in controlled ponds

(3) induced spawning

- kinds of hormone substance used (pituitary glands, HCG)
- effective dosage, number and time of injection
- stripping and fertilization of sperms and eggs
- incubation and hatching of eggs
- embryonic development

(4) nursing of larvae

- design of nursing facilities
- larval food (living organisms, prepared materials)

(5) culturing of fingerling

- design of nursing facilities
- food for fingerling

Work Program

Time required for this study is 1½ years, starting in 1984 and ending in 1985. In the first year, research activities concerned with techniques of breeding and nursing of fry will be done. Research activities on culture of fingerling will occupy the last six months.

D. Title

Tawes larvae predator control

Proponent

Mr. Prawit Suraniranat

Importance/Significance of Research

The tawes, Puntius gonionotus (Bleeker) is an economically important freshwater fish in Thailand and some other countries in Southeast Asia. In Thailand in 1980, about 3,000 ha were used for tawes culture, with an annual yield of about 3,000 tons. This tonnage of yield was valued at over 2.5 million US dollars. The demand of seed production of tawes is increasing yearly. The induced spawning of the tawes has been done successfully by hormone injection method, but one of the major factors restricting production of the tawes is the predator for larvae and fry. Great mortality of the tawes at the nursery stage, especially in the first week after the introduction of the larvae into the ponds, can be caused by predators.

The common predator is backswimmer, an aquatic insect of the family Notonectidae. Suitable methods to control the predator of the tawes larvae and fry should be investigated. If these methods can be applied, successful farmers will be able to increase their seed production without any additional cost.

Objectives

(1) Determine the potential of some chemicals for controlling backswimmer

(2) Evaluate the effects of various chemicals on the survival rates of the tawes larvae

(3) Observe the chemical effects on water quality.

Procedure/Methodology

Thirty-six 2 - L glass containers will be used in phase I of the experiment. Each container will be filled with filtered pond water. In phase II, five 800 m^2 earthen ponds will be employed. The tawes larvae obtained from artificial breeding will be used, and the backswimmers will be collected from natural ponds at Department of Aquaculture, Faculty of Fisheries, Kasetsart University. They will be stocked in each glass container at 50 three-days larvae and ten backswimmers per liter of water. In the earthen pond, 3,000 - 5,000 larvae will be stocked per meter square.

Four different types of chemicals will be used: vegetable oil, animal oil, diesel oil and mixture of detergent and vegetable oil.

The experiment will consist of five treatments with three replications per treatment for each chemical in phase I, and phase II two treatments with two replications will be applied. In each phase a control will be conducted.

Phase I - All experiments will be done in Aquaculture Laboratory. Ten backswimmers and fifty larvae will be stocked in each container. Five different concentrations of each chemical will be added to each container by dropping on the surface of water. Fishes and insects activities will be observed. Timing record will be kept until all insects die. The total number of the larvae survived will be counted at different stages and at the termination of the experiment.

Water quality, including temperature, dissolved oxygen and pH, will be measured before and after each experiment.

Phase II - The experiment will be carried out in five earthen ponds. The two most effective chemicals and doses determined from phase I will be applied in phase II. Three thousand to five thousand of larvae per square meter will be introduced into each earthen pond. In the first two weeks, treatment chemical will be sprayed on the surface of water of each pond at different time intervals. Number of the backswimmers will be sampled periodically during chemical treatment to determine the effectiveness of the treatment. After four weeks, the total number of fried survived will be determined.

Water quality, including temperature, dissolved oxygen and pH, will be measured weekly throughout the experiment.

E. Sand Goby Seed Production

Introduction

The sand goby, Oxyeleotris marmoratus, is widely cultured in Thailand. The annual requirement of fingerlings for culture purpose is in great amount, all of which are collected from their natural habitats. Due to unpredictable fluctuations in occurrence and abundance of the fingerlings and difficulties in their collection, shortage of supply has been frequently encountered.

To determine the best practices for seed production, much research is required. Research programs on these techniques will be conducted at Kasetsart University with support from University of Michigan and AID.

Objectives

Specific objectives of the proposed study are:

(1) to secure the appropriate artificial feed and/or food organisms for feeding early and advanced fry,

(2) to determine the suitable size and density of artificial feed and/or food organism for fry,

(3) to extend the practical techniques of seed production to the fish farmers.

Personnel

Project Leader: Prof. Mek Boonbrahm
Aquaculture Department
Faculty of Fisheries
Kasetsart University

Study Scheme

To ensure a reliable source of supply of adequate quantity and quality of fry and fingerlings for satisfying the present requirement as well as for meeting the future need for intensification and expansion of culturing operation, the study herein is planned to cover the following activities:

(1) to document biology, spawning and feeding habits, specific information in Thailand

(2) preparation of brood fish

- holding and care in controlled ponds
- feeding with natural food to ensure good quality of sexual products

(3) preparation of food for fry

- culture of living food organisms
- prepared artificial feed materials

(4) spawning

- design of spawning facilities
- natural spawning
- induced spawning by hormone injection

(5) nursing of larvae to fingerling

- design of nursing facilities
- feeding fry with living food organisms
- feeding fry with artificial feed

<u>Work Program</u>

The study herein will be undertaken for 1½ years, starting in 1984 and ending in 1985. Research activities proposed for spawning and nursing of larvae and fry will occupy most of the entire first year of this project. The six months of the second year will be spent for the refinement of the first-year activities. The details of work program are attached.

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2.A-32

STENGTHENING OF SOUTH EAST ASIAN

AQUACULTURE INSTITUTIONS

A Progress Report

1 January - 30 June 1985

Grant number DAN-5543-G-SS-2103-00

by

James S. Diana
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University of Michigan
Ann Arbor, MI 48109-1115

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I. Summary

Progress on this grant since January 1985 has occurred in three main areas:

(1) Revision and submission of workshop document

(2) U.S. visit by Wit Tarnchalanukit

(3) Revision of computer models.

Each of these is detailed below.

II. Workshop Document

The workshop document has now been completed and submitted to the Great Lakes Research Division as a special publication. It is currently being externally reviewed, and should be completed soon.

III. U.S. Visit by Wit Tarnchalanukit

Wit Tarnchalanukit, dean of the Faculty of Fisheries at Kasetsart University, was brought to the U.S. under our sponsorship in April 1985. The purposes of his trip were to review the computer models, to visit other U.S universities, and to formalize research plans for 1985. The third purpose was decided upon since Wit has recently taken over as dean at Kasetsart University, and he has little first-hand knowledge of the U.S. university systems. He visited Auburn University, Michigan State University, Oregon State University, and the University of Hawaii, as well as UM.

Additionally, verbal permission was received from USAID in Washington to extend the duration of this grant until the end of March, 1985. With this in mind, new research initiatives were begun at Kasetsart University. The honoraria to be paid and research projects are listed in the appendix. Projects for Tim, Wit and Wiang remain unchanged, with each person replicating earlier work with better resolution or methods. Prawit will

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work to publish his experiments on Tawes, and will initiate new experiments on Tawes adult culture. Mek will now move to study the rearing of sand goby from 3 to 100 g in size, mainly by following up on the common practices of fish farmers. Yont, a new faculty member, will initiate a research project on Macrobrachium culture.

