Floodplain Resource Management: An Economic Analysis of Policy Issues in Bangladesh

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by

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Abstract

This paper investigates the tradeoffs between floodplain agriculture and fisheries production in the Brahmaputra river basin of Bangladesh, where both sectors are simultaneously affected by floodplain development policies. Current policies primarily include structural changes in the floodplain in the form of flood control, drainage and irrigation projects. Such development programs typically ignore the effects on floodplain fisheries, which is an important natural resource sector and a source of subsistence for the rural poor. This paper develops a floodplain land-use model, where net returns to agriculture and fisheries are jointly maximized. Special attention is paid to the tradeoffs between agriculture and fisheries production and the dynamics of the fishery. The model accounts explicitly for the effect of floodplain area on fisheries production. Productivity is a function of the flood land type, which is based on the average monthly depth of flooding. Numerical results from solving a simple version of the model are presented. These early results show that a combination of agriculture and fisheries production in the floodplain provides higher returns than agriculture production alone. This has implications for floodplain management policies, which to date have the stated goal of increasing agricultural productivity only. The effects of floodplain development policies on both agriculture and fisheries need to be studied in further detail to understand the long-term implications of such policies.
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1. Introduction

Floodplains are important wetland ecosystems providing a wide range of services. In their natural state, floodplains support diverse wildlife habitats, fisheries and forestry, whose productivity depend critically on the annual flood cycle. Economic development in river floodplains around the world often impose external losses on renewable resource production, such as fisheries, by altering the natural hydrologic regime of the floodplain (Sparks, 1995; Swallow, 1994; Welcomme, 1985). Floodplain development policies are often designed with the goal of increasing agricultural productivity with very little attention paid to the natural resource sector. This is increasingly becoming an issue of concern in Bangladesh, where eighty percent of the country is a floodplain of the Ganges, Brahmaputra, Meghna and other rivers. Floodplain fisheries are an important natural resource sector in the country, where both commercial and subsistence fishing are important (Tsai and Ali, 1997). However, the value of the fisheries sector is not adequately accounted for in traditional development planning. The policy issue is to effectively manage the floodplain such that the value of both agriculture and fisheries are taken into account. There is clearly a need for further research in this area as there are relatively few analytical studies that can provide policy recommendations.

Much of the research on wetlands has primarily focused on economic valuation in temperate wetlands. There have been few studies to date that address production tradeoffs in a wetland ecosystem, particularly in a tropical region. Where production tradeoffs have been studied, much of the work has focused on coastal wetlands. In a North American context, Swallow (1990 and 1994) addresses optimal tradeoffs between coastal zone development and renewable resource production, focusing on tradeoffs between agriculture and shrimp production. In a tropical context, Parks and Bonifaz (1994) and Barbier and Strand (1997) study mangrove-shrimp fishery linkages in Ecuador and Mexico respectively. In the context of river floodplains, Stavins (1990) address tradeoffs between agriculture and forestry in the Mississippi River valley. Barbier et al. (1991) estimate values of various wetland functions, including agriculture and fisheries, in a Nigerian floodplain. There has been little research to date that quantifies the production tradeoffs between agriculture and floodplain fisheries. This is particularly true for tropical wetlands in a developing country context, where the often large subsistence production sector needs to be accounted for. The analysis here is a step in that direction where both the agriculture and fisheries sectors are studied within one framework.

This paper investigates the tradeoffs between floodplain agriculture and fisheries production in the
Brahmaputra River floodplain in Bangladesh. A floodplain land-use model is developed that allows us to investigate optimal land allocations under alternative management strategies. The model focuses on the linkages between agriculture, fisheries and floodplain characteristics, where the productivity in each sector is a function of flooding condition. The goal is to quantify the production tradeoffs and understand the impacts of alternate policies. A simple version of the model is solved here and preliminary results are presented.

The outline of the paper is as follows. The next section provides additional background on floodplain management policies in Bangladesh and on agriculture and fisheries production systems. Section 3 further discusses production tradeoffs between agriculture and fisheries and the effect of flood land types (defined in that section). A conceptual model for floodplain land allocation is developed in section 4. Section 5 presents a simple version of the model that is numerically solved for this paper. Section 6 provides data sources and section 7 presents and discusses some preliminary results. Concluding comments are provided in section 8.

