Vol. 41: 65–76, 2000 | DISEASES OF AQUATIC ORGANISMS Dis Aquat Org | Published May 25

A logistic regression of risk factors for disease occurrence on Asian shrimp farms*

PingSun Leung[1,**], Liem T. Tran[2], Arlo W. Fast[3]

[1]Department of Biosystems Engineering, University of Hawaii at Manoa, 3050 Maile Way, Honolulu, Hawaii 96822, USA
[2]Center for Integrated Regional Assessment, Pennsylvania State University, 513 Deike Building, University Park, Pennsylvania 16803, USA
[3]Hawaii Institute of Marine Biology, University of Hawaii at Manoa, Coconut Island, Kaneohe, Hawaii 96744, USA

ABSTRACT: Serious shrimp-disease outbreaks have reduced shrimp production and slowed industry growth since 1991. This paper tests factors such as farm siting and design, and farm-management practices for relationships with disease occurrence. Logistic regression is used to analyze farm-level data from 3951 shrimp farms in 13 Asian countries. Disease occurrence is modeled as a 0-1 variable where 1 = disease loss of ≥20% to any 1 crop, and 0 = losses of <20%. Logistic regression is performed for each of 3 levels of shrimp culture intensity, i.e. extensive, semi-intensive, and intensive. Attempts to apply logistic regression models to each country were not successful due to insufficient data for most countries. Factors affecting disease occurrences were quite different for different farming intensities. Farms that had larger pond production areas, with larger number of farms discharging effluent into their water supply canals, and removed silt had greater disease occurrence. On the other hand, farms that practiced polyculture and took water from the sea through a canal had lower disease occurrence.

KEY WORDS: Shrimp disease · Logistic regression

INTRODUCTION

Globally, the shrimp-farming industry enjoyed phenomenal growth during the 1980s, mainly due to technological breakthroughs (such as hatchery seed and improved feed), high profit from farmed shrimp, and public support. Farmed shrimp production was 660200 metric tons (mt) in 1997, which was about 22% of total world shrimp production. The eastern and western hemispheres produced 70 and 30% of farmed shrimp respectively. Thailand was the leading producer during 1997, followed by Ecuador, Indonesia, China, India, Bangladesh, Vietnam, Taiwan, and the Philippines. Black tiger shrimp *Penaeus monodon* was the most important species farmed in the eastern hemisphere, while the western white shrimp *Penaeus vannamei* dominated western hemisphere production (Rosenbery 1997).

Diseases have emerged as a major constraint to shrimp-aquaculture sustainability. Serious outbreaks of shrimp diseases have occurred in most of the major producing countries. Especially since 1991, shrimp viral diseases have reduced production and slowed industry growth. Many diseases are linked to environmental deterioration and stress associated with shrimp-culture intensification. High profits from shrimp farming and increasing coastal land prices pushed shrimp farmers towards more intensive operation (first in Taiwan followed by Thailand and other countries). Conditions associated with intensification included: increased farm densities in shrimp-culture areas, greatly increased feed and other inputs per unit of pond area, increased effluent waste loads, and increased disease occurrences resulting from various causes. Frequent disease outbreaks often resulted in widespread crop failures. Shrimp-culture industry collapses in Taiwan during 1988 and in China in 1993 are 2 dramatic examples.

A solution to disease problems will involve both prevention and cure. However, because treatment options for many shrimp diseases are either non-existent or

*An earlier version of this paper was presented at the Fifth Asian Fisheries Forum, November 11–14, 1998, Chiangmai, Thailand. Senior authorship is not assigned

**E-mail: psleung@hawaii.edu

ineffective, current emphasis is on prevention. Disease prevention now focuses on use of specific-pathogen-free (SPF) or specific-pathogen-resistant (SPR) seed stock, seed stock pre-screened for specific pathogens, appropriate site selection and farm design, and application of sustainable farm-management practices. While many of these practices have been widely adopted and are believed to be beneficial for disease prevention, few studies have documented these benefits.

To better understand disease problems faced by Asian shrimp culturists, a regional study was conducted during 1994 and 1995 by the ADB (Asian Development Bank) and NACA (Network of Aquaculture Centres in Asia-Pacific). This study was a result of a recommendation by a previous ADB/NACA regional study (1990) which concluded that aquatic plant and animal diseases are closely linked to environmental issues. Specific objectives of the 1994 study were to assist governments in assessing policy options and in formulating policies to improve aquaculture sustainability. The study included in-depth surveys of 11000 shrimp and carp farms in 16 Asian countries and territories. The shrimp farm portion of the survey included 2898 extensive, 1022 semi-intensive, and 870 intensive farms.

The 1994 survey documented that shrimp disease caused significant monetary losses to shrimp farmers. Conservative estimates indicated $332.2 million per year total losses caused by shrimp diseases, including $143.3 million for intensive farms, $111.8 million for semi-intensive farms, and $77.1 million for extensive farms. All countries surveyed suffered in various degrees from shrimp disease problems. For example, the percentage of intensive farms affected by disease losses ≥20% of at least 1 crop ranged from 12% in Malaysia, to 100% in China. Semi-intensive and extensive farms also reported significant disease losses (ADB/NACA 1996).