Data collected during the first year were often informative, but physical/chemical techniques of water analysis were poor. I recently purchased materials to set up a water analysis lab under Yont's direction. Materials purchased include a YSI temperature-oxygen meter, a spectrophotometer, plus glassware and chemicals.

IV. Computer Models

Computer models were reviewed by Wit and revised to follow the choices available in common culture options utilized by Tai farmers. They are now complete, and our next major task is to write up the models in a descriptive format for publication.

PROJECT PLANS

Honoraria - 2.5 mm paid over 9 monthly installments

NAME	MONTHLY SALARY	TOTAL HONORARIA IN 1985	MONTHLY PAYMENT
Wit	13,310 bht	46,585 bht	5,176 bht
Prawit	8,712	30,492	3,388
Wiang	8,470	29,645	3,294
Tim	6,305	22,067	2,452
Mek	19,360	67,760	7,528
Yont	7,635	26,723	2,969

Research Budgets - to terminate 12/31/85

Person	1984 Budget	1984 Expense	1985 Budget
Mek	$1,470	$1,544	$1,500
Prawit	1,410	1,464	1,500
Wiang	2,075	136	*1,939
Tim	2,590	---	1,500
Wit	2,950	3,100	2,000
Yont	---	---	*3,000

* remaining funds from 1984

** includes purchase of water quality chemicals and $1,000 advanced to Kwei Lin.

c.D.,E.

2. A 36

Strengthening of South East Asian Aquaculture Institutions

A Progress Report

1 July - 31 December 1985

Grant Number DAN-5543-G-SS-2103-00

by

James S. Diana
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Ann Arbor, MI 48109-1115

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I. Summary

Progress on this grant since June 1984 has occurred in three main areas:

(1) Revision of the workshop document

(2) Clarification of the computer models

(3) Presentation and publication of data at a major conference

(4) Continuation of the experimental work in Bangkok.

Each of these areas is detailed below.

II. Workshop document

It was originally planned that the workshop document be completed and published by January 1985. This has not been possible. An additional editor (David Ottey, Ph.D. candidate at UM) was hired to review and improve the manuscript. His review led to the discovery that parts of the document had been taken from other published material, and that the publications had not been properly cited. A major effort was undertaken to ascertain that the material included was properly referenced, and this led to much delay. Currently, the document is revised and distributed to reviewers for evaluation as a Great Lakes Research Division Special Publication. This publication should be available by May 1985. The manuscript has been substantially improved, with major overview sections, is fully referenced, and is much improved over earlier drafts.

III. Clarification of Computer Models

The computer models for each of the five species have been reviewed and fully documented in the past few months. Dr. Lee Fuiman, a graduate of UM, has done much of this work. The models are now fully documented, so that each parameter and its units are listed at the start of each model. Also, the models have been made to run automatically with a menu and choice of model to run. They have also been improved by listing a table of output for the run which includes the individual growth rate, the number remaining alive, the total yield, and the D.O. level in the pond (if D.O. was included in the model) for each week of the culture period. We are currently beginning to do sensitivity analysis and write up the models into another document, which should be completed in the fall. This document may be combined with the workshop document and submitted for publication at that time. A diskette for use on an Apple computer is included with this progress report.

IV. Presentation of Data at a Major Conference

Dr. William Chang recently attended the Second International Conference on Warmwater Aquaculture and presented a paper entitled "Models of production systems for commonly cultured fishes of southeast Asia". The paper will also be published in the conference proceedings. A copy of that paper is included in this document (Appendix 1).

V. Experimental Work in Bangkok

The experimental work in Bangkok is also continuing as indicated in the progress report of June 1984. The major progress has been the completion of the project on Tawes (which is now being written for publication), and the successful induction of breeding in sand gobies. These projects are continuing into 1985, and the salary plans and subjects for these projects are included in Appendix 2.

In conjunction with the experimental work and the strengthening of the aquaculture training in Thailand, Dean Wit Tarnchalanukit is planning to visit the University of Michigan in April 1985. His visit will be for three main purposes: (1) To update us on progress of the experimental projects, (2) To review the workshop document, and (3) To visit a number of U.S. universities to become familiar with the personnel and facilities at each site. As dean of the Faculty of Fisheries at Kasetsart University, Wit will have many encounters with these institutions in the future, and his personal familiarity with them will be of great benefit to him and his colleagues. Tentative plans are for him to visit UM, Michigan State University, Auburn University, the University of Washington, Oregon State University, and the University of Hawaii.

Appendices

Appendix 1. Publication.

Appendix 2. Experimental projects.

Table 1. Investigators, subjects, and financial support for projects to be conducted in Bangkok in 1985.

Person	Subject	Financial Support
Mek	Sand Goby	$1,500
Prawit	Tawes	1,500
Wiang	Pangasius	1,500
Tim	Snakehead	1,500
Wit	Clarias	1,500

Table 2. Salary contributions from this project to Kasetsart University faculty in 1985.

Name	Monthly salary	Total Honoraria	Payment Each Month
Wit	13,310 bht	46,585 bht	5,176 bht
Prawit	8,712	30,492	3,388
Wiang	8,470	29,645	3,294
Tim	6,050	21,175	2,353
Mek	19,360	67,760	7,528

Modeling Production Systems for Commonly Cultured Fishes of Southeast Asia

by

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Faculty of Fisheries
Kasetsart University
Bangkok, Thailand

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Introduction

Fish is a major protein source for a great many third world nations. It provides important animal protein and needed cash for subsistence farmers. Increasing fish production in these countries will have a direct effect on alleviating malnutrition and provide supplemental income for improving the general livelihood of many residents. However, inland aquaculture as practiced in these countries is not efficient, and has many technological constraints which hinder its development.

A workshop was organized through the combined efforts of the USAID, the University of Michigan, and Kasetsart University in April of 1983 to devise means of reducing principal technical deterrents to current inland aquaculture production in the southeast Asia region, and to improve the production efficiency of the eleven species of fishes commonly cultivated in these areas (Diana et al. 1985). Twenty-six scientists and aquaculturists from the U.S.A., Malaysia, the Philippines, the Peoples' Republic of China, and Thailand participated in this workshop.

In order to complete the objectives of the project, production - limiting factors common to all pond culture systems were identified, particularly those factors pertaining to trophodynamics, fish seeds and stocking, nutrition, and environmental constraints. These are key aspects of technology which are of particular value to fish farmers, but of which the farmers may still be unaware. Critically needed areas of research that are practical and production-oriented were identified and prioritized.

