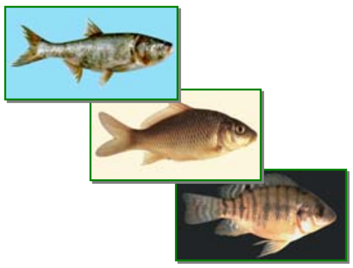
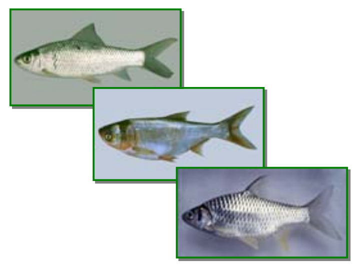
STATUS OF CAPTURE FISHERIES ACTIVITIES AND MANAGEMENT IN TRI AN RESERVOIR, VIETNAM

by

Phan Thanh Lam





A thesis submitted in partial fulfilment of the requirements for the Master of Science Degree in International Fisheries Management

Department of Economics and Management

Norwegian College of Fishery Science

University of Tromsø, Norway

May 2006

MSc. Thesis

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Tromsø, 12 May 2006

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Phan Thanh Lam

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ABBREVIATIONS

AMCF	Assessment of Mekong Capture Fisheries
$CPUE_{(E, S)}$	Catch per Unit of Effort as a function of Effort and Stocking
DNFC	The Dong Nai Fisheries Company
E	Effort
E_{MEY}	Effort at Maximum Economic Yield
E_{MSY}	Effort at Maximum Sustainable Yield
E_{OAY}	Effort at Open Access Yield
FAU	The University of Agriculture and Forestry
$H_{(E, S)}$	Harvest as a function of Effort and Stocking
MEY	Maximum Economic Yield
MoF	Ministry of Fisheries
MRC	Mekong River Commission
MSY	Maximum Sustainable Yield
MSPM	Modified Surplus Production Model
OAY	Open Access Yield
R^2	The coefficient of determination
RIA2	Research Institute for Aquaculture No.2
r_s	Intrinsic growth rate affected by fish stocking
S	Stocking
S_{MEY}	Stocking at Maximum Economic Yield
S_{MSY}	Stocking at Maximum Sustainable Yield
S_{OAY}	Stocking at Open Access Yield
SPM	Surplus Production Model
$TC_{(E, S)}$	Total Cost as a function of Effort and Stocking
$TR_{(E, S)}$	Total Revenue as a function of Effort and Stocking
VNDs	Vietnamese Dongs (currency, 15,908 VNDs is equivalent to 1$)
$\Pi_{(E, S)}$	Profit as a function of Effort and Stocking

ABSTRACT

Reservoir fisheries management must be based on an understanding that they are complex and dynamic ecosystem. This study describes fisheries activities status in the Tri An reservoir. The main objective is to determine an efficient exploitation level of fisheries resources affected by the stocking program. The Verhulst-Schaefer model (logistic growth) was applied and the classic model modified to also include the case of stocking. The modified surplus production model (MSPM) that considers fish stocking as a major factor influencing population growth has been employed to estimate static reference points. Adding economic components to the MSPM, a bioeconomic model was established and applied in analyzing the interaction between human harvesting pressures, stocking and biological resources regeneration. Data on catch/effort and stocking from 1993 to 2005 were used to analyze the fishery. Empirical results reveal that the stocking program was a major factor influencing both population growth and the harvest regime in the reservoir. Fish stocking was positively correlated to change in population growth, and led to a considerable enhancement in fish production. The fisheries resources cannot sustain current exploitation levels which have led to both biological and economic overfishing as a result of ineffective management. The current centralized top-down management has proven ineffective and inappropriate. Therefore, rational management is required to rescue the fisheries resources from depletion, to maintain the fisheries productivity capacity and to prevent further resource degradation. However, reservoir fisheries are currently dependent on harvesting and stocking regimes, so a change of management plan should be achieved by simultaneously changing the level of effort and stocking rate.

KEY WORDS: Reservoir, Stocking, MSPM, Harvest, Overfishing and Management

Chapter I

INTRODUCTION

1.1. Introduction

Reservoirs are an important water resource in Asia, the reservoir resources are diverse and therefore the strategies to be adopted for optimizing yields are also different (Bhukaswan 1980; Cowx 1996; De Silva 2001). Most reservoirs in Vietnam were impounded after 1954 for different purposes such as irrigation, hydroelectricity, flood control, and water supply for domestic consumption and industry (Hao 1997; Van & Luu 2001). With few exceptions, these reservoirs have been used for fish production by stock enhancement and cage culture (Luong *et al.* 2004). The fish production from reservoirs depends on nutrients, biomass, and the quantity of stocked fingerlings. There is a common belief that fish yields of reservoirs tend to be high in the initial few years after impoundment, and then begin to stabilize at a lower level (Van & Luu 2001). Recently the fisheries resources of reservoirs in Vietnam have shown a downward tendency, as the size and population structure of the fish species (including stocked species) in the reservoirs have decreased (Hao 1994; Lam 1994). As indicated by Bernacsek (1997) fisheries catch per unit effort is quite low in large reservoirs, mainly due to the low productivity of pelagic water. Recently, reservoir fisheries resources have tended to be overexploited (Coates 2002; Cowx 2002). First of all this is caused by ineffective or inappropriate management measures. Open access may be an important cause of overfishing, and lack of knowledge on fisheries resources may lead to or result in overfishing (Coates 2002).

Tri An reservoir was built in 1987, it has an average water surface area of 250 km^2, changing from 75 to 324 km^2. The main functions are hydroelectricity and agricultural irrigation for South-east Vietnam (Hao 1997). In addition, fisheries are beginning to be recognized as an important secondary function of the reservoir water resource (De Silva 2001; DNFC 1997). Fishing is traditionally an important occupation for local people living in reservoir areas and has a main role as a protein source in the diets of many households (DNFC 1995; Hao 1997; Sonny & Oscar 2001; Tung *et al.* 2004). Stocking has been a major component of reservoir fisheries management since 1995, for biological control, enhancement of fish yields and employment. The stocking program leads to an increasing number of species in the reservoir through introduction of exotic stocked fish as Tilapia, Indian carp, Grass carp, Silver carp and Big head carp (DNFC 2005; Tung *et al.* 2004). Although aquatic resources in the reservoir are highly diversified in species composition as well as abundant primary productivity, these resources have been reduced in terms of quantity and size of fish caught in recent years (Hao 1997; Tung *et al.* 2004). This suggests that the fishery is being overexploited, and that better fishery management needs to be imposed to maintain productivity of the fisheries resources on a sustainable basis (Luu 1998; Sonny & Oscar 2001).

Previous studies of fisheries in Tri An reservoir focused mainly on specific technical aspects and their specific solutions, whereas less attention was paid to other aspects influencing the development of fisheries such as research on data archives to estimate aquatic resources, management methods and fisheries assessment. This study, therefore, tries to show whether or not overfishing indeed exists and the impact of fish stocking on population dynamics. The findings of this study will contribute to fill some of the existing gap of empirical studies focusing on the bioeconomic analysis of sustainable use of fish resources. The thesis begins with the introduction chapter presenting the rationale of the study, and defines the main concerns and objectives. Background information on fisheries in the reservoir is presented in chapter 2. Chapter 3 summarizes the basic theory and introduces a surplus production model including the effects of a stocking program. Chapter 4 outlines the data used and steps of data processing, followed by the results of the study in chapter 5. Finally, chapter 6 presents the discussion and conclusion based on the findings in the previous chapter.

1.2. Main concerns of the study

To carry out the study, main concerns of the fishery in the reservoir are defined as follows:

i. The Dong Nai Fisheries Company (DNFC), a local government fishery enterprise, is responsible for managing fisheries activities in the reservoir. Generally, management is weak due to lack of specialized technicians and knowledge in management. The financial source of DNFC is mainly from the local government; with additional revenue from activities such as fish hatchery, forestry exploitation and taxation on fishing. Annually, a fixed share of fishing taxes is used for introducing fish fingerlings into the reservoir; however, the stocking density and species rations were suspected to be inappropriate. The stocking rate is only based on the budget of the DNFC, instead of depending on basic stocking principles. Although stocking was introduced as a fisheries management component 12 years ago, studies on stocking impact on population dynamics have not been carried out so far.

ii. As a result of ineffective or inappropriate methods of management, the average size of fish caught and catch per unit of effort (CPUE) have showed declining trends in recent years (FAU 2000; Hao 1997). Recent surveys report that harvests are decreasing in terms of fish size and quantity of commercial species. This indicates that the fish resources in the reservoir are reduced because of overfishing. Possible reasons of resource reduction are high fishing pressure, gears used with small mesh-size, ineffective management and poor stocking strategies.

In order to get insight into the above problems, this study aims to assess the status of existing capture fisheries activities and management in the reservoir. The main objective is to identify an efficient level of fisheries resources exploitation that are affected by the stocking program. Reference points as Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY) and Open Access Yield (OAY), represented by their corresponding effort and stocking levels and estimated by applying a theoretical bioeconomic model. Based on the findings, several possible management measures for sustainable development are discussed and recommended.

The study is based on empirical investigations that have provided insight into such questions as: How does the fish stocking influence population dynamics and fish harvest level? Is there overfishing in the reservoir? Is the current exploitation of fisheries resources sustainable?

Chapter II

BACKGROUND OF FISHERY IN TRI AN RESERVOIR

2.1. Characteristics of fisheries resources

2.1.1. The location, area and climate

Tri An reservoir lies between latitudes $10^0$00’ to $12^0$20’ North and longitudes $107^0$00’ to $108^0$30’ East. The reservoir was built and completely impounded in 1987, and is mainly used for hydro-electricity (DNFC 1997). It is also utilized for fisheries, and has been supplying water for agricultural irrigation and domestic consumption of the lower Dong Nai river basin. Tri An is the biggest reservoir of Vietnam, with a catchment area of approximately 14,800 km^2, an average annual outflow of 15,100 million m^3 and total volume of 2,765 million m^3 (see Fig. 2.1). The reservoir has a water surface area of around 324 km^2, with an average depth of 8.5 m, about 44 km in length and has a maximum width of 10 km (DNFC 2005; Tung *et al.* 2004).

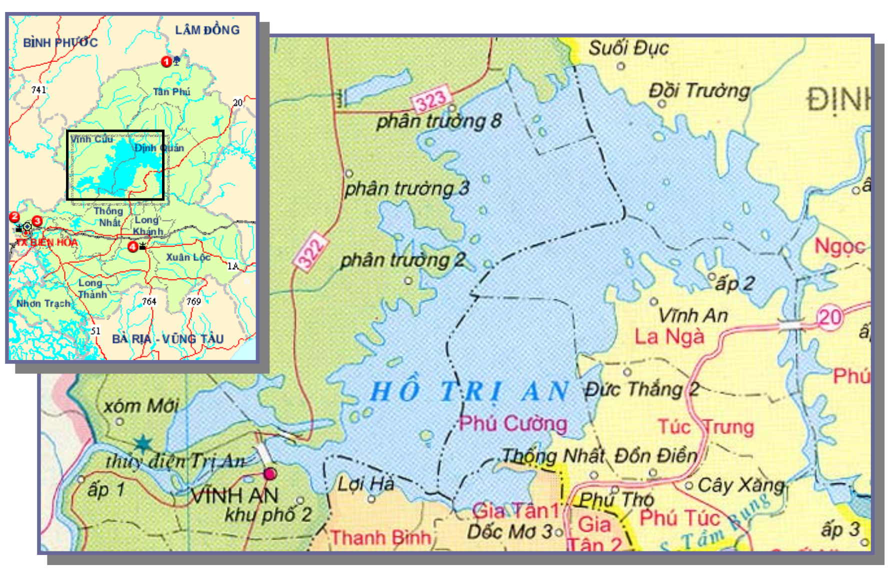


Figure 2.1. Map of Tri An reservoir showing the location and study area [Source: maps cited from Tran (2002)]

The reservoir belongs to a tropical climate region, with a water temperature range of 21^0C-31^0C, and a characteristic of two distinct seasons: the rainy season from June to

November, with high rainfall of 2,400 mm; and the dry season from December to June the following year (DNFC 1995; Tung *et al.* 2004). Additionally, the reservoir contains about 50 coves of various sizes, and connects to many tributaries of the Dong Nai and La Nga rivers (Hao 1997; Luong *et al.* 2004; Tung *et al.* 2004). Therefore, the Tri An reservoir has advantageous conditions of climate and topography for fisheries development. Although the initial principal purpose of the reservoir was not primarily fisheries development, the fisheries value has been recognized as an important secondary use of the water resource (De Silva 2001; DNFC 1997).

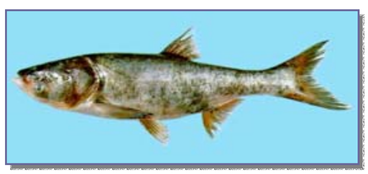
2.1.2. Species composition

The fish species composition in a reservoir is a result of the different reactions of the species to varying environmental conditions after impoundment (Bhukaswan 1980). Some species not able to adapt to the new conditions may become extinct while other species adapt to change to varying degrees and may continue to exist at a changed abundance (Li & Xu 1995; Tung *et al.* 2004).

The fish fauna of Tri An reservoir first of all reflects the fauna of the impounded Dong Nai and La Nga rivers (Li & Xu 1995; MoF 1996; Tung *et al.* 2004; Welcomme 2001). The current reservoir ecosystem is diverse and includes many species; the fish fauna is known to constitute 109 species, belonging to 28 families and 9 orders. The Cyprinids, constituting 56 species, are still dominant among species inhabiting the reservoir. The families of Cobitidae, Cichlidae, Siluridae and Bagridae with 5 species of each respectively accounted for 18.35% of total, followed by Belontiidae with 4 species; and other families were recorded with 29 species. There are 32 commercial species and 77 low value economic species. The highly commercial species are Common carp (*Cyprinus carpio*), Silver carp (*Hypophthalmichthys molitris)*, Big head carp (*Aristichthys nobilis)*, Grass carp (*Ctenopharyngodon idellus)* and Indian carp (*Labeo rohita*), and they constitute annually the main fish production for the reservoir (DNFC 1995; Hao 1997; Tung *et al.* 2004). These sources also confirm that the size and population structure of the fish species in the reservoir have decreased recently.

2.1.3. Fish stocking

Stocking and introduction of fish are frequently used throughout the world (Cowx 1998; 2002; Welcomme 1998; 2001). Stocking is a management measure to enhance and optimize yield of lacustrine bodies (Bhukaswan 1980; Li & Xu 1995). In Tri An reservoir, stocking has been a major management component since 1995. The stocking program was a main part of the project "Assessment of socio-economics and investment of fisheries potential exploitation of Tri An reservoir, 1995-1999" (DNFC 1995). The purposes of stocking are to reduce water pollution through increasing the biological filter capacity of suitable stocked species; to utilize ecological niches to which none of the existing species are adapted; to control aquatic weeds; to enhance the fish yields and provide more food fish; and to curb unemployment through fishery development (Bhukaswan 1980; Li & Xu 1995; Luu 1998). Annually, stocked fish which are re-caught contribute an average of 30% of fish production in the reservoir (An 2001; FAU 2001).



Bighead carp
(Aristichthys nobilis)

Silver carp
(*Hypophthalmichthys molitris*)

Common carp
(Cyprinus carpio)

Mud-carp
(Cirrhinus molitorella)

Figure 2.2. Photographs of main stocked fish in Tri An reservoir
[Source: photographs cited from MRC (2003)]

Series of management measures for stocking in the reservoir established, including choice of suitable species, species combinations, stocking size and measures for preventing escape of stocked fish (An 2001; DNFC 1995; Lorenzen *et al.* 2001).

Eight fish species, including 3 indigenous and 5 exotic species, were introduced into the reservoir (see Fig. 2.2). Recently, a change in species composition of fish in the reservoir is a result of stocking impact, 109 species were recorded when compared with 102 species during the pre-impoundment period (Tung *et al.* 2004). Some of exotic stocked fish such as Silver carp, Big head carp, Tilapia, Indian carp and Grass carp, lead to increase in the number of species (DNFC 2005; Tung *et al.* 2004).

2.1.4. Fishing community

Fisheries communities are located around or close to the reservoir at Vinh cuu, Thong nhat and Dinh quan districts of Dong Nai province (DNFC 1997). About 1,000 households are permanently involved in fishing activities (AMCF 2002; DNFC 2005; FAU 2000; Sonny & Oscar 2001), of which:

1. The full-time fishermen who are more specialized and operated their fishing as a main occupation and accounted for 60% of the total.
2. The part-time fishermen who usually operated their fishing as a consequence of lack of work in their main occupation, or who capture fish as feed supplying for their cage culture system was about 30% of the total.
3. The subsistence fishermen who mainly harvested fish for their own consumption occupied 10% of the total.

Fishing activities in the reservoir have supplied over 2,000 permanent employments, and ensured livelihoods for about 1,000 households with more than 5,500 inhabitants (DNFC 1995). The average household consisted of five to six persons with the father being the main income earner, and consistent with the characteristics of the extended family system, married couples tend to remain with their parents and involve themselves in fishing activities (Ahyaudin & Lee 1994; DNFC 1995). In general, most fishermen have a low education level, with about 17% being illiterate, 59% with primary school level of education (FAU 2000), and their fishing practices mainly depend on experience passed down from their forebears (AMCF 2002; FAU 2000; Luu 1998).

2.2. Status of fish stocking program

2.2.1. Trends of fish stocking program

Several species, including exotic and indigenous species, have been introduced into the reservoir since 1995. Annually, about 1.2 million fingerlings are introduced into the reservoir (DNFC 2005), of which planktivorous species such Silver carp and Big head carp are dominant and accounted for 36% of total, followed by Mud carp (13%), Common carp (12%), Tilapia (12%) and others (27%) (see Fig. 2.3).

