Deterrence analysis of compliance with fishery regulations among artisanal fishers in Sudan

by

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Submitted in partial fulfilment of the requirements for the degree of

PhD Environmental Economics

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Dedication

To my parents Awad and Jawahir and my sisters and brothers

Declaration

I declare that this thesis I hereby submit for the degree of PhD in Environmental Economics at the University of Pretoria is entirely my own work and has not been submitted anywhere else for the award of a degree or otherwise.

Parts of the thesis have been submitted for publication in Journals.
Any omissions or errors in thinking are entirely my own.

Signed: …………………….………………….

Name: Sana Abusin

Date: …………………….…………………. 2012

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Supervisor: Professor Rashid M. Hassan

Department: Agricultural Economics, Extension and Rural Development

Abstract

This study analysed causes of the problem of over-fishing in the Jebel Aulia Reservoir (JAR) in Sudan and investigated reasons behind the failure of current management and policy regimes to promote sustainable management and exploitation of fishery in this reservoir. To achieve these objectives existing analytical frameworks and methodological approaches to study noncompliance with regulations have been adapted to allow two important extensions: (1) using frequency instead of intensity as a measure of violation rate and, (2) modifying the probability of detection to depend on time to account for frequency of violation. The adapted analytical models have then been empirically implemented to develop a typology of fishers according to violation rates and to analyse determinants of noncompliance and extent of violation with mesh size regulations among artisanal fishers in the JAR. This study represents the first research effort investigating causes and implications of illegal fishing and noncompliance with fishery regulations in Sudan in general and particularly in the JAR.

The study extended the two times dynamic deterrence model (DDM) to use frequency instead of intensity of noncompliance as a measure of violation rate. The method of comparative statics was employed to derive analytical results on the sensitivity of optimal violation to a number of key

factors of high relevance to compliance with regulations designed to protect against over-fishing. Analytical results obtained with this extended DDM confirmed the findings of earlier empirical studies employing alternative static and dynamic formulations and revealed interesting economic meanings of modelled relations. The study concludes that a number of factors related to market and institutional failures make frequency more suitable than intensity as a measure of violation in artisanal fisheries of developing countries.

Applications of DDM have so far been limited to the case of constant probability of detection, which assumes independence of the length of time to detection. One objective of this study was therefore to modify the DDM to allow for more flexible and broader specification by introducing two important variables to the supply of offences function, namely, evasion activity and enforcement efforts .One of the major modifications made by this study is modelling the probability of detection as a Cox proportional hazard model instead of the survival hazard used in the literature. The new modelling of probability of detection also makes the previous specification only one of the three versions of the new model, since the new model accommodates the situations of constant and inconstant probability of detection. The results of comparative statics analysis revealed important potential ways of extending the standard DDM to allow for optimal choice among critical trade-offs between evasion efforts and violation rates.

The study then applied the adapted DDM to empirically analyse and test specific hypotheses about artisanal fishers' compliance behaviour using data from a survey of artisanal fishers in the JAR area. Survey data was collected from a sample of 241 fishers from five landing sites at the study area. Factors that determine the probability of violation as well as the extent of violation were analysed employing an ordered Probit model and a count data model respectively, in two steps. The first step analysed the determinants of the choice to belong to one of the defined fishers' typologies. In the second step, a zero truncated negative binomial model was applied to analyse determinants of the extent and frequency of violation among violators only. Results of the empirical analyses suggest that fishers seem to care more about the size of the penalty than the presence of regulation enforcing agents as a deterrent, mainly due to corrupt options and effective evasion activities used by fishers. The study also suggests that better education of fishermen is necessary, as well as the provision of alternative income generating activities especially during the fish reproduction season, access to credit for ownership of legal nets, and finally, effective regulation of the importation of illegal nets will be necessary to enhance compliance with mesh size regulations in Sudan. It is also necessary to promote community level organisation and awareness campaigns among fishers about the dangers for future fish stocks of eroding small fish quantities through the use of illegal nets and consequently endangering the social welfare of all.

TABLE OF CONTENT

LIST OF FIGURES

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LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

COXPH	Cox Proportional Hazard Function
CV	Chronic Violators
DDM	Dynamic Deterrence Model
FD	Fisheries Administration Department
FAO	Food and Agriculture Organization of the United Nations
HCENR	The Higher Council for Environment and Natural Resources
JAR	Jebel Aulia Reservoir
JAD	Jebel Aulia Dam
MAAWR	Ministry of Agriculture, Animal Wealth and Water Resources
MAARI	Ministry of Agriculture, Animal Resources and irrigation
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
NV	Non-Violators
OV	Occasional Violators
UNEP	United Nations Environmental Programme
VR	Violation Rate
SSA	Sub-Saharan Africa
WB	World Bank
WFP	World Food Programme
ZPM	Zero Poisson Model
ZTNBM	Zero Truncated Negative Binomial Model

