Evaluation of Shrimp Farming Impacts in Golfo de Fonseca Region, Honduras

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

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Abstract

An intensive data collection and modeling study has been underway for the past several years addressing two of the channel estuaries draining into the Gulf of Fonseca, namely Estero El Pedregal and Estero San Bernardo. Data have been compiled on the shrimp farm configurations, exchange rates, and effluent chemistry. Temperature/salinity/dissolved oxygen profiles have been measured in the estuary channels in both rainy and dry seasons. Physiographic, hydrographic, and meteorological data have been obtained to supplement the estuary data. This report examines the assimilative capacity of these estuaries with respect to dissolved oxygen (DO). The oxygen demand of organics is measured by biochemical oxygen demand (BOD). Shrimp farm BOD loadings were estimated from effluent data and exchange. A transport model for salinity and DO in the estuaries was applied to predict the tidal-mean, section-mean concentrations of salinity and DO. The model predictions of DO given 1995 BOD loadings were satisfactory. Future loadings based upon full shrimp farm development along these two estuaries were then input to determine the resulting DO under these conditions. It was found that the 1995 configuration is already pressing the carrying capacity of both systems, and the DO will be worsened at full development. Shrimp farms placed farther upstream than about 20 km from the mouth will most likely have excessive impact on the DO in the estuary. The impact is exacerbated under dry season conditions. Negative impacts of a specific farm can be ameliorated by reducing or eliminating pond discharges during the dry season, and by reducing the level of water exchange employed. This work needs to be extended to address additional water-quality parameters and to incorporate larger spatial scales, especially to establish the interaction between different estuaries draining into Fonseca.

Introduction

The Gulf of Fonseca, a large estuarine embayment on the Pacific coast of Central America, has become the focus of the shrimp aquaculture industry in Honduras, which represents the third most important export of the country. Much of the industry, representing a total of over 14,000 ha of operational pond area in 1998, is situated along the distributaries of the deltaic region in the eastern arm of Fonseca, designated Monypenny Bay in this report. The phenomenal growth of the shrimp industry in the past decade has raised concerns that the combined effluent from the ponds might accumulate in such concentration as to contaminate the estuary waters as a source of exchange influent. This self-limiting concentration is referred to here as the "carrying capacity" of the system, and corresponds to the concept of "assimilative capacity" in environmental engineering.

While it is tempting to think of "carrying capacity" as a single number, like passenger capacity of a bus, it is important to recognize that it is in fact a function of position, both in terms of the region of the watercourse in which acceptable water quality must be maintained and in terms of the actual locations of the sources of contamination. For this reason, there is not a unique value for carrying capacity, because different distributions in space in combination with different effluent loads can result in the same impact on water quality. On the other hand, if the combined effect of a collection of effluent loads is to reduce water quality below its acceptable value, then it can be said that the carrying capacity of the system has been exceeded.

This study addressed the effect of shrimp aquaculture on the single parameter of dissolved oxygen (DO) in two channel estuaries in the Monypenny Bay region that are the sites for the greatest development of shrimp farming operations in the country, the Estero El Pedregal and the Estero San Bernardo (Figure 1). During the past five years, data collection efforts have been underway in Honduras to quantify pond metabolism, receiving water quality, and basic hydrography of the distributaries of the Monypenny Bay region, especially Pedregal and San Bernardo. This work was accomplished under the aegis of the Auburn University/Honduras PD/A CRSP and involved collaboration among universities, the private sector, and the public sector. A full description of the program is given in Green et al. (1997). Since 1995, annual summaries of estuarine water quality findings have been published (Teichert-Coddington, 1995; Teichert-Coddington et al., 1997; Green et al., 1998; Green et al., 1999).

Hydrography and Hydrology

The Gulf of Fonseca is a tectonobay (e.g., Ward and Montague, 1996), a flooded coastal indentation formed by faulting and vulcanism. It has a free connection with the Pacific of some 30 km in width and 20 m average depth. The inland reaches of the Gulf of Fonseca exhibit features of a drowned-river-valley type estuary, with extensive mud shoals, and deltaic-like shoal areas, especially its eastern arms. Its coastal physiography consists of tidal flats, tidally flushed mangrove swamps fringing largely unvegetated tidal flats, and low-relief "sweet-land" punctuated by steep igneous formations.