The ADB/NACA survey also found that virtually all countries reported 'unknown' as the main cause of shrimp diseases (a clear indication that shrimp diseases are poorly identified). Research and improved extension activities are needed to properly identify shrimp diseases, a necessary step leading to prevention and cure.

With the above in mind, we attempted to identify factors affecting shrimp disease occurrence through further analysis of the ADB/NACA farm survey data. We evaluated logistic-regression models for predicting disease occurrence from a set of 31 variables, including site characteristics, farming systems, and farming practices. Logistic regression was performed separately for extensive, semi-intensive, and intensive shrimp farms for all countries.

METHODOLOGY

The logistic regression model has emerged as the technique of choice for predicting dichotomous medical outcomes (Tu 1996). Recently, Johnson-Ifearulundu & Kaneene (1998) used a logistic regression model to identify management practices that posed risk factors for *M. paratuberculosis* infection of dairy herds in Michigan. While disease-prediction models are widely used to predict incidence of either pests or pathogens in the field for crop protection and disease of land animals, application of disease prediction models in aquaculture is non-existent.

Logistic regression. A dichotomous outcome, y (for example, $y = 1$ if disease loss ≥20% of crop, or $y = 0$ if <20%)[1], has an expected value, $E(y)$, assumed to be P (P = the probability that the outcome occurs). One can usually assume that P is related to a set of potential explanatory variables in the form:

$$y = P + e = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + e \quad (1)$$

where β_0 is the intercept, $\beta_1, \ldots, \beta_n$ are the coefficients associated with each explanatory variable $x_1, \ldots, x_n$ and e is an error term. Regressing y on x's using ordinary least squares will lead to 3 problems. First, e is obviously not normally distributed as is generally assumed, and more importantly, estimated probabilities can lie outside the range (0,1). Furthermore, the error variance is not constant across levels of the x_i's. However, one can assume that P follows a logistic distribution:

$$P = 1/(1 + \exp[-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n)] \quad (2)$$

Rearranging terms, Eq. (2) can be expressed as:

$$P/(1 - P) = \exp[(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n)] \quad (3)$$

where $P/(1 - P)$ is the 'odds' of the outcome such as the occurrence of disease. It is clear from Eq. (3) that the logarithm of the odds, or simply log odds, is a linear function of the explanatory variables, x's, as follows:

$$\log[P/(1-P)] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \quad (4)$$

Since P is assumed to follow a logistic distribution, maximum-likelihood methods can be used to estimate the coefficients $\beta_1, \ldots, \beta_n$. The logistic-regression procedure in the SPSS package was used in this analysis (SPSS 1992).

Data and variables. Data for our analyses came from the 1994–1995 ADB/NACA farm survey mentioned previously. Of the 4855 shrimp farms surveyed by

[1]The NACA survey defined serious disease outbreaks as those causing more than 20% of stock loss in any one crop. This might underestimate the true total impact of disease because this definition excludes the long-term effects of disease which may cause low-level losses and reduced harvests

ADB/NACA, we used only 3951 farms in our analyses due to incomplete observations, as well as observations with large outliers with 904 farms. Of the 3951 farms analyzed, 779 farms were intensive, 910 were semi-intensive, and 2262 were extensive (Table 1). Thirty-one variables including 13 continuous and 18 nominal (categorical) variables describing the site, farming system and farming practice were used as potential factors in explaining disease occurrence. A list of the 31 variables is shown in Appendix 1, and summary statistics of these variables are presented in Appendix 2.

The choice of the 31 explanatory variables was based partly on existing theory and 'hunches' about explanations of shrimp disease occurrences. In general, 2 approaches can be found in the literature regarding the choice of variables to be included in a model (Hosmer & Lemeshow 1989). One approach is to include all scientifically relevant variables into the model and the other approach is to use a stepwise procedure in which variables are selected either for inclusion in or removal from a model in a sequential manner based on statistical criteria only. Proponents of the stepwise procedure argue that the parsimonious model is generally more stable numerically and is more easily generalized. On the other hand, others, particularly econometricians, criticize the stepwise procedure as an admission of ignorance about the phenomenon being studied (Studenmund & Cassidy 1987). Menard (1995, p. 54) sums it up very nicely as follows: 'Without going too deeply into the arguments about the use of stepwise procedures, there appears to be general agreement that the use of computer-controlled stepwise procedures to select variables is inappropriate for theory testing because it capitalizes on random variations in the data and produces results that tend to be idiosyncratic and difficult to replicate in any sample other than the sample in which they were originally obtained.'

It is well known in the econometric literature that pre-test estimators resulting from step-wise procedures yield worse estimators than least-squares estimators derived from an accurate prior specification (Charemza & Deadman 1997). Because the sample size is relatively large in our study, we chose to use the first approach by including all 31 variables for which we have data and which we believe might be relevant in our model estimations. Besides not running into pretest bias as in stepwise procedures, this approach also provides complete control of confounding. However, the major problem with this approach is that of the possibility of an overfitted model producing numerically unstable estimates with large standard errors. We will elaborate on this aspect in the results and discussion section below and also in Footnote 3 ('Results and discussion'). Finally, the choice of approach in variable selection varies by disciplines and is usually driven by the analytic philosophy of the analysts and the problems at hand.

