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The Value of Mangroves to an Off-Shore Fishery: The Case of Bandon Bay, Thailand

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Abstract

This paper models the impact of change in land-use of off-shore fishery production. A dynamic ecological-economic model is developed which examines the impact of mangrove reforestation on fish stock and offshore fisheries using nutrient status and biological productivity. The simulation results are illustrated using data from Bandon Bay, Thailand. The effects differ depending on regulations in the fishery sector. Under open-access conditions, an additional 1 km^2 of mangrove leads to an increase in fishery production, as well as total revenue and cost by almost 8% (equivalent to around 5 million baht/year or $130,000/year). Under monopoly conditions, an additional 1 km^2 of mangrove results in an increase in fishery production by around 5%. The profit increases by 4.36%, or around 1 million baht ($25,000/year). The discounted profit over 50 years increases to approximately 20 million baht ($615,000). The effects of the change in fishery regulation (open-access vs. monopoly) are also discussed. Changing regulatory regimes from open-access to monopoly increases the stock of fish in the area, from 7,226 tons to 10,230 tons. Net revenue increases to 20.2 million baht/year in long-run (almost $580,000). Discounted profit over 50 years is calculated to be more than 504 million baht ($14.4 million).

Keywords: Mangroves, Off-shore Fishery, Valuation Technique, Externalities, Regulation

1. Introduction

Mangroves are plants that grow in the tidal area between fresh water and seawater. Mangrove ecosystems have been widely recognized as a crucial system in most wetland ecosystems, especially in tropical areas. It provides several functions for both ecological and human usage. Major ecological benefits include coastal protection, control of soil erosion and a nursery ground for aquatic life. Despite its importance, mangroves in Thailand have been rapidly depleted. The major cause of mangrove depletion is the conversion of mangrove area into intensive shrimp farms. In 1961, the mangrove area in Thailand was approximately 3,679 km^2. This number has decreased by more than half in 30 years (to 1,763 km^2 in 1991). In 1996, there were only 1,675 km^2 of mangrove area remaining. However, awareness of the importance of mangrove ecosystems has increased in recent times and there are active movements to replant mangroves in many areas along the coastline. As a result, the total mangrove area has expanded over the last ten years. The current mangrove area in Thailand is approximately 2,700 km^2. (Royal Forest Department, 2006)

The policy failure in promoting intensive shrimp farming leads to an extensive clearance of mangrove in many areas. This can be explained by the fact that most of the mangrove areas are common property, and that the benefits of mangroves are external. As previously mentioned, the ecological benefits of mangroves, including coastal protection, control of soil erosion, nutrient recycling and a nursery ground for aquatic life, are often externalized to the area outside the mangrove. As a result, these massive external benefits are likely to be ignored when a decision is taken to convert mangroves to other uses. Failing to recognize the external benefits of mangroves results in a policy error and overexploitation of the mangroves. In order to manage a resource optimally, policy makers must have adequate information on the external benefits and costs of the resource. This paper uses dynamic stock-to-stock model to valuate the external benefits of mangroves to an offshore fishery in the Southern part of Thailand.

In the literature, many attempts have been made to address the economic benefit of mangroves. Reviews of mangrove valuations can be found in Spaninks and van Beukering (1997), and Spurgeon (1998). However, most of these studies consider the value of mangrove derived from its direct uses, for example, timber use and other products, charcoal production, and on-site fishery production, ignoring its massive off-site benefits. Spaninks and van Beukering (1997) identify various mangrove functions and methods in order to assess their economic values, and find that *"most studies limit valuation to use values: the availability of market prices or market prices for substitutes means that the valuation of use values is relatively easy."* It is also pointed out in the paper that, *"in most cases, valuation of the impacts of a management alternative on catches in off-site fisheries is based on somewhat arbitrary assumptions, rather than on detailed scientific information."*