The modeling approach was used and is thought to be one of the most efficient ways to accomplish these tasks. Recent developments in technology have made the microcomputer a popular and useful tool in research and scientific planning. Its rapid response time and low initial cost are especially attractive features for aquatic researchers and institutes. Microcomputers can be used to simulate various conditions that may be difficult to control in field experiments, as well as to examine individual parameters within a given system when evaluating the system as a whole. Such technology can increase our understanding of an aquatic system and thereby assist in both experimental design and in the detection of factorial interactions. The cost for running a computer simulation is generally much lower than that for carrying out an actual study, while the scope and parameters involved in a simulation can include most if not all of the major ones.

To use a modeling approach, the first step is to determine the parameters to be included in the model. The necessary parameters in this study were determined by comparing systems with high production rates to those with low yields. Those factors which have important effects on the increase in fish production are considered as the modeling parameters. Generally one finds that fish production is linearly related to the degree of intensification in fish culture. The ecological factors related to the intensification of fish culture are: (a) food, (b) oxygen, (c) water temperature, and (d) removal of metabolites. Although water temperature and removal of metabolites are important factors in fish production, the control of these factors has not often been practiced in ponds in southeast Asia, and they are not considered here.

Food and feeds

An adequate food supply is essential to maintain a healthy fish population. This includes both natural food and supplemental feeds. In extensive low input culture ponds, a constant supply of basic nutrients is critical to assure the healthy growth of natural food. Pond soil fertility and the rate of nutrient recycling together with adequate light and water transparency are key elements in assuring the growth of phytoplankton and macrophytes. These primary producers from photosynthesis are the food sources for zooplankton. Fish then selectively feed on phytoplankton (macrophytes) and/or zooplakton, depending on their species. Heterotrophic production by bacteria through degradation of organisms in general is not thought to play a major role in these culture systems. In more intensive culture systems, however, ponds are enriched with both inorganic fertilizers and organic wastes, with organic wastes contributing the larger portion of such enrichment. Much of the energy and material derived from the animal waste and from decayed plant matter passed along the heterotrophic food chain. In this detritus-based food chain, bacteria decompose the animal wastes, releasing inorganic nutrients for photosynthesis by algal, and degrade the plant material into fragments which are consumed by protozoa. Organisms such as midge larvae feed on protozoa and themselves become the major food items for benthic feeding fish.

In order to provide adequate food for culture fish, therefore, it is imperative to understand the types of biotic communities and the relationship between these communities in a pond so as to increase not only natural food production for fish but also the efficiency of food utilization in these systems. When natural food is insufficient to meet the needs of the fish, supplemental feeds are means to provide adequate food for them. Appropriate types and amounts of feeds for specific stages of fish development, given at the proper frequency, can greatly enhance the level of production and the quality of fish, and may also reduce the time needed to bring fish to maturity.

Oxygen

Oxygen is an important parameter in culture ponds and is a good indicator of the state of water quality in ponds. It is widely known that an inadequate concentration of dissolved oxygen (D.O.) can cause problems in culture ponds. Fish may feed poorly or grow slowly in ponds with low D.O.; more seriously, fish can die overnight when the shortage of D.O. is acute. This problem has grown more severe since in order to increase the production in ponds, many farmers have increased the stocking density, feeds and organic fertilizer. Such practices have greatly raised the frequency of oxygen depletion in culture systems.

Many events can lead to low D.O. in ponds. These include sudden stratification caused by unseasonally warm weather and phytoplankton die-offs, both of which are sporadic events. Although the likelihood of their occurrence is predictable, the time at which die-offs occur is difficult to predict, making this too complicated an event to consider in this model. However, the D.O. concentration resulting from respiration by fish and phytoplankton, production of D.O. by photosynthesis, diffusion due to temperature changes and convection by wind should be predictable and can be modeled.

An oxygen model for aqiatcc environments can be expressed as follows:

$$DO_t = DO_I + DO_{pp} \pm DO_{cf} - DO_f - DO_{so} - DO_{pl}$$

where

DO_{pp} = primary production

DO_t = DO concentration at day t

DO_I = initial DO concentration

DO_f = oxygen used by fish metabolism

DO_{cf} = gain or loss of oxygen to diffusion and convection

DO_{so} = loss of oxygen due to sediment respiration

DO_p = oxygen consumed by the plankton community

Fish Energetics

The aim of the study is to increase fish production, therefore, fish growth is the single most important part of the model. Fish growth is a complex response to a variety of factors, which include more than food supply and oxygen concentration. The major parameters influencing fish growth are temperature, stocking density, mortality due to overstocking and oxygen concentration, as well as energy used for consumption, respiration, egestion, and excretion.

Methods

The production model (Figure 1) for pond fish contains three major areas: natural food and supplemental feed, oxygen limitation and fish energetics. The discussion which follows includes a description of parameter considered and steps and equations used for model construction of each for these sections.

Food and Feeds

The natural food section considers the major biotic communities of phytoplankton, macrophytes, zooplankton, benthos (protozoa and other benthic species), and their relationship with fish. Physical and chemical parameters such as inorganic fertilizer, soil condition, organic fertilizer, light conditions, and water transparency are also considered in connection with biotic communities as one integrated unit. The relationship between each trophic level of energy transfer in the food is based on available data; when such data are not available, a level of 10% energy transfer is assumed.

Oxygen

The oxygen section includes parameters for gain or loss of oxygen due to diffusion or convection, oxygen used by fish metabolism, loss of oxygen by sediment respiration and organic wastes, and oxygen consumption by the planktonic communities. Temperature is a major factor affecting the gain or loss of oxygen due to diffusion. To evaluate this change, a regression equation is established between saturated D.O. in the water and water temperature. The gain or loss of oxygen is established by the level of D.O. and the temperature at which the model is applied. Wind is known to accelerate the mixing and convection process, thereby increasing the amount of D.O. in the water column. Wind also affects vertical oxygen distribution, which is critical for many benthic living species.

oxygen consumption by fish is controlled by the size and number of fish stocked in a pond (see fish energetics). The rate of oxygen uptake by sediment is available from literature. Currently a crude approximation is used to represent this uptake, which is affected primarily by the unused portion of supplemental feeds and by the oxidation of organic manures. oxygen consumption by the planktonic community is a major demand on D.O. at night. This consumption is positively correlated with temperature and secchi disc depth if planktonic organisms are the major source of turbidity. The expression from Boyd et al. (1978) is used for estimating the consumption.

The production of oxygen as a result of photosynthesis is approximated by using Talling's equation (1957). This equation takes into account surface light, intensity, vertical light extinction, and the maximum rate of primary production, and presents the total oxygen per square meter. This oxygen model uses one hour before sunrise as an initial point, since the dawn D.O. concentration in water is most critical in fish culture. For southeast Asia, 4 or 5 AM may be a good time for this point. The value of total D.O. in water is then calculated for use in estimating the level of mortality in fish. Levels of D.O. less than 2 PPM usually become stressful to fish. When the level of D.O. is less than 0.5 PPM, many species may have high mortality.

