ESTUARINE WATER QUALITY MONITORING AND ESTUARINE CARRYING CAPACITY

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

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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: 1) detect changes in estuarine water quality; 2) formulate and validate predictive models for estuarine water quality; and 3) 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 June 1997 to June 1998 from 20 sites on 12 estuaries. Data were added to the database on estuarine water quality established in 1993. 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. Examples of this effect already have been observed in the upper reaches of a couple of estuaries where stands of mangroves have died apparently because of sedimentation, which resulted from severe reduction of runoff caused by watershed land-use changes. 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 El Niño in Honduras this past year was 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 and 1997. Embayment water quality was less affected by the El Niño. Declines in water quality in riverine estuaries were exacerbated with increasing distance upstream because water exchange with the Gulf of Fonseca decreases rapidly with distance upstream. No trends for total nitrogen or total phosphorus enrichment were evident in riverine estuaries or embayments during the period from 1993 to 1998. Total nitrogen and total phosphorus concentrations in riverine estuaries were reduced by 10 to 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 Pond Dynamics/Aquaculture Collaborative Research Support Program (Teichert-Coddington, 1995; Green et al., 1997a). This project is a collaborative effort of universities and the private and public sectors, 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:

1) Detect changes in estuarine water quality over time;
2) Formulate and validate predictive models for estuarine water quality; and
3) 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 this past year, 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 yearly sample size 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.

Results of estuarine water quality monitoring are summarized in this report. Modeling work and estimates of assimilative capacity of selected estuaries will be reported separately.

METHODS AND MATERIALS

Estuarine water samples were collected from pump discharge on individual farms within one hour of high tide. It was 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-

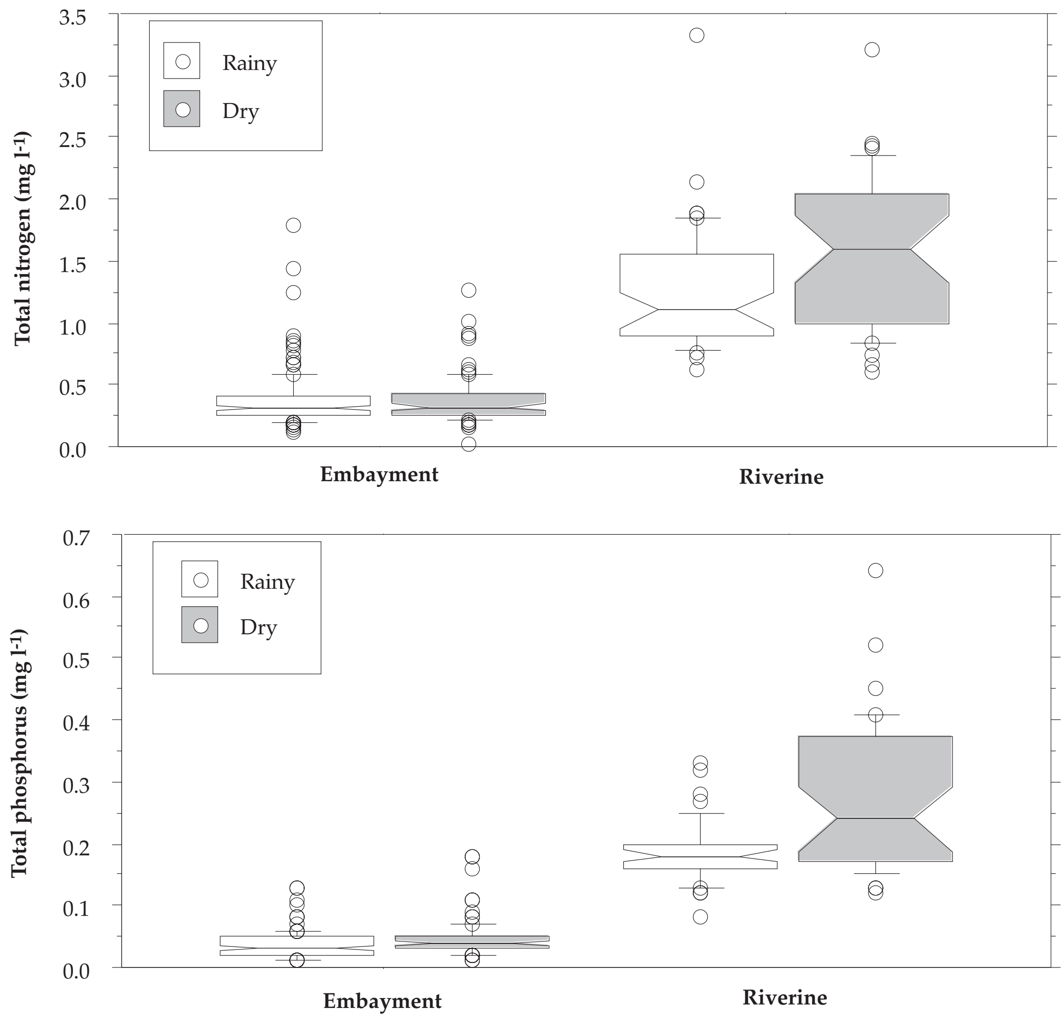


Figure 1. Comparison of median total nitrogen and total phosphorus concentrations in embayments (pooled data) and a riverine estuary, El Pedregal, using box plots. Data are from June 1997 to June 1998. Mid-June through mid-December was classified as the rainy season. The notches represent the 95% confidence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