For Thailand, Sathirathai (1998) estimates the economic value of mangroves in a village in the southern part of Thailand. The annual economic value of mangroves is estimated to be in the range of 8-10 million baht per km^2 ($210,000-260,000 million per km^2).[1] The off-site fishery benefit of mangroves is also estimated by applying the Ellis-Fisher-Freeman (EFF) model depending on the assumed demand elasticity and cost function. The off-site fishery benefit under open-access is calculated to be around 2.2 million baht per km^2 (around $58,000 per km^2). Barbier (2000) compares costs and benefits of mangrove restoration in Thailand. He estimates that the economic loss of fisheries in the Gulf of Thailand due to the removal of 192 km^2 (1200 ha) of mangrove is around $100,000 per year (or 19,791 baht per km^2 annually). A research team from Chulalongkorn University calculated the value of nutrient (carbon) input for oyster production, and estimated the total loss of value added from mangrove conversion to shrimp farm in the Bandon Area to be around 569 million baht (or 7 million baht per km^2) (Talaue-McManus et al., 2001). However, all of the above studies are static and are not integrated into a single quantitatively defined model. So, the results are partial equilibrium and do not consider the dynamic aspect of the benefits of mangrove off-site.

Aniya (2002), and Tingsabadh and Pongkijvorasin (2004) develop a simple dynamic model to estimate on and off-site values. The former emphasizes the importance of fishery regulation on the valuation of mangroves. However, the parameters used in the paper are arbitrary and are not drawn from scientific analysis. Furthermore, there are no specific mathematical expressions given for the derivation. Tingsabadh and Pongkijvoraisn (2004) focus more on modeling the ecological linkage between mangroves, nutrient and fish productivity in the area under open-access regulation.

In the following section, a dynamic "stock-to-stock" model (where a stock of mangrove determines a stock of fish) examining the impact of mangrove reforestation on the fish stock and offshore fishery using nutrient status and biological productivity as indicators is built. The details of study site and relevant data are listed in section 3. A simulation of the model valuating the benefits of mangroves to the off-shore fishery is performed. Section 4 presents the results from the simulation. Mangroves' values under different fishery regulation are also compared and discussed. The conclusions are in section 5.

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[1] The exchange rate of 38 baht/US$1 is applied in this paper

2. The Model

This paper models the benefits of mangroves to the off-shore fishery through the nutrient cycle. The model can be divided into three parts: nutrient discharge, fish production, and the fishery sector of the economy.

2.1 Nutrient Discharge

The ecological-economic model employed in this paper is based on de Kok (1998) which models the relationship between economy and ecology in the form of flows of materials between two systems. On one hand, the economy takes nutrients from the ecosystem as an input in order to produce goods. On the other hand, the economy discharges nutrients through waste disposal into the ecosystem. Then the value of nutrient in the bay can be estimated from the value of the good produced. In this paper, I model this nutrient link using carbon as a proxy. Land use changes are sources of nutrient discharges from economy to ecosystem. This includes the pattern of land use (mangrove, shrimp farm) and other economic activities. The nutrient uptake is represented in the relationship between nutrient and fish stock in the bay. Thus, this paper uses the value of fish as a proxy for the value of carbon.

The source of carbon discharges are divided into three parts: mangrove, shrimp farm, and other economic activities. Total carbon discharge in the area can be calculated by:

$$CAR_t = a_1 MA_t + a_2 SA_t + a_3 BOD_t \tag{1}$$

where CAR_t is the total carbon emission in time t

MA_t is the mangrove area in time t

SA_t is the shrimp farm area in time t

BOD_t is the Biological Oxygen Demand (BOD) loading from wastewater discharge from economic activities at time t

a_i is the conversion rate of activity i

The dynamics of fish population is explained in the model. Growth function of fish in the sea is assumed to be:

$$g = rF\,(1\text{-}F / Fcc) + b(CAR - CAR_0) \tag{2}$$

where F is the stock of fish and

Fcc represents the carrying capacity of fish.

r is the intrinsic growth rate

b is the ratio of carbon in marine animal

CAR_0 is the carbon stock in the baseline case

From equation (2), the growth of fish can be divided into two parts. The first part is the usual natural growth rate of fish, which depends on the intrinsic growth rate, stock of fish, and the carrying capacity. The second part represents growth relating to the nutrient (carbon) content of the area. The carbon stock is viewed as a supportive factor and is converted to be a part of fish biomass through the food chain. The carrying capacity is assumed to be constant.