2. Background

Large river floodplains around the world support heavy population settlements, where development goals most often include improved navigation, enhanced agricultural production and flood protection. However, by altering the annual hydrologic regime, many development programs have undesirable effects on the ecosystem. There is now considerable evidence that even the most vital floodplains in the world are not being managed efficiently and both economic and ecological factors need to be considered for more effective management (Rogers et al. 1989; Interagency Floodplain Management Review Committee, 1994; Naiman et al., 1995; Sparks, 1995). When properly measured, the total economic value of wetland services and resources may exceed the economic gains of developing the area and converting it to an alternative use (Barbier, 1994).

Agriculture and fisheries production in the floodplain are both dependent on the annual hydrologic cycle of wet and dry seasons. In Bangladesh, the dry season covers December-June where December-February is the winter dry season and March-June is the summer dry season. The wet season covers July-November where July-September is the monsoon season and October-November is the post-monsoon season. The monsoon rains start in late June/early July and typically last until September. This is the main flooding period. Water recedes from the plains over October and November. Adult fish are carried into the floodplains with the water in July. They spawn during the early monsoon months and the young fish grow...
in the floodplain. Some species leave with the water as it recedes in the fall while other species remain in
the natural backwater lakes (locally known as beels\(^1\)). Fish harvesting is carried out both in the floodplain
and in the beels by professional and part-time fishermen. The beels are leased out by the government for
fishing. The property rights arrangement in the floodplain is such that the lease is effective during the dry
season only. Floodplain fisheries, including the beel fishery, is an open access resource during the wet
season. Fish are harvested from July till November in the floodplain and all year round in the beels.

Agricultural productivity, the choice of crops grown and the cropping pattern in the floodplain are also
largely determined by hydrologic conditions (MPO, 1987). Most important of these are flood depth, timing
and duration of flooding, rainfall pattern, and the availability of dry season drainage and irrigation.
Anywhere from one to three crops a year are grown in the floodplain, where rice is the dominant crop.
Agriculture is the largest economic sector in Bangladesh, accounting for 32 per cent of the GDP and
employing over 60 per cent of Bangladesh’s labor force (BBS, 1996). Floodplain management policies
target the agriculture sector, with the goal of increasing productivity and achieving self-sufficiency in rice
production.

In Bangladesh, floodplain development has focused on structural changes in the form of Flood Control,
Drainage and Irrigation (FCD\(^2\)) projects. These projects are designed to enhance agriculture production,
where flood control structures, such as levees, are built to reduce flooding. Floodplain management
structures change the annual hydrologic regime, that is, they change flooding conditions, such as, the
intensity and the timing and duration of flooding. The area flooded and depth of flooding are reduced so as
to make more land available for agriculture and to increase agricultural productivity. However, while rice
production has boomed in floodplains protected by levees, some areas have noted declines in fish
population and species diversity. Changes in water management systems and the corresponding changes in
the hydrological cycle affect the fisheries in several ways. First, with a decrease in flooded area during the
monsoon, there is a loss of fisheries habitat and reduced spawning grounds in the floodplains. Second, there
is a decreased influx of riverine fish and hatchlings at the beginning of the flood season due to the blockage
of lateral migratory paths. Finally, there may be decreased dry season habitat as beels are drained to
provide irrigation water and/or to create dry land for agriculture. All of these factors result in a decline in
fish production both in the wet and dry seasons (FAP 20, 1994).

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\(^1\) Beels are permanent backwater lakes in the floodplain, which support fish year-round.

\(^2\) FCD projects are Flood Control and Drainage projects with no irrigation component. The notation FCD/I is used
to imply either a FCD or a FCDI project. Flood control projects here are levees with varying levels of protection.
Fish are an important source of income and protein for the rural poor, who rely heavily on this source for nutrition during the monsoon months when fish are carried onto the plains by floods. At that time, a variety of small fish species are harvested for local consumption only and are not brought to the market. Fish is second only to rice as a source of food for rural households and it is the primary source of protein for the poor. An estimated 73 percent of rural households in Bangladesh engage in part-time fish capture from floodplains, rivers and beels (FAP 16, 1995). Sixty-one percent of the reported subsistence fishery catch comes from river floodplains and beels – the sources most adversely affected by structural changes in the floodplain.

