Valuing Mangrove-Fishery Linkages: A Case Study of Campeche, Mexico

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SUMMARY

This paper explores the value of mangrove systems as a breeding and nursery habitat for off-shore fisheries, focusing on mangrove-shrimp production linkages in Campeche State, Mexico. We develop an open access fishery model to account explicitly for the effect of mangrove area on carrying capacity and thus production. From the long-run equilibrium conditions of the model we are able to establish the key parameters determining the comparative static effects of a change in mangrove area on this equilibrium. We then estimate empirically the effects of changes in mangrove area in the Laguna de Terminos on the production and value of shrimp harvests in Campeche over 1980-90. Our findings suggest that mangroves are an important and essential input into the Campeche shrimp fishery, but that the low levels of deforestation between 1980 and 1990 mean that the resulting losses to the shrimp fishery are still comparatively small. Over-exploitation of the fishery due to open access conditions remains the more pervasive threat, and without better management, any long-run benefits of protecting mangrove habitat are likely to be dissipated.

Keywords: bioeconomic; Campeche; deforestation; ecological; economic; fishery; habitat; harvest; Laguna de Terminos; mangrove; Mexico; open access; shrimp.

JEL: Q2, Q12

NON TECHNICAL SUMMARY

This paper explores the value of mangrove systems as a breeding and nursery habitat for off-shore fisheries, focusing on mangrove-shrimp production linkages in Campeche State, Mexico. If mangrove area in the Laguna de Terminos can be linked empirically to the production of shrimp, then there is evidence that mangrove depletion can have a deleterious effect on the shrimp industry and the entire Campeche economy. This evidence is especially important because the low price of mangrove areas is leading to their conversion to other than natural uses. In particular, the expansion of the city of Carmen, adjacent to Laguna de Terminos has led to mangrove deforestation in the last decade. There is also concern that lucrative shrimp aquaculture activities will begin encroaching on the mangrove areas.

In addition, by attempting to value the contribution of the Laguna de Terminos mangrove system to the commercial shrimp fisheries of Campeche, this paper aims to develop a general methodology for valuing mangrove-fishery linkages that can be applied to mangrove and coastal wetland systems elsewhere. This approach is also consistent with other attempts to assess the economic value of coastal wetland habitats in support of marine fisheries and other ecological functions, such as determining the value of marshlands as habitat for Gulf Coast fisheries in the southern United States (Bell 1989; Ellis and Fisher 1987; Farber and Costanza 1987; Freeman 1991; Lynne *et al.* 1981), analyzing the competition between mangroves and shrimp aquaculture in Ecuador (Parks and Bonifaz 1994), determining the value of a multiple-use mangrove system under different management options in Bintuni Bay, Irian Jaya, Indonesia (Ruitenbeek 1994), and examining general coastal system trade-offs, such as the effects of development on habitat-fishery linkages (Kahn and Kemp 1985; Swallow 1990 and 1994; Strand and Bockstael 1990). In contrast to many of these approaches, however, we attempt to value wetland-fishery linkages through a straightforward adaptation of the standard open access bioeconomic model to incorporate changes in habitat area, in this case mangroves.

Our analysis of fishery-mangrove linkages is conducted by examining the effects of a change in mangrove area on the long-run open access equilibrium of the Campeche shrimp fishery. In our model of mangrove-fishery linkages, the open access fishery adjusts to the impacts of mangrove loss by reducing both initial and equilibrium levels of effort. If the fishery fails to do this, then it may instead find itself on a path that leads to over-exploitation and 'near collapse' of shrimp stocks. We do not consider the latter case, and we therefore analyze the impacts of mangrove deforestation on the fishery in terms of changes in the equilibrium levels of harvesting and gross revenues. Estimates of these comparative static effects are obtained in the following manner. First, we use the bioeconomic equilibrium condition to establish a relationship between shrimp production, effort and mangrove area, which is estimated over time. From available price, effort and harvest data, we determine cost levels that ensure an open access equilibrium for the Campeche shrimp fishery for each year over the 1980-90 period. Utilizing both the parameter estimates from our regression and the economic data on prices and costs, we are then able to calculate the comparative static effects of the impacts of mangrove loss on harvesting and revenues of the shrimp fishery over 1980-90. Two principal findings emerge from this analysis:

First, the high marginal productivity of the mangrove habitat and the low elasticity of substitution of fishing effort for mangroves in shrimp production tend to support the claims of ecologists that the mangroves of the Laguna de Terminos are both an important and essential input into the Campeche shrimp fishery. However, given that only 2.3% of the mangrove area was deforested between 1980

and 1990, the actual losses each year in shrimp harvest amounted to about 28.8 metric tons, or a loss of US$278,704 in revenue. This is equivalent to a reduction of only around 0.4% in the annual harvest and revenues of the fishery. In the future, more substantial losses to the off-shore shrimp fishery of Campeche will occur if there is greater deforestation.

Second, although mangrove loss has an important economic influence on the Campeche shrimp fishery, a more pervasive problem over the 1980-90 period of analysis has been over-exploitation. Our estimate of the marginal productivity of fishing effort is actually negative over the entire period of analysis, reflecting the rapid expansion of fishing vessels over this period, from around 4,500 combined industrial and artisanal vessels in 1980 to 7,200 in 1990. As equilibrium levels of fishing effort rise and harvests subsequently fall, the welfare losses associated with mangrove deforestation become smaller. Open access conditions and over-fishing appear to lower the economic value of natural habitat.

