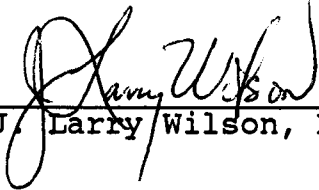
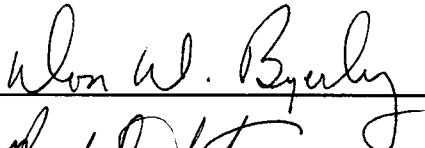
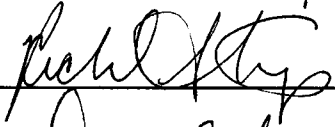
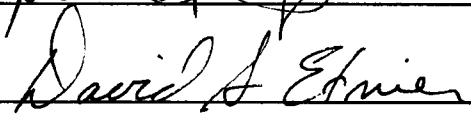


To the Graduate Council:

I am submitting herewith a dissertation written by Atchara Wongsangchan entitled "Impacts of Intensive Shrimp Cultivation on Water Quality in the Songkhla Basin, Thailand." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology.


J. Larry Wilson, Major Professor

PA
NYF
S
We have read this dissertation
and recommend its acceptance:

Accepted for the Council:


Vice Provost
and Dean of The Graduate School

IMPACTS OF INTENSIVE SHRIMP CULTIVATION ON
WATER QUALITY IN THE SONGKHLA BASIN,
THAILAND

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Atchara Wongsangchan

December 1990

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ABSTRACT

Water quality in intensive shrimp culture ponds was examined during one 5-month grow-out period. The measured parameters included temperature, salinity, Secchi disk transparency, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia-N, nitrate, phosphate, total suspended solids, chlorophyll a, and plankton abundance/composition. Most water quality parameters changed relatively little over time except for specific trends in BOD, NH_3 , pH, and transparency. There were increases in levels of BOD (2.8 to 12.1 ppm), and NH_3 (0.0 to 1.5 ppm); pH decreased from 8.8 to 7.3 and transparency decreased from 80 to 40 cm. DO levels were relatively unchanged and maintained at 6-10 ppm over the grow-out period. Other parameters were considered as optimum levels for tiger shrimp culture, such as temperature (25-32 C) and salinity (20-32 ppt). BOD was identified as the most significant (P value < .05) parameter that affected shrimp feed efficiency; as BOD levels increased, feed efficiency decreased. During the grow-out period, the blue-green algae Oscillatoria sp. and the "pennate" diatoms were the dominant groups in the phytoplankton community while nauplius and rotifers were dominant in the zooplankton community. Phytoplankton densities and chlorophyll a concentrations increased as

the grow-out proceeded. There were no significant effects of water exchange practices on the water quality parameters throughout the grow-out period.

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CHAPTER I

INTRODUCTION

Brackishwater shrimp farming in Thailand has become an important industry which generates large amounts of employment and foreign exchange. The giant tiger prawn (Penaeus monodon Fabricius) and the banana prawn (P. merguensis de Man) are commonly cultured, but the giant tiger prawn is becoming the most important species because of its high demand in the international market. Between 1983 and 1986, shrimp production in Thai ponds increased steadily from 14,196 tons worth 1,261 million baht (\$50.44 million) from 35,200 ha (220,000 rai) to 18,000 tons valued at 1,600 million baht (\$64 million) from 46,880 ha (293,000 rai). The area devoted to shrimp ponds, total annual production, and value of the crop have increased at a much greater rate in the last three years. Shrimp farming was included in the recent (sixth) National Economic and Social Development Plan (1987-1991). The targets set by the Department of Fisheries, Ministry of Agriculture and Cooperatives, i.e., to improve yields and increase the pond area to achieve an annual production of 70,000 tons of shrimp by the early 1990's, have apparently already been exceeded.

The great surge in shrimp production has been realized through rapid expansion of intensive culture

methods. For example, coastal areas of the Songkhla Basin (southern Thailand) are rapidly being converted to intensively cultured shrimp farms. This expansion of the shrimp industry is occurring at a time when rapid development of other resources is causing environmental degradation of coastal areas. This degradation of the environment could seriously impact shrimp farming. Also, the rapid expansion of intensive shrimp farming may further contribute to the degradation of water quality in coastal areas. The government is emphasizing careful planning of future shrimp farm development to minimize the influence of pond effluents upon the environment and upon the water supplies of existing farms.

In the coastal provinces of the inner Gulf of Thailand where water pollution is most severe, virtually all of the shrimp farmers in a given locality rely on the same canal for water intake and discharge. As more farmers adopt intensive culture practices, water quality will deteriorate in supply canals because of the increasing load of pond effluents. Pollution of canals by pond effluents will limit the production potential and possibly prevent continued shrimp farming. An existing example can be seen in the shrimp farming area in Samutprakarn Province in 1987 when shrimp production dropped from about 312.5 kg/ha (50 kg/rai) to about 37.5 kg/ha (6 kg/rai); this was apparently due to pollution.

The area of shrimp culture ponds has grown by about 2,400 ha (15,000 rai) annually, and if the trend continues, the total brackishwater shrimp pond area will be 54,720 ha (342,000 rai) in 1991. Although it has been estimated that there is an additional 25,600 ha (160,000 rai) of marginal land which is suitable for development into brackishwater shrimp ponds, much of this land is located in mangrove forests which the government seeks to preserve. Expansion further inland would require improved water management and would generate increased competition for mangrove forest and agricultural land. Thus, lack of space and deteriorating environmental conditions are serious problems facing the shrimp farming industry in Thailand.

Shrimp production methods are generally classified into three categories based on the level of production: extensive, semi-intensive, and intensive (Shang, 1983; Kungvankij, 1984; and Liao, 1989). Extensive production is practiced in large earthen ponds or lagoons where the density is less than 1 shrimp/m² and the yield is 50 to several hundred kg/ha. Water exchange generally depends on tidal action and food for the shrimp comes from natural productivity of the ponds which can be enhanced by organic and inorganic fertilization. Semi-intensive culture is practiced in earthen ponds of different sizes ranging from thousands of square meters to 50 ha.

Although current management practices vary from country to country and within each country, they generally involve higher stocking rates, use of supplementary feed, and a regular water management scheme. The normal stocking rate varies from 5-15 shrimp/m², supplemental feeds are given daily in addition to existing natural food produced through application of fertilizers, and water pumping is required to maintain good water quality. The estimated yield from semi-intensive culture operations is 1-6 tons/ha/year.

Intensive shrimp culture is the most sophisticated management system and requires very high financial input. Features of intensive shrimp culture include: use of hatchery-produced seed, high stocking density, use of formulated diets, application of aeration to increase dissolved oxygen concentrations in ponds, and more sophisticated pond inlet and outlet systems to ensure better water exchange and water quality. Stocking rates and yields vary greatly depending on the degree of intensification. For example, in a highly intensive culture system developed by Dr. Shigueno (Shigueno, 1975) in Japan, a stocking density of 200 to 250 shrimp/m² in earthen ponds with concrete dikes was used, which produced an average production of 10-20 tons/ha/year. Currently, the intensive culture systems practiced in Thailand are of lesser degree of intensification than the

above. Farm sizes average about 10 ha each, and a size of more than 16 ha is considered large. The average stocking density is about 30 shrimp/m² and the yield is about 3-10 tons/ha/crop. Two crops per year are produced: one begins in January or February and is harvested from April to June, and the second begins in June or July and is harvested in November or December. The primary goal of this system is economy of production by rearing more animals in less time and space. However, increasing the culture density creates a large demand for water, produces environmental problems within culture ponds, and represents a source of water pollution. A major limiting factor in intensive shrimp culture operations is water quality because of the lack of adequate water quality control mechanisms for pollution removal and detoxification by biological, chemical, and physical processes (Roger et al., 1983; Chiang et al., 1989; Liao, 1989).

The maintenance of good water quality is essential for survival and optimum growth of shrimp. Physical, chemical, and biological processes are principal factors controlling the composition of pond waters. The variability of these factors is extreme and to a great extent this effects the success or failure of the cultural operations. The most important parameters in shrimp production include salinity, dissolved oxygen

(DO), temperature, pH, suspended solids, biological oxygen demand (BOD), and potential toxic substances such as ammonia, nitrite, and hydrogen sulfide. Possibly other factors such as phytoplankton abundance and nutrient concentrations (Shigeno, 1978; Liu, 1983; Roger et al., 1983; and Chiang et al., 1989) may also play an important role.

Water pollution from domestic, agricultural, and industrial wastes already has had serious effects on surface water which is the supply for most aquacultural ponds. Water quality in shrimp ponds depends partly on the quality of the surface water which is used to fill ponds and to exchange water. Serious problems may occur when this water is polluted. Chaing et al. (1990) suggested that the failure of shrimp grow-out in coastal ponds in Taiwan was due to wide fluctuations of salinity and water quality of the supply source (i.e., from polluted intertidal canals which served as both intake and discharge for a culture system). In the evaluation of water quality in shrimp ponds in Thailand, Boyd (1987) reported that the mortalities of P. monodon in ponds appeared to be related to low concentrations of DO and low salinity during the wet season. Organic pollution of canals which supply water to ponds was partly responsible for low DO, but environmental factors within ponds also contributed to this situation. In intensive shrimp ponds

where a large quantity of feed is needed, excess feed, waste materials, and other metabolites can enhance the rapid growth of algae and microorganisms. The sudden increase (bloom) and decrease (die-off) in plankton and microorganism populations can cause drastic changes in water quality parameters which may affect the growth and survival of shrimp. A water quality study in intensive shrimp ponds in Samutsakorn Province found that the minimum level of DO (over a 24-hour period) dropped to 3.7 ppm and the BOD value increased to 20.5 ppm during the third and fourth month of the culture period (Musig et al., 1989). A similar study conducted in shrimp ponds in Songkhla Province reported that during the grow-out period the minimum DO level (during a 24-hour period) dropped to 2.4 ppm and the BOD increased to 10.5 ppm at 99 days of culture (Predalumpraburt et al., 1989). Chen and Wang (1990) reported that ammonia-N drastically increased to more than 3 ppm after 80 days of culture in P. monodon ponds. Poor water quality in grow-out ponds, which affected the mortality rate and production of P. monodon, was also recognized in Taiwan and Japan (Shigeno, 1978; Liao, 1983).

The effluent water from intensive aquaculture ponds is considered as a possible potential pollution source. There is almost a complete absence of literature on effluent from intensive shrimp ponds; however, there is

evidence that water pollution can result from other aquacultural farming activities (Boyd, 1979). The report from the Thai National Applied Scientific Research Institute in 1986 indicated that the level of DO and biological oxygen demand (BOD) in mg/L in inlet and outlet of snakehead fish ponds averaged 3.5 (DO) and 5.0 (BOD), and 1.6 (DO) and 26.0 (BOD), respectively (Sithichaikaset, 1987). A BOD value of 26.0 mg/L in the effluent is substantially higher than the standard maximum value of 20.0 mg/L for industrial waste water control.

A study of water quality of inflow and outflow at six trout hatcheries in the United States indicated that fish cultural activities caused a progressive degradation of water quality, i.e., high BOD in the effluent, in both the hatchery system and the receiving water (Hinshaw, 1973). A survey of effluents from intensive fish farm in 15 European countries by EIFAC indicated a significant increase of the concentration of BOD and chemical oxygen demand (COD) and a reduction in DO and pH (Albaster, 1982) as compared to the inflowing water. Water passing through trout raceways increased in BOD (64%), ammonia (64%), and nitrate (77%) (Liao, 1970a,b; Querellou, 1982). Estimates of pollution loadings from Norwegian fish farms indicated that the concentrations of organic matter (BOD, COD), suspended solids, and nutrients

increased when water passed through the fish tanks and ponds. Although aquaculture effluents have high concentrations of potential pollutants, environmental effects depend largely upon the extent of dilution of effluents by the receiving water. In estuaries and coastal areas, the extent of dilution will depend upon river discharge, which is seasonal, and tidal action.

The ultimate goal of water quality research in shrimp farming is to improve pond management, attain more efficient production, and alleviate problems with effluents. However, to achieve this goal, more information is required about water quality dynamics in ponds. The main objectives of this research were to monitor and characterize water quality parameters in shrimp ponds and to determine the impacts of shrimp culture operations on these parameters. This effort was especially important in the Songkhla Basin where shrimp farming has just recently been initiated, and little information on water quality is available. Information obtained from this study can be used by the shrimp industry and the government to develop guidelines for pond management practices and environmental protection.

CHAPTER II

DESCRIPTION OF STUDY AREA

Fifteen existing intensive shrimp culture ponds along the coastal areas of the Songkhla Basin were provided by private industry for the study; ponds were available for water quality studies during one 5-month grow-out period. These 15 ponds were located on four different farms between Songkhla and Nakhonsrithamrat Provinces (Fig. 1):

Ponds 1-5 : Aquastar Company Farm (AQC)

Ponds 6-9 : Aquastar Farmer Project Farm (AQF)

Ponds 10-11: Siam Taksin Farm (STS)

Ponds 12-15: Dr. Teerawat Farm (TRW)

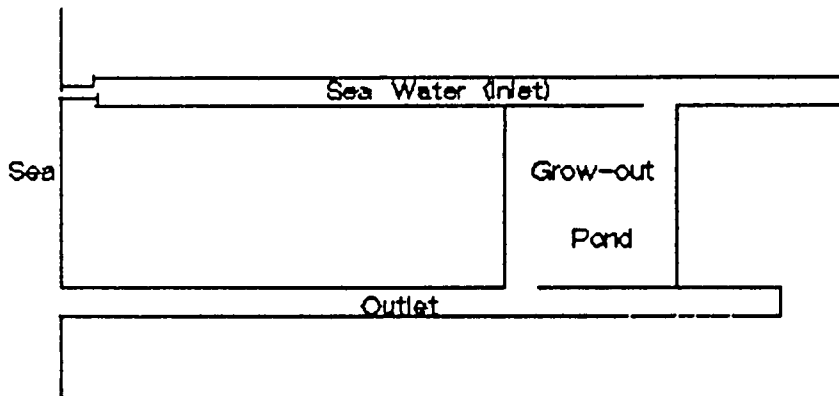
The Aquastar Company Farm and Aquastar Farmer Project Farm are about 1 km from each other while the other two farms are located 25 km away and adjacent to each other. The nine study ponds in the AQC and AQF farms were very similar in size and pattern of pond layout. Their water supply canals (inlets) and pond discharges also had a similar arrangement. These two farms were closer to the sea than the STS and TRW farms so that their water supply could be pumped directly to water holding ponds and the supply canal (Fig. 2).

The other six study ponds in Siam Taksin and Teerawat farms varied in size, pond layout pattern, and



Figure 1. Map of Thailand and location of the study area.

AQC AND AQF FARMS



STS AND TRW FARMS

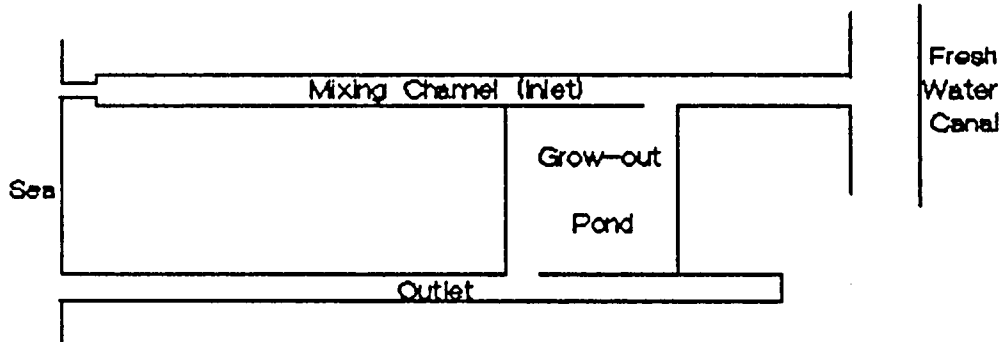


Figure 2. Water supply schematic for four shrimp farms.

water system. They were located on the opposite side of the highway away from the sea; thus, there was a greater distance to pump the sea water supply. However, they were located adjacent to the freshwater canal which was used as a source of freshwater in the mixing water supply canal (Fig. 2). Each of the 15 study ponds had one inlet and one discharge location.

The locations of all the study farms were such that water was pumped directly from the sea eliminating the use of the intertidal canal for their supply. In addition, each had a reservoir for sea water which enabled water exchange to be performed at the rates and times as needed.

CHAPTER III

METHODS

Water Sample Collection and Preparation

The initial water sample for each pond from the 15 selected intensive shrimp culture ponds was taken within one week of the stocking date (Table 1). All ponds were then monitored biweekly during the entire grow-out period which varied among ponds from 4 to 6 months per crop. The first sampling date for the study was on June 5, 1989; data collection ended on December 15, 1989.

Three locations for each pond were designated as water sampling sites:

1. inlet (1)
2. pond middle (2)
3. pond discharge (3)

The number of inlet sampling points differed among farms; AQC(4), AQF(3), STS(1), and TRW(1). This was due to the fact that the selected study ponds in the AQC and AQF farms were not adjacent to each other such that they could be served by a single inlet sampling point; in addition there was more than one inlet canal (Fig. 3). The ponds in the STS and TRW farms were next to each other and the inlet supply required only one sample site (Fig. 4).

Table 1. Physical characteristics and stocking information of 15 shrimp culture ponds.

Pond	Farm	Area (ha) ^a	Date Stocked	Number Stocked	Age ^c PL ^b	Wt ^d
1	AQC	0.9	6/08	250,000	20	1.0
2	AQC	0.9	6/05	270,000	35	1.7
3	AQC	0.9	6/08	250,000	20	1.0
4	AQC	0.9	6/13	193,000	50	4.8
5	AQC	0.9	6/13	193,000	50	4.8
6	AQF	1.0	6/30	200,000	20	0.8
7	AQF	1.0	6/30	200,000	20	0.8
8	AQF	1.0	6/29	200,000	20	0.8
9	AQF	1.0	6/29	200,000	20	0.8
10	STS	0.8	7/21	266,750	25	1.2
11	STS	0.9	7/21	317,000	25	1.2
12	TRW	1.0	8/05	400,000	18	0.7
13	TRW	0.7	8/05	300,000	18	0.7
14	TRW	0.6	8/05	220,000	18	0.7
15	TRW	0.7	8/05	300,000	18	0.7

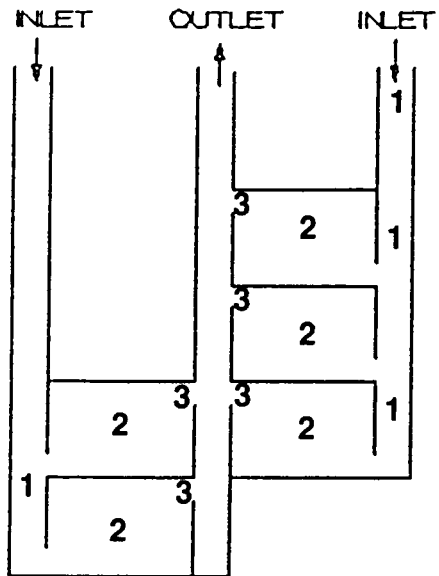
^a 1 ha = 6.25 rai; 1 rai = 1600 m²

^b PL = shrimp post larvae

^c Age = age of post larvae (days)

^d Wt = average initial weight of post larvae (g)

AQC FARM



AQF FARM

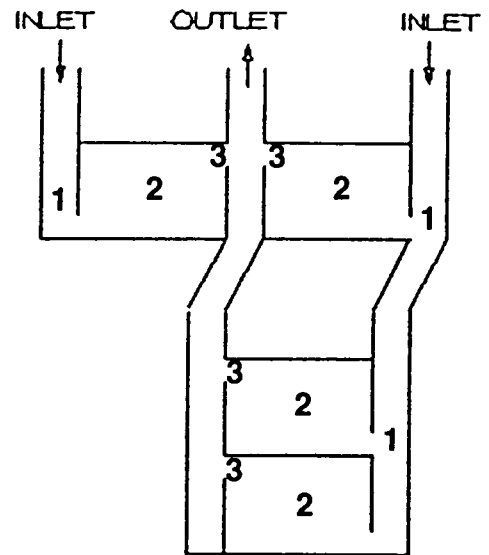
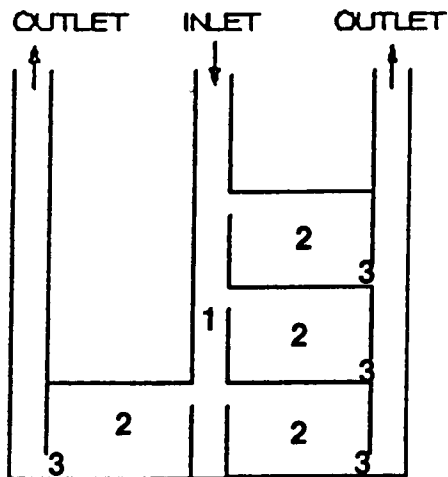


Figure 3. Diagram of sampling sites at AQC and AQF farms: (1) inlet, (2) pond middle, and (3) pond discharge.

TRW FARM



STS FARM

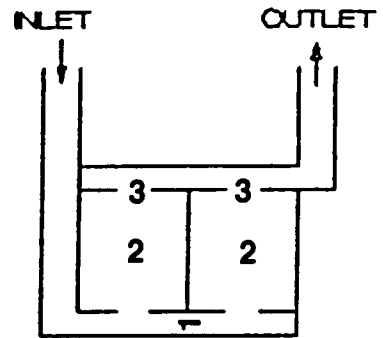


Figure 4. Diagram of sampling sites at TRW and STS farms: (1) inlet, (2) pond middle, and (3) pond discharge.

Water samples were taken at approximately 1000 to 1200 hours on each sampling date and at 15 cm above the mixing channel substrate or the pond bottom with a Kiahara water sampler (Boyd 1979). The following parameters (with identification symbol in parentheses) were measured for each water sample:

- water temperature (WT), C
- air temperature (AT), C
- dissolved oxygen (DO), ppm
- salinity (SAL), ppm
- Secchi disk transparency (TRAN), cm
- pH
- total suspended solids (TSS), g/100 mL
- total ammonia nitrogen (NH₃), ppm
- nitrate (NO₃), ppm
- reactive inorganic phosphate (PO₄), ppm
- biological oxygen demand (BOD), ppm
- chlorophyll a (CHL), ug/L
- plankton abundance/composition.

Data on pond management techniques (stocking, feeding, aeration, and water exchange rates) and shrimp performance (growth, survival, and production) were obtained from the farmers through records for each particular study pond. Generally, the farm management practices in this study include: stocking rate of 20-40

larvae/m²; feeding with commercial pelleted feed (different farms used different feed brands but the general composition was 35-40 % crude protein, 2.7-3.0 % crude lipid, < 3 % cellulose, < 15 % ash, and 12 % moisture) at 3-20 % of shrimp body weight depending on shrimp size (large to small) and 3-6 times/day; number of aerators used increased from 2-8 and operation hours increased from 12-24 hours as the shrimp grew larger; and daily water exchange rates increased from 5-10 to 20-30 % as the grow-out proceeded. In addition, before shrimp larvae were stocked, fertilization [e.g., applications of poultry manure, rice bran, or chemical fertilizer (i.e., 15-15-15 at 12-15 kg/ha)] was usually practiced to induce the growth of plankton which would serve as a natural food for small shrimp. When the water turned brownish-green, the water level was raised to about 80 cm and the pond was ready for stocking.

Shrimp growth measurements were done by the farmers at specific periods through the entire growing period. Cast net sampling was the most common method used to obtain shrimp samples with 4 to 5 samplings per 1.0-ha pond being used at each collection. The measurement obtained was the average weight of shrimp (g) at that period. The time period of measurement varied somewhat among the study ponds due to different management schemes. For all ponds, the initial growth measurement

was taken at 30 culture days; the next measurements were done at 15-day intervals for ponds 1-9, at 10-day intervals for ponds 10 and 11, and once every one or two weeks for ponds 12-15 until harvest. The amount of feed used for each pond was also recorded to determine the adjusted feeding rates.

Water and air temperature, pH, DO, transparency, and salinity (Table 2) were recorded at each sampling location (in the field). Measurements for the remaining parameters were completed at the laboratory within one week; samples were stored in the refrigerator at 4 C until analyzed.

Plankton collection was done by using a 50-micron mesh plankton net. A sample of 30 liters of water from three locations along a transect in the pond was collected by a bucket and filtered through the net. Each sample was kept refrigerated at 4 C until it was preserved with 10% formalin in the laboratory. The contents of these samples were later identified and quantified by using the APHA Standard Methods (1985).

All water quality analyses followed methods described in "Standard Methods for the Examination of Water and Wastewater", 1985, 16th ed., APHA, AWWA, and WPCF, Washington, D.C., USA. or "Methods of Seawater Analysis", 1983, 2nd ed., K. Grasshof, M. Ehrhardt, and K. Kremling, eds., Verlag-Chemie, Weinheim. In addition,

specific tests were taken from "A Practical Handbook of Seawater Analysis", 1972, J.D.H. Strickland, and T.R. Parsons. Laboratory equipment was periodically calibrated to ensure precision and accuracy according to the standard methods. More details on analytical techniques are provided in Table 2.

Statistical Analyses

Water quality data from inlet, pond water, and pond discharge for each pond (Appendix A) were evaluated to determine any changes brought about by the shrimp operation. All data were analyzed using procedures available in PCSAS (SAS Institute, 1987). The specific procedures used in each analysis are detailed in the following sections. Lotus Freelance Plus (Lotus Development Corporation, 1989) software programs were also used for all of the graphics.

Variations of Study Area and Collection Data

There were 15 ponds and three water sampling locations used in this study. The number of water quality sampling periods (2-week intervals) ranged from 8 to 13 depending on the different farm grow-out periods.

Twelve water quality parameters including chlorophyll a and phytoplankton were measured during the study. For statistical convenience each was given a

Table 2. Sample preparation and analytical procedures for pond water quality parameters.

Test	Procedure	Sample preparation	Analysis time
Temperature	Thermometer	none	immediately
DO	DO meter (YSI Model 57)	none	immediately
Salinity	Salinometer (ATAGOS-28)	none	immediately
Transparency	Secchi disk	none	immediately
pH	pH meter	none	immediately
TSS	Standard Methods (p.96, 1985)	refrigerate	within one week
NH ₃	Grasshoff (1983)	refrigerate	within one week
NO ₃	Strickland/Parson (1973)	refrigerate	within one week
PO ₄	Strickland/Parson (1973)	refrigerate	within one week
BOD	Standard Methods (p.525, 1985)	refrigerate; dilution	within five days
Chlorophyll a	Chuan/Sugahara (in Strickland, 1973)	refrigerate	within one week
Plankton	Standard Methods (1985)	refrigerate; preserve in 10% formalin	within one week

specific symbol that will be used throughout this analysis. These water quality data were classified by farm, pond, location, and period.

Water Exchange

Data on water management for each study pond were provided by the farm managers which included only the daily record of pond water level (cm), water level after withdrawal (cm), and water level after input (cm); actual volumes of water exchange were not provided. Water exchange was done routinely throughout the study period by gravity flow and generally was not simultaneous. The data from the Dr. Teerawat farm (ponds 12,13, 14, and 15) were not available; therefore, the number of ponds used in this analysis was 11.

To examine the changes of water exchange practices over time, the mean values at each 2-week interval of withdrawal and input water levels and net water exchange (cm) from the AQC, AQF, and STS farms were plotted against the periods of water quality data collections at the same period (2-week intervals). These plots were performed by Lotus Freelance Plus.

Data Testing for Normal Distribution of Residuals of Models

A univariate procedure (SAS, 1987) was used for this particular task to determine whether transformations were

needed before any statistical analyses could be conducted. The procedure was applied to each water quality variable over the total period of water samplings (2 week periods) and separated by farm and pond. Three types of plots (Stem Leaf, Box, and Normal Probability) were included in the procedure to show data distribution.

Differences of Water Quality Data Among Locations

Differences in water quality parameters among the three locations and across the farms, ponds, and periods were tested via GLMM (a computer program that fits a class of general linear mixed models to data). In this analysis, classification variables were pond, location, and period; random effects were pond, pond*location, and pond*period; fixed effects were location, period, and location*period. The response variables were the water quality variables including the minimum, mean, and maximum values. Only 13 ponds were used in the analysis. Ponds 4 and 5 were excluded.