Table 1. Sample distribution used in analyses by country and by culture intensity

Country	Intensive	Semi-intensive	Extensive	Total
Bangladesh	0	13	93	106
Cambodia	29	0	1	30
China	33	63	83	179
India	6	142	734	882
Indonesia	147	353	884	1384
Korea	9	0	0	9
Malaysia	40	40	0	80
Myanmar	0	0	68	68
Philippines	31	101	113	245
Sri Lanka	35	124	17	176
Taiwan	62	0	0	62
Thailand	387	0	2	389
Vietnam	0	74	267	341
Total	779	910	2262	**3951**

RESULTS AND DISCUSSION

Logistic regression models were fitted for each level of shrimp culture intensity (using all 31 variables described above).[2] The χ^2 values of all 3 models are statistically significant ($p = 0.0000$), implying that the fitted models (containing the constant and the explanatory variables) fit the data quite well. In other words, there is a significant relationship between the log of odds of a disease occurrence with the explanatory variables.

Table 2 shows the estimated βs for the logistic regressions and their significance levels (p-values).[3]

[2]We have also fitted a model combining all farms and with an additional variable representing culture intensity. However, it became apparent from resulting statistical analyses that factors affecting shrimp disease occurrence as well as their levels vary with different culture intensity. Thus, such a formulation is not deemed appropriate and we decided to fit separate models for each culture intensity

[3]Given the insignificance of some important variables, collinearity checks among explanatory variables were conducted. While presence of multicollinearity does not affect the unbiasedness of the estimates, high collinearity may cause the estimates to be extremely imprecise and unstable (Greene 1990). Bivariate correlation and variance inflation factors among the explanatory variables indicated that there is no serious multicollinearity. This is also supported by the robustness of the estimates from both forward and backward stepwise estimations. These led us to believe that no strong presence of multicollinearity exists in the sample

Table 2. Fitted logistic-regression models for intensive, semi-intensive and extensive shrimp farms, all countries combined. Level of significance (p-value) was also presented for each nominal variable as a group

Variable	Intensive		Semi-intensive		Extensive	
	$\hat{\beta}$	p	$\hat{\beta}$	p	$\hat{\beta}$	p
Site characteristics						
1. No. of years of shrimp farming at site	0.04	0.01	-0.004	0.84	-0.03	0.00
2. Inter-tidal zone (mangrove land as base)		0.00		0.05		0.00
Wetland	-0.04	0.91	0.77	0.03	-1.69	0.00
Salt pan	1.03	0.02	1.03	0.04	-0.47	0.19
Other	0.90	0.00	0.19	0.49	-1.15	0.00
3. Supra-tidal zone (mangrove land as base)		0.00		0.27		0.00
Rice farming	0.46	0.17	0.01	0.99	-1.04	0.01
Coconut	-0.74	0.08	1.00	0.12	-6.38	0.21
Upland crops	0.05	0.95	1.05	0.15	-0.92	0.07
Other	-0.03	0.93	0.46	0.28	0.36	0.30
4. Soil (clay soil as base)		0.30		0.00		0.00
Acid-sulphate soil	0.61	0.07	-1.11	0.05	-0.04	0.91
Sandy soils	0.42	0.12	0.97	0.00	-0.02	0.90
Peat/organic rich soil	0.02	0.96	-6.78	0.53	-0.85	0.11
Loam soil	0.38	0.13	-0.37	0.24	-0.45	0.01
Other	-0.03	0.94	1.23	0.00	1.11	0.00
5. Farm operator (owner operator as base)		0.35		0.01		0.07
Cooperative	-0.53	0.28	-1.69	0.07	-0.19	0.71
Lessee/tenant	0.15	0.55	0.12	0.71	0.23	0.34
Share/contract farmer	-0.70	0.14	-0.97	0.07	0.85	0.04
Manager	-0.32	0.36	-1.09	0.00	-0.84	0.08
6. Area of production ponds	0.004	0.81	0.03	0.01	0.03	0.00
7. Salt/brackish water (saltwater creek as base)		0.00		0.00		0.00
Estuary/river	0.28	0.41	-0.47	0.10	-0.76	0.00
Direct from sea	1.03	0.00	0.25	0.49	-0.13	0.71
Canal from sea	-0.52	0.04	-1.53	0.00	0.05	0.75
Other	-6.78	0.45	-0.23	0.61	-1.18	0.00
8. Wet-season salinity of intake water	-0.05	0.80	-0.24	0.29	0.30	0.04
9. Dry-season salinity of intake water	-0.28	0.17	0.23	0.37	-0.07	0.64
10. No. of farms within 3 km	-0.01	0.05	-0.004	0.19	-0.0002	0.74
11. No. of farms share water supply	0.003	0.58	-0.04	0.05	-0.01	0.10
12. No. of farms discharge effluent into water supply canal	0.003	0.50	0.06	0.01	0.02	0.00
13. Measures taken to reduce environmental impacts	-0.13	0.07	-0.44	0.00	-0.08	0.37

