The United Nations University
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MANAGEMENT OF THE COMMERCIAL PRAWN FISHERY IN TANZANIA

Amin Mohamed Abdallah
Marine Parks and Reserves Unit
Fisheries Division
Ministry of Natural Resources and Tourism
P.O. Box 7565, Dar es Salaam
Tanzania
Tel: +255 22 2150621
Fax: +255 22 2150420 or +255 22 2110352
marineparks@marineparktz.com
amin445@hotmail.com

Supervisor
Prof. Ragnar Arnason
Department of Economics, University of Iceland

ABSTRACT

A simple bio economic model of the commercial prawn fishery in Tanzania was developed to assess the fishery and determine the policy that will maximize economic rents and ensure sustainable biomass growth. The model indicates that the fishing effort that will bring the fishery into optimal level is between eight and 13 vessels. The appropriate policy that will maximize economic benefit and sustain shrimp biomass growth is to reduce fishing effort from the current 26 fishing vessels to 13. At this fishing effort the fishery attains long term maximum net present value of more than US$ 39.5 million. Adjusting the average number of fishing days to 300 while reducing the fishing effort to eight vessels increases the net present value to US$ 60.4 million.

LIST OF ABBREVIATIONS

BoT	Bank of Tanzania
CPEU	Catch per Unit Effort
CSY	Competitive Sustainable Yield
EEZ	Exclusive Economic Zone
EU	European Union
FD	Fisheries Division
FJS	Fisheries Judicial System
FMS	Fisheries Management System
GDP	Gross Domestic Production
GRT	Gross Registered Tonnage
HACCP	Hazard Analysis Critical Control Point
IQ's	Individual Quota system
MCS	Monitoring Control and Surveillance
MEY	Maximum Economic Yield
MNRT	Ministry of Natural Resources and Tourism
NPV	Net Present Value
NE	North East
OSY	Optimal Sustainable Yield
R/V	Research Vessel
SW	South West
TAFICO	Tanzania Fisheries Cooperation
TAFIRI	Tanzania Fisheries Research
TURFs	Territorial User Rights
URT	United Republic of Tanzania

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1 INTRODUCTION

The fisheries management regime is the institutional framework under which the fishing industry operates. This framework may be set by social custom, the government (fisheries authority), fisher groups or by other means e.g. environmental pressure groups. Irrespective of the fisheries management regime, the fisheries management process consists of human socioeconomic interactions involving the biological resource. It follows that fisheries management process must been seen in this light rather than just looking at the resource only. This process should therefore involve participation of all stakeholders, (resources users, resource managers and researchers) to minimize conflicts and maximize its acceptance (Kailis 1996). The alternative; remote management by commands backed up by force is both extremely costly and probably not very effective. Conflicts and users refusing to abide by regulations tend to lead to unsustainable resource use. More effective management relies on co-management and property rights (Crean and Symes 1994). Fisheries policy or management regimes developed with sufficient involvement and participation of all stakeholders often creates a level of self compliance among people.

In recent years there has been an increasing trend towards property rights based fisheries management systems (Runolfsson 1999). Currently more than 10% of global fish landings come from rights based fisheries regimes (Arnason 2001). This trend is probably a reflection of a successful organisation of economic activities on land through a private property rights regime which has led to high level of productivity (Runolfson 1997, Scott 2000). Likewise, good property rights-based fisheries management may lead to increased economic efficiency and maximize economic rents (Arnason 1993, 1996)

Property rights based fisheries management such as individual quotas have shown promise in developed countries such as Iceland, New Zealand, Australia and Norway (Arnason 2001) as well as in developing countries such as Namibia (Iyambo 2000).

Arnason (2000) argued that secure property rights not only lead to efficient fisheries but also encourage investment in the fish stocks and their habitat. Therefore according to Arnason secure property rights constitute an effective way to both maximize economic rents and promote good resource stewardship. Note, however, that the efficiency of a property rights-based regime depends on the quality of the rights, the higher the quality of the property rights the more efficient the regime (Arnason 2000, Scott 2000).

In Tanzania fisheries management systems have been entirely developed based on biological fisheries management measures, which the government has put in place to avoid stock collapses. Despite these measures, the fisheries sector is still faced with problems of increased fishing effort which hurts profitability and may lead to over-fishing, especially in inshore marine waters where most of the artisanal and industrial shrimp fisheries are taking place (Jiddawi and Ohman 2002). The open access nature of the fishery has not only caused increasing fishing effort that creates conflicts between and among (resident and migrating) fishers in different places but also removes the ability of the fishery sector to maximize social benefits.

In order to solve the problem of open access, the Fisheries Division has developed a national fisheries policy in 1997 and recently reviewed fisheries regulations to provide room for rights based fisheries regimes such as community based fisheries management and others regimes that are compatible with the social and political situation of the country (MNRT 1997).

Introduction of a rights based fisheries regime such as individual quota (IQ) seems to be a practical solution for effective and efficient management of the prawn fishery in Tanzania. This system is expected to reduce fishing effort and detrimental competition for shrimp catches. Generally under an IQ system, competition is geared towards reducing fishing costs while watching individual quota shares and improving the quality of landings to maximize quota share revenue. This eventually leads to maximizing economic rents of the fishery which is good for fisheries development and the nation at large. The individual quota system may also result in reduction of enforcement costs on the government side as fewer observers will be needed for surveillance of the fewer vessels which have quotas. In an IQ system there is more incentive for the vessel owners to act and operate sensibly for the common good as opposed to open access fishery. The individual quota may also increase government revenue if quota allocated to fishers is taxed or auctioned.

The purpose of this is report is to study the Tanzanian prawn fishery and determine the policy that maximizes economic benefits from the fishery while ensuring sustainability of the resource. A simple dynamic prawn fishery model will be used to determine management option(s) for the prawn fishery in Tanzania so as to maximize economic benefit and contribute towards social welfare development. The findings of this study will contribute towards policy formulation for effective management of the prawn fishery in Tanzania. Sound management of this resource is then expected to contribute towards long term social welfare development of coastal communities and the nation as a whole.

2 BACKGROUND

2.1 Overview of the Tanzanian fishery sector

Tanzania lies between latitude 1^o and 12^o S and longitude 29^o 21′ and 41^o E bordering Kenya and Uganda to the North and Rwanda, Burundi and the Democratic Republic of Congo to the West, Zambia, Malawi and Mozambique to the South and the Indian Ocean to the East (Figure 1). With total land area of 945,040 km^2 Tanzania is the largest country in East Africa. Bordering all three great lakes of Africa (Victoria, Tanganyika and Nyasa) and the Indian Ocean, in addition to several minor water bodies, Tanzania has a great fisheries potential (MNRT 1997).

Figure 1: Geographic location of Tanzania with major water bodies and rivers (Government of Tanzania 2003. National Integrated Coastal Environment Strategy URT 2003).

The Tanzanian coast along the Indian Ocean is 1450 km long. The coastline is characterized by sand beaches, sea grasses, rocky outcrops and extensive fringing reefs, except in areas where rivers enter the Indian Ocean where there are often extensive mangrove forests (Government of Tanzania 2003). Several rivers flow to the Indian Ocean influencing coastal environment, by creating productive estuarine ecosystems (Government of Tanzania 2003), which provide important nurseries and feeding grounds to diverse marine species. Coastal environment is also influenced by monsoon winds. There are two monsoon seasons: The North East (NE) monsoon blows during the period November – March and is normally characterized by high air temperatures and low winds with relatively calm seas, while the strong winds of the South West (SW) monsoon occur between May – September (Iversen *et al*. 1984, Jiddawi and Ohman 2002). The SW monsoon also brings heavy rains and nourishes estuaries and coastal areas with lots of nutrients (Haule 2001). The continental shelf is generally narrow, less than 6 km, except at the Mafia and Zanzibar channel where the shelf reaches up to 62 km (Government of Tanzania 2003). The marine territorial waters (up to 12 NM) cover 64,000 km^2 and the Exclusive Economic Zone (EEZ) covers 223,000 km^2 (Government of Tanzania 2003). The total area of fresh waters including shared waters on Lake Victoria, Tanganyika, Nyasa, several minor lakes, ponds and rivers exceeds 54,000 km^2.

Tanzanian fisheries are categorized as artisanal or commercial. Artisanal fishery in marine as well as in freshwater is primarily inshore fishery which is done by independent fishermen in small boats usually using simple gear like traps, gillnets and hand lines. Artisanal fishery accounts for over 95% of the total fish landings annually. Fishing is one of the major economic activities which provide highly needed protein rich food and income for majority of coastal communities. Fish contributes more than 30% of total animal protein consumed by Tanzania (MNRT 1997). The contribution of fish protein in the diet of coastal communities is even higher. The average per capital consumption of fish of Tanzania is 13 kg/year. In general fishing activities also provide income through direct or indirect employment. In 2003 more than 168,000 fishers were directly employed in fishing activities and produced more than 350,000 mt (Figure 2) (Fisheries Division 2003). Most of the catch is consumed locally either processed or fresh while catches of Nile perch, shrimps, lobsters, and octopus are also exported. There is no effective central marketing agency at the villages. Traders (fish mongers) buy fish at low prices from fishers located far from major urban centres. The traders visit different fish landing sites daily buy fish and transport to markets in major towns. Price is set depending on the demand for fish and distances of villages from the major coastal towns. Hence, prices of fish are attributed to the variable costs of transportation. Prices tend to be lower farther away from the towns. Artisanal fishers operate from small boats, small outrigger canoes, dhows, dugout canoes and dinghies. They use different fishing gears including traps, gillnets, hand lines, beach seines, purse seines, ring nets, deep nets, cast nets and small long lines (Jiddawi and Ohman 2002). On the other hand, industrial or commercial fisheries are mainly operated from shrimp trawlers on inshore waters and purse seiners and long liners offshore. The contribution of the sector to GDP for the past five years has been between 2 to 3% (BoT 2001).

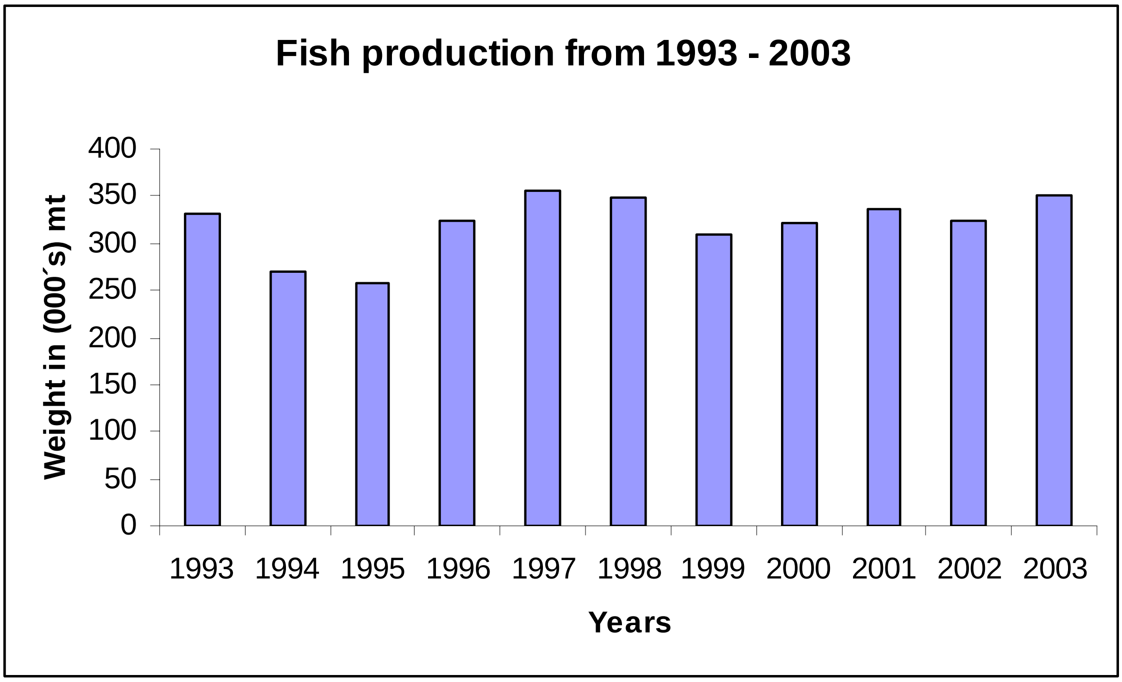


Figure 2: Fish production in Tanzania from 1993 to 2003 (FD 2003).