Changes of Water Quality Over Time

Mean values of each water quality parameter at each sampling period for all 15 ponds were plotted against the number of water sampling periods in each farm throughout the growing period by using Lotus Freelance Plus computer software. Data on plankton abundance and chlorophyll a

concentrations were treated similarly. In addition, correlation analysis (Pearson Correlation Coefficient) was applied to all water quality parameters via SAS.

Shrimp growth

Mean body weights of shrimp in all 15 ponds, obtained from each specific growth measurement period in each pond, were used to plot against days of culture to determine the growth curves. These plots were performed and separated by farm by Lotus Freelance Plus. The averages of mean body weight of shrimp in each farm were also plotted against the specific days of culture at 30, 60, 90, and approximately 120 days to compare growth of shrimp at each study farm.

Impacts of Water Quality Changes on Shrimp Performance: Feed Efficiency

Feed efficiency was used to determine the production efficiency of each pond. This parameter was derived as follows:

$$\begin{array}{lcl} \text{Feed efficiency} & = & \text{Total amount of feed (kg)} \\ \text{(FEDEFF)} & & \text{-----} \\ & & \text{Total production (kg)} \end{array}$$

To determine the relationships between water quality parameters and feed efficiency, the stepwise statistical procedure called Maximum R² Improvement (MAXR) has been employed. It is an automated procedure to select a

suitable subset of the independent variables for any particular data. For any given number of independent variables (such as water quality parameters), MAXR will provide the subset whose estimated equation produces the best fit, that is, the subset whose estimated equation produces the minimum residual sum of squares or, equivalently, the maximum coefficient of determination, R^2 .

The number of water quality parameters used in the MAXR procedure was determined under two different conditions:

a. Biological Basis

The considered variables were those that were assumed to have the most biological importance in shrimp performance. They were BOD, DO, SAL, and StRate. Although stocking rate (StRate) was not a water quality parameter, it was considered to be equally important. MAXR was used in the initial analysis using these four variables. Other variables (i.e., pH, NH_3 , and CHL) which were also presumed to be biologically important were added to complete the analysis.

b. Non-Biological Basis

All water quality variables were used in the MAXR analysis. Each variable was randomly entered into the model and the procedure would select the variable that best fit the model.

Impacts of Water Exchange on Water Quality

The General Linear Model (GLM) was used to test the effects of water exchange in terms of net changes (DELTA) on water quality at four different periods during the grow-out season. The independent variables for the model were as follows:

DELTA = the difference between the previous water level (cm) at the beginning of the period and at the end of the period.

PERIOD = an interval of 28 culture days. Four periods (28, 56, 84, and 112) were selected to correspond with the periods (2-week intervals) of water quality data collection.

DELTA*PERIOD = interaction term of both effects.

The parameters included in the analysis were WT, TRAN, LSAL, LDO, LBOD, NO₃, NH₃, PO₄, pH, and TSS. The value of each parameter was averaged over each specific period. CHL was not used because data were not collected until later in the growing season. The number of ponds used in this analysis was 11 (see water exchange, p. 23).

CHAPTER IV

RESULTS AND DISCUSSION

Relevant information on the stocking rate, sampling frequency, and records of all study ponds is presented in Table 3. These data were used throughout the statistical analyses, particularly stocking rate (StRate), total amount of feed (TotFed), total shrimp production (TotProd), and yield.

The numbers of ponds and water samples used in each analysis varied. Fifteen ponds were used when all water quality parameters throughout the grow-out period were evaluated; only 13 ponds (excluding pond 4 and 5) were used where the analysis involved any feeding data because of the different feeding regimes of ponds 4 and 5 (see growth and feed efficiency). Only 11 ponds were used when water exchange practices were examined because there were no water exchange data available from the Dr. Teerawat farm (ponds 12, 13, 14, and 15).

The number of water sampling periods (2-week intervals) varied from 9 to 13 according to differences in pond management (i.e., length of grow-out period). For the purpose of the analysis of all water quality parameters across the farms and ponds, only nine sample periods (approximately 18 weeks) were used for the

Table 3. Stocking rates, sampling frequency, and production records for shrimp culture ponds.

Pond No.	Area (ha)	StRate ^a	No.of Samples ^b	TotFed ^c	HarvWt ^d	TotProd ^e	Yield ^f
1	0.9	28	10	9004.3	30.3	4704.0	5345.5
2	0.9	31	10	10586.5	26.3	4507.4	5122.1
3	0.9	28	10	8010.0	32.3	3055.3	3471.9
4	0.9	22	8	7706.5	30.3	2316.8	2638.7
5	0.9	22	10	8969.0	32.3	1901.1	2165.3
6	1.0	20	13	8640.0	32.9	4514.8	4514.8
7	1.0	20	13	8110.0	28.4	4607.1	4607.1
8	1.0	20	13	9166.7	31.4	5164.4	5164.4
9	1.0	20	13	8611.9	28.9	4997.5	4997.5
10	0.8	35	10	7856.2	33.3	5130.0	6750.0
11	0.9	36	10	9441.8	33.3	6633.0	7537.5
12	1.0	40	9	13321.5	25.6	9086.0	9086.0
13	0.7	40	9	17024.5	25.0	6298.3	8488.3
14	0.6	37	9	11695.1	27.0	5079.0	9285.2
15	0.7	43	9	10712.2	25.0	7248.0	10384.0

^a stocking rate (number of shrimp larvae per m²)

^b total number of water sampling dates

^c total amount of feed used for the grow-out period (kg)

^d average weight of shrimp at harvest (g)

^e total shrimp production (kg)

^f average production per unit area (kg/ha)

comparisons. However, all data were used in other specific analyses.

Water Exchange

Water exchange is an important pond management practice in intensive shrimp culture systems in which shrimp are reared in a high stocking density and given supplemental feed. In order to prevent water quality deterioration in the ponds, frequent water replacement is needed.

In general, during the first month of shrimp larvae stocking, the water level was maintained at a predetermined level (e.g., the average depth from all study ponds was between 80-90 cm) with no water exchange. This permitted a moderate plankton community to develop, which was necessary as food source for small shrimp. Results of the plots among the three farms (AQC, AQF, and STS) on mean water withdrawal level (Fig. 5) and mean water input level (Fig. 6) verified this practice; there was little change in levels during the first month.

It is usual practice that in intensive shrimp ponds in the second, third, and fourth months the rate of water exchange should continuously increase until it reaches a maximum exchange of about 30-50% daily in the last phase of the grow-out season (Chiang et al., 1989). Overall, water levels are raised to approximately 1.2 to 1.5 m as

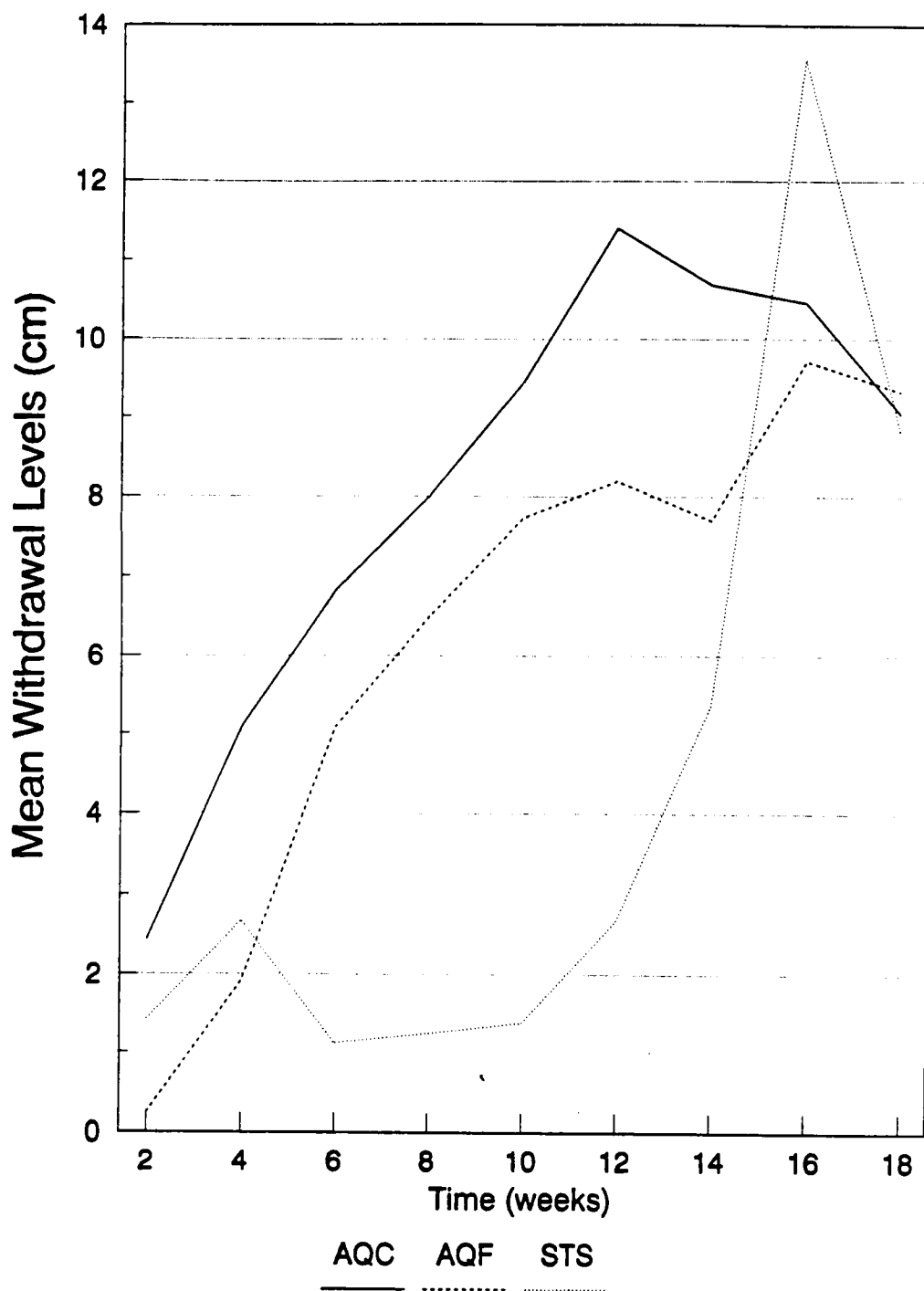


Figure 5. Mean withdrawal levels (cm) of the AQC, AQF, and STS farms during one grow-out period.

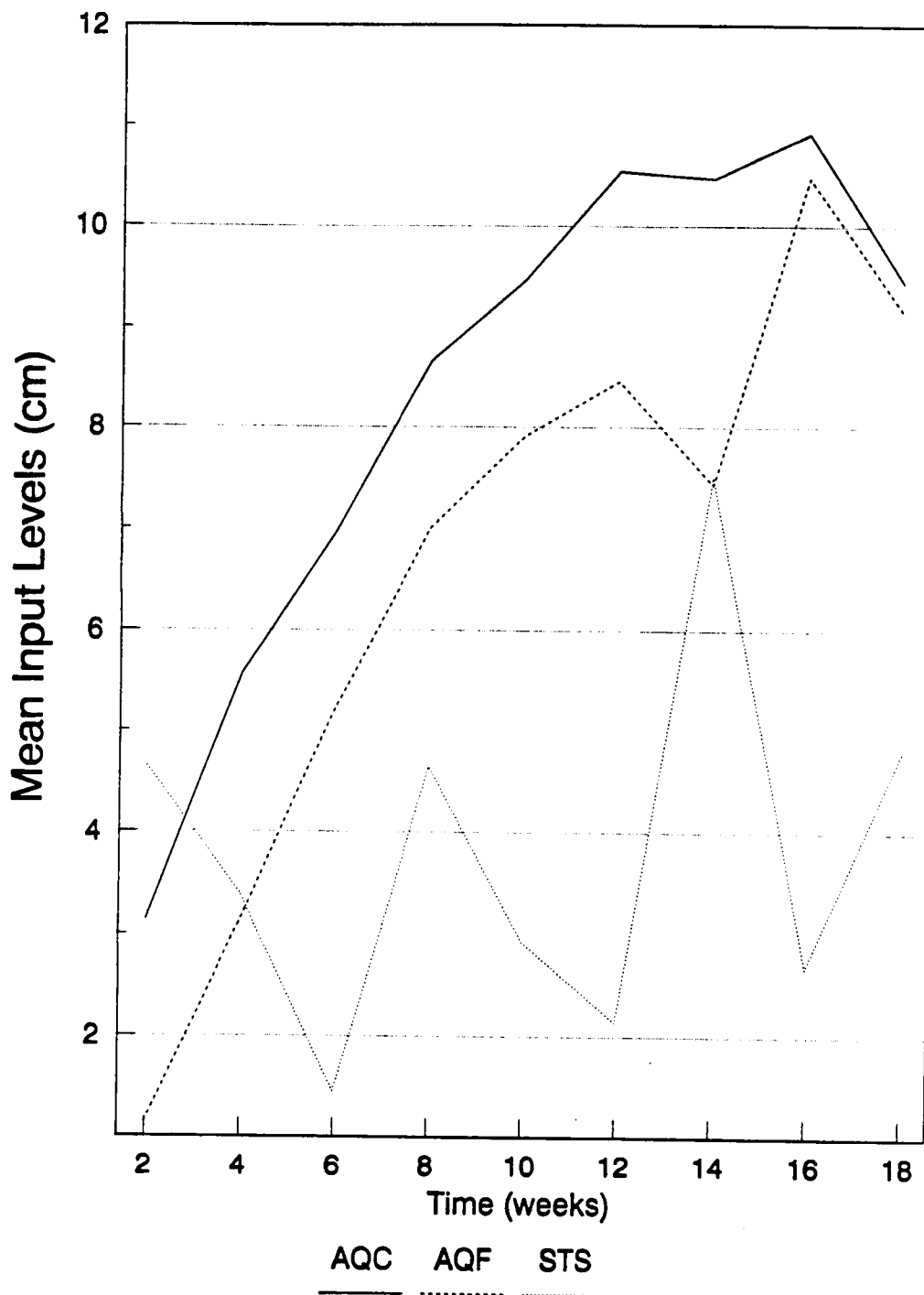


Figure 6. Mean input water levels (cm) of the AQC, AQF, and STS farms during one grow-out period.

the shrimp grow larger. Water at this depth also provides more stable temperature in the pond. Although the results of the plots of net water exchange (DELTA) for the three farms showed little change over time (Fig. 7), the mean values for withdrawal and input water clearly indicate an increasing trend for all the farms (Figs. 5 and 6). This suggests that as the grow-out proceeded, frequent water exchanges were done in all farms which corresponded to the expected pattern of water exchange in intensive shrimp ponds. It was observed that in the Siam Taksin (STS) farm the average of withdrawal water appeared to exceed that of input water, particularly at 16 weeks. From observation, rainfall was very heavy during that period and water levels in ponds 10 and 11 (STS farm) had reached the average of 158.3 cm from the previous average level of 142.4 cm. Accordingly, the farmers may have tried to maintain a suitable pond level by increasing the rate of water withdrawal. The change in water quality at the STS farm during this period was observed in the decrease of average salinity level from 19 to 16 ppt (see salinity, p. 41) during that period.

Seasonal Effects

The study was conducted during the months of June through December, which corresponded with the second crop

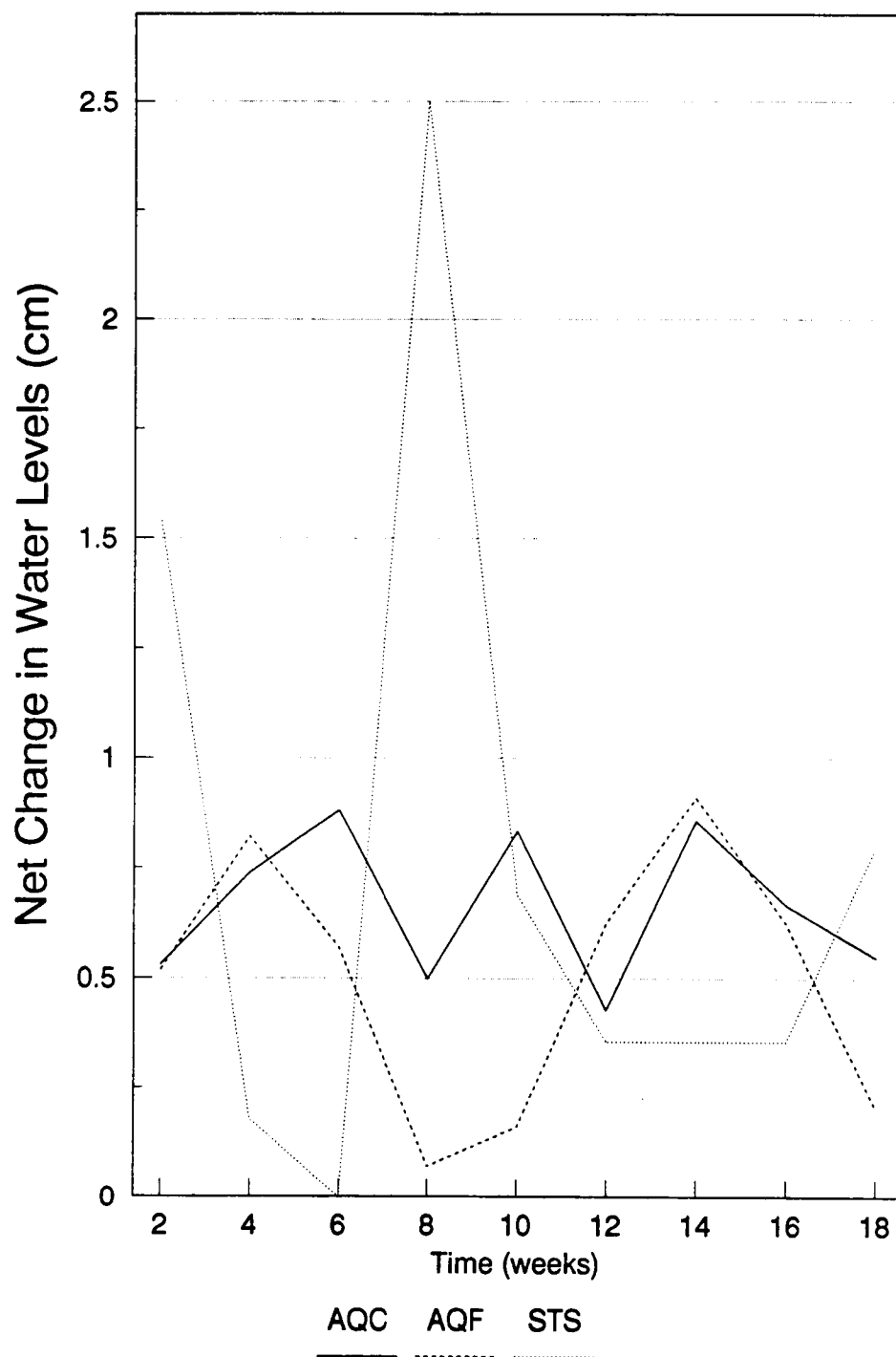


Figure 7. Net change in water levels (cm) of the AQC, AQF, and STS farms during one grow-out period.

production period for shrimp culture in Thailand. During this period in the southern part of Thailand where the study sites were located (Songkhla Basin), the rainy or monsoon season usually begins in October and lasts until January or February. Therefore, the latter part of data collections were done during the rainy season. Consequently, some effects of rainfall on water quality in the study ponds could be expected. The most important water quality parameters most likely to be affected were temperature, salinity, and possibly pH. In case of DO concentrations, heavy rain can cause stratification of water layers in the ponds where the lighter freshwater floats on the top of the more dense salt water and results in oxygen depletion in the lower salt water layer. In this study, no drastic change of DO concentrations was observed due to heavy rains in any study ponds. This could be the result of increased aerator operations or wind action on the pond surface during that period.

Data Testing for Normal Distribution of Residuals of Models

Preliminary analyses (univariate procedure) were conducted to examine the potential problem of heteroscedastic errors (Sokal and Rohle, 1981) in the data. The results of the univariate procedure on water

quality data and the three types of data plot (Stem Leaf, Box, and Normal Probability) suggested that for some response variables (water quality parameters) a log transformation was deemed appropriate to alleviate the problem. Therefore, a logarithmic transformation (common) of three variables, BOD (LBOD), SAL (LSAL), and DO (LDO), were the chosen matrices in subsequent analyses. The log values were converted to antilog wherever the statistical plots were applied to those variables. Other variables were not transformed.

Differences of Water Quality Data Among Locations

In this study it was assumed that the quality of water taken from the water supply source (e.g., inlet) was different (i.e., better) than the quality of water in the pond and at the pond discharge. This, however, was not always the case especially for the shrimp farms that obtained their water supply from the public canal that also served as the discharge canal for upstream culture operations. However, farmers in these farms always make sure that they pump in the supply water when the tide is at its peak; therefore, better water quality would result from tidal dilution.

Water quality parameters from locations 2 and 3 (pond middle and discharge, respectively) were expected to be similar because both locations had been managed

under similar culture practices (feeding, stocking, aeration, etc.) and directly utilized by the cultured animal. In addition, the pond water was expected to be well-mixed because of intensive aeration before being discharged from the pond.

The General Linear Mixed Model (GLMM) was used to examine whether there were differences among the water sample locations. The water quality variables used in the GLMM tests were LBOD (as BOD), LSAL (as SAL), LDO (as DO), NH_3 , pH, and CHL. The number of ponds used was 13 as mentioned earlier; ponds 4 and 5 were not included in the analysis due to a different feeding regime. It was felt that the different feeding practice would influence water quality parameters to such a degree that results could not be compared.

The results of GLMM tests are summarized in Table 4. The P values in the table indicate whether the test was statistically significant or not (at P value = .05) when comparing differences among the locations.

The overall results verified the assumptions. Water quality values from the inlet (location 1) were significantly different from those from the pond middle (location 2) and pond discharge (location 3) with the exception of the variable DO. There were no differences in DO levels at any of the locations; this may be the

Table 4. Results of General Linear Mixed Models (GLMM) on the comparisons of water quality variables, LBOD, LSAL, LDO, NH₃, pH, and CHL from three locations [inlet (1), middle (2), and discharge (3)].

Variables	Means ^a			Contrasts (P value)	
	1	2	3	1 vs. 2 and 3	2 vs. 3
LBOD	1.79	7.24	7.39	.0001*	.6151
LSAL	21.54	23.57	23.57	.0001*	.9149
LDO	7.61	7.69	7.61	.6903	.7526
NH ₃	0.08	0.31	0.32	.0001*	.8921
pH	7.90	8.09	8.09	.0001*	.8362
CHL	16.92	104.45	108.89	.0001*	.7761

*P value < .05

^avalues in ppm for BOD, DO, and NH₃; ppt for SAL; ug/L for CHL

result of aeration practices in the culture ponds, such that the levels of DO were kept as high as the levels in inlet water. The significant differences between location 1 and the average of locations 2 and 3 suggested that the animals themselves and the pond management practices (stocking, feeding, water exchange, etc.) contributed to these differences. As the grow-out proceeded, shrimp grew larger, needed more feed, and produced more waste materials; these cycles of feeding and waste production continued and therefore, residuals were accumulated to the extent that changes of water quality resulted in the ponds regardless of frequent water exchange.

There was no difference between quality of water from pond middle and the pond discharge (Table 4). The results suggested that, for future water quality research, the collection of water samples from both locations may not be necessary. Samples could be collected from either location thereby improving the economic feasibility of the research by reducing labor costs and time spent at study sites.

For this particular study, the location chosen for analyses was location 2 (pond middle) because it is where the shrimp were living throughout the culture period. In addition, it is the place where significant interactions between the shrimp and the water quality parameters

measured were most likely to occur. Therefore, unless otherwise indicated, the subsequent statistical analyses were based on the water quality data from the pond middle sample site.

Changes of Water Quality Over Time

Results of each water quality parameter were based on the analysis of water quality data collected from location 2 (pond middle). It was assumed that shrimp spent most of the time feeding and resting in or on the sediments in the ponds (location 2).

Air temperature (AT) was not addressed because it was obvious that it changed seasonally. However, preliminary data indicated that AT showed a slight decreasing trend toward the end of the growing season (which was the rainy season) in this study.

a. Water Temperature

Water temperature is one of the most important factors for shrimp growth and survival. Metabolic rates of shrimps increase rapidly as the temperature rises. Each species has a temperature range that it can tolerate, and within that range, it has optimal temperature for growth and reproduction. For tiger shrimp, water temperatures higher than 20 C were suitable for their culture while temperatures between 25 and 32 C were considered optimum for their growth (Chiang et al.,

1989; C.P. Group, 1989). Chiang and Group (1989) also reported that shrimp became less active in feeding when water temperatures dropped below 18 C. In this study, the average water temperatures for all ponds were between 25 and 32 C (Fig. 8) which corresponded to the optimal temperature for growing tiger shrimp. However, mean water temperatures for all farms over time decreased slightly toward the end of the grow-out period (Fig. 8). This probably was due to the change of the season from dry to wet (rainy) when temperatures were usually cooler (see seasonal effects, p. 35).

b. Salinity

Penaeus monodon is considered euryhaline because it can tolerate wide fluctuations of salinity. However, its optimum salinity falls within a range of 15-25 ppt (Kungvankij, 1987; Chiang et al, 1989; C.P. Group, 1989; Liao, 1990). In this study the average salinity concentrations of all ponds were between 20-32 ppt during the grow-out periods. The results indicated that the mean salinity levels of AQC and AQF ponds were between 30-35 ppt while those of STS and TRW farms ranged from 16 to 25 ppt. From observations, these differences may be explained by different management practices. The AQC and AQF farms located right on the coast and were designed to use a water supply directly from the sea (i.e., without any dilution or mixing with freshwater).

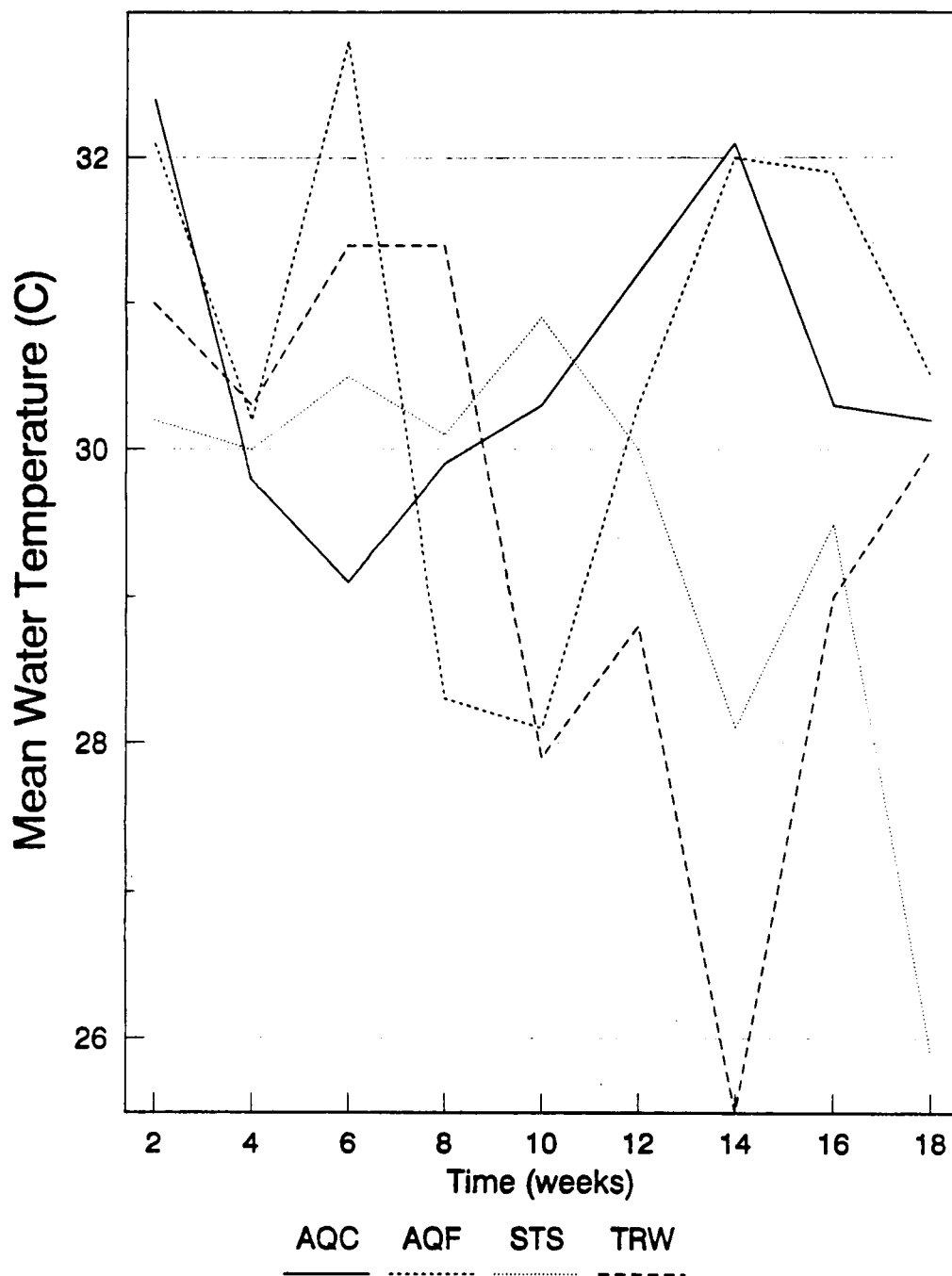


Figure 8. Mean water temperature (C) of the AQC, AQF, STS, and TRW farms during one grow-out period.