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 June 1997 to June 1998 were tabulated by sampling site. Box plots were used to compare total nitrogen and total phosphorus concentrations by estuary type (embayment or riverine) and season. Time-series graphs (1993 to 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 El Niño in Honduras during this past year 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 through 1997.

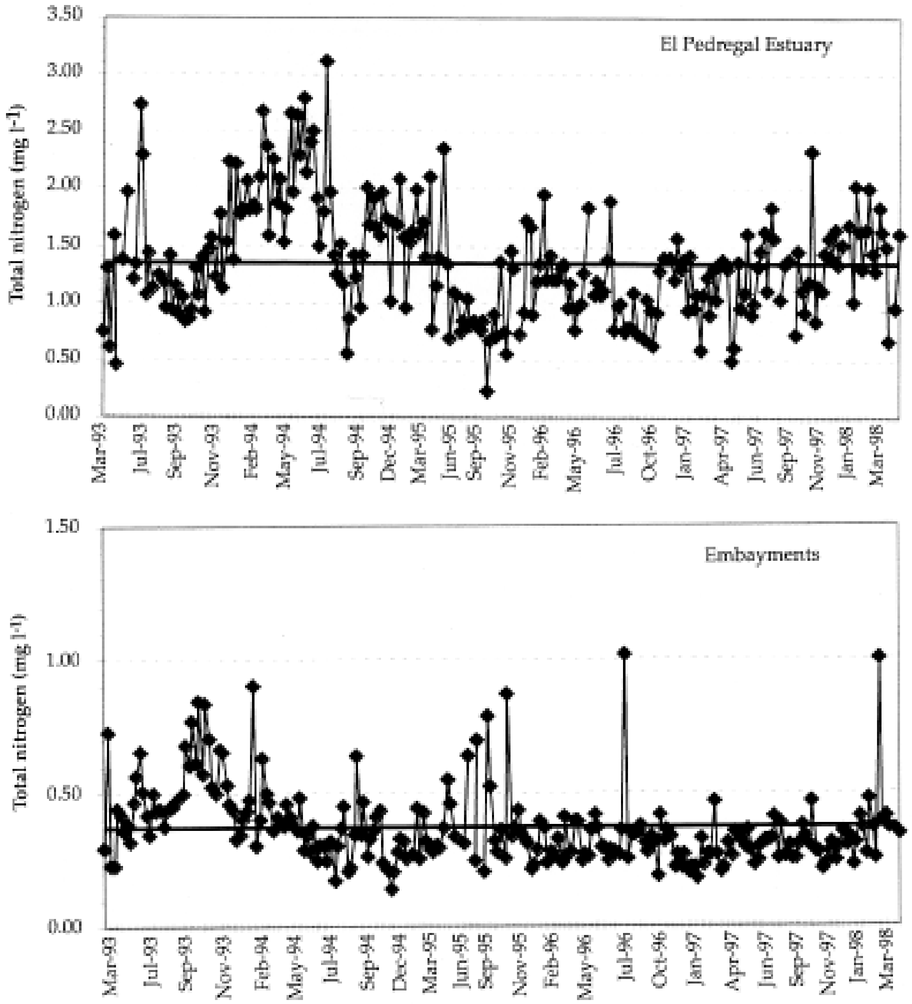


Figure 2. Mean total nitrogen concentration in the riverine El Pedregal estuary and embayments of the Gulf of Fonseca from 1993 to 1998. Total nitrogen concentration trends in other monitored riverine estuaries were similar to El Pedregal estuary. Solid horizontal line in each graph is the grand mean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

Nutrient concentrations in embayments were not affected noticeably by the El Niño.