The resulting management implications are clear. In the case of an open access fishery such as the Campeche shrimp industry, protection of the nursery and breeding habitat function of the Laguna de Terminos mangroves may be important for reducing losses in the fishery, but control of over-fishing is more critical. We expect that this conclusion holds also for other open access fisheries elsewhere, which are supported by mangroves and other estuarine and coastal wetland that provide breeding habitats and nurseries for the fisheries.

Valuing Mangrove-Fishery Linkages: A Case Study of Campeche, Mexico[1]

1. Introduction

Shocked by ecologists' attempts to value wetland services (Gosselink *et al.* 1974), economists have spent over twenty-five years refining methods and estimated values (e.g. Barbier 1994; Batie and Wilson 1978; Bell 1989; Hammack and Brown 1974; Lynne *et al.* 1981; Shabman and Bertelson 1979; Turner 1991). There have even been joint efforts by the disciplines to determine wetland and estuarine system values (Farber and Costanza 1987; Kahn and Kemp 1985). In the process, the exchange of economic and ecological concepts has likely improved our knowledge of the contributions that wetlands make to our well-being.

One component of wetland valuation methodology, valuing the effects of wetlands on the flow of output from commercial fisheries, may have overlooked a fundamental characteristic of many fisheries, open access. Although most studies appreciate the necessity of controlling for human effort while assessing the marginal productivity of wetlands, the fishery is generally not modeled in a framework that reflects the characteristics of open access.[2] In this paper, we intend to present a model which allows the vagaries of open access fishing to be considered, albeit crudely. In addition, we establish a value for one of the non-market functions of mangroves by exploring the relationship between mangroves and shrimp production in the State of Campeche, Mexico. Other fish species are also dependent on the mangroves, but we focus on shrimp because it is critical to the region, its production is likely to be separable from the rest of the area's fishing, and its data are available. However, by focusing solely on shrimp, we obtain only a partial accounting of the entire indirect use value of the mangroves.

Campeche has been chosen because it contains one of the largest and most productive mangrove areas on the Gulf of Mexico. Its Laguna de Terminos is thought to support one of the largest shrimp fisheries on the Gulf (Yañez-Arancibia and Aguirre-Léon 1988). Here, shrimp are produced from both an industrial and artisanal fleet. The industrial fleet is comprised of large vessels, each having a crew of around six. The artisanal fleet has vessels with outboard motors or without power entirely. The crew per vessel is usually no more than two. The artisanal fleet numbers over 5000 boats (all under 10 gross tons) and employs about 13% of the entire Campeche labor force. The industrial shrimp fleet has over 350 vessels, which are all over 10 gross (metric) tons but averaging about 50 gross tons (Ramos-Miranda *et al.* 1991).

If mangrove area in the Laguna de Terminos can be linked empirically to the production of shrimp, then there is evidence that mangrove depletion can have a deleterious effect on the shrimp industry and the entire Campeche economy. This evidence is especially important because the low price of mangrove areas is leading to their conversion to other than natural uses. In particular, the expansion of the city of Carmen, adjacent to Laguna de Terminos, has depleted the acreage of mangroves by more than 2% in the last decade. There is also concern that lucrative shrimp aquaculture activities will begin encroaching on the mangrove areas.

In addition, by attempting to value the contribution of the Laguna de Terminos mangrove system to the commercial shrimp fisheries of Campeche, this paper aims to develop a general methodology for valuing mangrove-fishery linkages that can be applied to mangrove and coastal wetland systems elsewhere. This approach is also consistent with other attempts to assess the economic value of coastal wetland habitats in support of marine fisheries and other ecological functions, such as determining the value of marshlands as habitat for Gulf Coast fisheries in the southern United States (Bell 1989; Ellis and Fisher 1987; Farber and Costanza 1987; Freeman 1991; Lynne *et al.* 1981), analyzing the competition between mangroves and shrimp aquaculture in Ecuador (Parks and Bonifaz 1994), determining the value of a multiple-use mangrove system under different management options in Bintuni Bay, Irian Jaya, Indonesia (Ruitenbeek 1994), and examining general coastal system trade-offs, such as the effects of development on habitat-fishery linkages (Kahn and Kemp 1985; Swallow 1990 and 1994; Strand and Bockstael 1990). In contrast to many of these approaches, however, we attempt to value wetland-fishery linkages through a straightforward adaptation of the standard open access bioeconomic model to incorporate changes in habitat area, in this case mangroves.

The outline of the paper is as follows. The next section provides additional background on the mangrove-shrimp fisheries linkage in Campeche State. Subsequent sections develop the theoretical and empirical methodology for investigating this linkage. We assume throughout that shrimp harvesting occurs through open access management that yields production which is exported internationally, and we modify a standard open access fishery model to account explicitly for the effect of mangrove area on carrying capacity and thus production. We derive the conditions determining the long-run equilibrium of the model, including the comparative static effects of a change in mangrove area on this equilibrium. Through regressing a relationship between shrimp harvest, effort and mangrove area over time, we estimate parameters based on the combinations of the bioeconomic parameters of the model determining the comparative statics. By incorporating additional economic data, we are able to simulate an estimate of the effect of changes in mangrove area in Laguna de Terminos on the production and value of shrimp harvests in Campeche state. We conclude by discussing the policy implications of our findings, which we believe to have general relevance for the economic analysis of similar ecological linkages between fisheries and mangroves or other coastal wetland habitats elsewhere.

