PD/A CRSP Seventeenth Annual Technical Report

Estuarine Water Quality Monitoring and Estuarine Carrying Capacity

Eighth Work Plan, Honduras Research 2-1 (8HR2-1)
Final Report

Bartholomew W. Green, David R. Teichert-Coddington, and Claude E. Boyd
Department of Fisheries and Allied Aquacultures
Auburn University, Alabama, USA

Delia Martinez and Eneida Ramírez
Laboratorio de Calidad de Agua
La Lujosa, Choluteca, Honduras

Abstract

Water quality was monitored in estuaries of the shrimp-producing regions of southern Honduras. This project is a collaborative effort of universities, the private sector, and the public sector, with each group contributing time and resources to the overall effort. The project goal is to provide a scientific basis for estuarine management and sustainable development of shrimp culture in Honduras. Specific objectives are to: a) detect changes in estuarine water quality; b) formulate and validate predictive models for estuarine water quality; and c) estimate assimilative capacity of selected estuaries in the shrimp-producing region of southern Honduras based on water quality, farm chemical budgets, and estuarine fluid dynamics. Samples were collected from October 1996 to October 1998; during 1997–1998 data were collected from 20 sites on 12 estuaries. Nutrient sources for riverine estuaries include nutrient load in river discharge and rainfall or irrigation runoff from the watershed, and shrimp farm discharge. Changes in land-use patterns in the Gulf of Fonseca watershed also will affect estuarine water quality because of changes in runoff patterns and volumes. Water quality in riverine estuaries continues to be influenced directly by seasonal variation in river discharge and watershed runoff, while embayments of the Gulf of Fonseca experience less seasonal variation in water quality. The impact of the 1997–1998 El Niño in Honduras were delayed and reduced rains, which resulted in higher observed salinity, total nitrogen and chlorophyll *a* concentrations at sampling sites along riverine estuaries in comparison to 1996–1997. Embayment water quality was less affected by the El Niño. No trends for total nitrogen or total phosphorus enrichment were evident in riverine estuaries or embayments during the period 1993–1998. Total nitrogen and total phosphorus concentrations in riverine estuaries were reduced by 10–30% during the rainy season because of river discharge and watershed runoff.

Introduction

A long-term water quality monitoring project in estuaries of the shrimp-producing regions of Honduras was initiated in 1993 as part of the Honduras project of the Pond Dynamics/Aquaculture Collaborative Research Support Program (Teichert-Coddington, 1995; Green et al., 1997a). This project is a collaborative effort of universities, the private sector, and the public sector, with each group contributing time and resources to the overall effort. The goal of this monitoring effort is to provide a scientific basis for estuarine management and sustainable development of shrimp culture in Honduras. Specific objectives of the water quality monitoring are to: a) detect changes in estuarine water quality over time; b) formulate and validate predictive models for estuarine water quality; and c) estimate assimilative capacity of selected estuaries in the shrimp-producing region of southern Honduras based on water quality, farm chemical budgets, and estuarine fluid dynamics. Since 1993 the project has generated a continuous, long-term, systematic database on estuarine water quality in shrimp-producing areas of southern Honduras.

Estuarine water quality was monitored at 13 sites on 6 different estuaries when the project began in 1993. During 1998, 20 sites on 12 estuaries were monitored. The number of sites sampled has varied from 13 to 20 on 6 to 12 estuaries. Variation in participation is attributed in part to farms closing for the dry season, farms going out of business, change of farm ownership, change in managers or technical staff responsible for collection and delivery of water samples to the lab, logistical difficulties (e.g., no transport available) or distraction caused by crisis situations on farm. There is an ongoing effort to maintain continuous participation in the project and to incorporate additional farms.

This report summarizes results of water quality monitoring conducted under the PD/A CRSP Eighth Work Plan. Hurricane Mitch made landfall in Honduras at the end of October 1998 and resulted in massive flooding and losses to shrimp farmers (Green, 1999). As a consequence, estuarine water quality monitoring was suspended. Modeling work on assimilative capacity of selected estuaries will be reported separately (Ward, 2000).

Materials and Methods

Estuarine water samples were collected from pump discharge on individual farms within plus-or-minus one hour of high tide. It is assumed that the water samples collected represented a mixed water column sample of the estuary at the pump station because of the superficial vortex caused by the 60- to 90-cm-diameter pump intakes, which are located near the bottom of the estuary. Samples were placed on ice and transported to the water quality laboratory where analysis began within 12 hours of collection. The Choluteca River also was sampled weekly at La Lujosa, which is located downstream from the city of Choluteca and upstream from tidal influence.

Samples were analyzed for total settleable solids (APHA, 1985), nitrate-nitrogen by cadmium reduction to nitrite (Parsons et al., 1992), total ammonia-nitrogen (Parsons et al., 1992), filterable reactive phosphorus (Grasshoff et al., 1983), chlorophyll *a* (Parsons et al., 1992), total alkalinity by titration to pH 4.5 endpoint, salinity and BOD_2 (APHA, 1985), and reactive silicate (Strickland and Parsons, 1977). Total nitrogen and total phosphorus are determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation in a strong base (Grasshoff et al., 1983).

Data collected from October 1996 through October 1998 were tabulated by sampling site. Time-series graphs (1993 through 1998) of total nitrogen and total phosphorus concentrations were made using data from El Pedregal estuary (illustrative of riverine estuaries) and embayment estuaries (pooled data).

RESULTS

Results of water quality analyses by site are summarized in Table 1. Water quality in riverine estuaries is influenced directly by seasonal variation in river discharge and watershed runoff, while embayments of the Gulf of Fonseca experience less seasonal variation in water quality. Nutrient concentrations in riverine estuaries follow a cyclical trend that is controlled by season with higher concentrations of total nitrogen and total phosphorus occurring during the dry season and lower concentrations occurring during the rainy season. Rains in southern Honduras generally begin in May, remain strong through June, taper off during July and August, and resume during September and October. However, the effects of the 1997–1998 El Niño in Honduras were delayed and reduced rains. As a result, observed salinity, total nitrogen, and chlorophyll *a* concentrations were higher at sampling sites along riverine estuaries in comparison to 1996–1997 (see Green et al., 1998). Nutrient concentrations in embayments were not affected noticeably by the El Niño.