CHAPTER ONE

INTRODUCTION

1.1 Background and statement of the problem

Fisheries in developing countries are experiencing serious over-harvesting stress and often consequent collapse of fish resource stocks due to many market and policy failure situations such as poor management and open access conditions (Andrew *et al*. 2007; Sterner, 2003). The number of under-harvested inland fish stocks has decreased from 40 % in 1990 to 23 % in 2004 (Millennium Ecosystem Assessment, 2005). This was mainly driven by the rapid increase in fish consumption, which has doubled in developing countries in the past three decades due to increase in population (MEA, 2005). On the other hand, the growth in the international fish trade (exporting fish from developing to developed countries) increases the price of fish on local markets due to demand from exporters. This therefore results in illegally-caught fish entering markets due to increasing consumer demand that is met by increasing production, putting serious pressure on fish stocks (DFID 2005; Policy Brief 7). Particularly, African tropical fresh water lakes are believed to be fully exploited and even over-fished in many parts (MEA, 2005). This presents a big threat to the capacity of these fishery ecosystems to continue providing for the livelihood of many communities that are highly dependent on them (FAO, 1999a; UNEP, 2010; Millennium Ecosystem Assessment, 2005). Inland fisheries in Africa, however, remain of significant importance in terms of their potential to contribute to provision of employment, improved nutrition, poverty reduction, and food security (FAO, 1999a; FAO, 2009; UNEP, 2010). Africa contributed 25 % of the global inland fish catch of 10 million tons in 2008 (FAO, 2009; UNEP, 2010) and it is estimated that over 200 million Africans consume fish on a regular basis (Heck *et al*. 2007). Despite its high importance, most African countries lack essential statistics on the current status and potential contribution of fishery resources to livelihoods and food security (World Fish Centre, 2003).

The stress on tropical fresh water fisheries is worsened by the practice of illegal fishing and noncompliance with regulations, which has serious consequences in most of these regions. The practice of illegal fishing, particularly the use of small mesh sizes in an already over-fished resource, will undoubtedly lead to stock collapse and fishery closure. It removes small fish before they can finish their life span and hence limits the opportunity for reproduction (Clark, 1990). This calls for urgent action to reduce noncompliance with fishery regulations, especially the use of small mesh sizes in these regions. Noncompliance with regulations on the continent also contributes to lack of accurate statistics about the status and potential role of fishery resources both at local and national levels (World Fish Centre, 2003). It is believed that the actual catch from inland water is 2-3 times larger than what is reported in official statistics due to illegal fishing and noncompliance with regulations, especially in the artisanal systems predominant in sub-Saharan Africa (SSA) (FA0, 2003; Welcomme *et al*. 2010). Failure to account for illegal fishing therefore gives incorrect estimates of the resource and misleads fishery policy formulation and management decisions based on this information (Hatcher and Pascoe, 2006, Atta-mills *et al*, 2004). Achieving compliance with fishery regulations is accordingly becoming an issue of serious concern to managers and policy makers worldwide and especially in the tropical freshwater fisheries of SSA.

Studies show that noncompliance with mesh size regulation is very common in Africa driven by the motive of maximising harvest from open access fishing waters and the difficulties associated with enforcing regulations, seriously affecting fishery resources on the continent (Akpalu, 2008a, 2009; Eggert and Lokina, 2010). Sudan is no exception and is experiencing the same pressures of stock declines and over-fishing as a result of noncompliance with mesh size regulation, especially in Jebel Aulia Reservoir (JAR) (FAO, 2008; FAO 1999b).

Although the fishery sector's contribution to national income in Sudan is small (i.e. 0.4 % of gross domestic product – GDP), fishing is the source of employment and livelihood for large communities (Ali, 2000 and FAO, 2008). It is estimated that the sector provides employment to more than 64 500 people, supplying more than 64 550 thousand tons of fish every year (based on 2006 FAO statistics), and 90 % of the estimated production potential of the country from inland waters (FAO, 2008). The inland waters of Sudan are populated with over 126 fish species in various localities in the country and the main inland fisheries are lakes and reservoirs (FAO, 1991; Hamid *et al*. 2009).

JAR is the main source of inland water of Sudan, inhabited by over 56 species, and is the major supplier of fresh and processed fish, contributing 23 % of the total inland catch (about 52 %, excluding the Sudd region) (FAO, 2008). Important consequences of noncompliance with mesh size regulations in JAR area include changes in fish biodiversity, as some species become rare or disappear. A decrease in sizes and length of the population of commercial species and fish production has been observed in this area (Fisheries Department, 2004; FAO, 1999b). A number of studies conducted in this area show that the size of *Alests spp. and Hydrocyns spp.* has decreased from over 15 and 30 cm to10 cm, in both cases. Furthermore, *Protopterus senegalus spp* appear only from time to time and *Citharinus scitharus spp* has not been seen for many years (Hamid, 2000; Fisheries Research Centre, 1985; Abusin, 2005). It is believed that fishers usually own two type of nets, illegal nets, which are used during active fishing breeding, and legal nets, used when catches of normal size are available (Hamid, 2000).