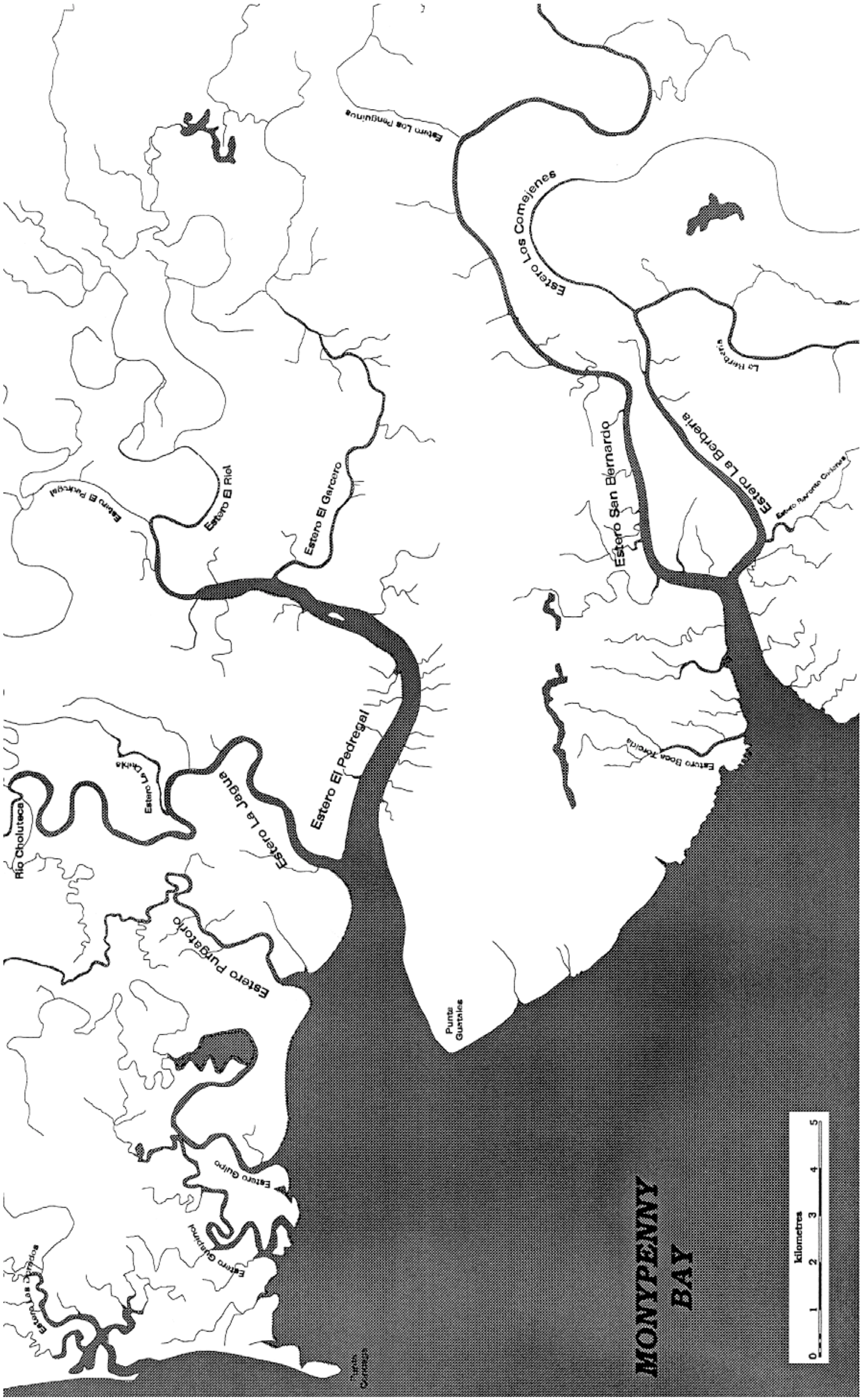

Figure 1. Location map of study area.