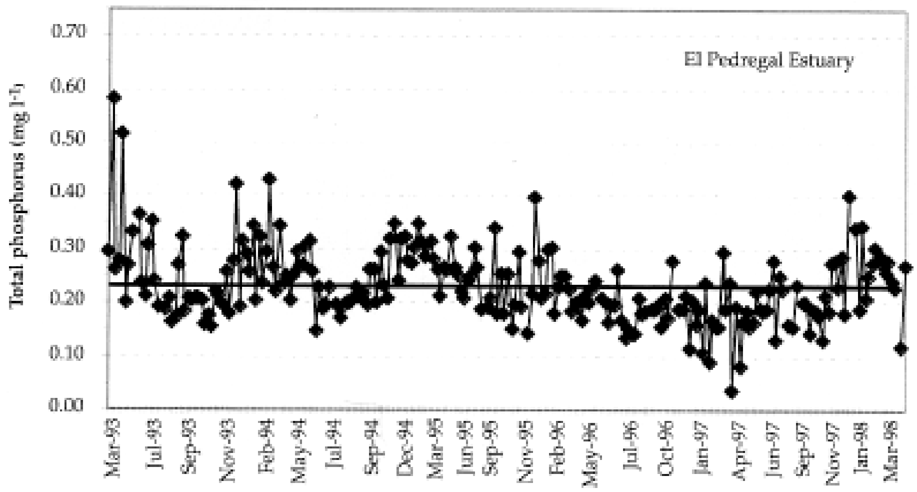
During the rainy season, heavy watershed runoff and river discharge quickly flushed out riverine estuaries and reduced salinity to zero or nearly zero parts per thousand, while embayment salinities dropped only moderately. Concentrations of other nutrients in riverine estuaries decreased, but not to 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 (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 embayment estuaries were pooled because of the small number of sampling sites. Trends in nutrient concentrations in other riverine estuaries were similar to those shown in Figures 2 and 3.

Water quality also varied with position in riverine estuaries (Figure 4). Total nitrogen concentration increased with distance upstream from the Gulf of Fonseca during both rainy and dry seasons; however, total nitrogen concentrations were lower in the rainy season. Concentrations of total phosphorus followed a similar pattern (Table 2), and similar patterns were observed in other riverine estuaries.

DISCUSSION

Water quality in riverine estuaries is related to season. Global climatic events such as El Niño, which provoked drought conditions in Honduras, exacerbate poor water quality conditions 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 zero or nearly so 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



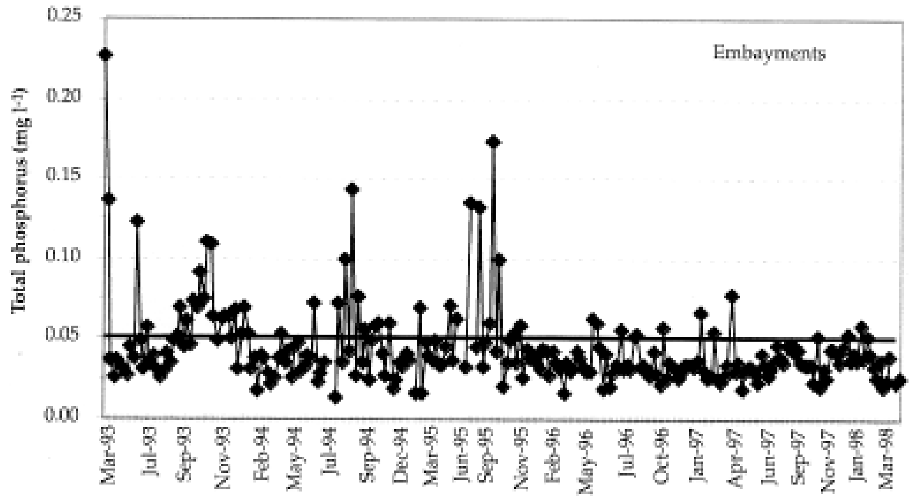


Figure 3. Mean total phosphorus concentration in the riverine El Pedregal estuary and embayments of the Gulf of Fonseca from 1993 to 1998. Total phosphorus concentration trends in other monitored riverine estuaries were similar to El Pedregal estuary. Solid horizontal line in each graph is the grand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

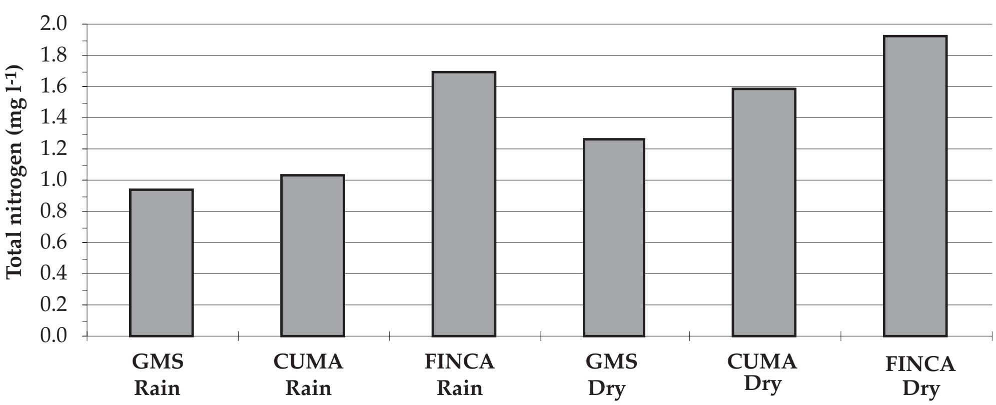


Figure 4. Total nitrogen concentrations in the San Bernardo estuary in relation to distance from the mouth of the estuary and season during the period from June 1997 to June 1998. The GMSB sample site is nearest to the Gulf of Fonseca and the FINCA SUR site is farthest. Mid-June through mid-December was classified as the rainy season.