These estimated coefficients ($\hat{\beta}$s) reflect the effects of corresponding explanatory variables on the log odds of a disease occurrence. A negative coefficient indicates a positive (decreased) effect on disease occurrence (i.e. an increase in the level of that variable will reduce disease occurrence, ceteris paribus). Conversely, a positive coefficient suggests that an increase in the corresponding variable will increase disease occurrence (again given that all other variables remain the same). Because we cannot confirm that the linearity assumptio is met[4], our odds ratios for continuous variables should not be interpreted literally, Rather, they can be used to tell the direction of the association and perhaps to see if the association is likely to be strong. This latter could be told if the implied change across the range of values of the risk factor is relatively large. Had we been able to confirm that our coding met the underlying assumptions, the interpretation would have been, for example, with intensive shrimp culture, for each additional year shrimp farming occurs at the same site, the log odds of disease occurrence increases by 0.04.

[4]As pointed out by one reviewer, the log odds is assumed to be linear across the observed ranges of the continuous variables in our formulation. We did not test this assumption because of the exploratory nature of this analysis and the fact that with the large number of continuous variables the testing and the subsequent remedies can become exceedingly tedious

Table 2 (continued)

Variable	Intensive β̂	Intensive p	Semi-intensive β̂	Semi-intensive p	Extensive β̂	Extensive p
Farming systems and practices						
14. Stocking density	1.87×10^7	0.40	1.35×10^6	0.22	-5.1×10^7	0.69
15. Polyculture (monoculture as base)						0.00
Polyculture — shrimps only	0.14	0.83	−1.02	0.03	−0.89	0.00
Polyculture — shrimp and fish					−0.66	0.00
16. Dry pond	0.49	0.19	0.16	0.77	−0.74	0.00
17. Silt removal (no removal as base)		0.02		0.05		0.00
Flushing, deposit silt on-farm	0.28	0.42	0.15	0.71	1.53	0.00
Flushing, deposit silt off-farm	0.29	0.47	0.05	0.91	1.40	0.00
Flushing, deposit on and off-farm	1.51	0.01	1.12	0.04	2.35	0.00
Mechanical or manual removal	0.65	0.07	−0.30	0.49	0.40	0.06
18. Maintain/repair dykes	0.45	0.03	−0.04	0.87	0.004	0.98
19. Turn soil (tilling)	−0.22	0.31	−0.39	0.10	−0.57	0.00
20. No. of days after filling to stock shrimp	−0.003	0.66	−0.02	0.31	−0.01	0.01
21. Aeration	−0.09	0.74	0.76	0.01	0.15	0.67
22. Some forms of screening water	0.74	0.02	−0.16	0.57	0.58	0.00
23. Apply chemical	−0.16	0.83	−1.73	0.02	−0.26	0.24
24. Apply fertilizers (not using fertilizer as base)		0.26		0.34		0.07
Inorganic	0.14	0.50	−0.41	0.09	0.34	0.05
Organic	−0.42	0.22	0.16	0.72	0.59	0.04
Inorganic and organic	−0.32	0.25	−0.09	0.79	0.13	0.49
25. Frequency of water exchange	−0.03	0.00	0.02	0.09	0.01	0.05
26. Amount of water added each time	−0.01	0.03	0.01	0.26	0.001	0.32
27. Discharge (no discharge as base)		0.22		0.00		0.00
Discharge to settlement pond	0.46	0.33	−0.22	0.68	0.41	0.50
Discharge to drainage canal	0.57	0.03	−0.46	0.12	0.83	0.00
Discharge to intake/drainage canal	0.62	0.08	0.16	0.64	0.79	0.00
Reuse water on farm	0.01	0.97	−1.24	0.17	1.22	0.10
Some forms of discharge	0.44	0.11	0.89	0.03	0.77	0.01
28. Feed (no supplemental feed as base)		0.04		0.00		0.14
Simple diet	0.69	0.24	0.99	0.24	−0.20	0.41
Formulated	0.74	0.05	0.36	0.63	−0.16	0.50
Mixed	0.23	0.55	1.43	0.06	0.29	0.25
29. No. of shrimp management/monitoring measures	0.62	0.00	0.09	0.55	0.07	0.41
30. No. of water monitoring measures	0.15	0.01	0.10	0.13	−0.18	0.00
31. No. of feeding and cost measures	−0.22	0.07	0.10	0.43	0.41	0.00
Constant	−4.55	0.00	−0.82	0.52	−0.66	0.19
Model χ^2	221.7	0.00	411.2	0.000	950.2	0.00
No. of observations	779		910		2262	

Put another way, the odds of disease occurrence increases by a factor of 1.04 [= exp(0.04)] for every year shrimp farming occurs at a given site (Table 3). exp(*b*) represents the expected change in the odds of disease occurrence versus no disease per unit change in the explanatory variable, other things being equal.