2.2 Fishery Sector

Fish catch is assumed to be a function of effort and the total fish biomass. The Cobb-Douglas function is used to explain the relationship in this case.

$$C = e * E^{0.5} * F^{0.5} \quad (3)$$

where C is catch

E is effort (for example, days or hours used in fishing)

e is a parameter

Total revenue generating from the fishery production is explained by

$$TR = p * C \quad (4)$$

where TR is the total revenue

p is the price of the fish

Total cost of fishery production is equal to

$$TC = c * E \quad (5)$$

where TC is the total cost

c is the unit cost of effort

3. Study Site and Data

The Bandon Bay area of Suratthani province lies to the west of the Gulf of Thailand. The area receives the inflow of freshwater from the Tapi River. It is one of the most productive coastal areas in Southern Thailand. The estuary area is fringed with mangrove forest, which has been reduced by conversion to shrimp farming and urban development. Mangrove coverage in Suratthani province was decreased extensively during 1986-1991 (from 43.36 km^2 to 22.30 km^2), and has been recovering since then (31.71 km^2 in 1996, and 34.89 km^2 in 2000). At the same time, total area in shrimp farms in Suratthani province increased from 37.40 km^2 in 1986 to 96.42 km^2 in 1992. This area has decreased since then. In 1996, the total area of shrimp farm in Suratthani province was around 69.46 km^2. On the Bandon Bay coastline, the mangroves area decreased from 23.32 in 1993 to 17 km^2 in 1998, while the total shrimp farm area increased from 64.56 km^2 in 1993 to 80.88 km^2 in 1998 (Talaue-McManus et al., 2001).

As estimated in Talaue-McManus et al. (2001), the total emissions of BOD from economic activities in the Bandon Bay area is 6,260 ton/year, which results in total carbon emissions from BOD equal to 10,642 tonC/year. Mangrove input of organic carbon per km^2 is estimated to be 1,118 tonC/km^2/year (Wattayakorn et al., 1990, cited in Talaue-McManus et al., 2001). The total carbon from shrimp farms discharged into Bandon Bay is estimated to be 3,189.91 tonC/year (Talaue-McManus et al., 2001). With 80.88 km^2 of shrimp farms in the area, the emission rate of carbon from shrimp farms is equal to 39.44 tonC/km^2/year.

According to the biological study component, Talaue-McManus et al. estimates that the conversion from primary production to fishery production in the bay area occurs at the rate of 0.84%. Marine animal carbon content is assumed to be 5%. This implies that 1 kg of carbon can contribute to (1/0.05)(0.0084) = 0.168 kg of marine life.

In this paper, the intrinsic growth rate of fish is assumed to be 0.5. Thus, the growth function of fish biomass can be presented by: $g = 0.5F(1\text{-}F/Fcc) + 0.168\,(CAR\text{-}CAR_0)$. In 1993, the price of fish was 37.81 baht/kg. The amount of fish harvest was 1,545 tons per year (Sathirathai, 1998). The unit cost of fishing effort (pushnet boat) was estimated to be 400 baht per effort (fishing day) (FAO, 2001). The catch function is assumed to be $C = 1.5E^{0.5}\, F^{0.5}$. From these data and parameters, and assuming that the existing conditions are in equilibrium, under the open-access fishery (zero profit), the existing fish stock and fish carrying capacity is calculated to be 7,266 tons and 12,643 tons, respectively (these number correspond to the actual catch occurred in the bay). The discount rate used in this paper is 3%.

4. Results

The objective of this paper is to model the effect of a change in land use (an increase in mangrove area) on the off-site fishery production. The simulations are done under both open-access and managed (monopoly) conditions in the fishery sector. In this section, four scenarios are compared. The first scenario (A) is the baseline case, which assumes that the fishery sector operates under open-access conditions, and that the existing conditions (as explained in section 3) are at equilibrium. The second scenario (B) simulates the model given that there is a 1 km^2 increase in mangrove area, again, under open-access fishery production. The third scenario (C) investigates the effects of a change in fishery regulations, from open-access to monopoly. The model is run such that the discounted net profit over 50 years is maximized. The last scenario (D) shows the effects of an increase in mangrove area under the monopoly assumption.