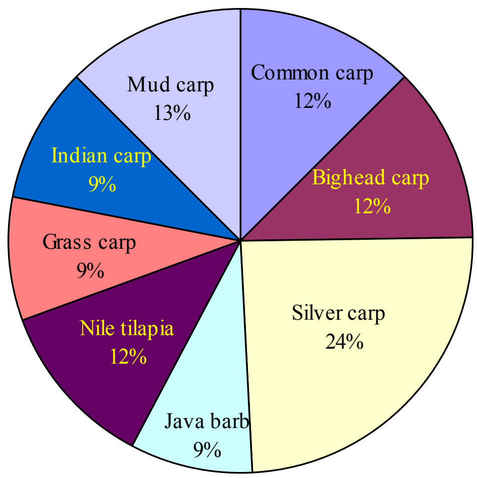


Figure 2.3. The distribution of stocked species from 1995 to 2003
[Source: data calculated and cited from DNFC (2005)]

At the first three-year period, the DNFC received financial support from the local government to begin the stocking program; thus, the quantity of fish stocking increased quickly from 1.3 million fingerlings in 1995 to 5.0 million in 1997. After that, the local government stopped financial support for the stocking program, so the quantity of stocked fish reduced dramatically and fluctuated slightly, with an average of 1.2 million fingerlings in the following years (see Fig. 2.4). At that time, only a fixed share of fishing taxes was used for introducing fish fingerlings into the reservoir, with an average of 10% of fishing taxes, however, this expenditure was not enough to ensure fingerling quantity and to attain objectives of the stocking program (DNFC 2005; Tung *et al.* 2004).

Although the stocking program was limited in terms of stocking quantity, it still led to considerable increase in fish yield from 45 kg per ha in 1995 without fish stocking, compared to over 60 kg per ha in the following years affected by the stocking program (see Fig. 2.4). In general, the fingerlings were introduced with lower density, around 48 fingerlings/ha/year compared with stocking principles, so re-capture rate of stocked fish and productivity were too low to be economical (An 2001).

Recently, the DNFC has been changed it operating regime; hence, the stocking program was stopped. The DNFC will continue introducing fish fingerlings into the reservoir when they re-organize completely, but interruption to the stocking program led to an immediate reduction in fish yield (An 2001; Van & Luu 2001).

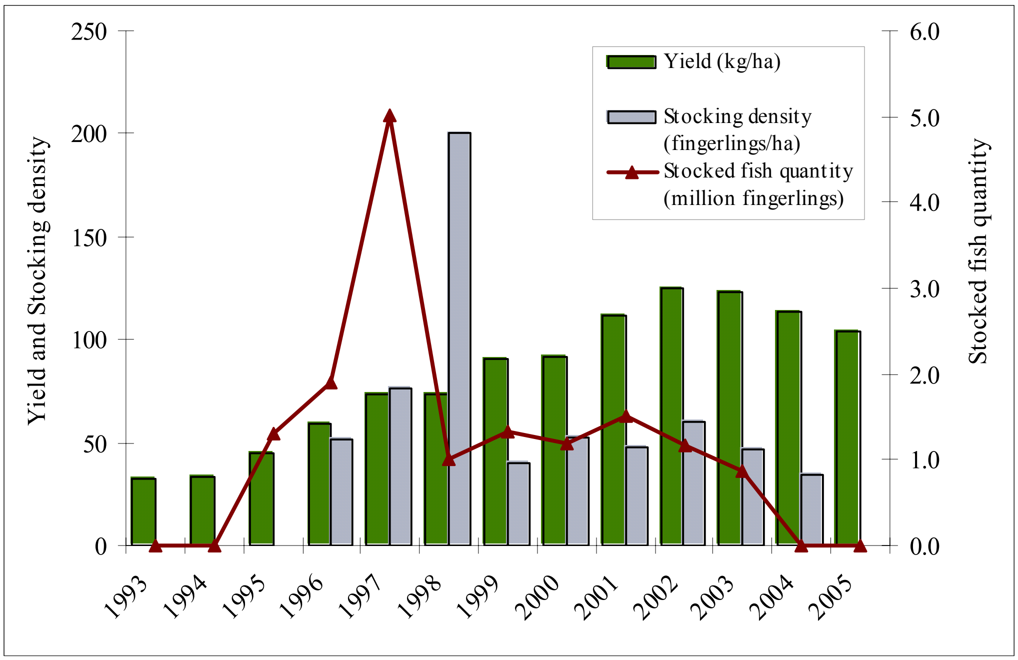


Figure 2.4. Trends of fish stocking program from 1993 to 2005
[Source: data calculated and cited from DNFC (2005)]

2.2.2. Optimal stocking density for Tri An reservoir

Technically, estimation of maximum stocking density needs to be considered in the process of stocking planning and management. According to Li & Xu (1995), the theoretical equation used for stocking density estimated is:

$$d = \frac{F}{WR} \qquad (2.1)$$

Where d is stocking density (fingerlings/ha), F is potential yield (kg/ha), W is average size of harvested fish (kg), and R is re-capture rate of stocked fish (% of stocked quantity).

In Tri An reservoir, the maximum stocking density is around 600 fingerlings/ha/year, the corresponding level of stocked fish into the reservoir is 15 million fingerlings/year or 100 tons fingerlings/year (see Table 2.1).

Table 2.1. Estimating the maximum stocking density for Tri An reservoir

Items:		Value	*Unit*
Potential yield of stocked fish (F)[1]		90	*(kg/ha)*
Re-capture rate (R)[2]		10	*(% of stocked quantity)*
Mean weight of fish at capture (W)[3]		1.5	*(kg)*
Maximum stocking density (d)[4]		600	*(fingerlings/ha)*
Average surface area (A)		25,000	*(ha)*
Maximum stocking in:	- Quantity (Q)[5]	15,000,000	*(fingerlings)*
	- Weight (TW)[6]	100,000	*(kg)*

1, 2 & 3. Data are cited from Hao (1997), Van & Luu (2001) and Welcomme (1998).

4. Stocking density is maximum when re-capture of stocked fish reaches the potential yield of stocked fish, it is calculated by Eq. (2.1).

5. Quantity of stocked fish (Q) equals average surface area (A) multiplied by maximum density (d).

6. Weight of stocked fish equals Q divided by an average of 150 fingerlings per kg (DNFC 2005).

2.3. Status of capture fisheries activities

2.3.1. Fishing season

Fishing is a highly seasonal activity in most parts of the world (Welcomme 2001). The seasonality of fishing in Tri An reservoir is determined mainly by the outflow regime. Fishing seasons can be distinguished as dry season with low water level and rainy season with high water level (DNFC 2005), as follows:

i. Dry season (from January to June) is main fishing season, and the highest fishing intensity starts from April to the end of May. Trawl net, gillnet, long line, big cast net and beach seine are widely used, and their catches are larger than for other gear types. The fishing grounds are mainly concentrated at the middle and the lower basin of the reservoir.

ii. Rainy season (from July to December) is the supplemental fishing season. Fishing gears widely used with high catches are the sprat scoop net, shrimp basket trap, scoop net and gillnet. In this season, the water surface area may vary from 25,000 ha to 32,400 ha, hence, most fishing grounds are used.

2.3.2. Fishing gears

The reservoir capture fishery reflects the general state of inland fisheries in Southeast Asia by being multi-species and multi-gear fisheries, primarily artisanal and small-scale (Ahyaudin & Lee 1994; Coates 2002). The types of fishing gear used depend mainly on the habitats exploited, fishing season, the target species and the purpose of exploitation (AMCF 2002). The DNFC divided these gears into 17 categories (see Appendix 2). The fishing gears widely used are gillnet 1 (average of 28% of total households use), followed by shrimp basket trap (29%), gillnet 2 (8%), sprat scoop net (7%) and long line (6%) (see Table 2.2 and Appendix 4). They also contribute mainly and largely to the total fish production of the reservoir (DNFC 2005). The use of illegal gears and prohibited destructive fishing activities like the use of explosives, toxicants (poisoning), and certain other destructive fishing methods such as filtering barrier with small mesh size, have been banned since 1995. However, many fishermen still operate these types of prohibited activities (Bhukaswan 1980; DNFC 2005).

Table 2.2. Major fishing gears used in Tri An reservoir

Gear name	Description	% of households used	% of total catch	Average catch (kg/year)
Gillnet 1	- a net 1,000 metres in length/gear - the mesh size ranges 40–60mm	16 ÷40	13 ÷33	1,448 ÷2,521
Gillnet 2	- a net 1,500 metres in length/gear - the mesh size ranges 70–140mm	4 ÷10	4 ÷8	710 ÷3,251
Long line	- a long-line 1,000-1,500 hooks	2 ÷9	1 ÷3	527 ÷2,538
Scoop net	- a scope net with 1 oil-lamps/gear	4 ÷5	5 ÷24	3,101 ÷16,542
Shrimp basket trap	- It is made by bamboo. - a 100 basket-traps/boat	24 ÷34	5 ÷9	334 ÷914
Sprat scoop net	- a scope net with 18 lamps/gear - the mesh size ranges 2–5mm	5 ÷12	28 ÷32	5,405 ÷17,151
Trawl net	- a net 500 metres in length/gear - the mesh size ranges 70–150mm	2 ÷5	2 ÷5	1,182 ÷7,088

[Source: data calculated and cited from DNFC (2005)]

2.3.3. Fish production and market

Capture fisheries in the reservoir have increased both in fish production and in effort over a period of ten years (1993-2002). The growth rate of fish production rose quickly as a result of introducing fish fingerlings into the reservoir, and increasing effort (DNFC 1997; 2005). Recently, both production and effort were reduced, from 2003 up to now (see Fig. 2.5). The reasons for this are the interruption of the stocking program when the responsible fishery company is changing the operating regime, and weakness in fisheries management. Declining profit of fishing activities is the main reason for many fishermen leaving the fishery (AMCF 2002; DNFC 2005; FAU 2000). Average of approximately 2,500 tons fish is landed annually, representing about 80% of the total fish production of Dong Nai province. Fishing activity is also an important occupation of local people living in the area close to the reservoir; giving permanent jobs for over 1,000 households and more than 2,000 employees (DNFC 2005; Tung *et al.* 2004).

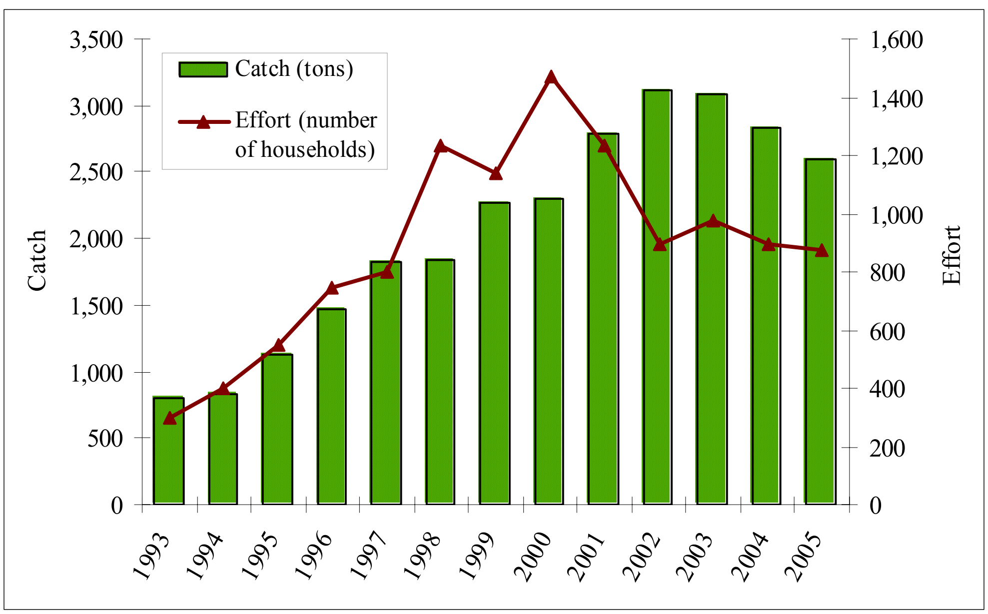


Figure 2.5. Trend of catch and effort from 1993 to 2005
[Source: data cited from DNFC (2005)]

Fish landed are transported from the fishing grounds to six commercial landing sites close to the reservoir, each controlled and operated by about 10 permanent wholesalers and a landing centre of local government through various middlemen.

Most fishermen sell their harvest to the middlemen. The relationship between middlemen and fishermen has been set up for a long time. Middlemen often buy catches from fishermen at low prices, while the middlemen on their side ensure the fishermen that all their catches will be bought and also provide small loans to fishermen if needed (Ahyaudin & Lee 1994; DNFC 1995; 2005; Sonny & Oscar 2001). Price on harvest is mostly decided by middlemen when fishermen have a debt to them. Landed fish prices tend to be lower in the dry season compared with the rainy season, because of differences in available catches and productivity between dry and rainy seasons (DNFC 2005; Hannesson 1993). Many fishermen sell their product directly to retailers and consumers at market prices in order to achieve higher profits. Harvested fish with low economic value as trash fish are often sold directly to owners of cage culture farms to be processed and supplied as a fish feed source for cage culture (DNFC 2005).

2.4. Fisheries management practices

After impoundment, the DNFC is responsible for running the hatchery, producing fingerlings for stocking and managing fisheries activities. The usual management problems related to ownership are therefore avoided. However, production of a plan is initiated by the DNFC depending on its investment capacity, availability of financial resources and marketing. The problem of controlling illegal fishing is substantial, being one of the most important social issues in reservoir fisheries. In addition, property-sharing in water resources among the DNFC and other stakeholders such as Tourism and Industrial Companies has produced conflict (Luu 1998; Van & Luu 2001).

A series of fisheries management measures employed in the reservoir was set up by the DNFC in 1995, including introduction of fisheries regulations, fish stocking strategies and monitoring strategies (DNFC 1995; 1997; FAU 2000).

2.4.1. Fishing regulations

The principal purpose of fishing regulations and control is to ensure a high, but sustainable yield (Bhukaswan 1980). Decision Nº 171/QD-UBNDTDN on 1 August 1995 (DNFC 1995), which describes the legal framework regarding the exploitation of fisheries resources in the reservoir, comprises mainly protection and conservation measures to control fishing such as:

i. Technical measures: the DNFC set up management measures such as closed area and closed season which are to establish localities and times of the year when fish must not be taken to protect the brood-stocks and fry fish/or fingerlings in spawning seasons/areas (Charles 2001; Welcomme 2001). However, where the fishing depends on multi-species resources, it is difficult to design appropriate closed season and closed area regulations to ensure adequate protection for all species (Bhukaswan 1980; De Silva 1988), the DNFC suggested closed seasons and closed areas for 10 high value economic species. Limitations on minimum mesh size of fishing gears were also established. Pollution regulation and control of prohibited wastes release into the reservoir are enforced for all stakeholders using the water resources. Partitioning off the reservoir with a barrier net fixed across those cove mouths which are spawning grounds or passage for migration in spawning season is prohibited for all fishermen (DNFC 1995).

ii. Input control: although the capture fishery in the reservoir is open access due to local community pressure, entry to the fishery is restricted only to the local people. All local fishermen can access fishing, however, they have to sign a contract to license/or pay operation fees with the DNFC before entering the fishery. Based on type of gears used and operating time, fishermen have to pay operation fees to the DNFC (DNFC 1995).

iii. Output control: the minimum size regulation on fish caught is considered to be an important control measure, particularly for species with low reproductive capacity. As a result of the difficulties in setting up proper minimum size regulation in a multi-species fishery (Bhukaswan 1980; De Silva 1988), the DNFC only identified and implemented size limitations to protect about 20 commercial species. The size limitations of fish caught are enforced for both fishermen and wholesalers. In particular cases, if fishermen want to harvest fry fish/or fingerlings used for cultivation in coves and cage culture systems, the fishermen have to apply for a license and will be controlled by managers from the DNFC (DNFC 1995).

Although fishing regulations were implemented in 1995, the effects have been limited and it has been difficult to achieve targets due to weakness of management capacity and low awareness level of fishermen about conservation issues (Luu 1998).

2.4.2. Fish stocking strategies

Fish stocking has proven to be one of the most successful tangible tools in reservoir fisheries management (An 2001; Li & Xu 1995). The DNFC set up strategies for the stocking program as follows:

i. Choice of suitable species, species combinations, stocking size and rate, and measures for preventing escape of stocked fish were studied. Stocked fish feed on phytoplankton, zooplankton, organic detritus and periphyton to be of priority. Stocked fish must be well and minimum size of fingerlings is 8-12 cm in length (An 2001; DNFC 1995; Luu 1998).

ii. Annually, about 2-3 million fingerlings have been introduced into the reservoir, with an average density of 100 fingerlings/ha. The stocking time is from August to December, and the harvesting time of stocked fish is from February the following year. The DNFC also chooses suitable areas for stocking, and establishes the closed areas and seasons for all fishing gears (DNFC 1995; 2005; Luu 1998).

iii. To ensure the stable and annual budget source for the stocking program, all fishermen who enter the fishery have to pay operation fees. The fee size varies by type of gears and intensity level from 10 to 20% of the value of the total catch. This taxes source will be used to control fishing activities and stocking at the following year (DNFC 1995; 2005).

Overall, because of ineffective management and financial constraints, the above stocking regulations could not be implemented correctly and it is difficult to obtain clear objectives of the current stocking program. Annually about 10% of fishing taxes was used for stocking, hence, the stocking density was low leading to low recapture rate and ineffectiveness of the stocking program (An 2001; Van & Luu 2001).

