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Abstract

The inland fishery in South Sumatra, Indonesia, is an important source of income, employment and protein to small-scale fishers. Some overall indicators, such as virtual disappearance of certain important species and continuous reduction in the size of harvested fish, indicate that the fishery is not being exploited on a sustainable basis. In this study, an evaluation of the status of the existing fish stock is undertaken, and an analytical model for identifying efficient levels of exploitation of the fishery is developed. Primary data are used to describe the current costs of fishing effort. Secondary data, combined with results of analysis of primary data, are then used to derive a supply function for the fishery. Different types of fishing gear are standardised into a single type of fishing unit, and mixed species of harvested fish are treated as an aggregated fish stock. Empirical results reveal that both riverine and swamp fisheries in South Sumatra were biologically and economically over-fished during the period of study. This implies that regulation is required to reduce the level of fishing effort.

Key Words: smallholder fisheries, bioeconomic analysis, Inland fisheries, Indonesia, Sumatra.

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Introduction

Fishing in inland water body resources, such as floodplains, rivers and lakes, has an important role for rural people in parts of Indonesia. Fishing can generate significant income and provides employment opportunities. It also has an important role as a source of protein in the diets of many households, both in rural areas and urban centres. Welcomme (1985) observed that, in most artisanal fishing communities, fishing patterns and local traditions enable communities to integrate culturally with the general ecology of fishery resources on their area.

Unlike marine fisheries, inland capture fisheries have received relatively little attention from scientists. The problems, however, may be more complicated than those in marine fisheries. For government decision-makers, the problem of assigning property rights is difficult because it involves an assessment of who can use the resources in the best interests of society. A major problem is the determination of the type and level of controls which should be applied to fisheries in order to achieve the objectives of maintaining the flow of benefits derived from the fishery and improving the productivity of the resource on a sustainable basis.

Fishing is traditionally an important occupation for many rural people living in the floodplains of the Musi river and its major tributaries in South Sumatra, Indonesia. The inland fishery in South Sumatra extends from the main river itself to swamp areas (*rawang*) and small lakes (*lebung*). The river and small lakes contain water throughout the year, while the swamp areas tend to lose their water during the dry season.

A decline in stocks of certain commercial species has occurred in the inland fishery in South Sumatra. This suggests that the fishery is being over-fished, and that better fishery management needs to be imposed in order to maintain productivity of the fishery resource on a sustainable basis.

In general, the objective of this study is to identify an efficient level of fishery resource exploitation which will maximise social welfare. Specifically the study evaluates existing fishery management; formulates analytical tools to analyse fisheries resource allocation and property right systems; and determines the type and level of management options which may be applied.

Characteristics of Inland Fisheries in South Sumatra

Tropical floodplain rivers, such as the Musi River, are characterised by energetic exchanges between terrestrial and aquatic components of the ecosystem (Jackson 1989), and provide an appropriate environment for spawning and early life history stages for the majority of fish in tropical floodplain fisheries (Welcomme 1985).

The inland fishery in South Sumatra is a typical ‘floodplain fishery resource’. The resource is basically formed by the main river, the Musi, and its major tributaries. The middle section of the river system is characterised by extensive floodplains which are locally called *‘lebak lebung’*. The river levees, which are locally called *‘talang’*, are only slightly higher than the surrounding terrain. Often the rivers cut through the embankment, creating direct connections with the extensive floodplains. The vegetation in the floodplains is variable and includes forest, sedge and grasslands. Some floodplains, which are close to settlements, are used for rice production.

The floodplain and the river system exhibit hydrological cycles typical of tropical floodplain rivers. During the rainy season, the river basins flood and water levels in the rivers are high, whereas, during the dry season, the floodplains drain and water levels in the rivers fall.

The catchment has an area of about 60,000 km^2 and a cumulative length of over 2,000 km (Danielsen and Verheught, 1989). The fishery resource consists of the main river itself, swamp areas (*rawang*), and small lakes (*lebung*). Swamp and lake resources are usually distinct geological entities; however, ecologically they are integrated into the river and floodplain system. The river and small lakes contain water throughout the year while the swamp areas tend to lose water during the dry season (July to September).

Fishing is an important occupation for many rural people living in the area, and fishing patterns are significantly affected by fluctuations in water levels. The fishing seasons can be distinguished as high water (December to February), receding water (March to May), low water (June to August) and rising water (September to November). The types of fishing gear operated depend on both area and season.

Previous studies indicate that environmental degradation occurs and it has become a major public issue in the area. The overall impact of economic development in the region is felt through growth in the number of fishers entering the fisheries and is unlikely to be accompanied by increases in fishery resource productivity.

Most floodplain river fisheries experience increased fishing during periods of low flow with the greatest catch per unit of effort (CPUE) often associated with falling or rising water levels (Jackson 1989; Malvestuto 1989). Fish are more concentrated in low water and tend to become migrationally active during rising and falling water. Hence, they are more susceptible to capture during these times. In this regard, the structure and functional composition, as well as abundance of fish stock, are reflected in the types and intensities of fishing effort operated during this time of the year. Fish stock typically recover from intense low water exploitation during the high water season, when fishing efficiency is low due to dispersion of fish in newly inundated areas.

Fishing gear and techniques

Many different types of gear are used by fishers; the South Sumatra Fishery Service divides these units into 10 categories (Table 1). The filtering barrier has been banned since 1991, however, fishers still operate this type of prohibited gear.

Almost all fishing units in the tropical floodplain fishery are artisanal, small-scale and labour-intensive. Many of the fishing units can only be operated for a short time, given water levels appropriate to use of a particular gear. Consequently, fishers tend to operate a succession of fishing units as water levels change.