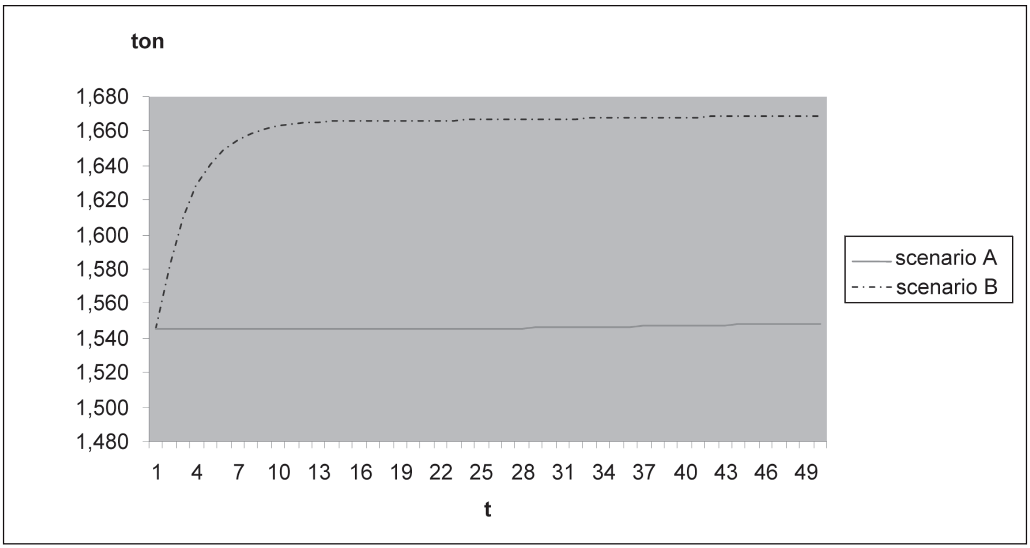
4.1 Baseline Case (A)

Under the baseline scenario, where there are approximately 17 km^2 and 80.88 km^2 of mangrove and shrimp farm respectively, total carbon discharge in the bay area is estimated to be 32,837.91 tonC. According to the parameters explained in the earlier section, and assuming that the fish is harvested in an open-access manner (zero profit) and that the system is originally at equilibrium, the initial level of fish stock is 7,266 tons. The carrying capacity of the fish is computed to be 12,643.88 tons. The natural growth of fish and catch are equal (1,545 tons). This level of catch is comparable to the real catch occurred in the area. The profit is zero.

4.2 Mangrove +1 km^2, Under Open-access (B)

This scenario assumes that there is a 1 km^2 increase in total mangrove area. The additional mangrove area helps trapping and releases the nutrients from the rivers. In this case, the carbon discharged in the area increases by 1,118 tonC/year. This results in a 190-ton additional growth of fish annually (1118 tonC * 0.17 ton/tonC). As a result, the catch jumps from 1,545 tons to 1,583 tons in the first year, and reaches a steady state at 1,669 tons (see Figure 1). The revenue increases from 58 million baht to around 63 million baht, or 5 million baht per year. This is equivalent to an increase by approximately 7.8% of catch and total revenue. However, because the fishery sector is assumed to be open-access, the profit is zero for each year.

Figure 1 The Comparison Between Amounts of Fish Harvested Under Open Access



4.3 Monopoly Case (C)

This scenario assumes that fish is harvested in order to maximize discounted net profit over time. Given existing data and parameters, in order to optimize the profit from fishery, catch in the first year must be at 648 tons, and gradually increases to around 957 tons in a steady state (Figure 2). The stock of fish in the area increases from 7,226 tons to 10,230 tons. Total revenue at the steady state is approximately 36 million baht. Although the revenue is lower than the case of open-access (A), the cost of fishery decreases dramatically to around 16 million baht. Net revenue increases from 14 million baht in the first year to around 20.2 million baht in the long-term (Figure 3). The discounted net benefit over 50 years is calculated to be more than 504 million baht.