During the rainy season heavy watershed runoff and river discharge quickly flush out riverine estuaries and reduce salinity to zero or nearly zero parts per thousand, while embayment salinities drop only moderately. Concentrations of other nutrients in riverine estuaries decrease, but not to the degree observed with salinity because of the nutrient load carried by the increased river discharge and watershed runoff. Nutrient concentrations in embayments were lower and less affected by season than in riverine estuaries; data from 1996–1997 are shown to illustrate effect of season on water quality (Figure 1).

No trends for long-term total nitrogen or total phosphorus enrichment were evident in the El Pedregal estuary or embayments of the Gulf of Fonseca (Figures 2 and 3). Data from all

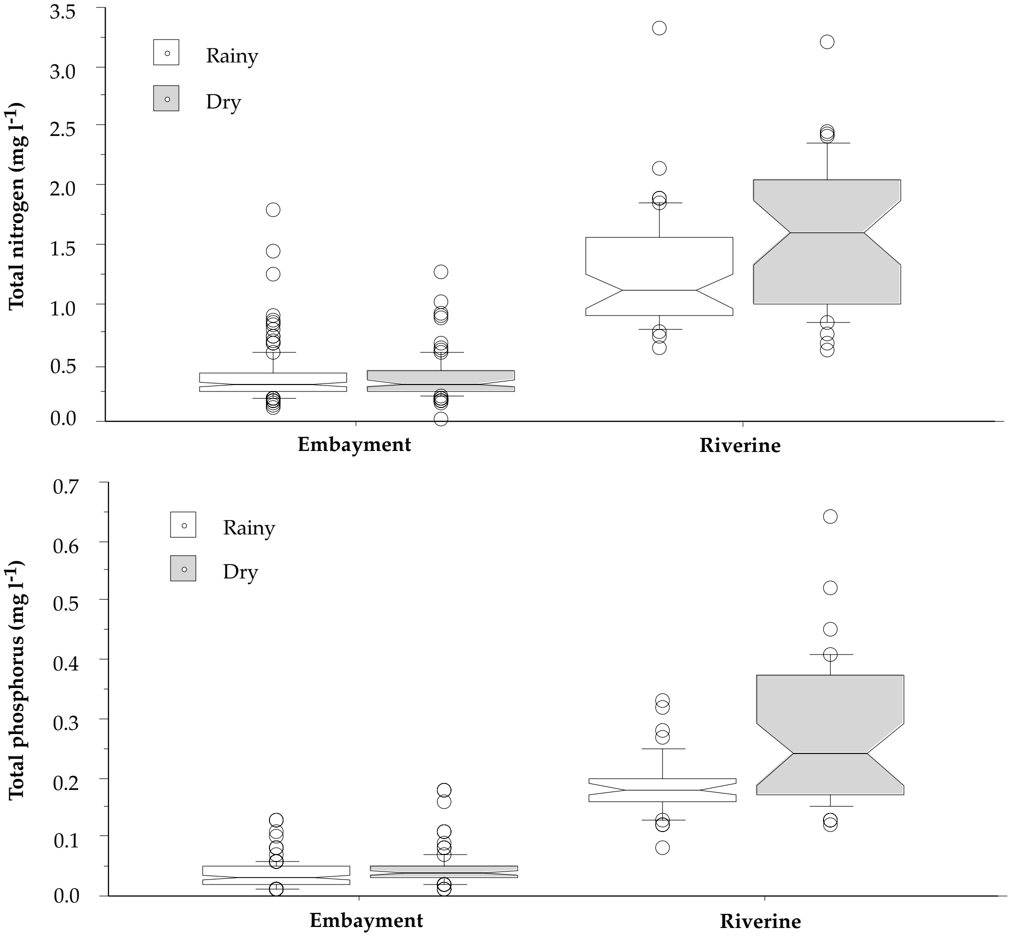

Figure 1. Comparison of median total nitrogen and total phosphorus concentrations in embayments (pooled data) and a riverine estuary, El Pedregal, using box plots. Data are from June 1997 to June 1998. Mid-June through mid-December was classified as the rainy season. The notches represent the 95% confidence limits around the median.

embayment estuaries are pooled because of the small number of sampling sites. Trends in nutrient concentrations in other riverine estuaries are similar to those shown in Figures 2 and 3.

DISCUSSION

Water quality in riverine estuaries is related to season. Global climatic events such as El Niño, which provoked drought conditions in Honduras, exacerbate water quality decline in riverine estuaries of the Gulf of Fonseca. In normal years, seasonal rains increase river discharge and watershed runoff, which serve to dilute nutrient concentrations in riverine estuaries. While salinity in riverine estuaries may be reduced to near zero during the rainy season because of massive freshwater inflow, total nitrogen and total phosphorus concentrations decrease only by 10 to 30% because of nutrient load in inflow. Changes in land-use patterns in the Gulf of Fonseca watershed also will affect estuarine water quality because of changes in runoff patterns and volumes. Catastrophic climatic events, such as tropical storm Mitch, provoked massive flooding in the estuarine areas of the Gulf of Fonseca. In addition, two important rivers, the Choluteca and Negro Rivers, experienced changes in their courses as a result of tropical storm Mitch. Reduction of river flow in the pre-Mitch channels reportedly was moderate to severe. If these two rivers do not return completely to their pre-Mitch channels during the next rainy season, it is possible that water quality in these riverine estuaries will be negatively impacted, as could shrimp farms located along these riverine estuaries.

Nutrient concentrations in riverine estuaries increase during the dry season because of evaporation and evapotranspiration, reduced river discharge, the absence of watershed runoff, and shrimp farm discharge. Although river discharge drops dramatically and nutrient concentrations increase significantly during the dry season, total nutrient discharge by rivers is significantly lower during the dry season. In fact, river discharge can drop to zero during very dry years. Water quality in the upper reaches of riverine estuaries deteriorates during the dry season, making maintenance of water quality very difficult on farms located in these regions. The deterioration in water quality in riverine estuaries during the dry season is exacerbated because water exchange with the Gulf of Fonseca decreases rapidly with distance upstream (Teichert-Coddington, 1995). Some farms located in the upper reaches of estuaries close during the dry season, probably because of slow growth attributed to lower water temperatures (Teichert-Coddington et al., 1994) and impaired water quality.

Water quality in embayments is less variable because embayments have better exchange with the Gulf of Fonseca, which is low in nutrients. In addition, the Gulf of Fonseca has a high tidal range (1.5 to 3.5 m) which promotes water exchange and nutrient dilution with the Pacific Ocean. River discharge and watershed runoff result in lower salinities, but not as low as those observed in riverine estuaries. Mean total nitrogen and total phosphorus concentrations increase from 11 to 25% during the rainy season because of nutrient load in river discharge and watershed runoff.