In the STS and TRW farms, the water supply was pumped directly from the sea but was mixed with freshwater from the freshwater canal near the farms before entering the ponds. Thus, salinity levels in the ponds were obviously higher than STS and TRW farms.

The plots of mean salinity over time (Fig. 9) in the STS and TRW farms indicated a slight decreasing trend during the third and fourth month of the growing periods. This may be due to rainy season effects. The AQC and AQF farms did not appear to have these effects due to the fact that they may have had more frequent exchange of sea water to the culture ponds. However, the overall range of mean salinity for all ponds fell in the optimal range for shrimp growth; therefore, no drastic problems such as retarded growth or stress mortality were observed during the study period.

When comparing the shrimp production between the two groups, the average production (kg/ha) of STS (7143.8) and TRW (9292.9) was considerably higher than that of AQC (3748.7) and AQF (4821.0) (Table 3). This presumably indicated that tiger shrimp grew better at the intermediate salinity level (i.e., 15-25 ppt) when compared to normal sea water (i.e., 30-35 ppt). However, there is no documentation on the effects of salinity on growth of P. monodon. Additional research is necessary to clarify this relationship.

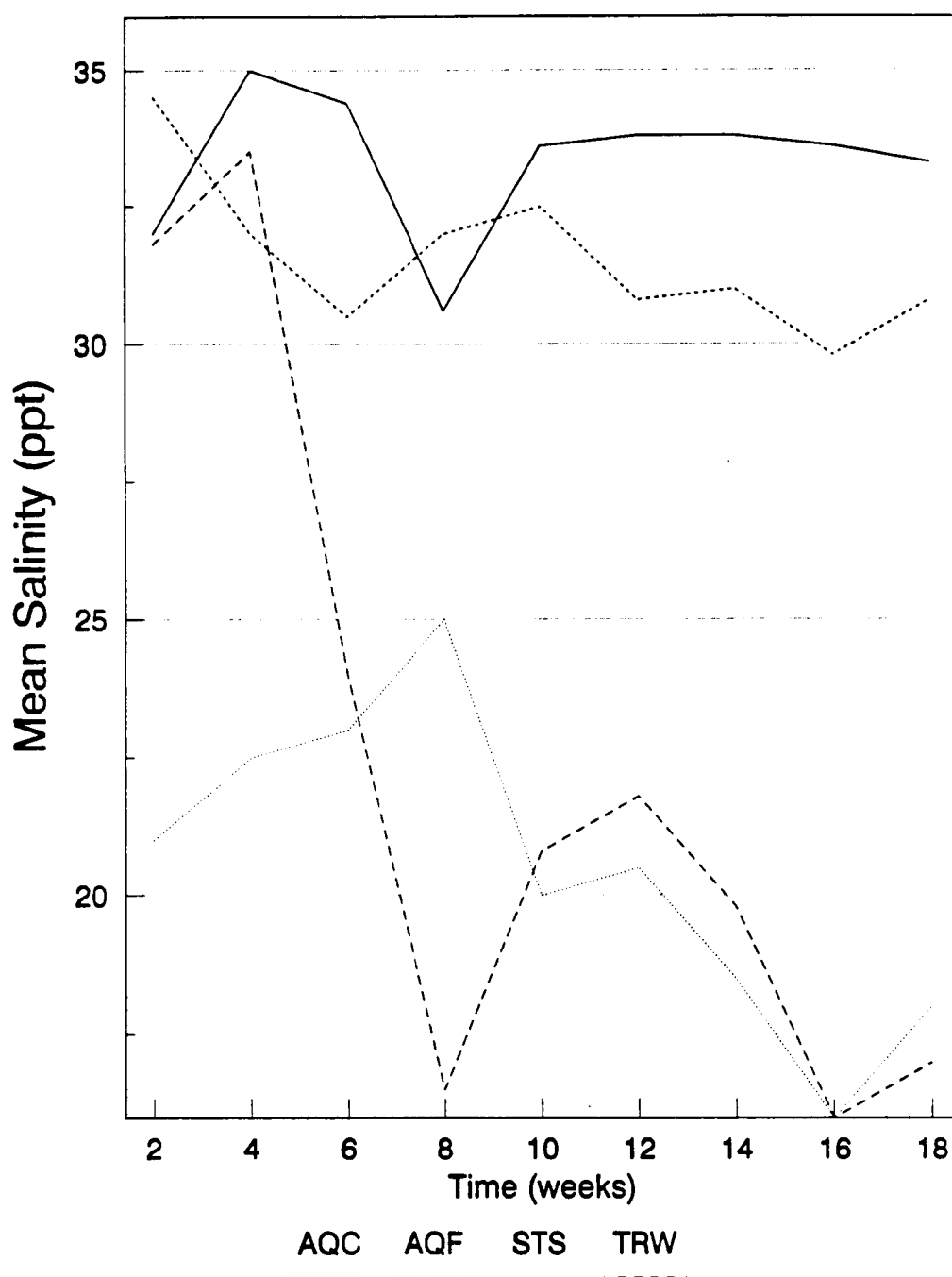


Figure 9. Mean salinity levels (ppt) of the AQC, AQF, STS, and TRW farms during one grow-out period.

c. Transparency

Transparency, or Secchi disk visibility, is the method used to determine the water color and turbidity due to the plankton mass or other particulate matter. Boyd (1979) reported that there was a high correlation between Secchi disk visibility and plankton abundance. In aquaculture ponds, transparency in the 30-60 cm range is considered as the optimal level of plankton (Boyd, 1979; Chiang et al., 1989; C.P. Group, 1989). In this study, the overall range of transparency values was 40-80 cm throughout the growing period. Although the plots of mean transparency from all farms clearly suggested an increasing trend in phytoplankton abundance (Fig. 10), the correlation coefficients between transparency and chlorophyll a concentrations and phytoplankton density were not highly significant ($r = .5232$ and $.3679$, respectively). This suggested that the decreased transparency was not totally due to increased concentrations of chlorophyll a or phytoplankton abundance. The increase in water color and turbidity (as measured by decreased transparency) in shrimp ponds may have also resulted from increased movements by the growing shrimp which stir up the pond bottom that is loaded with excess feed and waste materials. The increase of aerator operations later in the growing

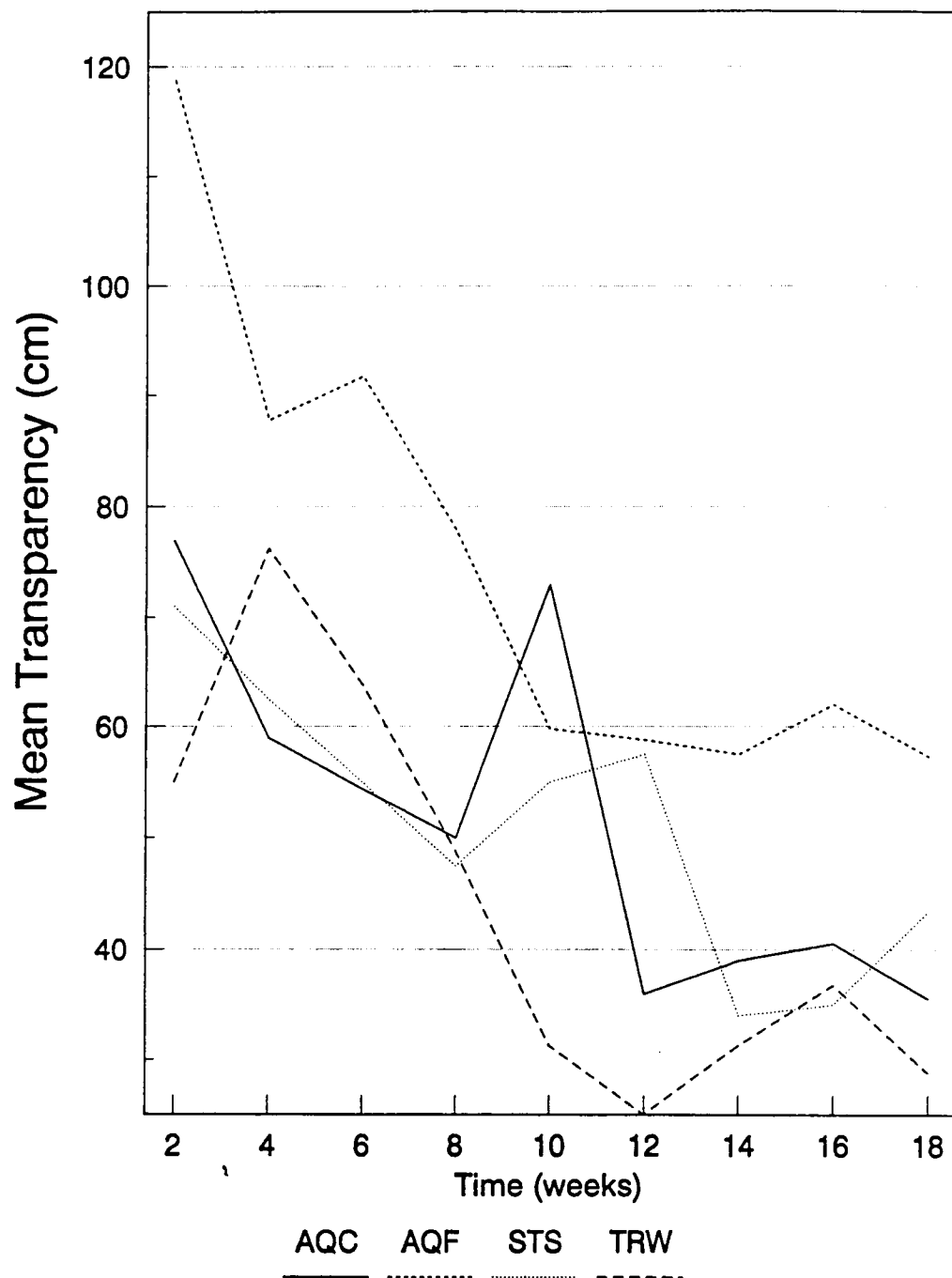


Figure 10. Mean Secchi disk transparency (cm) of the AQC, AQF, STS, and TRW farms during one grow-out period.

season could also contribute to additional water turbidity.

d. pH

The pH, a measure of the hydrogen ion concentration, indicates whether the water is acidic or basic. Phytoplankton and other aquatic vegetation remove carbon dioxide from the water during photosynthesis, thus the pH of water rises during the day and decreases during the night. In intensive shrimp culture ponds where high nutrient concentrations favor phytoplankton growth, a high rate of photosynthesis is expected. This can cause pH levels to fluctuate over a 24-hour period where the pH could be between 6.5-7.0 in the morning and about 9.0 or above in the afternoon (Boyd, 1985). The pH data in this study were collected around noon throughout the study period; the average values from individual ponds range between 7.3-8.8. The plots of mean values for all ponds indicated a clear decreasing trend over time (Fig. 11). Chiang et al. (1989) reported that the optimal pH for P. monodon was between 7.5-9.0 which corresponded to the average values found in this study. Factors which may account for the decrease in pH over time were the increase of plankton densities (p. 62) and chlorophyll a concentrations (p. 69). An increase in number of plankton together with larger size of shrimp in the pond could result in a higher rate of respiration causing

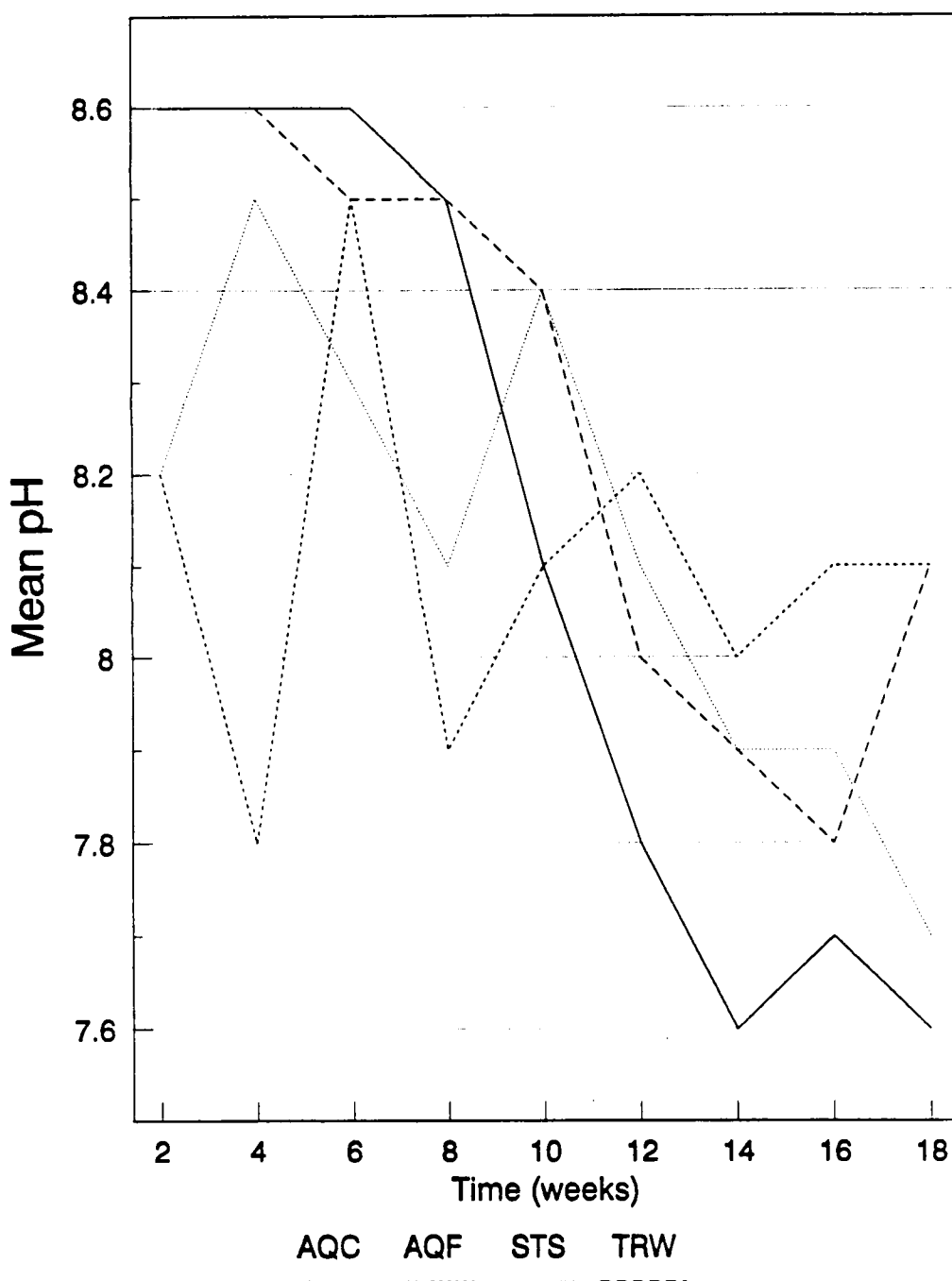


Figure 11. Mean pH levels of the AQC, AQC, STS, and TRW farms during one grow-out period.

more carbon dioxide to be released into the water, thus resulting in a lower pH. Chen and Wang (1990) reported the decrease of pH from 8.8 to 7.4 for P. monodon culture ponds during a growing season but did not discuss reasons for its occurrence.

e. Dissolved Oxygen

Dissolved oxygen (DO) is the most important factor in intensive aquaculture ponds where success or failure in aquatic farming often depends upon the ability of the farmer to cope with problems of low DO. Low DO is one of the most common causes of mortality and growth reduction in shrimp ponds (Boyd, 1987; Tsai, 1989). Tsai (1989) reported that the critical DO level for growth of P. monodon was estimated at 2.2 ppm and the minimum level of DO for optimal shrimp growth was about 4 ppm. It is widely known that the levels of DO in the ponds fluctuate greatly between day and night. Photosynthesis is the major contributor of DO during the day when levels may be very high, but at night when there is no photosynthesis, the high demand for oxygen by shrimp and organic matter (including phytoplankton) may cause nighttime depletion of DO.

For this particular study, DO measurements were taken only during the day. However, the overall mean of DO levels for all ponds ranged between 6 and 10 ppm, which could be considered as sufficient for shrimp

growth. Since the DO data were taken in the morning hours, it was assumed that night time levels did not decrease to stressful levels for the shrimp.

The plots of mean DO levels of all farms showed some fluctuations with a slight increasing trend over time (Fig. 12). The peak of DO at the eighth week of the TRW farm may have been due to the highest plankton density among the farms at that period (see Fig. 18). Several factors may account for the increased DO over the growing periods. The first is that there were increases in phytoplankton density and chlorophyll a concentration over the same period of time (Figs. 18 and 19). The second factor is that during the last phases of the grow-out period, increased aeration was done with paddle-wheel aerators in all the farms; this practice would help in maintaining high DO levels in the ponds. Musig et al. (1989) reported a similar pattern of DO concentrations in shrimp ponds with increasing aeration later in the growing season. The third factor that contributes to relatively high DO concentrations is the increased rate of water exchange. In this study, the DO levels of incoming water remained above 5.0 ppm.

f. Biochemical Oxygen Demand

The biochemical oxygen demand (BOD) is a measure of oxygen required for the biochemical degradation of

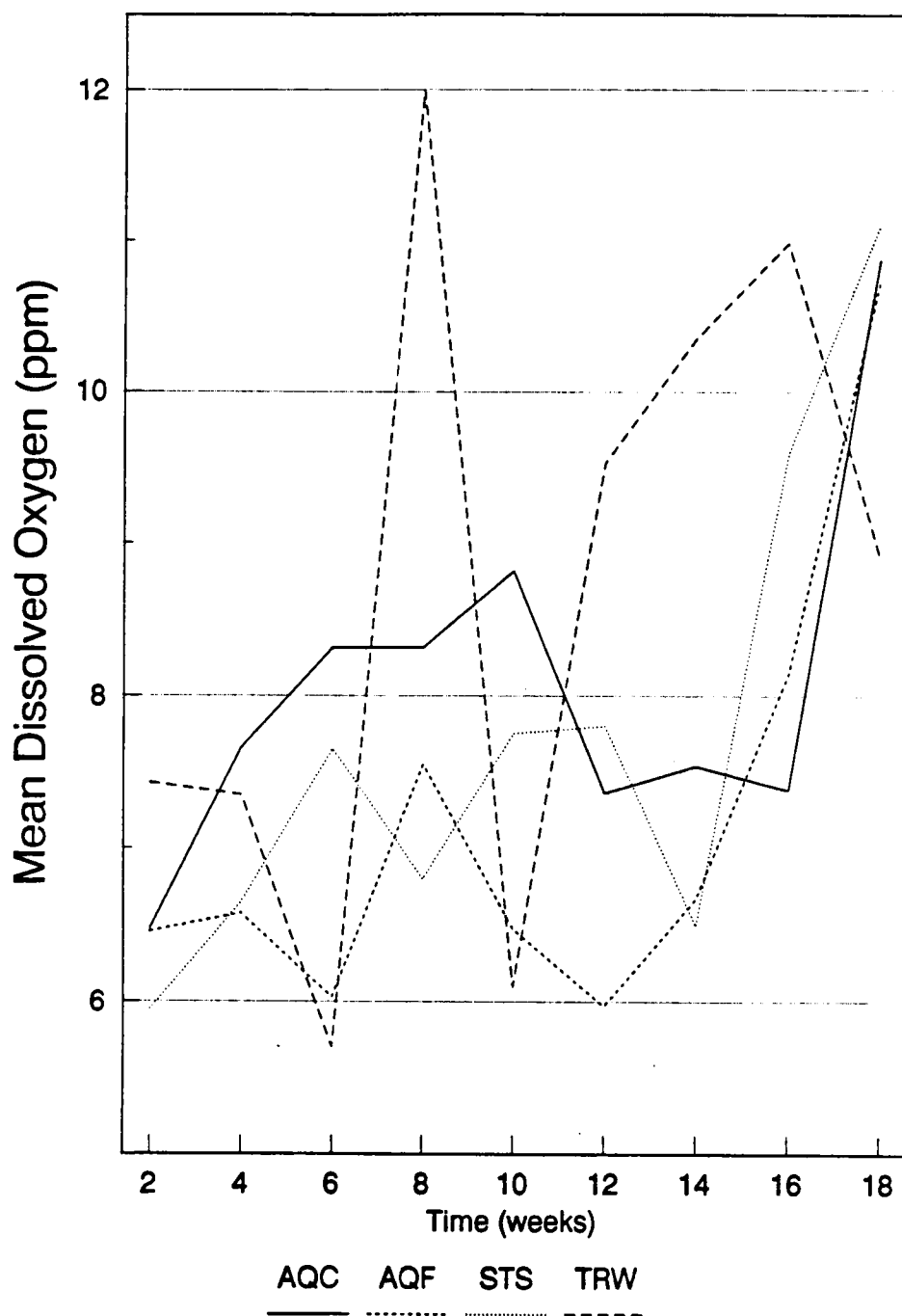


Figure 12. Mean dissolved oxygen levels (ppm) of the AQC, AQF, STS, and TRW farms during one grow-out period.

organic material in a water sample (Standard Methods, 1985). Measuring the decline of DO during incubation (5 days at 20 C in the dark) determines BOD which is a valuable parameter in evaluating the pollution strength of the water. In intensive culture operations, high stocking densities and large quantities of feed can lead to increased BOD levels due to waste materials (i.e., animal excretions, excess feed, etc.) which accumulate in the pond. There is little available research on BOD in intensive shrimp ponds because the main focus of water quality studies is generally concerned with DO, ammonia, pH, and hydrogen sulfide.

In this study, the plots of BOD₅ (BOD at 5 days) concentrations clearly indicated an increasing trend for all farms over the growing period (Fig. 13). The overall mean BOD₅ value for all farms ranged between 2.8 and 12.1 ppm. Other studies of water quality in intensive shrimp ponds in Samutsakorn and Songkhla Provinces indicated similar trends where BOD₅ averaged between 3.1-19.1 ppm for the first study and 0.2-10.5 ppm for the second study (Musig et al., 1989; Predalumpaburt et al. 1989). The increase in BOD₅ clearly indicated that despite the increased water exchange (Figs. 5 and 6), BOD continued to increase over time.

Boyd (1979) studied intensive catfish culture ponds and found that over time chlorophyll a concentrations

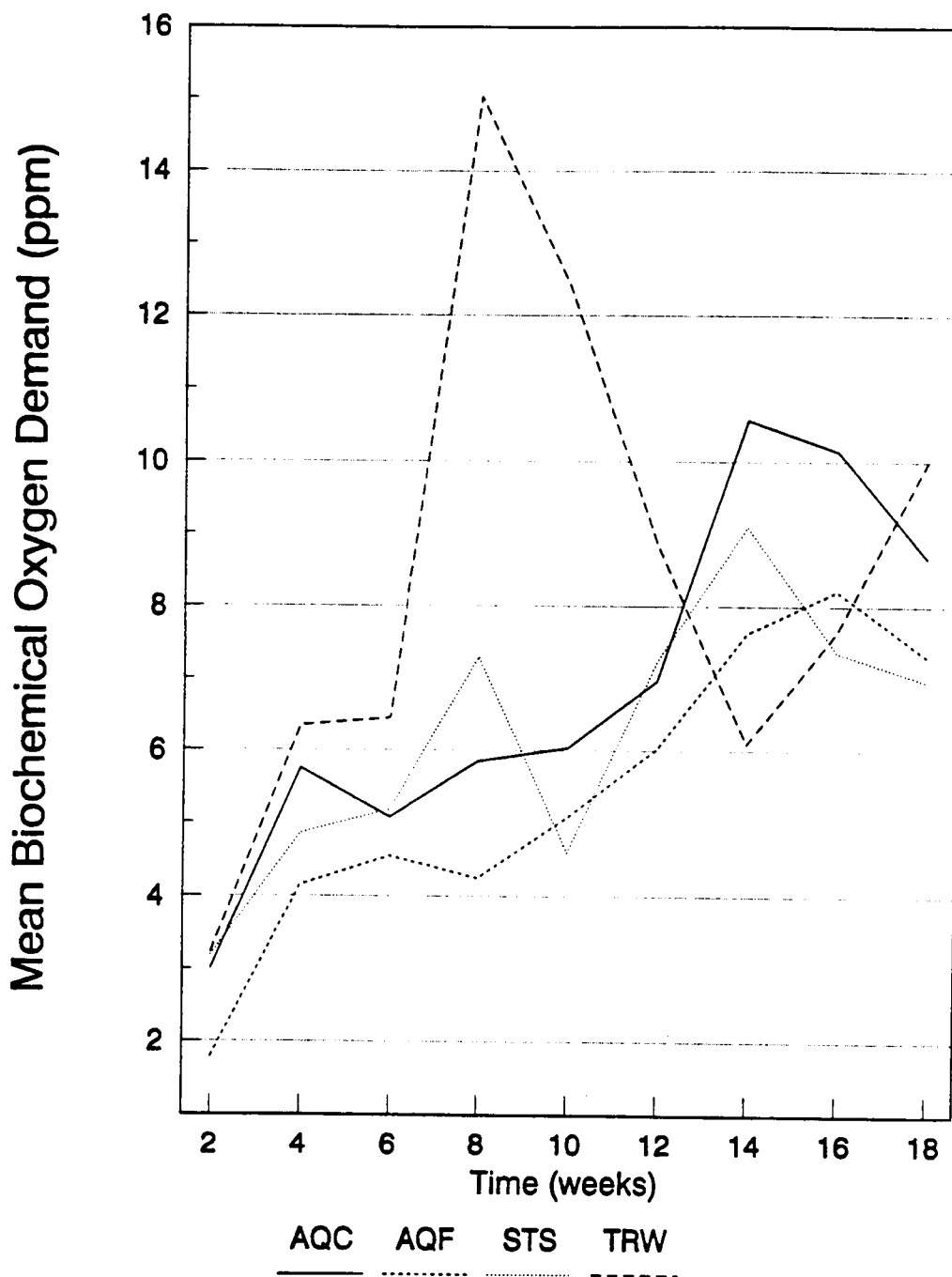


Figure 13. Mean biochemical oxygen demand (ppm) of the AQC, AQF, STS, and TRW farms during one grow-out period.

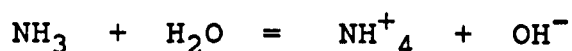
increased to their highest levels when BOD was highest; this verified that phytoplankton (in terms of chlorophyll a) was a major contributing factor to oxygen demand in the pond. In the present study, chlorophyll a levels showed the highest correlation with BOD ($r = 0.6155$) than other parameters; thus, it appeared to be a similar situation to the catfish pond study. Although the impact of BOD on DO level in this study was not clearly identified, the correlation of chlorophyll a and BOD could possibly indicate adverse effects of high BOD on DO dynamics in the pond. In addition, a pond bottom stirred up by shrimp (as mentioned under transparency, p.45) would possibly contribute to increasing BOD levels. High BOD levels suggested a trend of water quality deterioration as growth proceeded in shrimp ponds.