Figure 2 The Comparison Between Amounts of Fish Harvested Under Open Access and Monopoly

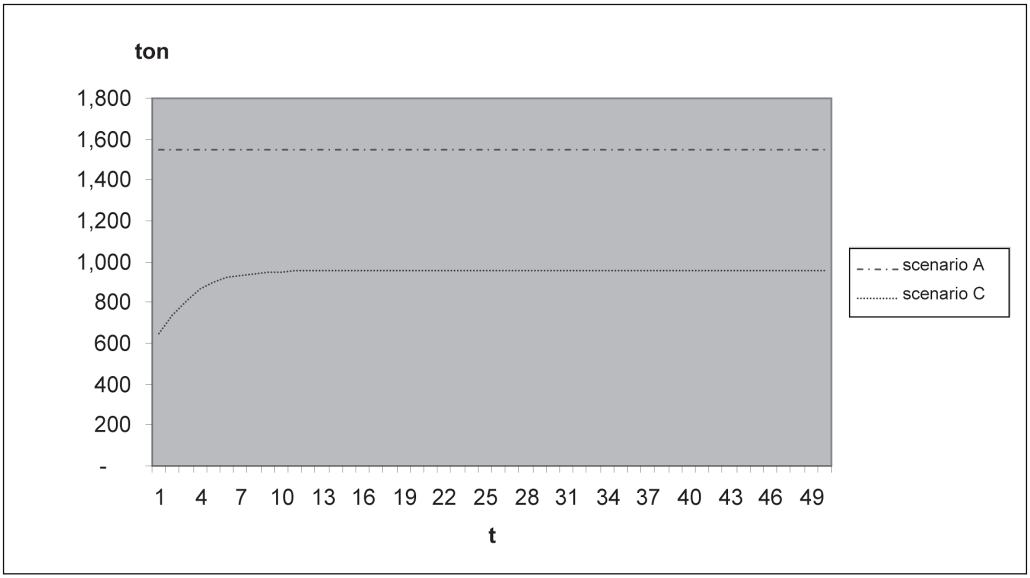
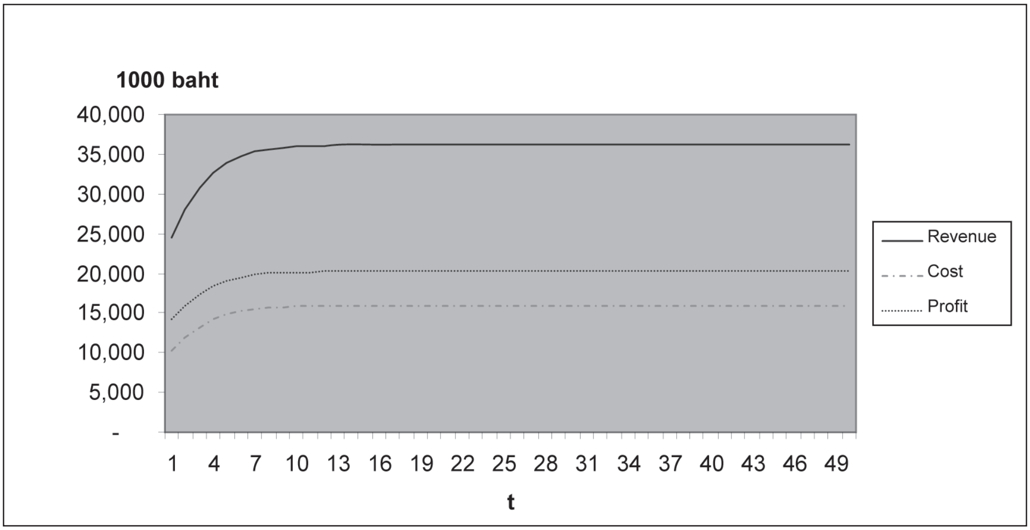


Figure 3 Revenue, Cost, and Profit of Fishery Production Under Monopoly



4.4 Mangrove +1 km^2, under Monopoly (D)

Under optimal fishery management, if the mangrove area increases by 1 km^2, the steady state catch level is approximately 1,007 tons. The fish stock increases to 10,655 tons. The total revenue and total costs are around 38 and 17 million baht respectively. This leads to an annual profit of approximately 21.5 million. The discounted net profit over 50 years is more than 526 million baht. The effects of an increase in mangrove area under monopoly are shown in Figures 4-5.