2.2 Tanzania's fisheries potential and development

The overall potential of fish production is estimated at 730,000 mt per year (MNRT 1997) with 100,000 mt estimated to come from inshore marine waters. The potential yield of the EEZ is not known and by 1997 it was assumed to be unexploited (MNRT 1997). However, currently 39 deep sea fishing vessels have been given licence to fish in the EEZ (Wilson 2004). Currently, fish production in Tanzania stands slightly above 350,000 mt per year and that shows that there is great potential for increase fish production especially from the EEZ.

2.3 Marine fisheries in Tanzania

The standing stock of marine fish resources is not well known, however from the fishery resource survey carried out by the Norwegian Research Vessel R/V Dr. Fridtjof Nansen in 1982/1983 the standing stock of marine fishes in waters below 20 m depth was estimated between 100,000 to 210,000 mt (Iversen *et al.* 1984)**,** while the potential yield was estimated at 25,000 to 44,000 mt per year (Ardill and Sanders 1991).

Coastal and marine resources including fish and prawns provide important source of food, income and significant economic contribution to coastal communities and to the nation as a whole (Jiddawi and Ohman 2002). Small-scale artisanal fishery in inshore waters accounts for over 95% of marine fish landings (Jiddawi and Ohman 2002). The productive areas being coral reefs, reef flats, sea grass and estuarine areas. These areas are subjected to heavy fishing pressures from artisanal fishers (Jiddawi and Ohman 2002). In 2003 a total of 49,270 mt were produced by more than 19,000 fishers in the country, (Figure 3, Fisheries Division 2003), mainly using traditional small boats, small outrigger canoes, dhows, dugout canoes and dinghies and a variety of fishing techniques (Mgaya *et al.* 1999). Due to this limitation (use of small crafts) artisanal fishery is confined to shallow waters of less than 30 m and sheltered bays (Jiddawi and Ohman 2002). The Tanzanian fishery is an open access fishery and therefore is faced with many problems associated with open access system, including increasing fishing effort (Figure 4), increasing enforcement costs, and poor management that lead to unsustainable resource use. The fishery needs to be organized and properly managed to provide economic benefit and sustainability of the resource base.

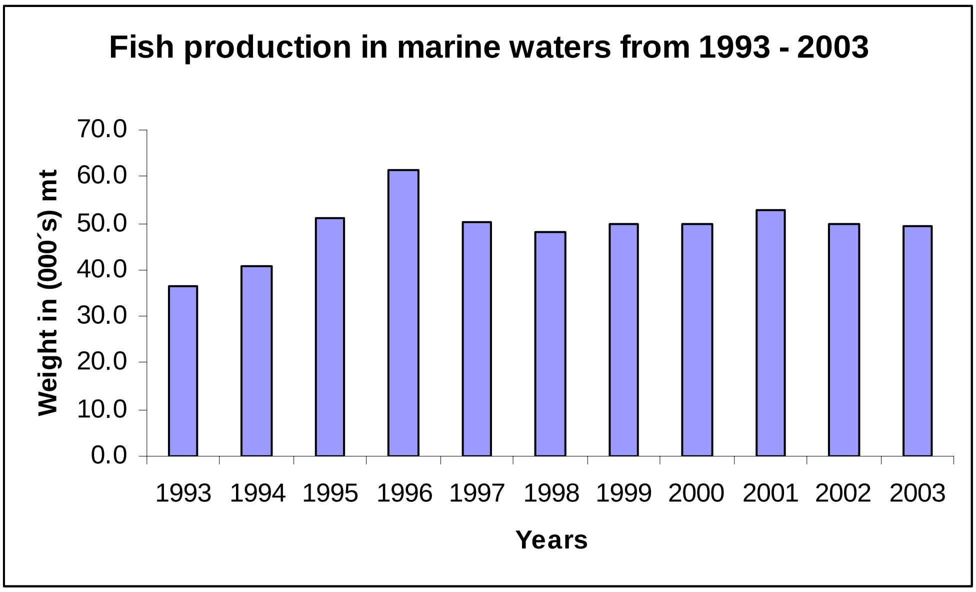


Figure 3: Fish production in Tanzanian marine waters from 1993 – 2003 (FD 2003).

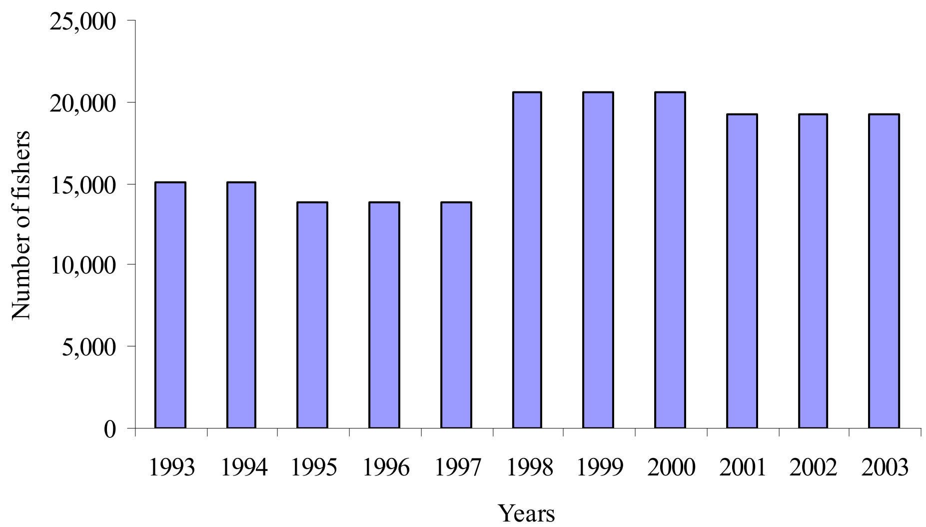


Figure 4: Number of fishers in marine waters from 1993 – 2003 (FD 2003)

2.4 Shrimp biology

The shrimp biology and behaviour in Tanzania is not well known. However, Gulland and Rothschild (1984) argued that biological behaviour of most tropical shrimp species around the world is similar. Most of the marine prawns fall under the Order Penaeidae and are normally referred to as penaeids (Gulland and Rothschild 1984). Penaeids are short lived species with their life cycle usually ranging from 12 to 18 months (Gulland and Rothschild 1984). Like in many tropical areas, most shrimp species in Tanzania spawn offshore; young or juvenile shrimps then move or drift to the estuaries which serve as nurseries where they spend considerable time growing before migrating offshore again as sub-adults or adults for spawning (Bwathondi *et al.*

2002). Spawning is believed to be throughout the year with peaks observed during rain seasons (Bwathondi *et al.* 2002). Penaeid species live predominantly on or near sandy or muddy bottom substrate and among sea grasses in shallow water (5 to 30 m) (Gulland and Rothschild 1984). Commercial shrimp fishery in Tanzania is based on four major species: the white prawns (*Fenneropenaeus indicus* (formerly known as *Penaeus indicus*), giant black prawns (*P. monodon*), and tiger prawns (*P. semisucatus*) and brown shrimp (*Metapenaeus monoceros*). White prawns make up most of the catch (Bwathondi *et al.* 2002, Haule 2001).

2.5 Shrimp fishery in Tanzania

Shrimps are valuable marine resource, not just for domestic use but also for export product. Shrimp in Tanzania are caught by artisanal fishermen as well as the industrial fishery. The artisanal fishery operates from small dugout canoes and small planked boats which are powered mainly by pedals, poles, oars and sails. Few fishers also use boats with outboard engines. The industrial or commercial shrimp fishery is operated from trawlers of up to 500 hp and 150 gross registered tonnages. Shrimp trawlers use stern trawl, double rigged, beam or outrigger trawls with codend mesh size of up to 40 mm. Most of the trawling is operated in inshore waters especially in the estuaries where there is a tendency of over increasing effort, and a corresponding reduction in catch per unit effort (Figure 5). However, the overall catch has been increasing with time (Figure 6). Industrial or commercial prawn fishery in Tanzania is based on four major species: the white prawns (*Fenneropenaeus indicus* (formerly known as *Penaeus indicus*), giant black prawns (*P. monodon*), and tiger prawns (*P. semisucatus*) and brown shrimp (*Metapenaeus monoceros*), with white prawns making up the majority of the catch (Bwathondi *et al.* 2002, Haule, 2001). In 2002 the commercial shrimp fishery contributed to US$ 6.6 million as revenue through export royalties (URT 2003).

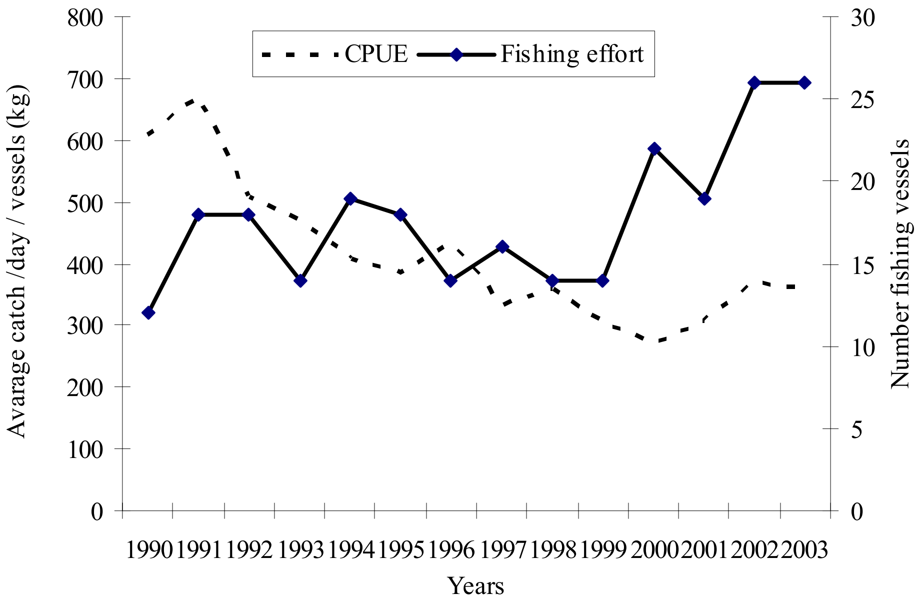


Figure 5: Fishing effort and CPUE of the commercial shrimp fishery.

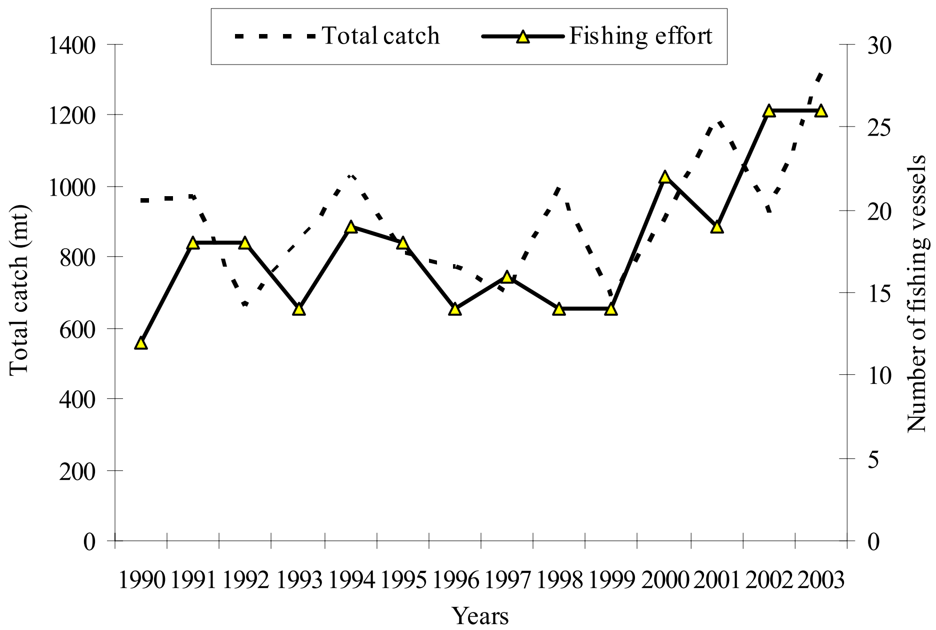


Figure 6: Fishing effort and total catch of the commercial shrimp fishery.

The actual standing stock of shrimp is not known; however Sanders (1989) estimated maximum sustainable yield (MSY) to be between 1000 mt and 1400 mt. Sanders (1989) estimate differs with that of the FAO which estimates the MSY of shrimp at 2000 mt per year. This discrepancy highlights the existing problem of limited information on the MSY and biomass. Information on the biomass is crucial in formulation of proper policies to regulate the shrimp fishery.