It was observed that there was a drastic increase in BOD at the eighth week of the Teerawat farm (Fig. 13). Because no water exchange data were available from the farm and there was no indication of unusual management practices (i.e., feeding, etc.), this relatively high BOD level was unexplained. However, it was suspected that there was very little or no water exchange during the period.

g. Ammonia Nitrogen

Nitrogenous waste products from protein digestion can accumulate to dangerous levels (as ammonia nitrogen)

in intensive culture ponds. Ammonia nitrogen released by shrimp excretion and bacterial decomposition is either absorbed as a nutrient by algae or oxidized first to nitrite and then to nitrate by aerobic nitrifying bacteria (Boyd, 1982). In intensive culture ponds where supplemental feeds are given, ammonia concentrations can increase to undesirably high levels. In water, Ammonia nitrogen exists in a pH- and temperature-dependent equilibrium with the ammonium ion:



Un-ionized ammonia (NH_3) is highly toxic to shrimp but the ammonium ion (NH_4^+) is relatively nontoxic. The sum of the two ions is called total ammonia nitrogen which is the value that is obtained from the analytical procedure used in this study (Grasshoff, 1973). The proportion of un-ionized ammonia (toxic form) increases as pH and temperature increase (Boyd, 1982). The plots of the average total ammonia of all farms indicated a drastic increase during the last phases of the grow-out period (Fig. 14), particularly in the STS and TRW farms. Chen and Wang (1990) reported a similar increase of ammonia nitrogen from 0.2 to 6.0 ppm in tiger shrimp ponds during one grow-out period. Boyd (1985) suggested that the toxic level for un-ionized ammonia for short term

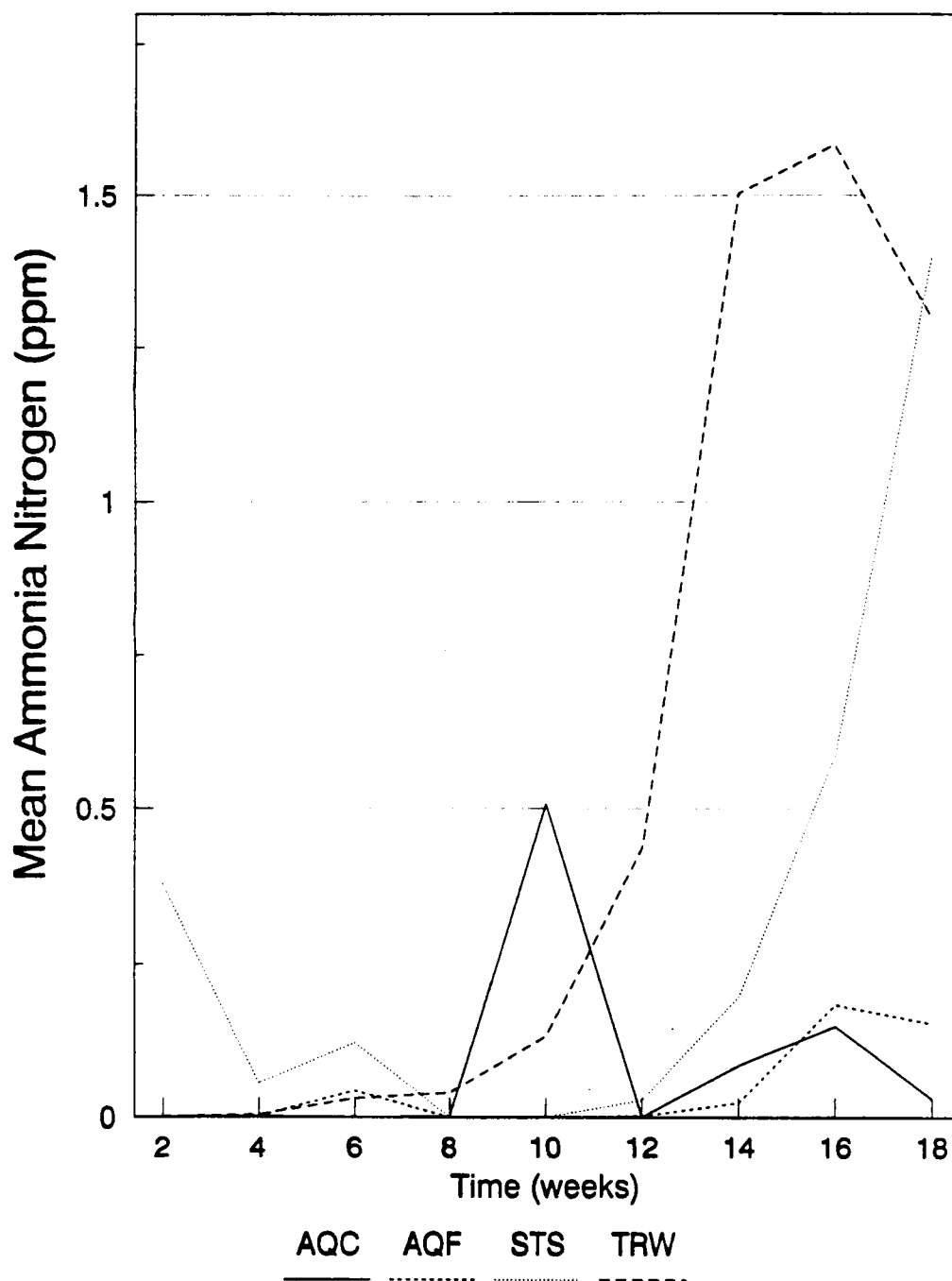


Figure 14. Mean total ammonia nitrogen (ppm) of the AQC, AQF, STS, and TRW farms during one grow-out period.

exposure was between 0.6-2.0 ppm. Although the highest value of total ammonia found in this study was 1.5 ppm (TRW farm), it was not considered toxic to the shrimp because of the low percentage of un-ionized ammonia in the pH range of 7.6-8.6 (Fig. 11) and temperatures of 25-32 C (Fig. 8) (Boyd, 1982). Although it is possible for ammonia toxicity to occur in intensive shrimp ponds, no mortality due to ammonia was observed in the study ponds. In addition, other studies on water quality in shrimp ponds have not suggested that any shrimp die from ammonia toxicity (Musig et al., 1989; Predalumpaburt et al., 1989).

h. Nitrate

Nitrate is the result of the oxidation of ammonia nitrogen to nitrite and then nitrate by nitrification carried out by chemoautotrophic bacteria. For this particular study, preliminary water analyses indicated that little if any nitrite was found in water samples from the study shrimp ponds. This is probably due, in part, to the fact that the nitrification process is most rapid at a pH of 7.0-8.0 and at temperatures of 25-35 C (Boyd, 1979). Thus, nitrite was not included as a water quality parameter to be collected during this study. Predalumpaburt et al. (1989) studied water quality in shrimp ponds from the same area as the present study and

found that very little nitrite (0.000-0.031 ppm) was detected during the grow-out period. These concentrations were much lower than the reported nitrite LC_{50} for shrimp of 8.5-15.4 ppm (Predalumpaburt et al., 1989).

The plots of the mean nitrate concentrations of all farms (Fig. 15) showed some fluctuations over time. However, the magnitude of the fluctuations was very low (.0024-.0800 ppm). Nitrate is not toxic to shrimp unless at very high concentrations.

i. Phosphate

Phosphorus is one of the most important nutrients relative to productivity of aquatic ecosystems, and the supply of this element often regulates natural productivity of the pond water. Orthophosphoric acid (H_3PO_4), which is the simplest form of phosphorus in water, is ionized into various soluble orthophosphate ions (H_2PO_4 , HPO_4 , and PO_4), and those ionic species present in the water depend upon pH (Boyd, 1979). In the range of pH of 7.3-8.8 which was recorded in this study, the dominant ion was likely to be H_2PO_4 . Phosphorus is not toxic to aquatic life but high levels can enhance the rapid growth of plankton which may result in DO depletion when it dies off and subsequently decays. Boyd (1979) found substantial levels of soluble orthophosphate (0.00-0.05 ppm) present in channel catfish ponds during the

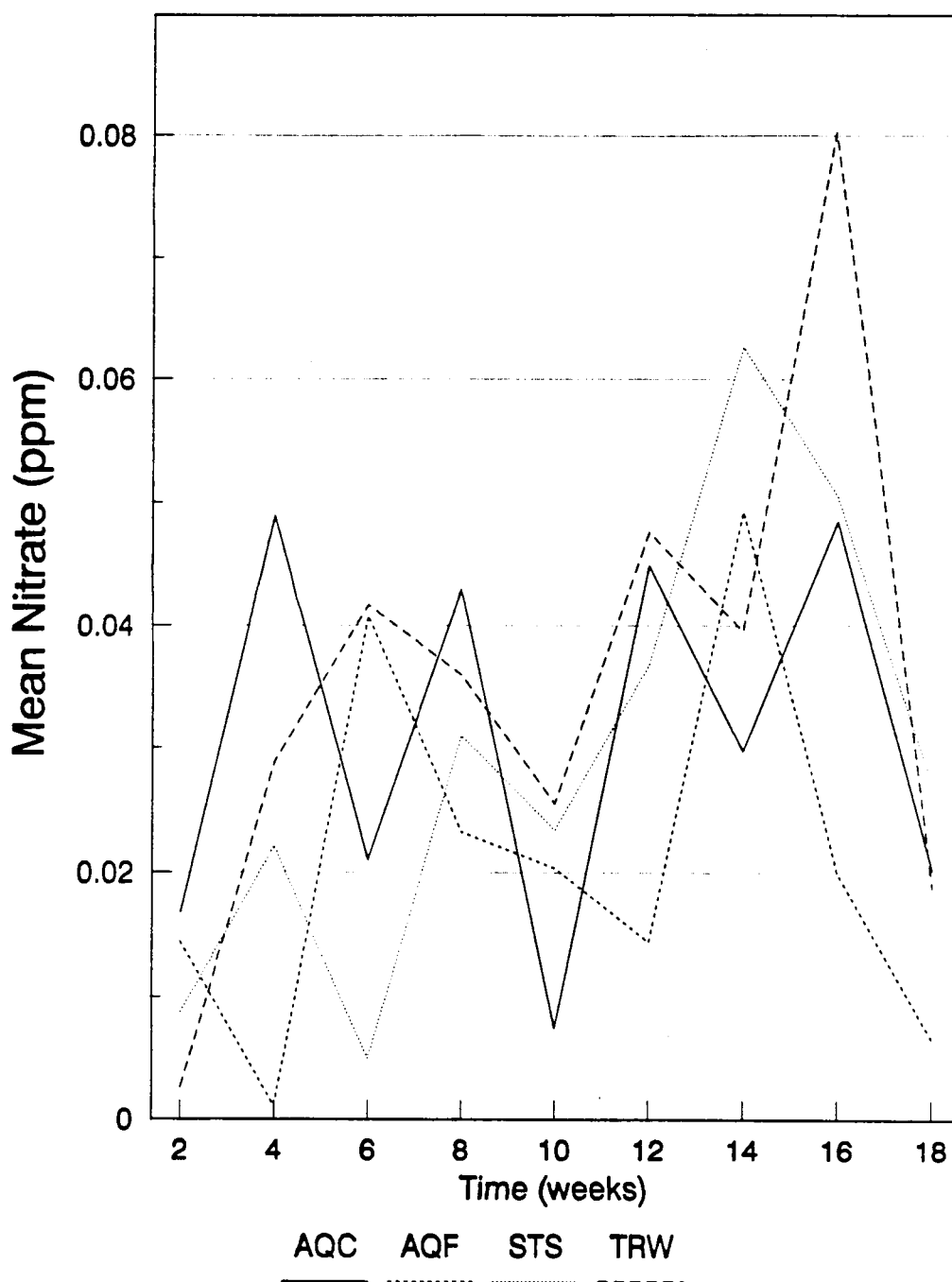


Figure 15. Mean nitrate levels (ppm) of the AQC, AQF, STS, and TRW farms during one grow-out period.

growing season. In the present study, the average levels of orthophosphate were between 0.0022-0.5526 ppm which was slightly higher than in the catfish ponds. The plots of the average orthophosphate concentrations of all farms indicated relatively stable levels throughout the growing period (Fig. 16). The fluctuation during the first month was assumed to be due to fertilization to induce plankton growth for the larval shrimp.

j. Total Suspended Solids

The measurement of total suspended solids (TSS) refers to particulate matter suspended in water or wastewater (Standard Methods, 1985). Except in the intermediate vicinity of aerators, suspended solids entering shrimp ponds settle out rapidly and thus result in accumulation of sediments in the ponds. Shrimp farmers usually spend considerable efforts to remove these sediments. The average TSS concentrations in this study (Fig. 17) varied little throughout the growing period (0.0020-0.0260 g/100mL). Boyd (1987) reported that water supplies for shrimp ponds in Ecuador usually have a heavy load of suspended solids; as a result, sediment ponds were required for almost all Ecuadorian farms. In the present study, data of total suspended solids do not reflect the need for those management practices.

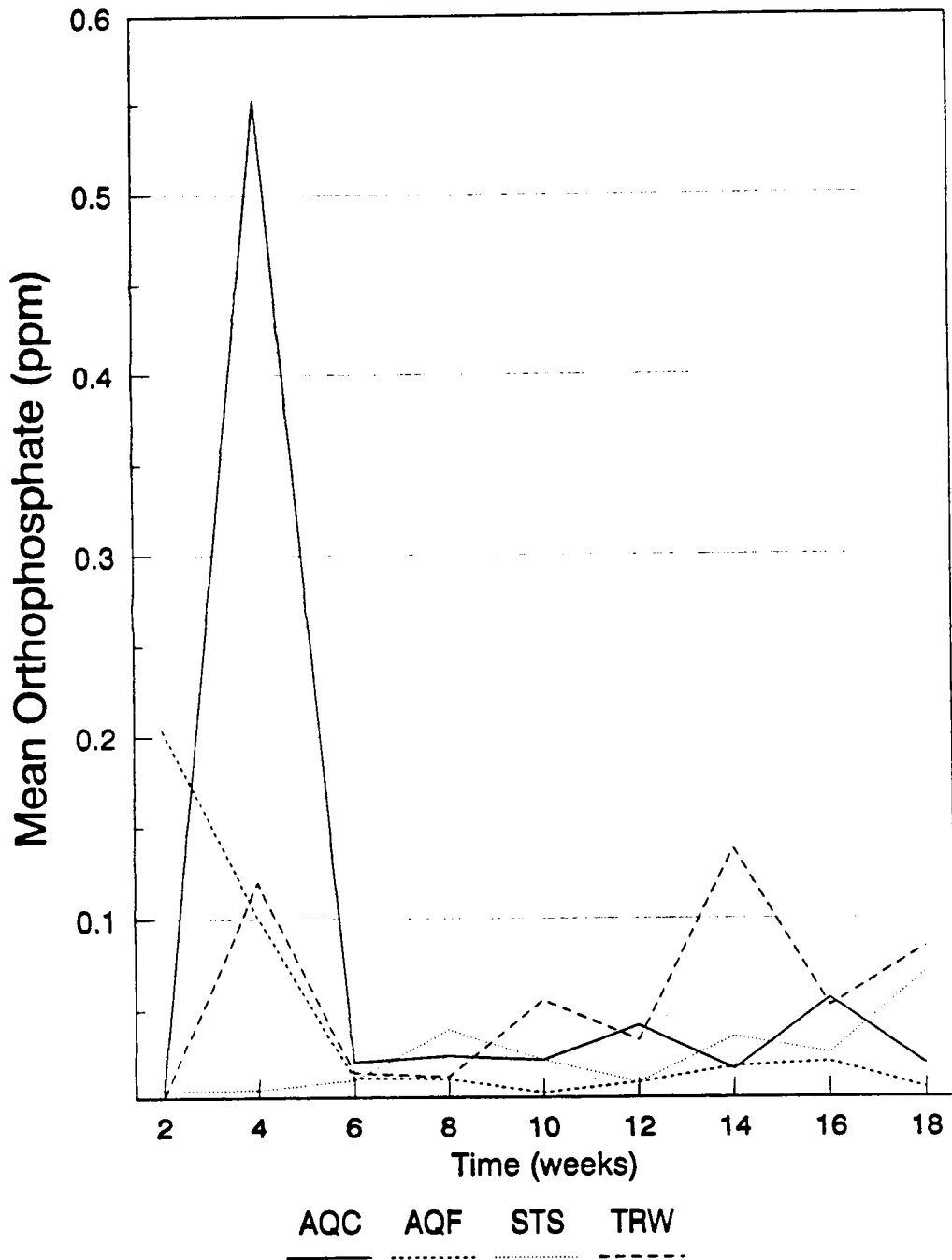


Figure 16. Mean reactive inorganic phosphate (orthophosphate, ppm) of the AQC, AQF, STS, and TRW farms during one grow-out period.

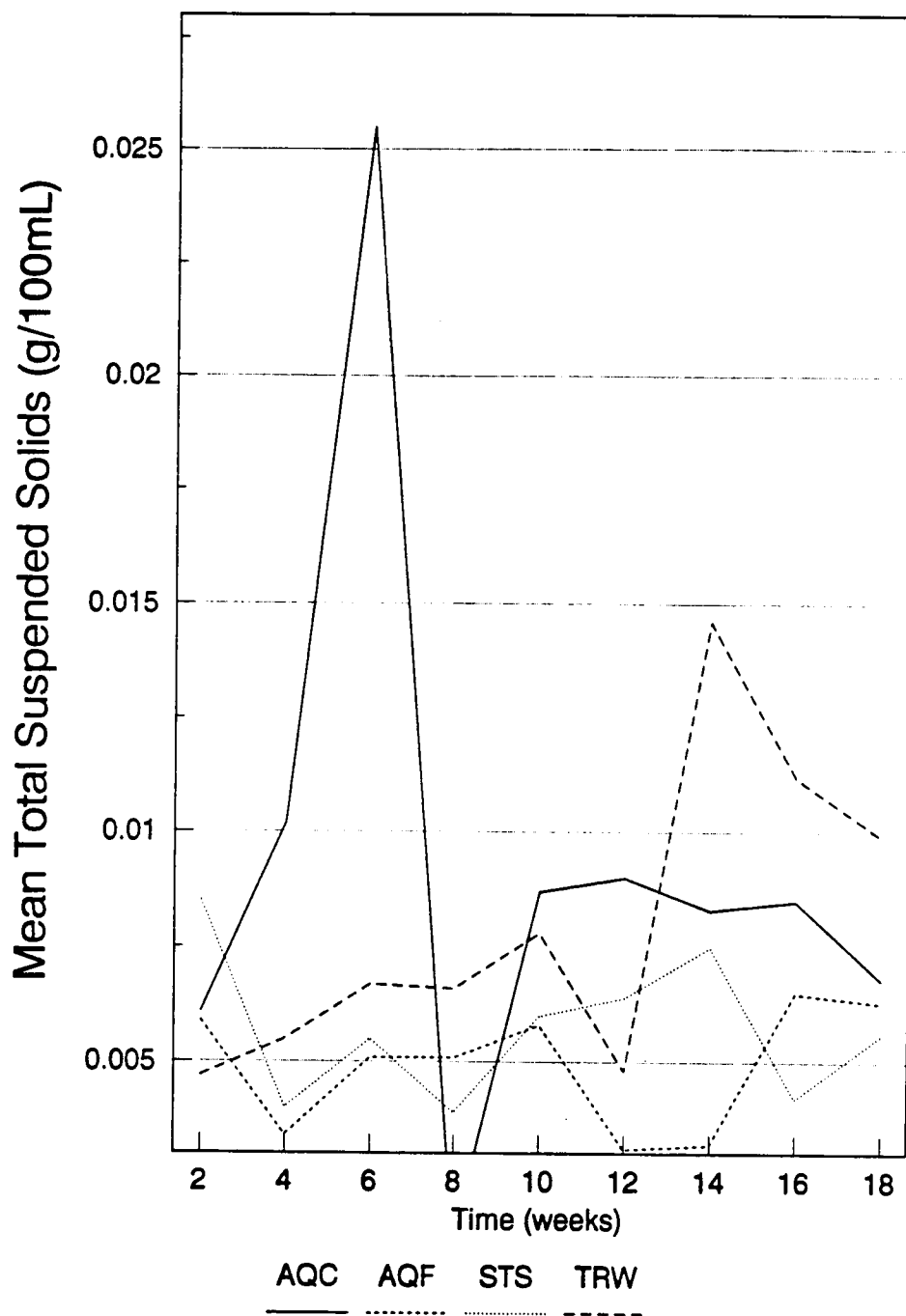


Figure 17. Mean total suspended solids (g/100mL) of the AQC, AQF, STS, and TRW farms during one grow-out period.

Plankton

The plankton community is comprised of all the microscopic organisms which are suspended in water and includes small plants (phytoplankton), small animals (zooplankton), and bacteria. In shrimp ponds, plankton are an important feed for the shrimp larvae (i.e., average weight about 0.50 to 1.50 g) when they are first stocked, and are important as the basis of the food chain which serves as a natural food source for the shrimp. However, in intensively-cultured shrimp ponds, the major source of nutrients is a commercially prepared feed. Large quantities of feed are loaded into the pond so that excess feed, waste materials, and other metabolites become available in large quantities for the rapid growth of plankton (i.e., bloom). The increase in density of plankton, particularly phytoplankton, can cause a large diel fluctuation in DO, CO₂, and pH and can increase the risk of a die-off that would result in rapid DO depletion (Boyd, 1985). It is difficult to maintain low levels of plankton production in intensive shrimp ponds due to supplemental feeding practices; therefore, maintaining moderate plankton production is necessary and perhaps more desirable. An experienced shrimp farm manager can determine the water color and turbidity due to the plankton mass by a simple method called Secchi Disk Visibility (transparency). If the disk is still visible

at depth of 30-50 cm it indicates that the plankton density is optimum (Boyd, 1979, 1985; Chiang et al., 1989).

For this study, phytoplankton densities for each water sample were examined in conjunction with the results of chlorophyll a concentrations, transparency, and other water quality parameters (i.e., DO, BOD, etc.). The average phytoplankton densities of each farm indicated an increasing trend in numbers over the grow-out period for most of the farms (Fig. 18). The slight fluctuations during the period were due to the fact that plankton communities were constantly changing in species composition and in total abundance over time. However, the overall increasing trend over time was expected because of the accumulation of unused feed, waste materials, and other metabolites that enhanced phytoplankton growth.

The plankton species composition in water samples from shrimp ponds fluctuated widely in both abundance and frequency of occurrence throughout the study period. A total of 45 species of phytoplankton and 12 species of zooplankton was found (Appendix B). The total number of phytoplankton species in each water sample ranged from 2 to 15 (2 to 7 species for zooplankton). Preliminary data indicated that approximately 70 to 90% of the total

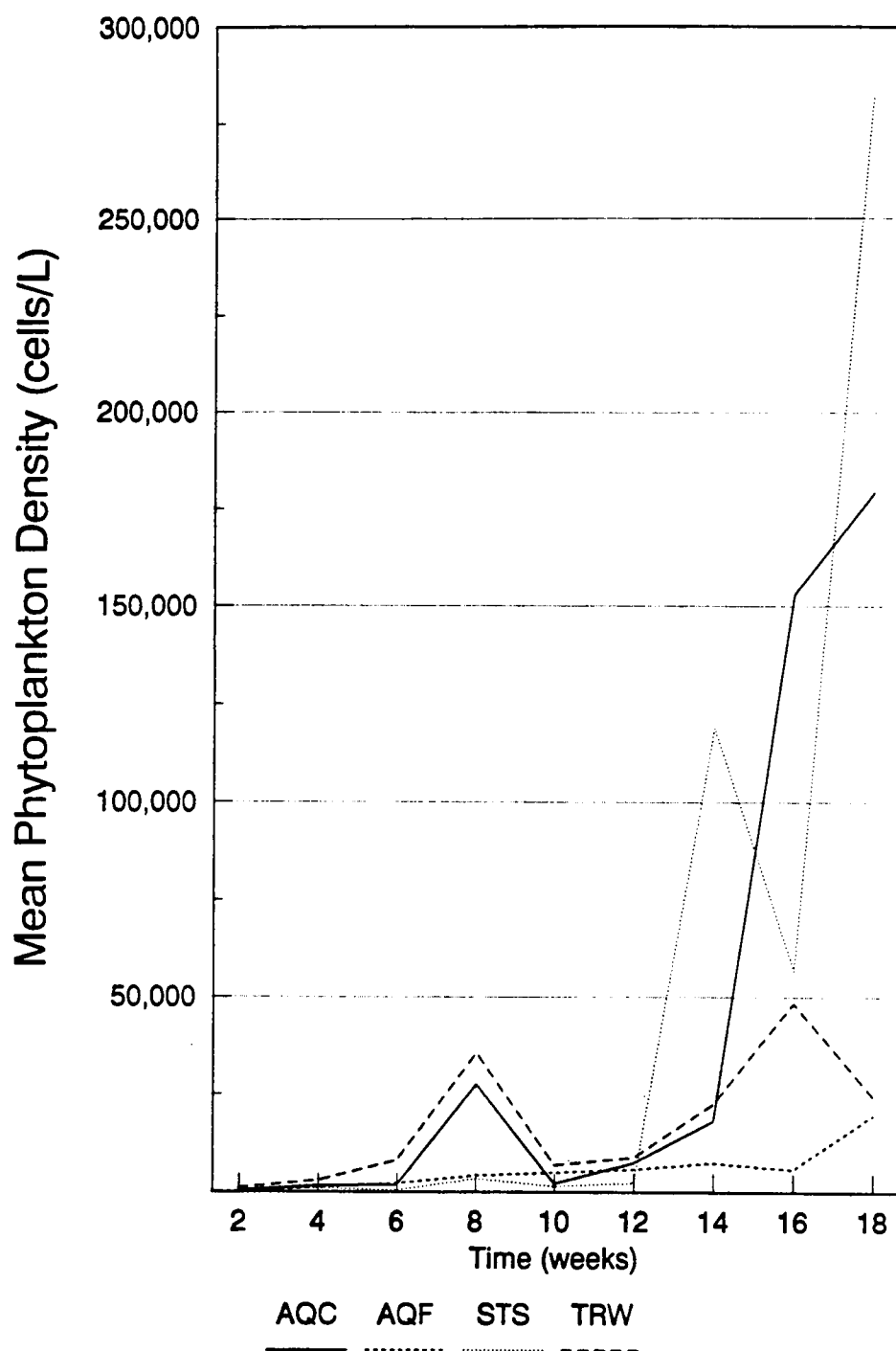


Figure 18. Mean phytoplankton density (cells/L) of the AQC, AQF, STS, and TRW farms during one grow-out period.

number of organisms in each sample was comprised of only 3-5 species. Therefore, for the purpose of this analysis, only five (or less) of the most abundant species from each water sample in each pond were considered in the determinations of relative frequency and relative abundance of the plankton (Table 5).

In the phytoplankton communities, a blue-green algae Oscillatoria sp. and a group of attached diatoms collectively called "pennate" (Navicular sp., Gyrosigma sp., Pleurosigma sp., Cambella sp., and Synnedra sp.) were the dominant groups in all ponds throughout the study period. While Oscillatoria sp. was always dominant and numbers remained relatively stable, the "pennate" diatoms were more stable in their frequency of occurrence than numbers (ranked third in relative abundance). Aside from the two dominant phytoplankton groups, periodic blooms of several other algae were observed. A diatom (Thallasiosira sp.) was observed as the second most abundant species found but its relative frequency was less than that of Peridinium sp., Coscinodiscus sp., and Ceratium sp. (Table 5). Although Peridinium sp. and Ceratium sp. were high in relative frequency, their numbers were rather low (ranked eleventh). The diatom Coscinodiscus sp. was prominent in both relative frequency (44.2%) and relative abundance

Table 5. Phytoplankton and zooplankton observed in 15 ponds over one grow-out period, ranked by relative frequency and relative abundance.

