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Economic Loss of Pollution to Fisheries: An Economic Analysis of the Jakarta Bay Fisheries

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Introduction

Coastal resources play an important role in the economic development of coastal states. Besides providing goods and services worth more than US$10 trillion a year, coastal resources also provide direct employment for more than 200 million small-scale and commercial fishermen. In addition, more than half a billion of people rely their livelihood indirectly on coastal related activities (Hinrichsen 2002). For example, in Asia alone, of 3.7 billion of total Asia's population, 60% of them live within 400 km of coastal area and engages in coastal dependent activities such as fishing, harvesting, and mining. Consequently, coastal resources have been under tremendous pressure due to rapid economic development. According to a study by World Resource Institute, over one-half of the world's coastlines have suffered from severe development pressure (Fauzi and Anna 2002; Fauzi and Anna 2003).

The pressures on coastal resources are also amplified by economic externalities such as pollution which flows through the river runoff to the coastal areas. It is not doubt that pollution has contributed significantly to the falling catches of the coastal fishing. There are number of cases of externalities which involve environmental degradation for coastal resources. For example, wastes, or even toxic wastes, dumped by households or industries located on the watershed area, may enter into water (or river) causing pollution to the coastal waters once valued for fishing and water recreation. Examples from coastal waters from developing countries reveal how badly pollution problems in coastal areas. Hinrichsen (2002), for example, noted that in Chile, the Bays of Valparaiso and Concepcion receive a combined of total of 244 million metric tons of untreated effluents a year. Worst yet, in India, the cities of Calcutta and Bombay, dump more than 400 million metric tons of raw sewage and 365 million metric tons of other municipal wastes into coastal waters every year causing a huge economic loss to society.

Much analysis of the externalities such as pollution has been focused on the ecosystem in general as well as the environmental effects associated with it. Several analyses, however, have been attempted to study the the effect of

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pollution on fishing activities. Collins et al. (1998), for example, have modeled the fishery–pollution interaction using a bioeconomic model by incorporation pollution variable as the driver for stock contamination and its effect on effort displacement. Grigalunas et al. (1988) and Grigalunas et al. (2001) have modeled the fishery–pollution interaction by assuming that pollution will cause economic loss to the fishery through a decline in fishing mortality. Using a slightly different bioeconomic approach, this paper develops a fishery–pollution interaction by embedding pollution variable into fishery production function and analyze its effect on the economic loss to the fishing industry.

The Model

To construct the bioeconomic model of fishery-pollution interaction, it is worth considering the specific functional form of biomass growth function as well as the harvest function. Let the biomass growth function be represented by the Gompertz function,

$$F(x) = rx\ln(K/x)$$

where r is the intrinsic growth rate and k is the environmental carryng capacity. Let the harvest function be given by the following Cobb-Douglass type production function:

$$h = qxE$$

where q is catchability coefficient and E is level of effort exerted to fishery. Now suppose, the pollution variable affects directly into the biomass production function, then the dynamic of the biomass can be written as:

$$\chi = \left(rx\ln(K/x) - \gamma P\right) - qxE$$

where is P pollution variable and g is a constant coefficient. The estimation of biological parameters as well as pollution parameter can be carried out by transforming equation (1.3),

$$x_{t+1} - x_t = rx_t \ln(K/x_t) - \gamma P_t - qx_t E_t$$

By introducing variable catch per unit effort (CPUE) at time t as $U_t = h_t / E_t$, using algebraic simplification, equation (1).4) can now be modified as:

$$U_{t+1} - U_t = rU_t \ln Kq - \\ rU_t \ln U_t - q\gamma P_t - qU_t E_t$$

Parameters r, q, k, and γ can then be estimated using ordinary least square (OLS) technique from time series data of CPUE, pollution load and effort level. For the purpose of this study, sixteen years of time series data of catch and effort of demersal fishery as well as the data of pollution load were gathered. The pollution load is defined as total load of COD, BOD, and TSS collected from the Jakarta Environmental Impact Agency. The load is an aggregate measure of pollution discharge from 13 rivers runoff.