2.5.1 The artisanal shrimp fishery in Tanzania

Several traditional fishing techniques are employed including small seine nets, baited traps, cast nets and small beach seines of 45 m length and 1.5 m width (Haule 2001). Small beach seines are normally operated by two fishers by dragging the net along the beach in shallow waters of up to 1.5 m depth (Haule 2001). Fishing by this method is done during low tide and calm periods. Artisanal fishing is normally done all year around expect during rough weather and heavy rains.

2.5.2 Shrimp marketing from artisanal fishery

The catch from artisanal shrimp fishery is either sold directly to local agents (collectors) who store the shrimp on ice in insulated boxes. The shrimp is transported to a processing company or directly to the main fresh fish market in urban centres. Local agents supply fishing gears and iceboxes and ensure fast transport of the product to the market or processing factory (Richmond *et al.* 2002). At the main market shrimps are sold directly to consumers either chilled or frozen. Transportation from remote areas to processing factories or market places is unreliable hence contributing to post harvest losses. The rainy season normally corresponds to higher catches from the artisanal fishers but at the same time roads to remote fishing villages become impassable thus post harvest losses are probably high during this time. To prevent post harvest losses some prawn catches are either smoked or sun dried in villages when there is no one to buy or fishers have run out of ice. It is not known how many artisanal fishers are directly engaged in shrimp fishery as most artisanal fishers are also targeting other species.

2.5.3 Shrimp processing in factories

In processing factories, shrimps are weighed, washed in chilled water, graded, peeled, washed and packed in boxes of 2 kg either head-on or head less. The shrimp is then quick frozen before stored in freezers at -24^{o} C ready for export. All fish processing meet EU hygiene standards and apply HACCP criteria as set by the European Union which has been incorporated into Tanzanian fisheries regulations. As a condition for getting a license, a fish processing factory must first be inspected and meet all criteria set. All licensed fish processing factories are subject to regular inspections both planned as well as surprise, to ensure that high quality processing practice is maintained. European Union inspectors are also making planned as well as surprise visits to factories to ensure that the HACCP criteria is followed.

2.6 Commercial or industrial shrimp fishery

Different trawlers are engaged in the fishery including double rigged, beam or outrigger trawlers with engine capacity of up to 500 HP and the length of prawn trawlers is about 26 m (Haule 2001). Shrimp catch from commercial trawlers is processed on board, sorted and quick frozen in boxes of 2 kg. Most of the catch is exported to countries in the European Union (EU) and Japan (Haule 2001). Commercial prawn trawling in Tanzania waters commenced in 1969 after an exploratory shrimps fishing survey jointly conducted by the Government of Tanzania and Japan. Actual industrial shrimp fishing started 1982 after acquisition of a shrimp trawler by the Tanzania Fishing Cooperation (TAFICO) a parastatal organization (Haule 2001). TAFICO enjoyed monopoly on the industrial shrimp fishing for a number of years. As the government policy changed (in 1985) towards liberalized economy following structural adjustment and economic liberalization, many companies showed interest to enter the industry. In 1987 the government licensed three foreign trawlers which brought the total number of licensed trawlers to seven. Policy changes attracted many entrants to the fishery. As more vessels entered the fishery, fishing effort increased resulting in a decline of the abundance and sizes of prawns in most locations (Bwathondi *et al*. 2002). Decline of prawn catches lead to resource use conflicts between commercial trawlers and artisanal fishers and among the commercial trawlers themselves.

2.7 Current management measures

In an attempt to ensure proper management of the shrimp fishery, fisheries authorities have passed several regulations.

2.7.1 Zoning and rotation of fishing vessel on fishing grounds

This regulation was introduced in 1988 just a year after the government had licensed foreign fishing vessels. The objective of this regulation was to spread fishing effort evenly over the fishing grounds and minimize environmental degradation on a particular fishing ground where most of the fishing vessels seemed to cluster (Haule 2001). The regulation was also aimed at encouraging fishing vessels to search for new fishing grounds and minimize conflicts which were starting to arise among trawlers and artisanal fishers (Mongi 1990). At first, five zones were delineated. With time some of the zones were merged together to form three zones. Although this measure seemed to work to reduce conflict among trawlers, it did not solve the conflict between artisanal fishers and trawlers. Artisanal fishers complained that they are denied their livelihoods by trawlers who destroy their fishing gears. As the conflict grew the need to introduce new measures to try to protect artisanal fishers became more apparent.

2.7.2 Vessel observers

Conflict between the commercial and artisanal fisheries led to a regulation to put fisheries observers onboard fishing vessels in 1987. The objective was to monitor fishing activities of the commercial shrimp fishery, gain experience and engage in scientific work while onboard. The aim was to put observers in each fishing vessels but this was not realized due to insufficient financial and human capacity. Due to this limitation observers were put on one or two vessels in particular fishing grounds and were supposed to monitor the activities by also communicating with other vessels which did not have observers (Haule 2001).

2.7.3 Restricting fishing time

A regulation to restrict fishing time was introduced in 1990 aiming to solve the conflict between artisanal fishers and trawlers as well as reducing fishing pressure. Fishing time for trawlers was set and they were allowed to operate between 06.00 hours and 18.00 hours. This includes scouting time and steaming time to the fishing grounds. The regulation was believed to give artisanal fishers time to set their nets at night and haul them at dawn without being fouled by trawl nets (Haule 2001). Day time operation was also thought to allow for captains ensure good visibility so that they could avoid coming into contact with fishing gear. However, limiting fishing time did not reduce fishing effort as more investment went to increase engine capacity (from 1990 – 1996 engine capacity increased from 220 hp to 992 hp) (Haule 2001). As effort increased resource-use conflict between artisanal fishers and commercial fishery became even more pronounced. Immature shrimps were caught necessitating the introduction of other measures to protect immature shrimps and prevent a possible stock collapse.

2.7.4 Closed fishing season

In 1990 the fisheries authorities introduced a closed season from December to February (this was a time where many young shrimps were observed in catches) to protect young shrimps. Limiting fishing effort by restricting fishing time and closing the season did not seem to reduce fishing pressure as now vessel owners' increased fishing pressure by investing more in vessel improvement and technology. Vessel capacity and number of gears used increased. To overcome this, the fisheries authorities came up with yet another measure to try to reduce fishing effort.

2.7.5 Restriction on vessel capacity

In 1997 the fisheries authorities introduced a regulation to restrict vessel capacity to no more than 500 hp. This regulation managed to reduce the capacity of the vessel to 500 hp. Before this regulation engine power of the vessels were ranging between 220 to 992 hp while gross registered tonnage ranged between 45 and 296 (Haule 2001). However this did not reduce fishing effort either as operators opted to circumvent this regulation by the use of four trawl nets instead of one trawl net (Wilson 2004). This suggests that the fishing effort is still increasing despite measures to limit fishing vessel capacity.

2.7.6 Fishing licence and registration fees

All fishing vessels are subjected to registration fees which are paid when vessels are commissioned for the first time and vessel and fishing licence fees which are paid annually. Registration fees are aimed to keep track of how many vessels enter the industry and also to collect revenue, while licence fees are seen as means to control entry to some extent, keep track of how many vessels are actively engaged in fishing activities each year and also as a way to collect revenue.

In the commercial shrimp fishery, fishing vessels licences are charged per gross registered tonnage (grt) and the rates vary with vessels size, flagship and shore infrastructure (Wilson 2004). For example, for a Tanzanian registered vessel with land processing facility, both the licence and fishing licence fee is US$ 2.4/GRT, while for a foreign vessel without land based processing facility the fee is US$ 108/GRT for fishing and US$ 162/GRT for a fishing vessel licence (Wilson 2004). This annual fishing licence fee is one way to reduce fishing effort in commercial shrimp fishery (Wilson 2004).

Despite of all the management measures which have been put in place, fishing effort continues to increase and many more entrants demand to join the fishery. Currently the fisheries authorities are not issuing new licences for commercial shrimp fishing, however, there is an increasing pressure from those who want to join the fishery. The decision to stop issuing new licences for the commercial shrimp fishery was made due to concerns that the fishery is not sustainable. Therefore there is a need to assess the current status of prawn and determine the policy that will maximize economic rent while ensuring sustainable development of the country’s prawn resources.

3 MODEL SELECTION

Fisheries managers are confronted with the challenge to regulate fisheries to ensure maximization of social benefit flowing from the activity. For fisheries managers to do this they need good information on the biological processes of the resource as well as the socio-economic processes associated with using the resource. Availability of information alone does not guarantee sound management unless the information is prepared in a way that can be used in the decision making process. One way of achieving this is to develop a bio economic model of the fishery to predict what will be the outcome of different management policies. The best policy identified in this way can then be adopted for that particular fishery. In a situation where information is inadequate, the authorities must the use best available information to develop a bio economic model to help reach a sound decision.

In this study a very simple bio economic model is employed. This approach was selected for the following reasons: Firstly, the Tanzanian shrimp fishery data is very limited and thus does not support an advanced model. Secondly, the fishery itself is not very complicated therefore there is no need for a very complicated model. Thirdly, the model developed here can later be extended and refined when more and better data becomes available.

The model chosen is based on the work of Gordon (1954) and Schaefer (1957) who developed a famous basic bio economic model for fisheries management. The model consists of biomass growth, harvest, cost and profit functions. The basic model may be expressed as follows:

(i) $\dot{x} = G(x) - N \cdot q$

(ii) $q = Q(e, x)$

(iii) $c = C(e)$

(iv) $\Pi = p \cdot N \cdot q - N \cdot c$

Where $\dot{x}$ is the biomass change, $G(x)$ is the biomass growth function, q is the harvest by each vessel, N is the number of vessels, $Q(e, x)$ is the biomass harvesting function, e is effort, c denotes cost, $C(e)$ is harvesting cost function, p represents market price of the catch and Π denotes profit.

To apply this model on the shrimp fishery we need to specify the following functions:

(a) Shrimp biomass growth function $G(x)$
(b) Shrimp harvest function $Q(e, x)$
(c) Cost function $C(e)$

Moreover, in addition to the functional specification we need to obtain estimates of the parameters of the functions. Both functional forms and parameters have to be as empirically accurate as possible. Finally, since shrimp fishery data is in discrete time my model will also have to be formulated in discrete time.

The model equations can be expressed as follows:

(1) $$x_{t+1} - x_t = G(x_t) - Q_t = \alpha \cdot x_t - \beta \cdot x_t^{\;2} - Q_t \,.$$

Where x_{t+1} is the stock size in a year t+1 and x_t stock size in a year t. The biological parameter α is the intrinsic growth rate of the harvestable stock and the parameter ratio $\frac{\alpha}{\beta}$ represents the carrying capacity of the biomass (or virgin stock equilibrium). Q_t denotes the aggregate harvest.

The individual vessel harvest function is modelled by the following function,

(2) $$q_t = Q(e_t, x_t) = a \cdot G_t^b \cdot D_t^{cc} \cdot x_t^{\varepsilon}$$

Where q_t represents harvest from individual vessel at a year *t*, G_t is the gross registered tonnage of the fishing vessel, D_t is the number of fishing days. As before, x_t represents the biomass at year *t*. The parameters *a*, *b*, *cc* and *ε* are constants.

The expression $G^{b/cc} \cdot D$ may be regarded as fishing effort *e*. Given this equation (2) may be rewritten as:

$$q_t = a \cdot e_t^{cc} \cdot x_t^{\varepsilon},$$

where $e_t \equiv G_t^{b/cc} \cdot D_t$.

The aggregate harvest is defined by:

(3) $$Q_t = N_t \cdot q_t$$

Where Q_t is the total harvest from the fleet, N_t denotes number of fishing vessels and qt is harvest from individual vessel.

The total cost of an individual vessel can be expressed as:

(4) $$tc_t = Fk + d \cdot D_t \cdot G_t \,,$$

Where as *Fk* is fixed cost of fishing, *d* expresses the constant coefficient of effort

The aggregate costs for the fleet are:

(5) $$TC_t = N_t \cdot tc_t$$

Finally, we have the aggregate profits at time *t* as:

(6) $$\Pi_t = p \cdot Q_t - TC_t \,,$$

where p is the price of landings.

The net present value of a fisheries policy (NPV) is defined as the difference between the present value of benefits and the present value of costs. All costs and benefits are adjusted to "present value" by using discount factors to account for the time value of money. The concept of present value is a way of making costs and benefits occurring in different years comparable. The net present value can be expressed as follows:

(7) $$PV = \sum_{t=0}^{T} \frac{\Pi_t}{(1+r)t} .$$

Where r is discount rate and Π_t is the profit at time t. PV measures the total net benefits flowing from a project over some interval of time. Naturally, the higher the PV, the more beneficial the project.