Chapter III

MODEL

The abundance of fish stock in a particular area is a function of interactions between environmental factors and the fish stock properties. The stock tends to stabilize at a particular set of environmental conditions (Gulland 1977). When the surplus production is not harvested, 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 (Clark 1990; Haddon 2001; Hannesson 1993). This implies that fishing plans can be expressed in terms of surplus production. The surplus production models are very flexible and have different variations; Verhulst-Schaefer, Gompertz-Fox and Pella-Tomlinson models are some of the best known and popular (Frank *et al.* 1979; Seijo *et al.* 1998). In this study a modified surplus production model that was developed from Verhulst-Schaefer model has been built and used for assessment of fish stock affected by the stocking program.

3.1. The logistic growth model

Population growth has been typified in several ways, but most commonly, the logistic model of population growth has been found to fit a large number/or stock biomass of populations both in nature and in captivity. Generally, the Verhulst (1838)/Pearl (1925) surplus production model (SPM) was defined as change in population biomass per unit of time (Clark 1990; Flaaten 2004), and is described by the logistic equation:

$$F_{(X)} = rX\left[1 - \frac{X}{K}\right] = \frac{dX}{dt} \tag{3.1}$$

Where X is *stock biomass*, and r and K are positive constants referred to as the *intrinsic growth rate* and *environmental carrying capacity*, respectively. The reason for these terms is simple: r represents the maximum relative growth rate of population, which is the approximate rate of growth, when $X \ll K$. Similarly, K represents the stable equilibrium biomass level: if X is a positive solution of Eq. (3.1), then $X \rightarrow K$ as $t \rightarrow \infty$ (Clark 1985). $F_{(X)}$ is *natural population growth* describing change in population biomass per unit of time. Natural population growth is usually positive, but may even be negative if the stock level for any reason is higher than K. $F_{(X)}$ has its maximum for a specific stock level that may be found by maximizing F with respect to X, at which the productivity of resource is maximum (Clark 1990; Flaaten 2004).

In order to apply the logistic growth model to fish population dynamics that considers the effect of fishing (Clark 1985; Frank *et al.* 1979; Gordon & Clark 1980), Schaefer model (1957) is the most commonly used among SPMs (known as Biomass Dynamics Models), it bases precisely on the logistic population growth model of Verhulst (1838)/Pearl (1925). To include the effect of fishing in Eq. (3.1), Schaefer introduces the rate at which fish are caught, that is, the catch rate H of the fishery, is given by:

$$H = qEX \tag{3.2}$$

Where H denotes the catch rate in terms of fishing effort E, and q is a constant called catchability coefficient and X is the fish stock biomass.

When catch/or harvest (Eq. 3.2) is included in the Eq. (3.1) in order to model the effect of fishing on fish population dynamics, Schaefer (1957) altered Eq. (3.1) to

$$\frac{dX}{dt} = rX\left[1 - \frac{X}{K}\right] - H \tag{3.3}$$

While the Verhulst-Schaefer model (Eq. 3.3) is desirable to utilize the fish resources, it is intuitively clear that if many fish are harvested, then the fish population may be reduced below a useful level, and possibly even driven to extinction (Boyce & DiPrima 1992). Thus, the sustainable harvest of fish resources generally requires that the catch rate should not exceed the growth rate of fish stock (Charles 2001). Setting $dX/dt=0$ is the condition of a sustainable equilibrium in the Verhulst-Schaefer model, this model helps to find MSY of the fish resources, corresponding to the equilibrium value $X=K/2$. This indicates that the fishery is unsustainable if the catch rate exceeds MSY. The fishery is considered to be overexploited if the stock is reduced to a level below $K/2$ or sustainable yield falls below MSY (Boyce & DiPrima 1992).

3.2. Modified surplus production model

In practice, fish fingerlings are frequently introduced into reservoirs, thus fish stocking directly influences fish population dynamics (Cowx 2002). The previous studies for reservoir fisheries show that sexual maturation of stocked fish under natural conditions is impossible or very low, and stocked fish are unable to reproduce locally or to adapt and compete successfully with local species in terms of growth and competition for food (Ali 1998; Hao 1997; Welcomme 1998). Therefore, stocking is the principal method used in reservoir fisheries to enhance fish production, to maintain fisheries productivity or to improve recruitment and bias fish assemblage structure which is a result of overfishing (Cowx 2002; Welcomme 2001). Regarding the stock assessment of the reservoir, the Verhulst-Schaefer model can be applied in order to provide initial reference points for management in the reservoir, however, the SPM needs to be modified due to the stocking program's impact on fish population growth. The following modification is proposed:

$$F_{(X,S)} = (r_0 + aS)X\left[1 - \frac{X}{K}\right] = \frac{dX}{dt} \tag{3.4}$$

Where $(r_0 + aS)$ is intrinsic growth rate affected by stocked fish S, and $F_{(X,S)}$ is population growth, it is the change in population biomass per unit of time affected and depended on stocked fish, in the case of no fishing. When $S=0$, Eq. (3.4) is reduced to Eq. (3.1).

Cowx (1998) and Welcomme (1998) report that when stocked fisheries have been managed well, usually in terms of stoking strategies and fishing regulations, the stocking could help to maintain the fisheries productivity at the highest possible level. Furthermore, the stocking may help to compensate for recruitment overfishing, because the stocking may provide sufficient quantity of catch demands to increasingly higher fishing pressure levels (Cowx 2002). It is reasonable to assume that the rate at which fish are harvested depends on the fish population: the more fish stock including wild fish and stocked fish there are, the easier it is to catch them (Boyce & DiPrima 1992). Thus, the stocking can help to reduce fishing pressure for natural fish stock, and the fish stock may increase as positive results of the stocking.

In this point of view, we assume that the stocking is positively related to population growth through intrinsic growth rate of population (r); it means that r will increase when fingerlings are introduced into the reservoir, because stocked fish are unable to reproduce and they help to reduce fishing pressure for natural fish stock. This indicates that the fish population growth affected by stocked fish will increase and approach the carrying capacity of the environment more quickly compared to change with no stocking (King 1995; Lever 1998) (see Fig. 3.1). As the result of the change in intrinsic growth rate affected by fish stocking, the population growth tends to be positively trended with stocking rate, it rises when stocked fish increase and vice versa (see Fig. 3.2).

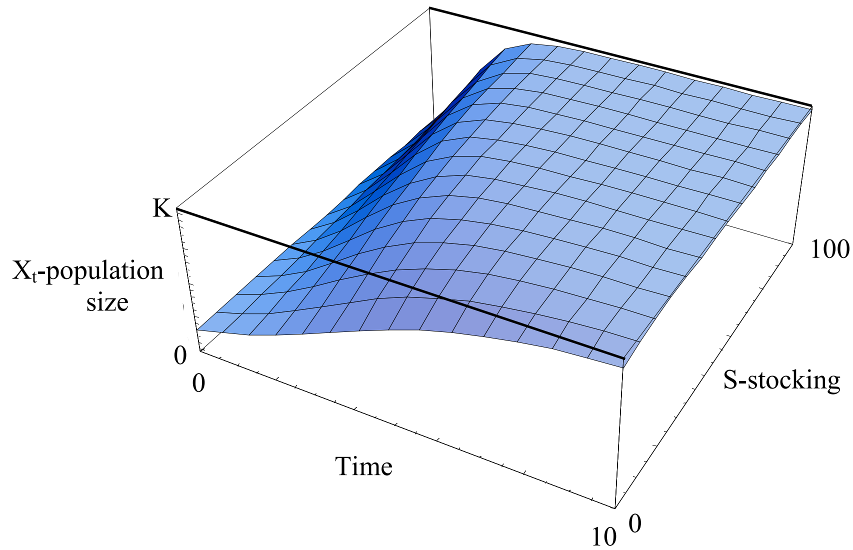


Figure 3.1. Population growth according to the logistic curves

The graph shows the trajectories of population growth for the different values of r. Integrating Eq. (3.4) leads to the continuous solution to the logistic equation, giving the expected population size X_t at time t after some starting time and population size X_0 , $X_t = K / \left[1 + (K - X_0) / \left(X_0 e^{(r_0 + aS)}\right)\right]$. The top dashed line represents the asymptotic carrying capacity *K*. Maximum growth rate is at *K/2*, where the inflection exists in the curve. The population size affected by stocked fish will increase and approach the environmental carrying capacity more quickly compared to change with no stocking.

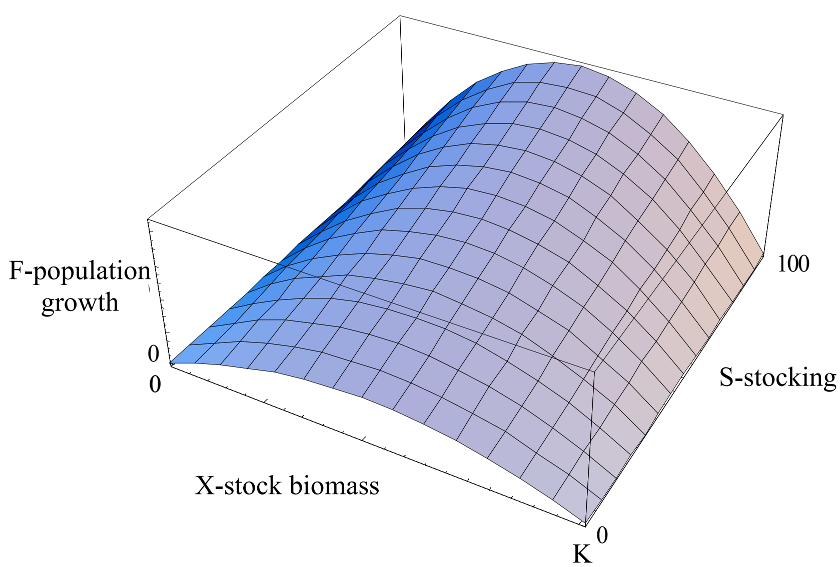


Figure 3.2. Plot of population growth versus stock biomass and stocking rate

The graph shows the relationship of population growth with stocking and stock levels. Population growth is a function of stock and stocking rates, $F_{(X,S)} = (r_0 + aS)X[1-X/K]$

In this case, in order to model the effect of fishing on fish population dynamics, the catch rate H (Eq. 3.2) is included in the Eq. (3.4), we obtain the MSPM as:

$$\frac{dX}{dt} = (r_0 + aS)X\left[1 - \frac{X}{K}\right] - H \tag{3.5}$$

Sustainable equilibrium of the population dynamics model occurs when setting *dX/dt=0;* the MSPM helps to find the MSY of the fish resources exploitation in the reservoir, it indicates that the catch rate should not exceed the MSY level to ensure sustainable harvesting, and the fish resources are overexploited when sustainable yield is reduced to a level below MSY.

Replacing Eq. (3.2) into Eq. (3.5) and rearranging Eq. (3.5), the stock biomass can be expressed in equilibrium condition as:

$$X_{(E,S)} = K\left(1 - \frac{qE}{r_0 + aS}\right) \tag{3.6}$$

Substituting Eq. (3.6) into Eq. (3.2) and rearranging Eq. (3.2), the harvest rate is estimated in equilibrium condition as:

$$H_{(E,S)} = qEK\left(1 - \frac{qE}{r_0 + aS}\right) \tag{3.7}$$

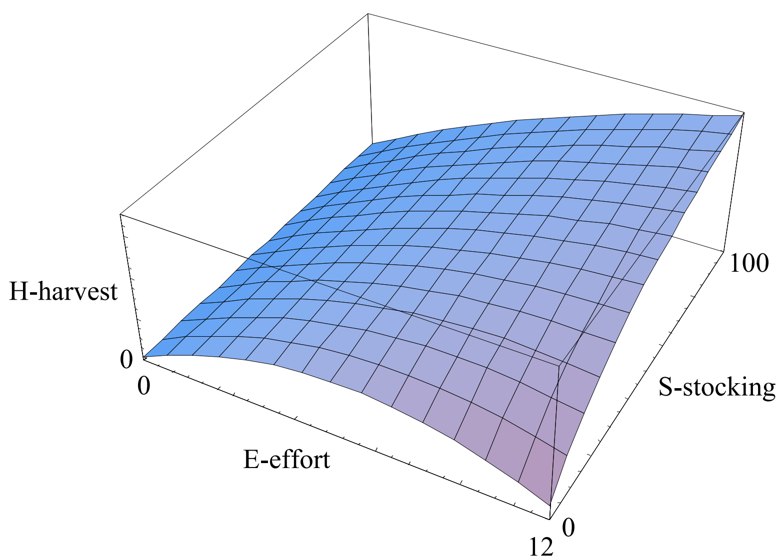


Figure 3.3. Plot of harvest curve versus effort level and stocking rate

The graph is plotted from Eq. (3.7), and shows relationship of harvest rate with effort and stocking. At a given stocking rate, Eq. (3.7) is quadratic in E, the effort is only positively increase in harvest rate up to a certain limit, after which yields decline. Whereas, at a given effort level Eq. (3.7) is a line up in *S*, the stocking is positively correlated to harvest rate.

We assume the constant q *(i.e.* no changes in gear or vessel efficiency have taken place), and biologically it implies that environmental conditions are constant/or no environmental factors affect the population. The intrinsic growth rate affected by stocked fish responds instantaneously to changes in biomass. The CPUE, a direct (proportional) index of stock abundance $X_{(E,S)}$, can be expressed as:

$$CPUE_{(E,S)} = qK\left(1 - \frac{qE}{r_0 + aS}\right) \quad (3.8)$$

3.3. Biological analysis

The SPM which utilizes catch and effort data has been used widely in fisheries management (Clark 1985; King 1995). Biological analysis help managers to know levels of change in population biomass per unit of time, the MSY is introduced as the simplest management objective that shows the level of biological stock not being exploited too heavily without an ultimate loss of productivity (Clark 1990). Applying annual effort level E_{MSY} and stocking rate S_{MSY} will produce the maximum harvest of fish that can, in theory, be caught year after year indefinitely into the future.

The MSY can be obtained when partial derivative of harvest function in the long run (see Eq. 3.7) that depends on effort or stocking variables equals zero, as follows:

$$\begin{cases} \dot{H}_{(E)} = qK - \dfrac{2q^2KE}{(r_0 + aS)} = 0 & (3.9) \\[2ex] \dot{H}_{(S)} = \dfrac{aE^2q^2K}{(r_0 + aS)^2} = 0 & (3.10) \end{cases} \Bigg\} \qquad \begin{aligned} E_{MSY} &= \frac{r_0 + aS_{MSY}}{2q} & (3.11) \\[2ex] S_{MSY} &= \frac{2E_{MSY}q - r_0}{a} & (3.12) \end{aligned}$$

The E_{MSY} can be estimated based on Eq. (3.9). While, $\dot{H}_{(S)}$ in Eq. (3.10) is always positive or $\dot{H}_{(S)} \rightarrow 0$ when $S \rightarrow +\infty$. The harvest is positively related to stocking rate (see Fig. 3.3), however stocking rate is technically and biologically limited in terms of stocking density. In context of stocking practices, technically the S_{MSY} cannot exceed a given maximum stocking quantity (see Table 2.1). The Eqs. (3.11) and (3.12) indicate that E_{MSY} is a function of S_{MSY} and vice versa, thus they cannot be solved separately. We carried out the numerical solution by Mathematica 5.2, the S_{MSY} is estimated and the E_{MSY} is also solved with a given range of stocking quantity. Inserting the E_{MSY} and S_{MSY} into Eq. (3.7), one has the local maximum yield.

3.4. Economic analysis

In order to analyze the interaction between human harvesting pressures, stocking and biological resource regeneration, economic analysis is used in the study of fisheries exploitation (Clark 1973; Lokina 2000; Seijo *et al.* 1998). Economic analysis can help managers to answer the questions of why resources are used as they are, why fisheries are economically inefficient, and how fisheries could be better managed (Hannesson 1993; Jennings *et al.* 2001).

The total fishery cost and total revenue are essential in an economic analysis. It is assumed that the objective is to maximize the resource rent of the fishery. Cost per unit of effort C_1, cost per unit of stocking C_2 and harvested fish price p are constants being used for economic analysis. In the long run, we assume that vessels are homogenous with respect to cost and catchability, C_1 is constant and equal for all vessels. The reason for this is the long run perspective where it is reasonable to assume that adding homogenous vessels to the fleet can expand effort at a constant C_1 (Flaaten 2004). The C_2 varies slightly among types of stocked species, thus we also assume that C_2 is a constant. The p is largely dependent on the quality of landed fish that is mixed fish, however, mixed fish caught should be treated as an aggregated fish stock in order to estimate an average fish price, and let us assume that p is constant. Introducing a bioeconomic model, in which:

Total cost TC is the sum of cost for effort and cost for stocking, it is a function of effort and stocking:

$$TC_{(E,S)} = C_1E + C_2S \qquad (3.13)$$

Fish price multiplied by harvest rate in Eq. (3.7) gives the total revenue TR, it is a function of effort and stocking:

$$TR_{(E,S)} = pqEK\left(1 - \frac{qE}{r_0 + aS}\right) \qquad (3.14)$$

The economic rent/or profit Π is the difference between TR and TC, it is also a function of effort and stocking:

$$\Pi_{(E,S)} = pqEK\left(1 - \frac{qE}{r_0 + aS}\right) - \left(C_1E + C_2S\right) \qquad (3.15)$$

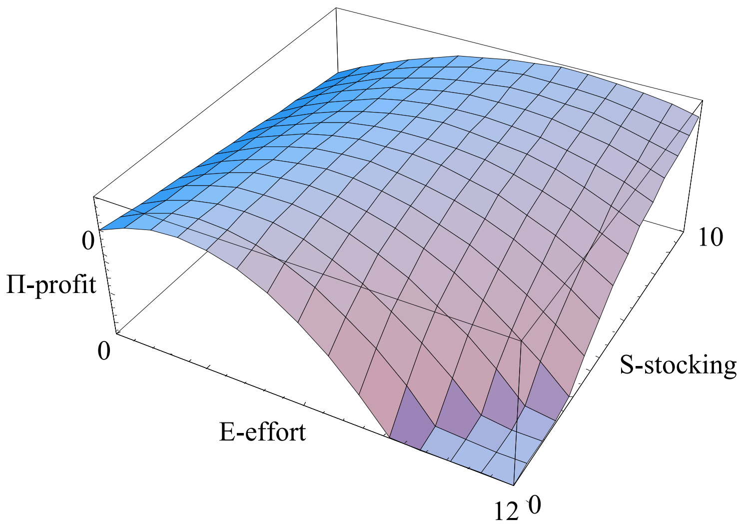


Figure 3.4. Plot of profit curve versus effort level and stocking rate

The graph is plotted from Eq. (3.15), and shows the relationship of fishing profit with effort and stocking. At a given stocking rate, Eq. (3.15) is quadratic in E, the effort is only positively increase in the profit up to a certain limit, after which the profit declines. Whereas, at a given effort level Eq. (3.15) is line in *S*, the stocking is mostly positive trend to the profit. However, if high effort level combined with low stocking rate and vice versa will produce negative profit, thus the fishing profit is managed by simultaneous control on both stocking rate and effort level.