2. Background

The Gulf of Mexico is the source of nearly half of all fisheries production in Mexico and nearly one third of the total production in shrimp (Yañez-Arancibia and Aguirre-Léon 1988). Landings in Campeche account for one third of all Gulf finfish production and one half of all shrimp landings. Although several coastal ecological factors determine the biological productivity of the Gulf fisheries, the most important production mechanisms underlying these fisheries is thought to be the combination of estuaries and lagoons with coastal vegetation (mangroves), which provide the ideal habitat as breeding grounds and nurseries (Soberón-Chavez and Yañez-Arancibia 1985; Yañez-Arancibia and Day 1988). The five Gulf states of Mexico - Campeche, Tabasco, Tamaulipas, Veracruz and Yucatan - all have important mangrove-lagoon systems, but by far the largest and most important of these systems is the Laguna de Terminos in Campeche.

The two fleets that exploit the shrimp fishery of Campeche have been in transition since about 1980, with the artisanal fleet increasing in size and the industrial fleet decreasing. The artisanal fishery has gone from less than 800 boats in 1980 to over 5000 by the early 1990s. In the same period, the industrial fleet has decreased by about half, from around 700 to 380 boats. A cooperative of industrial vessels was established when the Federal government helped the cooperative purchase vessels from private firms. It is alleged that the new vessel owners have have difficulty maintaining the large vessels and have sold them. With the proceeds of the sale, they have invested in boats for the artisanal fishery. It is estimated that the artisanal fishery accounts for approximately 13% of the economically active population in Campeche state (Ramos-Miranda *et al.* 1991).

During this transition in the commercial and artisanal fisheries, shrimp production stagnated and then collapsed. From 1980-1987, production fluctuated steadily between 7-8 thousand metric tons (KMT) but by 1990 production had fallen to 4.6 KMT. The average real price of the shrimp catch from Campeche also increased steadily through the 1980s until 1987 and then halved by 1989-90 and remained at this level. Revenues in the Campeche shrimp industry have followed the same pattern.

Less is known about changes in the mangroves of Laguna de Terminos. Mangrove area was estimated to be around 860 km^2 in 1980 (SARH 1980). The area of mangroves was estimated to decline to about 835 km^2 in 1991, a loss of around 2 km^2 per annum.[3] The primary reason for the loss is the encroachment of population from Carmen, the large city adjacent to Laguna de Terminos (Yañez-Arancibia and Benitez-Torres 1991; Benitez-Torres *et al.* 1992). Future threats are expected to come from expansion of shrimp aquaculture through conversion of coastal mangroves.

Although several commercial fish species are thought to be dependent on the mangrove habitat of Laguna de Terminos as a breeding and nursery ground, shrimp is considered to be the most economically important species. For example, in 1990 shrimp catches accounted for over 55% of the total production tonnage of the mangrove dependent fisheries in Campeche, and shrimp is by far the most commercially valuable of these species.[4]

3. A Model of Mangrove-Shrimp Fishery Linkages

Given the evidence suggesting that shrimp production in Campeche is dependent upon the mangroves contained in the Laguna de Terminos as a habitat and nursery, in this section we modify a standard open access fishery model to account explicitly for the effect of mangrove area on carrying capacity and thus production. For analytical convenience, we choose to employ a discrete time model of the open access fishery.

Defining X_t as the stock of shrimp in the fishery measured in biomass, change in this stock over time can be represented as

$$X_{t+1} - X_t = F(X_t, M_t) - h(X_t, E_t), \quad F_X > 0, \; F_M > 0. \tag{1}$$

Thus net expansion in the shrimp stock occurs as a result of biological growth in the current period, $F(X_t, M_t)$, net of any harvesting, $h(X_t, E_t)$. We make the standard assumption that harvesting is a function of the stock as well as fishing effort, E_t ; however, we modify the biological growth function to allow for the influence of mangrove area, M_t , as a breeding ground and nursery, and we assume that this influence on growth is positive, i.e. $\partial F/\partial M_t = F_m > 0$.

Although equation (1) and its underlying growth and harvesting functions can take several forms, we follow the convention of many analytical fishery models developed for empirical purposes and assume a simple Schaefer-Gordon model (Clark 1976; Conrad 1995). Several other studies have also employed the Schaefer-Gordon model to estimate the impacts of habitat influences on fisheries (Lynne *et al.* 1981; Bell 1989).

Thus we assume a basic Schaefer production process for harvesting, h_t

$$h_t = qX_tE_t, \tag{2}$$

with q_t as the 'catchability' coefficient. Representing (1) as a logistic growth function and substituting in (2) yields

$$X_{t+1} - X_t = [r(K(M_t) - X_t) - qE_t]X_t, \tag{3}$$

where r is the intrinsic growth of shrimp each period, K is the environmental carrying capacity of the system and mangrove area, M_t, has a positive impact on carrying capacity, i.e. $K_M > 0$.

Finally, as stated in the introduction, the management of the Campeche shrimp fishery has the characteristics of an open access fishery. Following standard analysis, this suggests that fishing effort next period will adjust in response to the real profits made in the current period (Clark 1976; Conrad 1995). Letting p represent constant shrimp prices per unit harvested, c the real unit cost of effort and $\phi > 0$ the adjustment coefficient, then the fishing effort adjustment equation is

$$E_{t+1} - E_t = \phi[ph(X_t, E_t) - cE_t] \tag{4}$$

The above system of equations constitute our basic model for analyzing fishery-mangrove linkages in Campeche. Next, we use this model to deriving an open access equilibrium, and to determine the comparative static effects on this equilibrium of a change in mangrove area.