To calculate the economic loss due to pollution, let assume that the economic rent generated from the fishery without pollution variable is in the form of $\pi(h_t, E_t)$, while that with pollution variable is defined as $\pi(h_t, E_t, P_t)$. The economic loss to the fishery due to pollution is then defined as the difference between these two (i.e., L = $\pi(h_t, E_t, P_t) - \pi(h_t, E_t)$), where L denotes economic loss.

Economic loss was also approximated by calculating the loss in producer's surplus. This welfare effect is an important indicator to determine how the economic loss due to pollution affects the producers (i.e. the fishermen). The measurement of consumer's surplus was derived using backward bending supply curve and perfectly elastic demand curve. The formula for consumer's surplus is described as the following equation:

$$PS = P_0\, h_0 - \left(\frac{1}{2} \frac{c\alpha \ln(h)}{\beta} + \frac{c\sqrt{-4\beta h + \alpha^2}}{\beta} \right) \Bigg|_0^{h_0} + \left. \frac{\frac{1}{2} c\alpha \ln(\alpha - 4\beta h + \alpha^2)}{\beta} \right|_0^{h_0} \Bigg|$$

$$- \left. \frac{1}{2} \frac{c\alpha \ln(\alpha + \sqrt{-4\beta h + \alpha^2}}{\beta} \right|_0^{h_0}$$

where parameters α and β are constant coefficients of yield effort curve by solving simultaneously equation (1).1) and equation (1).2) under steady state condition. By employing time series data of catch and effort these parameters can simply be derived using OLS technique. Parameter P and c represent price per kg of fish and cost per unit of effort, respectively. Parameter h represents average landing from the fishery under pollution scenario, while h_0 represents landing under untainted scenario. Data for these landings were obtained from adjacent landing sites with and without polluted waters.

Case Study: The Jakarta Bay Fishery

The Jakarta Bay, located in the north coast of Indonesia capital, Jakarta, has been an important area for both fishing as well as nonfishing activities. The bay is also well known for its high pollution discharge emanating from various river run-off (Anna 1999).

In terms of fishing activities, the Jakarta Bay serves as fishing ground for small-scale fishermen. Since the area is relatively narrow, only some particular fishing gears operate in the area. These include, stationary liftnet, gillnet, traps and hook and line. Some mollusk fishermen also operate along the estuarine area. Besides being fishing area, the Jakarta Bay also serves as the gate for shipping and marine transportation to and from the busiest fishing port in the capital city namely Tanjung Priok Port. Other fishing gears such as liftnet (know as *bagan* to local fishermen) and traps (*bubu*) are often being accused of obstructing the transportation activities around the Bay.

The fishery production in the Jakarta Bay was primarily dominated by demersal fish cought by gears described above. The demersal landing accounts for more than 50% of the total landing of the Jakarta area. The demersal fish such as groupers and red snapper are considered as highly economic fish in the market. The prices of these fish are substantially higher than the average pelagic fish. It is not surprising, therefore some fishermen often use destructive fishing practice such as cyanide and bombing, which have caused damage to almost 80% of the coral reefs in the Bay and along the Seribu Island.

Results from analysis can be seen from Table 1 through Table 4. As can be seen from Table 1, pollution has significantly reduced the present value of economic rent that could have been generated from the fishery. This can be seen from the negative number of resource rent generated under pollution scenario. On average, more than Rp 2.5 billion rupiah (approximately U.S.$ 3 million) of the present value of resource rent has lost due to the pollution. This is a significant loss for small-scale fishery such as the Jakarta Bay fishery.

The economic loss could also be viewed from the loss in economic surplus that could have been secured from the fishery. As can be seen from Table 2, an average of Rp 310.92 million per year would loss because of pollution. This Figure is considerably significant for the mostly traditional fishermen of the Jakarta Bay whose income from fishing is relatively low.

Table 3, Table 4, and Figure 1 provide a general overview and summary of total net benefits obtained under the baseline and pollution scenarios. The combined yearly total economic loss to the fishery due to pollution is approximately Rp 700 million rupiah (or US$80,000). It is important to note, how-

Table 1. Yield and present value of rent under baseline and pollution scenario.