Over-exploitation by local inhabitants who are highly dependent on fishing and the use of destructive gear are believed to be the main causes of extreme over-fishing in the JAR area (FAO, 2008; Hamid, 2000 and FAO, 1999b). This indicates that prudent fishery management is of particular importance to the survival of fishing communities and the potential of fish consumption as an alternative high value animal protein in Sudan. Moreover, given current population growth rates of 2.5 % per annum (U.S. Census Bureau, 2011) and very high urbanisation patterns, it is expected that demand for fish will rapidly overtake current supplies, exacerbating the pressure on fisheries' ecosystems.

Other factors that are responsible for the pressure on the JAR area fishery are the lack of effective institutional structures, insufficient monitoring manpower and equipment in fisheries departments' enforcement sections and the little assistance received from other supporting agencies (e.g. the police and judiciary), making monitoring and enforcement of regulations too expensive (FAO, 1999b; Jebel Aulia Regulation Office, 2004). Tolerance of corruption and widespread poverty among fishers are also believed to be reasons for noncompliance with fishery regulations (FAO, 1999b). These factors are also confounded by the difficulties associated with modernisation and mechanisation of a largely subsistence fishery industry, still using primitive technology for fishing gear, preservation and curing methods (Ali, 2000). Reasons for this pressure and opportunities for correction are currently poorly understood. However, noncompliance with fishery regulations is considered to be the key current challenge to sustainable fishing in the JAR.

A number of studies have been carried providing descriptive analyses of the fisheries of JAR (Adam, 1986; Fisheries Research Centre, 1985; FAO, 2008; Faisal, 2007; Khalid, 1994; Hamid, 2000; Fisheries Research Centre, 1985; Osman, 2009, Ali, 2000 and Hamid *et al*., 2009). These studies focus mainly on documenting and analysing fishing techniques, gear selectivity, and biological and ecological aspects of the fishery plus basic socio-economic analysis of fish as a source of nutrients and processed food. Lack of essential data and methodological deficiencies limit the value of current research to policy and management improvements. Some attempts have been made to estimate fish stocks in the JAR (Fisheries Research Centre, 1985; Marc and Khalid, 1998; Faisal, 2007; Khalid and Salih, 2006), giving a recent estimate of a stock size of 12 600 tons (Khalid *et al*., 2008). All these estimations were based on biological measurement methods. The gap in fisheries research in Sudan is particularly large when it comes to investigating the behaviour and reactions of fishers to regulations.

Good understanding of the motives for illegal fishing is necessary to help policy makers and managers design appropriate intervention measures that would improve effectiveness and efficiency of enforcement of regulations and ensures sustainability of the resource use. The present study intends to analyse causes of the problem of over-fishing in the JAR and identify reasons behind the failure of current management and policy regimes to promote sustainable management and exploitation of fishery in this reservoir. In pursuit of the above purpose, the intended research will attempt to adapt existing analytical frameworks and methodological approaches to study noncompliance with regulations. The adapted models will be empirically implemented to specifically investigate determinants of noncompliance with mesh size regulations in the JAR. Results of the study will provide useful policy information on the nature and extent of violation of mesh size regulation and identify the factors that influence violation rates. This is the first research effort investigating the causes and implications of illegal fishing and noncompliance with fishery regulations in Sudan in general and particularly in the JAR.

1.2 Objectives of the study

The overall objective of this study is to analyse current management problems in the JAR fishery, particularly illegal fishing and their local and national implications. Under this main goal, the study attempts to pursue the following specific objectives:

1. Extend the existing analytical framework of noncompliance with fishery regulations to allow studying implications of the following adjustments to the DDM:
    - Use of frequency rather than intensity of violation as a measure of violation rate
    - Modify the hazard rate to suit frequency of violation as a measurement of violation rate in DDM; and
2. Employ the adapted model to:
    - Investigate determinants of violation decision in JAR; and
    - Measure the extent of violation within artisanal violators
3. Identify potential policy intervention measures for sustainable management and exploitation of the JAR fishery.

1.3 Hypotheses

In pursuit of above objectives the study aims to test the following hypotheses:

1. Social influence, decreases the degree of violation in JAR
2. The majority of artisanal fishers in the JAR belong to the occasional violators group;
3. The higher the penalty (net seizure), the lower the violation to mesh size regulation
4. The higher the social discount rates, the higher the decision to violate and the higher the degree of violation among violators' groups

1.4 Approach of the study

To conduct the above described analyses, this study intends to adapt analytical approaches currently used to study noncompliance with fishery regulation, introducing two distinct extensions to the commonly used DDM. First, the study plans to adapt the DDM to use frequency rather than intensity of violation as a measurement of violation rate. This allows for differentiating fishers into group behaviour typologies, which improves the policy relevance of noncompliance analysis. Second, the study extends and modifies the standard DDM to allow for non-constant probability of detection in analysing determinants of noncompliance with fishery regulation. The adapted models are then used to analyse the determinants and intensity of noncompliance with mesh size regulation among artisanal fishers in the JAR of Sudan. The study employs an ordered Probit model to conduct empirical analysis of influences of various factors of relevance on fishers' decision to choose which category of violator groups to join. A zero-truncated negative binomial model also employeds to investigate the determinants of and measure the degree of violation among violators of mesh size regulation in the JAR. The specified models are implemented empirically to data from a survey of artisanal fishers in the study area.