Table 1. Summary of estuarine water quality at shrimp farm pump station sites in southern Honduras from June 1997 to June 1998. Sites are labeled as "riverine" or "embayment" depending on whether or not a river discharges directly into the estuary.

Variable	Mean	SD	Count	Minimum	Maximum	Median
AQUACULTURA FONSECA - RIVERINE						
Salinity (ppt)	19.83	12.38	32	3.00	48.00	18.50
Total Ammonia Nitrogen (mg l^{-1})	0.24	0.10	32	0.06	0.41	0.23
Total Nitrogen (mg l^{-1})	1.46	0.41	32	0.24	2.11	1.45
Nitrates + Nitrites (mg l^{-1})	0.15	0.12	32	0.02	0.53	0.13
Total Phosphorus (mg l^{-1})	0.25	0.06	32	0.14	0.36	0.24
Sol. Reactive Phosphate (mg l^{-1})	0.14	0.05	31	0.04	0.22	0.15
Total Alkalinity (mg l^{-1})	146.67	42.64	31	63.00	202.98	153.65
Chlorophyll *a* (mg m^{-3})	32.68	17.08	32	0.92	69.84	31.06
BOD_2 (mg l^{-1})	2.44	1.14	30	0.70	6.40	2.23
Settleable solids (mg l^{-1})	0.67	0.70	29	0.00	2.80	0.40
Reactive Silicate (mg l^{-1})	4.15	1.89	13	0.85	9.03	4.02
AQUACULTIVOS #1 - RIVERINE						
Salinity (ppt)	18.00	11.34	45	0.50	41.00	18.50
Total Ammonia Nitrogen (mg l^{-1})	0.14	0.10	43	0.02	0.46	0.12
Total Nitrogen (mg l^{-1})	1.16	0.41	45	0.48	2.17	1.05
Nitrates + Nitrites (mg l^{-1})	0.37	0.33	43	0.02	1.46	0.27
Total Phosphorus (mg l^{-1})	0.19	0.06	45	0.08	0.32	0.19
Sol. Reactive Phosphate (mg l^{-1})	0.12	0.04	43	0.05	0.21	0.11
Total Alkalinity (mg l^{-1})	126.30	37.36	42	49.00	198.65	128.03
Chlorophyll *a* (mg m^{-3})	25.38	20.69	43	2.53	111.31	20.07
BOD_2 (mg l^{-1})	1.90	0.69	41	0.65	3.60	1.85
Settleable Solids (mg l^{-1})	1.07	1.68	41	0.05	10.00	0.60
Reactive Silicate (mg l^{-1})	3.64	1.39	15	1.87	7.94	3.62
AQUACULTIVOS #2 - RIVERINE						
Salinity (ppt)	4.18	10.07	45	0.00	36.5	0.50
Total Ammonia Nitrogen (mg l^{-1})	0.07	0.09	43	0.01	0.54	0.04
Total Nitrogen (mg l^{-1})	0.99	0.55	45	0.26	2.46	0.86
Nitrates + Nitrites (mg l^{-1})	0.34	0.42	43	0.00	1.78	0.11
Total Phosphorus (mg l^{-1})	0.24	0.06	45	0.14	0.40	0.23
Sol. Reactive Phosphate (mg l^{-1})	0.18	0.06	43	0.04	0.29	0.16
Total Alkalinity (mg l^{-1})	136.34	62.47	42	46.00	300.72	123.05
Chlorophyll *a* (mg m^{-3})	35.61	37.20	43	0.00	165.44	23.18
BOD_2 (mg l^{-1})	2.57	1.40	41	0.25	5.80	2.35
Settleable Solids (mg l^{-1})	0.81	2.06	40	0.00	12.00	0.20
Reactive Silicate (mg l^{-1})	7.78	5.80	14	1.50	22.79	6.04
BIOMAR - RIVERINE						
Salinity (ppt)	26.11	6.73	37	15.50	46.00	25.00
Total Ammonia Nitrogen (mg l^{-1})	0.03	0.03	37	0.01	0.16	0.03
Total Nitrogen (mg l^{-1})	0.77	0.37	37	0.42	2.29	0.65
Nitrates + Nitrites (mg l^{-1})	0.17	0.09	37	0.00	0.37	0.17
Total Phosphorus (mg l^{-1})	0.15	0.06	37	0.06	0.33	0.13
Sol. Reactive Phosphate (mg l^{-1})	0.08	0.02	37	0.03	0.15	0.08
Total Alkalinity (mg l^{-1})	129.59	19.32	36	95.00	177.80	125.73
Chlorophyll *a* (mg m^{-3})	20.13	19.07	37	2.34	75.34	10.05
BOD_2 (mg l^{-1})	1.45	1.24	35	0.10	5.40	1.15
Settleable Solids (mg l^{-1})	0.96	1.73	31	0.00	7.00	0.20
Reactive Silicate (mg l^{-1})	2.34	0.76	14	0.74	3.37	2.46