Interpretation of the dummy (nominal) variables relates to the base category. For example, after controlling for the effects of all other variables, the odds of disease occurrence with intensive farms increases by a factor of 2.79 [= exp(1.03)] and 2.45 [= exp(0.90)] respectively if the intensive farm was situated in inter-tidal zone previously used as salt pan or as other, when compared with mangrove land (Table 3). In other words, the chance of disease with intensive farms in the inter-tidal zone is lower for converted mangrove when compared with converted salt pan or other.

Site characteristics

Odds of disease occurrence increased with time farmed at a given site for intensive culture — while the opposite was true for extensive culture (Table 3). As with all other variables, our models do not tell us why a relationship exists, only whether one does and its rela-

Table 3. Factors with significant positive (less disease; odds ratio <1.0) and negative (greater disease; odds ratio >1.0) effects on disease occurrences (only values significant at the 5% are shown). Values for the individual items of each nominal variable are not shown if the significance level for the nominal variable as a group is not significant at the 5% level

Variable	Intensive	Semi-intensive	Extensive
Site characteristics			
1. No. of years of shrimp farming at site	1.04	–	0.97
2. Inter-tidal zone (mangrove land as base)			
Wetland	–	2.16	0.18
Salt pan	2.79	2.79	–
Other	2.45	–	0.32
3. Supra-tidal zone (mangrove land as base)			
Rice farming	–	–	0.35
Coconut	–	–	–
Upland crops	–	–	–
Other	–	–	–
4. Soil (clay soil as base)			
Acid-sulphate soil	–	–	–
Sandy soils	–	2.65	–
Peat/organic rich soil	–	–	–
Loam soil	–	–	0.64
Other	–	3.43	3.04
5. Farm operator (owner operator as base)			
Cooperative	–	–	–
Lessee/tenant	–	–	–
Share/contract farmer	–		2.33
Manager	–	0.34	–
6. Area of production ponds	–	1.04	1.03
7. Salt/brackish water (saltwater creek as base)			
Estuary/river	–	–	0.47
Direct from sea	–	–	–
Canal from sea	0.59	0.22	–
Other	–	–	0.31
8. Wet-season salinity of intake water	–	–	–
9. Dry-season salinity of intake water	–	–	–
10. No. of farms within 3 km	0.995	–	–
11. No. of farms share water supply	–	0.96	–
12. No. of farms discharge effluent into water supply canal	–	1.06	1.02
13. Measures taken to reduce environmental impacts	–	0.64	–

tive magnitude and direction of impact on disease. Perhaps old, intensive farms were more susceptible to disease because they were built in areas where shrimp farms already existed.

While converted mangrove in the inter-tidal zone had lower odds of disease occurrence compared to other previous land use for intensive and semi-intensive farms, the reverse was true for extensive farms.

For intensive and semi-intensive farms situated in supra-tidal zone, prior land use did not seem to affect disease occurrence (Table 3). For extensive farms, odds were lower for farms that were previously used for rice farming and upland crops, compared to converted mangrove.

No overall pattern can be discerned for soil types versus disease occurrence; although of 15 soil comparisons with clay as the base, only one showed less chance of disease compared with clay. This indicated that, overall, clay may be a desirable soil type.

There was no difference in odds of disease occurrence with different types of operators for intensive farms (Table 3). With semi-intensive and extensive farms, manager had lower odds of disease compared with owner operator, while lessee/tenant (semi-intensive) or share/contract farmer (extensive) had higher odds.

Farms with larger total pond production areas had greater chance of disease with semi-intensive and extensive cultures (Table 3).

Intensive and semi-intensive farms that took salt and brackish water through a canal from the sea tended to have lower odds of disease. Extensive farms that took

Table 3 (continued)

Variable	Intensive	Semi-intensive	Extensive
Farming systems and practices			
14. Stocking density	–	–	–
15. Polyculture (monoculture as base)			
Polyculture — shrimps only	–	0.36	0.41
Polyculture — shrimp and fish	–	–	0.52
16. Dry pond	–	–	0.48
17. Silt removal (no removal as base)	–	–	–
Flushing, deposit silt on-farm	–	–	4.60
Flushing, deposit silt off-farm	–	–	4.07
Flushing, deposit on and off-farm	4.52	3.06	10.53
Mechanical or manual removal	–	–	–
18. Maintain/repair dykes	1.57	–	–
19. Turn soil (tilling)	–	–	0.57
20. No.of days after filling to stock shrimp	–	–	0.99
21. Aeration	–	2.13	–
22. Some forms of screening water	2.09	–	1.78
23. Apply chemical	–	0.18	–
24. Apply fertilizers (not using fertilizer as base)			
Inorganic	–	–	–
Organic	–	–	1.80
Inorganic and organic	–	–	–
25. Frequency of water exchange	0.97	–	1.01
26. Amount of water added each time	0.99	–	–
27. Discharge (no discharge as base)			
Discharge to settlement pond	–	–	–
Discharge to drainage canal	–	–	2.29
Discharge to intake/drainage canal	–	–	2.20
Reuse water on farm	–	–	–
Some forms of discharge	–	–	2.15
28. Feed (no supplemental feed as base)			
Simple diet	–	–	–
Formulated	2.11	–	–
Mixed	–	–	–
29. No. of shrimp management/monitoring measures	1.85	–	–
30. No. of water monitoring measures	1.16	–	0.83
31. No. of feeding and cost measures	0.80	–	1.50

water from estuary/river and other sources tended to have lower odds of disease.