4 PARAMETER ESTIMATION

4.1 Estimation of biomass growth parameters

Information on the fish biomass and biomass growth are among the crucial pieces of information required for the management of fisheries resources. In Tanzania the actual shrimp biomass is not known. However, based on a shrimp survey of 1988, it was estimated (Sanders 1989) that the maximum sustainable yield (MSY) was between 1000 mt and 1400 mt. On the basis of the Sanders estimation, we will assume a MSY of 1200 mt. We will moreover assume a virgin stock equilibrium of 2000 mt. On this basis we can determine the biological parameters, α and β according to the equations:

$$x_{vir} = \frac{\alpha}{\beta}$$

$$MSY = \frac{\alpha^2}{4\beta},$$

derived from the biomass growth function $G(x) = \alpha \cdot x - \beta \cdot x^2$ defined in section 3. On the basis of these equations, we can calculate α and β as:

$$\alpha = \frac{4MSY}{x_{vir}}$$

$$\beta = \frac{4MSY}{x_{vir}}.$$

Assuming MSY to be between 1000 mt and 1400 mt and virgin biomass of shrimp not less than 1000 mt and not more than 5000 mt, estimates of different values of α and β that correspond to different assumptions of the MSY and virgin biomass of shrimps are given in Table 1 below.

Table 1: Estimates of α and β at different levels of assumption of virgin biomass of shrimp and MSY.

x_{vir}	MSY 1000		MSY 1200		MSY 1300		MSY 1400	
	A	**β**	**α**	**β**	**α**	**β**	**α**	**β**
1000	4	0.004	4.8	0.0048	5.2	0.0052	5.6	0.0056
1500	3.99	0.00266	3.2	0.00213	3.466	0.0023	3.735	0.00249
2000	4	0.002	2.4	0.0012	2.6	0.0013	2.8	0.0014
2500	4	0.0016	1.92	0.000768	2.08	0.00083	2.24	0.000896
3000	3.99	0.00133	1.6	0.00053	1.73	0.000577	1.866	0.00062
3500	4	0.001142	1.37	0.00039	1.485	0.00042	1.6	0.000457
4000	4	0.001	1.2	0.0003	1.3	0.000325	1.4	0.00035
4500	4	0.00088	1.066	0.000237	1.155	0.000256	1.24	0.000276
5000	4	0.0008	0.96	0.000192	1.04	0.000208	1.12	0.000224

Assuming that the MSY is 1200 mt and virgin biomass is 2000 mt my estimated basic parameters for α and β will be 2.4 and 0.0012 respectively.

4.2 Estimation of harvest function parameters

Catch and effort data for individual vessels in the commercial shrimp fishery of Tanzania from 1997-2003 is available. I use this data to estimate by econometric means the parameters of the harvest function specified in section 3.

The catch data is expressed as the total catch (kg) of shrimp (per fishing vessel per year). Fishing effort is expressed as fishing vessel characteristics (in terms of gross registered tonnage, length of the fishing vessel in meters and vessel engine capacity in horse power), and number of fishing days (per vessel per year). All this data was obtained from the Fisheries Division. Data consisted of observations recorded on a number of fishing vessels annually between the years 1997 – 2003, there being 134 observations in total. Descriptive statistics of the data and regression analysis is given in Table 2 below.

Table 2: Descriptive statistics of catch and effort data from the Tanzanian commercial shrimp fishery from 1997 – 2003.

Variable	Number of observations	Mean	St. Dev	Variances	Min	Max
LENGTH	134	22.147	3.7094	13.760	16.900	38.100
GRT	134	112.01	40.659	1653.1	34.000	256.00
HP	134	402.10	135.80	18441.0	220.00	992.00
CATCH	134	49.593	30.675	940.96	0.96000E-01	138.21
DAYS	134	148.80	63.358	4014.3	3.0000	265.00

The econometric software SHAZAM (White *et al.*1988). was used to analyse the data and to estimate a harvesting function. The final estimation equation was:

$$\ln q_t = \ln a + b \cdot \ln G_t + cc \cdot \ln D_t + \varepsilon \cdot \ln x_t$$

where the variables and constants are as specified in the section above. ln(*z*) denotes the natural log of *z*.

The most pertinent results of an ordinary least squares estimation of this equation are given in Table 3 below.

Table 3: Coefficients estimates of the harvest function. Catch and effort data from 1997 – 2003. Number of observations: 134.

Variable	Estimated Coefficient	Standard Error	T- Ratio 131 DF	P-value
LDAYS	1.1953	0.5981E-01	19.98	0.000
LGRT	0.53398	0.9844E-01	5.424	0.000
LX	1	(restricted)		
CONSTANT	-4.6723	0.5195	-8.993	0.000
R^2=0.78				

Table 3 shows that coefficient estimates of catch and effort variable (ln days and lngrt) are statistically significant with P-values = 0.000. The relationship explains 78% of the total variation in catches.

4.3 Estimation of parameters for the cost function

Catch and cost data from the commercial shrimp fishery of Tanzania for the year 2003 was used to estimate parameters (coefficient) for the cost function. Catch and cost data includes; total catch (kg) of shrimp (per year per fishing vessel), gross registered tonnage, length of the fishing vessel, vessel engine horse power, total number of fishing days (per vessel per year) and total costs (fuel, labour, maintenance, royalties and other costs). Catch data was obtained from the Fisheries Division while cost data was obtained from interviewing some vessel owners. Obtaining cost data from vessel owners was a difficult task as this information is usually treated as confidential by companies. Vessel owners are hesitant to disclose this information for two main reasons: First, there is the fear of jeopardizing their business in case information lands in the hands of competitors. Second, is the fear that government authorities might use this information to calculate profits and use this as a basis for taxing their business.

I used my connections with a former owner of a fishing company to obtain this information. Doing this I managed to get cost information on five vessels. This, of course, is a very small sample. Moreover, despite using a former fishing company owner, the cost data obtained might not accurately reflect the real cost of the fishing vessels. Descriptive statistics for the data can be found in Table 4 below.

Table 4: Descriptive statistics on fishing cost, total catch and effort variables for some of the vessels for 2003.

Variable	Number of observations	Mean	St. Dev	Variances	Min	Max
LENGTH	5	20.200	4.3818	19.200	17.000	25.000
GRT	5	103.00	42.450	1802.0	72.000	150.00
HP	5	341.00	145.15	21068.	235.00	500.00
CATCH	5	54673.	34197.	0.11694E+10	24776.	94540.
DAYS	5	171.60	39.361	1549.3	113.00	208.00
TC	5	0.264540 +06	0.10868E+06	0.11811E+11	0.16227E+06	0.38744E+06

The econometrics software SHAZAM was used to run ordinary least square regression analysis of total fishing costs, total catch and effort variables for 2003. The equation for estimating cost coefficient is $TC = Fk + d \cdot D_t \cdot G_t$.The coefficient estimates and standard statistics are given in Table 5 below.

Table 5: Coefficients estimates of total fishing cost for shrimp fishery for 2003. Number of observations = 5.

Variables	Estimated coefficient	Standard error	T- ratio 3 DF	P-value
EFFORT	9.7743	0.6564	14.89	*0.01*
CONSTANT	*81,663*	*0.1389E+05*	*5.880*	*0.10*
R^2 = 0.98.				

Table 5 above shows that both coefficient estimates are statistically significant. The relationship explains by 98% of the variations.

4.4 Estimation of Price

Information about the price of shrimps was obtained by interviewing some companies owning shrimp trawlers. The average price of shrimp is given at 9 US$ per kilogram of shrimp.

4.5 The rate of discount

The discount rate, *r*, employed in this study is the one offered by different commercial banks in Tanzania in 2003 for long term (3-5 years) loans of 6.5% Since shrimp fishery requires long term investments, I assume that most of the fisheries companies might have obtained loans from banks to run their activities. This rate, therefore, is probably close to their opportunity cost of capital.

4.6 The Completer Numerical Model

Substituting the above estimated parameters into my bio economic model, the complete model consists of the following equations:

(1) $$x_{t+1} - x_t = 2.4 \cdot x_t - 0.0012 \cdot x_t^2 - N_t \cdot q_t$$

(2) $$q_t = 0.0094 \cdot G^{0.534} \cdot D^{1.2} \cdot x_t^1$$

(3) $$TC = 81,663 + 9.7743 \cdot D_t \cdot G_t$$

(4) $$\Pi_t = 9 \cdot q_t - TC_t$$

(5) $$PV_t = \sum_{t=0}^{T} \frac{N_t \cdot \Pi_t}{(1+0.065)^t}$$

5 APPLICATION OF THE MODEL

Equations (1) to (5) above explain the evolution of prawn biomass, harvests, costs and profits as a function of the number of fishing vessels applied to the fishery, N_t. Selecting a path of N_t over time we can use the model to simulate these fishery outcomes over any time period selected. In this study we use Microsoft EXCEL for this purpose

5.1 Evolution of the shrimp fishery under no management

In an open access fishery or where there is no management, fishing vessels enter and leave the fishery according to profits (Clark 1976, Conrad and Clark 1987). When the fishery is profitable it attracts news entrants and when it suffers losses some vessels leave the fishery. In this case, number of fishing vessels (*N*) at year *t* will be an increasing function of profits (and therefore also the biomass and the other variables that contribute to profits). According to Gordon (1954) the open access fishery finds an equilibrium at a point where there are no profits. At this point there is no incentive either to leave or enter the fishery. In this case the number of fishing vessels (*N*) at year *t* will be an increasing function of profits (and therefore also biomass and the other variables that determine profits). This can be expressed by the following equation:

(6) $$N_{t+1} - N_t = \varepsilon \cdot \Pi_t ,$$

where ε is a positive constant. Adding this equation to the model of the previous chapter makes the number of vessels endogenous. In other words equations (1)-(6) define an autonomous dynamic fisheries system. This system may or may not have an equilibrium and the equilibrium, if it exists, may or may not be stable. In what follows we take ε=0.05 since this value seems to generate fishery behaviour in accordance with what has been historically observed.

Simulating the model shows that the fishery has a stable equilibrium characterized by 27 fishing vessels, annual prawn harvest of approximately 1200 metric tonnes, biomass of 985 metric tonnes and, of course, no profits.

The dynamic adjustment to this equilibrium starting from the current state of the fishery (26 vessels and 1000 metric tonnes of biomass) is found to be cyclical as illustrated in Figure 7. The outcome of the simulation is detailed in Appendix I.

Figure 7a illustrates the path of vessels over time. Since the initial number of vessels is very close to the equilibrium number the cycles are comparatively small. Starting from a vessel or biomass levels further away from the equilibrium point leads to much larger cycles.

Similarly the amount of biomass will respond to effort (number of vessels) applied to the fishery. When the effort is low, more biomass builds up whereas higher effort causes biomass to decline (Figure 7b). The biomass build up is slow and oscillates around 985 mt (Figure 7b). On other hand, more effort will respond to more harvest (for any level of biomass) and vice versa (Figure 7c). In the absence of mechanisms to exclude or limit new entrants into the fishery, there are no means to control the level of shrimp harvesting effort and effort applied will continue to increase as long as profit is realised until cost of fishing effort is equal to total revenue and rent is zero (Figure 7d). As effort increases stock size decreases and oscillates until it reaches an equilibrium point where there is no net profit of the fishery (Figure 7d). At this point some of the fishing vessels will leave the fishery as the revenue accrued is insufficient to cover the cost of fishing, in other words the fishery is not profitable. The tendency to leave the fishery will reduce fishing effort which will have two effects: it allows for the stock to recover towards equilibrium state; and allows those remaining to start realising some profits. As soon as the fishery starts to become profitable new entrants will join the fishery and the cycle begins again. This cyclical motion of ups and down of the fishery is expected to happened in an open access fishery condition or where there is no management.

Of course open access is not good way to manage the shrimp fishery as it (i) may lead to resource collapse with the consequence of huge economic losses especially if the fishers' act more irrationally by tending to expect profits during periods of downturn and (ii) will lead to no profits in the long run. Note, however, that any economic losses in the fishery will only be temporary as some vessels will be forced out of the fishery due to losses. Even in an open access situation the fishery may still generate a positive present value of profits if the fishery begins at a favourable point (e.g. low number of boats and high biomass) (Appendix 1). Thus, in our simulation above, the fishery realizes present value of profits amounting to US $ 140, 000 (Appendix 1). It is useful to note that in an open access or under no management situation during periods of downturn where the fishery is making economic losses there is more incentive to cheat on the landed volume as well as under declare export invoices to avoid taxes.