1.5 Organisation of the thesis

The study is organised into six chapters. The next chapter provides background information on current policy and management systems of fisheries in Sudan and specifically the status of JAR fisheries including the problem of illegal fishing and noncompliance with mesh size regulations. Chapter 3 reviews relevant literature on approaches and methods for studying determinants of noncompliance with fishery regulations. The analytical framework and approach of the study are presented in Chapter 4. Chapter 5 employs the adapted models to conduct empirical analyses of the determinants and intensity of noncompliance with mesh size regulation in the JAR and describes sources of the survey data used to estimate model parameters for artisanal fishers in the study area. Chapter 6 concludes the study with a summary of results and implications for policy and future research.

CHAPTER TWO

FISH PRODUCTION, MANAGEMENT POLICIES AND FISHING PROBLEMS IN SUDAN

2.1 Introduction

Sudan has a total inland water surface of 13 million hectares, which amounts to 5 % of the country's total area. The River Nile and its tributaries comprise the main feature of Sudan's hydrology, with a number of man-made lakes covering a surface area of 3 000 km^2. Natural lakes and the swamps of the Sudd region cover a total flood area of over 80 000 km^2, of which about 8 000 km^2 are permanent swamps. Flooding during the August to October season contributes about 80 % of the overall Nile water flow (FAO, 1991). This inland water ecosystem is of very high economic and environmental significance for the welfare of current and future generations in the country providing many critical ecosystem services. Fish is one of those important ecosystem services that inland waters support.

Like in the rest of the developing world, fish consumption and the demand for fish in Sudanese diet has been on a steady rise over the past years. Inland fisheries contribute more than 88.3 % (based on 2006 statistics) of total fish catch in Sudan, which amounts to 57 000 tons per year (FAO, 2008). Though fish resources have significant potential and are considered important for food security and socio- economic development in Sudan, the fisheries sector is still dominated by small scale and subsistence production systems employing relatively traditional technology. Fishers are the poorest among the Sudanese and most lack alternative sources of livelihood making them intimately tied to this resource and their very survival is highly vulnerable to the health status of this ecosystem (FAO, 1999). The sector is expected to contribute to reduction of poverty in Sudan, a country with population estimated to stand at nearly 40 million people, with a current annual growth of about 2.5 %, but the fisheries of Sudan face many political and economic constraints (FAO, 2008).

This chapter is organised into four sections. The next section provides a brief overview of the status of inland fisheries production, fish consumption patterns in Sudan, and the related management policies and regulation system. Section three takes a closer look at the study area of JAR fisheries and provides background information on fisheries production and fishing problems such as over-fishing and use of illegal fishing gear in the area. A summary concludes the chapter.

2.2 Fish production and consumption patterns in Sudan

Marine and fresh fish resources are considered important for food security and socio-economic development in Sudan. The country has a high potential for the development of aquaculture, given its rich biodiversity of fish and a favourable environment with many cultivable species, and its land and water resources (Khalid *et al*. 2008). Sudan fisheries play important role in the economy, employing over 12 900 full-time fishers in addition to 51 600 people supported by the secondary sector (FAO, 2008). Table (2.1) shows the total fish catch of Sudan distributed by sector.

Table 2.1: Sudan total fish production by sector in 2006

Fishery sub-sector	Total production tons/year
Marine	5 550
Inland	57 000
Aquaculture	2 000
Recreation	-
Total	64 550

Source: FAO (2008)

According to the FAO (2008), the southern Sudan Sudd region is capable of producing 75 000 tons of fish per year on a sustainable basis. However, reported fish landings don’t exceed 32 000 tons per year. That means the Sudd region’s potential is under-utilised. The current low catch is mainly attributed to conditions of civil war running over several decades and use of primitive harvesting.

Though the contribution of Sudan’s fishery sector to GDP is marginal, amounting to only 0.4 %, fish is considered to be the main source of protein for poor and landless communities. The sector contribution to the overall agricultural GDP decreased from 1.4 % in the eighties to 1.3 % in the nineties (WFP, 2006). Total fish catch in Sudan has increased over the past two decades reaching 64 550 tons in 2006 (Figure 2.1, Table 2.1).