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
CADELPA - RIVERINE						
Salinity (ppt)	20.11	13.43	39	2.00	51.00	15.50
Total Ammonia Nitrogen (mg l^{-1})	0.19	0.11	38	0.03	0.40	0.17
Total Nitrogen (mg l^{-1})	1.66	0.68	42	0.00	3.32	1.66
Nitrates + Nitrites (mg l^{-1})	0.11	0.13	38	0.01	0.57	0.06
Total Phosphorus (mg l^{-1})	0.28	0.11	40	0.13	0.64	0.25
Sol. Reactive Phosphate (mg l^{-1})	0.15	0.07	38	0.02	0.41	0.14
Total Alkalinity (mg l^{-1})	148.10	41.55	37	53.93	215.11	149.00
Chlorophyll *a* (mg m^{-3})	51.76	36.34	38	9.44	164.24	44.67
BOD_2 (mg l^{-1})	3.62	1.93	35	0.95	9.35	3.30
Settleable Solids (mg l^{-1})	0.35	0.43	36	0.00	2.00	0.20
Reactive Silicate (mg l^{-1})	4.25	1.51	14	0.94	7.51	4.49
CRIMASA - RIVERINE						
Salinity (ppt)	23.20	8.96	32	7.50	46.00	21.50
Total Ammonia Nitrogen (mg l^{-1})	0.09	0.08	32	0.00	0.27	0.07
Total Nitrogen (mg l^{-1})	1.15	0.39	32	0.56	2.15	1.11
Nitrates + Nitrites (mg l^{-1})	0.16	0.13	32	0.01	0.55	0.12
Total Phosphorus (mg l^{-1})	0.18	0.06	32	0.08	0.29	0.18
Sol. Reactive Phosphate (mg l^{-1})	0.11	0.04	32	0.04	0.23	0.12
Total Alkalinity (mg l^{-1})	129.68	24.69	31	75.00	182.58	131.26
Chlorophyll *a* (mg m^{-3})	31.45	32.13	32	2.41	124.32	16.60
BOD_2 (mg l^{-1})	1.87	0.92	30	0.50	4.55	1.67
Settleable Solids (mg l^{-1})	0.48	0.53	31	0.00	2.50	0.40
Reactive Silicate (mg l^{-1})	3.46	0.55	6	2.78	4.33	3.34
CULCAMAR - EMBAYMENT						
Salinity (ppt)	26.19	2.00	32	21.50	34.00	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.16	0.02	31	0.00	0.05	0.01
Total Nitrogen (mg l^{-1})	0.52	0.71	32	0.23	4.11	0.36
Nitrates + Nitrites (mg l^{-1})	0.01	0.01	31	0.00	0.02	0.00
Total Phosphorus (mg l^{-1})	0.03	0.01	32	0.01	0.07	0.03
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.05	31	0.00	0.30	0.00
Total Alkalinity (mg l^{-1})	114.09	11.88	30	88.00	133.62	113.45
Chlorophyll *a* (mg m^{-3})	9.80	10.69	31	1.70	41.78	4.82
BOD_2 (mg l^{-1})	1.17	0.64	28	0.05	2.50	1.10
Settleable Solids (mg l^{-1})	0.00	0.01	29	0.00	0.05	0.00
Reactive Silicate (mg l^{-1})	1.51	1.29	7	0.27	4.27	1.17
CUMAR - RIVERINE						
Salinity (ppt)	19.96	15.64	26	1.00	51.00	20.25
Total Ammonia Nitrogen (mg l^{-1})	0.12	0.08	26	0.01	0.34	0.11
Total Nitrogen (mg l^{-1})	1.31	0.53	26	0.62	3.14	1.28
Nitrates + Nitrites (mg l^{-1})	0.24	0.15	26	0.00	0.53	0.22
Total Phosphorus (mg l^{-1})	0.27	0.16	26	0.12	0.98	0.25
Sol. Reactive Phosphate (mg l^{-1})	0.18	0.05	26	0.11	0.34	0.19
Total Alkalinity (mg l^{-1})	153.39	43.33	26	84.45	222.36	146.52
Chlorophyll a (mg m^{-3})	33.39	21.57	26	4.65	106.80	30.45
BOD_2 (mg l^{-1})	2.42	1.00	26	1.05	4.50	2.20
Settleable Solids (mg l^{-1})	1.03	1.38	23	0.10	5.50	0.50
Reactive Silicate (mg l^{-1})	3.92	0.98	12	2.22	5.77	4.00