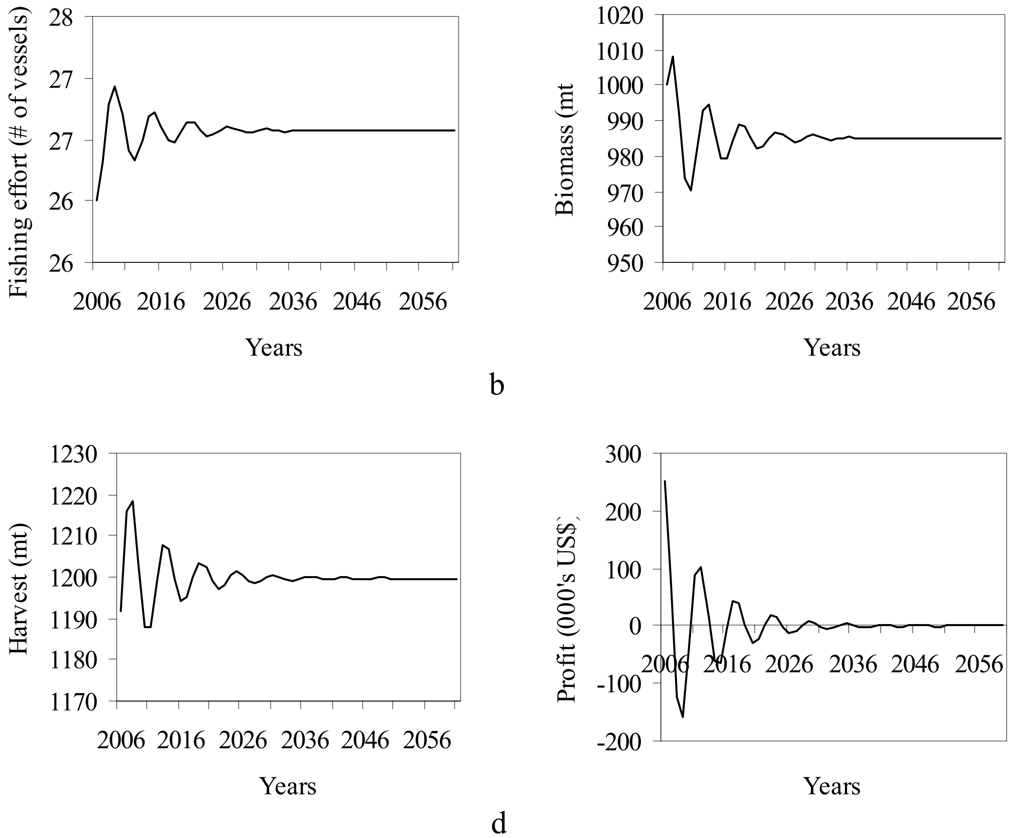


Figure 7: Fishing effort over time in an open access situation (a), response of biomass on effort over time (b), harvest over time (c) and profits over time (d).

5.2 Optimal shrimp fishery

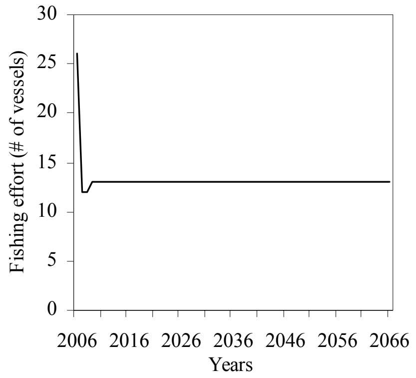
The first step towards an optimal management of the Tanzanian shrimp fishery is the management objective. Reasonable management objectives are: to maximize economic rents, maximize the sustainable harvest or improve the socio-economic conditions of the local communities utilizing the resource. This leads to the quick conclusion that the best approach could be to set a management objective that combines all of the above. However, such an objective is generally not achievable. Maximizing sustainable harvest for instance is not compatible with maximum rents. In an attempt to solve this dilemma the authorities in Tanzania have set an overall goal of the national fisheries policy in Tanzania to promote conservation, development and sustainable management of the fisheries resources for the benefit of present and future generations (MNRT 1997). To achieve this goal the fisheries authorities have set a number of key objectives among them is *'to put into efficient use available resource in order to increase fish production so as to improve fish availability as well as contribute to the growth of the economy'* (MNRT 1997, p 6). To achieve the above stated goal and objective the fisheries authority has taken measures to protect fisheries resources including shrimp fishery by using command and control methods including effort control, licensing, gear restrictions, closed area, closed season and input control. In general these measures have not solved the fundamental problem of the shrimp fishery in Tanzania. The objective of sustainable resource use and economic growth can only be achieved if the fishery is properly organized to provide for sustainable growth and maximizing economic benefit. One way of achieving this is by managing the fishery at a level where sustainable level and maximum economic rent can be achieved. In so doing we need to find the optimal path of number of fishing vessels over time required to bring the fishery to an equilibrium.

5.3 Optimal path of shrimp fishery

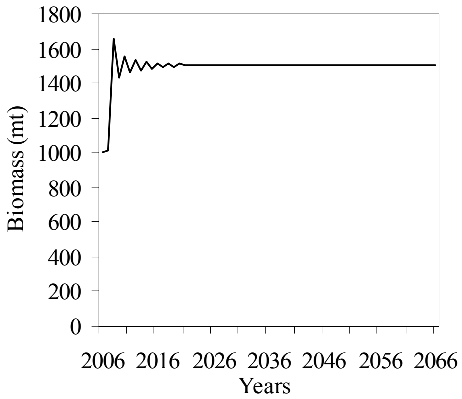
Applying the model in equations (1) to (5) we may select a path of fishing vessels that may generate fisheries outcomes (biomass, harvest and profits) over time. Our objective is to select a time path for the number of fishing vessels that will maximize the economic return from the fishery measured as present value of profits. This incidentally leads to a comparatively large and sustainable biomass. It also maximizes the contribution of the shrimp fishery to the GDP and can thus be said to maximize employment in the country.

The key outcome of this exercise (detailed in Appendix 2) is that the number of vessels should be drastically reduced from the current number. This will build up biomass and generate substantial profits in the fishery. The present value of this path is found to be some US$ 40 million. The long term harvest rate corresponding to this policy is slightly less than the current harvest level.

The main outcome of this policy is illustrated in the time paths in Figure 8. Detailed numerical outcomes year by year can be found in Appendix 2.



a



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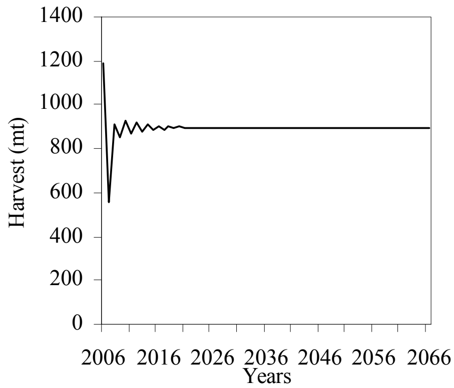
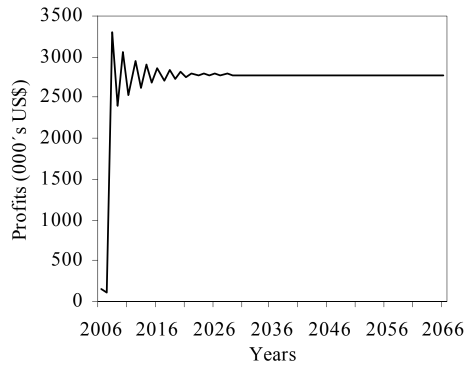


c



d

Figure 8: The fishing effort over time in an optimal fishery situation (a), response of biomass on effort over time (b), harvest over time (c) and profits over time (d).

The rent maximizing policy for the shrimp fishery is to reduce fishing effort from the current level of 26 vessels to 13 fishing vessels (Figure 8a). This is done in two steps (see Appendix 2). In the first year, effort is reduced to 12 vessels. This number of vessels is maintained in the second year. In the third year the number of vessels is increased to 13 vessels This initial excessive reduction in fishing vessels compared to the long run level is to hasten the build-up of the biomass level to the long run rent maximizing level of some 1500 mt compared to the initial level of 1000 mt (Figure 8b). This increased biomass level will ensure sustainability of the resource. Note that under this policy the biomass is expected to oscillate at a low magnitude along the path toward the long run optimal equilibrium at (1503 mt) (Figure 8b). Due to controlled effort the harvest is expected to be 896 mt at optimal equilibrium (Figure 8c). The policy of reducing the fishing effort is also expected to improve profit of the fishery. The profit will oscillate at a low magnitude and attain equilibrium state at 2.7 million US$ (Figure 8d). This policy will also create long run net present value of 39.5 million US$

Overall, this policy appears to achieve the Fisheries Division objective of '*putting into efficient use available resource in order to increase fish production so as to improve fish availability as well as contribute to the growth of the economy'* (MNRT 1997, p

6), because it allows for good biomass growth and ensures greater economic rents. Good biomass growth ensures sustainability of the resource while greater economic rents can stimulate economic growth.

However, the long run net present value of the shrimp fishery can be further increased if fishing days and number of vessels are adjusted to the level which will bring maximum economic benefit. In Appendix 3 the average number of fishing days per fishing vessel have been adjusted to 300 from 148. By adjusting the average number of fishing days to 300 the number of fishing vessels may be reduced to eight. This adjustment is expected to realize the net present value of US $ 60.4 million with annual marginal profits of US$ 4.7 million to the fishery which is twice the amount realized without adjusting the fishing.

The expected net present value can be used by the government or by fishing companies as collateral of the fishery for investment opportunities. The calculations presented in Appendix 3 also show that each of the eight fishing vessels will be able to harvest 138 mt per year. If the policy of reducing fishing efforts is backed with the introduction of individual quota systems, then 138 mt could be set as an individual quota per fishing vessels. This quantity of shrimps can either be auctioned or sold to individual fishing vessels and revenue can be used by the government for funding management activities such as data collection, storage, management and dissemination, research activities, monitoring, control and surveillance, extension, quality control and others. The revenue can also contribute to the national coffers and be used for social development activities. Giving fishing companies individual quotas through their fishing vessel of this amount (138 mt) per year, may encourage some companies to invest in processing factories to process shrimps and increase value added to the product for higher prices in international markets or even local markets. Processing companies will create employment for local people directly and indirectly (through supporting industry). Overall, this policy might stimulate fast development of the fishery and hence social welfare development of the coastal communities.

5.4 Comparison between open access and optimal shrimp fishery

In an open access fishery or no fisheries management, the shrimp fishery is generally not expected to make profits even if fishers act rationally. Some profits may be registered during the adjustment path. Since the net present value of the fishery is small, its contribution to economic growth will be small as well. On the other hand if the government is depending on revenue from this operation, the revenue collection might be affected during downturns (i.e. when the fishery is making losses during the adjustment path). During this time, there is also high incentive for cheating and thus making enforcement even more difficult.

In open access fishery or no fisheries management, individualistic competition may run down the stock hence causing fishery collapse. Since during the adjustment path the shrimp stock may well experience severe oscillation there is a risk that the biomass goes below a biological threshold. This might lead to a risk of fishery collapse, and if so, shrimp stocks may take long to recover. This may have a negative effect not only on the shrimp industry but also on other supporting industries and may cause large economic losses.

Management measures are needed to ensure that the fishery is operating at an optimal level. If the fishery at present is operating at a higher fishing effort with corresponding lower biomass, the appropriate policy is to reduce fishing effort to a level where it will be optimal. The policy of reducing fishing effort is expected to cause some losses to the fishery during the adjustment path for a few years when the fishery adjusts to the optimal level. After that the fishery is expected to make more profit and long term positive net present value.

The stock biomass is expected to oscillate less which is good in case of unfavourable conditions. Under this system the effort is controlled and there is no danger that there will be more entrants into the fishery. Controlling effort at optimal levels allows for good biomass growth and hence ensures sustainability of the stock and the fishery as a whole.

5.5 Sensitivity analysis of the optimal policy

The model used to calculate the optimal shrimp policy discussed above is subject to considerable uncertainty. Among other things, the parameter estimates used in the model may well be erroneous. To check the robustness of the calculated optimal policy to parameter misspecification, a sensitivity analysis of the optimal policy to parameter values was conducted. More precisely we calculated the optimal long number of fishing vessels for other values of the parameters. The results of this exercise are reported in Table 6 and Figure 8.