Table 1. Fishing gear used on riverine, swamp and lake fishery resources in South Sumatra

Fishing gear	Description	Resources where used[\1]	Mesh size (mm)
Gillnets Drift gillnet Fixed gillnet	Fished in open-water or channels	R, S, L	19 - 40
Cast nets Anco	Fished in open-water from canoes	R, S, L	17
Lift nets Serok	Fished in open-water or channels by small portable bamboo frame. This fishing gear has different types of local name, such as tangkul and langgian.	R, S,	6
Hooks and lines Rawai Pancing	 Longlines of 10 - 100 hooks Fishing rod, single hook	R, S, L	7 - 12 (hook gape)
Filtering barriers Jermal	Fished in river by wide shallow barriers with net plumes to strand fish. This fishing gear has different types of local name which can be classified into two: static and active barriers. The static barrier has different types of local name, such as kilung, tuguk, empang and corong. The active barriers are ngesek, ngesar and ngubek lubuk.	Rivers	7 - 9
Portable traps Sero Bubu	Fished without bait in fish migration routes in open-water or channels. There are different types of local name, such as pengilar rotan (rattan fish trap), bengkirai bilah (bamboo fish trap), bengkirai kawat (chicken wire fish trap), lapun (wire predator trap), menteban (bamboo, baited trapdoor trap) and sero (bamboo bullet-shaped baitfish trap).	R, S, L	12 -100
Other gear		R, S, L	

[\1.] ***(R) River, (S) Swamp, (L) Lake.***

Table 2. Selected species of harvested fish from Lubuk Lampam fishing ground in South Sumatra, 1985-1993

	Harvest by species (tonnes)				
Year	Common Snakehead	Catfish	Giant Snakehead	Featherback	Freshwater Prawn
1985	6,897	4,180	987	36	2,063
1986	8,689	2,441	200	-	469
1987	6,091	1,869	2023	50	410
1988	12,517	1,693	808	84	356
1989	643	4,053	500	152	640
1990	7,616	1,524	290	179	1,501
1991	9,566	4,684	52	134	736
1992	21,387	1,472	50	-	177
1993	15,043	2,772	891	2	497

Source: Research station of RIFF Mariana, South Sumatra (Sub Balai Penelitian Perikanan Air Tawar, Marinana, Sumatra Selatan), various years

Fish populations

The composition of the fish stock may vary both spatially according to environment and temporally due to variation in spawning success (Gulland and Garcia 1984). Many species of fish exist in response to the diversity of available foods. In terms of growth, the fish stock may be characterised as fast-growing and seasonal. Many large species grow particularly fast in their first season. This is possibly an adaptation to avoid intense predation on the floodplain by rapidly exceeding edible size before the shelter of the floating vegetation disappears in the dry season. Other species remain vulnerable to predators all their lives but mature and breed as early as possible. Given the above, the effect of mortality due to fishing on such aggregated variable fish stock is complicated and difficult to gauge.

Over one hundred species of fish are currently being harvested from the fishery. However, official records of the Fishery Service on harvested fish consider only 17 species. Table 2 presents harvest figures for some common species in the area.

According to the Research Institute for Freshwater Fisheries (RIFF Mariana) of South Sumatra, the inland fishery was likely to face a problem of over-fishing. Recently, the harvested fish in major fishing grounds have decreased 5 to 10 per cent (Pollnac and Malvestuto, 1992). The perception of fishers interviewed on the study sites indicated that their current fishing was less successful. They indicated that decreases in harvested fish were due to increases in the number of fishers and fishing units and possibly changes in the quality of the environment. Jackson (1989) and Malvestuto (1989) reported that the fish harvest was represented by multiple species, and dominated by detritivorous fish with a significant portion of piscivorous species. However, large size fish were rare. Harvested fish have never been observed being discarded by fishers. This may indicate over-fishing in that particular fishing ground.

The Fishing Community

Welcomme (1985) divides fishers into three groups: occasional, part-time and full-time. Occasional fishers harvest fish for their own consumption and are comparatively unproductive. Part-time fishers tend to use a range of fishing gear and usually operate their fishing as a consequence of lack of work in their main occupation. Full-time fishers are more specialised and operate their fishing as a main occupation.

Harvested fish are transported from fishing grounds to principal landing centres and wholesale markets through various market intermediaries and middlemen Fishers sometimes sell their harvested fish to the middlemen on credit and are paid when middlemen receive cash from other middlemen or retailers. In more remote fishing areas middlemen sometimes provide credit to fishers. The credit is repaid by fishers on the basis of their daily fish harvest. Based on the reported experience of fishers this system seems to be fair. Both fishers and middlemen appear to be satisfied. Middlemen often provide ‘gifts’ which may not be considered as credit to fishers. With this, middlemen seem to provide security to fishers and have a guaranteed source of supply from them.

Pricing of harvested fish is decided by the middlemen when fishers have a debt to them. According to fishers, this system is satisfactory. Fishers can also sell their product directly to retailers and consumers at market prices. Prices of harvested fish tend to be lower in the dry season than in the wet season, in line with the size of the harvest. During the dry season most fish harvested are salted and dried (Bailey, Polnac and Malvestuto 1990). Both individual fishers and small-buyers may hold live fish in cages prior to sale or further distribution.

Fishery Management Practice

Fisheries management is often assumed to be a government responsibility (Gordon 1954). However, previous experience indicates that the effective capacity of a government agency to manage a widely scattered fishing ground is limited (Bailey and Zerner 1992). This is true in the case of inland tropical fisheries in Indonesia. The government rents out access to inland fishery resources to the highest bidder. Annual rents are charged for sections of tributary rivers and floodplain areas in the basin. In addition to this, there are official government taxes on successful bidders.

The government sets different rates for different areas. These rates are costly and hence traditional fishers can rarely afford to pay them. Commonly, the highest bidders are concerned with distribution and marketing of fish from their rented areas. Most likely, the winner of the government auction will in turn rent a portion of the area to second parties such as middlemen or small-buyers who have previously covered that region. Hence, the winner can make a direct profit on his/her initial rental transaction. Then, small-buyers may split up the area into smaller parcels and rent these out to fishers. Traditional fishers may be allowed by the small-buyer to catch the fish in that area, but they must sell their product directly to them. It is typical for the government to ignore official rates and rent the areas to highest bidders.