4. The Open Access Equilibrium

Our analysis of fishery-mangrove linkages is conducted by examining the effects of a change in mangrove area on the long-run open access equilibrium of the Campeche shrimp fishery. In equilibrium, both the shrimp stock and the level of fishing effort are assumed to be constant over time, i.e. $X_{t+1} = X_t = X$ and $E_{t+1} = E_t = E$. In addition, we assume initially that mangrove area is in equilibrium, i.e. $M_t = M_{t+1} = M$. Equations (3) and (4) can therefore be solved for steady-state levels of shrimp stock, X, and effort, E

$$X = \frac{c}{pq}, \qquad \text{for } E_{t+1} = E_t = E \tag{5}$$

$$E = \frac{r(K(M) - X)}{q}, \qquad \text{for } X_{t+1} = X_t = X. \tag{6}$$

Equation (5) is the standard open access condition that assumes that any profits in the fishery will be competed away in the long run. Equation (6) indicates the combinations of fishing effort and shrimp stock size (and thus also mangrove area) that will lead to a constant level of shrimp stock in the fishery in the long run. Figure 1 depicts the equilibrium conditions in X - E space. The $E_{t+1} = E_t = E$ curve is of course vertical, given (5). From (6), the slope of the $X_{t+1} = X_t = X$ curve in X - E space is downward sloping, i.e. $\frac{dE}{dX} = -r/q < 0$.

Two possible trajectories for fishing effort and shrimp stocks are depicted in Figure 1, assuming an initial level of stock X_0. Trajectory 1 is essentially a stable spiral that leads to an open access equilibrium denoted by (X^A, E^A). Trajectory 2 leads to rapid decline of the shrimp fishery from the outset to near extinction or ‘collapse’levels, which as depicted, could occur if the initial level of effort is too high, given X_0.[5]

As shown in Figure 1, because mangrove area affects the carrying capacity of the shrimp fishery, the impact of mangrove deforestation on the system represented by equations (5) and (6) is to shift down the $X_{t+1} = X_t = X$ curve. This results in a lower steady-state level of effort, $E^{A'}$, although equilibrium stock is unchanged. Assuming that a trajectory to this new equilibrium is still feasible given the initial stock X_0, then the impacts of mangrove loss on carrying capacity will also mean a lower level of initial fishing effort. Thus in our model of mangrove-fishery linkages, the open access fishery adjusts to the impacts of mangrove loss by reducing both initial and equilibrium levels of effort. If the fishery fails to do this, then it may instead find itself on a different exploitation path, such as trajectory 2, that leads to‘near collapse’ of shrimp stocks.[6]

In our analysis, we estimate the impacts of mangrove deforestation on the stable open access equilibrium, assuming that fishery effort adjusts instantaneously to allow a new equilibrium to be attained. We do not consider the case where the effect of deforestation is to make a steady-state equilibrium infeasible, thus causing the shrimp fishery to switch to a different exploitation path, such as that represented by trajectory 2 in Figure 1. As discussed above, there is evidence that mangrove deforestation in Laguna de Terminos is affecting the Campeche shrimp fishery, but it is unlikely that the fishery is currently in danger of the ‘near collapse’ scenario depicted by trajectory 2. Thus in the following analysis of the effect of a change in mangrove area, we assume that the fishery has attained a stable open access equilibrium, such as the steady-state (X^A, E^A) depicted in Figure 1, and we therefore analyze the impacts of mangrove deforestation on the fishery in terms of changes in the equilibrium steady-state conditions.

5. The Comparative Static Effects of a Change in Mangrove Area

For simplicity, we assume a proportional relationship between mangrove area and carrying capacity, i.e. let $K(M) = \alpha M,\ \ \alpha > 0$. Thus, from (6), the comparative static effect of a change in mangrove area on the equilibrium level of fishing effort, E^A is

$$r[\alpha dM - dX^A] - qdE^A = 0$$

$$\text{or} \quad \frac{dE^A}{dM} = \frac{\alpha r}{q} > 0. \tag{7}$$

This confirms that loss of mangrove area results in a lower level of equilibrium fishing effort. From (2), it is clear that there will be a loss of harvest as well. Utilizing (7) and (5), the impact on the equilibrium harvest level can be solved for explicitly

$$dh^A = qX^A dE^A = \alpha r X^A dM = \frac{\alpha rc}{pq} dM > 0. \tag{8}$$

The resulting change in gross revenue of the fishery is then

$$pdh^A = \frac{\alpha rc}{q} dM > 0. \tag{9}$$

A fall in mangrove area will therefore result in a decline in both steady-state shrimp harvest and the gross revenue of the fishery. Moreover, given that these impacts are based on the bioeconomic parameters of our model (α , r, and q) combined with prices and costs for the fishery (p and c), it is possibly to estimate these comparative static effects explicitly.

6. Empirical Estimation of Mangrove-Fishery Linkages

By employing one of the above equilibrium conditions of our model, it is possible to establish a relationship between shrimp production, effort and mangrove area that can be estimated over time. We run this regression utilizing the Campeche shrimp fishery and mangrove area data over the 1980-90 period. The resulting parameter estimates allow us to determine the appropriate combinations of α , r, and q that underly the comparative static results of our model. By also incorporating values for the economic parameters p and c, we are therefore able to simulate the comparative static effects of a change in mangrove area on equiibrium harvest and gross revenue of the shrimp fishery over the 1980-90 period of analysis.