3.4.1. MEY, the corresponding effort and stocking rate

Regarding economic efficiency in the fishery, an aspect that needs to be considered in the harvesting of fish resources is the maximization of the economic rent (Lokina 2000). That refers to attaining the economic equilibrium, which is referred to as the MEY. It is important not only because it protects fish stock and guarantees sustainability, but also because it assures that resources will be allocated to the fishery correctly and in a way that maximizes the returns from fishing (Kompas 2005). Setting annual effort level E_{MEY} and stocking rate S_{MEY} generate theoretically a maximum level of sustainable economic rents from the fishery, obtainable each year indefinitely into the future. The MEY is attained when the partial derivative of profit function (Eq. 3.15) that bases on effort or stocking variables equals zero as follows:

$$\dot{\Pi}_{(E)} = -C_1 + pqK\left(1 - \frac{2qE}{r_0 + aS}\right) = 0 \quad (3.16)$$

$$\dot{\Pi}_{(S)} = -C_2 + \frac{aE^2q^2Kp}{(r_0 + aS)^2} = 0 \quad (3.17)$$

$$E_{MEY} = \frac{(-C_1 + Kpq)(r_0 + aS_{MEY})}{2Kpq^2} \quad (3.18)$$

$$S_{MEY} = \frac{E_{MEY}q\sqrt{a}\sqrt{K}\sqrt{p} - r_0\sqrt{C_2}}{a\sqrt{C_2}} \quad (3.19)$$

The E_{MEY} can be estimated by Eq. (3.16), and solving Eq. (3.17) gives two values of S_{MEY} but the negative value is excluded. The E_{MEY} is a function of S_{MEY} and vice versa. In general, to obtain MEY, the E_{MEY} and S_{MEY} cannot be solved separately, and then one value of E_{MEY} and S_{MEY} respectively has been determined by the numerical solution from Mathematica 5.2. As mentioned above, technically the S_{MEY} cannot exceed a given maximum stocking quantity (see Table 2.1). Thus, the S_{MEY} is estimated with this range, and the E_{MEY} is also calculated. The local maximum yield is estimated by inserting E_{MEY} and S_{MEY} into Eq. (3.7).

3.4.2. OAY, the corresponding effort and stocking rate

Fisheries based on biological highly productive resources with large *r* and *K*, may sustain a large fishing effort under open access (Flaaten 2004). In some cases, stocking is to develop a largely culture-based fishery while maintaining high exploitation rate, it helps to curb unemployment through fishery development (Lorenzen *et al.* 2001). Thus, the stocked fisheries may take place in an open access system. Applying annual effort level E_{OAY} and stocking rate S_{OAY} will still produce normal profits for the fishermen but zero economic rents from the fishery. The OAY is obtained when total cost (Eq. 3.13) equals total revenue (Eq. 3.14) as:

$$pqEK\left(1-\frac{qE}{r_0+aS}\right)=C_1E+C_2S \tag{3.20}$$

$$\begin{cases} E_{OAY}=\dfrac{-C_1r_0+Kpqr_0-aC_1S_{OAY}+aKpqS_{OAY}}{2Kpq^2}+ & (3.21)\\[2ex] \quad +\dfrac{\sqrt{\left(C_1r_0-Kpqr_0+aC_1S_{OAY}-aKpqS_{OAY}\right)^2-4Kpq^2\left(C_2r_0S_{OAY}+aC_2S_{OAY}^2\right)}}{2Kpq^2} & \\[3ex] S_{OAY}=\dfrac{-aC_1E_{OAY}+aE_{OAY}Kpq-C_2r_0}{2aC_2}- & (3.22)\\[2ex] \quad -\dfrac{\sqrt{\left(-aC_1E_{OAY}+aeKpq-C_2r_0\right)^2+4aC_2\left(-E_{OAY}^2kpq^2-C_1E_{OAY}r_0+E_{OAY}Kpqr_0\right)}}{2aC_2} & \end{cases}$$

Solving Eq. (3.20) gives two values of E_{OAY} and S_{OAY} respectively, and the small values are excluded because the main purpose of an open access system is maximum employment (see Fig. 3.5). The E_{OAY} is a function of S_{OAY} and vice versa, thus E_{OAY} and S_{OAY} cannot be solved separately. Technically, the S_{OAY} cannot exceed a given maximum stocking quantity (see Table 2.1). The E_{OAY} and S_{OAY} can be calculated by the numerical solution from Mathematica 5.2, with a given range of stocking quantity. The OAY is achieved by inserting E_{OAY} and S_{OAY} into Eq. (3.7).

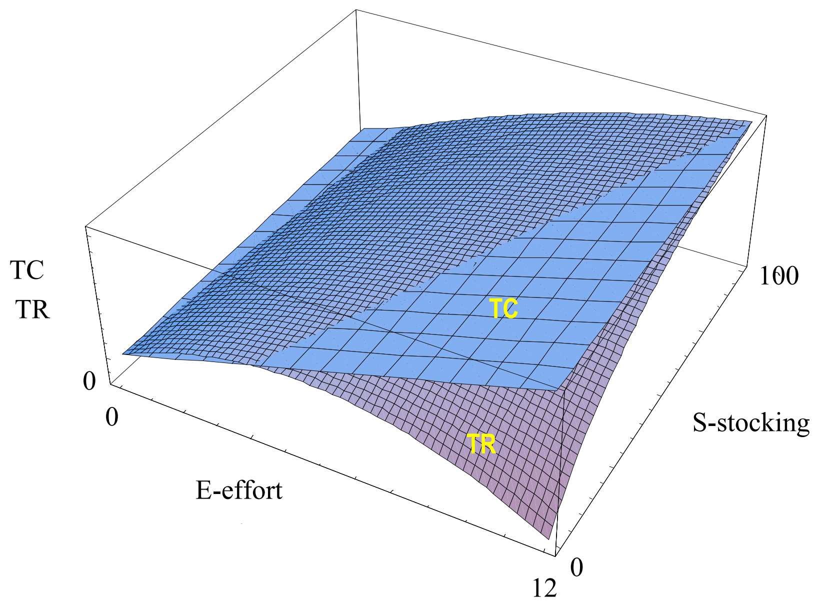


Figure 3.5. Plotted curves of TR, TC vs. effort and stocking

The graph is plotted from Eqs. (3.13) and (3.14), and shows the relationship of total cost and total revenue with effort and stocking. The TC curve intercepts the TR curve at two points, but only the intercepted point that produces the higher effort level and stocking rate is selected because of maximum fishing employments in open access systems.

Chapter IV

DATA AND PARAMETERS ESTIMATION

4.1. Type of data

To carry out the study, time-series of data (1999-2005), which is considered more accurate and sufficient to set up a detailed modified surplus production model, was gathered on the following variables catch, effort, harvested fish price, stocking and fishing cost. Data on catch, effort and cost of stocking were collected from the DNFC, and the fishing cost data came from the survey in July 2005 and cited from research in 2004 of Agriculture and Forestry University.

4.1.1. Catch and effort data

The DNFC has recorded catch and effort data through the Fisheries Tax Office and surveyed fishing data (see Table 4.1). The DNFC has annually implemented collection of statistics for catch/effort data by types of fishing gears, and fishing effort data have been recorded and being represented by number of households, boats and days of fishing (see Appendix 2).

Table 4.1. Actual catch and efforts data of capture fisheries, 1993-2005

Year	Catch (tons)	Type of fishing effort		
		No.of fishing households	No.of fishing boats	No.of fishing days
1993	800	300	-	-
1994	833	400	-	-
1995	1,126	550	-	-
1996	1,475	748	-	-
1997	1,825	800	-	-
1998	1,840	1,234	-	-
1999	2,269	1,136	992	147,602
2000	2,301	1,470	1,470	143,363
2001	2,786	1,237	1,020	125,840
2002	3,118	892	822	162,065
2003	3,080	978	978	165,354
2004	2,835	898	898	148,937
2005	2,589	872	809	132,520

[Source: data cited from DNFC (2005)]

4.1.2. Cost of fishing effort data

Operating costs reflect method, intensity of fishing effort and the amount of capital invested in the study site. Two types of cost for fishing activities are in Table 4.2, as follows:

1. The fixed costs are calculated in terms of the payment for fishing tax and depreciation of both fishing boat and gear used in Tri An reservoir; and
2. The variable costs include the costs of bait, energy, cost for gear and boat repairing, other accessories and actual labors costs.

All cost data were collected from 116 surveyed fishing households in 2004 of Agriculture and Forestry University (Vietnam) and 22 surveyed fishing households in July 2005. The average cost of fishing was 17.26 million VNDs/year for a fishing household operation (see Table 4.2).

Table 4.2. Average investment fishing costs of households (2004-2005)

Type of costs:	Value *(million VNDs/household)*	% of total cost
Fixed costs:		
Depreciation of boat	0.60	3.47
Depreciation of gear	2.60	15.08
Operating tax	2.21	12.83
Variable costs:		
Operating costs	9.29	53.82
Labors	2.55	14.80
Total cost	17.26	100.00

[Source: data calculated and cited from FAU (2004) and Survey in July 2005]

4.1.3. Harvested fish price data

Harvested fish price data have annually been recorded from 1999 to 2005 through the Fisheries Tax Office and annual fisheries statistics by 17 types of fishing gear from the DNFC. However, fish price depends on species caught and species group, some of them are very expensive and another is low (see Appendix 2).

4.1.4. Fish stocking data

Fish stocking data, containing quantity and weight of stocked fish, fish composition and fish stocking cost, has been recorded since 1993 through the Technical Fisheries Office of the DNFC (see Table 4.3 and Appendix 1). The cost per unit of stocked fish C_2 was about 25,000 VNDs per kg of fingerlings/or 150 fingerlings, therefore, the total cost of stocking is the cost of all individual stocked fish multiplied by cost per unit of stocked fish (DNFC 2005).

Table 4.3. Fish stocking activity in Tri An reservoir, 1993-2005

Year	Number of species stocking	Fish stocking		
		Quantity (fingerlings)	Weight (kg)	Total cost (million VNDs)
1993	0	0	0	0
1994	0	0	0	0
1995	8	1,300,000	8,827	220.68
1996	8	1,900,000	12,900	322.50
1997	8	5,006,000	33,986	849.65
1998	8	1,000,000	6,789	169.73
1999	8	1,317,000	8,941	223.53
2000	6	1,200,633	7,233	180.83
2001	8	1,500,165	11,056	276.40
2002	8	1,168,705	8,178	204.45
2003	8	868,348	5,698	142.45
2004	0	0	0	0
2005	0	0	0	0

[Source: data cited from DNFC (2005)]

4.2. Data analysis

4.2.1. Effort standardization

To get one measure of fishing effort for the annual total catches, the effort values from individual gear type had to be converted into standard units of effort. According to Mark & Andre (2004), various methods for standardizing catch and effort data have been developed by Gulland (1956), Beverton and Holt (1957), Robson (1966), and Honma (1973). However, the approach developed by Beverton and Holt (1957) was commonly applied, this method involves selecting a 'standard vessel/gear' and determining the relative fishing power of all other vessels/gears (Beverton & Holt 1993).

In this study, fishing effort is described in terms of the number of fishing days, number of boats and number of households used associated with types of fishing gears. The data showed that the fishing gears used most frequently are the sprat scoop nets, gillnet 1, gillnet 2 and shrimp basket traps. The gillnet 1 is selected as standardized gear for 17 types of fishing gear. There are several criteria to select this gear, as follows:

i. Gillnet 1 is a main fishing gear, and being used as commercial and full-time fishing in the study site;
ii. The number of households and boats use of gillnet 1 is higher;
iii. The composition of fish caught by gillnet 1 is the most diversified; and
iv. Gillnet 1 contributes higher catches to fish production of the reservoir.

The fishing effort is measured in days of fishing, and the effort values from individual gear type are converted into standard effort unit, the "gillnet 1". The set of fishing gears are labeled from 1 to 17, and the total catches of each fishing gear is H_1, H_2,...H_{17}, respectively, and the corresponding levels of fishing effort are E_1, E_2,...E_{17}. Therefore, the CPUE of fishing gear *i* is defined as:

$$CPUE_i = \frac{H_i}{E_i} \tag{4.1}$$

Where $CPUE_i$ is catch per unit of effort of gear i, H_i is catch of gear i, E_i is effort of gear i, and i is type of fishing gear used.

The Gillnet 1 denoted as gear number 1 being chosen as the standard fishing unit in this study. The stock was assumed to follow logistic growth, then a year-by-year procedure is used to obtain the standardized effort values, and then total standardized fishing effort can be calculated as:

$$E_S = E_1 + \sum_{i=2}^{17} \frac{CPUE_i}{CPUE_1} E_i \tag{4.2}$$

Where E_S is total standardized effort, E_1 is effort of gillnet 1, E_i is effort of gear i, $CPUE_1$ is catch per unit of effort of gillnet 1, $CPUE_i$ is catch per unit of effort of gear i, and i is type of fishing gear used.

Table 4.4 shows the converting factors for dominant gears and the effort standardizations respectively; whereas cast nets, spears, seine nets, lift-nets and small traps were also treated and presented in the same group "others" because of less important and less frequent using in the reservoir.

Table 4.4. Effort standardizations by type of fishing gears from 1999 to 2005

Gears:	Items:	1999	2000	2001	2002	2003	2004	2005
Gill net 1	Actual effort[1]	77.13	56.35	32.33	31.25	40.58	38.04	35.50
	Factor[2]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Std. effort[3]	77.13	56.35	32.33	31.25	40.58	38.04	35.50
Gill net 2	Actual effort[1]	4.56	9.25	18.55	22.95	21.75	18.25	14.75
	Factor[2]	3.56	0.65	0.54	0.65	0.93	1.10	1.36
	Std. effort[3]	16.22	5.99	10.09	14.81	20.15	20.08	20.01
Long line	Actual effort[1]	3.75	9.14	8.71	8.16	13.25	11.28	9.31
	Factor[2]	0.46	0.56	0.69	0.96	0.76	0.85	0.98
	Std. effort[3]	1.72	5.14	6.04	7.82	10.10	9.60	9.11
Scoop net 1	Actual effort[1]	2.85	2.53	7.60	6.80	7.90	7.50	7.10
	Factor[2]	4.52	6.58	6.13	7.60	8.97	9.03	9.11
	Std. effort[3]	12.89	16.64	46.55	51.70	70.87	67.76	64.67
Shrimp basket trap	Actual effort[1]	23.20	46.14	27.25	52.85	48.25	43.63	39.00
	Factor[2]	0.49	0.31	0.32	0.37	0.53	0.49	0.44
	Std. effort[3]	11.35	14.48	8.76	19.70	25.45	21.22	16.97
Sprat scoop net	Actual effort[1]	16.12	6.81	7.85	9.90	8.93	8.29	7.65
	Factor[2]	4.67	7.08	7.47	7.93	10.11	10.01	9.89
	Std. effort[3]	75.27	48.23	58.63	78.55	90.25	82.95	75.63
Trawl net	Actual effort[1]	9.35	3.12	6.02	7.60	3.25	2.69	2.12
	Factor[2]	1.34	1.06	0.95	1.14	3.44	4.39	5.84
	Std. effort[3]	12.52	3.32	5.71	8.66	11.19	11.79	12.40
Others[4]	Actual effort[1]	10.65	10.03	17.54	22.56	21.45	19.27	17.09
	Factor[2]	0.31 ÷4.69	0.22 ÷3.62	0.31 ÷4.02	0.92 ÷3.58	0.84 ÷6.98	0.83 ÷7.01	0.78 ÷3.82
	Std. effort[3]	28.69	20.05	25.25	33.71	45.57	38.88	32.15
Total standard effort		235.8	170.2	193.4	246.2	314.2	290.3	266.4

1. Data are calculated from data presented by DNFC (2005), with unit in 1,000 fishing days.
2. Converting factors estimated base on gillnet 1 as standard gear, and Eqs. (4.1) and (4.2).
3. Data estimated base on Eqs. (4.1) and (4.2), with unit in 1,000 fishing days.
4. Present other gears with converting factor varied largely from 0.31 to 7.01.

4.2.2. Cost of fishing effort and fish price estimation

We assume that the gears/vessels are homogenous with respect to cost and catchability, because in the long run adding homogenous gears/vessels to the fleet can expand effort when setting a constant cost per unit of effort C_1 for all gears/vessels (Flaaten 2004).