Year	SYB (mt)	SYP (mt)	PVRbase (Rp million)	PVRP (Rp million)
1986	77.8	71.65	1251.88	1042.06
1987	91.98	67.88	1526.22	630.4
1988	38.47	59.29	786.48	1594.86
1989	39.91	60.49	858.64	1701.69
1990	82.54	70.77	1745.24	1208.62
1991	49.82	66.99	1285.61	2149.39
1992	52.72	68.36	1424.3	2254.41
1993	98.52	65.08	2498.11	540.52
1994	110.87	58.31	2905.38	-495.32
1995	139.07	37.87	3109.41	-4063.81
1996	118.51	53.32	3467.87	-1488.44
1997	39.67	60.29	2763.8	5499.08
1998	53.3	68.61	3656.12	5722.46
1999	115.7	55.22	6760.68	-2242.79
2000	102.67	63	7230.3	645.84
2001	124.68	48.95	8465.28	-5554.33

Note: SYB=Sustainable Yield baseline, SYP=Sustainable Yield with Pollution, PVRbase=Present value rent baseline, PVRP=Present value rent with pollution.

Table 2. Change in producer's surplus due to pollution.

Year	Producer's Surplus *baseline* (Rp million)	Producer's Surplus Pollution (Rp million)	Δ SP (Rp million)
1986	386.285	364.031	22.254
1987	492.73	376.343	116.387
1988	220.133	342.198	-122.065
1989	241.553	369.121	-127.568
1990	546.477	480.666	65.811
1991	370.074	502.376	-132.302
1992	412.31	540.27	-127.96
1993	823.856	567.509	256.347
1994	1005.215	561.849	443.366
1995	1263.005	397.853	865.152
1996	1240.808	602.698	638.11
1997	776.56	1190.01	-413.45
1998	1060.35	1379.363	-319.013
1999	2388.563	1222.899	1165.664
2000	2419.975	1557.172	862.803
2001	3127.719	1346.458	1781.261

Table 3. Comparison of total benefit between the baseline and pollution scenario.

	Baseline (Rp million)			Pollution (Rp million)			ΔTB
	FR	PS	T B	FR	PS	TB	(Rp million)
Year							
1986	187.78	386.29	574.07	156.31	364.031	520.34	-53.73
1987	228.93	492.73	721.66	94.56	376.343	470.9	-250.76
1988	117.97	220.13	338.1	239.23	342.198	581.43	243.32
1989	128.8	241.55	370.35	255.25	369.121	624.38	254.03
1990	261.79	546.48	808.26	181.29	480.666	661.96	-146.3
1991	192.84	370.07	562.92	322.41	502.376	824.78	261.87
1992	213.64	412.31	625.95	338.16	540.27	878.43	252.48
1993	374.72	823.86	1198.57	81.08	567.509	648.59	-549.99
1994	435.81	1005.22	1441.02	-74.3	561.849	487.55	-953.47
1995	466.41	1263.01	1729.42	-609.57	397.853	-211.72	-1941.13
1996	520.18	1240.81	1760.99	-223.27	602.698	379.43	-1381.56
1997	414.57	776.56	1191.13	824.86	1190.01	2014.87	823.74
1998	548.42	1060.35	1608.77	858.37	1379.363	2237.73	628.96
1999	1014.1	2388.56	3402.67	-336.42	1222.899	886.48	-2516.18

Note: FR=fishery rent, PS= Producer's Surplus, TB=Total Benefit

Table 4. Summary of some important indicators.

Variable	δ=6.2%	δ=15%	Δ=0	δ=6.2%	δ=15%	δ=0	δ=6.2%	δ=15%	δ=0
Sustainable Yield (Hs) (mt)	77.38	77.38		60.30	60.30		-22.07	-22.07	
Optimal Effort (E*) (000 days)	2.57	3.09		4.72	6.00		83.66	94.17	
Optimum Biomass (X*) (mt)	412.25	324.55		217.25	155.38		-47.30	-52.12	
Optimal Yield (h*) (mt)	176.74	167.63		70.42	64.02		-57.99	-63.78	
Sustanable rent (ð)	466.27	466.27		85.73	85.73		-81.61	-81.61	
Optimal Rent (ð*) (Rp million)	2216.00	2101.89		882.57	802.18		-60.17	-61.84	
Depreciated *rent* (Rp million)	529.08	1280.03		3234.38	337.50		511.32	4.49	
Producer's Surplus (PS)			1048.48			737.55			-29.66
Total Benefit (TB) (Rp million)			1514.74			823.28			-45.65
Degradation rate (Θ) (%)			18.00			21.00			16.67