If we assume in our analysis that the shrimp stock is constant, i.e $X_t = X_{t+1} = X$, then we can use steady-state condition (6) to derive a relationship between shrimp production, mangrove area and effort. By substituting (2) into (6) and re-arranging, we obtain

$$h = qEK(M) - \frac{q^2}{r}E^2 = q\alpha EM - \frac{q^2}{r}E^2. \tag{10}$$

Equation (10) can be estimated by employing the available time series data over 1980-90 on shrimp harvests, effort and mangrove area for Campeche, Mexico. By assuming that it would take 5.5 artisanal boats on average to harvest the same amount as an industrial boat, we can combine the data on the number of artisanal and industrial boats in the Campeche fishing industry to form a composite effort variable E.[7] In equation (10) h is represented as annual harvest in kilograms (kg) of shrimp by both artisanal and industrial boats, M is the annual mangrove area (sq km) in Laguna de Terminos and E is the composite, or aggregate, harvesting effort each year. We estimate this equation over the period 1980-1990, the years for which data are available, and assume that any resulting error term is identically independently distributed over time. A summary of the results is presented in Table 1. Except for not being able to reject autocorrelation (test is inconclusive), the regression results and the coefficient estimates are quite good and were fairly robust for slightly different specifications of the model.[8]

The marginal productivity and output elasticity estimates corresponding to the regression of equation (10) are also shown in Table 1. Calculated using the mean level of effort (5,556 combined vessels), the marginal productivity of mangrove area is 24.7 metric tons per km^2.[9] This is because MP_M is proportional to the level of effort, and over the 1980-90 period the number of vessels in the Campeche shrimp fishery increased substantially, from around 4,500 combined vessels in 1980 to over 7,200 in 1990.[10] In contrast, the marginal productivity of fishing effort (calculated at mean effort and mean mangrove area, 849 km^2) is actually negative in the regression, at an average of -0.997 tons per vessel. MP_E was slightly negative in 1980, at -26 kg per vessel, but fell to -2.48 tons per vessel by 1990. Part of this decline in the marginal productivity of effort is due to the loss in mangrove area in the Laguna de Terminos from 1980 to 1990, but by far the more important influence appears again to be the increase in the number of small fishing vessels over this period.

The output elasticity for mangrove area (2.80) indicates that a decline in mangrove area in the Laguna de Terminos has a more than proportionate impact on output in the Campeche shrimp fishery. However, the overall impact of mangrove loss during the 1980-90 period on the fishery was still relatively small. Only 2.3% of the mangrove area was deforested between 1980 and

1990, which would suggest that the corresponding loss in fishery output was around 6.5%. The negative output elasticity for effort (-0.74) indicates that the increase in fishing effort over the 1980-90 period had a significant negative impact on shrimp production. As the number of combined vessels increased by 61.5% over this period, the corresponding loss in shrimp harvest was 45.5%.

As it yields only two coefficient estimates, the regression of equation (10) is insufficient to determine explicitly the three bioeconomic parameters (α , *r*, and *q*) . However, it is not necessary to solve for the values of these three parameters in order to estimate the comparative static relationships (8) and (9). For example, denoting the estimated coefficients of (10) as $b_1 = \alpha q$ and $b_2 = - q^2/r$, it follows that (8) and (9) can be rewritten as

$$dh^A = \frac{\alpha rc}{pq} dM = -\frac{cb_1}{pb_2} dM \tag{8'}$$

$$pdh^A = \frac{\alpha rc}{q} dM = -\frac{cb_1}{b_2} dM . \tag{9'}$$

Thus to determine the comparative static effects (8') and (9') requires imputing values for prices and costs (*p* and *c*) and combining these values with the parameter estimates b_1 and b_2 from our regression of (10). We impute values to *p* and *c* through the following approach.

As noted above, the assumption underlying the estimation of equation (10) is that the 1980-90 shrimp harvest and effort data for the Campeche fishery satisfy one of the open access equilibrium conditions of our model, i.e. equation (6). However, the latter is only one of the conditions necessary for an open access equilibrium. The other is (5), which assumes zero profits in the long run. Values of h and E that satisfy both equation (10) and the long-run zero profit condition will therefore also satisfy the open access equilibrium.

For the purposes of illustrating the comparative static effects of a change in mangrove area on equilibrium harvest and revenues, it would be convenient to assume that the 1980-90 harvest and effort levels satisfy simultaneously both open access conditions, (5) and (6). This will be the case if the price and cost parameters in each of the years of data attain levels that equate with zero profits, i.e. $ph = cE$. Price data in terms of US$/kg of imported fresh/frozen shrimp from Mexico are available for the 1980-90 period. Assuming a 100% mark-up from the ex-vessel prices, we use this data to generate a price series for the Campeche shrimp fishery.[11] Consequently, based on the price, effort and harvest data, we calculate for each year of the analysis the corresponding 'equilibrium' cost per unit effort levels that yield zero profits, and denote these cost values as c^A. Thus by employing our estimated parameters, b_1 and b_2 , and the economic parameters, p and c^A, we are able to calculate the comparative static effects of the impacts of mangrove loss over 1980-90 on the open access Campeche shrimp fishery, as indicated by conditions (8') and (9'). The results of the simulation are shown in Table 2.