Riverine inflow affects the hydrography of the estuary by establishing a gradient of salinity across the system and further influences the water quality by its associated influx of constituents of terrestrial origin, including human wasteloads. Several major rivers drain into Monypenny Bay (Figure 1). The primary riverine inflow to this region from Honduras is the Río Choluteca, but there are also several other major rivers mainly from Nicaragua, most prominent of which are the Estero Real, whose watershed extends to Lago de Managua, and the Río Negro, which enters the head of the San Bernardo. Numerous distributaries lace this deltaic region, most carrying freshwater throughflow deriving from local runoff, but each in itself is a channel estuary.

The climatology of Honduras is characterized by two distinct seasons in the year, the dry season and the rainy season. These seasons are keyed to the annual movement and intensity of the Intertropical Convergence Zone. The winter dry season typically extends from November through May, during which the region becomes quite arid. The rainy season, typically extending from May through October, is in fact interrupted in July by a brief dry period, known as the *canícula* in Honduras. This produces a characteristic bimodal shape to the annual pattern of precipitation. Daily precipitation measurements from Marcovia and Yusgüare were compiled for the period 1973–96 and analyzed to provide insight into the flows of ungauged rivers. The estuarine data analyzed in this paper were collected in 1995. The rainfall data demonstrate that the rainy season in 1995 was exceptional, the regional precipitation being the highest in the 1973–96 record. August 1995, in particular, logged the highest rainfall for any month in this entire period, by a substantial factor.

The only one of the inflows for which we have gauged data is the Río Choluteca. The annual pattern of flow in the Río Choluteca, based upon 1979–90 gauged data, is clearly bimodal, with two high-flow seasons, spring and fall, separated by dry seasons of winter and summer. Other inflows to the study area had to be estimated from the precipitation data at Marcovia and Yusgüare, using the approximate drainage areas of the tributaries and a coefficient of runoff (e.g., Larsen and Concepción, 1998).

Hydrology is dominated by the terrestrial environment. Hydrography, on the other hand, is decidedly marine. Most important is the effect of tides. The effect of the coastal bight and the morphology of the Gulf is to amplify the Pacific tide within the Gulf, so that the mean amplitude is over 3 m in many of the coastal inlets and channel estuaries. Moreover, this is a semidiurnal tide (period 12.4 hours), so the movement of water with the flood and ebb is substantial. Coastal pilots note tidal currents in the Estero Real exceeding 3 knots (e.g., Admiralty, 1951).

SHRIMP FARMS

Because the field data employed in this analysis were collected mainly in 1995, it was necessary to characterize the state of shrimp farm operation at this time. A concerted effort was made by the CRSP personnel in Honduras to obtain data on pond area, exchange, and management from the various farm operators with installations on the El Pedregal or San Bernardo systems. Details on the physical facilities at each of the farms were compiled by this effort. From the standpoint of determining the impact of shrimp farm operations on receiving water quality, the important data are the flow out of the pond, its oxygen-demanding constituents, and the point at which pond effluent enters the watercourse.

The biochemical oxygen demand (BOD) was employed as a gross measure of the oxygen-demanding potential of the effluent. Samples from both influent and effluent of GMSB were analyzed for ultimate BOD (BODu), as the asymptote of an oxygen depletion series (Teichert-Coddington et al., in prep.), so the incremental BODu added by the pond to that already in the estuary water could be isolated. Detailed data from GMSB were scaled to the other farms in the El Pedregal/San Bernardo study area according to their individual exchange rates. The product of the resulting effluent BODu concentration and the discharge flow (with appropriate units conversions) is the BODu load (mass per unit time), tabulated in Table 1.

Table 1. Estimated BOD loads for 1995 shrimp farms.