A cost-efficiency analysis of all gears can be implemented to select the most cost-efficient. The interest rate of capital investment may be evaluated to find the fishing gear that produced the most cost-efficient, and it can be expressed as:

$$IR_i = \frac{R_i - C_i}{C_i} 100 \qquad (4.3)$$

Where IR_i is interest rate of capital investment, R_i is total revenue of gear i , and C_i is total cost of gear i operating that includes fixed costs and variable costs.

The cost per unit of effort for this study can be estimated as: $C_1 = \frac{C_i}{E_{iS}}$ (4.4)

Where C_i is total cost of gear i that can be produced the most cost-efficiently, and E_{iS} is effort standardization that is converted into standard units of the "gillnet 1".

Table 4.5 shows that "Seines net 1" is produced in the most cost-efficient manner, therefore its cost per unit of effort can be selected for this study. The cost per unit of effort for fishing in Tri An reservoir was 64,867 VNDs.

The average harvested fish price of "Seines net 1" was 12,429 VNDs/kg. However, this price cannot be attained for aggregate fish caught that are multi-species, and may not be applied for this study, some reasons are:

i. The "Seines net 1" often harvests the big fish, with a range of mesh size from 4 to 14cm. Thus, price of harvested fish was always higher than that of others.

ii. The fish fauna in the reservoir are multi-species resources, so the price of harvested fish varies largely and depends on species caught in terms of harvested size, fish quality and type of fishing gear used.

iii. According to fishermen and wholesalers interviewed, they indicated that the average of aggregate fish caught price was generally around 5,500 VNDs/kg.

The results of cost-efficiency analysis show the average interest rate was always positive for all gears (see Table 4.5). Mixed fish of harvested fish should be treated as an aggregated fish stock, hence, in order to estimate an average price of harvested fish for this study; the weighed data method was applied and expressed as:

$$p = \frac{\sum_{i=1}^{17} PGA_i . TCC7_i}{\sum_{i=1}^{17} TCC7_i} \tag{4.5}$$

Where p is the average of harvested fish price, i is type of fishing gears, PGA_i is the fish price of gear i, and $TCC7_i$ is total catch in 7 years of gear i (data: 1999-2005).

Based on Eq. (4.5), the average price of landed fish in Tri An reservoir was 5,485 VNDs per kg (see Appendix 2).

Table 4.5. Cost-efficiency analysis by fishing gears

Type of gears[1]	Total Cost[2]	Total Revenue[2]	Interest rate[3]	Fish price[4]	Stand. Effort[5]	Cost per unit of effort[6]
Gill net 1	10.04	12.69	26.40	4.750	150.79	66.56
Gill net 2	13.07	25.95	98.58	6.67	248.42	52.61
Long line	8.49	25.51	200.47	9.80	144.49	58.75
Scoop net 1	32.08	33.07	3.09	5.69	1688.05	19.00
Shrimp basket trap	25.45	44.29	74.03	10.80	78.41	324.57
Sprat scoop net	11.64	44.43	281.61	3.03	1402.48	8.30
Trawl net	13.42	33.05	146.33	8.20	671.72	19.97
Seines net 1	36.77	140.35	281.66	12.43	566.91	64.87
Seines net 2	26.85	35.18	31.04	5.67	354.03	75.83
Shrimp pull net	20.50	52.89	158.03	9.00	286.47	71.55
Mussel trawl net	8.48	18.51	118.40	8.93	155.28	54.59
Small cast net	7.17	15.60	117.57	5.00	167.86	42.71
Lift net 2	10.05	11.93	18.65	5.50	259.13	38.80
Big cast net	15.53	18.14	16.81	10.00	394.05	39.41
Scoop net 2	24.23	27.31	12.70	5.50	368.13	65.82

1. Missing values of "Lift-net 1" and "Spears". Data are calculated from data presented by 116 surveyed households in 2004 of FAU (2004) and 22 surveyed households in July 2005.
2. Data were estimated for operation of a fishing gear per year, with unit in million VNDs
3. Interest rate was estimated by Eq. (4.3), with unit in percent
4. Average harvested fish price (1,000 VNDs/kg)
5. Standardization effort was converted into standard units of Gillnet 1, with unit in number of days
6. Cost per unit of effort was calculated by Eq. (4.4), with unit in 1,000 VNDs/day of fishing.

4.3. Parameters estimation

When sustainable equilibrium occurs, CPUE is an index of stocked abundance that is expressed in Eq. (3.8). It is that change in CPUE from one year to the next dependent on effort and stocked fish levels. This is a complicated function whose parameters a, q, r_0 and K can be solved by a non-linear regression model (Gallant 1987). We carried out the numerical solution of Eq. (3.8) by Mathematica 5.2 Software (Wolfram 2005). Data on Table 4.1, 4.3 and 4.4 were used for solving Eq. (3.8). The estimation of parameters is showed in Table 4.6, Appendix 3, and the original CPUE equation is expressed as:

$$CPUE_{(E,S)} = 0.093561\left(0.20267 - \frac{0.018962E}{0.496084 + 0.0117891S}\right) \tag{4.6}$$

Most parameters are statistically significant, with p-values less than 0.05. The R^2 value is about 0.74, it means that 74% of CPUE variation is explained by the model. Consequently, the relationship of CPUE with effort and stocking rates is significant and has the expected signs. It indicates that stocking S is positively correlated to changes in CPUE, whereas effort E is negatively correlated to changes in CPUE values.

Table 4.6. Estimated parameters based on non-linear regression model

Parameters[1]:	Estimate	SE	t-stat	p-value	CI
q	0.093561	0.01808	5.17331	0.01402	0.036÷0.151
K	0.20267	0.02539	7.97981	0.00411	0.122÷0.283
r_0	0.496084	0.01283	38.65784	0.00004	0.455÷0.537
a	0.0117891	0.01437	0.82013	0.47223	-0.03÷0.058
ANOVA table:	DF	SS	MS	R^2	Variance
Model	4	0.000922	0.00023	0.73748	2.304×10^{-6}
Error	3	6.91×10^{-6}	2.31×10^{-6}		
Uncorrected Total	7	0.000929			
Corrected Total	6	0.000026			

[1] $CPUE_{(E,S)}$ is catch per unit of effort (tons/day); q is catchability coefficient (tons/100,000 days/year); K is carrying capacity (100,000 tons); $(r_0 + aS)$ is intrinsic growth rate affected by stocked fish; S is fish stocking (tons), and E is effort standardized (100,000 days). Assumption: there is no change in fishing technology over time, biologically environmental conditions are constant, and the multi-species fisheries is technical with no predator prey relationship.

Chapter V

RESULTS

5.1. Trends in catch, effort, CPUE and stocking

5.1.1. Trends of actual catch, effort and CPUE over time

Catch data reflects aggregate freshwater fish instead of a single species of harvested fish. This is because data on a particular species or even species groups are not available for the study site. Catch and effort increased quickly from 1993 to 2000, and then catch continued to increase and reached a peak of around 3,100 tons in 2002. Whereas, the effort reduced slightly up to now. The corresponding CPUE fluctuated largely over time, and has been declining in recent years (see Fig. 5.1).

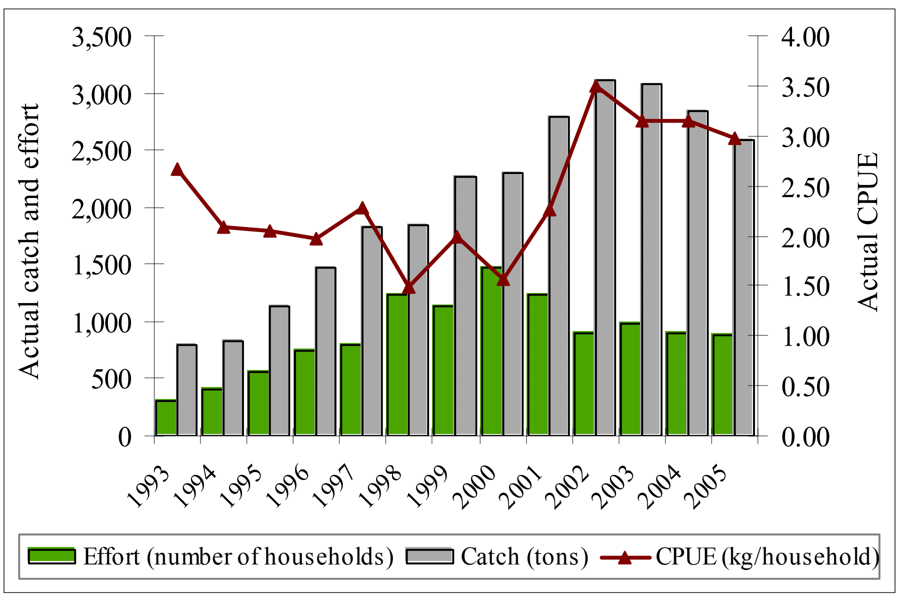


Figure 5.1. Trends of actual catch, effort and CPUE over time

5.1.2. Trends of standardized effort, catch, CPUE and stocking over time

Trends of standardized effort, catch[2] and stocking increased slightly from 2000 to 2003, and then dropped down after 2003 to 2005 (see Fig. 5.2 and Table 5.1). Recently, the decreasing number of fishing days may be explained by fishermen leaving or reducing their activity because of a poor fishing season, declining profit and interruption of the stocking program. Figure 5.2 also depicts that the standard

CPUE decreased gradually between 2000 and 2003, after that CPUE reduced faintly and tends to remain stable. This may indicate that fisheries resources were declining initially, and may be a reason for fishermen leaving the fishery in recent years.

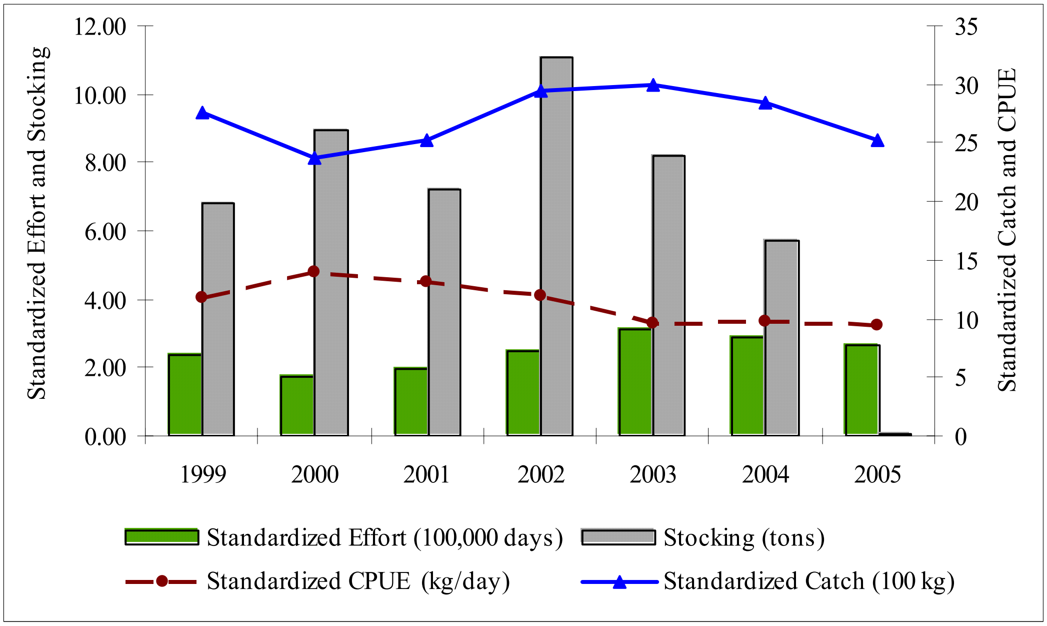


Figure 5.2. Trends in standardized catch, effort and CPUE, 1999-2005

Table 5.1. Standardized catch, effort and CPUE, 1999-2005

Year	Standard effort (10^5 days)	Fish stoking[1] (tons)	Standard CPUE (kg/day)	Standard catch[2] (tons)	Actual catch (tons)	Difference of catch[3] (tons)	
						(tons)	*(%)*
1999	2.36	6.79	11.70	2,759	2,269	-490	-17.77
2000	1.70	8.94	13.94	2,373	2,301	-72	-3.02
2001	1.93	7.23	13.06	2,526	2,786	260	10.29
2002	2.46	11.06	11.99	2,952	3,118	166	5.63
2003	3.14	8.18	9.56	3,002	3,080	78	2.59
2004	2.90	5.69	9.82	2,850	2,835	-16	-0.55
2005	2.66	0	9.45	2,517	2,589	72	2.87

1. The fingerlings are often introduced into the reservoir at the end of year (August - December), so the impact of stocking to population growth is assumed to begin from the following year.

2. "*Standardized catch*" or sustainable yield is theoretical harvest level, it is estimated by harvest function (Eq. 3.7) of the modified surplus production model in Chapter III.

3. It presents the difference between the actual catch and the standardized catch, and the ratio of the difference between the actual catch and the standardized catch to the standardized catch.

Table 5.1 shows the ratio of the difference between actual catch and standardized catch[2] to the standardized catch fluctuated from 0.55% to 17.77%. Actual catch tended to more than the standardized catch from 2001 (see Fig. 5.3); hence, the fisheries resources have been diminished.

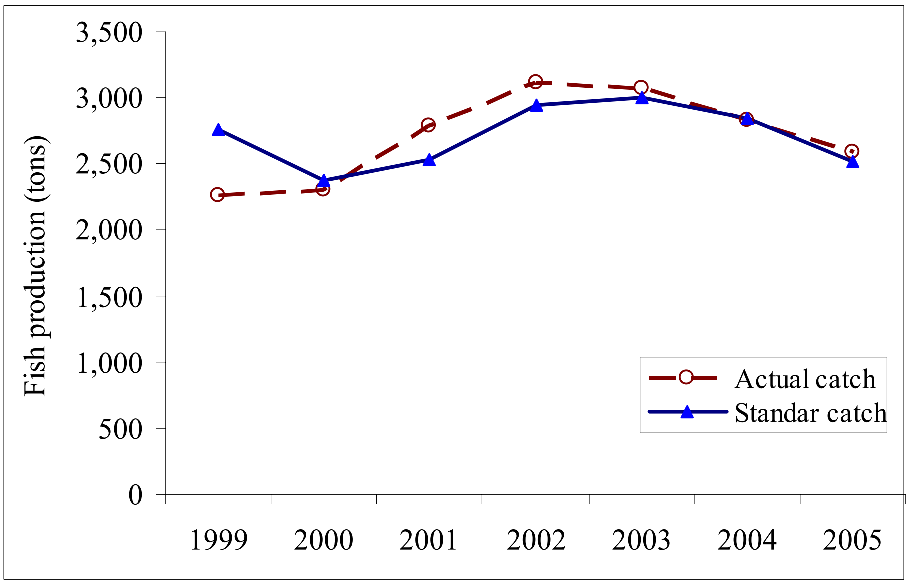


Figure 5.3. Trends of actual catch and standardized catch, 1999-2005

5.1.3. Relationship of standard CPUE with effort and stocking levels

Based on the parameters estimated by non-linear regression model (see Table 4.6), and replacing these parameters into Eq. (3.8), the CPUE equation found is plotted in Figure 5.4 and the below equation:

$$CPUE_{(E,S)} = 0.018962 - \frac{0.0017741E}{0.496084 + 0.0117891S} \qquad (5.1)$$

Where the unit of effort E is 100,000 days of fishing, stocking S is tons of stocked fingerlings, and catch per unit of effort $CPUE_{(E,S)}$ is tons per day of fishing.

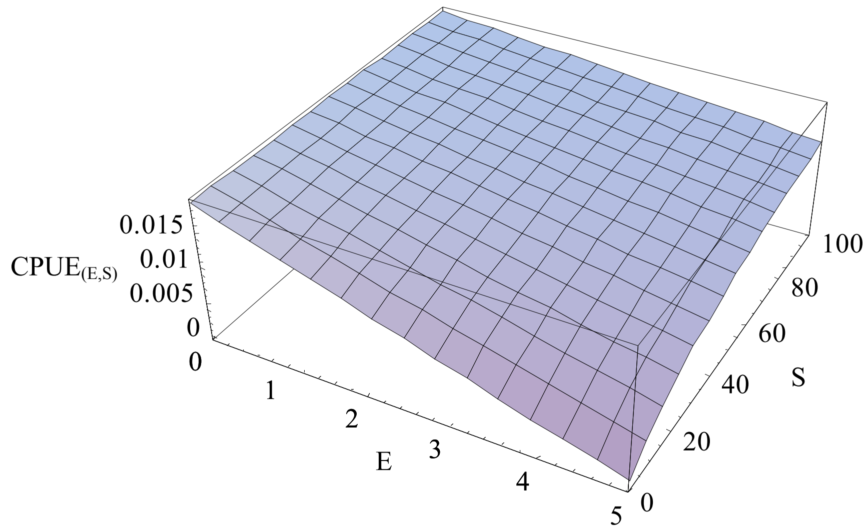


Figure 5.4. Plotted curve of standardized CPUE vs. effort and stocking

5.2. Impact of stocking on population growth and harvest regime

5.2.1. Impact of stocking on population growth

The MSPM found the population growth equation that was determined by substituting the parameters estimation in Table 4.6 into Eq. (3.4), and expressed as:

$$F_{(X,S)} = (0.496084 + 0.0117891S)X\left(1 - \frac{X}{20267}\right) \tag{5.2}$$

Where the unit of stock biomass *X* is tons, stocking *S* is tons of stocked fingerlings, and population growth $F_{(X,S)}$ is tons.