On average over the 1980-90 period, a marginal (in km^2) decline in mangrove area produces a loss of 14.39 metric tons of shrimp harvest and US$139,352 in revenues from the Campeche fishery each year. This is equivalent to a reduction of 0.19% in the annual harvest and revenues of the fishery.[12] Since over the simulation period mangrove deforestation occurred at the rate of around 2 km^2 annually, the resulting loss each year amounts to about 28.8 metric tons, or US$278,704. As our theoretical analysis would suggest, mangrove conversion in the Laguna de Terminos clearly has a negative impact on the Campeche shrimp fishery. However, given the relatively small rate of annual mangrove deforestation in the Laguna de Terminos over the 1980-90 period, the resulting loss in shrimp harvest and revenues does not appear to have been substantial. If as expected mangrove deforestation accelerates in the region, perhaps as a result of urban expansion and the conversion of mangrove swamps to mariculture ponds, then it is likely that more substantial losses to the off-shore shrimp fishery will occur.

An interesting feature of our simulation is that it indicates how the economic losses associated with mangrove deforestation are affected by long-run management of the open access fishery. As noted previously, the early years of the period (e.g. 1980-81) were characterized by much lower levels of fishing effort and higher harvests (e.g. on average around 4,800 combined vessels extracting about 8.5 KMT annually). Table 2 shows that, if this earlier period represented the open access equilibrium of the fishery, the economic impacts of a marginal (km^2) decline in mangrove area would be a reduction in annual shrimp harvests of around 18.6 tons, or a loss of about US$153,300 per year. In contrast, the last two years of the analysis (e.g. 1989-90) saw much higher levels of effort and lower harvests in the fishery (e.g. around 6,700 combined vessels extracting 5.3 KMT annually). As a consequence, if this latter period represents the open access equilibrium, then a marginal decline in mangrove area would result in annual losses in shrimp harvests of 8.4 tons, or US$86,345 each year.

Thus, the value of the Laguna de Terminos mangrove habitat in supporting the Campeche shrimp fishery appears to be affected by the level of exploitation. This suggests that, if an open access fishery is more heavily exploited in the long run, the subsequent welfare losses associated with the destruction of natural habitat supporting this fishery are likely to be lower. Intuitively, this makes sense. The economic value of an over-exploited fishery will be lower than if it were less heavily depleted in the long run. The share of this value that is attributable to the ecological support function of natural habitat will therefore also be smaller.

7. Conclusion

Our model of mangrove-shrimp fishery linkages demonstrates that it is possible to modify a standard bioeconomic fishery model to account explicitly for the effect of a change in mangrove habitat area on carrying capacity and thus production. By employing a dynamic discrete-time model and assuming open access conditions, we are able to solve for the impacts on steady-state levels of shrimp harvest and revenues that result from a change in mangrove area. In our model, mangrove habitat loss leads unambiguously to a decline in both steady-state shrimp harvest and revenue. More importantly, we are able to calculate these effects explicitly from our model, given regression estimates of two coefficients based on the bioeconomic parameters of our model (α , r, and q) and imputed economic data on prices and costs (p and c) for the Campeche shrimp fishery. The empirical application of our model to the relationship between mangroves in Laguna de Terminos and shrimp production in Campeche has led to two principal findings.

First, the high marginal productivity and ouptput elasticity of the mangrove habitat in terms of shrimp production tend to support the claims of ecologists that the mangroves of the Laguna de Terminos are both an important and essential input into the Campeche shrimp fishery (Soberón-

Chavez and Yañez-Arancibia 1985; Yañez-Arancibia and Day 1988). However, given that only 2.3% of the mangrove area was deforested between 1980 and 1990, the actual losses that have occurred in the shrimp fishery as a result of mangrove deforestation are still comparatively small. We calculate that over 1980-90 with an average annual rate of mangrove deforestation of 2 km^2 the resulting loss in shrimp harvest each year amounted to about 28.8 metric tons, or a loss of US$278,704 in revenue. This is equivalent to a reduction of only 0.4% in the annual harvest and revenues of the fishery.[13] In the future, mangrove deforestation in the Laguna de Terminos is expected to increase substantially in the region, most likely from urban expansion and the conversion of mangrove swamps to mariculture ponds.[14] If this is the case, then it is likely that more substantial losses to the off-shore shrimp fishery of Campeche will occur.

Our empirical analysis also shows that, although mangrove loss has an important economic influence on the Campeche shrimp fishery, a more pervasive problem over the 1980-90 period of analysis has been over-exploitation. Our estimate of the marginal productivity of fishing effort is actually negative over the entire period of analysis, reflecting the rapid expansion of fishing vessels over this period, from around 4,500 combined industrial and artisanal vessels in 1980 to over 7,200 in 1990. In common with the analysis of wetland-fishery linkages by Freeman (1991), we also find that open access conditions and the level of exploitation affect the economic value attributed to the role of the mangrove habitat in supporting the shrimp fishery. As equilibrium levels of fishing effort rise and harvests subsequently fall, the welfare losses associated with mangrove deforestation become smaller. Over-fishing appears to lower the economic value of natural habitat.

The resulting management implications are clear. In the case of an open access fishery such as the Campeche shrimp industry, protection of the nursery and breeding habitat function of the Laguna de Terminos mangroves may be important for reducing losses in the fishery, but control of over-fishing is more critical. As long as effort levels continue to rise, harvests will fall, even if mangrove areas are fully protected. Moreover, any increase in harvest and revenues from an expansion in mangrove area is likely to be short-lived, as it would simply draw more effort into the fishery. Better management of the Campeche shrimp fishery to control over-exploitation may be the only short-term policy to bring production back to respectable levels, as well as being essential for realizing the more long-term economic benefits of protecting mangrove habitat. We expect that this conclusion holds also for other open access fisheries elsewhere, which are supported by mangroves or other estuarine and coastal wetlands that provide breeding habitats and nurseries for the fisheries.