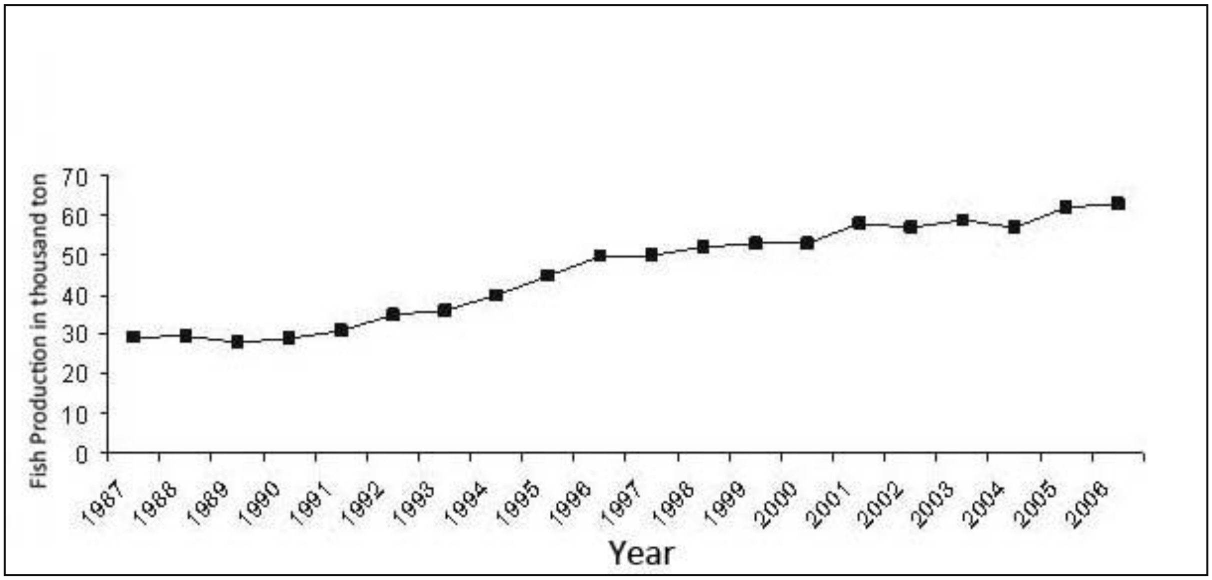

Figure2.1: Total fish production in Sudan in 000 tons from 1987–2008

Source: FAO (2006)

Sudan per capita fish consumption was estimated in 2008 at 1.6 kg per annum, which is considered low compared to other parts of the world (FAO, 2008). However, with current population growth rates of 2.5 per annum and very high urbanisation patterns, especially the influx to the capital city (Khartoum) region, it is expected that demand for fish will rapidly overtake current supplies, placing serious pressures on fisheries' ecosystems and hiking fish prices in the country. Fish consumption in Khartoum has increased markedly since 2005 when the influx of displaced people began (Figure 2.2). More than 70 % of the actual fish production is consumed fresh (basically caught from the White Nile-JAR and the upper southern reaches of the White Nile and the Sudd Region). Fish processing is very common (by salting, drying, fermenting and smoking) (FAO, 1999). Growth value of fisheries output reached US$ 1.2 billion in 2006 (FAO, 2008).

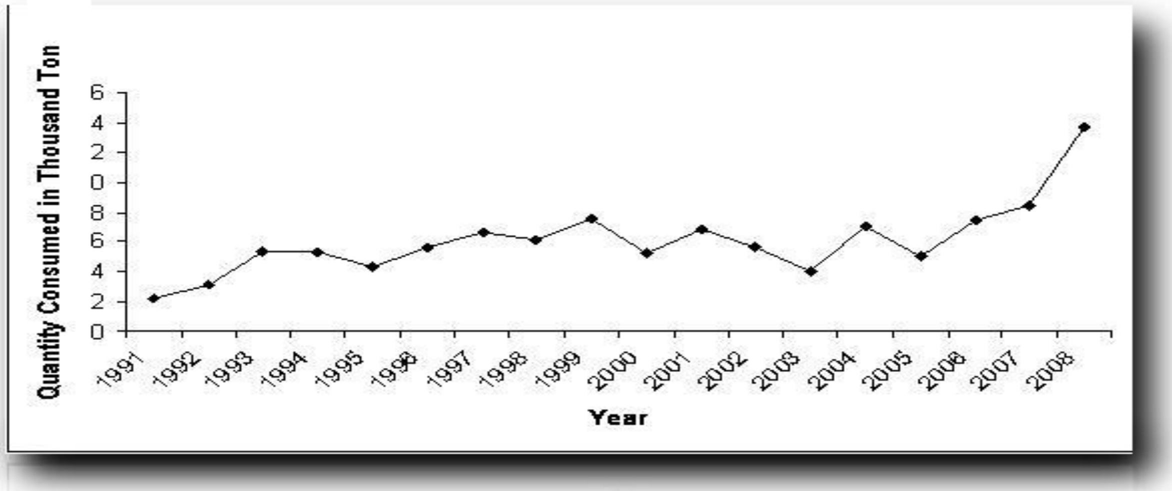

Figure 2.2: Quantities of fish consumed in Khartoum state, including production from both Khartoum and other states

Source: Adapted from Fisheries Department (MAAWR, 2006)

Inland fisheries contribute 88.3 % of the estimated production potential of Sudan. The main fishing localities are: the Sudd swamps in the south and the man-made lakes on the White Nile (JAR), the Blue Nile (Roseries and Sinnar Reservoirs), the Atbara River (Khashm El Girba Reservoir) and the main Nile River (Lake Nubia) (FAO, 2008). Most inland fisheries in Sudan are operated as small-scale artisanal systems. Different ethnic groups harvest these waters with relatively primitive equipment.