Intake-water salinity during both the wet and dry seasons showed no association with disease for all culture intensities (Table 3). (The salinity variable as used here is a dummy variable which takes on a value of 1 if salinity is between 5 to 35 ppt [generally considered to be the desirable range] and 0 for salinity outside this range.)

We expected that farm density would increase odds of disease occurrence. However, the number of farms within 3 km did not show any effect for semi-intensive and extensive, and a positive effect for intensive farms (Table 3). In other words, for intensive operations, more farms within the vicinity can lead to less disease occurrence. Similarly, one might expect that more farms sharing a given water supply might lead to higher disease occurrence. However, this did not appear so. On the other hand (as we expected), the number of farms discharging effluent into a common water supply canal led to higher odds of disease occurrence for both semi-intensive and extensive farms.

Finally, semi-intensive farms that took more measures during design and planning to reduce impacts on the adjacent environment had lower odds of disease but these measures had no effect on intensive and extensive farms (Table 3). These measures include environmental-impact assessment, site selection to avoid impacts on other users, site selection to avoid impacts of other users, design of separate water supply/drainage system, retention of mangrove buffer zone, and use of an effluent treatment pond.

Farming systems and practices

Stocking densities within each farm type did not have significant associations with disease occurrence (Table 3). However, polyculture in semi-intensive and extensive cultures was protective.

Pond preparation and water management. Extensive farms that dried pond soils between crops were found to be less prone to disease, while pond drying had no effect on disease with intensive and semi-intensive culture (Table 3).

The association of silt removal with disease was one of the most revealing analyses: in no cases was silt removal beneficial (Table 3). This finding suggests several possible relationships. First, silt removal either exposes disease-producing sediments, or perhaps newly exposed sediments somehow stress shrimp (thus leading to disease problems). Second, farms located in areas with low sediment loads in source waters have less disease potentials.

Contrary to our expectation, intensive farms that maintained/repaired dykes had greater odds of disease (Table 3).

As expected, extensive farms that turned soil between crops showed lower odds of disease (Table 3), presumably due to the sterilization of soils by UV light. The longer extensive farmers waited to stock shrimp after filling the pond, the lower the odds of disease. Contrary to our expectation, aeration increased odds of disease occurrence in semi-intensive operations, while some form of screening influent waters increased disease occurrence with intensive and extensive operations. Perhaps what we observed with aeration and screening were the results of disease, rather than the cause. Farms with disease problems might be more likely to use aerators, intake screens, and/or other remediations compared with farms without disease problems.

Semi-intensive farms which applied chemicals had lower odds of disease compared with no chemical applications. Again, chemical applications might have been a response to disease problems by the farmers. Fertilizer application with extensive farms increased the odds of disease compared to no fertilizer application. Perhaps fertilizers were more likely used in ponds with water quality problems related to inability to establish healthy algal blooms.

Although water exchange frequency during the last month of crop growout might lower odds of disease with intensive culture, the reverse was found with semi-intensive and extensive culture. Similarly, although amount of water added during each water exchange might lower the odds with intensive culture, no association was found with extensive culture. As with sediment removal, the nature of water discharge had only negative or no association with disease compared with the no-discharge option (Table 3). These relationships suggest that disease organisms are perhaps recycled or transferred between farms more readily when farms discharge more. This suggests that use of SPF or SPR shrimp coupled with minimal discharge may reduce disease.

Feed. Intensive farms that used only formulated diet had greater odds of disease compared to farms with no supplementary feed. However, supplemental feeding in any form did not increase the odds of disease with semi-intensive and extensive farms.

Regular management activities. Most shrimp-culture practitioners might assume that increased management activities on a farm would decrease the chance of disease occurrence. Shrimp management and monitoring included regular monitoring of stock survival, daily monitoring of shrimp behavior, and on-farm and off-farm shrimp-health checks. Pond water-quality monitoring parameters included pH/alkalinity, salinity, dissolved oxygen, nutrients (N and/or P), water color and turbidity, sediment condition, and quality of influent and effluent waters. Feeding and cost measures included use of feeding tray to check feed consumption, regular feed conversion ratio (FCR) calculations, and regular production/operating cost analyses. More shrimp-management and -monitoring measures, and more water-monitoring measures increased odds of disease occurrence in intensive farms (Table 3). Farms with disease problems might have performed more of these measures in an effort to reduce disease problems. Thus, these measures may be a direct result of disease rather than a cause of disease. Also, contrary to expectation, more feeding and cost measures were associated with increased disease occurrence with extensive farms. However, more water-monitoring measures in extensive farms, and more feeding and cost measures in intensive farms were associated with reduced disease odds. None of these management activities seemed to affect disease occurrence in semi-intensive farms.

CONCLUDING REMARKS

Common factors associated with higher odds of disease occurrence with at least 2 of the 3 levels of culture intensity were: silt removal between crops versus no removal; larger area of production ponds; and larger number of farms discharging pond effluents into water supply canals.