Table 6: Sensitivity analysis of shrimp fishery fishing effort on different percentage changes of biological parameters, prices and fixed costs (fk).

	-30%	-20%	-10%	0%	10%	20%	30%
alpha	3	6	10	13	16	20	23
beta	19	17	15	13	11	9	7
price	7	9	11	13	15	17	18
fk	16	15	14	13	12	11	10

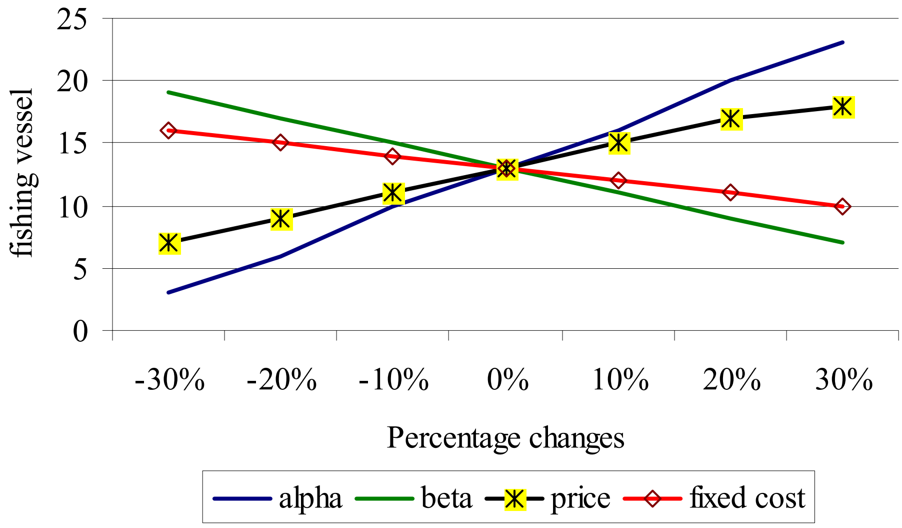


Figure 9: Sensitivity Analysis chart of shrimp fishery of Tanzania.

Table 6 shows the rent maximizing long run number of fishing vessels when the parameters are altered by the stated percentage. As can be seen, the optimal solution is quite sensitive to the specification of the biological parameters and somewhat less so the fixed costs and landed price of fish. Thus, if alpha (the intrinsic growth of the biomass) is increased by 30%, the optimal number of boats becomes 23 vessels instead of the calculated 13. Similarly if beta is increased by 30%, the optimal number of boats drops to seven.

In general, sensitivity analysis of the shrimp fishery shows that the required fishing effort to maximize economic rent and ensure good biomass growth must be in the range between 3 to 23 fishing vessels, if parameters are subjected to percentage changes between -30% to 30%. These findings indicate that even if the biological parameters estimation and information on price and costs are wrong the current fishing effort is still too high.

6 FISHERIES MANAGEMENT SYSTEMS

6.1 Basic fisheries management theory: The fisheries management regime

The fisheries management regime is the institutional framework under which the fishing industry operates. This framework may be set by social custom or tradition, the government (the fisheries authority), groups of fishermen and their associations or by other means (e.g. environmental pressure groups). Usually more than one of the above is involved in setting the fisheries management regime. The fisheries management regime may be explicit (i.e. written rules and regulations) or implicit (i.e. informal rules of conduct held by a group of fishers). In most cases an informal fisheries management system achieves a high level of compliance due to the fact that it originates from within the group itself. Implicit fisheries management is generally most effective in small fishing communities with limitations on new entrants and little technical change. In the case of large fishing and highly dynamic communities, implicit fishery management arrangement might not be very effective unless it is also supported by an explicit fisheries management regime. In general one expects fisheries management regimes that are based both on explicit and implicit rules to have a higher chance of success than those that rely exclusively on one form.

The fisheries management regime has three main components, the fisheries management system (FMS), monitoring, control and surveillance (MCS) and the fisheries judicial system (FJS). The first component, the FMS, is mainly concerned with setting the appropriate rules for fishing. The other two components, the MCS and the FJS, are mainly concerned with enforcing these rules. Each of these components should be regarded as links in the same chain with all links equally important. If one fails the fisheries management regime as a whole fails. It also follows that each component must be designed with regard to the others.

6.2 Fisheries management systems

The fisheries management system consists of rules for the conduct of fisheries. These rules may pertain to a great number of biological and economic fisheries variables. There may be rules on species, areas, fishing times, fishing gear, minimum size of fish, number of fishing vessels, permissible equipment, operating times, harvest volumes etc. Given the high number of fisheries variables subject to management, it should be clear that the number of possible fisheries management systems (i.e. sets of rules) can be very high. For this reason it is useful to classify fisheries management systems. Arnason (2004 (lecture notes)) offers a particularly convenient classification. First, possible fisheries management systems are divided into two basic classes: biological fisheries management and economic fisheries management (Figure 10). The main difference between the two is that biological fisheries management is trying to improve the biological yield of the resource while economic fisheries management is trying to improve the economic outcome of the fisheries operation. Economic fisheries management is further divided into direct and indirect fisheries management. The former consists of restrictions and commands, and the latter attempts to change behaviour by changing economic incentives. Finally indirect economic fisheries management is divided into taxes and property rights.

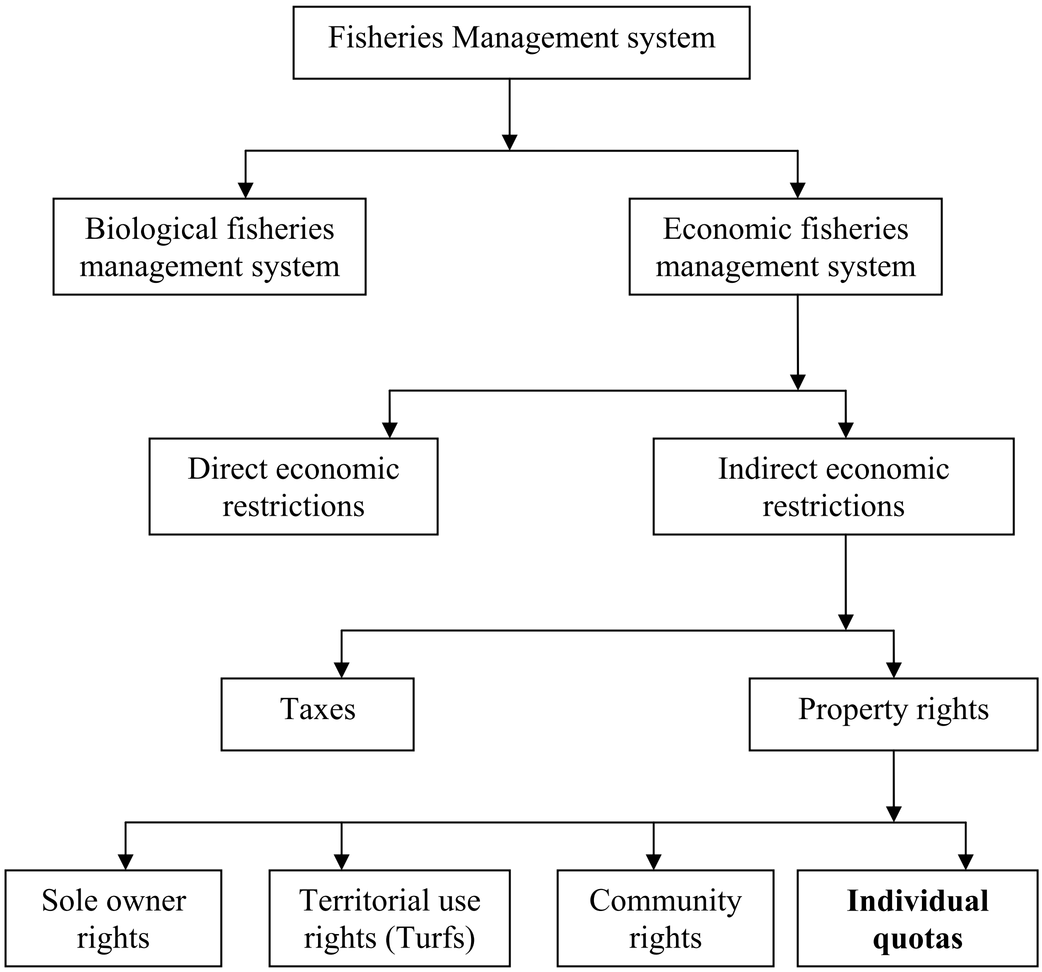


Figure 10: Categories of fisheries management systems (Adapted from Arnason 2004).

6.2.1 Biological fisheries management system

Biological fisheries management generally aims at maximizing biological yield of the resources by protecting spawning stocks, young fish and habitats. Measures used include, setting total allowable catches (TAC), closing areas for fishing, seasonal closures, gear and vessel restrictions and restrictions on habitat degradation or pollution.

Biological fisheries management is very common in fisheries throughout the world. In fact, it is probably the most common class of fisheries management systems used. The system, if properly operated and enforced, can be effective in avoiding total fish stock collapses and increasing the sustainable yield from the fishery. However, it has invariably been found not to solve the root cause of the fisheries problem, namely the common property problem (Arnason 2001). In fact, as argued by Arnason (2001), biological fisheries management is by design incapable of removing or even alleviating the common property problem. Consequently, biological fisheries management results in very little or no long term economic gains in the fishery. Taking the cost of management into account, the net result may easily be negative.

6.2.2 Economic fisheries management system

Economic fisheries management systems aim at maximizing economic rents. This management system can be categorized into direct economic restrictions and indirect economic restrictions.

Direct economic restrictions

Direct economic restrictions include limited effort (restriction on number of fishing days at sea, fishing time etc), capital restrictions (vessel size, engine capacity, shape of the vessel, types of equipment), investment restrictions (how much investment is allowed), fishing gear restrictions (mesh size, number of gears and types) and so on. Direct economic restrictions often lead to increased investment in and employment of inputs that are not restricted. In this way they tend to lead to distortions of the fishing fleet, fishing gear and the technology employed (Pascoe and Coglan 2002). Similarly, the observed changes of using more nets from a single net is one way of avoiding effort restrictions set by the fishing authority (Wilson 2004).

Just as biological restrictions, direct economic restrictions do not remove the common property problem which is at the root of the fisheries problem. Hence direct economic restrictions are incapable of improving the economic efficiency of the fishing fleet in the long run. Indeed, they will also be rent dissipating in the short term as new restrictions are added on already inefficient fishing operations. On top of this there is the cost of imposing and enforcing direct economic restrictions.

Unlike biological fisheries management, direct economic restrictions will not necessarily improve the biological state of the resource. In addition they tend to distort the capital structure of the fishing industry. Therefore, direct economic restrictions are probably inferior to biological fisheries management

Indirect economic restrictions

Indirect economic restrictions include taxes and property rights. This system aims to change the incentive structure in the fishery in order to induce the participants to act in an economically more efficient manner (Arnason 1993).

<u>Taxes</u>

Taxes are an indirect method of controlling fishing effort and harvest. The government or fisheries authority may impose tax on inputs (i.e. fuel, spare parts, gears, utilities etc) or on outputs (landings) so as to increase cost of production and make the industry less profitable, thus indirectly controlling total catch. The tax would be calculated to achieve the objective of attaining maximum economic yield (MEY) of the fishery.

Taxation can guide the industry (from Competitive Sustainable yield (CSY)) towards competitive equilibrium (Optimal Sustainable Yield (OSY)) while the government makes profit from the taxation (Figure 11). However, the tax increases cost of production, hence creating an economic disadvantage situation to companies along the adjustment path to the new equilibrium, hopefully the MEY point. In an already overcapitalized fishery, the taxation will have to be heavy enough to force a number of companies out of the industry. Generally, this implies severe economic hardship and bankruptcies. Once the new equilibrium is reached, however, company profitability will revert to the original level, namely just sufficient profits to stay in business.