Over 126 species are observed in the fresh water fisheries of Sudan (Hamid *et al*. 2009). Nilotic and Falata[1] tribes use dugout canoes while Arab tribes use oar-propelled or motor-driven wooden and steel boats (Ali, 2000; FAO, 1999b). Although the inland fisheries of Sudan are in general poorly performing, a steady increase in market-oriented activities has occurred in recent years, particularly in the JAR area on the White Nile, which is the main source of processed fish, especially *fasiekh* [2] (FAO, 1999b). *Fasiekh* is the most popular fish food in Sudan and JAR has witnessed a large increase in the number of small industries supplying *Fasiekh* that is sold either wet or dried and distributed all over the country where local demand is very high. Due to the very high local market demand of *Fasiekh*, its price highly exceeds the price of fresh *Tilapia*.

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[1] The Falata are an indigenous tribe of Sudan with a long-standing fishing tradition.
[2] *Fasiekh* (salted fish) is a popular food in Sudan.

Table 2.2: Sudan's *Fasiekh* exports (1985-1993)

Year	Export (metric tonnes)
1985/86	943
1986/87	800
1987/88	166
1988/89	690
1989/90	378
1990/91	244
1991/92	129
1992/93	39

Source: FAO (1999)

The country used to export large quantities of *Fasiekh* (95 % from JAR) to Egypt during the period of the seventies and eighties, but recently growth in local demand has led to a steady decline in surplus fish and fish products for export (Table 2.2). Another reason for the decrease is also the biological fact that the species that make up *Fasiekh* (*Hydrocyonus* and *Alestes)* are becoming small in quantities due to over-fishing (FAO 1999b).

Fish products other than *Fasiekh* that are consumed in Sudan include *Terkeen* (fermented fish), *Mandasha* (smoked and sun-dried), and *Seer*, a very small fried fish sold cheap. The home made *Terkeen* encourages the use of destructive gear, since the smaller the fish size the higher the market value of this product. The poultry industry is also obtaining undersized fish for preparation of chicken feed (FAO 1999b).

Fish imports from some African and Arab countries are reported to be growing. According to The Ministry of Agriculture, Animal Resources and Irrigation (MAARI), the amount of shrimp imported from Saudi Arabia, Egypt and United Arab Emirates (UAE) was 36 759 kg in 2006. This is in addition to 92 181 kg of inland fish (Nile perch) imported from both Uganda and Ethiopia in 2006 (Table 2.3) (FAO, 2008).

Table (2.3): Fish import through Khartoum market in 2006

Month	Product type and origin			
	Shrimps	Origin	Nile perch	Origin
January	550	UAE	2 500	Uganda
February	600	UAE/Saudi Arabia	10 100	Uganda/Ethiopia
March	-	-	1 065	Uganda/Ethiopia
April	505	Egypt/ UAE	7 500	Ethiopia
May	8 750	Egypt/Saudi Arabia/UAE	12 500	Uganda/Ethiopia
June	8 038	Egypt/ UAE	11 002	Ethiopia
July	8 326	Egypt/Saudi Arabia/UAE	17 704	Uganda
August	-	-	29 810	Uganda
Total	36 759		92 181	

Source: MAAWR (2006).

On the other hand, Sudan exports marine fish products. The main destinations for exports are Egypt, Saudi Arabia and Europe (Table 2.4). Cultured shrimps are exported to Saudi Arabia and the exported quantities were estimated for the years 2003 and 2004 to be 2 125 and 4 124 tons, respectively. Limited exports of shark to Asia are also reported (FAO, 2008).

Table 2.4: Sudan total fish exports during 2001-2006 in kg

Year	Fin fish	Trawl fish	Sardine	Sea cucumber	Shrimp	Trochus
2001	39 965	31	-	36 700	-	378
2002	70 250	358 895	1 614	44 920	39 46	367
2003	102 400	806 600	717	30 630	12 400	364
2004	153 210	973	1 638	19 000	71 120	336
2005	65 200	782	1 466	20 009	46 220	385
2006	37 700	-	-	9 750	-	341

Source: MAAWR (2006)

Table 2.5 gives the scientific and local names of Sudan's commercial fish species. Further details on contributions of each species to total catch and threats from over-fishing pressures in the JAR are presented in the following sections.

Table 2.5: Sudan's Commercial Species' Scientific and Local Names and Families

Scientific name	Family	Local names
Barbus bayad	Cyprinidae	Byad
Telapi zilli	Cichlidae	Bulty
Labeo niloticus	Cyprinidae	Dabes
Hydrocyonus forshalii	Characidae	Kass
Alestes dentex	Characidae	Kwara
Citharus citharus	Citharinidae	Bitkwya
Protopterus aethiopicus	Protopteridae	Umquro

Source: FAO (1999)

2.3 Fishery policies, administration and management systems in Sudan

The Fisheries administration in the Federal Ministry of Agriculture, Animal Wealth and Water Resources (MAA&WR) of Sudan is mandated to develop and enforce regulations all over the country. Fishing in Sudan in general is managed as a regulated, open-access resource; however, there is no limit to the size of the catch and no seasonal closure although some regulations have to be obeyed. Those include access licenses and a ban on destructive gear and small mesh sizes. Licensed fishers also receive subsidies to reduce fishing costs and help them overcome conditions of poverty (Fisheries Department, 2004).