Fish Energetics

The fish energetics section considers those factors which affect the growth of fish, including temperature, stocking density, mortality due to overstocking and oxygen depletion as well as those parameters which involve not only the growth but energy intake, metabolism, and storage, such as the energy for consumption, respiration, egestion, and excretion. The energy budget for fish in the production systems can be shown as follows in units of kcal $.g^{-1}$ $.d^{-1}$ (Rice 1983).

$$\frac{dB}{Bdt} = C - (R_{SA} + R_{SDA} + F + U)$$

where $\frac{dB}{Bdt}$ = specific growth rate

C = specific consumption rate

R_{SA} = specific rate of standard metabolism plus metabolism due to activity

R_{SDA} = apparent specific dynamic action

F = specific egestion rate

U = specific excretion rate

Energy consumption (C) by fish is a function of weight and temperature. This relation can be described by the following expression (Kitchell et al. 1977).

$$C = a_1 B^{b_1} \; r_c \; p$$

where B = biomass in grams

a_1 = intercept of consumption-mass relationship at optimum temperature

b_1 = mass exponent for consumption at optimum temperature

C_{max} = $a_1 B^{b_1}$ = the weight specific maximum consumption rate for the optimum temperature

r_c = a temperature dependent proportion adjustment of consumption rate

p = a proportionality constant for C_{max} actually consumed

Maximum consumption-temperature relationships (r_c values) are very important in scaling growth rate, yet have seldom been evaluated for many fish species. In this model, we have used the maximum growth-temperature relationship (more commonly available) to substitute for r_c. In the absence of consumption data, this less efficient scaling factor is mandatory.

Respiration energy (R) cost can be divided into three groups: maintenance costs, cost of activity, and apparent specific dynamic action (SDA), where SDA is the amount of energy spent for food processing and includes energy uses for digestion, assimilation, transportation, biochemical treatment and incorporation of food. For this study, SDA is estimated for each species, as it varies depending on food type. The rate for maintenance and activity is calculated by the equation shown below (Rice 1983).

$$R = a_2 \; B^{b_2} \cdot e^{mt}$$

where R = specific rate for maintenance energy cost plus metabolism due to activity ($mgO_2 \cdot g^{-1}$)

B = weight (g)

m = coefficient for temperature dependence of respiration

t = temperature (^{o}C)

a_2 = intercept of metabolism-weight regression for a 1 g fish at $0^{o}C$.

b_2 = exponent of metabolism-weight regression.

The values for a_2, b_2, and m also vary by species. When data for a species were unavailable, a best estimate from another species was used. The total amount of oxygen used for respiration is estimated by the R value times the total weight of the fish in a pond and is used for the oxygen consumption by fish respiration in the oxygen concentration model.

Energy losses through egestion (F) and excretion (U) are assumed to be constant proportion of the total energy consumed by fish. These proportions change with temperature, size, diet, and species of fish. In most cases, data for each species or a closely-related species were available.

Model Results

The general network for the fish production model assumes that fish utilize as food the biotic communities and supplemental feeds, and are controlled by low oxygen concentration. However, when models are analyzed the species considered differ in their feeding habits and in dependence on oxygen. For instance, some species use only specific kinds of natural food, or rely completely on supplemental feeds; the adult and fry stages often feed on different types of food and use different food chains; and a few species are not even affected by low oxygen. Models for these major variations are developed from the general model network to describe these special cases. The factors of food, supplemental feeds, growth stage (adult vs fry), and relationship of culture to dissolved oxygen are used to illustrate these specific network models for the eleven species considered. These species are grass carp, silver carp, bighead carp, nile tilapia, freshwater prawns, snakeskin gouramy, tawes, snakehead, sand goby, walking catfish and Sutch's catfish.

Feeding habits: Natural food or supplemental feeds

The fish which primarily feed on natural food for all stages of their life are bighead carp, silver carp, and snakeskin gouramy. The model network shown for this group is for silver carp (Figure 2). The major natural foods considered in this model are phytoplankton, zooplankton, macrophytes, and protozoa. Whereas phytoplankton, macrophytes, and protozoa production depends on the level of soil fertility and the amount of organic fertilization added, the zooplankton population is assumed to be related to the biomass of phytoplankton and protozoa.

Species depending completely on supplemental feeds as the food source include walking catfish, adult catfish, sand goby, and snakehead. The model network shown for this group is for adult Sutch's catfish (Figure 3). Since in this system natural food has little or no effect on fish growth, the ecological factors which enhance the growth of natural food communities are not considered.

Growth stage: fry vs. adult

Most of the fish considered have different feeding habits during the fry and adult stages. In general, fry feed on natural food such as zooplankton and high protein supplemental feeds, while the adults depend on different types of natural food and supplemental feeds. The groups of fish which require different models for different growth stages are grass carp, silver carp, freshwater prawns, tawes, and catfish. The examples shown for this group is for Sutch's catfish (Figures 3 & 4).

Dissolved Oxygen

Dissolved oxygen is essential for most of the fish discussed in this study, but a few species are not affected by low oxygen concentration and have no minimum D.O. requirements. Basically, three major patterns exist in the relationship of culture to dissolved oxygen: some extra-sensitive, some sensitive, and others unaffected by D.O. concentration. Freshwater prawns (Figure 5) are an extra-sensitive group and require a relatively high oxygen concentration for their growth. Also, since they are benthic species, they are often affected by insufficient D.O. the bottom strata of ponds even though the oxygen concentration at the surface is near saturation. A parameter to predict vertical oxygen changes due to the stratification therefore needs to be constructed in order for this model to accurately reflect the condition oxygen in ponds.

While most of the fish discussed are sensitive to oxygen concentration, a few need little or no D.O. in the water. No oxygen compartment is included in the model for the evaluation of these species, which include Sutch's catfish (Figure 4), walking catfish, and snakeskin gouramy.

Discussion

These models are written specifically for fish culture and includes all major biotic communities in a pond and their relationship to the physical and chemical environment. It treats the pond ecosystem and its various components as one integrated unit. This approach avoids the problem associated with the use of models primarily written for other aquatic systems such as reservoirs or lakes, and reduces the disadvantages of dealing with each compartment individually rather than dealing with the complete pond system. However, numerous areas still need development and improvement. These areas can be divided into two major groups. The first group pertains to adding parameters and modifying network design. The second group includes those areas in which the relationship between the factors under consideration needs to be improved or in which more information about specific rates or coefficients is needed. Both these types of insufficiencies can be found in the models presented. The identification of these insufficiencies is discussed below.

In the natural food and feed compartment, the relationship between the aerobic and anaerobic zones in ponds has not been adequately addressed in the modeling. Much of the current attention in the model is based on the carbon assimilation resulting from photosynthetic cycles, rather than on the bacteria production in anaerobic cycles. The latter is poorly understood, although it has an important effect in enhancing benthos, protozoa, and some zooplankton growth. Nutritional levels and energy contents have not been included in this study for evaluating the natural food and supplemental feeds, but they are important parameters for evaluating the quality of the food.