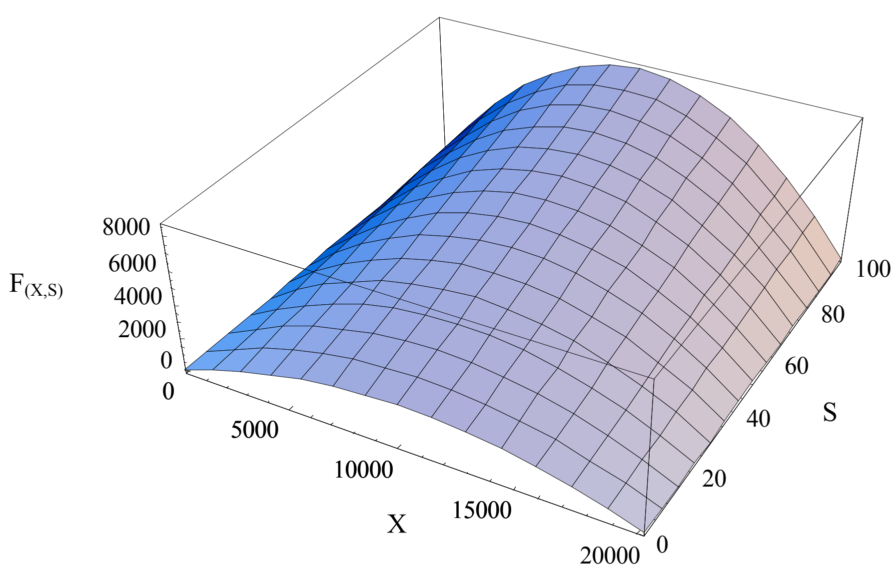


Figure 5.5. Population growth curve vs. stocking and stock biomass levels

5.2.2. Relationship of the harvest regime with effort and stocking levels

The harvest function for the capture fisheries based on Eq. (3.7), and by inserting of parameters estimated from Table 4.6 is expressed as the Eq. (5.3) and is depicted in Figure 5.6.

$$H_{(E,S)} = 1896.2E - \frac{177.41E^2}{0.496084 + 0.0117891S} \tag{5.3}$$

Where the unit of effort E is 100,000 days of fishing, stocking S is tons of stocked fingerlings, and harvest $H_{(E,S)}$ is tons.

Harvest function indicates that stocking is always positively trended to catch. Thus, the fish stocking is positive impact to natural growth rate in population that is found as the intrinsic growth rate equation: $r_s = 0.496084 + 0.0117891S$ (5.4)

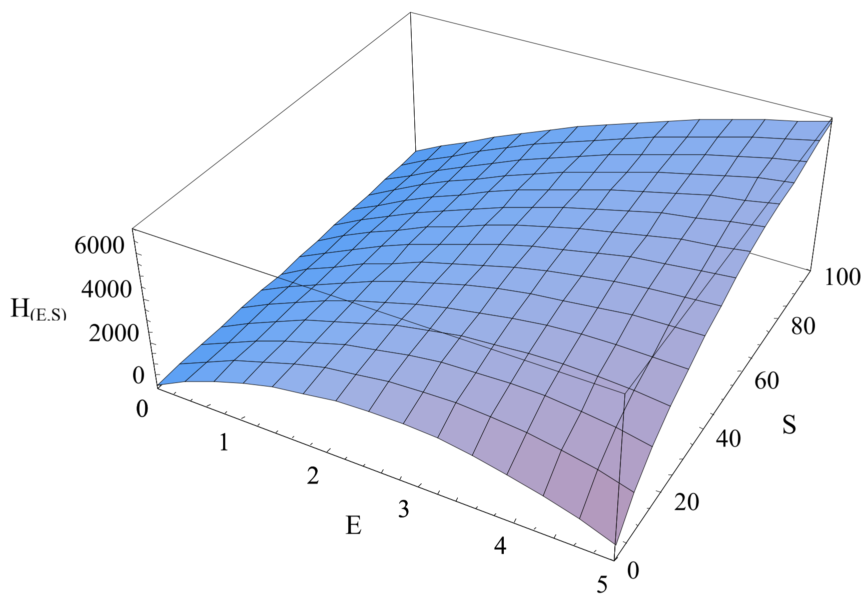


Figure 5.6. Plotted curve of harvest vs. effort and stocking

5.3. Estimations of reference points and economics rents

5.3.1. Relationship of the fishing profit with effort and stocking levels

The profit equation is aggregated from total revenue and total cost components; these were found as the below equations and plotted in Figure 5.7.

i. Total cost of fishing activities includes cost of effort plus cost of stocking, as:

$$TC_{(E,S)} = 6486.7E + 25S \tag{5.5}$$

ii. Total revenue of fishing activities is landed fish price multiplied by harvest, as:

$$TR_{(E,S)} = 10400.7E - \frac{973.096E^2}{0.496084 + 0.0117891S} \quad (5.6)$$

iii. Profit of fishing activities equals total revenue minus to total cost, as:

$$\Pi_{(E,S)} = 3913.96E - \frac{973.096E^2}{0.496084 + 0.0117891S} - 25S \quad (5.7)$$

Where the unit of effort E is 100,000 days of fishing, stocking S is tons of stocked fingerlings, and $TR_{(E,S)}$, $TC_{(E,S)}$, $\Pi_{(E,S)}$ are million VNDs.

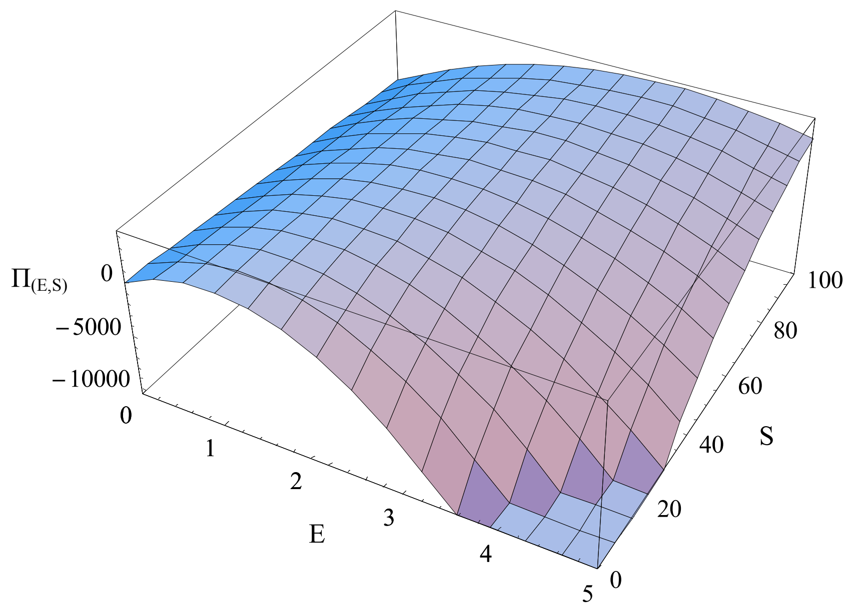


Figure 5.7. Plotted curve of profit vs. effort and stocking

5.3.2. Estimations of MSY, MEY, OAY and Economic rents

When sustainable equilibrium occurs, the MSPM was used to calculate the indicators of reference points for the fishery in the reservoir as presented in Table 5.2. The parameterized harvest function (see Eq. 5.3) indicates that fish harvested was positively correlated to the stocking rate. To estimate the reference points, the stocking rate and effort level have to be solved simultaneously. The stocking rate technically cannot exceed a given maximum stocking density, consequently, the values of MSY, MEY, OAY and the corresponding effort levels are local maximum values and limited in terms of a given range of stocking quantity.

Table 5.2. Calculation indicators of the reference points and economic rents

Items:	Harvest condition 1[1]			Harvest condition 2[2]			Harvest condition 3[3]			Current status[4]
	MSY	MEY	OAY	MSY	MEY	OAY	MSY	MEY	OAY	
Effort[5] (days of fishing)	265,113	99,767	199,534	315,514	118,734	232,243	895,133	336,855	602,258	266,444
Catch (tons)	2,514	1,536	2,360	2,991	1,828	2,783	8,487	5,186	7,578	2,589
Stocking[6] (tons)	0	0	0	8.00	8.00	8.00	100	100	100	0
Total Revenue (million VNDs)	13,787	8,424	12,943	16,408	10,025	15,265	46,550	28,443	41,567	14,200
Total Cost[7] (million VNDs)	17,197	6,472	12,943	20,666	7,902	15,265	60,565	24,351	41,567	19,197
+ Cost for fishing (million VNDs)	*17,197*	*6,472*	*12,943*	*20,466*	*7,702*	*15,065*	*58,065*	*21,851*	*39,067*	*19,197*
+ Cost for stocking (million VNDs)	*0*	*0*	*0*	*200*	*200*	*200*	*2,500*	*2,500*	*2,500*	*0*
Profit (million VNDs)	-3,410	1,952	0	-4,259	2,124	0	-14,015	4,092	0	-4,997

1. Harvest condition 1: stocking quantity is limited or not introduced into the reservoir.
2. Harvest condition 2: stocking quantity is actually introduced into the reservoir, with an average of 48 fingerlings/ha (i.e. corresponding 1.2 million fingerlings/year or 8 tons fingerlings/year). This rate of stocking is suitable with investment capacity of the DNFC at present.
3. Harvest condition 3: stocking quantity is set up at optimal level. Stocking rate technically cannot exceed a given maximum stocking density, with about 600 fingerlings/ha (i.e. corresponding 15 million fingerlings/year or 100 tons fingerlings/year) (see Table 2.1).
4. The current fishing status (in 2005), data calculated from DNFC (2005).
5. Standardized effort measured in terms of number of fishing days, if it is converted to the corresponding number of households, it will be an average of 156 fishing days per household per year.
6. Weight of fish fingerlings was introduced into the reservoir at different levels of investment capacity.
7. Harvested fish price is 5,485 VNDs/kg; cost per unit of effort is 64,867 VNDs/days of fishing; cost per unit of fish stocking is 25,000 VNDs/kg of fingerlings; and an average of 150 fingerlings/kg.

Regarding the capture fisheries in Tri An reservoir, the harvest condition can be separated to three levels that depend on given ranges of stocking quantity, as follows:

1. **Harvest condition 1**: fish stocking is limited or not introduced into the reservoir.
2. **Harvest condition 2**: stocking quantity is still kept as the same as the current level. Stocked density actually introduced was 48 fingerlings/ha. This rate of stocking is suitable with the current investment capacity of the DNFC.
3. **Harvest condition 3**: stocking quantity is set up at optimal stocking level. Stocking rate technically cannot exceed a given maximum stocking density, with about 600 fingerlings/ha.

As indicated in Table 5.2, the values of MSY level are different at the harvest conditions. When these estimated values are compared with the actual catch and effort values in Table 5.1, the MSY at the harvest condition 1 was attained back in late 2001. At the harvest condition 2 the MSY level occurred back to 2002, whereas, value of MSY at the harvest condition 3 was never reached before total catch stated reducing (see Fig. 5.8).

On the other hand, there are different values of MEY level related to three harvest conditions respectively. Comparing these values with the actual catch and effort figures in Table 4.1 and Table 5.1, at the harvest condition 1 and 2, the MEY level was attained back in late 1996 and 1997, respectively, while the MEY level at harvest condition 3 has never been reached (see Fig. 5.8 and Fig. 5.9).

Regarding the issue of open access at different harvest conditions, Table 5.2 also shows that the values of OAY level are different. Compared to figures in Table 4.1 and Table 5.1 indicated that values of the OAY level were reached in late 2000 and 2001 related to harvest conditions 1 and 2, respectively. At harvest condition 3, the OAY level is still not attained, because the stocking program was not funded sufficiently to ensure the maximum stocking quantity.

The computed total revenues, total costs and economic rents using the MSPM are also shown in Table 5.2. Considering the economic efficiency, if operated at MSY target, the fishing profit is always negative at all harvest conditions. Conversely, if operated at MEY target, the positive profit increases from 1,952 to 2,124 and 4,092 million VNDs associated to the harvest condition 1, 2 and 3, respectively.

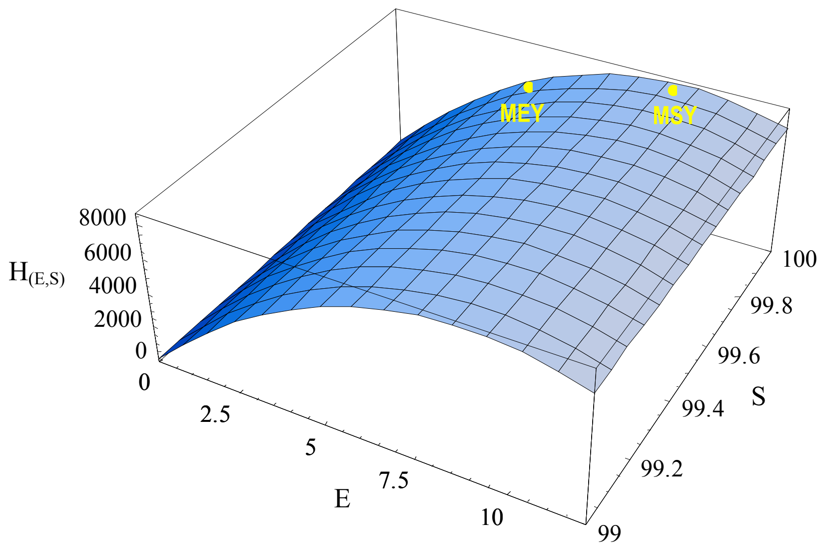


Figure 5.8. Harvest curve vs. stocking and effort at harvest condition 3

The graph is plotted from Eq. (5.3) in the case of optimal stocking; it shows that MSY may reach at 8,487 tons when effort level is set up at 895,133 days of fishing. MEY value may attain at 5,186 tons as long as the corresponding effort level is set up at 336,855 days.

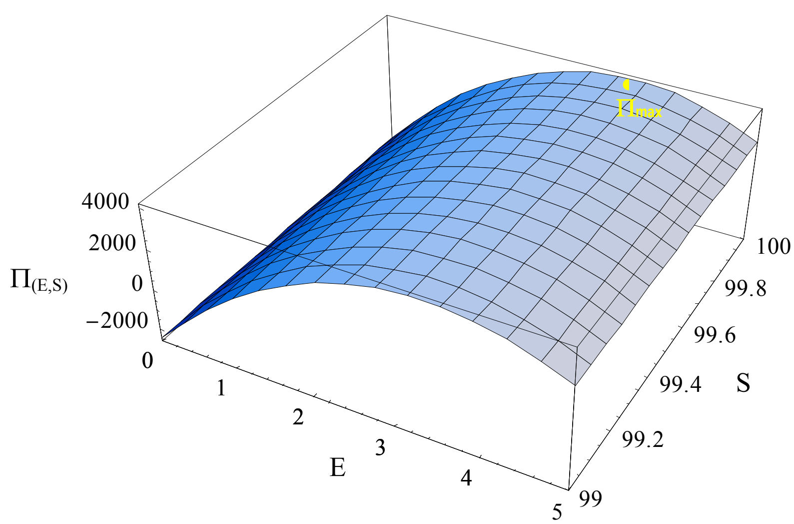


Figure 5.9. Profit curve vs. stocking and effort at harvest condition 3

The graph is plotted from Eq. (5.7) in the case of optimal stocking; it shows that maximum profit may attain at 4,092 million VNDs when effort level is set up at 336,855 days of fishing.

Chapter VI

DISCUSSION AND CONCLUSION

6.1. Discussion

6.1.1. Impact of fish stocking on population dynamics

Restocking and conservation measures are frequently implemented where the fisheries resources have been overexploited or suffered environmental perturbation. Introduction of fish into a reservoir may improve fish production where native stocks have declined due to overfishing (Muli 1998; Welcomme 1998). Stocking may thus be a method to meet to the problem of overexploitation (Cowx 2002). The major aims of the stocking program in the reservoir are biological control and balancing a depleted fish population, however the impact of stocking to fish population dynamics was not considered in previous studies. This study initially points out the relationship between stocking and the rate of population change. The MSPM describes one possible interaction between fish stocking and population growth (see Eq. 5.2).

The stocking rate is found to be positively correlated to population growth, as the change in population biomass per unit of time increased rapidly when many fingerlings were introduced into the reservoir (see Fig. 5.5). Most of the stocked species are non-predatory species, mostly plantivorus, zooplankton, organic detritus and/or periphyton species, with the dominant species of Silver carp and Big head carp (see Fig. 2.3). According to Luu (1998) and Luong *et al.* (2004), development of these stocked species relies on natural food within the reservoir being ecologically sound and most likely more sustainable. In addition, previous studies also point out that these stocked fish are unable to reproduce locally or to adapt and compete successfully with the local species in terms of growth and competition for food in the reservoir (Ali 1998; An 2001; Hao 1997). Consequently, the stocking needs to compensate for recruitment overfishing, and to maintain the fisheries productivity of a water body at the highest possible level (Welcomme 1998). The findings of this study and results of previous studies indicate that fish stocking in the reservoir is positively related to changes in population growth and leads to a faster increase in the population biomass compared with growth in the case of no stocking.

6.1.2. Influence of fish stocking on harvesting regime

In order to evaluate the role of stocking in enhancing fish production, the fish yield or harvest level needs to be considered (An 2001; Cowx 1998). Stocking in inland waters in Southeast Asia is proven and recognized as a successful methods of increasing and sustaining fish catch (An 2001; Li & Xu 1995; Welcomme 1998). In connection to this study, the findings in Figure 2.4 and Figure 5.2 showed that the yield increased considerably when fish fingerlings were stocked into the reservoir, compared to the year before the stocking program. The stocking was positively trended to change in catch; it led to an increase in actual catch from 2,269 tons in 1999 to 3,118 tons in 2002, corresponding to an increase in stocking quantity. After that, the actual catch reduced as a result of stocked fish quantity declining (see Table 5.1). The MSPM also found the harvest function for fishing activity in the reservoir (see Eq. 5.3).