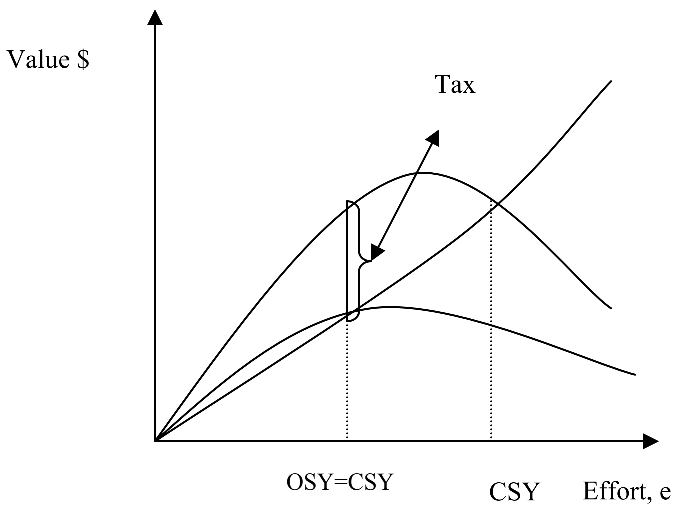


Figure 11: Effect of taxes (on landings) (Arnason 2004).

It is advisable to tax landings rather than inputs because taxing inputs may lead to input substitutions and thus a distorted fishing industry. If revenues accrued from taxes are not ploughed back to the industry, this may weaken the industry compared to its competitors domestically and abroad which may be socially counterproductive. However, if the taxation revenues are returned to the industry this may lead to increased fishing effort and thus work against the basic objective of the taxation

Management by taxation also faces strong social and political problems. Taxation is never popular and even less so when the taxpayers are poor fishermen making little or no profits. Taxation is also often very costly to enforce due to high incentives for avoiding tax among stakeholders. Throughout the world taxation has increasingly become unpopular due to wasteful behaviour by the responsible authority, tendency of diverting accrued revenue to other sectors and increasing production costs.

Property rights

The other main form of indirect economic fisheries management is allocation of property rights. The basic idea is that by introducing property rights the common property problem, the root cause of the fisheries problem, is simply removed. The property rights regime aims to eliminate tragedy of the common by giving rights to the individual in the form of sole owner rights, territorial use rights, community rights or individual quotas. Property rights can be in an explicit or implicit form depending on the functional structure of a given society.

Arnason (2000) argues that secure property rights encourages investment and a more effective way to maximize economic rent and hence the best stewardship for fisheries resource management. However, the efficiency of the regime depends on the quality of the rights. The higher the quality of the property rights the more efficient the fishery and vice versa (Arnason 2000). Although a property rights regime may solve the root cause of the tragedy of the common problem, it may, in many cases, lead to a perception of unequal distribution of the resources that may result in a social and political upheaval among affected user group (Arnason 2000). Therefore, the major challenges of a property rights system as a fisheries management tool concerns who receives the right to use the resources; how the rights should be allocated, i.e. what criteria should be used; and how the rents accrued should be divided among the population.

Despite these challenges, (Arnason 2001) argues that a property rights regime provides a promising solution to the tragedy of the common problem in fisheries management and maximizes economic benefit of the resource. A property rights regime has shown promising success in many parts of the world including New Zealand, Iceland, Canada, USA, Norway and Namibia (Arnason 2001, Iyambo 2000) (see also many references in Shotton 2000).

Sole owner rights

Sole ownership is a form of property right where the rights over resources is assigned to an individual. This system originates from the concept of land ownership where a farm owner has rights over the land to use it for production. Sole owner rights are also very common in forests, mining, as well as oil extraction, where an individual or a company is assigned rights over the resource and its uses. This system does not eliminate competition but it guides competition towards achieving economical advantage (on production, processing and marketing) over the others so as to maximize economic rent (Scott 1955). This type of competition is economically beneficial as it forces individual owners to consider sustainability of the resource base he/she owns.

Sole owner rights might work well in closed systems with limited externalities. However, it may imply unfairness and unequal distribution of the resources. A sole owner by definition does not involve the rest of the population. However, there are of course ways to alleviate the perceived inequality of the regime by e.g. taxing the sole owner.

Territorial use rights (TURFs)

Territorial use rights is a property rights regime where exclusive rights to resources in a specific area are assigned to an individual (firm). TURFs divide the fishery within a country's jurisdiction into several geographical areas or territories. Each geographical area or territory is exclusively assigned to a single firm or, possibly, a small group of fishers.

The exclusivity will reduce the need to regulate the fishery especially on the government side hence reducing enforcement costs. Exclusive rights also provide incentives to the owner to look after and maintain the fish stock. In most cases the need to attain and sustain maximum economic rents from the resource will likely lead to wise user behaviour and consequently prevent resource overfishing.

TURF systems have a long history in the management of coastal fisheries in Japan and is increasingly gaining popularity in other parts of Asia (Willmann 2000).

This system has limitation in the management of migratory fish stocks or marine organisms (Willmann 2000). To the extent that the resources move in or out of TURFs, the quality of the property right and hence the associated efficiency will be diminished. Likewise it is often difficult to demarcate large areas of the sea and protect it against externalities.

Community rights

Historically, community rights fisheries management has been practised in many parts of Africa, Asia and other parts of the world. This applies in particular, where fishers live in small fishing communities that are socially and economically organized through traditional values. This traditional community organization creates a social group that often stands together and takes on the responsibility to defend and manage resources in its areas. However, it is not a rule of thumb that when people come together they will act rationally, sometimes the opposite is true. When rights over resources are vested in people who benefit from good management and bear the burden of mismanagement of those resources, incentives to use the resources fairly and wisely are generated (Pomeroy 1995).

For many years community rights were primarily working well in some small isolated communities and in inland fisheries (Willmann 2000). However, limited legal protection against outsiders and ability to accommodate fisheries technological advances has often led to inefficiency of this regime as noted by Willmann (2000). On the other hand, fishing authorities or government interference has also weakened this system (Pomeroy 1995).

Despite challenges, community rights fisheries management remains the most effective means of managing resources in circumstances were other property rights management regime cannot be implemented due to social and political reasons.

Individual quotas

Individual quota system (IQ) is another form of property rights regime where percentage shares of total allowable catch (TAC) is given to an individual for production purposes. This gives power to an individual to use his/her share of TAC in production and compete with other IQ holders to harvest fish until allocated quota is reached. Giving exclusive power to an individual creates incentives to invest in technology that will give him an economic advantage in competition and hence eliminate the tragedy of the common behaviour (Scott 2000). IQs do not remove competition but rather encourage competition on technological advancement and investments towards maximizing economic return. This type of competition is good in economic terms as it leads to the economic development of the fishery. The quality of the IQs depend on exclusivity, security, transferability and durability (Arnason 2000). Exclusivity refers to the right of an individual to use, manage and enjoy his allocated quota without interference. The second characteristic is security. This refers to the right of ownership of the resource. Security also refers to legal rights to own the resources. The third equally important characteristic is durability (permanence). The duration of individual quota is essential in determining harvest as well as investment level of individual quota holders. Long period individual quota encourages sound investments due to expected length period of recovery of investment costs as opposed to short duration quota. Allocating individual quota for short periods might discourage investments that will take long to recover in IQs. Transferability is another characteristic that determines the quality of IQs. Transferability refers to the ability to transfer allocated quota to another individual quota holder (Arnason 2000). The higher the degree of transfer of property rights from one individual to the other the higher the quality of IQ system. Transferability creates a mechanism for good harvesting plan of individual quota holder hence ensures economic efficiency. One need not go out to sea when it is not economically efficient, but instead might opt to transfer few remaining shares by selling, leasing, or through joint management with another IQ holder and hence maximizing economic benefit of the allocated quota. Individual quota systems offer the best solution to many fisheries management problems and ensure maximum economic rent of the fishery if well established and enforced as Arnason (2000, 2001) noted.

7 MANAGEMENT OF THE PRAWN FISHERY IN TANZANIA

All measures taken so far to manage the shrimp fishery in Tanzania are yet to produce fruitful results at reducing fishing efforts and the trend is towards overcapacity. Over the years, operators have reacted to effort restrictions by increasing effort through the use of more nets and there are certainly no signs of reduction of effort, despite observed trends of declining catch per unit effort (Wilson 2004). The Fisheries Division is faced with challenges to come up with long lasting solutions and a best way to manage the fishery in Tanzania.

The bio economic models developed here show that if the shrimp fishery is left in an open access situation or in a no fisheries management state, the shrimp fishery is generally expected to make profit if fishers act rationally. Some profits are registered during the adjustment path and in the long run the fishery is expected to realize positive net present value (but a rather low amount). However, this will be at the expense of the stock. Since the biomass will oscillate towards equilibrium at a very low level (600 mt) there is a danger or resource collapse if fishers act irrationally. This might happen if there is prospect of expecting more profits or even moving to other places where they can harvest similar type of resource. Under this situation the long run net present value of the fishery is small, its impact on economic growth might as well be small. On the other hand if the government is depending on revenue from this operation, the revenue collection might be affected during the down turn (i.e. when the fishery is making losses during the adjustment path) where there is high incentive for cheating and thus making enforcement even more difficult.

On the other hand the bio economic model shows that the fishing effort required to make shrimp fishery attain maximum economic benefit and ensure sustainable biomass growth is between 8 to 13 trawlers. At this fishing effort level the fishery is more profitable and able to attain long term maximum present value of US $ 39.5 million in an optimal fishery which is much higher compared to US $ 140,000 expected under a no management situation. This indicates that the best fishery policy is to reduce current fishing effort of 26 vessels to 13 fishing vessels. For the Fisheries Division to achieve its objective of ensuring sustainable resource use that will contribute to economic growth, then the policy of reducing fishing effort from the current 26 vessels to 13 is the best policy. This policy will ensure both good biomass growth and maximize economic benefits. However, as discussed above the reduction of fishing effort by reducing fishing vessels in most cases does not keep effort down due to inherent behaviour of fishers to invest more and more in technology to elude regulations to reduce effort. This policy must therefore be supported by other measures to ensure that effort reduction does not translate into increased competition among the remaining vessels. One way of achieving this is to introduce a rights based fisheries regime such as individual quota.

An IQ system is recommended to be introduced based on the TAC that will be set by the authority. In this case, if the number of fishing days are adjusted to maximum days that can effectively be used for fishing and the number of fishing vessels should be adjusted accordingly. The model shows that the seven vessels will maximize economic rents when operating at 300 days per year. Under this adjustment each vessels is expected to be able to harvest 147 mt of shrimps. This amount can be used as a basis to set up TAC. Each IQ right holder should be allocated a permanent percentage share of the TAC. Once the TAC is set by the authorities, the percentage share is used to determine the TAC of each individual quota holder. The responsibility of advising the Fisheries Division on the level of TAC based on best scientific knowledge available should be vested in the Tanzania Fisheries Research Institute (TAFIRI). However, the fisheries authority is solely responsible over the setting of the TAC, setting it in the best interests of the industry and the country as a whole. Individual quotas should be granted to licensed vessels and not to an individual or a firm to avoid economic inefficiency whereby many vessels target limited quota. This may lead to losses and encourage cheating or catch hiding during landings in an attempt to avoid the TAC limit. Instituting and operating effective monitoring, control and surveillance is therefore an essential element for successful implementation of IQ system if introduced.

Enforcement should include among other thing onboard observers to monitor fishing activities. Fewer observers will be required to monitor few boats compared to the current system. Apart from observing fishing activities, shrimp landings must be properly monitored and weighted to keep track of TAC of each individual quota holder and provide information on how much is landed by individual quota holders. In order to ensure proper monitoring and control of landings, the following regulations are suggested to be put in place: regulation to limit prawn landings to specified ports;

regulation to restrict prawn landings prior to informing the authority on intention to do so in advance; and the intention of landing note should include, among other things, port of landing and expected time and date of landing. After receiving this information the fisheries authority must make sure that an inspector is at the place on that particular date and time to inspect the landings and vessel. The fisheries authority together with the industrial prawn fishery association should workout modalities of how to handle emergency landings. Tough measures must be put in place to deter unreported landings.

Although the contribution of artisanal prawn fishery to the overall catch is not properly known, measures need to be put in place to avoid effort shift following introduction of suggested individual quota system in the commercial fishery. Formation of fisher's association that will be given rights to harvest a specific quota is suggested. Only a specific number of fishers under the umbrella of their association should be given licenses to engage in prawn fishing activities. This is likely to be challenged due to belief that the sea is open to all. However, in order to ensure sustainable resource use that will realize maximum economic benefit to contribute to economic growth, the fishery need to be organized so as to achieve what is best for the common good. The fisheries authority and decision makers have to make this tough decision in order to sustain maximum economic benefit which include benefits to artisanal fisher's as well.

8 CONCLUSION

The purpose of this study was to assess the prawn fishery of Tanzania and determine the policy that will maximize economic benefits while ensuring sustainable biomass growth.