The auction system was initiated by the Dutch colonial government as a means of generating revenue and over time has proliferated into a complex series of localised versions of the original plan. Recently, this system has dominated management practice in the inland fishery in South Sumatra.

The Bioeconomic Model

According to Sparre and Venema (1992), biological fisheries models can be either holistic or analytical. The holistic approach is characterised by consideration of a fish stock as a homogeneous biomass. This approach does not take account of growth parameters, such as age structure and rate of growth of individual fish. Included in this approach are 'surplus production models' which have been widely used by scientists because of their simple data requirements and applicability to solving long-run problems. Although biological systems change over time and vary according to available resources and the size of the fish stock (Hilborn and Walters 1992), the decision on the type of model to be used is often limited by the quality and quantity of available data.

An attempt to describe a fundamental law of population growth due to fishing was formulated by Schaefer (1954). In his formulation, fishing is proportional to effort and stock while biomass is estimated as the ratio between catch per unit of effort and catchability. Schaefer's formulation is appropriate for situations in which the population tends to be stable, environmental factors are constant and food is limited. Whenever the rate of fishing equals the rate of natural growth, equilibrium will occur. The model is now commonly referred to as the 'Schaefer Surplus Production Model'. A similar model was developed by Fox (1970), in which a logarithmic relationship between catch per unit of effort and fishing effort was introduced.

In the context of an inland tropical fishery, biological data such as fish growth, mortality, age class and stock recruitment, required to set up a detailed population dynamics model, are not available. In this situation, simple biological models, such as surplus production models, are more useful to analyse fishery dynamics (Sparre and Venema 1992; Tai 1992).

Following Russell (1931) the gains and losses of fish stock in a particular fishery can be described as:

$$\frac{dX}{dt} = F(X) = R + I - M \tag{1}$$

where X is fish stock (or biomass), R is recruitment, I is individual growth and M is mortality. The amount of fish stock in a particular area is regulated by interactions between environmental factors and the fish themselves (Gulland 1978). The stock tends to stability for a particular set of environmental conditions. At the level of maximum fish stock size, the addition of recruitment and growth to the stock is just sufficient to compensate for natural mortality and hence, surplus production will equal zero. This implies that fishing plans can be expressed in terms of surplus production.

Graham (1935) assumed a parabolic relationship of the form:

$$F(X) = r \cdot X\left[1 - \frac{X}{K}\right] \tag{2}$$

where *K* is carrying capacity, a parameter corresponding to the unfished equilibrium stock size, and *r* is intrinsic growth rate of the fish.

Fishing mortality can be expressed relative to the stock size and fishing effort. The fishing function is expressed as:

$$Y = Y(E, X) = q \cdot X \cdot E \tag{3}$$

where *Y* is the catch measured in term of biomass, *E* is fishing effort, *X* is the stock, and *q* is a constant catchability coefficient. Technologically, the constant *q* implies that there is no change in technology over a certain period of time; biologically, it implies that environmental conditions are constant. Equation (3) also implies that catch per unit of effort is an index proportional to stock abundance:

$$\frac{Y}{E} = q \cdot X \tag{4}$$

Sustainable yield occurs when (Schaefer 1954):

$$\frac{dX}{dt} = F(X) - Y\big(E, X\big) = 0 \tag{5}$$

Which, by equations (2) and (3) occurs when:

$$X = K\left[1 - \frac{q \cdot E}{r}\right] \tag{6}$$

Substituting (6) into (3) and rearranging we obtain:

$$Y = (q \cdot K)E - \left[\frac{q^2 K}{r}\right]E^2 \tag{7}$$

This is a quadratic function whose parameters can be estimated from catch and effort data through linear regression as:

$$Y = a \cdot E - b \cdot E^2 \tag{8}$$

where $a = (q \cdot K);\ b = \left[\frac{q^2 K}{r}\right]$

A convenient way of estimating this equation is to redefine the relationship in terms of catch per unit of effort as a function of fishing effort:

$$CPUE = \frac{Y}{E} = a - b \cdot E \tag{9}$$

Fox (1970) modified the model by assuming a Gompertz growth function instead of a logistic function. Fox's model results in the equivalent relationship:

$$Ln\left(\frac{Y}{E}\right) = a - b \cdot E \tag{10}$$

So equations (9) and (10) can be used to estimate the Schaefer model (logistic form) and the Fox model (Gompertz form).

A simple economic model, in which total cost (*TC*) is proportional to effort, and total revenue (*TR*) is proportional to catch, was introduced by Gordon (1954):

$$TC = c \cdot E \tag{11}$$

$$TR = p \cdot Y = p\left(a \cdot E - b \cdot E^2\right) \tag{12}$$

The Gordon-Schaefer model represented by (11) and (12) has been criticised because total revenue is measured in terms of inputs (effort) instead of outputs (catch). The conversion of cost of fishing effort into cost of catch provides a conventional supply curve for the product. This approach was first introduced by Copes (1970) by incorporating the sustainable yield curve into the cost of output relations. The Copes model is known as the 'backward bending supply' model. The backward slope implies the nature of the common property resource and the biological dynamics of the fishery.

Solving equation (8) for effort as a function of catch results in:

$$E = \frac{a \pm \sqrt{a^2 - 4b \cdot Y}}{2b} \tag{13}$$

Substituting (13) into (11) and calculating average cost (*AC*) we have:

$$AC = \frac{TC}{Y} = \frac{2c}{a \pm \sqrt{a^2 - 4b \cdot Y}} \tag{14}$$

The long-run average cost function represented in equation (14) is the supply function for the fishery.