3. Flood Land Type and Production Tradeoffs

Agriculture and fisheries production in the floodplain critically depend on flooding conditions. In the floodplain land-use model developed here, production depends on two important factors, the area flooded and the depth of flooding. Floodplain land is classified into five types based on the depth of flooding in each month. These flood land types are defined in Table 1 below. Crop choice and cropping patterns vary across these flood land types, as do fish yield and species diversity. This is where the agriculture and fisheries production tradeoffs come in. Agriculture is feasible in land types F₀ to F₃. Fishing is feasible is land types

<table>
<thead>
<tr>
<th>Flood Land Type</th>
<th>Flood Depth</th>
<th>Flooding Condition</th>
<th>Note: Type of crop grown in wet season</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₀</td>
<td>0-30 cm</td>
<td>Intermittent</td>
<td>HYV rice</td>
</tr>
<tr>
<td>F₁</td>
<td>30-90 cm</td>
<td>Seasonal</td>
<td>Local and HYV rice</td>
</tr>
<tr>
<td>F₂</td>
<td>90-180 cm</td>
<td>Seasonal</td>
<td>Local varieties of rice</td>
</tr>
<tr>
<td>F₃</td>
<td>180-300 cm</td>
<td>Seasonal</td>
<td>Local varieties of rice</td>
</tr>
<tr>
<td>F₄</td>
<td>Greater than 300 cm</td>
<td>Perennial deepwater body - permanent backwater lakes (beels).</td>
<td>No crops grown in the wet season. Some areas may be drained for agriculture in the dry season.</td>
</tr>
</tbody>
</table>

F1 to F4 in the wet season and in land type F4 (beels) in the dry season. There is a tradeoff between agriculture and fisheries in the wet season in land types F1 to F3. Floodplain development policies, such as FCD/I projects, alter the natural floodplain by changing the areas of land in each flood land type in the different months. More specifically, areas are converted from high to low flooding conditions and is made more suitable for agriculture. As the areas in each flood land type change, so does the productivity of land for crops versus fish. As more land is converted for agriculture, there is less land left in the natural floodplain to support fisheries. Production varies by flood land type and is modeled accordingly.

Fisheries productivity in the floodplain is also correlated to total inundated area. It has been shown that a larger flooded area leads to increased fish production. However, at the same time yield per unit area decreases with an increase in the area flooded. This relationship has been shown to be true for floodplains in Bangladesh and other tropical floodplains (FAP 20, 1994; Welcomme and Hagborg, 1977). Fish yield is therefore modeled explicitly as a function of the floodplain area maintained for the fishery.

4. A Model of Floodplain Land-use

A floodplain land-use model is developed here to study the tradeoffs between agriculture and fisheries production. Land is allocated either to crop production or to maintain fish habitat based on the highest return to land. The social objective is to determine a floodplain management plan and the land allocation that maximizes net returns from both agriculture and fisheries production in the floodplain. Management plans here include any measures that change the hydrologic regime in the floodplain. For our purposes, this includes any plans that directly affect the total area of land exposed to flooding and changes the area of land in each flood land type. Management plans include either structural changes in the floodplain such as different types of flood control, drainage and irrigation facilities or regulatory measures such as a minimum area requirement for fish habitat maintenance.

A single resource manager or social planner determines the optimal floodplain management plan and the corresponding optimal land allocation. In doing this, we are not accounting for any possible conflict between farmers and fishers but are concerned specifically with overall production tradeoffs and optimal outcomes in the floodplain. The planner observes a range of economic and hydrologic factors that affect the use of land for agriculture or fisheries production. These factors include prices and production costs, crop

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3 Please see the appendix for a complete list of notation used in the paper.
yields, fish productivity and the suitability of land for agriculture or fisheries production. A prime factor affecting the suitability of land for agriculture or fisheries and the productivity in each sector is the flooding condition, such as the timing, duration and depth of flooding. The model here incorporates the differences in productivity based on flood land type, as categorized by the average depth of flooding in each month. The flood land types are as defined in Table 1. Thus agriculture and fish production are modeled to vary with the flood land type, \( l \) in each month, \( m \). Given the evidence that fish production is dependent upon the floodplain for habitat and nursery, the effect of flooded area on fisheries productivity is explicitly modeled. Floodplain area is taken to be an input in fisheries production.