Farm	Pond Area	Exchange Throughflow		BODu	BOD Load	
	(ha)	(% d^{-1})	(Mm^3 d^{-1})	(mg l^{-1})	(kg d^{-1})	(lb d^{-1})
Aquacultura Fonseca	682	2	0.136	4	546	1,200
Aquacultivos de Honduras	600	8	0.480	16	7,680	16,896
BIMAR	47	10	0.0470	20	940	2,068
CADELPA	312	3	0.0936	6	562	1,236
CAYDESA	110	10	0.110	20	2,200	4,840
CRIMASA	1,068	6	0.641	12	7,690	16,917
CUMAR	600	7	0.420	14	5,880	12,936
EXMAR	149	8	0.1192	16	1,907	4,196
GMSB	1,987	6	1.192	12	14,306	31,474
HONDU-ESPECIES	357			(Not operating in 1995)		
HONDUFARM	350	10	0.350	20	7,000	15,400
INMAR	238	12	0.286	24	6,854	15,080
La Jagua	203	3	0.0609	6	365	804
PROMASUR	378	6	0.227	12	2,722	5,988

* For pond volume calculations, mean pond depth was estimated to be 1.0 m.

HYDROGRAPHY AND WATER QUALITY OF THE CHANNEL ESTUARIES

Hydrography of the channel estuaries was addressed through analysis of field data and application of a tidal hydrodynamic model. The hydrographic influences include channel morphology (bathymetry and cross sections), freshwater inflow, density structure, which is dominated by salinity, and forcing from the Gulf of Fonseca, most importantly tides. In the early work on these estuaries (Ward, 1995), there was virtually no information on channel geometry, so these parameters (depth, width, and cross section area) had to be estimated from inspection of topographic maps and from limited field excursions on the estuaries. The field work of the past five years obtained much better data on estuary depths and widths, much improving the physiographic depiction of the channel estuaries. An equally important feature is the large tidal flats which communicate with the main tidal channel through small scoured tidal passes through the mangrove fringe. These tidal flats have the capacity to store a great amount of water on the rising tide and release that water back to the tidal channel as the tide stage falls. The extent to which the flats are regularly flooded therefore is an important feature of the tidal functioning of this system.

One concern expressed early in this work (e.g., Ward, 1995) was the possibility that installation of shrimp pond levees might reduce the tidal prism and thereby diminish tidal flushing, contributing to degraded water quality in the tidal estuaries. In effect, these shrimp farms could eliminate the tidal flats, hydraulically isolating these areas by enclosure within levees to create their shrimp ponds. This potential was evaluated by determining the extent of regular inundation of the tidal flats before shrimp pond construction and locating as precisely as possible the actual extent of the farm levees, accomplished through examination of topographic maps and satellite photographs and through the efforts of Sr. Felix Wainwright (1996), who has studied these areas extensively. As matters turn out, the practice of most of the shrimp farms of placing the levees inside the mangrove fringe follows approximately the extent of normal tidal inundation, so the impact on tidal prism reduction is limited. The exception is for those farms in the upstream sections of the estuaries, but in these regions the more important control on water quality is the volume and quality of inflows.

The salinity structure is an important aspect of the hydrography of these channel estuaries because it is a direct demonstration of the movement of water in response to tides and because it provides an index to density stratification. Analysis of the 1995 field data on salinity indicate the tidal excursion in the lower reach of the estuaries to be at least 25 km in the Pedregal and 10 km in the San Bernardo. Moreover, within the salinity-intrusion zone, there is also substantial vertical stratification, especially on the flooding tide. This is due to the longitudinal salinity gradient created by the freshwater inflow, and to the tidal influx of more saline water from Monypenny Bay. Such dramatic stratification appears to be a phenomenon only of the combination of transient conditions during the high inflow freshet of the rainy season. With the stabilization of inflows in July, the longitudinal salinity gradient mixes out more, and the vertical stratification is much less pronounced.

A tidal hydrodynamic model was applied to the combined Pedregal and La Jagua system and the combined San Bernardo and Berberia system following the formulation of Dronkers (1964). Because of the importance of the tidal flats to the hydrography of this system, special provision for these is made in the numerical treatment (Hauck and Ward, 1980). The area of the tidal flat is an input to the model that must be determined from survey data, in this case from the tidal inundation areas provided by Wainwright (1996). Modeled tidal excursions appear to be on the correct order compared to observations of Currie (1994) and compared to the field observations of tidal excursion in salinity structure analyzed in this project (see above). The most important use of the tidal calculations is to provide a basis for estimating longitudinal dispersion in the transport modeling (see below) based upon tidal excursion and for computing oxygen reaeration, which is a strong function of current speed.