Figure 4 The Comparison Between Amounts of Fish Harvested Under Monopoly

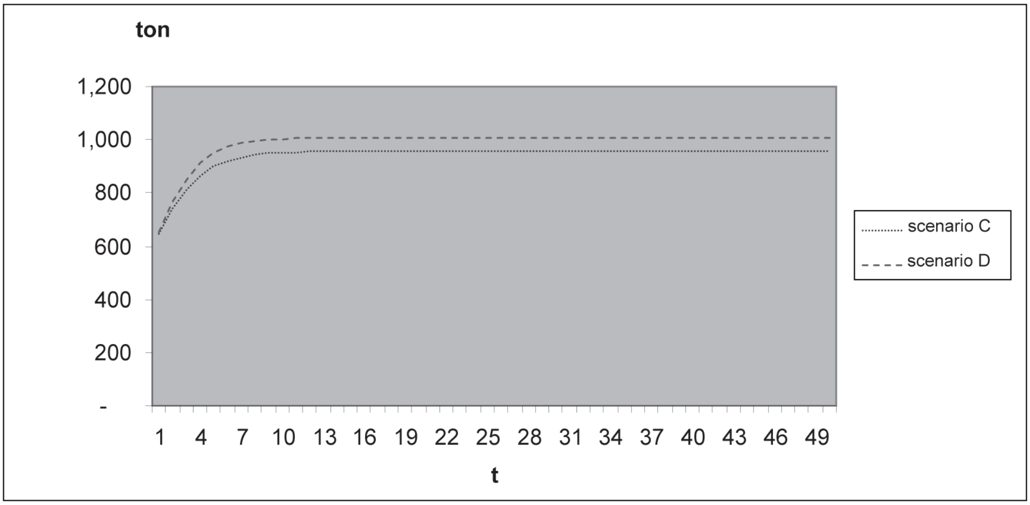
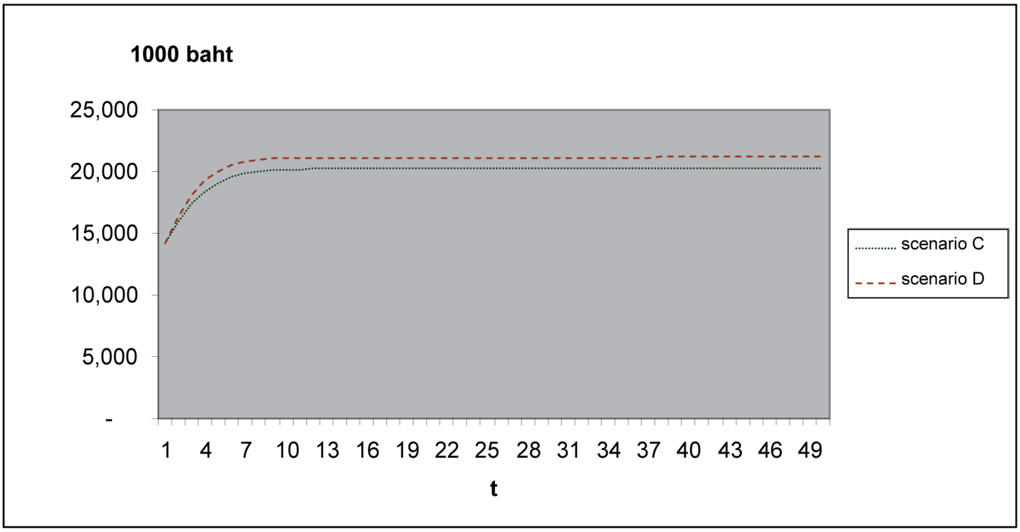


Figure 5 The Comparison Between Net Profits Under Monopoly



Compared to scenario C, an increase in total mangrove area results in a 5.15% increase in catch level and total revenue, 6.15% increase in the total cost, 4.16% increase in fish stock and 4.36% increase in profit each year in the long-run. The changes as a result of an increase in the mangrove area in the monopoly case are proportionally less than when the fishery is open-access. The results of four scenarios are summarized and compared in Table 1.