Currently, we assume the pond water is well mixed vertically. We found that this is not the case in the majority of the ponds in the area; oxygen depletion may be developed at the lower levels of a pond while surface oxygen is super-saturated. Vertical diffusion parameters and wind driven convection systems are needed in order to reflect the actual oxygen distribution in the pond water. Data on oxygen consumption by organic manure and excess quantity of supplemental feed need to be established, but this information cannot be obtained by modeling alone; additional field research is needed for gathering this information.

In the area of fish energetics, information is often unavailable for species- specific coefficients for food consumption, energy utilization egestion, and excretion. These values are also needed for various stages of fish development. Species specific rates for mortality due to low oxygen and over-stocking are not available. These are necessary for improving the model prediction.

By using the modeling approach, we were able to complete the tasks which we set out to do. The model networks provided a general framework around which participants were able to focus their discussions and exchanges of information on problems, solutions, and relevant technology. Critical areas of research were identified and limiting factors were assembled for all commonly cultured species in southeast Asia (Table 1). Participating scientists singled out water quality and feed availability as the most important limiting factors for overall pond fish production. Market potential; seed availability and quality; disease, parasites and predators; pond size and fertility; and pond management were also considered significant in affecting pond preduction. However, if limiting factors were considered statistically on a species by species basis, the rank of the factors is as follows: disease, parasites and predators, market potential, feeds or food supply, water quality and quantity, seed availability and quality, pond size and fertility, and pond management (Table 1). The ranks of the last two factors remained unchanged while the order of the first five factors varied somewhat. Since many of these factors are interrelated, improvements in one area could affect the situation with respect to other factors. The absolute ranking of first five factors is not critical; nevertheless, together they have much importance in ability to increase production.

We feel the modeling approach has enabled us to focus this problem and to enhance our understanding of these systems. When enough data are available, a simulation of real pond conditions can also be carried out for research, teaching and management.

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Table 1. Major limiting factors to freshwater fish production in southeast Asia. 1 = most important; + = important; - = not important for that species. Rank by question + that due to verbal response at workshop. Rank by table + summation over species.

Limiting factor	Grass Carp	Silver Carp	Bighead Carp	Nile Tilapia	Prawn	Snakeskin Gouramy	Tawes	Snake-head
Water Quality and quantity	+	+	+	-	1	-	+	-
Feeds or food supply	+	+	+	-	-	-	+	+
Market potential	-	1	1	-	-	-	+	-
Seed availability and quality	-	-	-	+	+	-	-	1
Disease, parasites, predators	1	-	-	+	+	+	1	-
Pond size, fertility	-	-	-	-	-	+	-	-
Pond Management	-	-	-	1	-	1	-	-

Limiting factor	Sand goby	Walking catfish	Catfish	Ranking by questions	Ranking by table
Water quality and quantity	-	-	-	1	4
Feeds or food supply	-	+	+	2	3
Market potential	-	+	1	3	2
Seed availability and quality	1	-	-	4	4
Disease, parasites, predators	+	1	-	5	1
Pond size, fertility	-	-	-	6	5
Pond management	-	-	-	7	6

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A Yield Model for Walking Catfish Production in Aquaculture Systems

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ABSTRACT

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A yield model for *Clarias* culture was produced using a combination of laboratory data for *Clarias lazera* and field data on *Clarias batrachus* culture in Thailand. The model was used for simulations to fulfil three distinct objectives: (1) to consolidate knowledge of fish physiology and aquaculture practices for *Clarias* into a model which can be validated; (2) to determine sensitivity of predictions to variation in model parameters; and (3) to predict yield of *Clarias* ponds under different stocking density, size at stocking, and type of containment. The accuracy of this model was tested with an independent data set of 32 grow-out periods. The model was relatively poor at predicting yield when the measured feeding rate was input ($r^2=0.022$), but reasonably good at predicting yield if maximum feeding rate was input ($r^2=0.52$). This may reflect poor data collection of feeding rate in the ponds. Sensitivity analyses indicated that changes in parameters related to maximum consumption showed high importance in predicting yield, while changes in metabolic parameters had low importance. A doubling of feeding rate increased yield 548% in earthen ponds and 465% in concrete tanks. Density stocked was of secondary importance in increasing simulated yield, while size at stocking was relatively unimportant. The maximum consumption rate of different food types (pellets, trash fish) was also extremely important in determining simulated yield.

INTRODUCTION

The walking catfishes, *Clarias batrachus* and *C. macrocephalus*, are very popular species for aquaculture in Southeast Asia and East Africa (Bardach et al., 1972). This popularity stems from several characteristics of the fish, which include the ability to tolerate anoxia, wide-ranging food habits, and extremely high yields. Yields up to 97 000 kg ha^{-1} yr^{-1}, reported by Bardach et al. (1972), were the highest for standing water systems and among the highest for any culture technique. The unique combination of biological characteristics leads

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to very high production with relatively unsophisticated pond management. *Clarias* culture is economically important in Thailand, with annual yields near 20 000 metric tons (FAO, 1983). Common culture techniques in Thailand include stocking fish in earthen ponds using pellets or trash fish as food, and use of concrete recirculating tanks with pellets (Diana et al., 1985). Average growth and mortality are much better in concrete tanks (5% body weight per day and 0.12%/d) than in earthen ponds (3% bw/d and 0.89%/d) (Tarnchalanukit et al., 1983; Diana et al., 1985). Variations in survival between ponds or tanks are believed to be due to differences in water quality (Tarnchalanukit et al., 1983). If this is true then earthen pond culture could also produce higher yields by improving water quality through better pond management.

We currently are unable to estimate the proximal factors causing differences in yield between the two culture techniques. The purpose of this paper is to develop a yield model for *Clarias* culture, utilizing basic energetic data to predict individual growth, and water quality data to estimate mortality. There are three distinct objectives to this work. The first is to consolidated our knowledge of fish physiology and aquaculture practices for *Clarias* into a model which can be validated; the second is to determine the sensitivity of the model to variations in the model parameters, and the third is to predict yield of *Clarias* ponds under different stocking density, size at stocking, and type of containment.

MODEL DESCRIPTION AND DEVELOPMENT

Energetics submodel

Information on *Clarias* energetics is rather limited. The best information comes from the various studies of Hogendoorn (1980, 1983; Hogendoorn et al., 1981, 1983) on *C. lazera*, and we have used these data in our energetics submodel. Specific parameters and equations for the *Clarias* energetics submodel follow the forms utilized by Kitchell et al. (1977) and are referenced to the balanced energy equation (Webb, 1978):

$$Q_G = Q_R - (Q_M + Q_F + Q_N + Q_{SDA}) \quad (1)$$

where all variables are in kcal/day and Q_G = growth rate, Q_R = daily ration consumed, Q_M = routine metabolic rate, Q_F = fecal loss, Q_N = nitrogen excretion costs, Q_{SDA} = apparent specific dynamic action.