A total of 13 data runs were made on El Pedregal and 10 on the San Bernardo in 1994–96, in both the dry and rainy seasons. Only a portion of the data collected has been analyzed and employed in the present study. The measurements consisted of vertical profiles at 0.5-m intervals from surface to bottom of temperature, dissolved oxygen, and salinity, using an electrometric probe and deck-readout.

A numerical transport model was applied to each of these estuaries to model salinity and DO. The model treats the longitudinal variation of properties, i.e., the tidal-mean, vertical-mean concentrations, and assumes an equilibrium profile, i.e., steady-state, as a balance between transports and kinetics. Each estuary was depicted by a network of computational nodes running up the channel to a point well above the region of shrimp farm development. The objective of the modeling is to determine the DO response to shrimp farm loading. The main purpose of modeling salinity is to provide some assurance that the transport terms are approximately correct in the model. The field data were used to analyze the behavior of the estuaries and to validate the salinity and DO models.

The model application to the Pedregal salinities for July 1995 (rainy season) inflows is shown in Figure 2a. For comparison, the tidal-mean vertical-mean observed salinities are shown also. (The vertical bars represent observed tidal range for that

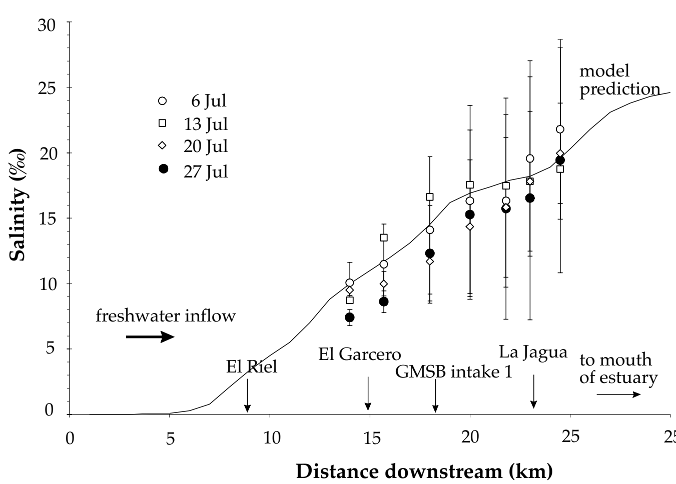

Figure 2a. Rainy season salinity, modeled and observed, in El Pedregal, July 1995.

sample run.) Generally, the agreement between model and observed salinities is considered satisfactory. Figure 2b shows El Pedregal DO profiles for the same conditions and the corresponding model prediction of DO. The total shrimp-farm BOD load to El Pedregal for 1995 conditions is about 16,000 kg d^{-1}. The data show decreasing DOs with distance upstream from the mouth. The model predicts a substantial zone of low oxygen, the combined result of the BOD loads from tributary runoff from the lowlands and the load from the shrimp farms. The relation between the locations of the shrimp farm loads (shown as arrows) and the region of low DO should especially be noted. All of the measured (vertical-mean) DOs upstream from about 13 km from the mouth are below 3 mg l^{-1} and some are less than 1 mg l^{-1}. The model results substantiate that these low DOs result in part from the BOD loads from the shrimp farms. These two facts indicate that the 1995 shrimp farm development is already approaching the carrying capacity of El Pedregal.

A problem in the modeling of the San Bernardo is the inflow of the Río Negro, which enters the head of the San Bernardo from its watershed in Nicaragua. This appears to be a major source of inflow for San Bernardo; moreover, it is evidently water of good oxygen content, originating in a mountainous basin in Nicaragua. Because we have no data on this inflow, it is a major source of error and had to be indirectly estimated in the present work. The model does a fair job of predicting a DO depression like that depicted in the data, but the location of the low point of the sag is some 5 to 10 km too far up the estuary. We also conclude that the San Bernardo is not as seriously stressed as the Pedregal *under these inflow conditions*. However, this estuary receives a total BOD load (in 1995) of some 24,000 kg d^{-1}, nearly twice that of the Pedregal. It seems certain that it is the extraordinarily high inflows during August 1995 that prevented occurrence of depressed DOs.