Despite these regulations, illegal fishing practices such as use of undersized mesh nets (e.g. monofilament silk nets) is very common (FAO, 2008). The Fisheries Departments responsible for administering issuance of licenses and monitoring and control operations face major difficulties including the wide spread of a large number of fishers along the extensive banks of the White Nile and other river and lakes, which makes it hard to monitor these fishing activities. Lack of effective institutional structures to carry out mandated monitoring and control tasks, leads to poor enforcement of fishery regulations. Moreover, most fishers who harvest from inland waters lack alternative income-generating options. It also receives little support from other related institutions such as the police and the judiciary.

These difficulties in managing the resource encourage illegal fishing, especially the use of undersized meshes, which is spreading rapidly throughout the inland waters of Sudan. This has become easily noticeable in the official markets as the numbers reported in Table 2.6 show quantities of fish caught illegally by using undersized mesh marketed in the different states of Sudan. The states of Kassala and Sinnar have the highest incidence of illegal fishing (in percentage) but the quantities caught (marketed) in these states are smaller than those caught in the White Nile state. Failure to control illegal fishing due to inability to enforce regulations is also attributed to poor definition and dissemination of regulations, which need to be updated regularly with new components (Jebel Aulia Regulation Office, 2004).

Seventy per cent of the fish is consumed fresh, some quantities are sun dried (25 %) or wet salted (5 %). Sun-dried fish is mostly marketed in rain fed and mechanized agricultural schemes (FAO, 2008). Wet-salted fish (mainly *Hydrocyonus* and *Alestes* spp.) is for local consumption or export and an insignificant amount goes into fish and poultry feed production. With the exception of some shrimp, all landings are of freshwater fish products (FAO, 1999b).

Table 2.6: Estimated Undersized and illegal Fishing marketed in Khartoum and other market destination in different States in 2005

State	Total prod Tons/year	% catch imported to Khartoum	Illegal fishing % of total catch
Gazera	750	7	2
Red sea	3 500	-	15
Blue Nile	595	80	2
Northern	2004	95	7
White Nile	65 00	70	17
Sinnar	850	3.5	27
Kassala	500	-	60
Khartoum	1 400	100	5

Source: MAAWR (2006)

Table 2.6 also gives information about amounts of fish marketed in Khartoum and other market destinations as a percentage of total production of different Sudanese states in 2005. A large difference is observed between the quantities that are traded in markets and estimates of total supply of fish reported earlier. This is attributed to a number of factors. First, a significant share of the catch is consumed at home given the subsistence nature of artisanal fisheries dominating

Sudan. Also, the Sudd region catches are not included in the figures reported in Table 2.6. Moreover, some fish quantities are used for animal feed and other purposes. In general, the fishery sector of Sudan is characterised by limited supply and high prices.

Other important factors behind the poor performance of Sudan fishery sector are the lack of effective coordination mechanisms among the institutions responsible for fisheries management and overlapping duties (Hamid *et al*., 2009). Sudan laws and acts for environmental management (fishery, forestry, water and wild life) are implemented and monitored on a sectoral basis that operates in a fragmented and uncoordinated manner, resulting in government institutions working in isolation from each other. The Higher Council for Environment and Natural Resources (HCENR), established in 1990, is mandated to coordinate implementation of these sectoral environmental management laws and policies but has been ineffective and unsuccessful in achieving its objectives (Hamid *et al.* 2009).

2.4 Status of the fishery and problem of illegal fishing in Jebel Aulia Reservoir

The JAR on the White Nile extends over 629 km south of the Jebel Aulia dam (JAD) upwards to Renk city, south of Kosti (see Figure 2.3). The White Nile extends 600 miles from Lake No in the south to Khartoum in the north. This reservoir is at present used for irrigation purposes and its water level decreases from February until May and reaches its highest level in September.this reservoir is believed to be endowed by ecological factors that create favourable environment for species to regenerate. These ecological factors are described by FAO report in 1999 as follows:

"In the area of Jebel Aulia reservoir zooplankton is characterised by a considerable diversity of forms and a high biomass quantity especially in the pre-dam area. Decrease in current velocity, reduction in the quantity of suspended substances and development of submerged vegetation are all favourable conditions for the development of plankton organisms in this lacustrine."