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
EL FARO - RIVERINE						
Salinity (ppt)	20.70	12.68	37	0.50	54.00	18.00
Total Ammonia Nitrogen (mg l^{-1})	0.13	0.09	36	0.02	0.42	0.13
Total Nitrogen (mg l^{-1})	1.53	0.52	37	0.78	2.95	1.43
Nitrates + Nitrites (mg l^{-1})	0.16	0.16	36	0.00	0.70	0.11
Total Phosphorus (mg l^{-1})	0.29	0.13	37	0.08	0.65	0.26
Sol. Reactive Phosphate (mg l^{-1})	0.19	0.07	36	0.08	0.38	0.18
Total Alkalinity (mg l^{-1})	177.08	55.38	35	46.00	280.50	172.00
Chlorophyll *a* (mg m^{-3})	39.84	38.51	36	0.00	177.72	31.83
BOD_2 (mg l^{-1})	2.57	1.37	33	0.60	5.30	2.70
Settleable Solids (mg l^{-1})	3.49	7.26	35	0.00	32.00	0.10
Reactive Silicate (mg l^{-1})	4.94	0.94	11	3.80	6.73	4.91
FINCA SUR #1 - RIVERINE						
Salinity (ppt)	16.50	9.22	29	2.00	44.00	16.00
Total Ammonia Nitrogen (mg l^{-1})	0.08	0.13	27	0.01	0.56	0.03
Total Nitrogen (mg l^{-1})	1.75	0.75	29	0.74	3.65	1.72
Nitrates + Nitrites (mg l^{-1})	0.42	0.08	27	0.00	0.26	0.01
Total Phosphorus (mg l^{-1})	0.33	0.09	29	0.18	0.51	0.31
Sol. Reactive Phosphate (mg l^{-1})	0.16	0.08	27	0.03	0.29	0.15
Total Alkalinity (mg l^{-1})	180.36	57.24	26	76.31	280.50	171.96
Chlorophyll *a* (mg m^{-3})	71.86	47.95	28	4.82	185.48	59.26
BOD_2 (mg l^{-1})	4.28	2.12	25	1.45	7.90	3.80
Settleable Solids (mg l^{-1})	0.80	1.43	25	0.00	6.50	0.20
Reactive Silicate (mg l^{-1})	4.14	1.53	6	1.20	5.47	4.36
FINCA SUR #2 - RIVERINE						
Salinity (ppt)	17.02	9.28	31	3.50	47.00	16.50
Total Ammonia Nitrogen (mg l^{-1})	0.06	0.07	29	0.00	0.27	0.03
Total Nitrogen (mg l^{-1})	1.77	0.59	31	0.66	3.16	1.60
Nitrates + Nitrites (mg l^{-1})	0.02	0.04	29	0.00	0.13	0.00
Total Phosphorus (mg l^{-1})	0.32	0.09	31	0.12	0.54	0.32
Sol. Reactive Phosphate (mg l^{-1})	0.16	0.07	28	0.01	0.27	0.16
Total Alkalinity (mg l^{-1})	179.36	56.05	28	84.45	277.44	172.98
Chlorophyll *a* (mg m^{-3})	65.66	37.04	30	19.53	148.80	55.92
BOD_2 (mg l^{-1})	4.00	1.94	28	0.80	8.30	3.53
Settleable Solids (mg l^{-1})	0.23	0.23	27	0.00	0.90	0.15
Reactive Silicate (mg l^{-1})	4.26	0.79	7	3.29	5.31	4.20
GMSB #1 - RIVERINE						
Salinity (ppt)	18.44	9.84	42	2.00	38.50	18.00
Total Ammonia Nitrogen (mg l^{-1})	0.14	0.08	40	0.03	0.32	0.13
Total Nitrogen (mg l^{-1})	1.08	0.32	42	0.60	1.88	0.99
Nitrates + Nitrites (mg l^{-1})	0.30	0.18	40	0.07	1.08	0.28
Total Phosphorus (mg l^{-1})	0.18	0.04	42	0.08	0.32	0.18
Sol. Reactive Phosphate (mg l^{-1})	0.11	0.03	40	0.06	0.23	0.11
Total Alkalinity (mg l^{-1})	124.35	36.58	38	25.00	210.12	127.10
Chlorophyll *a* (mg m^{-3})	21.70	16.34	40	2.57	80.59	15.82
BOD_2 (mg l^{-1})	1.47	0.67	38	0.50	3.75	1.38
Settleable Solids (mg l^{-1})	0.48	0.56	39	0.00	2.50	0.20
Reactive Silicate (mg l^{-1})	3.70	2.14	14	1.75	9.47	2.80