The focus here is to model the fisheries sector and the linkages between agriculture and fisheries in sufficient detail such that production tradeoffs can be studied. The agriculture sector is thus modeled simply, using constant input-output coefficients and assuming constant returns to scale. For analytical convenience, an annual model is used with discrete time increments of one month. Economic values are expressed in annualized equivalent and annual net profits for agriculture and fisheries. This is reasonable for both these sectors. Crop choice and cropping pattern are based on the per hectare net profits and area of land in each flood land type for that year. Floodplain fisheries are assumed to follow an annual cycle where new recruits migrate from the river to the floodplain at the beginning of each flood season and the adults leave with the receding floods. Some species remain in the beels, although fishing practices in Bangladesh leave less than two percent of the stock for the following year (MRAG, 1997; Halls, 1998). Thus, an annual fishery can be modeled with an initial stock dependent on flooding conditions.

The social objective is to maximize the annual value-added from floodplain production. The planner determines the management plan, \( X \), such that net returns from agriculture and fisheries are maximized given an optimal allocation of land between agriculture and fishing activities. Land is allocated to agricultural crops or maintained for fishing based on the net returns from each sector. The optimal area of land allocated to crop \( i \), is \( A_{ilm} \) and the optimal area maintained for the fishery is \( A_{jlm} \). The optimal fishing effort needed to maximize net returns is given by \( E_{lm} \). The objective is the sum of net returns from agriculture and fisheries minus the cost of the management plan, \( X \):

\[
\text{Max}_{X, A_{ilm}, A_{jlm}, E_{lm}} \sum_{i,l,m} \left( p_i y_{il} - c_{il} \right) A_{ilm} + \sum_{f,l,m} \left( p_f Q_{f|lm} - kE_{lm} \right) - CX
\]  

(1)
Prices, $p_i$ for crop $i$ and $p_f$ for fish type $f$, are exogenous. Crop yield, $y_{il}$, per ha agriculture cost, $c_{il}$ and fishing cost per unit effort, $k$ are also exogenous. $C_X$ is the total cost of the management plan expressed as an annualized equivalent.

The first term on the right-hand side of equation (1) is the value-added from agriculture. It is given by the revenue minus cost per ha for crop, $i$, multiplied by the area allocated to that crop, $A_{ilm}$. This is summed across all crops, land types and months. The second term is the value-added from fisheries given by the fishing revenue minus the cost of harvesting. This is summed across all fish types, land types and months. $Q_{flm}$ is the catch of fish type $f$ in flood land type $l$ and month $m$.

The total area, $A_{lm}$, available in each flood land type in each month is a function of the management plan $X$ and the hydrologic regime, $h$:

$$A_{lm} = L(X, h)$$ (2)

The management plan and the hydrologic regime jointly determine the area flooded in each month and the extent of flooding, which allows us to determine the total area in each flood land type. Alternate hydrologic regimes are defined as high flood (e.g. 1 in 20 year flood), medium flood (e.g. 1 in 10 year flood) and normal flood (e.g. 1 in 2 year flood). The total flooded area is greater in high flood years than in normal flood years for any given $X$. Also, for any given $h$, the total flooded area will be higher in the case of a natural floodplain than for management plans which include flood control projects.

Equation (3) is the land constraint. It ensures that the sum of all land allocated to agriculture and fishing in each land type for each month does not exceed that total available area of that land type in that month.

$$\sum_i A_{ilm} + A_{jlm} \leq A_{lm} \text{ for all } l \text{ and } m$$ (3)

The next set of constraints, equations (4) and (5) are the fisheries dynamics constraints:

$$Q_{f,l,m} = F(S_{f,l,m}, E_{l,m})$$ (4)

$$S_{l,m} = G(S_{l,m-1} - Q_{l,m-1}, A_{j,l,m}, \gamma, \delta)$$ (5)
Equation (4) is the fish production function. This is a common formulation used in fisheries problems, where the catch, \( Q \) at any time period is a function of the stock, \( S \) and the harvesting effort, \( E \). The Schaefer specification is often used where,

\[
Q_{flm} = \tau E_{lm} S_{flm}
\]