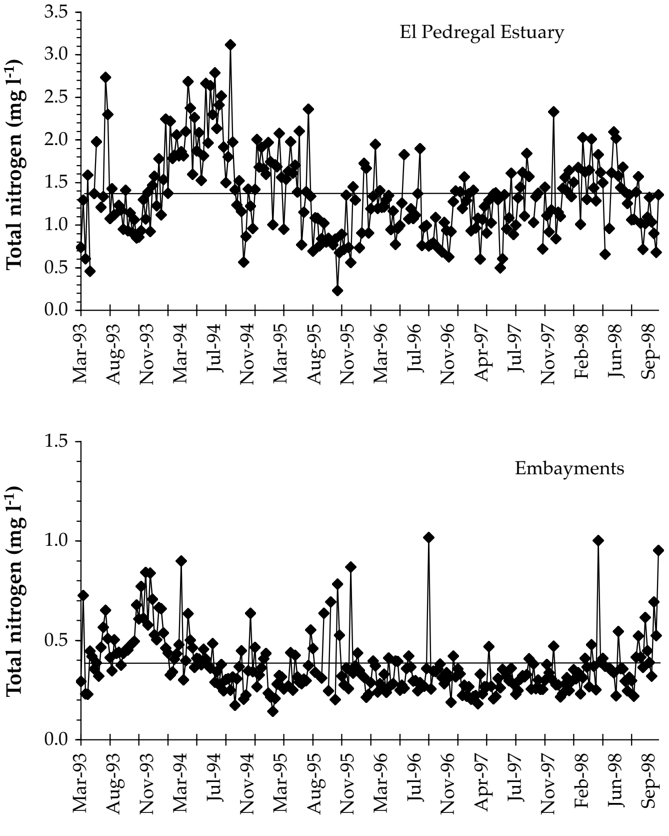

Figure 2. Mean total nitrogen concentration in the riverine El Pedregal estuary and embayments of the Gulf of Fonseca from 1993 to 1998. Total nitrogen concentration trends in other monitored riverine estuaries were similar to El Pedregal estuary. Solid horizontal line in each graph is the grand mean concentration during this period.

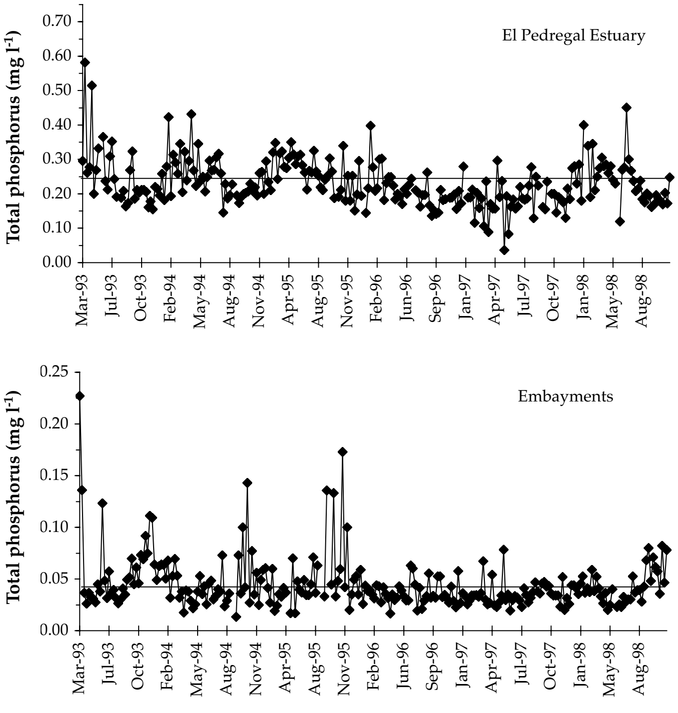

Figure 3. Mean total phosphorus concentration in the riverine El Pedregal estuary and embayments of the Gulf of Fonseca from 1993 to 1998. Total phosphorus concentration trends in other monitored riverine estuaries were similar to El Pedregal estuary. Solid horizontal line in each graph is the grand mean concentration during this period.

Table 1. Summary of estuarine water quality at shrimp farm pump station sites in southern Honduras from October 1996 to October 1998. Sites are labeled as "riverine" or "embayment" based on whether or not a river discharges directly into the estuary. Reactive silicate analyses began January 1998.