Common factors associated with lower odds of disease occurrence for at least 2 of the 3 levels of culture intensity were: used polyculture; and took water from the sea through a canal versus from a saltwater creek.

While most disease-related factors identified here were perhaps intuitive, others were not so apparent. It is also interesting to note that factors associated with disease occurrence were often different for the 3 levels of shrimp culture intensity. Logistic regression analyses as used herein can provide meaningful insights into causal relationships between shrimp disease problems and shrimp culture practices. These analyses are unable to establish cause and effect relationships, but they are able to draw attention to certain culture practices which need further evaluation. Some of our findings could be artifacts of data collection techniques, interviewer or farmer biases, or the way questions were worded. However, we are convinced that most of the significant relationships that we identified have some underlying biological, physical or chemical basis, and that the nature of these relationships can be discovered through further analysis. Logistic regression

Appendix 1. List of explanatory variables. C: continuous variables; N: nominal variables

Explanatory variables used	Variable type	Variable descriptions
Site characteristics		
1. No. of years of shrimp farming at site	C	
2. Prior land use — inter-tidal zone	N	1: mangrove land; 2: wetland; 3: salt pan; 4: other
3. Prior land use — supra-tidal zone	N	1: mangrove land; 2: rice farming; 3: coconut; 4: upland crops; 5: other
4. Dominant soil type	N	1: clay soil; 2: acid-sulphate soil; 3: sandy soil; 4: peat/organic rich soil; 5: loam soil; 6: other
5. Farm operator	N	1: owner; 2: cooperative; 3: lessee/tenant; 4: share/contract farmer; 5: manager
6. Area of production pond	C	ha
7. Source of farm water (salt/brackish water)	N	1: saltwater creek; 2: estuary/river; 3: direct from sea; 4: canal from sea; 5: other
8. Wet-season salinity of intake water	N	1. within the range of 5–35 ppt; 0: otherwise
9. Dry-season salinity of intake water	N	1: within the range of 5–35 ppt; 0: otherwise
10. No. of farms within 3 km	C	
11. No. of farms sharing water supply	C	
12. No. of farms discharging effluent into water supply canal	C	
13. No. of measures to reduce the environmental impacts	C	
Farming systems and practices		
14. Stocking density	C	PL m^{-2}
15. Polyculture	N	0: monoculture; 1. polyculture, shrimp only; 2: polyculture, shrimp with fish
16. Dry pond	N	1: yes; 0: no
17. Silt removal	N	0: no silt removal; 1: flushing, deposit silt on-farm; 2: flushing, deposit silt off-farm; 3: flushing, deposit on and off-farm; 4: mechanical or manual removal
18. Maintain and repair dykes	N	1: yes; 0: no
19. Turn soil (tilling)	N	1: yes; 0: no
20. No. of days after filling to stock shrimp	C	
21. Aeration	N	1: yes; 0: no
22. Some forms of screening water	N	1: yes; 0: no
23. Apply chemical	N	1: yes; 0: no
24. Apply fertilizers	N	0: no; 1: inorganic; 2: organic; 3: mixed — inorganic and organic
25. Frequency of water exchange	C	Times mo^{-1}
26. Amount of water added each time	C	cm $time^{-1}$
27. Discharge	N	0: no discharge; 1: discharge to settlement pond; 2: discharge to drainage canal; 3: discharge to intake/drainage canal; 4: reuse water on farm; 5: mixed — some forms of discharge
28. Feed	N	0: no supplemental feeding; 1: simple diet; 2: formulated diet; 3: mixed
29. No. of measures for management and monitoring of shrimp	C	0–4 depending on number of activities
30. No. of measures for pond water quality monitoring	C	0–8 depending on number of activities
31. No. of measures for feeding and costs	C	0–3 depending on number of activities

analyses can therefore be of considerable value to shrimp researchers, policy makers, and commercial venturists alike. Our findings should also help refine future farm surveys and thereby provide even greater insights into causes of shrimp diseases on shrimp farms.

Appendix 2. Summary statistics of variables used in logistic regression models for intensive, semi-intensive and extensive shrimp farms, all countries

Variable	Intensive (n = 779)			Semi-intensive (n = 910)			Extensive (n = 2262)		
	5th percentile	Median or % in category[a]	95th percentile	5th percentile	Median or % in category[a]	95th percentile	5th percentile	Median or % in category[a]	95th percentile
Site characteristics									
1. No. of years of shrimp farming at site	0.0	3.0	95.0	1.0	4.5	17.5	1.0	7.0	25.0
2. Inter-tidal zone									
Mangrove land		20			35			34	
Wetland		13			15			16	
Salt pan		6			4			4	
Other		61			46			46	
3. Super-tidal zone									
Mangrove land		9			6			3	
Rice farming		34			12			21	
Coconut		10			3			2	
Upland crops		1			2			2	
Other		45			76			71	
4. Soil									
Clay		42			40			39	
Acid-sulphate soil		9			4			4	
Sandy soil		19			18			15	
Peat/organic rich soil		5			3			1	
Loam soil		19			23			22	
Other		6			11			18	
5. Farming operator									
Owner		69			71			86	
Cooperative		3			2			2	
Lessee/tenant		16			12			6	
Share/contract farmer		4			6			3	
Manager		8			10			2	
6. Area of production ponds (ha)	0.4	1.4	9.5	0.3	2.0	16.7	0.3	2.0	16.0
7. Salt/brackish water									
Saltwater creek		36			33			38	
Estuary/river		9			29			27	
Direct from sea		34			15			3	
Canal from sea		20			15			26	
Other		2			8			6	
8. Wet-season salinity of intake water		57			51			36	
9. Dry-season salinity of intake water		34			20			41	
10. No. of farms within 3 km	0	9	100	0	10	140	0	20	300
11 No. of farms share water supply	0	0	30	0	5	70	0	12	95
12. No. of farms discharging effluent into water supply canal	0	0	56	0	4	61	0	10	90
13. Measures taken to reduce environmental impacts	0	2	5	0	1	3	0	1	3