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Table 1. **Regression Results for Time-Series Analysis of the Relationship between Campeche Shrimp Harvest, Effort and Mangrove Area**

Dependent Variable: Annual Shrimp Harvest (kilograms)
(Mean: 7,506,636 kg)

Parameter Estimates

Variable	Parameter Estimate	Standard Error	T-statistic	Prob > T
Mangrove area (M) x Effort (E)	4.4491	0.2991	14.877	0.00001
Effort squared (E^2)	- 0.4297	- 0.0439	- 9.797	0.00001

Adjusted R^2 : 0.745
S.E of Regression: 639745.7
Durbin-Watson: 1.461

F Statistic: 30.216
No of observations: 11
1st Order Autocorrelation: 0.254

Marginal Productivity Estimates (at means)

$$MP_M = \frac{\partial h}{\partial M} = 24{,}719 \quad MP_E = \frac{\partial h}{\partial E} = -997$$

Output Elasticity Estimates

$$\epsilon_{hM} = 2.80 \quad \epsilon_{hE} = -0.74$$

Notes: The marginal productivity and output elasticity estimates are evaluated at the mean M and E levels. ϵ_{hM} and ϵ_{hE} are the output elasticities for mangrove area and effort respectively.

Table 2. **Simulation Results for the Effects of Mangrove Loss on the Open Access Equilibrium of the Campeche Shrimp Fishery, 1980-90**

Parameter Estimates:

b_1 = 4.4491
b_2 = - 0.4297

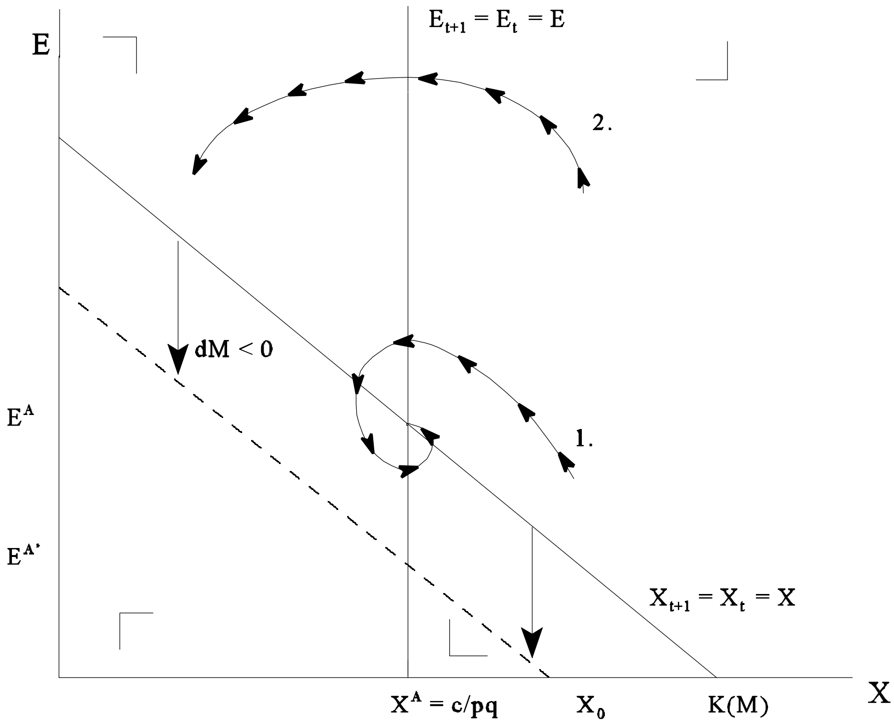
Simulation Estimates of a Marginal Change in Mangrove Area (d*M*)

Year	**Price (*p*) US$/kg a/**	**Cost (c^A) US$/vessel b/**	**Change in Equilibrium Harvest (dh^A) metric tons**	**Change in Equilibrium Revenues (pdh^A) US$**	**Change %**
1980	7.10	13,984	20.40	144,808	0.23
1981	9.68	15,628	16.72	161,826	0.20
1982	10.57	13,816	13.53	143,060	0.18
1983	9.80	13,636	14.41	141,197	0.18
1984	9.83	14,096	14.85	145,963	0.19
1985	9.80	16,687	17.63	172,798	0.20
1986	10.00	15,013	15.55	155,460	0.19
1987	10.22	14,363	14.55	148,731	0.20
1988	10.56	14,132	13.86	146,334	0.20
1989	10.21	10,000	10.14	103,547	0.17
1990	10.40	6,677	6.65	69,143	0.14
Mean	**9.83**	**13,457**	**14.39**	**139,352**	**0.19**

Notes: a/ US$/kg, in real (1982) prices.

b/ c^A is the 'equilibrium' (real) cost per unit effort, defined as the cost level necessary to attain zero profit in the fishery, i.e. $c^A = ph^A / E^A$.