Variable	**October 1996–October 1997**				**October 1997–October 1998**			
	Mean	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*
Aquacultura Fonseca - Riverine								
Salinity (ppt)	13.75	12.12	0.50	39.00	18.12	13.18	0.40	48.00
Total Ammonia N (mg l^{-1})	0.25	0.12	0.01	0.51	0.19	0.11	0.00	0.41
Total Nitrogen (mg l^{-1})	1.31	0.50	0.24	2.29	1.46	0.47	0.03	2.19
Nitrates + Nitrites (mg l^{-1})	0.25	0.24	0.02	0.79	0.15	0.16	0.00	0.74
Total Phosphorus (mg l^{-1})	0.20	0.06	0.08	0.33	0.25	0.06	0.14	0.39
Soluble Reactive Phosphate (mg l^{-1})	0.14	0.06	0.04	0.25	0.12	0.06	0.04	0.22
Total Alkalinity (mg l^{-1})	123.80	45.28	39.20	181.26	130.41	49.79	41.62	202.98
Chlorophyll *a* (mg m^{-3})	27.61	14.13	4.51	61.05	36.20	24.04	0.00	92.61
BOD$_2$ (mg l^{-1})	2.74	1.42	0.00	6.40	2.61	1.15	0.70	5.90
Settleable Solids (mg l^{-1})	1.45	2.33	0.00	12.80	0.52	0.63	0.00	2.50
Reactive Silicate (mg l^{-1})					4.69	1.71	0.85	9.65
Acuacultivos #1 - Riverine								
Salinity (ppt)	14.53	12.14	0.00	34.00	16.59	11.97	0.10	41.00
Total Ammonia N (mg l^{-1})	0.12	0.80	0.00	0.38	0.13	0.10	0.02	0.46
Total Nitrogen (mg l^{-1})	1.06	0.40	0.32	2.21	1.17	0.39	0.48	2.19
Nitrates + Nitrites (mg l^{-1})	0.38	0.26	0.02	1.26	0.34	0.32	0.01	1.80
Total Phosphorus (mg l^{-1})	0.17	0.06	0.09	0.36	0.20	0.05	0.08	0.30
Soluble Reactive Phosphate (mg l^{-1})	0.12	0.04	0.05	0.26	0.11	0.04	0.04	0.21
Total Alkalinity (mg l^{-1})	113.42	39.05	0.00	197.01	199.25	41.03	51.41	198.65
Chlorophyll *a* (mg m^{-3})	20.28	16.77	2.41	68.66	31.62	30.36	2.00	167.93
BOD$_2$ (mg l^{-1})	2.11	1.02	0.00	5.40	1.91	0.77	0.85	4.40
Settleable Solids (mg l^{-1})	1.82	3.06	0.05	16.00	1.10	1.54	0.00	9.00
Reactive Silicate (mg l^{-1})					5.24	2.84	1.62	11.77
Acuacultivos #2 - Riverine								
Salinity (ppt)	1.80	4.46	0.00	20.50	3.76	9.74	0.00	36.50
Total Ammonia N (mg l^{-1})	0.06	0.07	0.01	0.30	0.07	0.09	0.01	0.54
Total Nitrogen (mg l^{-1})	0.78	0.52	0.24	2.55	1.07	0.58	0.18	2.82
Nitrates + Nitrites (mg l^{-1})	0.24	0.34	0.00	1.22	0.46	0.58	0.00	2.30
Total Phosphorus (mg l^{-1})	0.22	0.08	0.11	0.41	0.25	0.06	0.14	0.38
Soluble Reactive Phosphate (mg l^{-1})	0.18	0.06	0.04	0.32	0.16	0.07	0.04	0.33
Total Alkalinity (mg l^{-1})	129.05	43.93	46.00	217.50	125.65	66.31	41.62	300.72
Chlorophyll *a* (mg m^{-3})	24.44	27.48	0.00	165.44	31.76	36.19	0.00	125.80
BOD$_2$ (mg l^{-1})	2.31	1.37	0.00	5.10	2.36	1.27	0.60	5.80
Settleable Solids (mg l^{-1})	0.31	0.48	0.00	2.80	0.90	2.04	0.00	12.00
Reactive Silicate (mg l^{-1})					8.78	4.25	1.36	21.50
Biomar - Riverine								
Salinity (ppt)	21.88	9.74	0.50	34.50	23.56	10.66	1.90	46.00
Total Ammonia N (mg l^{-1})	0.04	0.04	0.00	0.15	0.07	0.06	0.01	0.33
Total Nitrogen (mg l^{-1})	0.63	0.17	0.27	1.13	0.86	0.38	0.42	2.29
Nitrates + Nitrites (mg l^{-1})	0.20	0.12	0.00	0.41	0.18	0.10	0.00	0.41
Total Phosphorus (mg l^{-1})	0.14	0.06	0.06	0.38	0.20	0.18	0.06	1.30
Soluble Reactive Phosphate (mg l^{-1})	0.08	0.03	0.00	0.16	0.09	0.04	0.04	0.24
Total Alkalinity (mg l^{-1})	113.46	25.95	29.92	150.48	120.99	28.86	52.38	177.80
Chlorophyll *a* (mg m^{-3})	15.05	14.23	2.37	68.38	20.23	18.94	0.00	75.34
BOD$_2$ (mg l^{-1})	0.98	0.56	0.00	2.35	1.87	1.47	0.20	7.35
Settleable Solids (mg l^{-1})	0.66	1.35	0.00	7.00	0.64	1.20	0.00	6.00
Reactive Silicate (mg l^{-1})					3.54	2.19	0.00	8.81

Table 1. Continued.

Variable	October 1996–October 1997				October 1997–October 1998			
	Mean	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*
Cadelpa - Riverine								
Salinity (ppt)	14.82	11.93	0.00	39.00	18.30	15.16	0.30	51.00
Total Ammonia N (mg l^{-1})	0.22	0.12	0.03	0.50	0.14	0.10	0.01	0.40
Total Nitrogen (mg l^{-1})	1.30	0.51	0.00	2.23	1.62	0.60	0.64	3.32
Nitrates + Nitrites (mg l^{-1})	0.20	0.22	0.00	0.78	0.07	0.11	0.00	0.47
Total Phosphorus (mg l^{-1})	0.21	0.05	0.09	0.33	0.27	0.11	0.14	0.64
Soluble Reactive Phosphate (mg l^{-1})	0.15	0.06	0.00	0.29	0.14	0.08	0.02	0.41
Total Alkalinity (mg l^{-1})	130.99	39.85	53.93	182.16	131.07	53.58	31.47	215.11
Chlorophyll *a* (mg m^{-3})	34.51	27.89	8.11	119.64	51.46	36.08	0.16	164.24
BOD$_2$ (mg l^{-1})	3.15	1.58	0.00	8.70	3.54	2.04	0.00	9.35
Settleable Solids (mg l^{-1})	0.40	0.61	0.00	3.50	0.37	0.42	0.00	2.00
Reactive Silicate (mg l^{-1})					4.97	1.83	0.95	9.45
Crimasa - Riverine								
Salinity (ppt)	23.23	11.74	1.50	47.00	21.46	11.88	1.90	46.00
Total Ammonia N (mg l^{-1})	0.10	0.09	0.00	0.31	0.11	0.08	0.02	0.29
Total Nitrogen (mg l^{-1})	1.07	0.35	0.56	2.15	1.09	0.28	0.71	1.89
Nitrates + Nitrites (mg l^{-1})	0.23	0.18	0.00	0.64	0.18	0.12	0.01	0.45
Total Phosphorus (mg l^{-1})	0.19	0.05	0.08	0.29	0.18	0.05	0.12	0.28
Soluble Reactive Phosphate (mg l^{-1})	0.13	0.05	0.04	0.23	0.10	0.04	0.04	0.18
Total Alkalinity (mg l^{-1})	129.06	28.35	57.90	174.58	120.90	29.89	67.90	182.58
Chlorophyll *a* (mg m^{-3})	23.40	29.73	0.00	124.32	26.36	18.18	2.95	85.72
BOD$_2$ (mg l^{-1})	1.81	1.03	0.00	5.70	1.80	0.81	0.20	4.55
Settleable Solids (mg l^{-1})	0.64	0.71	0.00	3.00	0.48	0.57	0.00	2.00
Reactive Silicate (mg l^{-1})					4.29	1.91	2.39	9.35
Culcamar - Embayment								
Salinity (ppt)	27.01	6.31	0.00	35.00	25.58	1.35	21.50	27.00
Total Ammonia N (mg l^{-1})	0.01	0.01	0.00	0.05	0.02	0.02	0.00	0.04
Total Nitrogen (mg l^{-1})	0.49	0.66	0.14	4.11	0.37	0.12	0.26	0.67
Nitrates + Nitrites (mg l^{-1})	0.01	0.01	0.00	0.03	0.01	0.01	0.00	0.02
Total Phosphorus (mg l^{-1})	0.03	0.02	0.01	0.08	0.03	0.02	0.01	0.07
Soluble Reactive Phosphate (mg l^{-1})	0.00	0.00	0.00	0.01	0.02	0.07	0.00	0.30
Total Alkalinity (mg l^{-1})	108.22	11.34	85.88	124.97	119.77	9.76	103.79	133.62
Chlorophyll *a* (mg m^{-3})	8.03	7.62	2.05	43.50	11.73	13.17	1.70	41.78
BOD$_2$ (mg l^{-1})	1.04	0.63	0.00	2.60	1.27	0.58	0.30	2.50
Settleable Solids (mg l^{-1})	0.01	0.02	0.00	0.10	0.00	0.00	0.00	0.00
Reactive Silicate (mg l^{-1})					1.47	1.30	0.27	4.26
Cumar - Riverine								
Salinity (ppt)	7.10	6.81	0.50	20.00	16.12	14.88	0.10	51.00
Total Ammonia N (mg l^{-1})	0.15	0.11	0.02	0.34	0.12	0.09	0.01	0.44
Total Nitrogen (mg l^{-1})	0.61	0.61	0.00	1.67	1.30	0.48	0.62	3.14
Nitrates + Nitrites (mg l^{-1})	0.23	0.13	0.11	0.53	0.21	0.13	0.00	0.53
Total Phosphorus (mg l^{-1})	0.20	0.07	0.12	0.37	0.25	0.13	0.14	0.98
Soluble Reactive Phosphate (mg l^{-1})	0.13	0.04	0.09	0.23	0.15	0.07	0.05	0.34
Total Alkalinity (mg l^{-1})	108.37	20.32	84.45	138.38	130.03	50.50	50.44	222.36
Chlorophyll *a* (mg m^{-3})	25.26	16.60	4.65	47.86	31.11	24.26	0.00	106.80
BOD$_2$ (mg l^{-1})	2.52	0.97	1.40	4.35	2.34	1.04	1.05	5.40
Settleable Solids (mg l^{-1})	0.83	1.76	0.10	5.50	0.66	0.89	0.00	4.00
Reactive Silicate (mg l^{-1})					5.37	2.23	2.23	10.90