Species	Relative Frequency ^a	Rank	Relative Abundance ^b	Rank
Phytoplankton				
<u>Oscillatoria</u> (BG)	96.2	1	30.7	1
Pennate diatoms	92.3	2	17.8	3
- <u>Navicula</u>				
- <u>Gyrosigma</u>				
- <u>Pleurosigma</u>				
- <u>Cambella</u>				
- <u>Synedra</u>				
<u>Peridinium</u> (DF)	54.5	3	0.2	11
<u>Coscinodiscus</u> (D)	44.2	4	14.2	4
<u>Ceratium</u> (DF)	33.3	5	0.2	11
<u>Thallasiosira</u> (D)	20.5	6	24.0	2
<u>Rhizosolenia</u> (D)	17.9	7	8.8	5
<u>Thalassiothrix</u> (D)	15.4	8	0.3	10
<u>Merismopedia</u> (D)	11.5	9	0.5	9
<u>Nitzschia</u> (D)	11.5	9	0.03	12
<u>Chaetoceros</u> (D)	7.7	10	0.6	8
<u>Anabaena</u> (BG)	7.1	11	1.3	6
<u>Prorocentrum</u> (DF)	5.1	12	0.01	14
<u>Spirulina</u> (BG)	4.5	13	0.8	7
<u>Gymnodinium</u> (DF)	3.9	14	0.2	11
<u>Melosira</u> (D)	3.9	14	0.3	10
<u>Fragilaria</u> (D)	3.2	15	0.06	13
<u>Gammatophora</u> (D)	2.4	16	-	-
<u>Triceratium</u> (DF)	2.4	16	-	-
<u>Guinardia</u> (D)	2.4	16	-	-
Zooplankton				
Nauplius	96.2	1	14.2	2
Rotifer	80.1	2	66.4	1
Copepod	72.4	3	6.9	3
<u>Favella</u>	30.8	4	5.8	4
<u>Zoothanium</u>	3.9	5	0.1	6
<u>Codonellopsis</u>	1.9	6	6.6	5
<u>Globigerina</u>	0.0	7	0.0	7

- a = % of total of 5 most frequency species
 b = % of total of 5 most abundant species
 D = diatom
 BG = blue-green algae
 DF = dinoflagellate

(14.2%) when compared to other species. The other phytoplankton species shown in Table 5 were low in both relative frequency (<20%) and relative abundance (<10%).

The Standard Methods Handbook (1985) suggests that Oscillatoria sp. is likely to be present in polluted water. The relatively high density and frequency of occurrence of this species in this study indicated that water quality in the shrimp ponds may present a serious problem toward the end of the growing season and therefore will need proper attention. On the other hand, the presence of the "pennate" and other diatom species (Thallasiosira sp., Coscinodiscus sp., etc.) is a desirable condition due to their contribution to shrimp nutrition (Shigueno, 1984).

Zooplankton communities were less diverse in composition than phytoplankton (Table 5). Nauplius and rotifers were the most dominant groups in both relative frequency and relative abundance. Other groups were found in less than 10% of the total densities in Table 5. However, copepods and Favella sp. were found in rather high frequency (72.1 and 30.8%, respectively) when compared to the other species.

Chlorophyll a

Chlorophyll a is used as an algal biomass indicator (Standard Methods, 1985); differences in abundance of

phytoplankton are estimated by chlorophyll a concentrations. The overall mean chlorophyll a concentrations for all farms clearly indicated an increasing trend over time (Fig. 19). This corresponded to the increase in phytoplankton density (Fig. 18) and the decrease in transparency (Fig. 10). However, the overall average transparency for all ponds exceeded 40 cm which indicated that phytoplankton densities were optimum in the ponds. Similarly, Musig et al. (1989), in a water quality study in intensive shrimp ponds in Samutsakorn Province, reported that chlorophyll a concentrations were low during the first two weeks and began to increase in the fourth week until the end of growing season.

Shrimp Growth

The growth of shrimp in each study pond from each farm were plotted as mean body weight over time (days of culture) (Figs. 20-23). All growth curves from all ponds showed similar relationships. The most distinct growth was found at the AQC farm where two groups of the curves were clearly separated (Fig. 20). The first group (ponds 1, 2, and 3) appeared to have a lower mean body weight than that of ponds 4 and 5 for the same grow-out period. Several factors may account for these differences: first, ponds 4 and 5 were stocked with larger postlarvae (PL 50) than the others (Table 1);

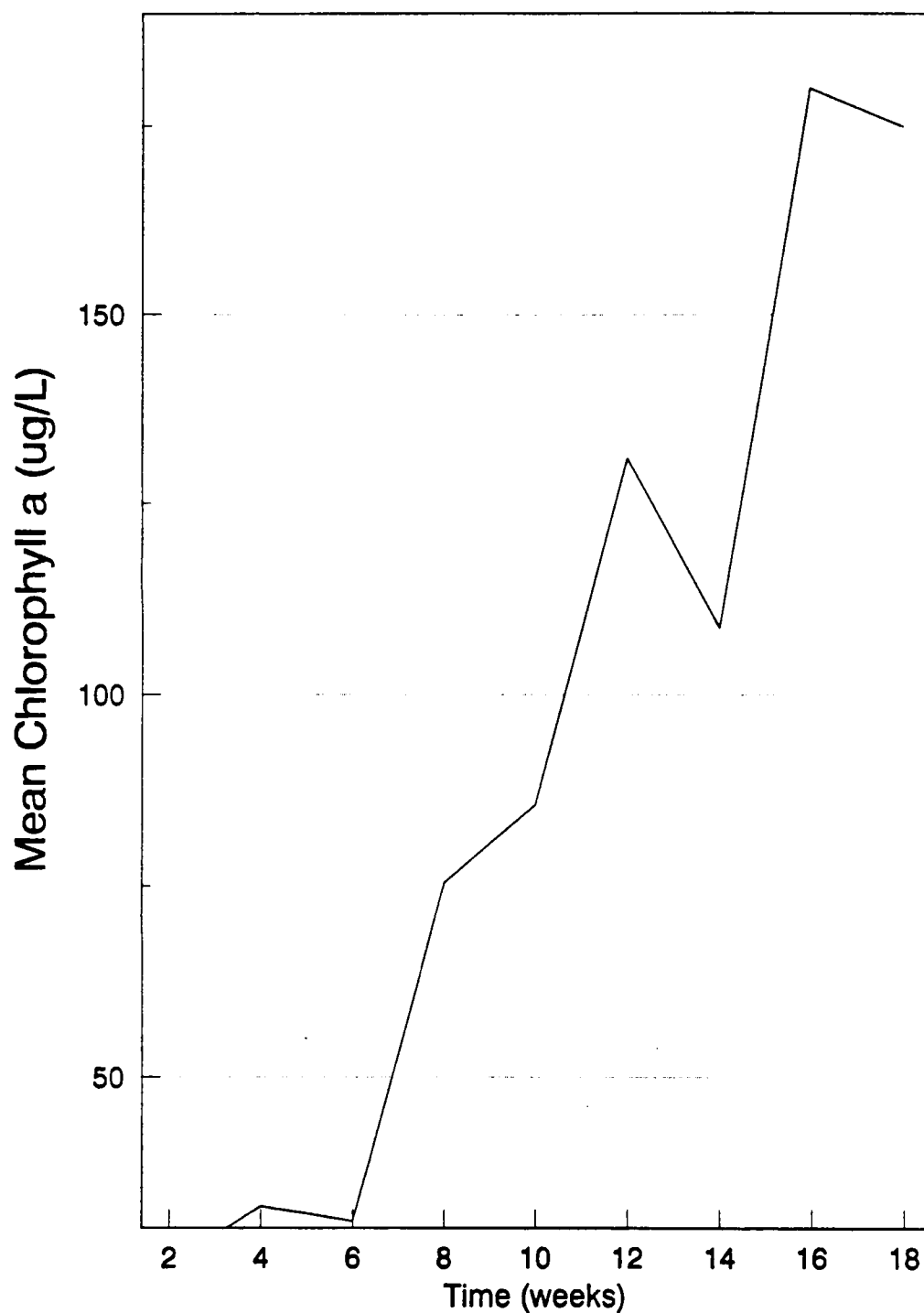


Figure 19. Mean chlorophyll a concentrations (ug/L) of the AQC, AQF, STS, and TRW farms during one grow-out period.

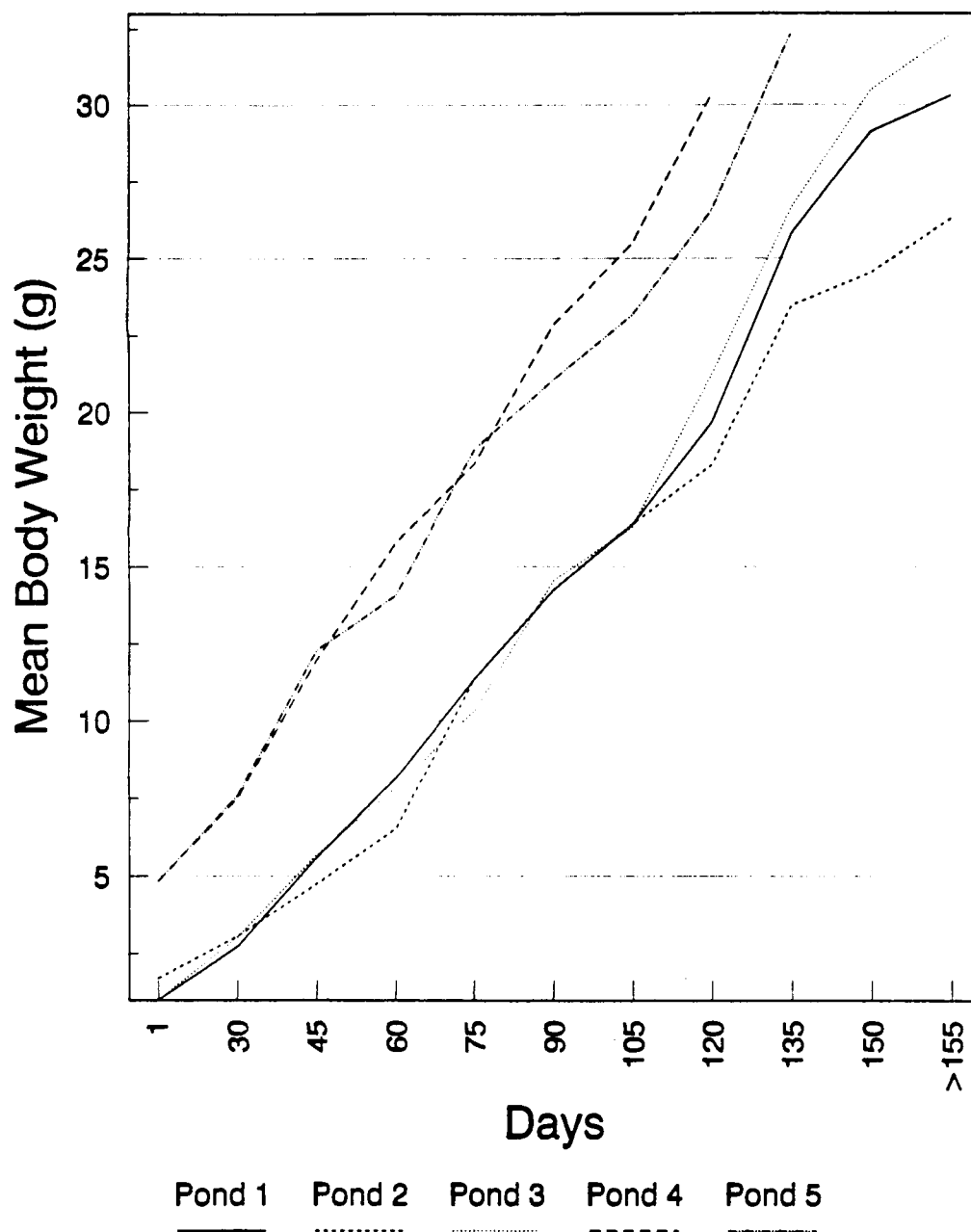


Figure 20. Mean body weight (g) of shrimp in ponds 1, 2, 3, 4, and 5 in the AQC farm during one grow-out period (> 155 days).

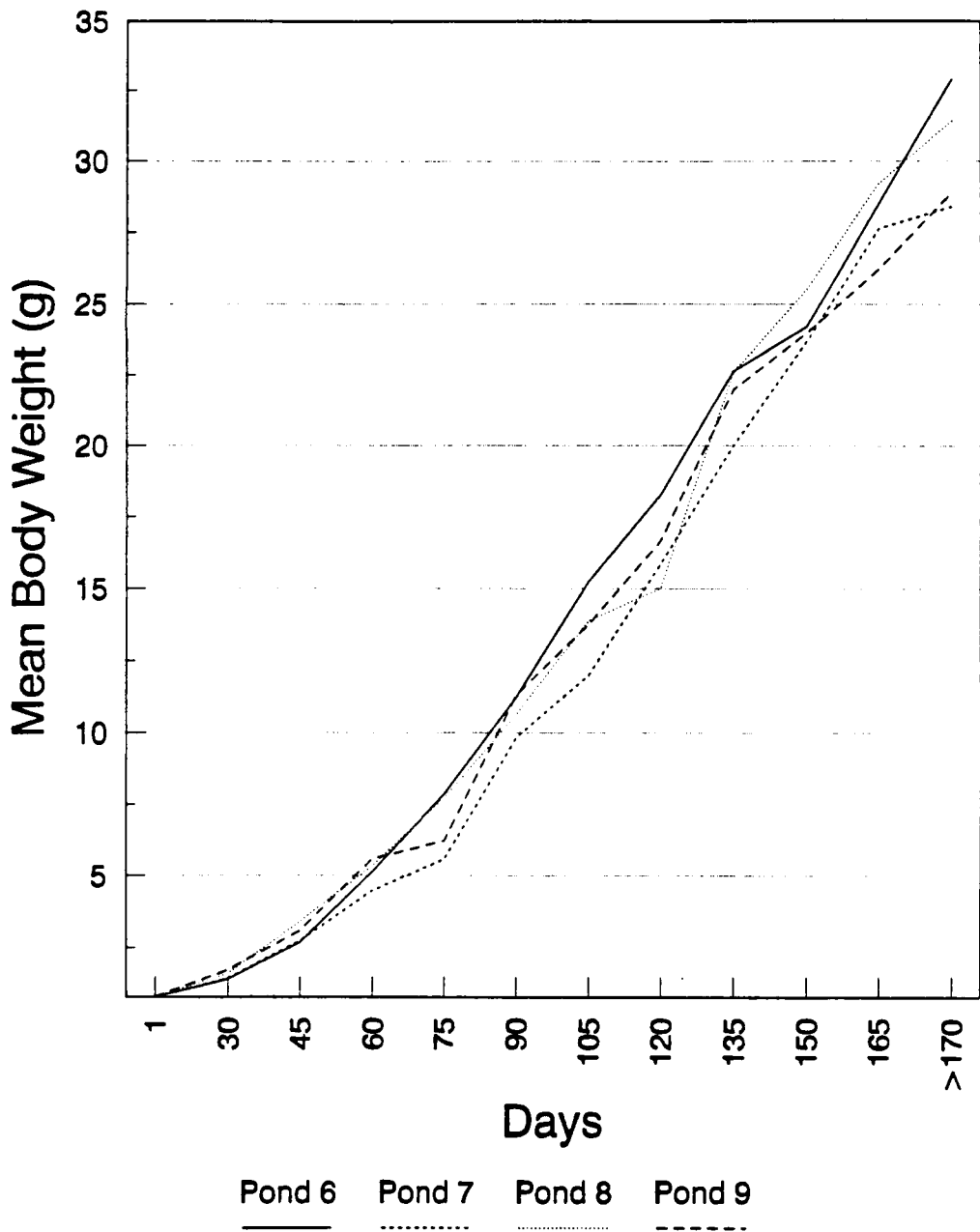


Figure 21. Mean body weight (g) of shrimp in ponds 6, 7, 8, and 9 in the AQF farm during one grow-out period (> 170 days).

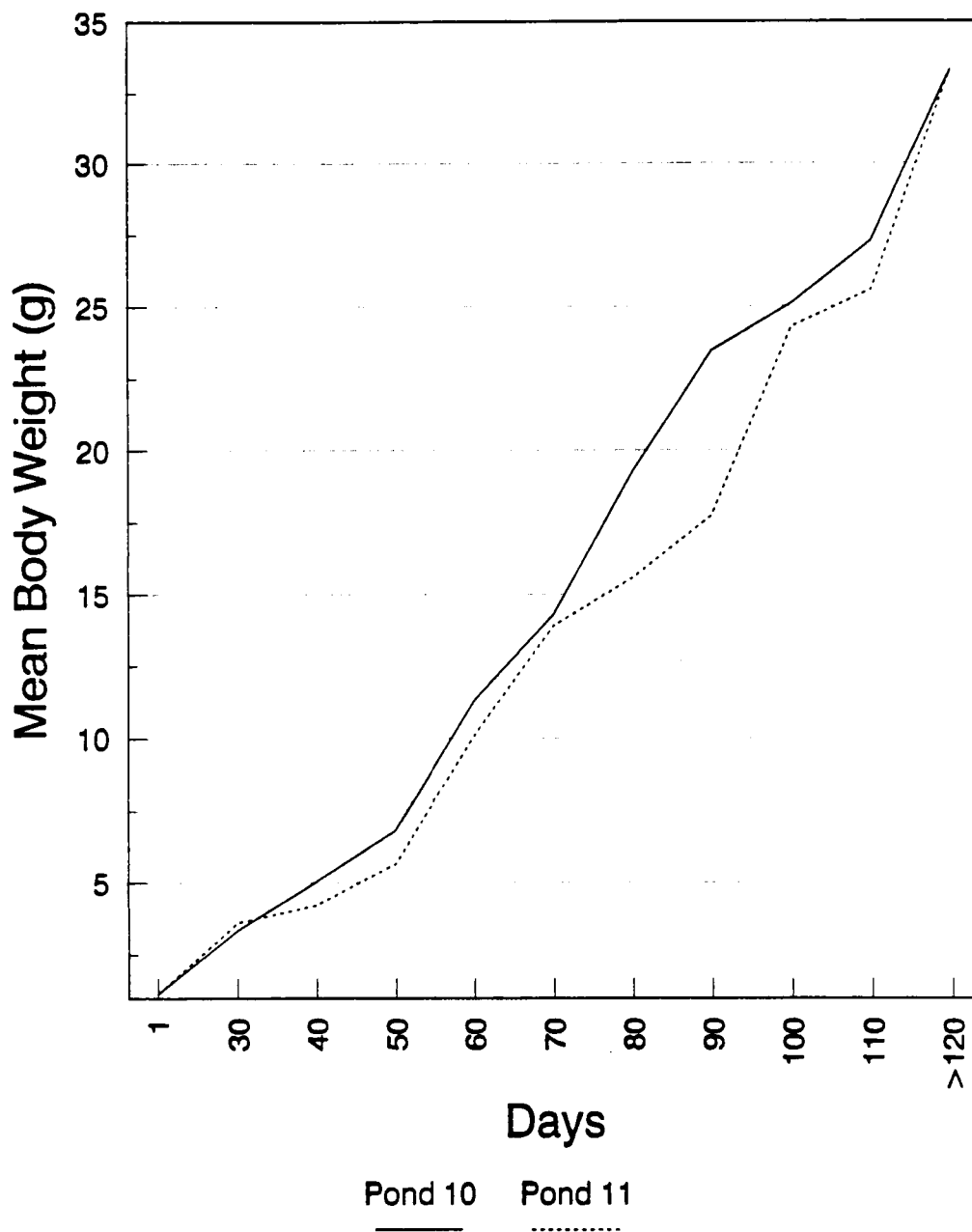


Figure 22. Mean body weight (g) of shrimp in ponds 10 and 11 in the STS farm during one grow-out period (> 120 days).

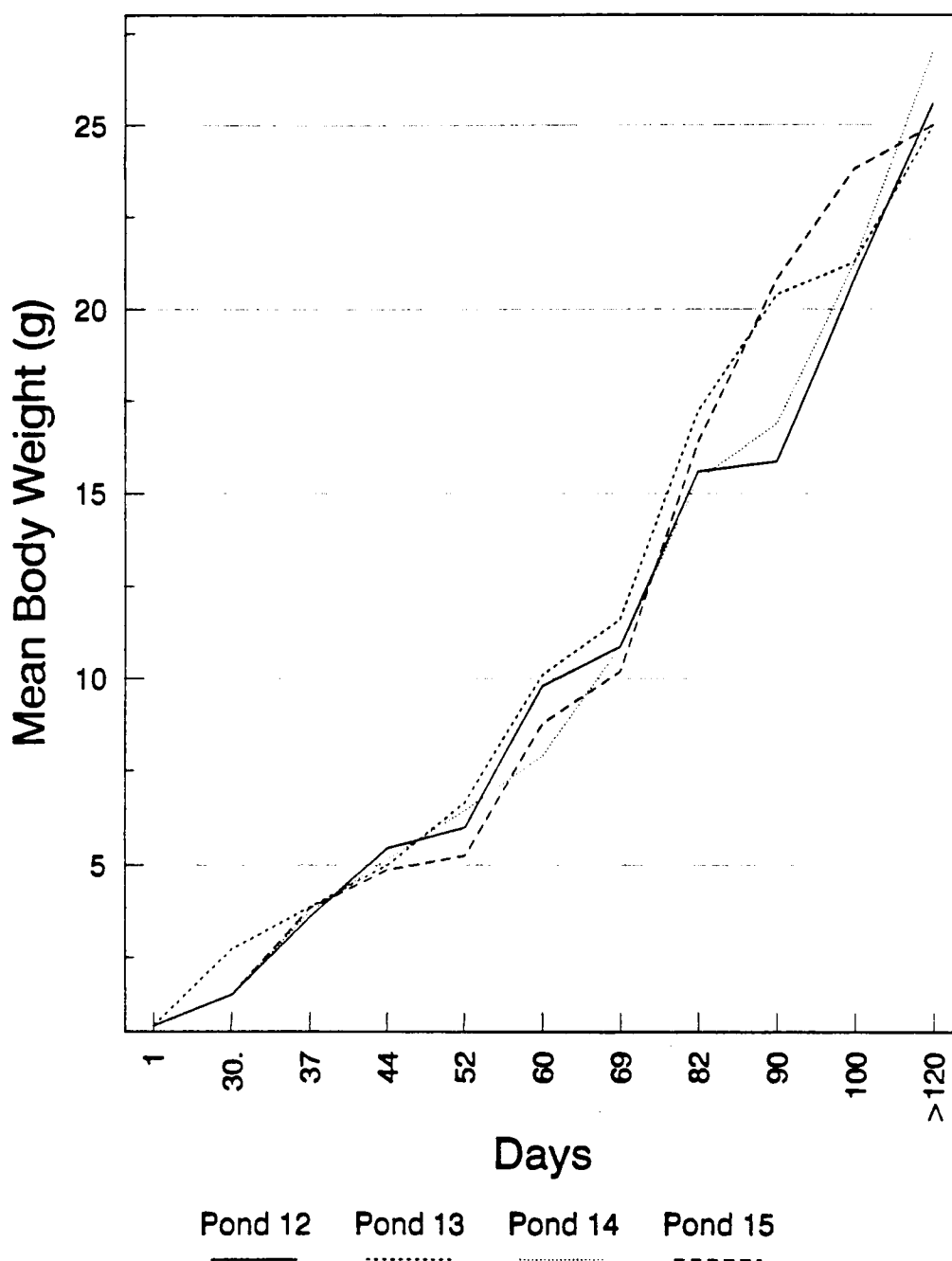


Figure 23. Mean body weight (g) of shrimp in ponds 12, 13, 14, and 15 in the TRW farm during one grow-out period (> 120 days).

second, ponds 4 and 5 had the lowest yield (2638.7 and 2165.3 kg/ha, respectively) while the total amounts of feed were similar to the others (Table 3); and third, different feeding regimes were observed in the latter two ponds. The plots of overall mean body weight of shrimp in each farm over time with and without ponds 4 and 5 (Figs. 24 and 25) confirmed that those two ponds were different from the others and may have been unduely influenced. Therefore, the number of ponds used in each specific analysis was determined using this fact.

Although all the farms showed similar growth rates, the STS farm appeared to have the best growth when compared at approximately 120 culture days while the AQF farm had the lowest growth rates (Fig. 25). This may be due in part to the fact that this farm had the longest grow-out period (about 170 days); therefore, it took the shrimp longer to reach marketable size (i.e., 30.0 g) than at the other farms. In other words, these shrimp had a slower growth rate than the others. This may have resulted from differences in pond management (i.e., feeding, water exchange). It was also noticed that the AQC and AQF farms that had an average salinity in shrimp ponds of about 30-35 ppt had slower growth rates than the STS and TRW farms which had the average salinity of 16-25 ppt (also see salinity, p. 41).

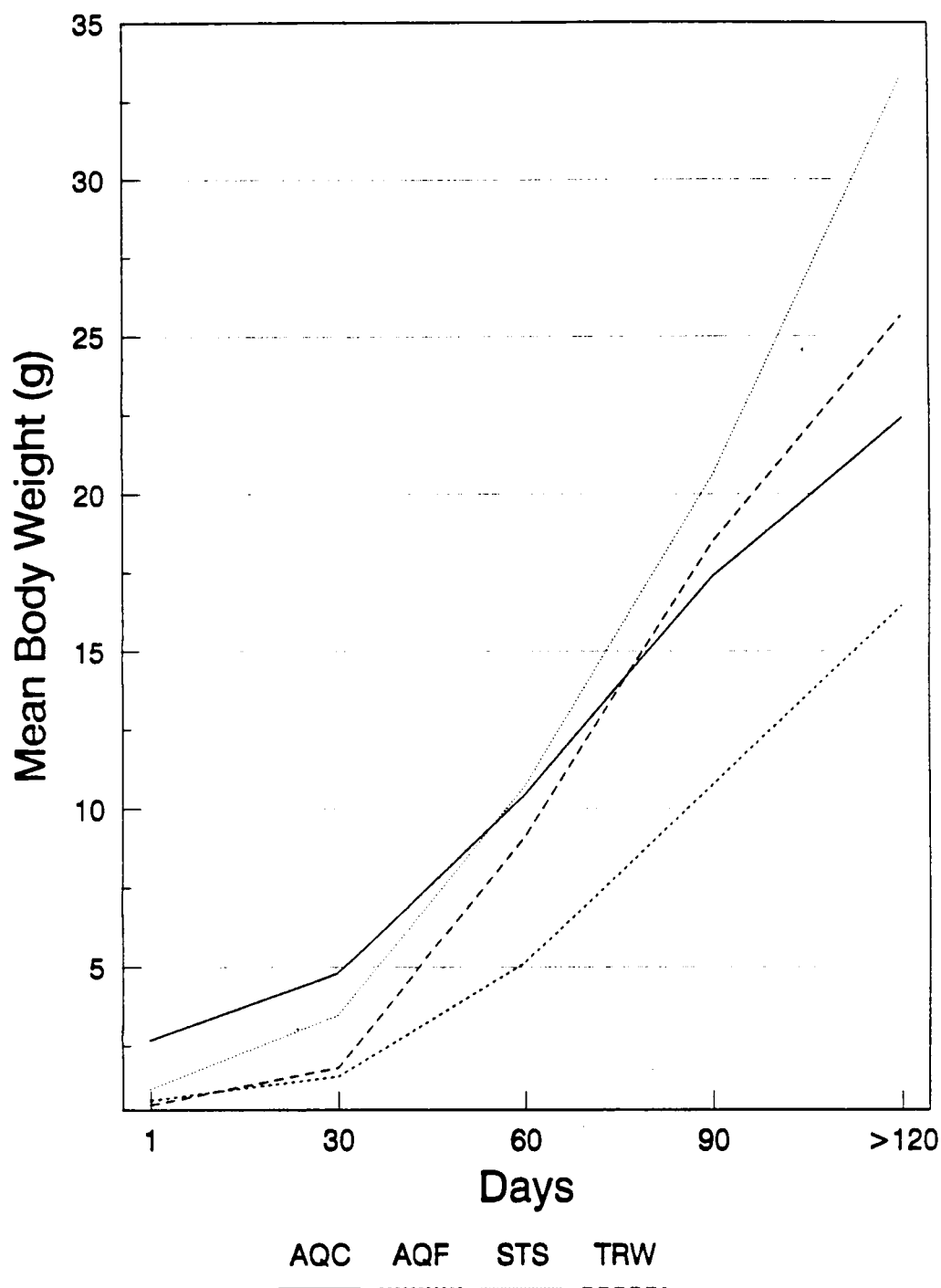


Figure 24. Comparisons of the overall mean body weight (g) of shrimp from the AQC, ACF, STS, and TRW farms at 30, 60, 90, and 120 culture days. The number of ponds used in this analysis was 15 (ponds 4 and 5 were included).