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
GMSB #2 - RIVERINE						
Salinity (ppt)	21.89	9.15	40	3.50	42.00	21.00
Total Ammonia Nitrogen (mg l^{-1})	0.09	0.06	39	0.01	0.24	0.08
Total Nitrogen (mg l^{-1})	1.08	0.62	41	0.29	4.08	0.88
Nitrates + Nitrites (mg l^{-1})	0.28	0.14	39	0.12	0.94	0.28
Total Phosphorus (mg l^{-1})	0.19	0.05	41	0.03	0.34	0.19
Sol. Reactive Phosphate (mg l^{-1})	0.13	0.04	39	0.08	0.27	0.12
Total Alkalinity (mg l^{-1})	134.31	32.93	38	52.00	225.42	136.60
Chlorophyll *a* (mg m^{-3})	17.94	15.32	39	2.37	72.45	13.78
BOD_2 (mg l^{-1})	1.42	0.61	36	0.30	2.85	1.40
Settleable Solids (mg l^{-1})	0.51	1.03	36	0.00	5.00	0.10
Reactive Silicate (mg l^{-1})	3.39	1.98	13	2.01	9.75	2.85
LA JAGUA - RIVERINE						
Salinity (ppt)	17.44	11.77	39	0.00	42.00	16.00
Total Ammonia Nitrogen (mg l^{-1})	0.17	0.12	37	0.01	0.48	0.13
Total Nitrogen (mg l^{-1})	1.30	0.45	40	0.46	2.35	1.21
Nitrates + Nitrites (mg l^{-1})	0.31	0.29	38	0.02	1.63	0.25
Total Phosphorus (mg l^{-1})	0.20	0.05	40	0.12	0.29	0.19
Sol. Reactive Phosphate (mg l^{-1})	0.13	0.03	37	0.07	0.18	0.12
Total Alkalinity (mg l^{-1})	135.61	37.56	36	50.88	196.45	135.68
Chlorophyll *a* (mg m^{-3})	33.12	19.68	38	6.52	83.15	28.53
BOD_2 (mg l^{-1})	2.63	1.43	34	1.05	8.00	2.58
Settleable Solids (mg l^{-1})	1.58	1.88	37	0.00	6.20	0.60
Reactive Silicate (mg l^{-1})	3.98	1.30	14	2.21	7.29	3.89
LAS ARENAS - EMBAYMENT						
Salinity (ppt)	26.88	3.13	43	22.50	35.50	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.03	0.03	40	0.00	0.15	0.02
Total Nitrogen (mg l^{-1})	0.33	0.13	43	0.16	0.89	0.30
Nitrates + Nitrites (mg l^{-1})	0.02	0.04	39	0.00	0.26	0.01
Total Phosphorus (mg l^{-1})	0.02	0.01	43	0.00	0.05	0.02
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.03	41	0.00	0.16	0.00
Total Alkalinity (mg l^{-1})	113.75	11.14	41	87.00	139.74	113.96
Chlorophyll *a* (mg m^{-3})	4.02	1.49	41	0.00	6.79	4.58
BOD_2 (mg l^{-1})	0.88	0.49	38	0.15	3.00	0.80
Settleable Solids (mg l^{-1})	0.01	0.05	40	0.00	0.30	0.00
Reactive Silicate (mg l^{-1})	0.72	0.18	13	0.24	0.88	0.77
LORETTE #1 - EMBAYMENT						
Salinity (ppt)	25.98	5.01	31	9.50	39.50	26.50
Total Ammonia Nitrogen (mg l^{-1})	0.04	0.03	31	0.00	0.14	0.03
Total Nitrogen (mg l^{-1})	0.53	0.30	32	0.00	1.44	0.47
Nitrates + Nitrites (mg l^{-1})	0.02	0.04	31	0.00	0.15	0.01
Total Phosphorus (mg l^{-1})	0.07	0.04	31	0.01	0.18	0.06
Sol. Reactive Phosphate (mg l^{-1})	0.02	0.04	31	0.00	0.14	0.00
Total Alkalinity (mg l^{-1})	133.92	15.59	30	99.72	169.32	133.30
Chlorophyll *a* (mg m^{-3})	9.88	8.27	31	0.00	34.75	8.39
BOD_2 (mg l^{-1})	1.78	1.26	30	0.20	6.05	1.40
Settleable Solids (mg l^{-1})	0.05	0.05	29	0.00	0.20	0.05
Reactive Silicate (mg l^{-1})	2.42	1.15	9	1.69	5.39	2.19