Table 1 The Main Results of 4 Scenarios

	Open Access			Monopoly		
	Baseline	+1 km^2	%change	Baseline	+1 km^2	%change
	A	B		C	D	
Catch (tons)	1,549	1,669	7.79	958	1,007	5.15
Fish stock (tons)	7,282	7,849	7.79	10,231	10,656	4.16
Total revenue (1000 baht)	58,551	63,114	7.79	36,225	38,089	5.15
Total cost (1000 baht)	58,551	63,114	7.79	15,950	16,930	6.15
Profit (1000 baht)	0.00	0.00	0.00	20,274	21,159	4.36
Discounted net profit (50 years) (1000 baht)	0.00	0.00	0.00	504,660	526,194	4.27

From these results, it is interesting to see that:

1. The value of mangrove on off-shore fishery is high and should not be overlooked. Under an open-access fishery regime, mangrove areas will increases the revenue of fishery production as high as 7.79% or almost 5 million per year per km^2. Albeit the zero net revenue because of the open-access assumptions.

2. Apart from the change in the mangrove area, the change in fishery institutional setup also has a huge impact on fishery production. Changing from open-access to optimal regulated fishery will increase the net revenue of fishery production in Bandon Bay area around 20 million baht a year, together with higher level of fish stock remaining in the bay.

3. The value of mangrove on off-shore fishery does depend on the institutional setup of the fishery sector. Under optimal fishery management, a 1 km^2 increase in mangrove area creates additional net revenues around 1 million baht to the fishery sector.

However, it should be emphasized that these calculations account for only the value of mangrove on off-shore fisheries alone. It does not take into account other benefits of mangroves, such as direct use of wood, coastal protection, control of soil erosion and a nursery ground for aquatic life functions. Considering the benefit of the mangrove area on off-shore fisheries will improve the benefit-cost analysis to become more accurate and will enhance the conservation and restoration of the mangrove[2].

[2] According to the Bureau of the Budget, Thailand, the cost of planting mangrove forest is equal to 4,200 baht/rai/year or 2.625 million baht/km^2.

5. Conclusions

Mangrove ecosystems are one of the most vital wetland systems, especially in the tropics. Mangroves can be used directly to produce charcoal. However, the benefits of mangrove ecosystems are most evident in its indirect ecological services, for example, coastal protection, control of soil erosion and a nursery ground for aquatic life. Because these external benefits are not internalized, the value of mangrove ecosystems is often underestimated. This leads to suboptimal decision-making where the mangroves are overexploited.

This paper models the impacts of a land-use change of an off-shore fishery. A dynamic ecological-economic model which examines the impact of mangrove reforestation on fish stock and the offshore fishery using nutrient status and biological productivity as key indicators is developed. The effects of an increase in mangrove areas differ depending on the regulation in the fishery sector. Under an open-access regime, an additional 1 km^2 of mangroves lead to an increase in fishery production, as well as an increase in total revenues and costs by almost 8% (equivalent to around 5 million baht/year). Under a monopoly regime, an additional 1 km^2 of mangroves results in an increase in fishery production of around 5%. Profit increases by 4.36%, or 1 million baht. The discounted profit over 50 years increases to 20 million baht.

The effects of the change in fishery regulation (open-access vs. monopoly) are also discussed. Changing from open-access to monopoly increases the stock of fish in the area, from 7,226 tons to 10,230 tons. Net revenue increases to 20.2 million baht/year in the long-run. Discounted profits over 50 years are calculated to more than 504 million baht.

However, it must be emphasized that the value calculated in this paper is only the value on an off-shore fishery. It does not take into account other benefits of mangroves, such as direct use of wood, coastal protection, control of soil erosion and a nursery ground for aquatic life functions. In order to do a benefit-cost analysis of mangrove restoration, other benefits must be incorporated.

This research emphasizes the importance of mangroves to nearby ecosystems. The ecological benefit of mangroves should be incorporated in decision making process. For example, off-shore benefits of the mangrove should be included with other costs of converting the mangrove to a shrimp farm. The model could be improved with additional scientific data, especially regarding the nutrient transfer of the livings in the bay (in the food-web).

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