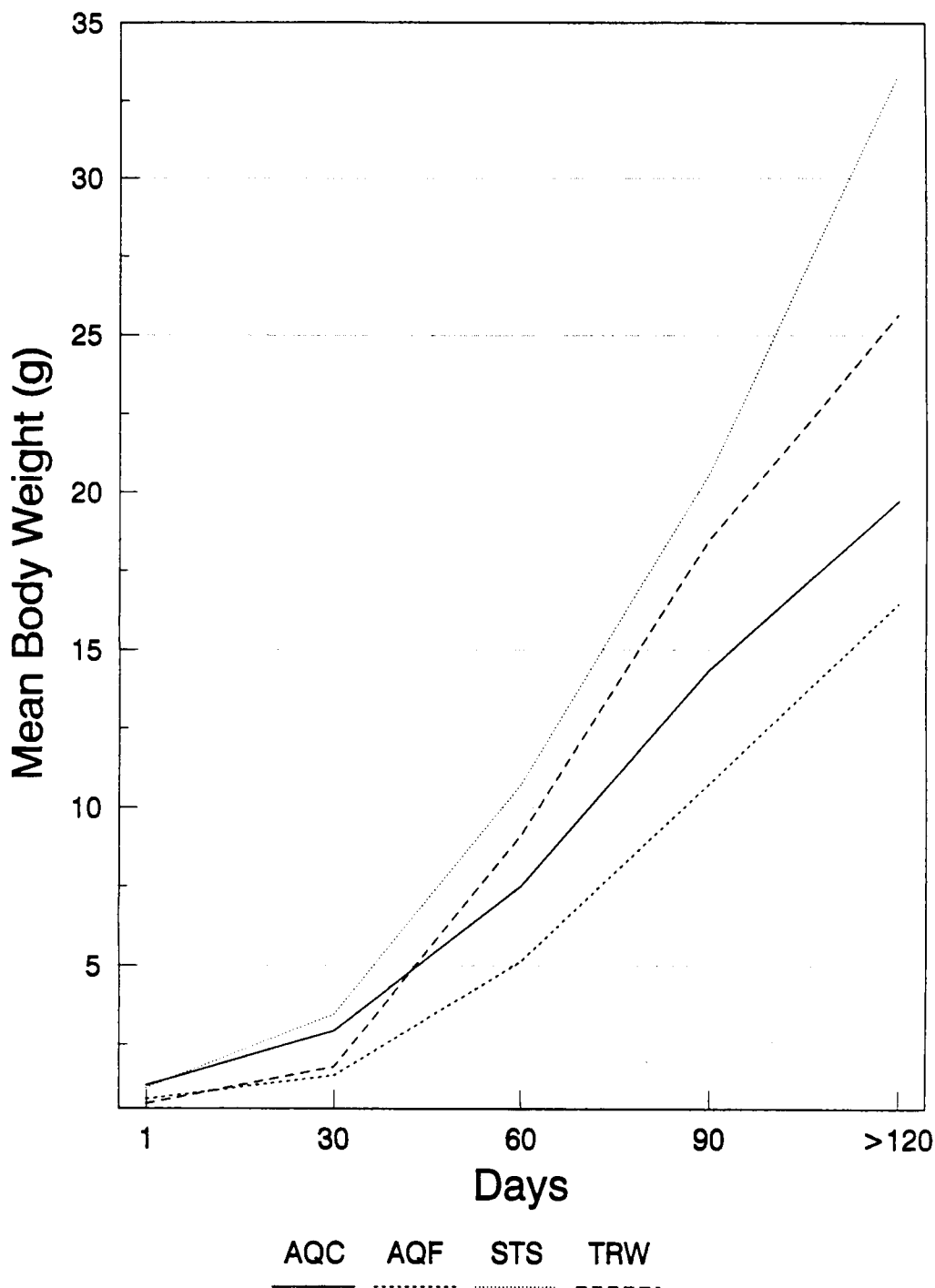


Figure 25. Comparisons of the overall mean body weight (g) of shrimp from the AQC, AQF, STS, and TRW farms at 30, 60, 90, and 120 culture days. the number of ponds used in this analysis was 13 (ponds 4 and 5 were excluded).

Impact of Water Quality Changes on Shrimp Performance:

Feed Efficiency

One principal objective of this study was to determine the impacts of water quality changes over the grow-out period on shrimp performance, as measured in terms of feed efficiency. Feed efficiency of shrimp (Table 6) from each study pond was derived from the following formula:

$$\begin{array}{rcl} \text{Feed efficiency} & = & \text{Total amount of feed (kg)} \\ \text{(FEDEFF)} & & \text{-----} \\ & & \text{Total production (kg)} \end{array}$$

In the table, the smaller values indicate the better feed efficiency, or in other words, the least amount of feed needed to produce one kilogram of shrimp growth. It is the goal for any commercial aquaculture industry to obtain the lowest possible value for feed efficiency (i.e., the nearest to 1), which is also the most economical.

It should be noticed that the values of feed efficiency for pond 4 (3.33) and pond 5 (4.72) were much higher when compared to the values from other ponds. This confirmed the preliminary assumption (see p. 75) that these two ponds had different feeding regimes from other study ponds, and therefore, might show different results which would not be comparable to other ponds.

Table 6. Feed efficiency of shrimp for each study pond.

Farm	Pond No.	Feed Efficiency
AQC	1	1.91
AQC	2	2.35
AQC	3	2.62
AQC	4	3.33
AQC	5	4.72
AQF	6	1.91
AQF	7	1.76
AQF	8	1.77
AQF	9	1.72
STS	10	1.53
STS	11	1.42
TRW	12	1.47
TRW	13	2.70
TRW	14	2.30
TRW	15	1.48

Therefore, the two ponds were excluded from the analysis concerning shrimp feeding to avoid any inaccurate comparisons of feeding efficiency data.

A stepwise procedure (Maximum R^2 Improvement, MAXR) will maximize the R^2 for a given number of predictor variables (i.e., water quality parameters). Thus, with a small number of observations (i.e., 15 ponds), there exists a risk that the inclusion of one or more variables into the model may be due more to chance than any underlying biological causative mechanism. Thus, a hypothetical model considering only biological rationale (model a) was fitted to the water quality data to afford a comparison with the model chosen by MAXR (model b).

By using the MAXR procedure, the relationship between feed efficiency (FEDEFF) and water quality parameters under two different models (a = biological judgment applied, and b = no biological judgment applied) was determined. Two sets of results, the 4-variable and the the 7-variable models, appeared to be appropriate models for this specific analysis; therefore, they were considered in the comparisons between model a and b (Table 7).

Model a: Biological Basis

According to the above assumption, four specific water quality variables were considered in the subsequent analysis. Their biological rationales were as follows:

Table 7. Summary of results of the statistical analysis on water quality and shrimp feed efficiency (Dep. Var., FEEDEFF)

Model No.	P	R ²	MSE	Var.	Rank	P	Relationship	Dep.Var.	Var.
a	4	.0403*	68	.0936	MAXLBOD	1	.0117*	I	I
				MSAL	2	.0145*	I	I	
				StRate	3	.0914*	I	I	
				MLDO	4	.1472	I	D	
	7	.0214*	91	.0410	MAXLBOD	1	.0031*	I	I
				MSAL	2	.0071*	I	I	
				StRate	3	.0124*	I	I	
				MLDO	4	.0199*	I	D	
				MINCHL	4	.0192*	I	I	
				MNH ₃	5	.0298*	I	D	
				MpH	6	.0774	I	I	
b	4	.0009*	88	.0349	MAXLBOD	1	.0002*	I	I
				MAXNO ₃	2	.0012*	I	D	
				MINNO ₃	3	.0023*	I	I	
				MAXTSS	4	.1028	I	I	
	7	.0021*	97	.0154	MINNO ₃	1	.0005*	I	I
				MAXNO ₃	1	.0005*	I	D	
				MAXLBOD	2	.0014*	I	I	
				MAT	3	.0143*	I	I	
				MINTRAN	4	.0175*	I	D	
				MINTSS	5	.1144	I	I	
				MAXpH	6	.1360	I	I	

P = P value, *significant at P < .05
Model = (a) with biological judgment applied (selected variable), and (b) without biological judgment (all data were examined)
No. Var. = number of variables in model
MSE = Mean Square Error
Var. = water quality variables
Rank = statistical significance rank from the most to the least
Relationship = relationship between response variable (water quality parameters) and dependent variable (FEEDEFF) when holding all other variables in the model constant. I for increase, D for decrease.

1. BOD: The Biochemical Oxygen Demand is the index of the quality of water. It is a measure of the amount of oxygen required by microorganisms to decompose the organic matter in a water sample under a specific set of conditions which normally is an incubation period in the dark for 5 days at 20 C (Standard Methods, 1985). The decline in DO during incubation is the BOD which is a valuable parameter in evaluating the pollution strength of a waste (i.e., pond effluents). Therefore, a high value of BOD indicates that the water quality is deteriorating and can adversely affect aquatic animals (i.e., shrimp).
2. DO: Dissolved Oxygen is an essential factor for all aquatic life. If its concentration is below the critical level (<1 ppm, Boyd 1978), the impact is severe and may result in sudden mortality. The optimal level (>5 ppm, Boyd 1978) should promote the optimal growth and the best survival rates for cultured shrimp.
3. SAL: Salinity is important because the shrimp is a marine species. Although P. monodon has

been reported to tolerate a wide range of salinity (10-30 ppt, Kungvankij, 1987), the optimal range of concentrations (20-25 ppt, Chiang et al., 1989) should promote the best performance.

4. StRate: The stocking rate was selected because of its importance in intensive culture systems. It is one of the limiting factors that can influence the growth, development, and survival of aquatic organisms. When densities are increased, individual growth may decrease as a result of increased competition for food. In intensive crustacean rearing, high stocking densities have often been used to maximize production per unit area (without testing the effects of such densities). The impact of the stocking rate is, therefore, expected in intensive shrimp culture operations.

These four variables were used as the response variables in the MAXR procedure. The addition of other variables (pH, NH_3 , and CHL) was considered later.

The 4-variable model (MAXLBOD, MSAL, StRate, and MLDO) was significant at a P value = .0403 and MSE = .0936. All the variables contributed about 68% (R^2 =

68%) of the total effects on feed efficiency. When considering each variable separately (partially contributed), only two variables (MAXLBOD and MSAL) were significant while the other two variables (StRate and MLDO) were not significant (Table 7). When the maximum value of BOD increased or the mean value of salinity increased, shrimp feed efficiency was reduced (i.e., more food is required to produce one kilogram of shrimp). The effect of BOD is in line with the biological rationale that the higher level of BOD can adversely affect shrimp performance (i.e., poor feed efficiency). The effects of salinity, stocking rate, and DO on feed efficiency were not clear. More detailed study is needed to confirm the effects.

The 7-variable model (MAXLBOD, MSAL, StRate, MLDO, MINCHL, MNH_3 , and MpH) was significant at P value = .0214 and MSE = .0410. All variables contributed about 91% ($R^2 = 91\%$) of the total effects on feed efficiency. The partial contribution for each variable was similar to the 4-variable model where all variables (except MpH) had a significant effect on feed efficiency (Table 7). Although the analysis considered several more water quality variables, BOD appeared to be the most prominent parameter that affected feed efficiency of shrimp under this set of specific conditions.

Model b: Non-Biological Basis

MAXR was used with all water quality variables to examine all possible combinations of the relationships among feed efficiency and water quality. The computer generated the best possible models according to this set of conditions. The results of the MAXR procedure are also reported in Table 7.

The 4-variable model (MAXLBOD, MAXNO₃, MINNO₃, and MAXTSS) was significant at P value = .0009, R² = 88%, and MSE = .0349. All variables contributed about 88% of the total effects on feed efficiency. The most significant variable was BOD with the same direction of relationship with feed efficiency as in the previous models.

The 7-variable model (MINNO₃, MAXNO₃, MAXLBOD, MAT, MINTRAN, MINTSS, and MAXpH) was significant at P value = .0021, R² = 97%, and MSE = .0154. All variables contributed about 97% of the total effects on feed efficiency. BOD was indicated as the second most significant variable (the most significant variable was NO₃) in the model; the relationship was the same as in all previous models.

Regardless of the models (a or b), BOD appeared to have the most significant effect on feed efficiency of shrimp. High levels of BOD were expected as a result of the intensive feeding program (i.e., 4-6 times/day) in which residues of excess feed were inevitable. Meanwhile,

as the shrimp grew larger, they excreted more waste materials into the pond. The accumulation of these residues over time resulted in high BOD levels. The situation of high BOD levels would be very severe if there were inadequate or no management practices such as: (1) water exchange by letting good quality water into the pond to improve low dissolved oxygen levels by reducing the amount of algae, bacteria, and detritus in the water; (2) aeration, by increasing the numbers of aerators and time of operation in the pond to move highly-oxygenated surface water to the pond bottom to allow bacterial decomposition so that waste products can be oxidized quickly; and (3) the removal of "sludge" or waste (accumulated detritus) from the pond bottom by pumping or draining to improve pond bottom conditions and to prevent the accumulation of excessive waste materials. These practices would help to improve pond water quality, especially in lowering the BOD levels.

Impact of Water Exchange on Water Quality

The impacts of water exchange management, here discussed in terms of DELTA (differences of water levels at each period), on water quality during the growout season (PERIOD) were tested by using the GLM procedure. The results are summarized in Table 8.

Table 8. The effects of water exchange (DELTA), time (PERIOD), and the interaction terms of DELTA*PERIOD on water quality.

Model	WT	TRAN	LSAL	LDO	Response Variables ^a					
					LBOD	pH	TSS	NO ₃	NH ₃	PO ₄
DELTA	.9079	.1265	.3319	.0235	.6627	.3160	.4181	.1756	.2780	.4585
PERIOD	.0753	.0427*	.5633	.6038	4.E-06*	.0006*	.2308	.0302*	.0439*	.0025*
DELTA *PERIOD	.9354	.1893	.8696	.1457	.9363	.1005	.4862	.8289	.7098	.2094

* significant at P value <.05

^a P value based on Type III Sum of Squares (Type III SS): partial or adjusted sums of squares (comparison of main effects even in the presence of interaction, each effect is adjusted for all other effects).

The results of GLM (as the values of P value based on Type III Sum of Squares) in Table 8 indicated (with the exception of variable DO) that water exchange (DELTA) had no significant effects on the changes of water quality parameters. The effects of water exchange on the change of DO levels (P value = 0.0235) may have been caused by the differences in the levels of DO between inlet and pond water during water exchange practices. However, DO was expected to be kept at or above optimal levels under intensive aeration; therefore, the differences produced by the water exchange were assumed to be minimal.

The P values of Type III Sum of Squares of PERIOD (grow-out time) adjusted for the effects of DELTA (water exchange) clearly indicated that time during the grow-out period had significant effects on several water quality parameters including TRAN, BOD, pH, NO₃, NH₃, and PO₄ (Table 8). This confirmed that water quality in shrimp ponds changed over time regardless of water exchange schedules. Although the effects of PERIOD were not significant on the water quality parameters DO, SAL, and TSS, preliminary analyses (see changes of water quality over time, p. 40) indicated slight fluctuations of these parameters throughout the grow-out period. Several factors may have accounted for these changes including

the increase of waste products from shrimp excretion as they grew and the accumulation of unconsumed feed.

The effects of the interaction term (DELTA*PERIOD) showed no significance for all water quality parameters (Table 8). This indicated that water exchange and time (PERIOD) have no relationship, thus, no effect on the change in water quality.

CHAPTER V

CONCLUSIONS

The results of water quality data analyses indicated that under the existing shrimp pond management operations (i.e., stocking rates, feeding regimes, water exchange, and supplemental aeration), pond water quality was maintained at optimum levels for tiger prawn culture with the exception of specific trends in some parameters. Those trends included a substantial rise in BOD and NH_3 accompanied by a decrease in water transparency over the grow-out period. These changes in water quality did not appear to adversely affect the survival and growth of the shrimp.

Although no drastic impacts of increased BOD and NH_3 on shrimp were reported in this study, these trends suggested that at current levels of pond management (e.g., water exchange, aeration, etc.) pond water quality will continue to degrade over time. The continuous degradation of water quality in intensive shrimp ponds may have future impacts on surface water supplies which serve as the water source for shrimp farms. Future management practices should, therefore, consider how to improve these conditions by employing techniques such as adding sediment ponds for wastewater treatment, periodically removing the waste buildup from the pond

bottom, and by increasing aeration efficiency. These practices would help to maintain the optimal DO levels, offset BOD levels, and improve overall pond water quality. In addition, increased efficiency in aeration methods would improve the profit margin of the shrimp farms.

Because BOD was identified as the most significant water quality parameter that affected shrimp feed efficiency, special attention should focus on this parameter when examining water quality in shrimp ponds. Although BOD is difficult to measure by the shrimp farmers themselves, farm managers can take water samples to nearby government or private laboratories for complete analysis. If BOD levels in shrimp pond were kept to a minimum, better production could be obtained through the improved feed efficiency.

The overall average yield of approximately 6.5 tons/ha/crop (excluding ponds 4 and 5) was substantially higher than the national average of 3-10 tons/ha/crop. It was noticed that the average yield (tons/ha) of the STS and TRW farms (8.6) was higher than that of the AQC and AQF farms (4.6). The chief differences in pond management practices appeared to be salinity and stocking rate. The STS and TRW farms mixed fresh and sea water to obtain a salinity of 16-25 ppt while AQC and AQF used

unmixed sea water at 30-35 ppt salinity. This suggested that shrimp may grow better at an intermediate salinity rather than pure sea water.

The stocking rate of the STS and TRW ponds was also higher (39 shrimp/m²) than that of the AQC and AQF ponds (23 shrimp/m²). Although the former ponds produced more shrimp, it is not always true that a higher stocking rate can result in higher production. Other factors could have accounted for the increase of production, and maintaining suitable water quality during the entire grow-out period appeared to be one of the most important factors.

For future development of the intensive shrimp industry, potential environmental impacts of this culture should be clearly identified. Research should be conducted in several areas: (1) quality of water supplies, (2) relationships among feeding rates, water quality, nutrient chemistry, plankton communities, and shrimp production in ponds, (3) evaluation and improvement of management techniques such as water exchange and aeration, and (4) characteristics and environmental effects of effluents. These findings along with the present study could be used by both governmental agencies and the private sector to improve management practices, facilitate planning, establish regulatory guidelines, and minimize further environmental degradation from shrimp farming.

CHAPTER VI

SUMMARY

1. Fifteen intensively cultured shrimp ponds on four farms were sampled during one grow-out period to examine the effects of the culture operations on water quality and shrimp performances (growth and feed efficiency). Water quality parameters which were measured included water temperature (WT), dissolved oxygen (DO), salinity (SAL), Secchi disk transparency (TRAN), pH, total suspended solids (TSS), total ammonia nitrogen (NH_3), nitrate (NO_3), orthophosphate (PO_4), and biological oxygen demand (BOD).
2. For all study farms, the values of water quality sampled from the inlets were significantly (P value = .0001) different from the pond middle and discharge locations; the values from the pond middle sites were not significantly (P value = .7978) different from the corresponding discharges.
3. During the grow-out period, most water quality parameters in shrimp ponds changed relatively little (i.e., slight fluctuation). However, some parameters such as BOD, NH_3 , TRAN, and pH showed specific trends over time. These changes were in line with biological interactions that were expected to occur

in intensive shrimp ponds over time (i.e., there were increase in BOD and NH_3 , while pH and TRAN decreased).

4. The values of water quality parameters which changed relatively little were in line with the values that are considered optimal (in parentheses) for tiger shrimp culture: WT = 25-32 C (25-32 C), SAL = 20-32 ppt (15-25 ppt), pH = 7.3-8.8 (7.5-9.0), and DO = 6 - 10 ppm (> 5 ppm). The amount of NO_3 , PO_4 , and TSS concentrations were relatively small and did not seem to have any effects on shrimp performance.
5. DO was relatively unchanged over the grow-out period. The influx of water on a regular basis combined with increased aeration during the later phases maintained a DO concentration at greater than 6 ppm in all ponds.
6. Mean BOD levels in pond water for all farms increased from 2.8 to 12.1 ppm toward the end of the grow-out period. This indicated a trend of water quality deterioration as growth proceeded in shrimp ponds.
7. Mean pH values ranged from 7.3 to 8.8 which corresponded with the optimal pH for the tiger prawn culture (7.5-9.0). In addition, this range was essential in controlling some important chemical reactions in water (i.e., ammonia-ammonium

equilibrium, nitrification) to retain good water quality conditions.

8. The maximum value of total ammonia nitrogen concentrations was 1.5 ppm. However, it was not considered toxic to the shrimp because of the low percentage of un-ionized ammonia (toxic form) within the pH range of 7.3-8.8 and temperatures of 25-32 C. No mortality due to ammonia was observed in the study ponds.
9. Nitrification, which is the oxidation of ammonia nitrogen to nitrite and then nitrate, rapidly occurred under the conditions of pH 7 to 8 and temperatures of 25 to 35 C. These conditions were the usual situations found in this study; therefore, while some nitrate concentrations was present, little if any nitrite was found in water samples from the study ponds.
10. The overall average chlorophyll a concentrations in pond water showed an increasing trend that corresponded with increasing phytoplankton density and decreasing transparency over time. However, the correlation coefficient between CHL a and TRAN indicated that increased CHL a concentrations partly accounted for the decreasing TRAN. Accumulations of unused feed or other waste materials may also contribute to decreasing TRAN.

11. The phytoplankton community (numbers and taxa) widely fluctuated over time; however, there was an increasing trend in numbers that was probably due to the increase in nutrient levels which resulted from accumulation of excess feed. The relative frequency of occurrence and abundance data indicated that the blue-green algae Oscillatoria sp. and the "pennate" diatoms were the dominant groups found throughout the growing period. There was a possibility that Oscillatoria sp. may be an indicator of potential water quality deterioration.
12. The growth rates of shrimp (mean body weight over cultured days) from each study farm were similar in pattern although the average initial sizes were slightly different [AQC(1.23 g), AQF(0.08 g), STS(1.15 g), and TRW(0.65 g)]. Shrimp from the STS farm showed the best growth when compared at approximately 120 culture days and measured in terms of an average daily weight gain (g): STS (0.26), TRW (0.21), AQC (0.15), and AQF (0.13).
13. The STS farm also had the best average feed efficiency (1.48) among the farms; the other feed efficiency values were 1.79 (AQF), 1.99 (TRW), and 2.29 (AQC). It was noticed that ponds 4 and 5 in the AQC farm clearly had different growth rates and feed efficiency values (3.33 and 4.72, respectively) from

the other study ponds. This was thought to be due to a different feeding regime.

14. BOD was the most significant water quality parameter that affected shrimp performance (as feed efficiency); as BOD levels increased, feed efficiency decreased. The major increase in BOD values was during the third and fourth months of the grow-out period.
15. During the grow-out period, the net water exchange rates of the three farms (AQC, AQF, and STS) changed relatively little. The average levels of withdrawal and input water, however, indicated the increasing trends that corresponded with the usual increasing water exchange practices later in the grow-out period in intensive shrimp ponds.
16. Results of the General Linear Model (GLM) indicated no significant effects of water exchange practices on the changes of pond water quality throughout the growing period. It also confirmed that water quality in shrimp ponds changed through time under intensive pond management.

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APPENDIXES

APPENDIX A
ORIGINAL WATER QUALITY DATA

Original water quality data from 15 intensive shrimp ponds in four farms in the Songkhla Basin, Thailand, during June-December, 1989.