Bioeconomic Analysis

Optimal resource use in fisheries is often described by biologists in terms of maximising sustainable yield, or by economists in terms of maximising economic yield. Alternatively, optimal resource use can be defined as maximising social benefits, as explained below.

The level of effort which generates the maximum sustainable yield (*MSY*) can be obtained from equation (8) by taking the partial derivative of Y with respect to E and setting it equal zero, to obtain:

$$E_{MSY} = a/2b \tag{15}$$

Substituting (15) back into (8) the catch at MSY is:

$$Y_{MSY} = a^2/4b \tag{16}$$

In contrast, the maximum economic yield (*MEY*) is obtained when marginal revenue equals marginal cost, taking derivatives of (11) and (12), setting them equal to each other ($MR = MC$), and rearranging yields:

$$E_{MEY} = a/2b - c/2b \cdot p$$

which, by (15), can be expressed as:

$$E_{MEY} = E_{MSY} - c/2b \cdot p \tag{17}$$

Since c, b and $p > 0$, it follows that $E_{MEY} < E_{MSY}$, economic yield is maximised at a lower level of effort than physical yield, and hence at a higher equilibrium biomass.

Under an open-access or unregulated fishery, individual fishers attempt to maximise their income by expanding effort as long as their average revenue (*AR*) is greater than the average cost (*AC*) of their effort, and the fishery settles at an equilibrium level, called the bionomic equilibrium (*BE*), when $AR=AC$:

By (11) and (12), effort under open access is:

$$E_{BE} = \frac{a - c/p}{b} \qquad (18)$$

At this point profits are totally dissipated and no economic rent is obtained from the resource. These critical points are illustrated in Figure 1.

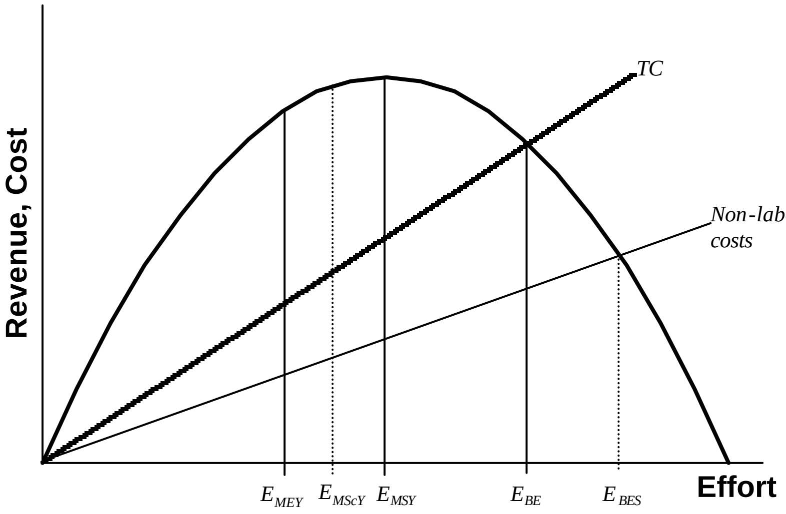

Figure 1. Various critical points of fishing effort under sustainable resource extraction.

Both *MSY* and *MEY* are essentially single-objective options. The concept of optimal sustainable yield can be extended and viewed in terms of multiple objectives (Charles 1988). The objective function is then defined as maximum social yield (*MScY*).

MScY may measure welfare in terms of factors such as income distribution and employment as well as profit. Crutchfield (1979) and Sinclair (1983) pointed out that fishery policy analysis should consider whether fishers' labour has low opportunity cost. In this study, *MScY* includes the scarcity of alternative employment opportunities, by dividing the cost of fishing into two components, private labour costs (wages) and other capital and operating costs. Given the high levels of unemployment in the study area, the opportunity cost of labour in the fishery is close to zero (see Figure 1).

The bioeconomic model implicitly assumes that the market price of fishing inputs reflects the true sacrifices which society makes in using these inputs for fishing rather than in other occupations. Under this assumption, attaining the level of *MEY* may require a large reduction in effort and force large number of fishers out of fishing. However, if fishers have no alternative income-earning activity, society makes little sacrifice in keeping them in the fishery. Under these conditions, the new total cost will be lower than previously. This results in a higher level of effort under $MScY$ than in under MEY, as shown in Figure 1. Similarly, under open access, the equilibrium level of effort is higher than E_{BE} when the low opportunity cost of labour is considered (E_{BES} in Figure 1).

Empirical Model

Catch and effort

Catch data have commonly been recorded in fishery statistics from many regions in Indonesia. However, fishing effort data is often not directly recorded in the statistics. Various studies have indicated that fishing effort may be represented by the number of fishing units, trips or days of fishing. Decisions about the type of data that may represent fishing effort are based on assumptions regarding the particular fishery being studied. In the current study, fishing effort is described in terms of the number of trips associated with fishing units.

Both swamp and lake fisheries in the study sites have similar characteristics in the sense that their patterns of receiving water through the year are similar. Hence, further analysis will consider only two types of fishery resource, the riverine and swamp fisheries. Hereafter, the ‘swamp’ fishery refers to the sum of lake and swamp fishery data.

Data on fishing gear used in the inland capture fishery in South Sumatra (see Table 3) record that gillnets, cast nets, hooks and lines and portable traps are widely used by fishers. Lift nets are used in such open water as rivers and swamps. Although the filtering barrier has been banned since 1991, fishers still operate this type of gear in the riverine fishery, which indicates that law enforcement is still a problem in the study sites. The data show that the most frequently used fishing unit in the study sites is the portable trap, followed by gillnets, then hooks and lines.

The highest number of trips was for units which use the *bubu* trap (bamboo portable trap). Based on this evidence (Table 3), all recorded fishing units are simplified into a standard unit, the *bubu* portable trap, using the procedure described below.