SHRIMP FARM IMPACTS AND CARRYING CAPACITY ANALYSIS

The present model development permits a reliable estimation of the combined impacts of the regional shrimp farms under various scenarios of increased development. Information was compiled on shrimp farm enlargements and new operations as of 1998, the additional pond area that could be developed on operating farms, and the concessions capable of future development. This information was used to construct a "full-development" scenario. The drain locations and corresponding loads were implemented in the BOD-DO model using the same 1995 rainy season conditions, so that the 1995 model runs (and associated field data) could be used as a baseline for comparison. The resulting DO profiles under rainy season conditions predicted by the model with these loads are shown in Figure 3a for El Pedregal and Figure 3b for San Bernardo. The result could be anticipated: even lower DOs in the main sag zones. For El Pedregal, this looks particularly crucial, as a reach of some 10 km results with *average* DOs less than 1 mg l^{-1}. For the San Bernardo, there is a reach with DOs below 2 mg l^{-1}, but with a higher assumed flow in the Río Negro this reach would not occur.

The data and the model suggest that under these rainy season conditions, well-aerated waters are brought into the channel estuaries from the adjacent Gulf of Fonseca on the flooding tide and poorly oxygenated waters enter the estuary channels from the tidal flats and tributaries draining the tidal lowlands. Even if shrimp farms did not exist, degraded water quality would result as a result of the latter intermixing with the former.

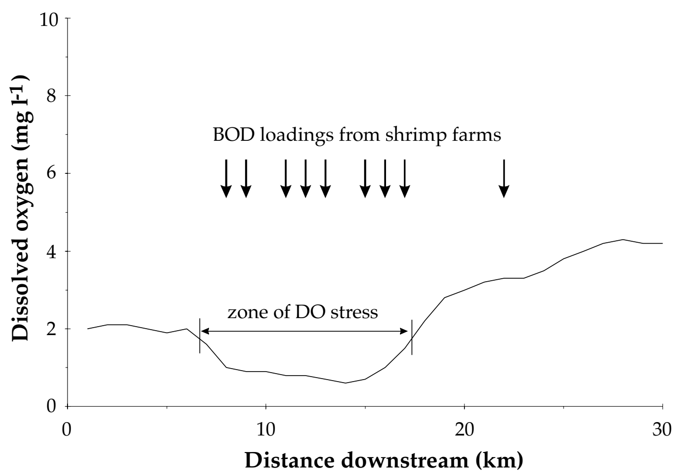

Figure 3a. Model prediction of DO in El Pedregal, 1995 rainy season conditions, full shrimp farm development.

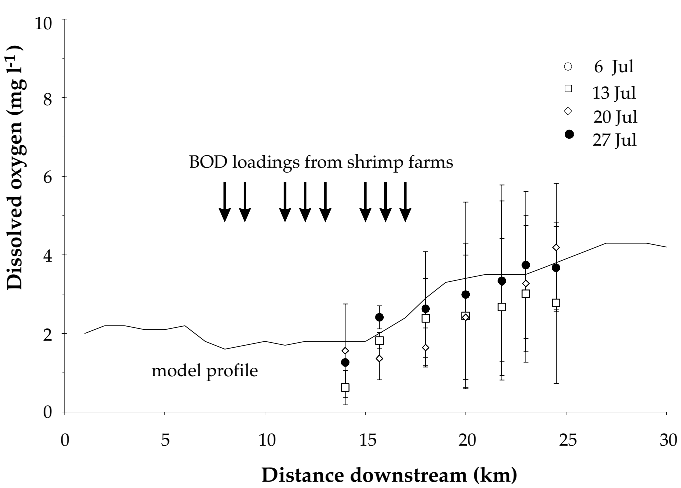

Figure 2b. Rainy season dissolved oxygen, model and observed, in El Pedregal, July 1995.