F A R M	P O N D	D A T E	LOC.	A.T. C	W.T. C	TRAN. cm.	SAL. ppt.	pH	D.O. ppm.	BOD ppm.	TSS g/100ml	NO3 ppm.	NH3 ppm.	PO4 ppm.	CHL a ug/L
1	-	1	1	26.0	32.5	100	34	8.35	5.90	2.50	0.0077	0.0038	0.0000	0.0007	-
1	-	1	1	26.0	33.0	100	34	8.40	6.40	2.21	0.0062	0.0043	0.0000	0.0036	-
1	-	1	1	27.0	32.0	150	34	8.10	6.20	2.01	0.0054	0.0154	0.0000	0.0953	-
1	-	2	1	28.0	31.5	85	33	8.20	7.40	2.80	0.0081	0.0188	0.1699	0.2730	-
1	-	2	1	28.0	31.5	95	33	8.15	6.80	3.00	0.0095	0.0743	0.0038	0.0530	-
1	-	2	1	28.0	31.2	110	33	8.30	6.00	4.90	0.0049	0.0576	0.0282	0.1850	-
1	-	2	1	28.0	31.0	100	33	8.05	6.30	2.50	0.0049	0.0410	0.0442	0.1120	-
1	-	3	1	29.0	29.0	90	33	8.20	7.40	1.80	0.0083	0.0199	0.0244	0.0030	-
1	-	3	1	26.5	29.0	100	32	8.20	8.10	1.20	0.0068	0.0188	0.0319	0.0040	-
1	-	3	1	28.5	29.0	150	34	8.20	7.10	1.40	0.0081	0.0104	0.0236	0.0040	-
1	-	3	1	29.0	28.5	75	34	8.20	7.50	4.70	0.0116	0.0116	0.0234	0.0080	-
1	-	4	1	30.0	30.5	120	31	7.80	7.30	2.30	0.0012	0.0410	0.0431	0.0080	10.92
1	-	4	1	30.5	31.0	80	30	8.20	8.00	2.10	0.0059	0.0490	0.0000	0.0000	-
1	-	4	1	29.0	31.0	150	35	7.60	7.00	1.80	0.0012	0.0320	0.0206	0.0051	9.72
1	-	4	1	30.0	30.5	90	36	7.90	8.20	1.50	0.0013	0.0330	0.0169	0.0036	10.08
1	-	5	1	31.0	30.8	90	34	7.80	7.30	0.70	0.0083	0.0066	0.0816	0.0022	2.56
1	-	5	1	30.0	30.5	90	35	7.80	8.20	1.30	0.0087	0.0004	0.0338	0.0196	3.28
1	-	5	1	30.0	30.5	75	35	7.80	7.70	1.00	0.0117	0.0110	0.0713	0.0007	2.48
1	-	5	1	30.5	31.0	115	35	7.70	6.70	1.30	0.0084	0.0071	0.0732	0.0000	-
1	-	6	1	32.5	32.3	60	33	7.60	8.70	1.50	0.0072	0.0232	0.0379	0.0080	17.12
1	-	6	1	32.0	30.8	85	33	7.70	6.00	0.36	0.0060	0.0232	0.0096	0.0065	5.96
1	-	6	1	32.0	30.9	75	34	7.80	5.40	0.10	0.0053	0.0404	0.0519	0.0124	6.44
1	-	6	1	32.0	31.3	120	30	7.60	5.80	0.30	0.0070	0.0271	0.0000	0.0124	7.08
1	-	7	1	32.0	31.4	105	34	7.40	8.30	5.18	0.0062	0.0193	0.0814	0.0000	0.00
1	-	7	1	32.5	32.0	72	34	7.45	7.40	6.68	0.0051	0.0127	0.0558	0.0007	6.72
1	-	7	1	33.0	32.3	48	34	7.45	7.00	12.38	0.0060	0.0393	0.0444	0.0000	8.44
1	-	7	1	33.0	32.3	90	34	7.40	6.40	5.98	0.0074	0.0265	0.0814	0.0000	5.32
1	-	8	1	30.0	30.0	88	34	8.00	6.90	1.62	0.0032	0.0526	0.0391	0.0000	-
1	-	8	1	31.0	31.0	90	34	7.70	6.90	1.80	0.0022	0.0438	0.0481	0.0051	6.96
1	-	8	1	28.0	28.0	120	34	7.70	6.70	2.02	0.0036	0.0199	0.0032	0.0124	5.40
1	-	8	1	32.0	32.0	50	33	7.65	7.60	1.42	0.0098	0.0460	0.0237	0.0051	0.92
1	-	9	1	31.0	31.4	58	33	7.60	10.40	2.34	0.0022	0.0204	0.0122	0.0000	11.44
1	-	9	1	30.5	30.5	85	33	7.60	9.00	2.34	0.0048	0.0249	0.0968	0.0000	10.72
1	-	9	1	31.5	30.3	90	33	7.50	9.70	1.34	0.0056	0.0171	0.0173	0.0000	23.64
1	-	9	1	30.3	30.4	95	34	7.70	9.20	1.54	0.0048	0.0277	0.0289	0.0000	7.44
1	-	10	1	30.0	30.2	70	33	8.10	6.46	3.30	0.0071	0.0332	0.2212	0.0051	20.72
1	-	10	1	30.0	31.0	50	30	8.40	6.15	4.54	0.0064	0.0243	0.1481	0.0225	34.44
1	-	10	1	30.0	30.2	80	34	8.20	6.46	2.12	0.0079	0.0132	0.0353	0.0022	6.88
1	-	10	1	30.0	30.7	90	33	8.20	6.24	2.54	0.0095	0.0243	0.0840	0.0211	13.92
1	1	1	1	26.0	32.5	85	32	8.40	6.00	3.33	0.0060	0.0943	0.0000	0.0051	-
1	1	1	2	26.0	33.0	75	32	8.45	6.10	2.67	0.0044	0.0090	0.0000	0.0022	-
1	1	1	3	26.0	33.0	70	33	8.45	6.10	4.96	0.0050	0.2076	0.0000	0.0036	-
1	1	2	2	28.0	29.0	60	35	8.40	7.60	7.30	0.0075	0.0410	0.0038	0.6560	-
1	1	2	3	28.0	31.0	55	35	8.35	7.80	9.24	0.0086	0.1132	0.0000	0.4940	-
1	1	3	2	30.0	29.0	50	34	8.60	7.60	6.10	0.0106	0.0249	0.0000	0.0000	-
1	1	3	3	29.0	28.5	49	34	8.60	8.40	5.90	0.0095	0.0254	0.0000	0.0000	-
1	1	4	2	30.0	30.0	50	31	8.40	8.70	4.38	0.0008	0.0430	0.0000	0.0153	72.12
1	1	4	3	30.0	30.0	48	32	8.40	7.80	6.10	0.0007	0.0360	0.0000	0.0225	-
1	1	5	2	30.0	30.0	50	35	8.10	8.00	6.00	0.0097	0.0116	0.0000	0.0153	7.32
1	1	5	3	30.0	30.5	60	33	8.00	8.30	5.40	0.0099	0.0066	0.0038	0.0036	1.92
1	1	6	2	32.0	31.0	37	34	7.60	6.60	6.80	0.0084	0.0310	0.0000	0.0240	113.04
1	1	6	3	32.0	31.0	50	34	7.60	6.20	6.70	0.0095	0.0282	0.0000	0.0269	96.72
1	1	7	2	32.0	31.9	40	34	7.50	7.90	10.38	0.0088	0.0593	0.0096	0.0000	142.92
1	1	7	3	32.0	31.8	38	34	7.50	7.10	9.78	0.0082	0.0127	0.0109	0.0000	133.12

F A R M	P O N D	D A T E	LOC.	A.T. C	W.T. C	TRAN. cm.	SAL. ppt.	pH	D.O. ppm.	BOD ppm.	TSS g/100ml	NO3 ppm.	NH3 ppm.	PO4 ppm.	CHL a ug/L
1	1	8	2	31.0	30.0	35	34	7.60	7.50	9.90	0.0070	0.0327	0.0000	0.0211	182.08
1	1	8	3	31.0	30.0	30	34	7.70	7.40	12.14	0.0089	0.0526	0.0000	0.0182	345.72
1	1	9	2	31.0	30.5	38	33	7.60	11.10	8.42	0.0075	0.0171	0.5957	0.0138	190.84
1	1	9	3	31.0	29.8	34	33	7.60	7.70	8.46	0.0070	0.0238	0.5932	0.0327	178.64
1	1	10	2	30.0	30.1	45	33	7.90	7.10	7.98	0.0110	0.0482	0.4239	0.0342	102.04
1	1	10	3	30.0	30.1	42	33	8.00	6.74	7.36	0.0117	0.0521	0.4380	0.0284	71.36
1	2	1	2	26.0	32.0	85	32	8.40	6.10	1.91	0.0053	0.0149	0.0000	0.0095	-
1	2	1	3	26.0	32.0	80	34	8.40	5.90	3.42	0.0120	0.0149	0.0000	0.0007	-
1	2	2	2	28.0	29.0	45	35	8.50	7.50	6.10	0.0121	0.0465	0.0000	0.5380	-
1	2	2	3	28.0	31.0	40	35	8.70	7.70	7.95	0.0101	0.0354	0.0048	0.8470	-
1	2	3	2	30.0	29.0	40	35	8.75	8.80	6.50	0.0102	0.0288	0.0000	0.0330	-
1	2	3	3	30.0	28.5	39	34	8.75	8.50	7.20	0.0119	0.0215	0.0000	0.0310	-
1	2	4	2	29.5	30.0	50	31	8.50	9.40	7.24	0.0020	0.0460	0.0000	0.0313	78.68
1	2	4	3	29.5	30.0	45	32	8.40	7.30	6.67	0.0003	0.0430	0.0000	0.0182	73.24
1	2	5	2	30.5	30.5	100	33	8.10	7.00	5.20	0.0083	0.0099	0.0732	0.0182	3.36
1	2	5	3	30.5	30.5	110	33	8.05	7.60	5.30	0.0088	0.0077	0.0000	0.0182	3.64
1	2	6	2	32.5	31.0	30	35	7.70	7.10	7.50	0.0108	0.0504	0.0000	0.0545	77.72
1	2	6	3	32.5	30.8	30	35	7.70	6.40	7.30	0.0169	0.0288	0.0000	0.0531	107.24
1	2	7	2	33.0	32.4	30	33	7.60	7.80	11.18	0.0098	0.0310	0.0442	0.0153	90.80
1	2	7	3	33.0	32.0	23	34	7.30	6.70	11.68	0.0084	0.0310	0.0635	0.0167	190.36
1	2	8	2	30.0	30.0	30	34	7.70	7.70	9.70	0.0066	0.0965	0.0442	0.1273	168.32
1	2	8	3	30.0	30.0	30	34	7.70	7.20	9.72	0.0103	0.0654	0.0442	0.0167	140.64
1	2	9	2	31.5	30.0	20	34	7.50	10.50	9.30	0.0060	0.0243	0.0083	0.0211	179.08
1	2	9	3	31.5	30.2	33	34	7.70	9.40	6.02	0.0060	0.0271	0.3726	0.0225	171.48
1	2	10	2	30.0	29.6	30	33	8.30	7.88	12.10	0.1000	0.0243	0.1815	0.0007	227.32
1	2	10	3	30.0	29.6	25	33	8.10	7.06	9.36	0.0140	0.0327	0.2135	0.0414	130.96
1	3	1	2	26.0	32.5	50	32	8.65	6.70	3.65	0.0085	0.0360	0.0000	0.0124	-
1	3	1	3	26.0	32.5	50	32	8.65	6.30	2.87	0.0065	0.0687	0.0000	0.0065	-
1	3	2	2	28.0	30.5	60	35	8.85	8.50	7.20	0.0112	0.0576	0.0029	0.4790	-
1	3	2	3	28.0	31.5	55	36	8.60	8.20	8.88	0.0098	0.0854	0.0076	0.4640	-
1	3	3	2	29.0	29.5	60	35	8.60	9.10	7.10	0.0114	0.0227	0.0000	0.0290	-
1	3	3	3	28.0	29.5	55	33	8.60	8.20	7.10	0.0102	0.0399	0.0000	0.0250	-
1	3	4	2	30.0	30.5	35	31	8.30	8.80	6.00	0.0006	0.0540	0.0009	0.0356	-
1	3	4	3	30.5	30.5	40	31	8.30	9.00	6.96	0.0011	0.0220	0.0000	0.0400	62.92
1	3	5	2	31.0	31.0	40	30	8.20	10.00	4.50	0.0088	0.0110	0.0009	0.0225	10.88
1	3	5	3	31.0	30.7	110	35	7.90	9.10	7.10	0.0090	0.0138	0.0000	0.0284	6.32
1	3	6	2	31.0	31.0	40	33	7.55	6.30	6.20	0.0075	0.0415	0.0000	0.0298	74.56
1	3	6	3	31.0	31.0	40	33	7.50	6.10	6.10	0.0109	0.0327	0.0000	0.0269	74.04
1	3	7	2	33.0	32.5	35	34	7.55	7.50	11.98	0.0076	0.0254	0.0263	0.0000	168.44
1	3	7	3	32.0	32.0	30	34	7.65	8.50	10.38	0.0080	0.0482	0.0968	0.0000	171.36
1	3	8	2	31.0	30.0	53	34	7.50	7.10	5.66	0.0091	0.0415	0.3674	0.0356	21.60
1	3	8	3	31.0	30.5	65	34	7.40	7.80	4.86	0.0136	0.0288	0.3418	0.0473	38.48
1	3	9	2	31.0	30.2	45	33	7.60	10.90	9.98	0.0061	0.0238	0.2584	0.0342	135.00
1	3	9	3	31.0	29.9	45	33	7.60	7.80	9.00	0.0068	0.0238	0.3803	0.0065	136.34
1	3	10	2	30.0	29.9	35	32	8.30	6.74	10.58	0.0094	0.0265	0.0096	0.0269	160.96
1	3	10	3	30.0	29.9	30	32	8.20	6.05	11.60	0.0114	0.0315	0.0648	0.0284	141.32
1	4	1	2	26.0	32.0	90	32	8.65	6.70	2.60	0.0070	0.0066	0.0000	0.0007	-
1	4	1	3	26.0	32.0	90	32	8.60	6.20	2.20	0.0040	0.0132	0.1461	0.0007	-
1	4	2	2	28.0	30.0	65	35	8.70	7.20	3.90	0.0124	0.0410	0.0000	0.6260	-
1	4	2	3	28.0	30.5	65	36	8.25	7.10	4.01	0.0091	0.0521	0.0000	0.4200	-
1	4	3	2	27.0	28.5	57	34	8.45	7.90	1.60	0.0101	0.0204	0.0000	0.0330	-
1	4	3	3	27.0	28.5	45	34	8.40	7.50	5.50	0.0183	0.0204	0.0274	0.0290	-
1	4	4	2	30.0	30.5	55	30	8.50	7.50	5.53	0.0004	0.0330	0.0000	0.0153	61.08
1	4	4	3	30.0	30.5	70	30	8.50	7.20	5.91	0.0006	0.0540	0.1182	0.0182	54.04
1	4	5	2	30.0	30.5	110	32	8.20	11.20	8.40	0.0067	0.0016	0.0394	0.0298	10.44
1	4	5	3	30.0	30.5	110	35	8.10	11.20	8.10	0.0074	0.0049	0.0591	0.0444	33.32
1	4	6	2	32.5	31.5	35	35	7.65	6.80	7.70	0.0089	0.0510	0.0000	0.0429	175.84
1	4	6	3	32.5	32.4	40	33	7.50	6.00	6.90	0.0080	0.0699	0.0000	0.0284	149.56
1	4	7	2	32.5	32.0	35	34	7.40	7.00	6.78	0.0086	0.0260	0.3059	0.0516	197.04
1	4	7	3	33.0	32.5	35	34	7.50	6.70	10.98	0.0064	0.0660	0.2302	0.0371	85.36
1	4	8	2	31.5	30.5	38	33	8.10	7.80	16.58	0.0107	0.0421	0.0019	0.0604	247.84

F A R M	P O N D	D A T E	LOC.	A.T. C	W.T. C	TRAN. cm.	SAL. ppt.	pH	D.O. ppm.	BOO ppm.	TSS g/100ml	NO3 ppm.	NH3 ppm.	PO4 ppm.	CHL a ug/L
1	4	8	3	31.5	30.5	45	33	8.15	7.40	17.80	0.0169	0.0327	0.0058	0.0676	174.48
1	4	9	2	-	-	-	-	-	-	-	-	-	-	-	-
1	4	9	3	-	-	-	-	-	-	-	-	-	-	-	-
1	4	10	2	-	-	-	-	-	-	-	-	-	-	-	-
1	4	10	3	-	-	-	-	-	-	-	-	-	-	-	-
1	5	1	2	26.0	32.5	85	32	8.70	6.80	4.23	0.0050	0.0177	0.0000	0.0022	-
1	5	1	3	26.0	32.0	95	32	8.65	6.30	2.20	0.0061	0.0082	0.0000	0.0007	-
1	5	2	2	28.0	30.5	65	35	8.40	7.50	4.24	0.0077	0.0584	0.0000	0.4640	-
1	5	2	3	28.0	31.5	65	36	8.15	7.23	4.88	0.0110	0.1132	0.0038	0.5530	-
1	5	3	2	29.5	28.0	65	34	8.45	8.20	4.10	0.0850	0.0082	0.0000	0.0120	-
1	5	3	3	29.0	28.5	50	34	8.45	7.90	4.00	0.0100	0.0210	0.0000	0.0240	-
1	5	4	2	30.0	30.5	60	30	8.60	7.20	6.13	0.0017	0.0390	0.0000	0.0269	78.84
1	5	4	3	29.5	31.0	55	30	8.40	8.50	6.67	0.0002	0.0310	0.0000	0.0211	97.20
1	5	5	2	30.0	31.2	65	38	7.90	7.90	6.10	0.0098	0.0032	0.1407	0.0269	3.04
1	5	5	3	30.0	31.2	110	35	7.85	8.50	5.00	0.0079	0.0110	0.0947	0.0138	-
1	5	6	2	32.0	31.4	40	32	8.35	10.00	6.70	0.0092	0.0504	0.0000	0.0574	114.92
1	5	6	3	32.0	31.9	50	33	8.20	8.70	9.90	0.0073	0.0221	0.0000	0.0444	137.56
1	5	7	2	32.5	31.5	55	34	7.70	7.50	12.58	0.0065	0.0071	0.0378	0.0211	138.20
1	5	7	3	32.0	32.1	55	34	7.60	6.70	11.18	0.0068	0.0077	0.0327	0.0080	142.04
1	5	8	2	32.0	31.0	47	33	7.50	6.80	8.90	0.0091	0.0299	0.3303	0.0400	25.44
1	5	8	3	32.0	31.0	50	33	7.60	7.70	6.88	0.0078	0.0365	0.4021	0.0240	86.48
1	5	9	2	30.5	30.2	40	33	7.70	11.00	6.96	0.0076	0.0154	0.3303	0.0124	113.96
1	5	9	3	30.5	30.4	45	34	7.30	9.60	5.30	0.0078	0.0254	0.2264	0.0248	57.92
1	5	10	2	30.0	30.2	35	29	8.40	7.06	13.82	0.0106	0.0388	0.3726	0.0211	121.88
1	5	10	3	30.0	30.2	37	29	8.30	6.60	11.80	0.0079	0.0687	0.3713	0.0000	220.68
2	-	1	1	30.0	32.5	130	33	8.00	6.11	2.00	0.0021	0.0093	0.0000	0.2000	-
2	-	1	1	30.0	32.0	130	35	8.00	6.00	1.05	0.0020	0.0321	0.0113	0.1260	-
2	-	1	1	30.5	31.5	130	34	8.10	6.58	0.86	0.0098	0.4752	0.3959	0.2140	-
2	-	2	1	29.5	30.0	70	31	7.70	6.80	1.25	0.0038	0.0016	0.0000	0.0000	-
2	-	2	1	28.0	30.0	65	28	7.60	6.80	1.67	0.0050	0.0000	0.0000	0.0090	-
2	-	2	1	29.5	29.0	80	26	7.60	7.00	1.47	0.0061	0.0360	0.0000	0.0820	-
2	-	3	1	34.0	33.5	130	30	8.15	6.70	1.35	0.0058	0.0450	0.0460	0.0670	2.92
2	-	3	1	34.0	33.0	130	26	8.10	7.20	1.54	0.0040	0.0480	0.0440	0.0000	3.40
2	-	3	1	34.0	33.5	130	30	8.10	6.80	1.29	0.0063	0.0860	0.0460	0.0090	6.04
2	-	4	1	30.0	32.0	80	28	8.10	7.70	3.33	0.0057	0.0088	0.0000	0.0095	5.04
2	-	4	1	30.5	31.5	60	25	8.15	7.20	3.29	0.0069	0.0000	0.0000	0.0036	2.56
2	-	4	1	30.0	32.0	88	27	8.00	9.10	3.47	0.0058	0.0338	0.0000	0.0167	3.28
2	-	5	1	30.0	29.2	100	29	7.90	6.80	0.50	0.0032	0.0132	0.0000	0.0000	4.28
2	-	5	1	30.0	28.3	85	33	7.90	7.40	1.00	0.0053	0.0193	0.0000	0.0000	3.12
2	-	5	1	30.0	29.6	80	32	7.90	8.20	1.36	0.0051	0.0188	0.0000	0.0000	5.44
2	-	6	1	32.5	30.7	105	31	7.90	6.80	1.20	0.0026	0.0254	0.0000	0.0022	2.96
2	-	6	1	34.0	31.0	130	28	7.65	6.00	1.90	0.0004	0.0138	0.0000	0.0000	9.00
2	-	6	1	34.0	31.1	95	31	7.95	6.10	1.50	0.0044	0.0104	0.0000	0.0000	9.64
2	-	7	1	32.0	31.5	87	27	7.40	7.40	3.18	0.0075	0.0382	0.0083	0.0065	14.48
2	-	7	1	33.0	32.2	85	31	7.45	7.00	2.58	0.0009	0.0515	0.0250	0.0240	10.36
2	-	7	1	32.0	31.8	100	27	7.60	7.90	5.78	0.0014	0.0304	0.0468	0.0080	7.52
2	-	8	1	32.0	31.0	130	29	8.00	6.87	0.32	0.0048	0.0125	0.0045	0.0095	5.04
2	-	8	1	33.0	32.0	80	30	8.00	8.59	0.52	0.0049	0.0177	0.0199	0.0080	6.32
2	-	8	1	32.0	32.5	75	30	8.30	9.80	0.34	0.0043	0.0165	0.0147	0.0022	-
2	-	9	1	30.0	31.2	75	30	8.10	10.00	2.83	0.0071	0.0060	0.0000	0.0000	3.12
2	-	9	1	30.0	30.2	66	27	8.40	9.60	2.63	0.0056	0.0171	0.0006	0.0000	2.76
2	-	9	1	30.0	30.5	83	31	8.20	10.10	1.01	0.0044	0.0104	0.3046	0.0000	4.04
2	-	10	1	28.0	28.9	34	19	7.20	5.50	0.52	0.0086	0.0204	0.1186	0.0036	17.20
2	-	10	1	28.0	27.3	21	18	7.40	7.70	0.52	0.0153	0.0327	0.1353	0.0080	8.68
2	-	10	1	28.0	28.3	37	24	6.80	7.90	0.52	0.0107	0.0249	0.1327	0.0342	13.92
2	-	11	1	31.0	30.2	90	22	7.60	8.30	1.22	0.0031	0.0000	0.1635	0.0051	9.36
2	-	11	1	31.0	31.0	57	20	7.35	8.20	0.40	0.0050	0.0243	0.1520	0.0138	16.32
2	-	11	1	31.0	31.0	75	20	7.60	9.30	0.10	0.0011	0.0304	1.0677	0.0007	8.24
2	-	12	1	27.0	29.5	90	22	8.05	9.59	2.52	0.0043	0.0000	0.0737	0.0531	29.60
2	-	12	1	30.0	30.5	65	19	7.95	7.70	1.72	0.0075	0.0000	0.1622	0.0385	18.24
2	-	12	1	28.0	30.5	70	17	7.25	8.17	7.98	0.0032	0.0000	0.1507	0.0298	28.32

F A R M	P O N D	D A T E	LOC.	A.T. C	W.T. C	TRAN. cm.	SAL. ppt.	pH	D.O. ppm.	BOD ppm.	TSS g/100ml	NO3 ppm.	NH3 ppm.	PO4 ppm.	CHL a ug/L
2	-	13	1	26.0	27.5	77	23	7.65	7.50	1.40	0.0027	0.0104	0.1507	0.0080	-
2	-	13	1	27.0	27.5	72	24	7.75	7.70	0.80	0.0009	0.1238	0.1238	0.0240	-
2	-	13	1	26.0	28.3	47	22	7.60	7.10	0.50	0.0034	0.0382	0.1738	0.0284	-
2	6	1	2	30.5	31.5	120	34	8.10	6.39	2.20	0.0104	0.0243	0.0000	0.1560	-
2	6	1	3	33.0	32.0	120	34	8.40	5.91	1.52	0.0059	0.0127	0.0123	0.2730	-
2	6	2	2	29.0	30.5	76	32	7.70	6.70	4.10	0.0025	0.0000	0.0000	0.0820	-
2	6	2	3	31.0	30.0	85	32	7.70	6.70	4.96	0.0066	0.0000	0.0000	0.1700	-
2	6	3	2	34.0	33.0	110	31	8.45	6.30	3.91	0.0063	0.0440	0.0460	0.1410	1.56
2	6	3	3	34.0	32.5	100	30	8.45	6.30	4.58	0.0065	0.0470	0.0500	0.1120	7.60
2	6	4	2	30.0	28.0	80	32	8.20	7.30	3.95	0.0050	0.0204	0.0000	0.0051	4.40
2	6	4	3	30.0	31.0	70	30	8.25	7.50	4.19	0.0057	0.0121	0.0000	0.0167	7.32
2	6	5	2	30.0	28.0	50	31	8.20	6.60	6.40	0.0057	0.0432	0.0000	0.0095	25.00
2	6	5	3	30.0	28.2	55	31	8.10	6.70	5.90	0.0118	0.0515	0.0000	0.0211	16.36
2	6	6	2	31.0	30.0	55	33	8.10	6.10	6.50	0.0018	0.0165	0.0058	0.0000	74.24
2	6	6	3	33.0	30.3	115	34	8.05	6.00	6.00	0.0021	0.0210	0.0032	0.0371	50.60
2	6	7	2	32.5	32.0	50	31	7.60	7.20	7.78	0.0032	0.0482	0.0391	0.0182	106.80
2	6	7	3	33.0	31.8	55	31	7.60	7.00	9.98	0.0047	0.0465	0.0378	0.0284	157.32
2	6	8	2	32.0	32.0	72	29	8.80	8.39	7.20	0.0039	0.0027	0.0635	0.0240	38.04
2	6	8	3	32.0	31.0	60	30	8.90	8.80	6.00	0.0051	0.0232	0.4701	0.0153	39.24
2	6	9	2	30.0	30.4	65	30	7.90	9.00	5.05	0.0058	0.0116	0.3046	0.0269	32.08
2	6	9	3	30.0	30.5	64	30	7.90	8.80	3.45	0.0065	0.0082	0.1302	0.0196	43.20
2	6	10	2	28.0	27.6	42	26	7.50	6.70	5.76	0.0075	0.0188	0.0866	0.0269	152.76
2	6	10	3	28.0	28.3	40	26	7.90	7.80	6.56	0.0118	0.0215	0.0648	0.0342	205.48
2	6	11	2	31.0	30.0	53	20	8.05	8.10	6.88	0.0042	0.0027	0.0776	0.0000	67.48
2	6	11	3	31.0	30.1	50	20	8.15	10.30	9.08	0.0035	0.0000	0.0814	0.0240	117.08
2	6	12	2	30.5	30.0	48	22	8.50	9.18	13.62	0.0104	0.0000	0.0891	0.0473	386.36
2	6	12	3	29.5	29.0	45	22	8.50	8.98	15.04	0.0146	0.0000	0.0609	0.0662	501.48
2	6	13	2	26.5	25.6	35	21	8.10	8.30	8.60	0.0060	0.0865	0.1392	0.0604	-
2	6	13	3	26.5	25.5	36	21	8.10	8.50	8.40	0.0050	0.0621	0.1597	0.0749	-
2	7	1	2	33.0	32.0	115	34	8.30	6.67	1.81	0.0059	0.0121	0.0000	0.2440	-
2	7	1	3	30.0	32.0	115	34	8.00	6.39	1.24	0.0035	0.0110	0.0000	0.0820	-
2	7	2	2	29.0	30.0	85	32	7.90	6.70	3.89	0.0018	0.0010	0.0000	0.1260	-
2	7	2	3	29.0	30.0	80	32	7.80	6.70	4.27	0.0055	0.0021	0.0000	0.0530	-
2	7	3	2	34.0	32.0	85	30	8.65	5.70	3.72	0.0081	0.0380	0.0600	0.1410	6.24
2	7	3	3	34.0	32.5	80	30	8.70	6.80	4.38	0.0061	0.0480	0.0550	0.1560	6.24
2	7	4	2	30.0	28.0	61	32	7.90	7.90	4.92	0.0001	0.0182	0.0000	0.0153	10.24
2	7	4	3	31.0	30.5	70	30	7.88	8.50	5.01	0.0217	0.0210	0.0000	0.0196	13.76
2	7	5	2	29.0	28.3	57	31	8.00	6.40	4.50	0.0045	0.0071	0.0000	0.0022	26.68
2	7	5	3	29.5	28.5	60	31	7.10	6.30	3.80	0.0045	0.0221	0.0000	0.0095	22.72
2	7	6	2	28.0	30.0	125	30	8.25	6.00	4.20	0.0007	0.0171	0.0000	0.0196	43.64
2	7	6	3	32.0	30.7	55	33	8.05	5.80	4.40	0.0014	0.0787	0.0737	0.0036	58.12
2	7	7	2	33.0	32.0	55	30	7.60	6.80	5.38	0.0031	0.0410	0.0224	0.0240	68.48
2	7	7	3	31.0	30.7	58	31	7.60	7.60	6.18	0.0045	0.0071	0.0378	0.0007	88.28
2	7	8	2	33.0	32.0	74	29	8.70	6.17	5.78	0.0061	0.0304	0.1712	0.0138	28.76
2	7	8	3	33.0	31.0	55	29	8.70	6.06	6.60	0.0049	0.0000	0.3444	0.0153	24.84
2	7	9	2	30.0	29.9	35	33	7.90	12.50	10.65	0.0083	0.0004	0.1289	0.0000	63.40
2	7	9	3	30.0	29.5	34	32	8.40	12.20	11.13	0.0081	0.0000	0.0096	0.0000	75.88
2	7	10	2	28.0	27.5	35	26	7.20	8.50	6.78	0.0089	0.0321	0.5804	0.0298	164.44
2	7	10	3	28.0	27.7	32	27	6.90	8.10	5.76	0.0128	0.0332	0.4842	0.0240	190.80
2	7	11	2	31.0	30.2	40	20	7.75	9.30	10.88	0.0071	0.0000	0.1097	0.0036	196.60
2	7	11	3	31.0	30.0	40	19	7.90	10.00	11.30	0.0068	0.0049	0.1186	0.0095	182.64
2	7	12	2	30.0	29.0	64	20	7.70	4.54	10.40	0.0064	0.0000	0.5149	0.0633	108.88
2	7	12	3	28.0	29.0	60	20	7.80	5.35	7.78	0.0063	0.0000	0.4585	0.0589	75.16
2	7	13	2	26.0	25.0	62	19	8.05	7.60	6.80	0.0042	0.0343	0.1289	0.0225	-
2	7	13	3	25.8	25.0	60	19	8.05	7.90	7.60	0.0034	0.0415	0.1276	0.0516	-
2	8	1	2	30.0	32.5	120	35	8.20	6.29	1.62	0.0043	0.0132	0.0000	0.2140	-
2	8	1	3	30.0	32.0	120	35	8.20	6.19	1.17	0.0019	0.0066	0.0000	0.1560	-
2	8	2	2	30.0	30.5	90	32	7.90	6.70	4.70	0.0052	0.0000	0.0131	0.0530	-
2	8	2	3	31.0	30.0	90	32	7.90	6.40	5.45	0.0015	0.0000	0.1407	0.0670	-
2	8	3	2	33.0	33.0	77	31	8.25	5.80	5.43	0.0002	0.0360	0.0350	0.0530	5.68
2	8	3	3	33.0	32.5	70	29	8.25	6.30	4.86	0.0040	0.0360	0.0400	0.1120	4.68