Here, catch or output is a product of the inputs which are the harvesting effort, stock and a technological efficiency parameter, \( \tau \). Equation (5) gives the evolution of the fishery. The fish stock in any month is a function of the stock minus catch in the last month, the area maintained for the fishery, fish growth rate \( \gamma \) and fish mortality rate \( \delta \). Evidence from other floodplains suggest that stock is an increasing function of the area flooded but stock per unit area is a decreasing function of the area flooded (Welcomme and Hagborg, 1977). The initial fish stock is the new recruits at the beginning of each flooding season. This depends on both the management plan and the hydrologic regime. For example, there will be more new recruits into the floodplain in a year of higher intensity flood than in a normal flood year. Also, flood control structures will lead to lower initial stocks as they block the migration paths of fish.

The last constraint is the labor constraint, which ensures that the labor requirement for agriculture, \( W \) plus the harvesting effort expended for fishing, \( E \) does not exceed the total labor availability, \( Z \) in any month:

\[
W_m + E_m \leq Z_m
\]  

Equation (1) is maximized subject to the constraints described by equations (2) - (6). The decision variables in this model are: the management plan, \( X \); area allocated to each crop, \( A_{ilm} \); area allocated to fishing, \( A_{jlm} \); and the harvest effort, \( E_{lm} \). Except for the first one, these variables all vary by land type and by month. Endogenous variables in the model include the stock of fish, \( S_{flm} \), the catch, \( Q_{flm} \), and agriculture labor requirement, \( W \). The full model when solved numerically will provide the optimal management plan and land allocation under alternate hydrologic regimes. This will allow us to study the implications of alternate floodplain development policies.
5. Empirical Model

The empirical model solved for this paper is a simplified version of what is presented above. The effects of different management plans and hydrologic regimes are not explored at this time. Also, due to a lack of sufficient data on floodplain fisheries dynamics, the fish stock dynamics are not modeled. Instead, fish production or catch, $Q$ is modeled directly as a function of the floodplain area maintained for the fishery. Thus, we have the following land allocation model:

$$\begin{align*}
\text{Max} & \quad \sum_{i,l,m} \left( p_i y_{il} - c_{il} \right) A_{ilm} + \sum_{f,l,m} p_f Q_{flm} - k' A_{jlm} \\
\text{subject to,} & \quad \sum_i A_{ilm} + A_{jlm} \leq A_{ilm} \quad \text{for all } l \text{ and } m \\
& \quad Q_{flm} = \alpha A_{jlm}^\beta \quad \text{where, } \alpha > 0 \text{ and } 0 < \beta < 1
\end{align*}$$

(7) (8) (9)

The objective is, as before, the sum of net returns from agriculture and fisheries. The optimal land allocation is found by maximizing equation (7) subject to the constraints (8) and (9). Equation (8) is the land constraint. Equation (9) is the fish production function. Total catch, $Q$ is an increasing function of the floodplain area available to the fishery. This functional form ensures that the catch per unit area is a decreasing function of the floodplain area. The optimal land allocated to fishing occurs where the marginal return to agriculture equals the marginal return to fishing.

Eleven agricultural crops and five fish types are specified in the model which include the most common varieties found in the floodplain. The crops include seven varieties of rice, wheat, jute, mustard and pulses. The fish types are small fish, carp, catfish, snakeheads and shrimp. These cover the range from high market value to low market value fish types that are common to the area and are found in both the wet and dry seasons. Constant input-output coefficients are used for each crop which gives a constant exogenous net profit per hectare for each crop. The fish production function is specified for total fish catch and the fish types are assumed to be a constant proportion of the total catch. The proportion varies between wet and dry seasons. The same production function specification is used for the entire year.
6. Data and Study Area

Data from Tangail District in the North-Central Region of Bangladesh are used for the analysis. Agriculture data are from the Tangail Compartmentalization Pilot Project (FAP 20, 1992). Fisheries data are from the Tangail Compartmentalization Pilot Project (FAP 20, 1994) and from the Center for Natural Resource Studies (CNRS). The data include both production data and economic data on prices and costs. The CNRS data are for the Elasin beel and floodplain area in Tangail, where data on fish catch, subsistence consumption and socio-economic variables are available for this floodplain. The Elasin floodplain area is a natural floodplain, covering a total area of 760 hectares of which 20 hectares are the perennial beel, about 200 hectares are seasonal floodplain and the rest consists of settlements and high croplands (EGIS, 1997). The beel is connected via a canal to the Dhaleswari River, which is a tributary of the Brahmaputra River. This area was chosen for the study because there are both natural and modified floodplains in the region. Also, data for this area were available from several sources. Table 2 shows some catch data for the years 1995-1997 for the Elasin beel and floodplain area.
Table 2: Catch Data from the Elasin Beel and Floodplain Area, 1995-1997.