Table 1. Continued.

Variable	**October 1996–October 1997**				**October 1997–October 1998**			
	Mean	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*
EL FARO - RIVERINE								
Salinity (ppt)	16.55	13.46	0.00	49.00	22.34	15.08	0.20	54.00
Total Ammonia N (mg l^{-1})	0.18	0.12	0.02	0.60	0.12	0.09	0.01	0.42
Total Nitrogen (mg l^{-1})	1.15	0.47	0.00	2.24	1.55	0.59	0.67	2.95
Nitrates + Nitrites (mg l^{-1})	0.26	0.22	0.00	0.79	0.12	0.19	0.00	0.95
Total Phosphorus (mg l^{-1})	0.23	0.08	0.08	0.48	0.32	0.12	0.14	0.65
Soluble Reactive Phosphate (mg l^{-1})	0.18	0.07	0.08	0.42	0.19	0.09	0.04	0.38
Total Alkalinity (mg l^{-1})	141.01	48.63	0.00	223.24	169.80	63.10	60.14	280.50
Chlorophyll *a* (mg m^{-3})	15.50	15.01	0.00	66.63	56.91	46.99	0.00	177.72
BOD_2 (mg l^{-1})	2.14	1.35	0.00	6.30	2.84	1.44	0.70	5.30
Settleable Solids (mg l^{-1})	4.10	8.72	0.00	32.00	2.09	4.71	0.00	24.00
Reactive Silicate (mg l^{-1})					5.26	1.90	0.00	10.46
FINCA SUR #1 - RIVERINE								
Salinity (ppt)	9.37	7.94	0.00	25.00	17.22	11.90	1.10	44.00
Total Ammonia N (mg l^{-1})	0.09	0.11	0.01	0.42	0.08	0.11	0.01	0.56
Total Nitrogen (mg l^{-1})	1.38	0.83	0.43	3.59	1.81	0.67	0.74	3.65
Nitrates + Nitrites (mg l^{-1})	0.05	0.11	0.00	0.37	0.04	0.08	0.00	0.25
Total Phosphorus (mg l^{-1})	0.26	0.09	0.10	0.44	0.35	0.09	0.18	0.51
Soluble Reactive Phosphate (mg l^{-1})	0.13	0.06	0.03	0.29	0.15	0.08	0.03	0.29
Total Alkalinity (mg l^{-1})	123.51	39.76	51.94	216.00	173.31	60.76	76.31	280.50
Chlorophyll *a* (mg m^{-3})	60.20	42.15	6.01	124.75	79.70	60.89	2.01	197.03
BOD_2 (mg l^{-1})	3.99	2.15	0.00	8.70	4.01	1.99	1.45	7.90
Settleable Solids (mg l^{-1})	1.51	4.65	0.00	22.00	0.70	1.37	0.00	6.50
Reactive Silicate (mg l^{-1})					5.30	1.95	1.20	9.35
FINCA SUR #2 - RIVERINE								
Salinity (ppt)	10.10	8.53	0.50	27.50	16.91	11.12	0.80	47.00
Total Ammonia N (mg l^{-1})	0.07	0.09	.00	0.36	0.08	0.08	0.01	0.31
Total Nitrogen (mg l^{-1})	1.39	0.78	0.00	2.84	1.76	0.58	0.66	3.16
Nitrates + Nitrites (mg l^{-1})	0.02	0.04	0.00	0.12	0.03	0.09	0.00	0.48
Total Phosphorus (mg l^{-1})	0.29	0.08	0.12	0.45	0.34	0.09	0.12	0.54
Soluble Reactive Phosphate (mg l^{-1})	0.14	0.08	0.00	0.31	0.15	0.07	0.04	0.27
Total Alkalinity (mg l^{-1})	122.47	29.24	80.36	177.00	173.86	60.08	84.39	277.44
Chlorophyll *a* (mg m^{-3})	68.24	32.14	24.31	147.62	66.61	46.50	0.94	205.63
BOD_2 (mg l^{-1})	4.49	1.86	0.00	8.30	3.70	1.71	0.80	6.95
Settleable Solids (mg l^{-1})	0.17	0.23	0.00	1.00	0.20	0.23	0.00	0.90
Reactive Silicate (mg l^{-1})					4.96	1.47	3.07	8.44
GMSB #1 - RIVERINE								
Salinity (ppt)	17.10	10.95	0.00	33.50	17.75	10.74	1.00	38.50
Total Ammonia N (mg l^{-1})	0.12	0.08	0.00	0.28	0.13	0.07	0.03	0.32
Total Nitrogen (mg l^{-1})	0.96	0.36	0.50	1.88	1.10	0.31	0.60	1.90
Nitrates + Nitrites (mg l^{-1})	0.29	0.15	0.10	0.67	0.29	0.21	0.01	1.08
Total Phosphorus (mg l^{-1})	0.16	0.05	0.04	0.32	0.19	0.04	0.12	0.26
Soluble Reactive Phosphate (mg l^{-1})	0.11	0.03	0.03	0.16	0.10	0.04	0.04	0.23
Total Alkalinity (mg l^{-1})	113.71	32.59	25.00	156.42	118.96	37.45	50.44	210.12
Chlorophyll *a* (mg m^{-3})	19.46	16.01	2.57	80.59	25.94	18.99	0.00	77.38
BOD_2 (mg l^{-1})	1.49	0.78	0.00	3.75	1.73	0.72	0.65	3.30
Settleable Solids (mg l^{-1})	1.12	1.64	0.00	8.00	0.56	0.78	0.00	3.50
Reactive Silicate (mg l^{-1})					4.73	2.20	1.79	9.24