For walking catfish, we have estimated respiration as routine metabolic rate (Q_M) since the respirometers commonly used allow movement of the fish between an air surface and the water, and therefore swimming speed is uncontrolled (see Hogendoorn et al., 1981). We assume that routine activity in the respirometer and nature are similar. In addition, we assume no reproduction occurs in culture. Thus the model may be inaccurate once fish reach a size at which they mature and spawn, which is about 150 g for *Clarias*.

Routine metabolism (Q_M) was calculated as:

$$Q_M = 0.18 W^{0.78} \qquad (2)$$

(Hogendoorn, 1983) where Q_M = kcal/day and W = wet body weight (g). Maximum daily ration ($Q_R$max) was considered:

$$Q_R \max = 0.23 W^{0.78} \qquad (3)$$

(Tarnchalanukit et al., 1983), where $Q_R$max = maximum kcal/day consumed (for pelleted feed). This set an upper limit for ration, and daily ration consumed (Q_R, an input variable) was compared to this to determine actual daily ration. Q_R was reduced to $Q_R$max when $Q_R > Q_R$max.

Excretion (Q_N) and fecal loss (Q_F) were considered functions of Q_R (0.03 and 0.26, respectively) (Hogendoorn, 1983). Specific dynamic action (Q_{SDA}) was calculated as (Hogendoorn, 1983):

$$Q_{SDA} = (0.24 W^{-0.26}) Q_R \qquad (4)$$

Initial fish biomass and feeding rate were input to the model, which then subtracted energy use ($Q_M + Q_F + Q_N + Q_{SDA}$) from daily ration ($Q_R$) to determine daily growth (Q_G). Growth was added to initial weight to calculate final weight each day. The time step for this submodel was 1 day.

The most difficult feature in the submodel was evaluating maximum consumption ($Q_R$max) for fish under different diets. As pellets or trash fish (common *Clarias* feeds) vary in quality, maximum consumption also varies. For example, satiation of *Clarias* with pellets measured by Hogendoorn (1983) and Tarnchalanukit et al. (1983) differed considerably for two types of pellet. Both probably differ from maximum consumption of trash fish. We used the data of Tarnchalanukit et al. (1983) for maximum consumption of pellets commonly used in Thailand (2.4 kcal/g) and then made two extrapolations for trash fish (assumed to be 1 kcal/g wet weight). Models run with maximum trash fish consumption equalling pellets in calories would yield identical values to runs with pellets. We also evaluated the range of production possible with trash fish feed by using maximum consumption in weight.

An additional assumption was that all delivered feed was consumed when feed application rate was less than maximum consumption. Although some food may not be eaten, there are no available data to define the relationship between food type, feed application rate, and percentage of applied food actually consumed. This assumption causes estimates of actual feed application rate to be low for a given growth rate, or will result in overestimates of growth rate.

Temperature normally influences energetics considerably (Brett and Groves, 1979). Data from Hogendoorn (1980, 1983) were for a temperature of 27°C.

Normal culture temperatures for *Clarias* vary in Thailand from 25 to 32°C. Therefore, we were forced to assume no temperature effects on the energetic model within the range of temperatures specified above.

Water quality submodel

Water quality, as indicated by dissolved oxygen, was modeled by comparing oxygen consumption of fish to oxygen addition. Total daily oxygen consumption (QO_2) per fish was calculated from Q_M (kcal/day) using an oxycalorific equivalent of 3.22 kcal/mg O_2 consumed (Brafield and Solomon, 1972). Total oxygen consumption by *Clarias* includes use of dissolved and gaseous oxygen, and the importance of each breathing method varies with pO_2 of the water. Our model used data from Jordan (1976) to determine the percentage of total respiration derived from consumption of dissolved oxygen. Oxygen addition could occur by primary production or diffusion into earthen ponds. Total daily oxygen consumption from water was calculated by multiplying QO_2 by the percent respiration from the water, then by the total number of fish (n, an input value). Oxygen addition and use by plankton and benthos were modeled using Romaire and Boyd's (1979) relationships for channel catfish ponds (with secchi disk depth assumed to be 50 cm). Once ponds became anoxic, we assumed no additional primary production.

Oxygen dynamics in recirculating tanks was modeled assuming that all addition was due to circulation of new water at air saturation, and all consumption was due to fish respiration as before. Primary production in tank waters, BOD of recirculating water, and diel oxygen cycles in supply water reservoirs were ignored. These simplifying assumptions were necessary since there were no data on those parameters for *Clarias* culture systems.

Water quality deterioration, as indicated by low dissolved oxygen, was used to estimate mortality rate for *Clarias* in earthen and concrete ponds. In earthen ponds at dissolved oxygen levels greater than 1 mg/l, daily mortality was considered constant at 0.89% per day (Tarnchalanukit et al., 1983). For DO less than 1 mg/l, mortality (% per day) was calculated as -0.8037 DO $+$ 1.6915. Comparable values used for concrete ponds were 0.11% per day when DO exceeded 1, and 0.915% per day when DO was less than 1. Values calculated for both of these culture systems are similar to average empirical values (Diana et al., 1985). Mortality rate was then multiplied by initial number of fish to calculate final number of fish each day.

Overall model

The overall model simply integrated the two submodels. Input parameters were daily ration, stocking density, culture duration (days, D) and individual weight at stocking. The energetics submodel was run to calculate daily individ-

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ual growth. The water quality model was run to calculate dissolved oxygen content and mortality rate. The total number of surviving fish (n) was then calculated and used to estimate total biomass ($n \times W$). All input values except ration were updated to new levels for the following day, and the calculations repeated for D days.

MODEL VALIDATION

Accuracy analysis

Accuracy of the model's predictions was tested with an independent data set collected by Kasetsart University, from earthen ponds in Thailand. These data were for 32 grow-out periods, with culture conditions varying from 32 to 167 days, with 12.5–156 g initial fish weights, and stocking densities of 65 000–211 000 fish/ha. Feed application rates, estimated by farmers during the first and last week of the grow-out, varied from 0.3× to 1× satiation ration. These overall culture conditions were much more variable than typical Thai grow-outs (Diana et al., 1985), and represent rigorous test conditions of simulation performance. The only output data available were observed yield of each pond, and these were compared to predicted yields.

The relationship between actual and predicted yields was extremely variable (Fig. 1). The mean percentage error (|actual – predicted| × 100/actual yield) was 35.8%, and there was a bias, though not significant, toward underestima-

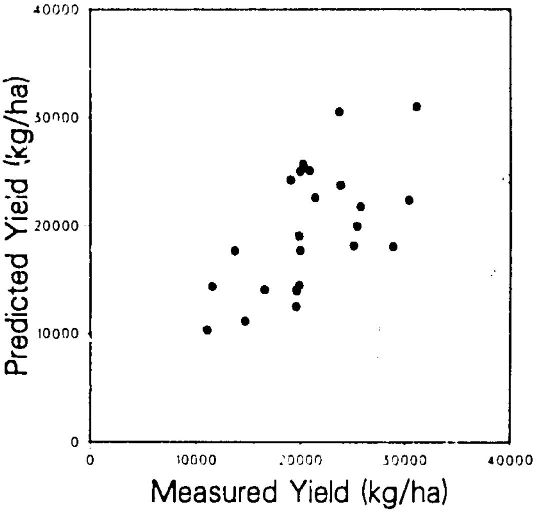

Fig. 1. Relationship between predicted and measured yields for *Clarias* in earthen ponds. The line for a perfect relationship is dotted. The regression is $y = 0.15x + 13103$ ($r^2 = 0.022$). Open circles signify the eight outliers mentioned in the text.

tion of actual yield (mean difference = −20.9% ± 37.3%). Measured yields were generally underestimated at high yields, while the predicted and measured yields agreed well at low yields.