The change of harvest level depended on stocking rate and effort level (see Eq. 5.3 and Fig. 5.5). This indicates that the higher rate of stocking led to the greater yields of harvested fish levels, while the effort rate was only positively increased in harvested fish up to a certain limit, after which yields decline. Stocked fisheries can be managed by changing the stocking rate or the fishing effort; however, they need to be controlled by simultaneous change in both effort level and stocking rate. The important issue of stocking management should define and note that high effort rates combined with low stocking density leads to overfishing, conversely, leading to overstocking/or superfluous stocking quantity (Lorenzen 1995). Welcomme (1998) notes that effort and stocking are positively correlated and increases in yield should be achieved by simultaneous increases in both effort and stocking rates, although an initial reduction in effort may be needed to give the stocked population time to establish.

6.1.3. Overfishing issues in the reservoir

In many cases, signs of overfishing are typically indicated in fisheries by decline in CPUE, reduction in size of capture, loss of large-sized species, and change in exploitation to smaller, less valued fish species (Clark 1985; Cowx 2002; Lokina 2000). In order to show whether or not overfishing indeed exists in the reservoir, CPUE is an index of abundance and level of fisheries resources exploitation. The MSPM indicated that relationship of CPUE with stocking and effort rates was defined as Eq. (5.1).

The CPUE was in negative trend with effort level and positive trend with stocking rate (see Eq. 5.1 and Fig. 5.4). The results in Table 5.1, Figure 5.2 and Figure 5.4 indicated that CPUE reduced gradually from 13.94 kg per fishing day in 2000 to 9.45 kg per fishing day in 2005, the tendency of CPUE corresponded to variations of effort and stocking rates at that time. Regarding effort in number of fishing households (see Fig. 5.1), the trend of CPUE decreased in the first three-year period, and then it increased quickly until 2002 as the positive results of the stocking program became evident. However, from 2003 up to now the CPUE has reduced steadily. It is evidence to conclude that the current fisheries resources in the reservoir are diminished and show signs of overfishing, and may suggest sustainability of the resource is under threat. Tung *et al*. (2004) and Hao (1997) report that aquatic resources of the reservoir have been reduced in terms of quantity and size of fish in recent years.

The trend of catch also showed that actual fish harvested has been more than the standardized catch from 2001 (see Table 5.1 and Fig. 5.3), so the fisheries resources have tended to be degraded. In addition, the decline in effort in last three years may be a sign of dwindling fisheries resources in the reservoir. Although the price of harvested fish has increased recently as an impact of “Bird Flu Event” in late 2003, the fishermen were still leaving the fishery. According to Lokina (2000), the fishermen do not see the increase in fishing effort as a problem that was to be relating to dwindling fish stocks. The interruption of the stocking program from 2004 was a major reason leading to reduction in the number of fishing efforts. On the other hand, the increase in the price of fuel may lead to decline of fishing profit, and this may be another reason for many fishing households leaving the fishery or reducing their fishing effort recently.

6.1.4. Main factors accounting for overfishing

The trend of CPUE showed that the current fisheries resources in the reservoir are overexploited. In order to gain insight into reasons leading to overfishing, several factors need to be considered such as:

i. The dramatical increase in fishing effort level: although the entry to the fishery was restricted to the local fishermen only, the fishing effort has increased quickly from 300 households in 1993 to 1,470 households in 2002, and then reduced gradually to 872 households in 2005 (see Table 4.1).

ii. Low awareness level of the fishermen about conservation issues: most fishermen have a low education level (FAU 2000), it implies that fishing is an easy livelihood for poor local people and that the provision of greater livelihood opportunities within the existing fishery could thus lead to increased fishing effort. Due to low education levels, most fishermen are still limited in perception on conservation of fisheries resources. They continued to use the prohibited fishing gears, and catch small fish with a higher intensity of fishing.

iii. Ineffective measures of fisheries management: although fishing regulation and controlling system for fishing activities were set up in 1995, the implementation is limited and difficult to achieve expected targets due to weakness of management capacity, and lack of knowledge and officers to manage and monitor (Luu 1998; Tung *et al.* 2004). Many illegal fishermen enter the fishery without fishing license/without control as the result of a lack of officers in license control and monitoring (DNFC 2005). The fishery has often been mismanaged, usually in terms of regulating catch and access, consequently the fish stock are overexploited or unable to support the fishing pressure imposed (Cowx 2002).

iv. Inappropriate strategies of the stocking program: the stocking program attracted a larger number of new fishermen to the fishery, with 748 households in 1996 and reached a peak at 1,470 households in 2002 compared with 400 in 1994 before the stocking program (see Table 4.1). However, the stocking strategies were inappropriate, fish fingerlings were stocked into the reservoir at low density (48 fingerlings/ha) compared with regulation of stocking (see Table 2.1 and Fig 2.4). Thus, stocking could not provide a sufficient quantity of catch demands to increasingly higher fishing pressure levels. Lorenzen (1995) points out that low stocking density combined with high fishing effort level lead to overfishing.

v. The use of illegal fishing gears and violation of fishing regulations: gear limitations and fishing regulation were also set up in 1995; however, many fishermen did not follow the regulations. Many violators of fishing regulations still operated these types of prohibited gear that result in destructive fishing activities such as explosives, toxicants, and certain other destructive fishing methods (eg. filtering barrier with small mesh size). For example, in 2005, the DNFC detected 165 violators who either used gears with small mesh size, explosives and/or operated in closed areas.

6.1.5. Sustainability and efficiency issues

In biological terms, MSY is a reference point used for control of the harvest regime. The MSY is itself based on a biological model and indicates that a fish stock cannot be exploited too heavily and shows the maximum harvest level that ensures sustainable development (Clark 1990). To assess whether or not ecological sustainability of the current stocking and fishing activities in the reservoir indeed exist, the MSY level was estimated and compared with actual catches.

Theoretically, if the actual catch, effort level and stocking rate exceed the values of the MSY level, it indicates that the current fisheries exploitation is unsustainable. The findings report that at the harvest condition 1 and 2, sustainable yields increased and reached values of the MSY level in late 2001 and 2002 respectively, and then reduced below MSY level from 2004 (see Table 5.1 and Table 5.2). Therefore, the fishery moved into a situation of biological overfishing. Currently, the interruption of stocking time (i.e. harvest condition 1), actual effort level was more than the E_{MSY} from 2003, while actual stocking rate was too small compared with required S_{MSY}. This indicates that the current fisheries moved into a situation of biological overfishing, because the high effort level combined with low stocking density lead to overfishing (Lorenzen 1995). The MSY were also less than the actual catch from 2002, which is evidence that the current fishery was unsustainable. However, regarding the harvest condition 3 values of MSY level have not yet been reached, this MSY level only reaches at 8,487 tons when ensured by simultaneously set up E_{MSY} at 895,133 fishing days and S_{MSY} at 100 tons of fish fingerlings (see Table 5.2 and Fig. 5.8). This MSY target may be impossible/or ineffective to be applied to management in the reservoir, because it is very difficult to implement in terms of monitoring and controlling, especially for a large reservoir as Tri An.

Regarding economics, economic efficiency occurs when the sustainable catch or effort level and stocking rate for the fishery as a whole maximizes profits. This point is referred as MEY that is the largest difference between total revenue and total cost of fishing and stocking (Clark 1985). At the MEY level, the stock biomass is larger than that associated with MSY level, so the economic objective of MEY is better than that of MSY in protecting the fishery from negative environmental shocks that may diminish the fish population (Kompas 2005). Catch and effort levels at MEY will vary due to a change in the price of harvested fish or the cost of fishing and stocking. As long as the cost of fishing and stocking increase, the MEY as a target will always be preferred to MSY, the harvested fish at the MSY level becomes economic overfishing (Kompas 2005).

The findings show that MEY at the harvest condition 1 and 2 attained at 1,536 and 1,828 tons when the corresponding E_{MEY} was produced at 99,767 and 118,734 days of fishing, respectively (see Table 5.2). Comparing these values at MEY with the actual data, the fishery sustained economic overfishing from 1996 up to now. The main reasons of economic overfishing were inappropriate stocking strategies and poor management. Regarding the harvest condition 3, the MEY can be reached at 5,186 tons, and produced at effort of 336,855 fishing days (see Table 5.2 and Fig. 5.8), however, this MEY level was never attained before. This MEY target may be applied for reservoir management, because it may be suitable with the existing management capacity.

6.1.6. Required rational management of stocked fisheries

The findings from the MSPM indicate that the current fisheries exploitation level constitutes overfishing and is unsustainable. At harvest condition 1 and 2, the current effort level exceeded the sustained effort at MSY, MEY and OAY. The fish fingerlings will continue to be introduced into the reservoir, thus a rational management of stocked fisheries is required in order to guarantee sustainability and efficiency of fish resources exploitation that can be exploited year after year indefinitely into the future. The optimal stocking regime is dependent on the harvesting regime and vice versa. Fishing activities are dependent on the harvesting and stocking regimes, thus, a change in the fisheries management plan should be ensured by simultaneous change in both stocking rate and effort level, and need to avoid overstocking or overfishing (Lorenzen 1995). The following management guidelines should be considered in order to improve the current fisheries management:

i. If the fishery operation is maintained at harvest condition 2 in which 8 tons of fingerlings are annually introduced into the reservoir, then change in fishing effort levels and stocking rates to achieve levels at the reference points may recover the current fisheries resources from degradation. In this context, the current effort should increase by 18.42% and 8 tons of fish fingerlings would be introduced into the reservoir to get the corresponding MSY level. Whereas, to attain the MEY and OAY the current effort levels have to be decreased by 55.44% and 12.84% respectively, and the stocking rates sets up at 8 tons of stocked fingerlings.

ii. Considering harvest condition 3, the MSY and OAY targets seem to be exceeding the management capacity, or are impossible and ineffective to be applied in the large reservoir. Only MEY target may be possible to be implemented for reservoir management. The current effort level is still less than the effort level at MEY, hence, in order to achieve this MEY target the current effort level would need to be increased by 26.43% while the stocking rate would need to be 100 tons of stocked fingerlings.

6.1.7. Limitations of the study and model

Data used in this study were collected mostly from the DNFC, so the quality of an assessment of capture fishery status and management was very dependent on the input information that can be limited in accuracy and reliability due to poor management and poor stocking strategies. The R^2 value of the non-linear regression model was limited due to a short time series of data. Based on 138 surveyed fishing households in 2004 and 2005, cost per unit of effort was calculated and assumedly used for the reference points and economic rents estimation in this study, therefore the results were still limited in accuracy.

The MSPM was assumed and has been developed for stock assessment in the reservoir; however, it has disadvantages that should be improved in future studies. The MSPM used and is based on some assumptions, and if these assumptions are not met such as change of catchability or environmental factors, then the MSPM is not suitable. The MSPM only used the catch/effort and stocking data to estimate the biological parameters by non-linear regression, so the findings were limited in accuracy because of the multi-species nature of the fisheries resource and lack of long historical data series. In addition, the bioeconomics approach including both biology of the stock and economics of the fishery was also modified based on the MSPM. This approach required many parameters concerning all aspects of fishing activities such as costs of effort/stocking, prices, etc., therefore, the complexity of the model increases its uncertainties. Moreover, the high fluctuation of landed fish price and cost of fishing effort were also reasons leading to uncertainties of this approach.

Based on the limitations addressed, in future the MSPM should be applied for single species that are commercial species. The impact of fish stocking will be tested more accurately based on the biological relationship between stocked species and native species. To ensure greater certainty of the MSPM and bioeconomics approach, future studies should use long data time-series of catch, effort and stocking, and more detailed and accurate fish price and cost of fishing by month.

6.2. Conclusion and management implications

The surplus production model of Verhulst-Schaefer was modified and it initially pointed out the relationship between fish stocking and the rate of population change. The model assumed that fish stocking in the reservoir was positively correlated to population growth and led to rapid increase in population growth compared with change in the case of no stocking impact, which was confirmed by available data. To evaluate the role of stocking in enhancement of fish production, the findings also found that harvest level was positively related to change of stocking rate, and the higher rate of stocking led to the greater yields of harvested fish. The harvest also depended on the effort level, thus stocked fisheries can be managed by simultaneous change in both effort level and stocking rate.

Empirically analyze and evaluate the status of fisheries resources exploitation affected by the stocking program were implemented. Empirical results indicated that CPUE declined steadily in recent years; therefore the current fisheries resources were overexploited and have been degraded. There were many factors leading to overexploitation of the fisheries resources, however, major factors can be specified as dramatic increase in fishing effort, low awareness level of fishermen of conservation issues, ineffective methods of management, and the use of illegal fishing gears and violation of fishing regulations. In addition, the stocking strategies were inappropriate, fish stocking of low density combined with high fishing effort also led to overfishing.

The current exploitation of fisheries resources in the reservoir has moved into an unsustainable situation of biological and economic overfishing. The main reason was an excess of the current effort combined with low stocking rate compared with the corresponding levels associated with the MSY target in harvest conditions 1 and 2. On the other hand, the actual catch, effort and stocking rates also exceeded the levels associated with the MEY target in these cases; hence, the fishery sustained economic overfishing from 1996 up to the present. The current centralized top-down management has proven ineffective and has faced many problems in fisheries management, hence, rational and improved management are required in order to ensure sustainability and efficiency of fish resources exploitation that can be obtainable each year indefinitely into the future.

Sustainability and efficiency issues in a fishery, or pursuing MSY and MEY targets, are important. To manage fisheries resources, the MSY and MEY are the simplest reference points used to control the harvest regime and protect the fish population. The values of MSY and MEY estimations based on the MSPM also helped to evaluate biological sustainability and economic efficiency. The MSPM indicates that:

i. Regarding the biological side, if the fishery operates at harvest condition 3, MSY reaches at 8,487 tons, with the effort level of 895,133 days. At present, it would not be possible or effective to apply this MSY target to the Tri An reservoir.

ii. From an economic point of view, if the fishery operates at harvest condition 3, the MEY attains at 5,186 tons as long as the corresponding effort level is set up at 336,855 days of fishing. This MEY target may be possible and can be applied for fisheries resources exploitation because the current effort level is less than the effort at MEY level and is suited to current management capacity.

Fisheries management in Tri An reservoir is based on a centrally controlled, top–down approach under provincial patronage, with the local authorities acting as the centralized management authority. There are still many problems in fisheries management related to the reservoir, for example, the current legal framework for management was not yet suitable, protection of the fisheries resources was still very limited, and funds for the stocking program into the reservoir was low. The current fisheries management regime should be improved. This study provided preliminary results on the status of stock and fisheries management to build and recommend several possible measures for reservoir fisheries management.

The findings indicate that current fisheries resources are overfished and fishing activities unsustainable. Since the fisheries resources have been depleted by overfishing, the following management plans should be considered (Lorenzen *et al.* 2001), as follows:

1) Stocking to develop a largely culture-based fishery while maintaining high exploitation rates; or

2) Supplemental stocking combined with more restricted harvesting to rebuild natural spawning stocks more quickly than would be possible through harvest restrictions alone.

Fisheries policy may be a choice between option (1) and option (2). In order to improve the current fisheries management for the reservoir, option (1) seems to be the

MSY target at harvest condition 3. This option is not feasible when applied to a large reservoir as Tri An, because the stocked fish have a low survival rate in a large reservoir and it is difficult to appropriately manage. Whereas option (2) seems to be the MEY target at harvest condition 3, it may be possible for the reservoir fisheries management because of the stocking program to compensate for recruitment overfishing and to maintain the fisheries productivity at the possible harvest level. Moreover, the MEY target is more suitable with existing management capacity. However, in implementation of new management measures the following need to be considered (Lokina 2000):

i. The policy should be flexible enough to allow for proper reaction to changes in economic and biological conditions; and

ii. Involve the participation and support of the local communities and ensure minimum resistance.

To implement simultaneously in both the restricted harvesting and supplemental stocking, there are some effective measures for the control of fishing and protection of fish resources (Bhukaswan 1980; Clark 1985; Cowx 2002), as follows:

1. Time and place restriction measures are more suitable for the reservoir because the species caught varies from area to area, or from season to season within the same area (DNFC 1997).

2. Regulation of the minimum size of fish caught, particularly by controlling the mesh size of the fishing gear is difficult to enforce in the reservoir due to the multi-species resources and multi-gears used. The application of this measure must be considered carefully in the reservoir because it is impossible to set a proper size limit suited for all species. However, regulation of mesh size should be used for controlling the minimum commercial size in protected fish populations in order to protect immature fish and first spawning fish.

3. Limitation of entry by limiting the fishermen and/or fishing units. This management measure is also difficult to implement in this fishery since the reservoir fisheries are open access and important firstly as a source of protein and secondly as providers of employment. Moreover, one of purposes of the fishery is to supply employment for people living around the reservoir, any regulation that limited employment, either directly or indirectly, would not be

favorable (Amarasinghe & De Silva 1999; Kapetsky 1983). However, to get the MEY target at harvest condition 3, this measure is not a serious problem due to the current effort level less than E_{MEY}. In this case, the policy makers should choose an optimal stocking regime that have in order to avoid the overfishing/overstocking situations.

4. The existing illegal fishing gears, non-registered fishermen and violation of fishing regulations are the biggest social issues in the reservoir. Therefore, in order to successfully implement the prohibition of destructive fishing activities by prohibition of the use of explosives, toxicants, and certain other destructive fishing methods, the policy actions on education of people living around the reservoir need to be considered foremost. Training courses should focus on protection of fisheries resources and the benefits of managed fisheries resources to promote awareness of the fishing communities about fisheries resource protection.