Consider the set of fishing units denoted as 1, 2, 3, ..., N, the total catches of each fishing unit are Y_1, Y_2, ..., Y_N, and the corresponding levels of fishing effort are E_1, E_2, ..., E_N. The catch per unit of effort of fishing gear i, is then defined as:

$$CPUE_i = \frac{Y_i}{E_i}, \quad i = 1, 2, ..., N \qquad (19)$$

Table 3. Average annual riverine and swamp fishery data of South Sumatra, Indonesia, 1979 –1994.

	River			Swamp		
Fishing gear	Number of units	Number of Trips	Catch (tonnes)	Number of units	Number of Trips	Catch (tonnes)
Gillnets						
Drift gillnet	1,936	308,472	3,005			
Fixed gillnet	1,342	171,431	1,272	2,817	476,861	3,053
Cast nets						
Anco	680	69,674	324	374	48,181	218
Lift nets						
Serok	489	83,737	379	494	37,663	175
Hook and lines						
Rawai	655	69,431	217	324	33,739	167
Pancing	2,961	438,991	2,364	2,525	431,417	2,252
Filtering barrier						
Jermal	776	149,278	2,549			
Portable traps						
Sero	1,435	237,816	5,163	1,228	147,027	2,839
Bubu	2,931	446,464	2,598	3,349	488,598	2,666
Other gear	5,820	774,417	5,382	4,256	532,133	3,633

Let fishing gear *1* be chosen as the standard fishing unit in the inland fishery. Then the standardised fishing effort (E_S) can be calculated as:

$$E_S = E_1 + \sum_{j=2}^{N} \frac{CPUE_j}{CPUE_1} \cdot E_1 \tag{20}$$

The total catch is calculated by summing up total fish caught by the standard fishing unit and other fishing units:

$$Y_S = Y_1 + \sum_{j=2}^{N} Y_j \tag{21}$$

and the standard catch per unit effort is calculated from equations (20) and (21) as:

$$CPUE_S = \frac{Y_S}{E_S} \tag{22}$$

The values of Y_S, E_S and $CPUE_S$ for the period 1979 to 1994 are presented in Figure 2 in terms of *bubu* standardised units.

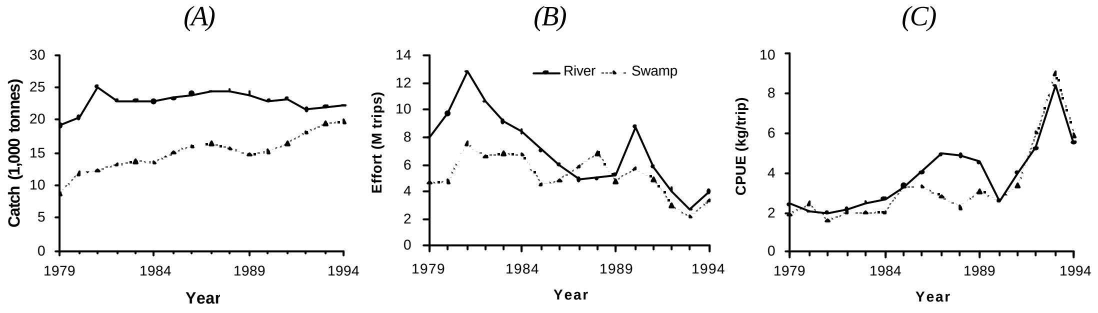

Figure 2. Standardised catch and fishing effort in terms of *bubu* portable trap in South Sumatra, 1979-1994.

Total river catch was relatively constant between 1979 and 1994, while swamp catch increased (Figure 2A). The data seems to indicate that both resources were capable of maintaining fishery production; but, this may not be the case, since there is evidence that harvested fish sizes are smaller than in previous years and some important species are reported to have disappeared.

The standardised fishing effort fluctuated between 1979 and 1994 and tended to decrease (Figure 2B). The largest fishing effort was in 1981; thereafter, effort decreased sharply in the riverine fishery and decreased slightly in the swamp fishery. The decreasing number of trips may be explained by fishers reducing their activity because of a poor fishing season. Another explanation for these decreases may be that recorded data on the inland fishery were changed to adjust to the national format (local and provincial level fishery officers 1994, pers. comm.).

Considering the technological efficiency of fishing units, catch per unit of effort has fluctuated and increased slightly (Figure 2C). This may indicate that efficiency of fishing units has increased over time, and may suggest sustainability of the resource is under threat.

The catch data in Figure 2 reflect aggregate freshwater fish instead of a single species of harvested fish. This is because data on particular species or even species groups are not available for the study site. Pauly (1979) and Pope (1979) have described such a problem in a mixed-species tropical fishery. They observed that when data were aggregated into major species groups, consistent trends in catch rate and yield became apparent. This was supported by Ralston and Polovina (1982) who based their studies on the multi-species tropical handline fishery in Hawaii. Similar procedures have been described by Hilborn and Walters (1992) where the dynamic interactions of mixed species were treated as aggregated fish stock and analysed using production models.

Cost of fishing effort

Operating costs reflect the method and intensity of fishing effort and the amount of capital invested in the study site. The fixed costs[1] are calculated in terms of the payment for leasing the resource and depreciation of both canoe/boat and gear used in the *bubu* fishing unit. The variable costs include the costs of bait and other accessories and actual labour costs. In this case, the actual labour costs reflect the opportunity cost of fishing in that region. All cost data were obtained through a cross-sectional survey undertaken by the senior author.

Most fishers have a small canoe or boat and operate various types of fishing unit which represent capital investment by the fishers. The capital investment is usually valued at acquisition cost but in cases where the assets are not new, as in the fishing units in the study site, replacement cost is used. Another investment cost is for leasing a particular fishing ground. The estimated average investment cost for 1994, in terms of standard fishing units, were Rp. 370,000 and Rp. 350,000 for river and swamp fisheries respectively (Table 4)

Table 4. Average investment costs of bubu portable traps in the inland fishery in South Sumatra, 1994.