ever, that this figure is applicable to the demersal fishery only with two dominant fishing gears. Extrapolating to the fishery of the bay as a whole, the economic loss could have been very much higher than that the number above. As can be seen from Table 4, overall, pollution has caused a significant reduction in the optimum harvest level and some monetary indicators such rent and producer's surplus. The optimum level of harvest or yield is calculated using standard bioeconomic model described in Clark (1990). This reduction in economic surpluses could be attributed to the resource degradation, which is as much as 21% per year due to pollution.

Conclusion

Studies on the economic analysis on the interaction between fishery and pollution are indeed a complex and difficult exercise. Complexity of fishery system and its interaction with environment make the modeling of fishery–pollution interaction a challenging one. Few have attempted such a modeling due to these complexities. This paper, however, offers a simplified modeling of fishery-pollution interaction by imbedding the pollution variable into a standard bioeconomic model of the fishery. By doing this, the model offers an alternative way of analyzing the economic impacts of pollution to the fishery which have long been neglected. In terms of the case study in the Jakarta Bay area, the economic loss due to pollution is quite significant. The total economic loss in terms of net benefit deriving from the loss in resource rent and producer's surplus is approximately Rp 700 million per year. An integrated fishery policy through what so-called Envo-Fishery should be encouraged. That is, pollution control in the Bay should take into account its impact on the

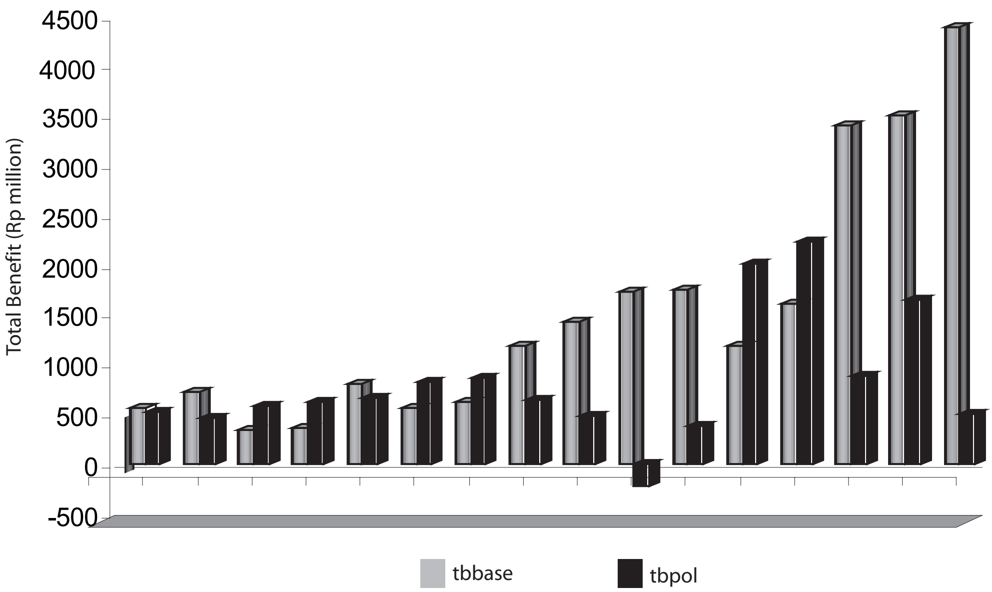

Figure 1. Yearly benefits accrued under baseline scenario and pollution scenario.

fishery in the area, not only in terms of its biological dimension but also in terms of its economic consequences. The study also reveals that due to excessive production and input level in the fishery, there seems no room for further expansion of effort for the demersal fishery in the area. Therefore, management of input and output in the fishery should be directed into efficiency of the industry, through for example, a combination fiscal and environmental policies. Finally, even though this study had attempted to incorporate all possible models with regards to analysis of fishery–pollution interaction, there might be some other things which could have been overlooked, such as incorporating stochastic process in the model. Further study to incorporate such a process, therefore, is strongly encouraged.

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