Yields for eight of the 32 ponds were largely underestimated. Regression of feed application rate and initial weight on the deviation between measured and predicted yields explained 76% of the variance in yield deviation. Pond area duration of culture, percent mortality, and measured yield were not significant explanatory variables. Outliers all were at low reported feeding rates (0.51 ± 0.13 $Q_R$max, mean ± SD)), which normally would not occur in commercial culture where the goal is to grow fish quickly (overall average feeding rate was 0.77 ± 0.23 $Q_R$max). It is likely that the measured rations (which were reported only for the first and last weeks of culture) did not accurately reflect actual rations fed throughout the culture period.

Sensitivity analyses

Simulations were also done to estimate the sensitivity of results to variations in model parameters. Routine metabolic rate (Q_M), apparent specific dynamic action (Q_{SDA}), assimilation efficiency (Q_F), nitrogen excretion (Q_N), and maximum food consumption ($Q_R$max) were varied by ± 10% of the parameter values. Variations in growth, yield, and the time (in weeks) when the oxygen in ponds first dropped below 1 mg/l were measured to assess sensitivity. Vari-

TABLE 1

Model sensitivity to changes of ± 10% for parameters listed. Analyses were done for standard runs with 4-g fish, fed ad libitum, at 500 000/ha (earthen) or 5000/15 m² (concrete), and run for 90 (concrete) or 120 (earthen) days

Parameters	% Change			
	Yield (kg/ha (or tank))	Final weight (g)	Mortality rate (%)	DO depletion
Earthen ponds				
Q_M	5.6	4.0	0.7	4.5
Q_{SDA}	4.6	4.1	0.2	4.5
$Q_F + Q_N$	9.3	13.2	1.8	9.1
$Q_R$max	20.0	28.4	7.2	40.9
Concrete ponds				
Q_M	5.4	3.7	4.5	16.7
Q_{SDA}	6.3	4.3	5.7	16.7
$Q_F + Q_N$	12.6	12.5	2.1	25.0
$Q_R$max	22.8	26.3	8.7	16.7

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ations were measured as percentage changes (|final – initial result| × 100/initial result), and averages of ± 10% variations were reported.

The model was not particularly sensitive to metabolic components, but was very sensitive to maximum consumption (Table 1). A 10% change in $Q_R$max gave a 20–33% change in yield, 26–28% change in growth, and 7–8% change in mortality rate. Routine metabolic rate and specific dynamic action affected yield much less, while egestion and excretion rates had intermediate effects. These and earlier analyses indicate that feeding and feed utilization are very important in modeling yield of *Clarias*.

MODEL EXPERIMENTATION

Techniques

Simulations of actual culture systems are complex due to the relationship between feeding, growth, and control of ration. Small fish can eat a very large ration (on a percent body weight basis) relative to larger fish (Brett and Groves, 1979). Holding ration at a fixed percent body weight underestimates feeding potential. Keeping ration at a fixed weight results in either overfeeding at small size or underfeeding at large size. We chose to control ration by using ad-libitum and 1/2 ad-libitum rations for all analyses, as this more likely represents feed application patterns used by culturists.

Comparative simulations were done on fish in earthen ponds for 120 days, at densities of 250 000, 500 000, 1 000 000, and 2 000 000 per ha, for fish stocked at 0.5, 1.0, 2.0, 4.0, and 8.0 g, to examine differences between various pond management options. Simulations for earthen pond culture were run with both trash fish and pelleted feed. Concrete tank simulations were similar to those for earthen ponds, except only pellets were used, culture duration was 90 days, and stocking densities were 2500, 5000 or 10 000 fish per 15-m^2 tank. Input values were set to mimic normal culture operations (Srisuwantach et al., 1981; Colman et al., 1982; Tarnchalanukit et al., 1983; Diana et al., 1985). Output values evaluated were fish growth, mortality, gross yield, and time (in weeks) before oxygen content of the water became less than 1 mg/l.

Earthen pond simulations

Yield in earthen ponds varied considerably in relation to the input parameters of initial stocking size, feeding rate, and stocking density (Table 2). Using a standard grow-out duration of 120 days, and assuming two harvests per year, predicted gross yields varied from near zero to 344 584 kg ha^{-1} yr^{-1}.

Changes in input variables altered yield substantially. The most important factor was feeding rate; yield was on average 549% ± 19% greater ($\bar{x}$ ± SD for 20 paired simulations) when fed ad-libitum than when fed 1/2 ad-libitum ra-

TABLE 2

Simulation results for earthen ponds, with a 120-day grow-out period and pelleted feed

Density (n/ha)	Stocking weight (g)	Final weight (g)	Total biomass (kg/ha)	% Mortality	1st week DO < 1
One half ad-libitum ration					
250 000	0.5	19	1655	65.7	—
	1	27	2308	65.7	—
	2	37	3214	65.7	—
	4	53	4526	65.7	—
	8	76	6492	65.7	—
500 000	0.5	19	3310	65.7	—
	1	27	4616	65.7	—
	2	37	6429	65.7	—
	4	53	9052	65.7	—
	8	76	12 985	65.7	—
1 000 000	0.5	19	6620	65.7	—
	1	27	9234	65.7	—
	2	37	12 857	65.7	—
	4	53	18 104	65.7	—
	8	76	25 969	65.7	—
2 000 000	0.5	19	13 240	65.7	—
	1	27	18 465	65.7	—
	2	37	25 697	65.7	17
	4	53	33 244	68.5	8
	8	76	33 771	77.6	1
Ad-libitum ration					
250 000	0.5	195	16 732	65.7	—
	1	230	19 733	65.7	—
	2	274	23 509	65.7	—
	4	332	28 443	65.7	—
	8	409	35 103	65.7	—
500 000	0.5	195	33 459	65.7	17
	1	230	39 045	66.0	15
	2	274	45 246	66.9	13
	4	332	52 249	68.4	11
	8	409	58 741	71.3	8
1 000 000	0.5	195	55 786	71.4	9
	1	230	62 922	72.6	8
	2	274	71 346	73.9	6
	4	332	81 573	75.4	4
	8	409	94 267	76.9	2
2 000 000	0.5	195	96 732	75.2	5
	1	230	109 383	76.2	4
	2	274	124 878	77.2	2
	4	332	139 683	78.9	2
	8	409	172 293	78.9	2