Figure 1. The Open Access Equilibrium



Notes

1. This study was based on data collected and preliminary work conducted at the Diploma short course "Ecological Economics in Tropical Coastal Ecosystems" held at the Programa de Ecologia Y Oceanografia del Golfo de México (EPOMEX), Universidad Autónoma de Campeche, Mexico, 10-28 February, 1992. We are grateful to the assistance provided by participants in this course, Andrés Gomez-Lobo, Julia Ramos-Miranda, Evelia Rivera-Arriaga, Maria Consuelo Sánchez-González and David Zárate-Lomeli, and to the two course organizers, Alejandro Yañez-Arancibia and Bob Costanza. Additional support for completion of this paper was provided by the Economy and Environment Program South East Asia (EEPSEA) for Ivar Strand, and the Department of Agricultural and Resource Economics, University of Maryland for Ed Barbier, who was a Visiting Professor at the Department in Fall 1996. A previous version of this paper was as presented at the Association of Environmental and Resource Economics (AERE) 1997 Workshop "The Economic Analysis of Ecosystems", 1-3 June 1997, Annapolis, Maryland, USA. We are grateful to participants at the AERE workshop, and particularly Jim Wilen, for helpful comments.

2. A notable exception is Freeman (1991), who extends the optimal management model of Ellis and Fisher (1987) based on the original analysis of the marginal productivity of marsh land acreage in terms of the Gulf of Mexico blue crab fishery in Florida developed by Lynne *et al.* (1981). However, Freeman's valuation of the effects of changes in wetland area on an open access fishery is based on a static market model. Here, we attempt to use the equilibrium conditions of a dynamic mangrove-fishery model to conduct such a valuation. An interesting example of investigating open access-wetland interactions on the input side of fisheries is explored by Parks and Bonifaz (1994), who develop a conceptual model to analyze open access collection of post-larval shrimp inputs and mangrove deforestation as two potential causes for the scarcity of these inputs to shrimp mariculture in Ecuador.

3. Information on the extent of mangrove loss since 1980 has been provided by Programa de Ecologia Y Oceanografia del Golfo de México (EPOMEX), Universidad Autónoma de Campeche, Mexico, who have estimated a total loss of around 2,500 ha in mangroves over the decade since 1980 (see Yañez-Arancibia and Benitez-Torres 1991; Benitez-Torres *et al.* 1992).

4. The other commercially important mangrove dependent fish species in Campeche State are clam, sea trout, crab, oyster, snapper and snook. In 1990, the real price of shrimp was nearly 60% higher than the next highest valued species (snook).

5. Although not shown in Figure 1, trajectory 2 is a spiral that is asymptotically bound (at low values of X) by the vertical and horizontal axes. The implications are that the shrimp fishery approaches what we term 'near collapse' but not complete exhaustion. As X declines towards zero, the slope of trajectory 2 tends to negative infinity, and thus the stock is never fully depleted. We are grateful to Jim Wilen for pointing this out to us.

6. However, as indicated in the previous note and from Figure 1, tajectory 2 is actually a spiral, so after the near collapse of stocks there should be a period of recovery, with the pattern repeating itself.

7. 5.5 is very close to the ratio of average annual catch per industrial boat to the average annual catch per artisanal boat.

8. Correction of the autocorrelation in the regression reduces the already limited degrees of freedom but does not change the parameter estimates substantially.

9. To place this estimate of the marginal productivity of mangrove area in perspective, Parks and Bonifaz (1994) report that the average productivity of shrimp ponds in Mexico was 96 metric tons/km^2, and generally around 40-133 tons/km^2 across a range of developing countries. This suggests that mangrove systems are highly extensive shrimp production systems, compared to shrimp ponds. See also note 14, below.

10. Although different to our equation (10), the production relationship between harvest, effort and marshland area estimated by Lynne *et al.* (1981) for the blue crab fishery of the Florida Gulf Coast also has an interactive term between fishing effort and habitat area (i.e. marshland). Their resulting estimate of the marginal productivity of salt marsh is therefore also influenced by the level of effort. Lynne *et al.* estimate this marginal productivity to be 2.3 pounds/acre (0.26 metric tons/km^2). Bell (1989) applies the Lynne *et al.* production relationship to a number of Florida Gulf Coast

fisheries, including shrimp. Although the marginal productivity of salt marsh area estimated by Bell is highest for the shrimp fishery, at around 4.6-5.9 pounds/acre (0.52-0.66 tons/km^2), it is still substantially lower than our estimate for the marginal productivity of mangrove area in the Laguna de Terminos.

11.This was in part verified by obtaining several years of Mexican ex-vessel prices and converting them into US $ using published exchange rate figures. We chose to present values in US $ and use the import prices because the US figures would be more meaningful to most readers and we would not have to convert using a exchange rate that varied wildly in the latter part of the decade.

12. As shown in Table 2, the percentage change in harvest and revenues are the same, as $p\mathrm{d}h/ph = \mathrm{d}h/h$.

13.Another way to put this figure into perspective is to note that the average per capita income in Mexico in 1985 was US $2,600.

14. Although mariculture development is not yet a major source of mangrove deforestation in Laguna de Terminos, shrimp ponds in Mexico and elsewhere in the tropics are increasingly being established through mangrove conversion, one of the attractions being that shrimp ponds offer a highly intensive shrimp production system, at least initially (see Parks and Bonifaz (1994) and note 9, above). However, Parks and Bonifaz also demonstrate that the mangrove deforestation associated with the establishment of shrimp ponds results in loss of post-larval shrimp inputs for the ponds, indicating a trade-off between short-term profits and long-term productivity. Our analysis additionally shows that the loss of mangrove area can have a detrimental impact on off-shore shrimp fisheries.