Investment component	Cost by type of resource	
	River (rupiah)	Swamp (rupiah)
Canoe/boat	200,000	200,000
Fishing gear	120,000	120,000
Lease of resource	50,000	30,000

Source : Cross-sectional survey 1994.

The total costs of fishing effort for the standard fishing unit in South Sumatra were Rp.2,974 and Rp.2,631 in river and swamp fisheries respectively (Table 5).

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[1] Panayotou (1985) defines fixed costs as those incurred irrespective of whether fishers operate their fishing units or not. This is because the costs are considered ‘sunk’ capital investment costs which cannot be recouped at short notice without large losses.

Table 5. Calculated costs of fishing effort by bamboo fishing traps (bubu) in South Sumatra.

Costs	Cost by type of resource River (rupiah)	 Swamp (rupiah)
Fixed Costs		
Depreciation of canoe/boat	26.20	103.71
Depreciation of gear	1,184.21	936.00
Lease of resource	131.58	266.67
Variable Costs		
Operating costs (e.g. bait and accessories)	631.58	325.00
Labour	1,000.00	1,000.00
Total Cost (*TC*)	2,973.57	2,631.48

Source : Cross-sectional survey 1994.

Price of freshwater fish

Landing prices for freshwater fish were provided by survey respondents. Prices of harvested fish were mostly provided by small-buyers based on the ‘quality of fish’ and ‘species group’. However, the perception of fishers interviewed on the study sites was that fish prices are often decided on the basis of average prices and quality of harvested fish. The average actual prices of freshwater fish at the producer level were Rp. 1,215 per kilogram (riverine) and Rp. 1,125 per kilogram (swamp). The difference in prices between resources may indicate that the quality of harvested fish from the river is better than from the swamp.

RESULTS AND DISCUSSION

Model Parameters

The surplus production model implicitly assumes that there is no change in the environment and that the food supply is limited so that the unexploited fish stock increases towards the carrying capacity. In the inland capture fishery system, environmental change affects the food supply and hence the maximum fish stock changes. Also, the surplus production model assumes a constant catchability coefficient. Therefore, Sparre and Vanema (1992) recommend the use of short data series. In contrast, for better results in a statistical sense, longer series of data are desirable to have as many degrees of freedom as possible. An alternative is to use a time trend in the regression equation. Two sets of models were estimated through linear regression, the Schaefer model was defined as:

$$\frac{Y}{E} = a + b \cdot (1 + d \cdot D) \cdot E + g \cdot t \tag{23}$$

and the Fox model was defined as:

$$\ln\left(\frac{Y}{E}\right) = a + b \cdot (1 + d \cdot D) \cdot E + g \cdot t \qquad (24)$$

Where a and b represent the biological parameters, as defined in equation (8); d is a coefficient specific to the swamp fishery, D is a dummy variable that takes on a value of zero for the river and one for the swamp fishery; t is a linear time trend, and γ is the time-trend coefficient. By definition, *CPUE* is non-negative, it is expected to exhibit diminishing returns and to increase with improvements in technology; hence a and $g > 0$, and $b < 0$. Furthermore, it is expected that $d < 0$, indicating that diminishing returns to effort are more severe in the swamp areas, where fish are captive when floods recede.

Models (23) and (24) were estimated by linear regression with and without the time trend, results are presented in Table 6. All the estimated coefficients are highly significant and have the expected signs, the adjusted R^2 and F values indicate that fishing effort explains much of the variation in catch. In both models, inclusion of a time trend improved statistical performance. The values of g indicate that, during the period of the study, fishing technology has improved. However, further analysis will consider only the models with no time trend, because policy analysis based on surplus production models implicitly assumes that technological change does not occur.

Table 6. Regression results for selected supply model in South Sumatra, 1979-1994 (*t* values shown in parentheses).

	Model			
Parameter	Schaefer-1	Schaefer-2	Fox-1	Fox-2
a	6.06	8.32	1.76	2.39
	(6.51)	(16.27)	(12.14)	(24.70)
b	-4.59×10^{-7}	-6.29×10^{-7}	-1.13×10^{-7}	-1.59×10^{-7}
	(-5.21)	(-8.92)	(-8.19)	(-11.98)
d	-2.78×10^{-7}	-3.37×10^{-7}	-7.57×10^{-8}	-9.22×10^{-8}
	(-4.82)	(-5.68)	(-8.44)	(-8.21)
γ	0.12		3.47×10^{-2}	
	(2.80)		(4.97)	
Statistics:				
R^2 (adjusted)	0.8	0.75	0.92	0.85
F	42.09	47.99	117.23	89.94
DF	28	29	28	29

Estimation of the supply functions for the inland fishery, based on equation (14) and the parameters in Table 6 for the Schaefer model yield:

$$AC = \frac{5948}{8.32 + \sqrt{69.22 - 2.52 \times 10^{-6} \cdot Y}} \tag{river}$$

$$AC = \frac{5262}{8.32 + \sqrt{69.22 - 3.86 \times 10^{-6} \cdot Y}} \tag{swamp}$$

Gordon-Fox and Gordon-Schaefer models

Various critical points for the Gordon-Fox and Gordon-Schaefer models and the average actual capture during the period of study are presented in Table 7. The profit (or resource rent, p) for the critical point j is defined as:

$$p_j = TR_j - TC_j; \ j = MSY, MEY, MScY, BE, BES$$

where TR and TC are as defined in equations (11) and (12) and the critical points represented by j are defined in Figure 1 and the associated discussion. Results indicate that the inland capture fishery in South Sumatra has been over-fished from both biological and economic perspectives during the period of the study, since actual effort is beyond both *MEY* and *MSY* levels (Table 7).