Table 1. Continued.

Variable	October 1996–October 1997				October 1997–October 1998			
	Mean	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*
GMSB #1 - Riverine								
Salinity (ppt)	19.04	11.40	0.00	37.00	20.29	11.34	0.20	42.00
Total Ammonia N (mg l^{-1})	0.40	2.20	0.00	14.48	0.10	0.06	0.01	0.24
Total Nitrogen (mg l^{-1})	0.91	0.28	0.45	1.79	1.06	0.57	0.29	4.08
Nitrates + Nitrites (mg l^{-1})	0.34	0.18	0.10	0.94	0.24	0.11	0.00	0.42
Total Phosphorus (mg l^{-1})	0.17	0.05	0.03	0.28	0.19	0.05	0.10	0.34
Soluble Reactive Phosphate (mg l^{-1})	0.12	0.03	0.07	0.18	0.12	0.05	0.01	0.27
Total Alkalinity (mg l^{-1})	122.57	28.46	52.00	160.27	125.42	36.64	56.26	225.42
Chlorophyll *a* (mg m^{-3})	14.11	14.53	0.00	72.45	19.76	14.60	0.00	57.82
BOD_2 (mg l^{-1})	1.38	0.81	0.00	5.25	1.71	0.87	0.35	5.05
Settleable Solids (mg l^{-1})	0.48	1.01	0.00	5.00	0.43	0.56	0.00	2.50
Reactive Silicate (mg l^{-1})					4.51	2.58	1.87	10.90
La Jagua - Riverine								
Salinity (ppt)	14.33	11.51	0.00	34.00	15.23	12.52	0.10	42.00
Total Ammonia N (mg l^{-1})	0.10	0.09	0.00	0.34	0.15	0.11	0.02	0.48
Total Nitrogen (mg l^{-1})	1.01	0.41	0.00	2.21	1.35	0.40	0.70	2.35
Nitrates + Nitrites (mg l^{-1})	0.38	0.20	0.02	1.01	0.35	0.35	0.05	1.76
Total Phosphorus (mg l^{-1})	0.18	0.04	0.11	0.28	0.21	0.04	0.13	0.35
Soluble Reactive Phosphate (mg l^{-1})	0.14	0.05	0.07	0.40	0.11	0.04	0.00	0.18
Total Alkalinity (mg l^{-1})	119.56	40.44	0.00	171.72	122.00	43.93	50.88	196.45
Chlorophyll *a* (mg m^{-3})	25.11	19.50	2.45	83.15	35.86	24.46	0.00	99.57
BOD_2 (mg l^{-1})	2.37	1.46	0.00	7.50	2.62	1.46	0.00	8.00
Settleable Solids (mg l^{-1})	1.99	2.96	0.00	14.00	1.35	1.89	0.00	8.50
Reactive Silicate (mg l^{-1})					5.84	2.74	2.07	11.33
Las Arenas - Embayment								
Salinity (ppt)	26.97	5.20	9.00	34.00	27.61	4.15	18.80	35.50
Total Ammonia N (mg l^{-1})	0.03	0.04	0.00	0.18	0.04	0.03	0.00	0.11
Total Nitrogen (mg l^{-1})	0.30	0.11	0.00	0.54	0.37	0.19	0.16	0.98
Nitrates + Nitrites (mg l^{-1})	0.03	0.04	0.00	0.26	0.02	0.02	0.00	0.06
Total Phosphorus (mg l^{-1})	0.02	0.01	0.00	0.08	0.03	0.03	0.01	0.20
Soluble Reactive Phosphate (mg l^{-1})	0.00	0.01	0.00	0.04	0.01	0.02	0.00	0.16
Total Alkalinity (mg l^{-1})	105.43	12.79	58.87	122.76	111.12	13.15	80.19	139.74
Chlorophyll *a* (mg m^{-3})	3.54	1.77	0.00	7.46	4.72	2.90	0.00	20.92
BOD_2 (mg l^{-1})	0.87	0.35	0.10	2.25	0.98	0.77	0.00	3.50
Settleable Solids (mg l^{-1})	0.01	0.05	0.00	0.30	0.00	0.01	0.00	0.05
Reactive Silicate (mg l^{-1})					1.42	2.16	0.25	12.06
Lorette #1 - Embayment								
Salinity (ppt)	24.50	5.32	9.50	33.00	24.16	6.33	2.90	39.50
Total Ammonia N (mg l^{-1})	0.04	0.04	0.00	0.10	0.04	0.04	0.00	0.14
Total Nitrogen (mg l^{-1})	0.46	0.26	0.00	0.90	0.63	0.32	0.27	1.44
Nitrates + Nitrites (mg l^{-1})	0.03	0.05	0.00	0.15	0.01	0.02	0.00	0.08
Total Phosphorus (mg l^{-1})	0.07	0.04	0.01	0.18	0.08	0.03	0.04	0.16
Soluble Reactive Phosphate (mg l^{-1})	0.04	0.05	0.00	0.14	0.01	0.02	0.00	0.07
Total Alkalinity (mg l^{-1})	130.42	17.28	99.72	169.00	128.57	17.69	93.12	169.32
Chlorophyll *a* (mg m^{-3})	9.24	8.55	0.00	28.73	15.58	15.59	0.00	71.11
BOD_2 (mg l^{-1})	2.04	1.33	0.65	6.05	1.69	1.01	0.20	4.60
Settleable Solids (mg l^{-1})	0.06	0.06	0.00	0.20	0.05	0.05	0.00	0.20
Reactive Silicate (mg l^{-1})					3.12	1.40	1.61	6.28