F A R M	P O N D	D A T E	LOC.	A.T. C	W.T. C	TRAN. cm.	SAL. ppt.	pH	D.O. ppm.	BOD ppm.	TSS g/100ml	NO3 ppm.	NH3 ppm.	PO4 ppm.	CHL a ug/L
3	10	3	3	31.0	30.0	55	23	8.00	5.80	4.10	0.0027	0.0000	0.0103	0.0153	28.04
3	10	4	2	31.0	30.1	50	25	8.10	6.70	7.20	0.0045	0.0227	0.0000	0.0327	37.12
3	10	4	3	31.0	29.8	50	24	8.00	5.60	6.60	0.0040	0.0410	0.0000	0.0400	45.84
3	10	5	2	31.0	30.8	55	20	8.30	7.90	3.90	0.0048	0.0254	0.0000	0.0225	29.80
3	10	5	3	31.0	30.8	55	20	8.35	6.80	3.80	0.0070	0.0204	0.0000	0.0196	37.96
3	10	6	2	32.0	31.0	45	21	8.15	8.50	9.70	0.0057	0.0432	0.0263	0.0153	-
3	10	6	3	31.0	30.5	30	20	8.10	7.90	9.98	0.0069	0.1393	0.0532	0.0167	85.56
3	10	7	2	30.0	28.2	33	18	7.70	6.80	6.88	0.0029	0.0221	0.3097	0.0327	65.00
3	10	7	3	30.0	28.1	33	18	7.70	5.50	6.45	0.0028	0.0426	0.3341	0.0298	61.04
3	10	8	2	28.0	29.5	35	15	7.90	9.10	6.82	0.0063	0.0460	0.7458	0.0284	179.20
3	10	8	3	28.0	29.4	42	15	7.90	8.50	5.26	0.0057	0.1743	0.7830	0.0604	127.96
3	10	9	2	27.0	25.9	45	19	7.40	10.00	7.36	0.0037	0.0249	1.4563	0.1011	56.04
3	10	9	3	27.0	26.1	45	18	7.50	11.20	5.98	0.0054	0.0327	1.5089	0.0982	61.80
3	10	10	2	28.0	28.0	35	13	6.95	6.80	2.53	0.0064	0.0132	1.8320	0.0560	21.24
3	10	10	3	28.0	27.9	35	13	7.15	6.80	3.33	0.0073	0.0260	1.9960	0.0545	61.52
3	11	1	2	30.5	30.0	67	20	8.60	7.20	3.24	0.0111	0.0088	0.2200	0.0060	-
3	11	1	3	31.0	30.5	60	19	8.35	7.60	3.43	0.0114	0.0038	0.2480	0.0130	-
3	11	2	2	30.0	29.0	65	22	8.55	7.50	4.67	0.0040	0.0204	0.0469	0.0000	-
3	11	2	3	30.5	30.0	65	24	8.40	8.00	4.26	0.0041	0.0232	0.2120	0.0284	-
3	11	3	2	31.5	31.0	60	22	8.60	8.50	6.67	0.0054	0.0099	0.2373	0.0065	52.80
3	11	3	3	32.0	31.5	45	23	8.40	8.30	6.39	0.0039	0.0204	0.0628	0.0051	54.92
3	11	4	2	30.5	30.0	45	25	8.10	6.90	7.40	0.0032	0.0393	0.0000	0.0458	35.76
3	11	4	3	30.5	30.1	40	25	8.10	6.30	6.80	0.0030	0.0310	0.0000	0.0182	42.80
3	11	5	2	32.0	31.0	55	20	8.50	7.60	5.30	0.0071	0.0215	0.0000	0.0225	48.32
3	11	5	3	32.0	30.5	60	20	8.45	7.50	4.70	0.0052	0.0404	0.0000	0.0269	40.88
3	11	6	2	30.0	29.0	70	20	8.00	7.10	4.78	0.0071	0.0304	0.0289	0.0051	69.44
3	11	6	3	30.0	29.9	70	22	8.05	8.10	3.18	0.0070	0.0000	0.0186	0.0000	16.96
3	11	7	2	30.0	28.0	35	19	8.00	6.20	11.32	0.0120	0.1032	0.0853	0.0385	56.16
3	11	7	3	30.0	28.0	35	19	8.20	6.00	13.12	0.0086	0.0382	0.1020	0.0589	88.16
3	11	8	2	28.0	29.4	35	17	8.00	10.10	7.92	0.0021	0.0549	0.4354	0.0240	189.40
3	11	8	3	29.0	29.6	40	17	8.10	10.50	7.88	0.0024	0.0204	0.3341	0.0124	194.00
3	11	9	2	27.0	25.8	42	17	7.90	12.20	6.58	0.0074	0.0293	1.3460	0.0414	235.48
3	11	9	3	27.0	26.2	40	17	8.10	12.00	5.36	0.0054	0.0876	1.4990	0.0240	135.76
3	11	10	2	29.0	28.0	38	13	7.90	7.50	5.13	0.0057	0.0488	0.9320	0.0057	110.12
3	11	10	3	29.0	28.0	38	13	7.60	8.30	1.71	0.0077	0.0876	1.1890	0.0109	162.56
4	-	1	1	33.0	30.0	40	17	8.40	7.80	1.81	0.0037	0.0321	0.0075	0.0000	14.84
4	-	2	1	30.5	30.9	45	35	8.00	6.80	1.50	0.0057	0.0471	0.0000	0.0618	8.72
4	-	3	1	32.0	31.4	35	12	8.35	6.10	2.50	0.0040	0.0393	0.0000	0.0000	54.00
4	-	4	1	33.0	32.0	28	4	8.30	8.40	3.98	0.0072	0.0116	0.0327	0.0095	28.60
4	-	5	1	30.0	29.7	70	30	8.20	5.70	2.20	0.0069	0.0138	0.0000	0.0065	33.80
4	-	6	1	28.0	30.3	30	24	8.10	8.70	3.12	0.0045	0.0360	0.0122	0.0000	14.12
4	-	7	1	28.0	26.7	55	27	8.40	12.00	4.14	0.0100	0.0104	0.1635	0.0182	28.40
4	-	8	1	29.0	29.5	35	14	8.00	13.10	1.93	0.0057	0.0165	0.0000	0.0298	17.32
4	-	9	1	29.0	29.5	30	8	8.30	8.17	3.44	0.0107	0.0000	0.2600	0.0400	51.96
4	12	1	2	32.0	31.0	45	33	8.75	7.70	3.62	0.0070	0.0000	0.0000	0.0036	11.64
4	12	1	3	33.0	31.0	34	33	8.72	7.60	4.48	0.0026	0.0000	0.0000	0.0036	23.28
4	12	2	2	31.0	30.5	75	33	8.70	7.40	6.00	0.0049	0.0188	0.0000	0.1912	29.60
4	12	2	3	29.0	30.0	53	35	8.65	7.40	7.40	0.0089	0.0310	0.0000	0.0589	58.60
4	12	3	2	32.0	31.0	70	28	8.55	6.20	7.60	0.0063	0.0199	0.0000	0.0036	48.40
4	12	3	3	32.0	31.2	50	26	8.50	6.20	6.70	0.0088	0.0227	0.0000	0.0065	52.44
4	12	4	2	32.0	31.2	35	17	8.40	11.90	14.98	0.0066	0.0921	0.0366	0.0211	141.76
4	12	4	3	31.0	30.5	35	19	8.40	12.10	16.98	0.0063	0.0032	0.0353	0.0022	155.96
4	12	5	2	30.0	27.8	40	21	8.20	5.50	13.14	0.0025	0.0227	0.0199	0.0182	106.68
4	12	5	3	30.0	28.6	35	21	8.10	4.80	13.14	0.0045	0.0199	0.0032	0.0284	95.60
4	12	6	2	28.0	29.1	30	21	7.90	7.70	5.04	0.0033	0.0565	0.8715	0.0298	103.16
4	12	6	3	28.0	29.3	25	22	7.90	8.60	6.70	0.0074	0.1470	0.0000	0.0196	62.04
4	12	7	2	28.0	25.7	25	19	8.50	11.00	7.98	0.0213	0.0471	1.2781	0.1694	120.72
4	12	7	3	28.0	26.0	23	19	8.70	12.60	17.06	0.0140	0.1693	1.2601	0.2378	171.00
4	12	8	2	28.0	28.5	35	15	7.25	7.20	4.73	0.0133	0.1254	1.3322	0.0516	194.12
4	12	8	3	28.0	29.0	32	15	7.20	6.90	6.75	0.0165	0.0538	1.2810	0.0851	244.00
4	12	9	2	29.0	30.0	20	15	8.60	14.02	12.32	0.0192	0.0088	0.4021	0.0734	299.84

F A R M	P O N D	D A T E	LOC.	A.T. C	W.T. C	TRAN. cm.	SAL. ppt.	pH	D.O. ppm.	BOD ppm.	TSS g/100mL	NO3 ppm.	NH3 ppm.	PO4 ppm.	CHL a ug/L
2	8	4	2	30.0	28.0	73	32	7.80	7.80	4.38	0.0073	0.0243	0.0000	0.0065	4.96
2	8	4	3	30.0	31.0	80	29	8.25	8.20	5.14	0.0082	0.0082	0.0000	0.0051	15.04
2	8	5	2	29.5	28.0	62	33	8.20	6.30	5.00	0.0041	0.0221	0.0000	0.0036	9.08
2	8	5	3	29.5	28.4	90	32	8.10	6.10	3.90	0.0031	0.0304	0.0000	0.0196	26.56
2	8	6	2	34.0	30.5	115	30	8.25	5.90	6.62	0.0053	0.0143	0.0000	0.0124	91.20
2	8	6	3	32.5	30.4	120	30	8.25	6.90	7.00	0.0035	0.0282	0.0000	0.0313	80.64
2	8	7	2	32.5	32.0	65	31	7.60	6.40	7.38	0.0017	0.0499	0.0199	0.0124	68.76
2	8	7	3	32.5	31.7	65	32	7.60	6.30	9.98	0.0026	0.0332	0.0224	0.0255	82.24
2	8	8	2	32.5	32.0	57	31	8.60	10.00	8.20	0.0082	0.0204	0.2636	0.0153	112.48
2	8	8	3	32.5	31.5	45	31	8.60	9.50	9.02	0.0055	0.0199	0.2597	0.0225	109.36
2	8	9	2	30.0	30.2	95	30	8.10	7.90	2.83	0.0047	0.0143	0.1610	0.0007	20.44
2	8	9	3	30.0	30.4	79	30	8.10	7.60	2.43	0.0066	0.0088	0.1507	0.0065	18.36
2	8	10	2	28.0	28.4	50	25	7.00	5.90	7.58	0.0060	0.0199	0.1699	0.0284	55.84
2	8	10	3	28.0	28.4	48	26	7.00	5.50	6.78	0.0084	0.0268	0.1892	0.0400	86.20
2	8	11	2	31.0	30.2	35	20	7.75	8.40	11.14	0.0071	0.0000	0.1302	0.0007	140.60
2	8	11	3	31.0	30.2	37	20	7.85	8.10	11.34	0.0070	0.0000	0.1315	0.0000	138.96
2	8	12	2	29.0	29.0	40	22	8.25	8.25	12.62	0.0103	0.0000	0.5650	0.0720	261.64
2	8	12	3	29.0	29.0	45	22	8.25	9.18	10.20	0.0101	0.0082	0.4649	0.0589	209.36
2	8	13	2	25.9	26.0	52	20	7.95	7.80	8.60	0.0044	0.0172	0.2289	0.0604	-
2	8	13	3	25.9	26.0	50	20	7.90	7.30	9.60	0.0059	0.0321	0.1853	0.0255	-
2	9	1	2	30.0	32.5	120	35	8.20	6.48	1.52	0.0028	0.0082	0.0000	0.2000	-
2	9	1	3	30.0	32.0	120	36	8.60	6.67	1.81	0.0022	0.0177	0.0000	0.1700	-
2	9	2	2	33.0	30.0	100	32	7.80	6.20	3.91	0.0041	0.0032	0.0000	0.1410	-
2	9	2	3	32.0	30.5	100	32	7.80	6.50	4.58	0.0046	0.0000	0.0000	0.0530	-
2	9	3	2	35.0	33.0	95	30	8.60	6.30	5.15	0.0058	0.0450	0.0290	0.1700	5.96
2	9	3	3	34.0	33.0	90	31	8.60	6.40	4.96	0.0045	0.0590	0.0370	0.0530	3.12
2	9	4	2	30.0	29.0	98	32	7.80	7.20	4.13	0.0081	0.0299	0.0000	0.0211	6.20
2	9	4	3	30.0	31.0	75	29	8.30	7.50	4.38	0.0069	0.0027	0.0000	0.0080	16.96
2	9	5	2	29.0	28.1	70	35	8.00	6.60	4.40	0.0087	0.0093	0.0000	0.0022	17.04
2	9	5	3	29.0	28.4	85	33	8.00	5.30	3.50	0.0084	0.0043	0.0000	0.0080	-
2	9	6	2	31.0	30.8	120	30	8.00	5.90	6.80	0.0047	0.0099	0.0000	0.0080	78.00
2	9	6	3	33.0	30.6	120	30	8.05	6.30	7.83	0.0006	0.0282	0.0000	0.0140	70.56
2	9	7	2	32.0	32.0	60	32	7.50	6.30	9.98	0.0047	0.0582	0.0109	0.0211	111.84
2	9	7	3	33.0	32.2	65	31	7.50	6.30	11.18	0.0024	0.0499	0.0340	0.0400	133.20
2	9	8	2	32.0	31.5	45	30	8.60	7.98	11.66	0.0076	0.0265	0.2405	0.0327	133.36
2	9	8	3	32.0	31.5	33	31	8.60	9.10	12.86	0.0069	0.0410	0.0366	0.0356	136.56
2	9	9	2	30.0	31.4	34	30	8.40	13.50	10.71	0.0065	0.0000	0.0173	0.0000	171.88
2	9	9	3	30.0	30.6	48	30	8.40	11.60	9.49	0.0068	0.0000	0.0000	0.0000	165.36
2	9	10	2	28.0	28.2	58	19	7.50	5.60	5.36	0.0073	0.0260	0.4444	0.0138	50.04
2	9	10	3	28.0	28.6	54	26	7.00	6.00	5.76	0.0183	0.0227	0.4662	0.0560	72.68
2	9	11	2	31.0	30.5	50	20	8.05	7.70	9.08	0.0044	0.0000	0.0866	0.0051	87.36
2	9	11	3	31.0	30.8	50	19	8.05	8.00	9.08	0.0045	0.0000	0.0763	0.0385	83.88
2	9	12	2	28.0	29.0	48	22	8.45	9.79	11.80	0.0072	0.0000	0.0699	0.0487	183.12
2	9	12	3	28.0	29.0	50	22	8.40	9.38	12.02	0.0086	0.0000	0.0776	0.0545	176.88
2	9	13	2	25.8	26.0	47	21	7.95	8.10	6.80	0.0042	0.0293	0.5624	0.0327	-
2	9	13	3	26.0	26.1	45	21	7.85	7.80	7.80	0.0066	0.0327	0.4277	0.0388	-
3	-	1	1	31.0	30.5	85	25	7.90	7.60	1.05	0.0052	0.0143	0.0470	0.0740	-
3	-	2	1	31.0	30.0	90	32	8.35	7.50	2.30	0.0070	0.0282	0.0516	0.0225	-
3	-	3	1	33.0	30.0	75	20	7.50	5.90	1.14	0.0032	0.0249	0.0713	0.0065	37.36
3	-	4	1	30.0	30.7	48	8	7.50	6.00	2.70	0.0009	0.0243	0.0000	0.0734	32.44
3	-	5	1	32.0	31.7	75	20	7.80	7.40	1.30	0.0040	0.0582	0.0000	0.0000	25.12
3	-	6	1	31.0	30.8	60	11	8.00	8.40	4.58	0.0141	0.0315	0.0468	0.0007	-
3	-	7	1	30.0	29.2	55	22	7.50	5.00	3.84	0.0012	0.0182	0.0353	0.0051	17.84
3	-	8	1	29.0	31.1	70	28	8.00	8.20	1.18	0.0058	0.0304	0.0584	0.0000	10.64
3	-	9	1	27.0	26.0	40	12	7.90	10.10	2.54	0.0056	0.0265	0.1662	0.6211	31.36
3	-	10	1	29.0	28.0	35	8	8.05	8.90	2.33	0.0061	0.0049	0.0000	0.0138	26.24
3	10	1	2	31.5	30.3	75	22	7.80	4.70	3.14	0.0059	0.0088	0.5380	0.0050	-
3	10	1	3	31.0	30.4	65	22	7.90	5.40	3.62	0.0088	0.0082	0.5540	0.0100	-
3	10	2	2	32.0	31.0	60	23	8.50	5.80	5.05	0.0039	0.0238	0.0647	0.0124	-
3	10	2	3	31.0	30.0	65	23	8.20	6.00	3.91	0.0040	0.0143	0.1716	0.2247	-
3	10	3	2	32.0	30.0	50	24	8.00	6.80	3.71	0.0057	0.0000	0.0047	0.0167	23.36

F A R M	P O N D	D A T E	LOC.	A.T. C	W.T. C	TRAN. cm.	SAL. ppt.	pH	D.O. ppm.	BOD ppm.	TSS g/100ml	NO3 ppm.	NH3 ppm.	PO4 ppm.	CHL a ug/L
4	12	9	3	28.0	29.0	25	15	8.45	11.30	8.28	0.0170	0.0193	0.7496	1.0130	71.44
4	13	1	2	33.0	31.0	55	29	8.40	7.20	3.04	0.0034	0.0104	0.0009	0.0000	11.64
4	13	1	3	32.0	31.0	50	31	8.48	7.40	3.24	0.0041	0.0000	0.0338	0.0000	23.28
4	13	2	2	29.0	30.0	100	33	8.50	7.00	4.50	0.0039	0.0588	0.0159	0.0807	27.84
4	13	2	3	28.5	30.0	86	35	8.50	7.40	5.40	0.0054	0.0204	0.0000	0.0778	25.00
4	13	3	2	32.5	31.0	40	23	8.55	5.70	6.40	0.0059	0.0599	0.0000	0.0458	118.32
4	13	3	3	33.0	31.4	30	23	8.55	5.60	7.20	0.0070	0.0449	0.0000	0.0414	114.96
4	13	4	2	32.0	31.0	25	13	8.60	14.20	16.98	0.0075	0.0016	0.0545	0.0225	181.60
4	13	4	3	32.0	31.4	25	13	8.70	10.90	17.98	0.0084	0.0104	0.0378	0.0298	166.08
4	13	5	2	30.0	27.9	25	21	8.60	5.90	14.96	0.0084	0.0354	0.0314	0.1011	370.56
4	13	5	3	30.0	28.7	15	21	8.70	7.00	15.56	0.0096	0.0510	0.0071	0.0924	330.60
4	13	6	2	27.0	28.8	20	23	8.20	10.80	15.18	0.0046	0.0095	0.0000	0.0589	226.16
4	13	6	3	27.0	29.7	25	23	8.00	10.50	15.84	0.0073	0.0127	0.0000	0.0531	104.80
4	13	7	2	28.0	25.4	33	20	7.50	7.80	2.66	0.0082	0.0232	1.7770	0.0258	32.32
4	13	7	3	28.0	25.6	35	20	7.70	8.70	8.58	0.0113	0.0382	1.5320	0.1767	73.04
4	13	8	2	29.0	29.5	45	15	8.05	9.70	7.55	0.0085	0.0704	1.7060	0.0531	271.16
4	13	8	3	29.0	29.0	38	16	7.60	9.80	8.37	0.0102	0.1037	1.8220	0.1069	270.84
4	13	9	2	29.0	29.5	35	18	7.70	4.74	13.32	0.0067	0.0127	1.6390	0.1636	279.36
4	13	9	3	30.0	29.0	35	18	7.75	5.85	14.50	0.0115	0.0121	1.8070	0.1316	178.36
4	14	1	2	30.0	31.0	60	32	8.52	7.10	2.19	0.0067	0.0000	0.0000	0.0051	24.48
4	14	1	3	31.0	31.0	55	33	8.60	7.00	3.34	0.0030	0.0099	0.0000	0.0000	19.24
4	14	2	2	29.0	30.0	75	33	8.50	7.50	7.30	0.0063	0.0099	0.0000	0.1433	40.16
4	14	2	3	29.0	29.9	71	35	8.50	7.30	7.50	0.0049	0.0143	0.0000	0.0807	44.64
4	14	3	2	33.0	32.0	75	21	8.30	5.50	5.20	0.0063	0.0238	0.0481	0.0036	43.36
4	14	3	3	32.5	32.0	57	22	8.25	5.50	4.90	0.0062	0.0310	0.0879	0.0000	41.16
4	14	4	2	32.5	31.5	60	16	8.40	12.10	17.18	0.0065	0.0349	0.0442	0.0036	215.72
4	14	4	3	32.5	31.5	55	16	8.40	10.90	12.58	0.0057	0.0143	0.0353	0.0007	62.16
4	14	5	2	30.0	27.7	25	20	8.80	7.80	14.16	0.0120	0.0238	0.0301	0.0764	369.72
4	14	5	3	30.0	27.9	25	20	8.80	8.10	15.36	0.0146	0.0265	0.0853	0.0647	508.00
4	14	6	2	27.0	28.8	35	22	8.00	10.00	9.30	0.0050	0.0621	0.6727	0.0313	18.32
4	14	6	3	27.0	29.1	30	20	8.00	10.00	8.16	0.0043	0.0476	0.1084	0.3003	513.08
4	14	7	2	28.0	25.4	42	20	7.80	11.30	8.18	0.0100	0.0499	1.3948	0.2712	239.88
4	14	7	3	28.0	25.4	40	20	7.50	11.50	4.34	0.0141	0.0493	1.8719	0.1185	146.04
4	14	8	2	28.0	28.9	35	19	8.05	12.40	7.97	0.0084	0.0521	1.9840	0.0836	306.24
4	14	8	3	28.0	29.0	32	18	7.85	11.90	10.99	0.0113	0.0615	1.6690	0.0545	218.20
4	14	9	2	28.0	29.8	35	18	7.55	3.73	6.46	0.0093	0.0388	1.6410	0.0749	39.48
4	14	9	3	28.0	29.0	35	18	7.55	3.13	9.28	0.0134	0.0099	1.6020	0.0705	85.04
4	15	1	2	32.0	31.0	60	33	8.60	7.70	4.29	0.0017	0.0000	0.0000	0.0000	16.20
4	15	1	3	33.0	31.0	50	32	8.60	7.60	4.10	0.0017	0.0000	1.5520	0.0036	20.25
4	15	2	2	31.0	30.5	55	35	8.60	7.50	7.60	0.0068	0.0282	0.0000	0.0647	34.08
4	15	2	3	30.0	30.1	50	35	8.55	7.20	7.50	0.0060	0.0260	0.0000	0.0487	35.36
4	15	3	2	32.0	31.6	70	24	8.45	5.40	6.60	0.0083	0.0632	0.0737	0.0095	70.96
4	15	3	3	33.0	32.0	63	24	8.40	5.70	7.00	0.0055	0.0754	0.0519	0.0036	48.84
4	15	4	2	33.0	32.0	75	20	8.55	9.80	10.98	0.0056	0.0154	0.0237	0.0065	119.28
4	15	4	3	32.0	31.4	25	18	8.60	10.00	17.18	0.0150	0.0310	0.0301	0.0022	-
4	15	5	2	30.0	28.2	35	21	8.10	5.20	7.48	0.0084	0.0199	0.4457	0.0269	67.00
4	15	5	3	30.0	28.0	30	21	8.00	5.40	7.06	0.0130	0.0210	0.2597	0.0080	79.48
4	15	6	2	28.0	28.5	15	21	8.00	9.60	5.86	0.0064	0.0621	0.2097	0.0153	371.28
4	15	6	3	28.0	28.9	15	23	8.00	9.30	7.82	0.0127	0.0654	0.2443	0.0429	312.80
4	15	7	2	28.0	25.6	25	20	7.80	11.30	5.58	0.0175	0.0382	1.5628	0.0851	91.52
4	15	7	3	28.0	25.5	23	20	8.10	11.10	7.36	0.0164	0.0332	1.4358	0.0924	343.84
4	15	8	2	28.0	29.0	32	15	8.00	14.60	10.32	0.0146	0.0732	1.3090	0.0211	603.00
4	15	8	3	28.0	29.0	30	15	8.20	13.70	13.81	0.0147	0.0449	1.4180	0.0414	575.16
4	15	9	2	28.0	29.5	25	17	8.55	6.05	7.88	0.0044	0.0149	1.5120	0.0269	127.64
4	15	9	3	28.0	29.0	25	17	8.69	5.05	7.48	0.0131	0.0304	1.4940	0.0487	151.28

FARM: 1 = Aquastar Company
2 = Aquastar Farmer Project
3 = Siam Taksin
4 = Teerawat

DATE: water sampling date at 2-week intervals each

LOC: water sampling locations;

1 = inlet

2 = pond middle

3 = pond discharge

APPENDIX B

PLANKTON SPECIES COMPOSITION FOUND IN THE STUDY PONDS

Phytoplankton and zooplankton species found in 15 study ponds during one growing season.

Phytoplankton

1. Anabaena sp.
2. Aphanocapsa Sp.
3. Asterionella sp.
4. Bacillaria sp.
5. Bacteriastrium sp.
6. Biddulphia sp.
7. Ceratium sp.
8. Chaetoceros sp.
9. Chorococus sp.
10. Coscinodiscus sp.
11. Dinophysis sp.
12. Dithyllum sp.
13. Fragillaria sp.
14. Gamatophora sp.
15. Guinardia sp.
16. Gymnodinium sp.
17. Hemiaulus sp.
18. Hemidiscus sp.
19. Landaria sp.
20. Leptocylindrus sp.
21. Melosira sp.
22. Merismopedia sp.
23. Microcystis sp.
24. Navicular sp.
25. Nitzschia sp.
26. Oikopleura sp.
27. Oscillatoria sp.
- Pennate Diatoms
28. Gyrosigma sp.
29. Pleurosigma sp.
30. Cambella sp.
31. Synedra sp.
32. Peridinium sp.
33. Prorocentrum sp.
34. Psuedogerinadia sp.
35. Radiolaria sp.
36. Phyrophacus sp.
37. Rhizisolenea sp.
38. Skeletonema sp.
39. Spilulina sp.
40. Spyrogyra sp.
41. Surirella sp.
42. Thalassiosira sp.
43. Thalassiothrix sp.
44. Triceratium sp.
45. Ulothrix sp.

Zooplankton

- Codonella sp.
- Copepod
- Cladocera sp.
- Favella sp.
- Gastropod
- Globigerina sp.
- Nauplii
- Nematode
- Paramesium sp.
- Phacus sp.
- Rotifer
- Zoothamnium sp.

VITA

Atchara Wongsangchan was born on November 29, 1958, in Aungthong Province, Thailand. She attended elementary school in Tak Province and junior and high school in Saraburi Province. After graduating from Saraburivithayakom School in Saraburi in 1978, she attended Kasetsart University, Bangkok, where she received her Bachelor of Science degree in Fisheries in 1981. Atchara has been working as a fishery biologist with the Department of Fisheries, Ministry of Agriculture & Cooperatives, Thailand, since October 1981. She entered graduate school at the University of Tennessee, Knoxville, in September 1985. In August 1987, Atchara received her Master of Science degree in Wildlife and Fisheries Science. The following September, she began her doctoral program at the University of Tennessee, Knoxville. She received her Doctor of Philosophy degree with a major in Ecology in December 1990.

Atchara currently pursues her career as a fishery biologist at the Department of Fisheries, Bangkok, Thailand.