The current management regime through a centralized top-down management approach has also proven ineffective in addressing and resolving the above issues, primarily because of the absence of participation with the local communities. In the search for alternative reservoir management approaches, the most promising option appears to be co-management (Lorenzen *et al.* 2001; Nathanael & Edirisinghe 2002), where all stakeholders, especially fishermen, collaborate with the government, to seek solutions to fishery related issues. The essential idea of co-management is the sharing of decision making and management functions between government and stakeholders in the fishery (Bavinck *et al.* 2005; Charles 2001). Moreover, an important advantage of a co-management approach for managers is that through co-operative societies, more reliable catch and effort statistics can be collected which are useful not only for monitoring the status of the fisheries but also for planning welfare programs (Amarasinghe & De Silva 1999).

In the reservoir, co-management tasks such as the introduction of a licensing system for fishing, setting up a monitoring system, establishment of a revolving fund to ensure continuous supplies of fingerlings and promotion of a managed hatchery should be implemented as a necessity. The fishing communities who invest funds in stocking activities through fishing taxes should be interested in fisheries management.

The participation of these communities in fisheries governance may ensure that stocked fish are harvested at optimum yield and fishermen who do not participate financially in stocking activities are kept out. Furthermore, the co-management approach allows all stakeholders to take roles in the governance process and to have the chance for sharing of responsibility and power. The work pressure of the DNFC and provincial government may be reduced, because other stakeholders as fishermen, farmed-fishers and wholesalers will be directly involved in governance to monitor and control all fishing activities.

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APPENDICES

Appendix 1. Data on fish stocking in Tri An reservoir, 1995-2003

[Source: data cited from DNFC (2005)]

Species name	Scientific name	Biological features	STATISTICAL DATA IN 1995			STATISTICAL DATA IN 1996			STATISTICAL DATA IN 1997		
			Weight[1]	Quantity[2]	Cost[3]	Weight[1]	Quantity[2]	Cost[3]	Weight[1]	Quantity[2]	Cost[3]
Silver carp	*H.molitris*	*Planktivorous*	2,105	314,317	52.63	3,077	459,387	76.92	8,106	1,210,363	202.66
Bighead carp	*A.nobilis*	*Planktivorous*	1,102	160,822	27.54	1,610	235,048	40.25	4,242	619,290	106.06
Grass carp	*C.idellus*	*Herbivorous*	793	114,320	19.82	1,159	167,083	28.97	3,054	440,221	76.34
Nile tilapia	*O.niloticus*	*Detritivorous*	1,026	150,120	25.64	1,499	219,406	37.48	3,950	578,078	98.74
Common carp	*C.carpio*	*Detritivorous*	1,049	162,310	26.22	1,533	237,222	38.33	4,039	625,018	100.98
Indian carp	*L.rohita*	*Detritivorous*	887	120,759	22.16	1,296	176,494	32.39	3,414	465,016	85.35
Mud carp	*C.molitorella*	*Detritivorous*	1,110	163,925	27.74	1,622	239,583	40.54	4,273	631,239	106.82
Java barb	*B.gonionotus*	*Detritivorous*	755	113,426	18.88	1,104	165,776	27.59	2,908	436,776	72.69

1. Weight of stocked fish, with unit in kg

2. Quantity of stocked fish, with unit in number of fingerlings

3. Total cost of stocked fish, with unit in million VNDs

Appendix 1. Data on fish stocking in Tri An reservoir, 1995-2003 (cont.)

[Source: data cited from DNFC (2005)]

Species name	Scientific name	Biological features	STATISTICAL DATA IN 1998			STATISTICAL DATA IN 1999			STATISTICAL DATA IN 2000		
			Weight[1]	Quantity[2]	Cost[3]	Weight[1]	Quantity[2]	Cost[3]	Weight[1]	Quantity[2]	Cost[3]
Silver carp	*H.molitris*	*Planktivorous*	1,619	241,782	40.48	2,133	318,427	53.32	1,630	268,425	40.75
Bighead carp	*A.nobilis*	*Planktivorous*	847	123,709	21.19	1,116	162,925	27.90	0	0	0.00
Grass carp	*C.idellus*	*Herbivorous*	610	87,939	15.25	803	115,815	20.08	970	178,550	24.25
Nile tilapia	*O.niloticus*	*Detritivorous*	789	115,477	19.72	1,039	152,083	25.98	1,120	176,115	28.00
Common carp	*C.carpio*	*Detritivorous*	807	124,854	20.17	1,063	164,433	26.57	1,225	212,350	30.63
Indian carp	*L.rohita*	*Detritivorous*	682	92,892	17.05	898	122,338	22.45	0	0	0.00
Mud carp	*C.molitorella*	*Detritivorous*	854	126,096	21.34	1,124	166,069	28.10	1,518	237,863	37.95
Java barb	*B.gonionotus*	*Detritivorous*	581	87,251	14.52	765	114,909	19.12	770	127,330	19.25

Species name	Scientific name	Biological features	STATISTICAL DATA IN 2001			STATISTICAL DATA IN 2002			STATISTICAL DATA IN 2003		
			Weight[1]	Quantity[2]	Cost[3]	Weight[1]	Quantity[2]	Cost[3]	Weight[1]	Quantity[2]	Cost[3]
Silver carp	*H.molitris*	*Planktivorous*	2,262	326,300	56.55	2,418	345,774	60.45	1,362	205,030	34.05
Bighead carp	*A.nobilis*	*Planktivorous*	1,216	172,505	30.40	1,776	255,765	44.40	1,023	157,847	25.58
Grass carp	*C.idellus*	*Herbivorous*	1,087	116,944	27.18	359	50,978	8.98	474	70,168	11.85
Nile tilapia	*O.niloticus*	*Detritivorous*	1,278	173,763	31.95	868	126,728	21.70	472	70,507	11.80
Common carp	*C.carpio*	*Detritivorous*	940	132,456	23.50	832	117,416	20.80	826	129,317	20.65
Indian carp	*L.rohita*	*Detritivorous*	2,374	315,763	59.35	531	75,296	13.28	326	49,048	8.15
Mud carp	*C.molitorella*	*Detritivorous*	1,157	158,942	28.93	612	86,904	15.30	757	113,717	18.93
Java barb	*B.gonionotus*	*Detritivorous*	742	103,492	18.55	782	109,844	19.55	458	72,714	11.45

Appendix 2. Data on capture fisheries activities in Tri An reservoir, 1999-2005

[Source: data cited from DNFC (2005)]

Type of fishing gear	STATISTICAL DATA IN 1999						STATISTICAL DATA IN 2000					
	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]
Sprat scoop net	134	134	134	16,120	724,240	2	68	68	68	6,808	652,120	2
Scoop net 1	40	40	19	2,850	124,050	5	52	52	52	2,530	225,000	5
Scoop net 2	25	25	25	2,750	72,500	4	2	2	2	210	4,840	4
Shrimp basket trap	13,050	279	156	23,200	109,240	7	21,360	356	356	46,140	195,750	7
Trawl net	46	46	46	9,350	120,450	4	38	38	38	3,120	44,920	4
Gill net 1	452	452	452	77,125	742,050	4	526	526	526	56,350	761,850	4
Gill net 2	48	48	48	4,560	156,050	4.5	114	114	114	9,250	80,980	4.5
Mussel trawl net	8	8	8	610	7,320	5	3	3	3	945	9,209	5
Lift net 1	6	6	6	450	3,650	4.5	17	17	17	812	8,050	4.5
Lift net 2	38	38	38	2,650	119,700	3	22	22	22	920	15,450	3
Long line	25	25	25	3,750	16,520	7	132	132	132	9,140	69,560	7
Spears	9	9	9	567	1,710	10	1	1	1	93	274	10
Small cast net	12	12	12	1,720	20,790	5	27	27	27	2,020	32,000	5
Big cast net	0	0	0	0	0	0	38	38	38	1,550	66,350	5
Seines net 1	0	0	0	0	0	0	35	35	35	1,550	75,790	4
Seines net 2	14	14	14	1,900	50,400	4	39	39	39	1,925	59,120	4
Shrimp pull net	0	0	0	0	0	0	0	0	0	0	0	0

[1.] Number of gears, [2.] Number of households, [3.] Number of boats, [4.] Number of fishing days, [5.] Catch with unit in kg, [6.] Price with unit in 1,000 VNDs/kg

Appendix 2. Data on capture fisheries activities in Tri An reservoir, 1999-2005 (cont.)

[Source: data cited from DNFC (2005)]

Type of fishing gear	STATISTICAL DATA IN 2001						STATISTICAL DATA IN 2002					
	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]
Sprat scoop net	78	78	78	7,850	844,606	2	58	58	58	9,900	994,776	2
Scoop net 1	68	68	68	7,600	670,600	5	42	42	42	6,800	654,756	5
Scoop net 2	3	3	3	596	34,500	4	1	1	1	100	3,897	4
Shrimp basket trap	26,320	378	214	27,250	126,240	7	25,500	304	234	52,850	249,450	7
Trawl net	68	68	68	6,020	82,320	6	28	28	28	7,600	109,662	6
Gill net 1	197	197	197	32,325	465,625	4	157	157	157	31,250	395,768	4
Gill net 2	90	90	90	18,550	145,350	6	90	90	90	22,950	187,560	6
Mussel trawl net	14	14	14	950	9,350	7	14	14	14	1,850	21,560	7
Lift net 1	41	41	41	1,450	17,250	5	22	22	22	1,950	23,552	5
Lift net 2	52	52	52	2,160	53,790	4	36	36	36	2,780	59,977	4
Long line	111	111	58	8,710	87,025	7	42	42	42	8,160	98,976	7
Spears	2	2	2	189	850	12	0	0	0	0	0	0
Small cast net	32	32	32	3,420	52,430	5	26	26	26	3,900	58,950	5
Big cast net	19	19	19	845	31,420	8	10	10	10	1,500	49,242	9
Seines net 1	17	17	17	850	40,250	8	10	10	10	1,050	47,545	9
Seines net 2	28	28	28	1,950	59,200	4	21	21	21	2,700	72,685	4
Shrimp pull net	39	39	39	5,125	64,725	7	31	31	31	6,725	89,505	7

[1.] Number of gears, [2.] Number of households, [3.] Number of boats, [4.] Number of fishing days, [5.] Catch with unit in kg, [6.] Price with unit in 1,000 VNDs/kg

Appendix 2. Data on capture fisheries activities in Tri An reservoir, 1999-2005 (cont.)

[Source: data cited from DNFC (2005)]

Type of fishing gear	STATISTICAL DATA IN 2003						STATISTICAL DATA IN 2004					
	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]
Sprat scoop net	61	61	61	8,925	884,776	2.5	60	60	60	8,288	809,888	4
Scoop net 1	42	42	42	7,902	694,756	5.5	40	40	40	7,501	661,628	9
Scoop net 2	1	1	1	54	3,697	5.5	1	1	1	27	1,849	5.5
Shrimp basket trap	27,300	273	273	48,250	249,450	9	25,300	253	253	43,625	207,175	18
Trawl net	26	26	26	3,248	109,662	7	22	22	22	2,686	115,081	10
Gill net 1	267	267	267	40,575	397,768	4.5	252	252	252	38,038	371,384	6
Gill net 2	88	88	88	21,750	197,560	6	76	76	76	18,250	196,030	10
Mussel trawl net	14	14	14	2,150	21,560	8	14	14	14	2,455	21,280	15
Lift net 1	22	22	22	2,850	23,552	5.5	20	20	20	2,850	23,026	8
Lift net 2	31	31	31	2,880	59,977	5.5	31	31	31	3,215	67,239	5.5
Long line	39	39	39	13,250	98,976	8	39	39	39	11,279	93,738	20
Spears	0	0	0	0	0	0	0	0	0	0	0	0
Small cast net	36	36	36	4,150	58,950	5	34	34	34	3,925	55,725	6
Big cast net	18	18	18	2,920	69,242	10	14	14	14	2,050	53,863	16
Seines net 1	10	10	10	1,250	47,545	12	7	7	7	1,335	45,273	15
Seines net 2	19	19	19	2,350	72,685	5	19	19	19	1,989	66,593	7
Shrimp pull net	31	31	31	2,850	89,505	9	16	16	16	1,425	44,753	9

[1.] Number of gears, [2.] Number of households, [3.] Number of boats, [4.] Number of fishing days, [5.] Catch with unit in kg, [6.] Price with unit in 1,000 VNDs/kg

Appendix 2. Data on capture fisheries activities in Tri An reservoir, 1999-2005 (cont.)

[Source: data cited from DNFC (2005)]

Type of fishing gear	STATISTICAL DATA IN 2005						STATISTICAL DATA IN 2006					
	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]	No.of gears[1]	No.of hhs[2]	No.of boats[3]	No.of f.days[4]	Total catch[5]	Fish price[6]
Sprat scoop net	58	58	58	7,650	735,000	4	–	–	–	–	–	–
Scoop net 1	38	38	38	7,100	628,500	9	–	–	–	–	–	–
Scoop net 2	0	0	0	0	0	0	–	–	–	–	–	–
Shrimp basket trap	25,090	295	232	39,000	164,900	18	–	–	–	–	–	–
Trawl net	17	17	17	2,124	120,500	10	–	–	–	–	–	–
Gill net 1	236	236	236	35,500	345,000	6	–	–	–	–	–	–
Gill net 2	64	64	64	14,750	194,500	10	–	–	–	–	–	–
Mussel trawl net	14	14	14	2,760	21,000	15	–	–	–	–	–	–
Lift net 1	17	17	17	2,850	22,500	8	–	–	–	–	–	–
Lift net 2	31	31	31	3,550	74,500	5.5	–	–	–	–	–	–
Long line	39	39	39	9,308	88,500	20	–	–	–	–	–	–
Spears	0	0	0	0	0	0	–	–	–	–	–	–
Small cast net	31	31	31	3,700	52,500	6	–	–	–	–	–	–
Big cast net	9	9	9	1,180	38,484	16	–	–	–	–	–	–
Seines net 1	4	4	4	1,420	43,000	15	–	–	–	–	–	–
Seines net 2	19	19	19	1,628	60,500	7	–	–	–	–	–	–
Shrimp pull net	0	0	0	0	0	0	–	–	–	–	–	–

[1.] Number of gears, [2.] Number of households, [3.] Number of boats, [4.] Number of fishing days, [5.] Catch with unit in kg, [6.] Price with unit in 1,000 VNDs/kg

Appendix 3. Results of non-linear regression statistics of CPUE function

The software used is "Mathematica 5.2.0 Windows" (Wolfram 2005)

```
Year       = {1999,    2000,   2001,   2002,   2003,   2004,   2005};
catch      = {2269,    2301,   2786,   3118,   3080,   2835,   2589};
effort     = {235794, 170212, 193379, 246188, 314146, 290314, 266444};
stockingw1 = {6789,    8941,   7233,  11056,   8178,   5698,      0};

<< Statistics`NonlinearFit`

data = Transpose[{effort / 100000, stockingw1 / 1000, catch / effort}] // N

{{2.35794, 6.789, 0.00962281}, {1.70212, 8.941, 0.0135184}, {1.93379, 7.233, 0.0144069},
 {2.46188, 11.056, 0.0126651}, {3.14146, 8.178, 0.00980436}, {2.90314, 5.698, 0.00976529}, {2.66444, 0., 0.00971686}}

NonlinearFit[data, q * (k - (e * k * q) / (r0 + a * sw1)), {e, sw1}, {q, k, r0, a}] // InputForm

0.09356099880920998*(0.20266996854655525 - (0.01896200468584688*e)/(0.49608421117464807 + 0.01178905853622247*sw1))

NonlinearRegress[data, q * (k - (e * k * q) / (r0 + a * sw1)), {e, sw1}, {q, k, r0, a},
 RegressionReport -> {BestFitParameters, BestFit, ParameterCITable, ParameterTable, EstimatedVariance, ANOVATable}]
```

Where: CPUE is catch/effort (tons/day of fishing); e is effort standardization (100,000 days of fishing); sw1 is stocking (tons of stocked fingerlings); q is catchability coefficient (tons/100,000 fishing days/year); k is carrying capacity (100,000 tons); and (r_0+ a*sw1) is intrinsic growth rate which affected by stocking.

{BestFitParameters → {q → 0.093561, k → 0.20267, r0 → 0.496084, a → 0.0117891}, BestFit → $0.093561\left(0.20267-\frac{0.018962\,e}{0.496084+0.0117891\,sw1}\right)$,

ParameterCITable →

	Estimate	Asymptotic SE	CI
q	0.093561	0.0180853	{0.0360054, 0.151117}
k	0.20267	0.0253978	{0.121843, 0.283497}
r0	0.496084	0.0128327	{0.455245, 0.536924}
a	0.0117891	0.0143745	{-0.033957, 0.0575351}

,

	TStat	PValue
q	5.17331	0.0140161
k	7.97982	0.00410646
r0	38.6578	0.0000380814
a	0.820138	0.472232

,

EstimatedVariance → 2.30379×10^{-6}, ANOVATable →

	DF	SumOfSq	MeanSq
Model	4	0.000922304	0.000230576
Error	3	6.91138×10^{-6}	2.30379×10^{-6}
Uncorrected Total	7	0.000929215	
Corrected Total	6	0.0000263268	

}

R - squares
0.737478

Appendix 4. Photographs of main fishing gears used

[Source: photos cited from AMCF (2002)]

Shrimp basket trap

Gill-net

Sprat scoop net

Long line

Source of photographs in the front page:

(1) Photos showing main fish species introduced into the Tri An reservoir cited from MRC (2003).

(2) Photo showing Tri An Hydro-Electric Plant cited from http://www.dongnai-industry.gov.vn/english/tp_bh.html#vc

(3) Photo showing "Scoop net" cited from AMCF (2002)