Table 1. Continued.

Variable	**October 1996–October 1997**				**October 1997–October 1998**			
	Mean	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*
LORETTE #2 - EMBAYMENT								
Salinity (ppt)	23.09	5.31	10.00	32.50	23.91	5.54	15.00	39.50
Total Ammonia N (mg l^{-1})	0.03	0.03	0.00	0.08	0.03	0.02	0.00	0.10
Total Nitrogen (mg l^{-1})	0.49	0.25	0.25	1.25	0.56	0.32	0.23	1.73
Nitrates + Nitrites (mg l^{-1})	0.04	0.05	0.00	0.16	0.02	0.03	0.00	0.16
Total Phosphorus (mg l^{-1})	0.05	0.04	0.02	0.18	0.06	0.03	0.03	0.16
Soluble Reactive Phosphate (mg l^{-1})	0.02	0.03	0.00	0.14	0.01	0.01	0.00	0.05
Total Alkalinity (mg l^{-1})	110.04	11.91	91.58	130.70	113.86	20.82	77.60	159.14
Chlorophyll *a* (mg m^{-3})	15.44	36.21	0.00	150.00	18.15	29.01	0.03	150.00
BOD$_2$ (mg l^{-1})	2.08	1.73	0.70	7.00	1.71	1.12	0.40	4.40
Settleable Solids (mg l^{-1})	0.18	0.42	0.00	1.50	0.15	0.33	0.00	1.50
Reactive Silicate (mg l^{-1})					2.49	1.14	1.18	5.04
CHOLUTECA RIVER AT LA LUJOSA								
Salinity (ppt)	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.20
Total Ammonia N (mg l^{-1})	0.04	0.06	0.00	0.40	0.05	0.03	0.00	0.12
Total Nitrogen (mg l^{-1})	0.83	0.60	0.31	4.23	1.05	0.55	0.38	2.98
Nitrates + Nitrites (mg l^{-1})	0.30	0.44	0.00	2.51	0.53	0.49	0.00	2.16
Total Phosphorus (mg l^{-1})	0.26	0.13	0.10	0.63	0.25	0.09	0.11	0.43
Soluble Reactive Phosphate (mg l^{-1})	0.20	0.09	0.10	0.41	0.19	0.09	0.06	0.35
Total Alkalinity (mg l^{-1})	113.80	34.93	43.75	166.00	109.57	42.14	43.75	183.28
Chlorophyll *a* (mg m^{-3})	25.08	20.31	0.00	79.98	13.54	15.66	0.00	92.03
BOD$_2$ (mg l^{-1})	2.39	1.51	0.00	8.25	1.87	0.78	0.60	3.60
Settleable Solids (mg l^{-1})	0.51	1.45	0.00	9.40	0.30	0.51	0.00	2.00
Reactive Silicate (mg l^{-1})					11.47	5.45	0.93	27.48
SEA FARMS #1 - EMBAYMENT								
Salinity (ppt)	28.20	3.77	16.50	35.50	27.78	4.05	15.20	34.50
Total Ammonia N (mg l^{-1})	0.04	0.04	0.00	0.12	0.05	0.03	0.00	0.17
Total Nitrogen (mg l^{-1})	0.27	0.08	0.11	0.44	0.31	0.12	0.17	0.84
Nitrates + Nitrites (mg l^{-1})	0.02	0.01	0.00	0.06	0.02	0.03	0.00	0.21
Total Phosphorus (mg l^{-1})	0.05	0.02	0.00	0.13	0.05	0.02	0.02	0.13
Soluble Reactive Phosphate (mg l^{-1})	0.03	0.02	0.00	0.10	0.03	0.02	0.01	0.11
Total Alkalinity (mg l^{-1})	113.74	7.93	97.00	127.71	115.19	10.88	68.01	135.66
Chlorophyll *a* (mg m^{-3})	4.85	4.55	0.00	25.39	5.43	3.50	0.00	22.53
BOD$_2$ (mg l^{-1})	0.94	0.36	0.00	1.60	0.92	0.68	0.15	4.45
Settleable Solids (mg l^{-1})	0.00	0.01	0.00	0.05	0.02	0.03	0.00	0.10
Reactive Silicate (mg l^{-1})					1.72	0.95	0.13	4.68
SEA FARMS #2 - EMBAYMENT								
Salinity (ppt)	28.36	2.89	23.00	35.50	28.17	3.57	23.00	35.00
Total Ammonia N (mg l^{-1})	0.03	0.03	0.00	0.13	0.05	0.04	0.00	0.16
Total Nitrogen (mg l^{-1})	0.27	0.08	0.00	0.41	0.33	0.13	0.02	0.84
Nitrates + Nitrites (mg l^{-1})	0.01	0.02	0.00	0.12	0.02	0.02	0.00	0.08
Total Phosphorus (mg l^{-1})	0.03	0.02	0.00	0.11	0.03	0.01	0.01	0.05
Soluble Reactive Phosphate (mg l^{-1})	0.01	0.01	0.00	0.04	0.01	0.01	0.00	0.02
Total Alkalinity (mg l^{-1})	109.96	7.13	92.64	120.78	110.14	9.86	91.18	130.56
Chlorophyll *a* (mg m^{-3})	4.57	4.75	0.00	28.09	4.44	3.63	0.00	23.74
BOD$_2$ (mg l^{-1})	1.01	0.46	0.00	2.50	1.02	0.67	0.30	4.00
Settleable Solids (mg l^{-1})	0.00	0.02	0.00	0.10	0.01	0.02	0.00	0.10
Reactive Silicate (mg l^{-1})					0.96	1.39	0.24	8.30