Table 7. Calculated effort, catch, costs, revenues and profits of the inland fishery in South Sumatra Indonesia based on empirical model.

	Harvest condition					
Model/ Resource	MSY	MEY	MScY	BE	BESc	Actual (mean)
Schaefer/River						
Effort (1,000 trips)	6,711	4,696	5,374	10,748	9,392	7,217
Catch (Tonnes)	27,350	24,884	26,264	17,458	22,986	22,833
Cost (M Rp)	19,957	13,964	15,979	21,459	27,928	21,459
Revenue (M Rp)	33,231	30,234	31,911	21,459	27,928	27,743
Profit (M Rp)	13,274	16,270	15,931	0	0	6,283
Schaefer/Swamp						
Effort (1,000 trips)	4,407	4,281	4,329	7,246	6,285	5,415
Catch (Tonnes)	17,960	17,945	17,955	10,508	14,701	14,830
Cost (M Rp)	11,597	11,265	11,391	11,822	16,538	14,249
Revenue (M Rp)	20,205	20,189	20,199	11,822	16,538	16,684
Profit (M Rp)	8,608	8,924	8,808	0	0	2,435
Fox /River						
Effort (1,000 trips)	6,472	3,763	4,468	12,053	9,400	7,217
Catch (Tonnes)	24,900	22,002	23,427	19,578	23,005	22,833
Cost (M Rp)	19,246	11,190	13,285	23,788	27,951	21,459
Revenue (M Rp)	30,253	26,733	28,464	23,788	27,951	27,743
Profit (M Rp)	11,007	15,543	15,180	0	0	6,283
Fox /Swamp						
Effort (1,000 trips)	4,120	2,450	2,951	8,140	6,170	5,415
Catch (Tonnes)	15,851	14,137	15,078	11,805	14,433	14,830
Cost (M Rp)	10,843	6,447	7,765	13,280	16,237	14,249
Revenue (M Rp)	17,832	15,904	16,963	13,280	16,237	16,684
Profit (M Rp)	6,990	9,457	9,197	-	-	2,435

The Fox model indicates that the current level of fishing effort in the river (7.2 million trips) would have to be reduced by 48% in order to reach *MEY*, or by 10% to reach *MSY*. However, in terms of total catch, the differences are much smaller, with reduced effort resulting in reductions of 8% and 4% to reach *MSY* and *MEY* respectively. In contrast, to reach the bionomic equilibrium (9.4 million trips), would require an increase in fishing effort of about 30%, and this would result in a reduced catch (from 22,833 to 19,578 tonnes).

Profits at *MSY* and *MEY* are 11,007 and 15,543 million rupiah, respectively, whereas actual profits are only 6,283 million rupiah. This means that additional profits of 4,723 million rupiah (at *MSY*) or 9,259 million rupiah (at *MEY*), could be obtained from the fishery, provided prices remain stable.

The swamp fishery follows the same patter as the riverine fishery (Table 7). The actual fishing effort would need to be reduced by 55% to reach *MEY* and by 24% to reach *MSY*. Whereas to reach *BE* effort would need to increase by 14%. Resource rent in the swamp is 2,434 million rupiah under actual effort, and this could be increased by 4,555 million rupiah (at *MSY*) or 7,022 million rupiah (at *MEY*).

Although *MEY* produces the highest resource rent, the required reduction in fishing effort implies that some fishers may be forced out of fishing, and hence it is not popular or commonly applied to small-scale fisheries in Indonesia. Policy action in the small-scale fishery, may instead be directed to maximising social yield (*MScY*) as explained before.

Under social optimisation (*MScY*), the fishing effort would also have to decrease relative to the actual situation, but not by as much as with *MEY*. Using the Fox model for the riverine fishery, the estimated effort under *MScY* (4.47 million trips), is 19% higher than under *MEY* (3.76 million trips).

The optimal solutions derived from the Schaefer and Fox models are similar. However, fishing efforts in the Schaefer model are higher than in the Fox model. In the riverine fishery, the Schaefer model yields values of E_{MScY} (5.37 million trips) that are 20% higher than in the Fox model. In the swamp fishery, the Schaefer model yields values of E_{MScY} (4.33 million trips) that are 46% higher than in the Fox model. The implication of these results is that biologists would prefer to use the Fox model, as it seems to be more conservative.

Sensitivity Analysis

The empirical results discussed above are based on statistical analysis of historical data, without information on whether the system was in equilibrium. The biological parameters (r, K and q) in equation (7) can be derived from a and b estimates (see Table 6) using the integral method described by Fox ((1970, p. 82-83; 1975, p. 26-27). The results were treated as the base-case (Table 8) and sensitivity analysis was conducted, as described in this section.

Table 8. Description and values of model parameters and variables based on the Copes model. The subscript *i* denotes the type of resource,1 = *river*, 2 = *swamp*.

Parameter	Definition	Resource	
		River	Swamp
r_i	Intrinsic growth rate	1.397	2.861
q_i	Catchability coefficient	1.058×1	3.325×1
K_i	Carrying capacity	78.62×10	25.01×10
X_i	Biomass (kg)	23.14×10	7.03×10
E_i	Effort (day trip)	9.32×10	6.18×10
Y_i	Catch (kg)	22.82×10	14.46×10
p_i	Price of fish (Rp)	1,215	1,125
c_i	Cost of fishing effort (Rp)	2,974	2,631

Sensitivity analysis was conducted by assuming changes in biological parameters. Results of the sensitivity analyses were expressed as changes in total catch and fish stock compared to the base-case model. Six scenarios were considered by assuming: (1) changes in each biological parameter, and (2) combined changes in parameters, as described in Table 9.

Table 9. Results of sensitivity analysis of biological parameters in terms of percent change in stock size and total catch under bionomic equilibrium (Copes model).