<table>
<thead>
<tr>
<th>Month</th>
<th>Year</th>
<th>Total Catch (kg)</th>
<th>Catch per ha (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul</td>
<td>1995</td>
<td>798</td>
<td>4.69</td>
</tr>
<tr>
<td>Aug</td>
<td>1995</td>
<td>2622</td>
<td>15.42</td>
</tr>
<tr>
<td>Sep</td>
<td>1995</td>
<td>3126</td>
<td>18.39</td>
</tr>
<tr>
<td>Oct</td>
<td>1995</td>
<td>5694</td>
<td>33.49</td>
</tr>
<tr>
<td>Nov</td>
<td>1995</td>
<td>5246</td>
<td>30.86</td>
</tr>
<tr>
<td>Dec</td>
<td>1995</td>
<td>5306</td>
<td>265.28</td>
</tr>
<tr>
<td>Jan</td>
<td>1996</td>
<td>4554</td>
<td>227.71</td>
</tr>
<tr>
<td>Feb</td>
<td>1996</td>
<td>3377</td>
<td>168.86</td>
</tr>
<tr>
<td>Mar</td>
<td>1996</td>
<td>533</td>
<td>26.65</td>
</tr>
<tr>
<td>Apr</td>
<td>1996</td>
<td>382</td>
<td>19.10</td>
</tr>
<tr>
<td>May</td>
<td>1996</td>
<td>206</td>
<td>10.32</td>
</tr>
<tr>
<td>Jun</td>
<td>1996</td>
<td>247</td>
<td>12.34</td>
</tr>
<tr>
<td>Jul</td>
<td>1996</td>
<td>777</td>
<td>4.57</td>
</tr>
<tr>
<td>Aug</td>
<td>1996</td>
<td>1652</td>
<td>9.72</td>
</tr>
<tr>
<td>Sep</td>
<td>1996</td>
<td>1628</td>
<td>9.58</td>
</tr>
<tr>
<td>Oct</td>
<td>1996</td>
<td>1654</td>
<td>9.73</td>
</tr>
<tr>
<td>Nov</td>
<td>1996</td>
<td>2016</td>
<td>11.86</td>
</tr>
<tr>
<td>Dec</td>
<td>1996</td>
<td>2287</td>
<td>114.37</td>
</tr>
<tr>
<td>Jan</td>
<td>1997</td>
<td>1217</td>
<td>60.86</td>
</tr>
<tr>
<td>Feb</td>
<td>1997</td>
<td>1246</td>
<td>62.31</td>
</tr>
<tr>
<td>Mar</td>
<td>1997</td>
<td>916</td>
<td>45.82</td>
</tr>
<tr>
<td>Apr</td>
<td>1997</td>
<td>331</td>
<td>16.53</td>
</tr>
<tr>
<td>May</td>
<td>1997</td>
<td>1468</td>
<td>73.41</td>
</tr>
<tr>
<td>Jun</td>
<td>1997</td>
<td>55</td>
<td>2.76</td>
</tr>
</tbody>
</table>

Annual Total: 1995-96 32091
Annual Total: 1996-97 15249
Wet Season Total: 1995 17486
Wet Season Total: 1996 7728
Dry Season Total: 1996 14605
Dry Season Total: 1997 7521

**Monthly Averages**
- Wet Season Average: 1995 3497 20.57
- Wet Season Average: 1996 1546 9.09
- Dry Season Average: 1996 2086 104.32
- Dry Season Average: 1997 1074 53.72
- Full-year Average: 1995-96 2674 69.43
- Full-year Average: 1996-97 1271 35.13

Source: CNRS, 1998 and author’s calculations.
Notes: Wet Season is Jul-Nov and Dry Season is Dec-Jun.
Catch per ha is an approximate calculation based on 170 ha of floodplain in the wet season and 20 ha of beel area in the dry season (exact inundated areas are not known for each month).
7. Results and Analysis

The optimization model is numerically solved using mathematical programming techniques. Estimates for the parameters $\alpha$ and $\beta$ were difficult to obtain due to a lack of data on catch and corresponding habitat areas. The parameters were chosen here based on characteristic yields from Bangladesh floodplains.