Appendix 2 (continued)

Variable	Intensive (n = 779)			Semi-intensive (n = 910)			Extensive (n = 2262)		
	5th percentile	Median or % in category[a]	95th percentile	5th percentile	Median or % in category[a]	95th percentile	5th percentile	Median or % in category[a]	95th percentile
Farming systems and practices									
14. Stocking density (1000 PL ha^{-1})	129	600	1200	50	100	300	6	29	148
15. Polyculture									
Mono		98			93			62	
Poly — shrimp only		2			7			29	
Poly — shrimp and fish		0			0			9	
16. Dry pond		93			97			88	
17. Silt removal									
No silt removal		9			11			27	
Flushing, deposit silt on-farm		41			46			35	
Flushing, deposit silt off-farm		13			10			11	
Flushing, deposit silt on and off-farm		5			6			4	
Mechanical or manual removal		31			27			23	
18. Maintain/repair dykes		46			66			67	
19. Turn soil (tilling)		40			60			42	
20. No. of days after filling to stock shrimp	0	7	30	0	7	20	0	10	30
21. Aeration		87			42			4	
22. Some forms of screening water		85			79			66	
23. Apply chemicals		98			98			88	
24. Apply fertilizers									
No use of fertilizer		45			50			62	
Inorganic		28			31			16	
Organic		11			5			6	
Mix some forms of inorganic and organic		16			14			16	
25. Frequency of water exchange (times mo^{-1})	0	4	30	0	6	30	0	3	31.7
26. Amount of water added each time (cm $time^{-1}$)	0	10	40	0	25	60	0	20	60
27. Discharge									
No discharge		25			21			30	
Discharge to settlement pond		4			4			1	
Discharge to drainage canal		36			42			14	
Discharge to intake/ drainage canal		8			25			47	
Reuse of water on farm		7			2			1	
Mix some forms of discharge		20			6			7	
28. Feed									
No. supplement feed		7			2			44	
Simple diet		4			5			13	
Formulated		59			74			28	
Mixed		31			19			16	
29. No. of shrimp management/monitoring measures	1	3	4	1	2	4	0	2	3
30. No. of water monitoring measures	2	5	8	1	4	8	0	2	6
31. No. of feeding and cost measures	0	2	3	0	2	3	0	1	3

[a]This column shows the median for continuous variables or % in each category for nominal variables

Acknowledgements. We greatly appreciate and acknowledge NACA for use of all farm data in our analyses. We are also grateful to the 4 anonymous journal reviewers and Dr Tim Flegel for their constructive comments on an earlier version of this manuscript. The usual caveats apply.

LITERATURE CITED

ADB/NACA (1990) Regional study of fish diseases and fish health management. Asian Development Bank and Network of Aquaculture Centres in Asia-Pacific, Bangkok

ADB/NACA (1996) Aquaculture sustainability and the environment. Report on a regional study and workshop on aquaculture sustainability and the environment. ADB Series. Asian Development Bank and Network of Aquaculture Centres in Asia-Pacific, Bangkok

Charemza WW, Deadman DF (1997) New directions in econometric practice. Edward Elgar Publishing, Cheltenham

Greene WH (1990) Econometric analysis. Macmillan Publishing Company, New York

Hosmer DW, Lemeshow S (1989) Applied logistic regression. John-Wiley and Sons, New York

Johnson-Iferulundu YJ, Kaneene JB (1998) Management-related risk factors for *M. paratuberculosis* infection in Michigan, USA, dairy herds. Prev Vet Med 37:41–55

Menard S (1995) Applied logistic regression analysis. Sage Publications, Thousand Oaks

Rosenbery B (1997) World shrimp farming. Shrimp News International, San Diego, CA

SPSS (1992) SPSS for Windows advanced statistics release 5. SPSS, Inc, Chicago

Studenmund AH, Cassidy HJ (1987) Using econometrics: a practical guide. Brown Publishing, Boston

Tu JV (1996) Advantages and disadvantages of using artificial neural networks versus logistic regression for predicting medical outcomes. Clin Epidemiol 49:1225–1231

Editorial responsibility: Timothy Flegel, Bangkok, Thailand

Submitted: January 20, 1999; Accepted: January 11, 2000
Proofs received from author(s): May 3, 2000