The policy that simultaneously meets both objectives, maximizing economic benefit while ensuring sustainable biomass, is to reduce fishing effort to 13 fishing vessels from the current 26 vessels. However, if the mean fishing days per vessel are increased to 300 (from the current 148) then the fishing effort required to maximize economic benefit is only eight fishing vessels.

To ensure that reduced fishing effort does not lead to competition among the remaining vessels, rights based fishing management of individual quota system seems to be the right approach, as it limits competition for the resource. Under this regime the emphasis of the operators will be to reduce fishing costs to ensure maximum profit from their share of TAC.

TAC shares can be sold or auctioned to prospective IQ rights holders and revenue used to fund fisheries management activities, including data collection, research, MCS and extension services. Similarly, revenue accrued can also be used by the government for other social development activities and hence contribute to economic growth.

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APPENDIX 1. Output of the model run on situation where there is no fisheries management or open access.

Years	Xt	N	q1	Q	Provisional Xt + 1	Corrected harvest	Corrected biomass	Revenue (1000 US$)	TC (000 US$)	Profit (000´s US $	NPV
2006	1000	26	46	1192	1008	1192	1008	10726	10565	161	161
2007	1008	26	46	1216	992	1216	992	10943	10691	252	237
2008	992	27	45	1218	974	1218	974	10966	10885	81	71
2009	974	27	45	1202	971	1202	971	10822	10946	-125	-103
2010	971	27	44	1188	981	1188	981	10693	10852	-159	-124
2011	981	26	45	1188	993	1188	993	10692	10731	-39	-29
2012	993	26	46	1199	994	1199	994	10788	10701	87	59
2013	994	26	46	1208	987	1208	987	10869	10768	102	65
2014	987	27	45	1207	979	1207	979	10863	10846	17	10
2015	979	27	45	1200	979	1200	979	10796	10859	-62	-35
2016	979	27	45	1194	985	1194	985	10748	10811	-63	-34
2017	985	26	45	1195	989	1195	989	10757	10763	-6	-3
2018	989	26	45	1200	989	1200	989	10802	10759	43	20
2019	989	27	45	1203	985	1203	985	10831	10792	39	17
2020	985	27	45	1202	982	1202	982	10822	10822	0	0
2021	982	27	45	1199	983	1199	983	10792	10822	-30	-11
2022	983	27	45	1197	985	1197	985	10775	10799	-24	-9
2023	985	27	45	1198	987	1198	987	10783	10781	2	1
2024	987	27	45	1200	986	1200	986	10803	10783	20	6
2025	986	27	45	1201	985	1201	985	10812	10798	15	4
2026	985	27	45	1201	984	1201	984	10806	10809	-3	-1
2027	984	27	45	1199	984	1199	984	10793	10807	-13	-4
2028	984	27	45	1199	985	1199	985	10788	10796	-9	-2
2029	985	27	45	1199	986	1199	986	10793	10790	3	1
2030	986	27	45	1200	985	1200	985	10801	10792	9	2
2031	985	27	45	1200	985	1200	985	10804	10799	5	1
2032	985	27	45	1200	984	1200	984	10800	10803	-3	0
2033	984	27	45	1199	985	1199	985	10795	10801	-6	-1
2034	985	27	45	1199	985	1199	985	10793	10796	-3	0
2035	985	27	45	1200	985	1200	985	10796	10794	2	0
2036	985	27	45	1200	985	1200	985	10800	10796	4	1
2037	985	27	45	1200	985	1200	985	10800	10799	2	0
2038	985	27	45	1200	985	1200	985	10798	10800	-2	0
2039	985	27	45	1200	985	1200	985	10796	10799	-2	0
2040	985	27	45	1200	985	1200	985	10796	10797	-1	0
2041	985	27	45	1200	985	1200	985	10797	10796	1	0
2042	985	27	45	1200	985	1200	985	10799	10797	2	0
2043	985	27	45	1200	985	1200	985	10799	10798	0	0
2044	985	27	45	1200	985	1200	985	10798	10799	-1	0
2045	985	27	45	1200	985	1200	985	10797	10798	-1	0
2046	985	27	45	1200	985	1200	985	10797	10797	0	0
2047	985	27	45	1200	985	1200	985	10798	10797	1	0
2048	985	27	45	1200	985	1200	985	10798	10797	1	0
2049	985	27	45	1200	985	1200	985	10798	10798	0	0
2050	985	27	45	1200	985	1200	985	10798	10798	0	0
2051	985	27	45	1200	985	1200	985	10797	10798	0	0
2052	985	27	45	1200	985	1200	985	10797	10797	0	0
2053	985	27	45	1200	985	1200	985	10798	10797	0	0
2054	985	27	45	1200	985	1200	985	10798	10798	0	0
2055	985	27	45	1200	985	1200	985	10798	10798	0	0
2056	985	27	45	1200	985	1200	985	10798	10798	0	0

2057	985	27	45	1200	985	1200	985	10797	10798	0	0
2058	985	27	45	1200	985	1200	985	10797	10797	0	0
2059	985	27	45	1200	985	1200	985	10798	10797	0	0
2060	985	27	45	1200	985	1200	985	10798	10798	0	0
2061	985	27	45	1200	985	1200	985	10798	10798	0	0
											140

APPENDIX 2. Output of the model run on optimal fishery.

Years	Xt	N	q1	Q	Provisional Xt + 1	Corrected harvest	Corrected biomass	Revenue (1000 USD)	TC (1000 USD)	Profit	NPV
2006	1000	26	46	1192	1008	1192	1008	10726	10565	161	161
2007	1008	12	46	555	1654	555	1654	4991	4876	115	108
2008	1654	12	76	910	1431	910	1431	8186	4876	3310	2918
2009	1431	13	66	853	1555	853	1555	7677	5283	2394	1982
2010	1555	13	71	927	1459	927	1459	8340	5283	3057	2376
2011	1459	13	67	869	1537	869	1537	7823	5283	2540	1854
2012	1537	13	70	916	1475	916	1475	8243	5283	2960	2029
2013	1475	13	68	879	1525	879	1525	7911	5283	2628	1691
2014	1525	13	70	909	1485	909	1485	8180	5283	2897	1751
2015	1485	13	68	885	1518	885	1518	7965	5283	2683	1522
2016	1518	13	70	904	1492	904	1492	8139	5283	2856	1522
2017	1492	13	68	889	1513	889	1513	8000	5283	2718	1359
2018	1513	13	69	901	1496	901	1496	8112	5283	2830	1329
2019	1496	13	69	891	1509	891	1509	8022	5283	2740	1208
2020	1509	13	69	899	1499	899	1499	8095	5283	2812	1165
2021	1499	13	69	893	1507	893	1507	8037	5283	2754	1071
2022	1507	13	69	898	1500	898	1500	8083	5283	2801	1023
2023	1500	13	69	894	1506	894	1506	8046	5283	2763	947
2024	1506	13	69	897	1501	897	1501	8076	5283	2794	899
2025	1501	13	69	895	1505	895	1505	8052	5283	2769	837
2026	1505	13	69	897	1502	897	1502	8071	5283	2789	791
2027	1502	13	69	895	1504	895	1504	8056	5283	2773	739
2028	1504	13	69	896	1503	896	1503	8068	5283	2786	697
2029	1503	13	69	895	1504	895	1504	8058	5283	2776	652
2030	1504	13	69	896	1503	896	1503	8066	5283	2784	614
2031	1503	13	69	896	1504	896	1504	8060	5283	2777	575
2032	1504	13	69	896	1503	896	1503	8065	5283	2782	541
2033	1503	13	69	896	1504	896	1504	8061	5283	2778	507
2034	1504	13	69	896	1503	896	1503	8064	5283	2782	477
2035	1503	13	69	896	1504	896	1504	8062	5283	2779	447
2036	1504	13	69	896	1503	896	1503	8064	5283	2781	420
2037	1503	13	69	896	1504	896	1504	8062	5283	2779	395
2038	1504	13	69	896	1503	896	1503	8063	5283	2781	371
2039	1503	13	69	896	1504	896	1504	8062	5283	2780	348
2040	1504	13	69	896	1503	896	1503	8063	5283	2781	327
2041	1503	13	69	896	1503	896	1503	8062	5283	2780	307
2042	1503	13	69	896	1503	896	1503	8063	5283	2780	288
2043	1503	13	69	896	1503	896	1503	8063	5283	2780	270
2044	1503	13	69	896	1503	896	1503	8063	5283	2780	254
2045	1503	13	69	896	1503	896	1503	8063	5283	2780	238
2046	1503	13	69	896	1503	896	1503	8063	5283	2780	224

2047	1503	13	69	896	1503	896	1503	8063	5283	2780	210
2048	1503	13	69	896	1503	896	1503	8063	5283	2780	197
2049	1503	13	69	896	1503	896	1503	8063	5283	2780	185
2050	1503	13	69	896	1503	896	1503	8063	5283	2780	174
2051	1503	13	69	896	1503	896	1503	8063	5283	2780	163
2052	1503	13	69	896	1503	896	1503	8063	5283	2780	153
2053	1503	13	69	896	1503	896	1503	8063	5283	2780	144
2054	1503	13	69	896	1503	896	1503	8063	5283	2780	135
2055	1503	13	69	896	1503	896	1503	8063	5283	2780	127
2056	1503	13	69	896	1503	896	1503	8063	5283	2780	119
2057	1503	13	69	896	1503	896	1503	8063	5283	2780	112
2058	1503	13	69	896	1503	896	1503	8063	5283	2780	105
2059	1503	13	69	896	1503	896	1503	8063	5283	2780	99
2060	1503	13	69	896	1503	896	1503	8063	5283	2780	93
2061	1503	13	69	896	1503	896	1503	8063	5283	2780	87
2062	1503	13	69	896	1503	896	1503	8063	5283	2780	82
2063	1503	13	69	896	1503	896	1503	8063	5283	2780	77
2064	1503	13	69	896	1503	896	1503	8063	5283	2780	72
2065	1503	13	69	896	1503	896	1503	8063	5283	2780	68
2066	1503	13	69	896	1503	896	1503	8063	5283	2780	64
											39542

APPENDIX 3. Output of the model run on optimal fishery with adjustment on fishing days and boats.

Years	*Xt*	*N*	*q1*	*Q*	Provisional *Xt* + 1	Corrected harvest	Corrected biomass	Revenue (1000 USD)	TC (1000 USD)	Profit	NPV
2006	1000	26	46	1192	1008	1192	1008	10726	10565	161	161
2007	1008	8	108	863	1345	863	1345	7769	5248	2521	2367
2008	1345	8	144	1151	1251	1151	1251	10363	5248	5116	4510
2009	1251	8	134	1071	1305	1071	1305	9637	5248	4389	3634
2010	1305	8	140	1117	1276	1117	1276	10051	5248	4804	3734
2011	1276	8	137	1093	1292	1093	1292	9835	5248	4587	3348
2012	1292	8	138	1106	1284	1106	1284	9955	5248	4707	3226
2013	1284	8	137	1099	1288	1099	1288	9890	5248	4643	2988
2014	1288	8	138	1103	1286	1103	1286	9925	5248	4678	2827
2015	1286	8	138	1101	1287	1101	1287	9906	5248	4659	2643
2016	1287	8	138	1102	1286	1102	1286	9917	5248	4669	2487
2017	1286	8	138	1101	1287	1101	1287	9911	5248	4663	2333
2018	1287	8	138	1102	1286	1102	1286	9914	5248	4667	2192
2019	1286	8	138	1101	1287	1101	1287	9912	5248	4665	2057
2020	1287	8	138	1101	1287	1101	1287	9913	5248	4666	1932
2021	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1814
2022	1287	8	138	1101	1287	1101	1287	9913	5248	4666	1703
2023	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1599
2024	1287	8	138	1101	1287	1101	1287	9913	5248	4666	1502
2025	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1410
2026	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1324
2027	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1243
2028	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1167
2029	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1096

2030	1287	8	138	1101	1287	1101	1287	9913	5248	4665	1029
2031	1287	8	138	1101	1287	1101	1287	9913	5248	4665	966
2032	1287	8	138	1101	1287	1101	1287	9913	5248	4665	907
2033	1287	8	138	1101	1287	1101	1287	9913	5248	4665	852
2034	1287	8	138	1101	1287	1101	1287	9913	5248	4665	800
2035	1287	8	138	1101	1287	1101	1287	9913	5248	4665	751
2036	1287	8	138	1101	1287	1101	1287	9913	5248	4665	705
2037	1287	8	138	1101	1287	1101	1287	9913	5248	4665	662
2038	1287	8	138	1101	1287	1101	1287	9913	5248	4665	622
											60433