TABLE 3

Comparison of yield for *Clarias* when maximum consumption of trash fish is equivalent to pellets in energy or in weight. Percent difference = $100 \times (Y_{Energy} - Y_{Weight}) / Y_{Weight}$

Density (n/ha)	Initial size (g)	Yield (kg/ha)		% difference
		Energy equivalence	Weight equivalence	
250 000	0.5	16 732	766	2084
	1	19 733	1183	1568
	2	25 509	1792	1323
	4	28 443	2714	948
	8	35 102	4155	745
500 000	0.5	33 459	1533	2083
	1	39 045	2366	1550
	2	45 246	3583	1163
	4	52 249	5427	863
	8	58 741	8310	607
1 000 000	0.5	55 786	3066	1720
	1	62 922	4732	1230
	2	71 346	7166	896
	4	81 573	10 855	651
	8	94 267	16 620	467
2 000 000	0.5	96 732	6132	1477
	1	109 389	9468	1055
	2	124 878	14 333	771
	4	139 683	21 709	543
	8	172 293	30 713	461

tions. Stocking density was next in importance, although at most a doubling in density could double yield. Due to density-dependent mortality, a doubling in density resulted in an 84% ± 19% increase in yield. Size at stocking was least important in increasing yield; a doubling of size only increased yield 29% ± 13%.

Oxygen reached levels below 1 mg/l in less than half of the simulations for earthen ponds. Oxygen usage was increased mainly by changes in feeding rate, followed by stocking density, then size at stocking.

Feeding with trash fish in earthen pond culture altered yield largely, depending on maximum feeding levels used. If feeding was assumed to be controlled by weight eaten, then use of trash fish declined yield by 91% (Table 3). Obviously, maximum food intake as related to food type is an extremely important factor in management of pond culture.

Recirculating pond simulations

Simulations for recirculating ponds showed trends somewhat similar to those for earthen ponds (Table 4). Doubling feeding rate resulted in an average

TABLE 4

Simulation results for concrete tanks, with a 90-day grow-out period and pelleted feed

Density (*n*/ha)	Stocking weight (g)	Final weight (g)	Total biomass (kg/tank)	% Mortality	1st week DO < 1
One half ad-libitum ration					
2500	0.5	9.8	22.3	9.5	—
	1	14.6	33.1	9.5	—
	2	21.6	48.9	9.5	—
	4	32.1	72.7	9.5	—
	8	48.6	110.0	9.5	—
5000	0.5	9.8	44.6	9.5	—
	1	14.6	66.3	9.5	—
	2	21.6	97.8	9.5	—
	4	32.1	145.5	9.5	—
	8	48.6	204.9	15.7	11
10 000	0.5	9.8	89.2	9.5	—
	1	14.6	131.0	10.5	13
	2	21.6	176.9	18.1	10
	4	32.1	240.5	25.2	6
	8	48.6	327.8	32.5	3
Ad-libitum ration					
2500	0.5	85.9	193.5	9.9	12
	1	106.0	238.4	10.0	11
	2	132.2	296.9	10.1	10
	4	167.5	375.3	10.3	9
	8	216.7	485.4	10.4	7
5000	0.5	85.9	343.1	20.1	8
	1	106.0	409.6	22.7	7
	2	132.2	494.5	25.2	6
	4	167.5	615.5	26.5	6
	8	216.7	765.0	29.4	3
10 000	0.5	85.9	616.1	28.3	5
	1	106.0	740.6	30.1	4
	2	132.2	893.2	32.4	3
	4	167.5	1086.9	35.1	3
	8	216.7	1363.6	37.0	1

465% ± 145% increase in yield. Doubling fish density increased yield 81% ± 14%, while increasing size at stocking increased yield 34% ± 19%.

Surprisingly, recirculating tanks reached low oxygen levels in 67% of the simulations, indicating lower simulated water quality in these systems than in earthen ponds. Again, the sensitivity of oxygen concentration was similar to that of yield, with feed application rate, density, and size having decreasing importance.

GENERAL DISCUSSION

The most pertinent outcome of the model is that factors increasing food consumption have the most significance to increasing production. Overfeeding may improve growth, but also results in food decay and decreased water quality, including increased bacterial levels (Colman et al., 1982). These factors were not included in our model. Nevertheless, factors affecting rate of food consumption as well as assimilation efficiency, are very important in predicting growth and yield. There remains a very large deficiency in our knowledge of feeding rates, conversion efficiencies, and nutritional requirements for *Clarias* and many other cultured tropical fishes (Colt, 1985; Yamada, 1985).

Two biological factors probably had a major effect on variability in actual vs. predicted yields: (1) outbreak of disease in natural systems, and (2) changes in *Clarias* growth after maturation. Disease outbreaks would result in very low or variable survival and drastically affect pond culture practices (Panayotou et al., 1982). Our simulation results indicate intermediate survival in all ponds, and thus underestimate changes in yield for any culture combination due to disease. However, the occurrence and extent of disease outbreaks and mortality cannot currently be predicted (Brock, 1985). Our modeling also assumes that *Clarias* growth continues at a constant rate throughout adulthood, while in reality growth probably declines in mature fish due to energy use for gonad growth, although this decline in growth is not well documented for *Clarias* (Hogendoorn et al., 1983).

As in any mathematical model, simplifying assumptions had to be made. Probably the most unrealistic feature of the model is its determinism. All fish are predicted to grow at the same rate, and no probabilistic processes, such as disease or weather variations, were included. Thus, model yields were always identical under any given combination of variables. Pond yields vary tremendously under similar management practices in nature, and reasons for this variability are unclear (Lannan et al., 1985). Errors in yield estimation in the present study could be related to natural variations in mortality rate, due to management practices. Fig. 1 indicates that the largest excursions from predicted yields occurred at high standing crops, where natural systems are most stressed and sporadic mortalities due to poor water quality most likely. Under these conditions, yields measured were often much greater than those predicted, apparently in the absence of large mortalities. While accounting for mortality variations might improve agreement between measured yield and predicted yield, it would not improve the ability to forecast average yield.

Estimation of oxygen consumption and production is another area of major concern in the model. Romaire and Boyd's (1979) models for conditions in channel catfish ponds may have limited applicability to conditions in *Clarias* ponds. Knowledge of primary and secondary production for Thai aquaculture systems is also limited, so we cannot improve on Romaire and Boyd's model at present. This is particularly true for anoxic ponds. Since so few fish species grow well in anoxic conditions, little is known of biological processes in these systems. However, available data indicate a cessation in photosynthesis once ponds become anoxic (National Inland Fisheries Institute, 1981).

Our results have done little to clarify differences between concrete tank and earthen pond culture of *Clarias*. Tarnchalanukit et al. (1983) indicate that the improved water quality in recirculating tanks allows greater growth and survival of *Clarias*. Water quality indicated by our predicted DO levels was no better in concrete tanks than in earthen ponds. Improved yield may result from better feeding practices possible in tank culture, where applied feed is probably consumed more efficiently, and better estimation of fish size and density in tanks also allows more precise feeding.

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