Three versions of the model were run. Model 1 has the agriculture sector only, where the objective was to maximize net returns from agriculture only subject to a land constraint only. Models 2 and 3 follow the specification of equations (7) to (9). That is, both the agriculture and the fisheries sectors are included. In model 2, fisheries are feasible in all flooded land except for land type $F_0$ (shallow-flooded land). In model 3 fisheries is restricted to only the land type $F_4$ (deepwater beel). That is, the floodplain is modified and used for agriculture only and is off-limits for the fishery. The same production function is used for both models.

Table 3: Results from Three Model Versions

<table>
<thead>
<tr>
<th>Annual Returns in Taka a/</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Returns from Agriculture</td>
<td>6,246,600</td>
<td>6,100,913</td>
<td>6,235,764</td>
</tr>
<tr>
<td>Returns from Fishing</td>
<td>555,829</td>
<td>274,985</td>
<td>274,985</td>
</tr>
<tr>
<td>Total Net Returns</td>
<td>6,246,600</td>
<td>6,656,742</td>
<td>6,510,749</td>
</tr>
</tbody>
</table>

Model 1: Agriculture only – no fisheries sector
Model 2: Agriculture and fisheries (unrestricted)
Model 3: Agriculture and fisheries (fisheries restricted to deepwater beel only)
Models 2 and 3 run with alpha=100 and beta=0.5.
Notes: a/ Taka 45 = $ 1.

Preliminary results from all three models indicate realistic crop choice and cropping patterns for the agriculture sector. The value of the objective function (total net returns) and returns from agriculture and fisheries under optimal land allocation are shown in Table 3. Model 1 has lower net returns compared to both Models 2 and 3. This implies that a combination of agriculture and fisheries production in the floodplain leads to higher net returns than agriculture alone. Optimal land-use indicates a combination of fishing and agriculture in the floodplain in land types $F_1$ through $F_3$ during the wet season. Only agriculture is optimal in land type $F_0$ (where fishing is not feasible). Only fishing is optimal in land type $F_4$ (where agriculture is not feasible). For the model specifications used here, we do not get a corner solution
for land types $F_1$ to $F_3$. This implies that marginal returns to agriculture equals marginal returns to fisheries for a non-zero level of area maintained for fisheries in these land types.

Different specifications of Models 2 and 3 were run with different parameter values for $\alpha$ and $\beta$. Realistic yields were obtained for alpha = 100 and beta between 0.4 and 0.6, although total annual production here is somewhat lower when compared to that from Elasin floodplain. Results are presented in Table 4.

### Table 4: Results from model runs with different parameter specifications

<table>
<thead>
<tr>
<th>Alpha</th>
<th>Beta</th>
<th>Total Returns (Taka)</th>
<th>Agriculture Returns (Taka)</th>
<th>Fisheries Returns (Taka)</th>
<th>Total Annual Catch (kg)</th>
<th>CPUA a/ (wet season) (kg per ha)</th>
<th>CPUA a/ (dry season) (kg per ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.4</td>
<td>6,372,468</td>
<td>6,217,166</td>
<td>155,302</td>
<td>2,427</td>
<td>15.41</td>
<td>13.45</td>
</tr>
<tr>
<td>100</td>
<td>0.4</td>
<td>6,553,060</td>
<td>6,172,076</td>
<td>380,985</td>
<td>5,789</td>
<td>28.27</td>
<td>26.90</td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
<td>6,407,501</td>
<td>6,203,652</td>
<td>203,849</td>
<td>3,155</td>
<td>17.69</td>
<td>16.74</td>
</tr>
<tr>
<td>100</td>
<td>0.5</td>
<td>6,656,742</td>
<td>6,100,913</td>
<td>555,829</td>
<td>8,417</td>
<td>28.74</td>
<td>33.48</td>
</tr>
<tr>
<td>50</td>
<td>0.6</td>
<td>6,459,957</td>
<td>6,170,356</td>
<td>289,601</td>
<td>4,445</td>
<td>20.03</td>
<td>20.84</td>
</tr>
<tr>
<td>100</td>
<td>0.6</td>
<td>6,849,749</td>
<td>5,954,164</td>
<td>895,584</td>
<td>13,512</td>
<td>31.28</td>
<td>41.67</td>
</tr>
</tbody>
</table>