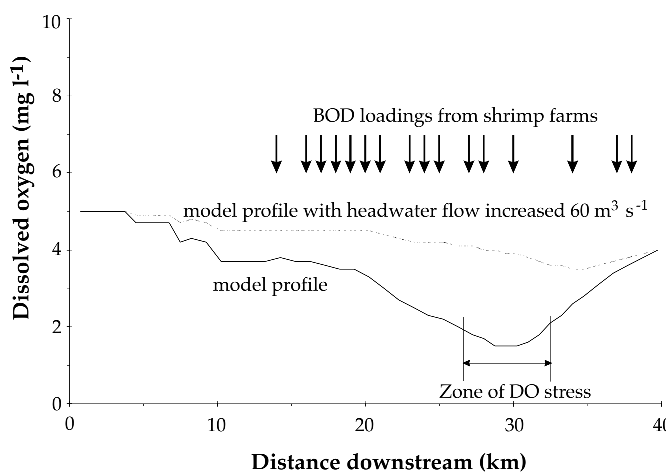

Figure 3b. Model prediction of DO in San Bernardo, 1995 rainy season conditions, full shrimp farm development.

ANTICIPATED BENEFITS

For systems such as Estero el Pedregal and San Bernardo, these studies establish that there is a level of development at which the estuary can become so degraded as to prohibit economical aquaculture, i.e., shrimp farming can become self-limiting. The field data and modeling allow quantification of this condition, and, more importantly, provide a tool to evaluate alternative shrimp farm development scenarios to minimize impacts.

LITERATURE CITED

Admiralty Hydrographic Office, 1951. West Coasts of Central America and United States Pilot. Her Majesty's Stationery Office, London.

Currie, D.J., 1994. Ordenamiento de camaronicultura, Estero Real, Nicaragua. Reporte de Estudio, GOPA Consultants, Alemania.

Dronkers, J.J., 1964. Tidal Computations in Rivers and Coastal Waters. North-Holland Publishing Co., Amsterdam, 518 pp.

Green, B.W., D.R. Teichert-Coddington, M.P. Micheletti, and C.A. Lara, 1997. A collaborative project to monitor water quality of estuaries in the shrimp producing regions of Honduras. 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.R. 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, C.E. Boyd, D. Martinez, and E. Ramírez, 1999. Estuarine water quality monitoring and estuarine carrying capacity. In: K. McElwee, D. Burke, M. Niles, and H. Egna (Editors), Sixteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 103–113.

Hauck, L. and G. Ward, 1980. Hydrodynamic–mass transfer model of deltaic systems. In: P. Hamilton and K. Macdonald (Editors), Estuarine and wetland processes. Plenum Press, New York, pp. 247–268.

Larsen, M. and I. Concepción, 1998. Water budgets of forested and agriculturally developed watersheds in Puerto Rico. In: R. Segarra-García (Editor), Tropical Hydrology and Caribbean Water Resources. American Water Resources Association, Herndon, Virginia, pp. 199–204.

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 Water. Proceedings of the Special Session on Shrimp Farming, Aquaculture '95. World Aquaculture Society, Baton Rouge, Louisiana, pp. 144–156.

Teichert-Coddington, D., L. Milla, D. Martinez, and G. Ward. Relationships between biochemical oxygen demand and selected water quality variables in shrimp farming water, in preparation.

Teichert-Coddington, D.R., B. Green, C.E. Boyd, D. Martinez, and E. Ramírez, 1997. Estuarine water quality. In: D. Burke, B. Goetze, D. Clair, and H. Egna (Editors), Fourteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 87–89.

Wainwright, F., 1996. Cuantificacion de areas de esteros que drenan al Golfo y que pertenecen a la cuenca del Rio Negro, Depto. de Choluteca (Unpubl. manuscript with maps).

Ward, G., 1995. Hydrographic limits to shrimp aquaculture in el Golfo de Fonseca. III Simposio Centroamericano sobre Camarón Cultivado, Tegucigalpa.

Ward, G. and C. Montague, 1996. Estuaries. In: L. Mays (Editor), Water Resources Handbook. McGraw-Hill Book Company, New York, pp. 12.1–12.114.

Cite as: [Author(s), 2000. Title.] 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. ___.]