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
LORETTE #2 - EMBAYMENT						
Salinity (ppt)	25.13	5.27	31	10.00	39.50	25.50
Total Ammonia Nitrogen (mg l^{-1})	0.03	0.03	31	0.00	0.10	0.03
Total Nitrogen (mg l^{-1})	0.49	0.24	31	0.23	1.25	0.42
Nitrates + Nitrites (mg l^{-1})	0.03	0.04	31	0.00	0.16	0.01
Total Phosphorus (mg l^{-1})	0.05	0.03	31	0.02	0.18	0.04
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.03	30	0.00	0.14	0.01
Total Alkalinity (mg l^{-1})	119.66	15.65	30	91.58	159.14	120.50
Chlorophyll *a* (mg m^{-3})	12.77	26.90	31	0.00	150.00	5.37
BOD_2 (mg l^{-1})	1.71	1.45	30	0.40	7.00	1.20
Settleable Solids (mg l^{-1})	0.13	0.32	28	0.00	1.50	0.00
Reactive Silicate (mg l^{-1})	1.98	1.23	9	1.16	5.11	1.62
CHOLUTECA RIVER AT LA LUJOSA						
Salinity (ppt)	0.00	0.00	46	0.00	0.00	0.00
Total Ammonia Nitrogen (mg l^{-1})	0.04	0.03	45	0.01	0.18	0.04
Total Nitrogen (mg l^{-1})	0.96	0.59	47	0.43	3.27	0.73
Nitrates + Nitrites (mg l^{-1})	0.45	0.56	45	0.00	2.51	0.22
Total Phosphorus (mg l^{-1})	0.27	0.10	47	0.11	0.63	0.25
Sol. Reactive Phosphate (mg l^{-1})	0.22	0.09	45	0.05	0.41	0.21
Total Alkalinity (mg l^{-1})	116.72	37.18	44	43.75	183.28	110.96
Chlorophyll *a* (mg m^{-3})	17.34	14.30	45	0.00	79.98	15.64
BOD_2 (mg l^{-1})	2.20	0.97	42	0.10	4.90	2.17
Settleable Solids (mg l^{-1})	0.53	1.59	43	0.00	9.40	0.05
Reactive Silicate (mg l^{-1})	11.86	7.49	15	0.88	24.57	9.33
SEA FARMS #1 - EMBAYMENT						
Salinity (ppt)	27.01	2.75	46	23.50	33.50	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.05	0.03	44	0.00	0.12	0.04
Total Nitrogen (mg l^{-1})	0.27	0.07	46	0.11	0.48	0.27
Nitrates + Nitrites (mg l^{-1})	0.02	0.03	44	0.00	0.21	0.02
Total Phosphorus (mg l^{-1})	0.05	0.01	46	0.00	0.08	0.05
Sol. Reactive Phosphate (mg l^{-1})	0.03	0.01	44	0.00	0.05	0.03
Total Alkalinity (mg l^{-1})	116.20	7.50	43	97.00	13.66	117.00
Chlorophyll *a* (mg m^{-3})	5.33	4.05	44	0.00	25.39	4.74
BOD_2 (mg l^{-1})	0.79	0.44	42	0.20	2.20	0.78
Settleable Solids (mg l^{-1})	0.01	0.02	43	0.00	0.05	0.00
Reactive Silicate (mg l^{-1})	1.18	0.50	14	0.13	1.96	1.17
SEA FARMS #2 - EMBAYMENT						
Salinity (ppt)	27.28	2.98	46	23.00	34.50	26.00
Total Ammonia Nitrogen (mg l^{-1})	0.05	0.04	44	0.00	0.16	0.04
Total Nitrogen (mg l^{-1})	0.32	0.13	46	0.02	0.84	0.40
Nitrates + Nitrites (mg l^{-1})	0.02	0.02	44	0.00	0.08	0.02
Total Phosphorus (mg l^{-1})	0.02	0.01	46	0.00	0.05	0.02
Sol. Reactive Phosphate (mg l^{-1})	0.01	0.01	44	0.00	0.02	0.01
Total Alkalinity (mg l^{-1})	112.18	8.62	43	93.00	130.56	112.00
Chlorophyll *a* (mg m^{-3})	4.47	4.38	44	0.00	28.09	4.35
BOD_2 (mg l^{-1})	1.04	0.69	42	0.30	4.00	0.90
Settleable Solids (mg l^{-1})	0.00	0.02	43	0.00	0.10	0.00
Reactive Silicate (mg l^{-1})	0.53	0.15	15	0.24	0.76	0.54

Table 2. Total phosphorus concentrations in estuarine water in rainy and dry seasons at three sites (GMSB, CUMAR, and FINCA SUR) located at increasing distances upstream from the Gulf of Fonseca.

Monitoring Site	**Total Phosphorus** (mg l^{-1})	
	Rainy Season	*Dry Season*
GMSB	0.16	0.22
CUMAR	0.21	0.34
FINCA SUR	0.28	0.39

Fonseca watershed also will affect estuarine water quality because of changes in runoff patterns and volumes. Examples of this effect already have been observed in the upper reaches of a couple of estuaries where stands of mangroves have died because of sedimentation, which resulted from severe reduction of runoff caused by watershed land-use changes.

Nutrient concentrations in riverine estuaries increase during the dry season because of evaporation, 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 increased by 11 to 25% during the rainy season because of nutrient load in river discharge and watershed runoff.

Nutrient sources for riverine estuaries include nutrient load in river discharge and rainfall or irrigation runoff from the watershed, and shrimp farm discharge. Shrimp farmers must be acutely aware of estuarine water quality because often the same estuary serves as both the source of water for production ponds and 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 through:

1) A reduction in exogenous nutrient inputs to ponds (i.e., feeds and fertilizers); and
2) The control of development in terms of both 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 the environmental impact of shrimp farm effluents. Additionally, 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 serves to increase awareness among shrimp farmers of their relation to the environment and encourages them to pursue sustainable production strategies. Data from this study will be used to develop 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.

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