**Model 2:** Agriculture and fisheries (unrestricted)

**Model 3:** Agriculture and fisheries (fisheries restricted to deepwater beel only)

Notes: a/ CPUA is Catch per unit Area

In all cases, as expected, Model 3 has lower returns than Model 2. That is, returns are lower when fishing is restricted to the beel only compared to when fishing is allowed in the floodplain also. For the various specifications of model 2, returns from fisheries range from 2.5 percent to 13 percent of total returns. For model 3, the fisheries returns range from 1.6 to 5.4 percent of total returns.

These early results are promising given the simple fisheries model utilized here. They show that a combination of agriculture and fisheries production in the floodplain provides higher returns than
agriculture production only. Area is allocated to maintaining the fishery as long as marginal returns from
the fishery exceed marginal returns from agriculture. The results here are driven by the production function
specification used for the fishery. It is assumed that marginal returns to fishing are a decreasing function of
the area, while marginal returns to agriculture are constant. As long as the returns to fishing are higher,
land will be allocated to fishing. The production function specified here does not take into account the
effect of flood intensity and flood depth. Also, fish composition is assumed to be the same across all flood
depths. These assumptions need to be relaxed and the fishery model extended in order to better understand
the tradeoffs between agriculture and fisheries.

The next step of the analysis is to solve the full model under different management scenarios and different
hydrologic conditions. This will change the initial distribution of flood land types and will lead to a
different optimal land allocation in the floodplain. The objective then is to find the management plan and
the corresponding land distribution that maximizes net returns in the floodplain.

8. Conclusion

This paper presents a model of floodplain land-use that can be used to quantify the tradeoffs between
floodplain agriculture and fisheries production. The analysis here considers several factors in one
framework. First, the primary natural resource sector, fisheries, is modeled along with the main economic
sector, agriculture. Second, the suitability of land for agriculture versus fisheries is based on a floodplain
characteristic, the flood land type, defined by the depth of flooding. The tradeoffs between agriculture and
fisheries are based on this land type. Third, fisheries production is a function of the floodplain area
maintained for the fishery. Early results indicate that a combination of floodplain fisheries and agriculture
production results in higher net returns than agriculture production only. The results are driven by the
production function specification used for the fishery. The fishery model has be extended to take into
account the effects of flood intensity and flood depth. Further analysis is also needed to understand the
effects of alternate management plans and hydrologic regimes on production. This will allow us to study
income effects and help to make policy recommendations.
References


**Appendix**

Notation used in this paper:

- $i =$ index for crop type
- $j =$ index for fishing activity
- $f =$ index for fish species category
- $m =$ index for month
- $s =$ index for season
- $l =$ index for flood land type, corresponds to land types $F_0$, ..., $F_4$
- $c =$ Cost of crop production per hectare
- $k =$ Cost of fishing per man-day
- $k' =$ Cost of fishing per hectare
- $p =$ Market price. Varies by crop, $c$ or fish type, $f$.
- $y =$ Crop yield -- output per hectare. Varies by crop $c$, land type $l$ and season $j$
- $\gamma =$ monthly growth rate of fish
- $\delta =$ monthly mortality rate of fish
- $\tau =$ technological efficiency parameter – for fishing.
- $h =$ hydrologic regime
- $A =$ Area. Varies by land type $l$ in each month $m$
- $E =$ fishing effort, measured in man-days per month. Varies by land type $l$ and month $m$
- $Q =$ total catch of fish. Varies by fish type $f$, land type $l$ and month $m$
- $S =$ total fish stock. Varies by fish type $f$, land type $l$ and month $m$
- $X =$ floodplain management plans
- $W =$ labor requirement for agriculture
- $Z =$ total available labor