Scenario	Parameter change (%)	Biomass (*X*) change (%)		Catch (*Y*) change (%)	
		River	Swamp	River	Swamp
1: Low growth rate	*r*–5	-21.1	-21.9	-21.1	-13.4
2: Low carrying capacity	*K*–5	-5.0	-5.0	-5.0	-5.0
3: High catchability	*q*+5	-12.0	-12.8	-7.6	-8.4
4: Mixed 1 and 3	*r*–5, *q*+5	-25.2	-77.8	-30.1	-52.0
5: Mixed 2 and 3	*K*–5, *q*+5	-16.4	-74.8	-13.4	-45.6
6: All	*r*–5, *K*–5, *q*+5	-29.0	-78.9	-33.6	-54.4

In general, the equilibrium levels of stock size and catch were very sensitive to small changes in biological parameter values. Results were most sensitive to the intrinsic growth rate (*r*), followed by the catchability coefficient (*q*) and finally by carrying capacity (*K*). A reduction of 5% in the base value of r_i resulted in reductions in equilibrium biomass of 21% and 22% in the river and swamp respectively; with corresponding decreases in catch of 21% and 13% (Table 9). Changes in K_i caused proportional changes in stock size and total catch in the same direction (5%). The impact of changes in q_i in the swamp fishery was relatively higher than in the riverine fishery. This implies that the effect of increasing the efficiency of fishing gear would be more destructive to fish stocks in the swamp than in the river.

The effects of simultaneous changes in r_i and q_i (case 4) were considerably higher in the swamp fishery than in the riverine fishery. In the swamp fishery, total catch in the long run was reduced by 52%, and equilibrium biomass decreased by 78%; while in the riverine fishery these changes resulted in a reduction in total catch of 30% and a reduction in biomass of 25%. Similar patterns were obtained with the combination of changes in K_i and q_i (case 5). The effect of all biological parameters changing simultaneously (case 6) resulted in the largest changes in catch and stock (34% and 29% in the river and 54% and 79% in the swamp).

Figure 3 shows the adjustment paths for selected changes in parameter values. The biological equilibrium is attained when catch is equal to surplus growth and then remains in steady state. For any change in parameter values, the swamp fishery requires relatively shorter time periods to reach equilibrium (between 5 and 9 years, Figure 3B) than the riverine fishery (between 9 and 17 years, Figure 3A). This may be explained by the characteristics of the fishery resources. The depth of water in the swamp is highly variable, it is low or dry in the dry season, whereas the river contains water throughout the year. This results in a relatively more concentrated fish stock in the swamp during low water. In addition, fish stock recover more readily from intense low-water exploitation during the high water season, when fishing efficiency is low due to dispersion of fish in newly inundated areas. By contrast, in the riverine resource the fish stock is relatively stable since there is water throughout the year.

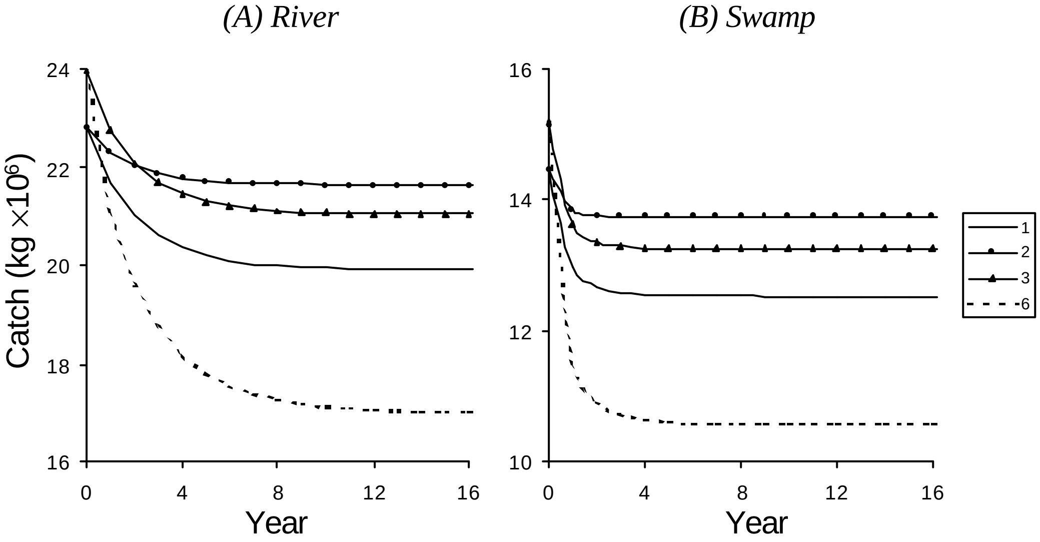

Figure 3. Adjustment trajectory caused by changes in biological parameters, selected cases (see Table 9 for details of scenarios 1-6).

These results indicate that the estimates of stock size and potential catch are relatively sensitive to estimates of biological parameters, and underline the importance of measuring these parameters as precisely as possible for management purposes.

Concluding Remarks

The tropical inland fishery of South Sumatra is very complex, comprising many small-scale fishers, multiple fish species and many types of fishing gear. This complexity is not captured in the statistical data. Because of this problem, simplification of the inland fishery system was carried out by deriving a supply function for the fishery using primary and secondary data. Ten types of fishing gear were standardised into a single fishing unit, and mixed species of harvested fish were treated as an aggregate fish stock.

Results indicate that the South Sumatra inland fishery during the period of the study was over-fished both biologically and economically. A social factor representing the opportunity cost of fishing was included in the bioeconomic model so that the objective of the fishery became maximisation of social yield. Given this objective, the required reduction in average fishing effort to achieve optimal resource allocation was less than with the standard bioeconomic model.

Sensitivity analysis indicated that results were most sensitive to the intrinsic growth rate (r), followed by the catchability coefficient (q) and carrying capacity (K). Policy analysis using this model is the subject of the second paper in this series.

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