Nutrient sources for riverine estuaries include nutrient load in the form of river discharge and rainfall or irrigation runoff from the watershed and shrimp farm discharge. Shrimp farmers must be acutely aware of estuarine water quality, as often the same estuary serves both as the source of water for production ponds and as the repository of production pond effluents. Nutrient concentration in shrimp farm effluents is the only source of estuarine nutrients that can be controlled by the farmer. The principal methods to achieve reduction of shrimp farm effluent nutrient load in Honduras are reducing exogenous nutrient inputs, i.e., feeds and fertilizers into ponds and controlling development both in terms of new pond area and intensification of production systems. Significant progress has been achieved in terms of feed use: feed conversion ratios have decreased from a mean of 3.2 in the early 1990s to 1.5 to 2.0 currently (Teichert-Coddington et al., 1991; Teichert-Coddington and Rodriguez, 1995; Teichert-Coddington et al., 1996; Green et al., 1997b). Results of PD/A CRSP research have demonstrated that feed protein content and daily feed ration can be decreased during the dry season without affecting yield (Teichert-Coddington and Rodriguez, 1995; Green et al., 1997b). Research on chemical fertilizer use and lower protein content diets is being conducted by some farms. Reduced use of exogenous nutrients in shrimp production during the dry season should reduce environmental impact of shrimp farm effluents. The development of assimilative capacity models for selected estuaries will provide information necessary in the formulation of strategies and regulations governing future development of shrimp farming.

ANTICIPATED BENEFITS

The estuarine water quality database serves to track long-term trends in estuarine water quality in shrimp-producing regions of southern Honduras. It also serves to increase awareness among shrimp farmers of their relation to the environment and encourages them to pursue sustainable production strategies. In the aftermath of tropical storm Mitch, it is critical that the water quality monitoring effort be sustained as the shrimp industry is reconstructed given the dramatic effects the storm had on river flow patterns. Unfortunately, this work could not be continued beyond the Eighth Work Plan because of severe budget reductions and the de-emphasis of shrimp production research by the PD/A CRSP. Fortunately, the Honduran National Association of Aquaculturists (ANDAH) assumed full ownership of the program and is committed to continuing the estuarine water quality monitoring program and operation of La Lujosa water quality laboratory. This occurrence demonstrates the significant development impact of the Honduras project of the PD/A CRSP. Data from this study will support development of models of assimilative capacity for selected estuaries. The assimilative capacity models will provide information necessary in the formulation of strategies and regulations governing future development of shrimp farming.

ACKNOWLEDGMENTS

We thank Jaime Lopez and farm personnel responsible for sample collection and transport to the La Lujosa Lab for their collaboration. This study was made possible by the collaboration of the General Directorate of Fisheries and Aquaculture (DIGEPESCA), Ministry of Agriculture and Livestock, and the Honduran National Association of Aquaculturists (ANDAH).

LITERATURE CITED

American Public Health Association (APHA), 1985. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, D.C., 1,268 pp.

Grasshoff, K., M. Ehrnhardt, and K. Kremling (Editors), 1983. Methods of Seawater Analysis. Verlag Chemie, Weinheim, Germany, 419 pp.

Green, B.W., 1999. The effect of tropical storm Mitch on the Honduran shrimp industry: A situation report. World Aquacult. 30(1):5–6.

Green, B.W., D.T. Teichert-Coddington, C.E. Boyd, D. Martinez, and E. Ramírez, 1998. Estuarine water quality monitoring and estuarine carrying capacity. In: D. Burke, J. Baker, B. Goetze, D. Clair, and H. Egna (Editors), Fifteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 87–98.

Green, B.W., D.R. Teichert-Coddington, M.P. Micheletti, and C.A. Lara, 1997a. A collaborative project to monitor water quality of estuaries in the shrimp producing regions of Honduras. In: Proceedings of the IV Ecuadorian Aquaculture Symposium, 22–27 October 1997, Centro Nacional de Investigaciones Marinas (CENAIM), Escuela Superior Politécnica del Litoral, (ESPOL), Camera Nacional de Acuacultura, Guayaquil, Ecuador. CD-ROM.

Green, B.W., D.T. Teichert-Coddington, C.E. Boyd, J.L. Harvin, H. Corrales, R. Zelaya, D. Martinez, and E. Ramírez, 1997b. Effect of diet protein on food conversion and nitrogen discharge during semi-intensive production of *Penaeus vannamei* during the dry season. In: H. Egna, B. Goetze, D. Burke, M. McNamara and D. Clair (Editors), Fourteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 77–86.

Strickland, J.D.H. and T.R. Parsons, 1977. A Practical Handbook of Seawater Analysis. Bulletin 167, Fisheries Research Board of Canada, Ottawa, Canada, 310 pp.

Parsons, T.R., Y. Maita, and C.M. Lalli, 1992. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, New York, 173 pp.

Teichert-Coddington, D.R., 1995. Estuarine water quality and sustainable shrimp culture in Honduras. In: C.L. Browdy and J.S. Hopkins (Editors), Swimming Through Troubled Waters, Proceedings of the Special Session on Shrimp Farming, Aquaculture '95. World Aquacult. Soc., Baton Rouge, Louisiana, pp. 144–156.

Teichert-Coddington, D.R. and R. Rodriguez, 1995. Semi-intensive commercial grow-out of *Penaeus vannamei* fed diets containing differing levels of crude protein during wet and dry seasons in Honduras. J. World Aquacult. Soc., 26:72–79.

Teichert-Coddington, D.R., B.W. Green, and R.P. Parkman, 1991. Substitution of chicken litter for feed in production of penaeid shrimp in Honduras. Prog. Fish-Cult., 53(3):150–156.

Teichert-Coddington, D.R., R. Rodriguez, and W. Toyofuku, 1994. Causes of cyclical variation in Honduran shrimp production. World Aquacult., 25(1):57–61.

Teichert-Coddington, D.R., W. Toyofuku, J. Harvin, and R. Rodriguez, 1996. Relationships among stocking density, survival and yield in ponds affected by the Taura Syndrome during wet and dry seasons in Honduras. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 85–94.

Ward, G.W., 2000. Evaluation of shrimp farming impacts in Golfo de Fonseca region, Honduras. In: K. McElwee, D. Burke, M. Niles, X. Cummings, and H. Egna (Editors), Seventeenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 95–100.