The reservoir is the main supplier of fresh and processed fish in Sudan, contributing 52 % of the total inland catch (excluding Sudd region in the south) (FA0, 2008). It is the largest second source of fish in Sudan after the Sudd region in southern Sudan (see Table 2.7). The location of the JAR near the capital city Khartoum gives it an economic advantage. The reservoir is endowed with over 56 fish species from 13 families. Fish in this reservoir are characterised by varied spawning seasons. For instance *Barbus binny, Hydrocyonus* spp. and *Alestes* spp. spawn during March–April (late winter) while *Lates niloticus* has a prolonged spawning period and other fish species spawn in (autumn) July–August (FAO, 2008).

Since construction of the JAR dam was completed in 1933, people began to settle in the area surrounding the dam. The JAR population is comprised of local fishermen living along the banks of the river. Small fish markets exist on a site next to the dam where transactions are made by middlemen and fish are transported to consumption areas by trucks using ice for preservation. Fishers land their catches on scattered beaches and normally in small quantities and fish traders (mongers) provide informal credit to fishers to support their families especially during seasons of limited catch and finance most of the marketing activities.

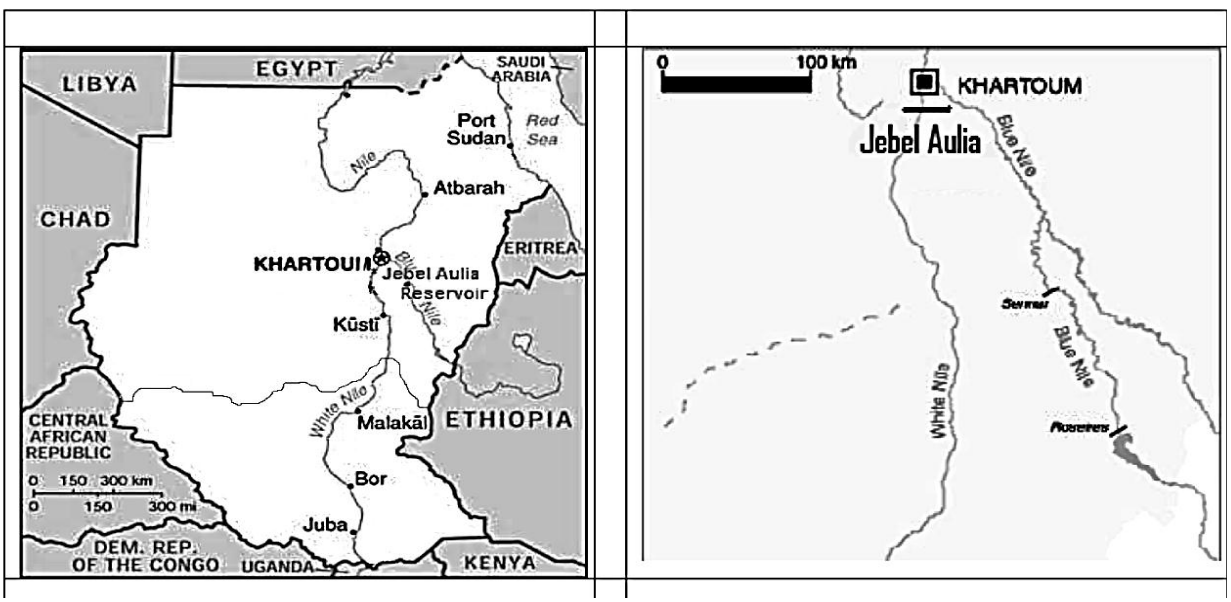

Figure 2.3 Map of Sudan showing the location of Jebel Aulia Reservoir on the White Nile

Source: Adapted from FAO (2008) and UNEP (2000)

The JAR witnessed a remarkable increase in population in the settlement camps as a result of displaced communities from southern Sudan because of the civil war (International Organization for Migration, 2005). This caused the emergence of major markets and triggered significant socio-economic changes related to food**.** For instance, the market for small-sized fish grew significantly and new types of products such as *Mandasha*[3] were introduced. The demand for small-sized fish rose because it was the basic food for displaced communities (Abusin, 2005). Some illegal undersized catches are processed at home to produce food that is cheap, easy to prepare and easily stored. The species used for home processing are *Hydrocyonus forkhali*, *Alestes dentex*, *Alestes nurse*, and *Labeo niloticus.* These are the species that currently threatened by over-fishing and their local names are *kass*, *kawara* and *dabis*, respectively (Abusin, 2005).

Table 2.7: Inland fish harvests in 2006 in Sudan by sources

Production source		Yield in tons
Sudd swamps, lakes and backwaters		32 000
Manmade lakes	Jebel Aulia Reservoir	13 000
	Roseries Reservoir	1 600
	Sinnar Reservoir	1 100
	Khashm El Girba Reservoir	800
	Lake Nubia	2 000
Dinder, Rahad Rivers and other River Nile tributaries		4 500
Impoundments and irrigation canals		2 000
Inland fishing total		57 000

Source: FAO (2008)

Fishers are increasingly setting their nets very close to the dam wall, inviting serious complaints from the Ministry of Irrigation for fear that these nets might negatively affect the proper operation of the evacuation sluices (FAO, 1999b).

The northern part of JAR has four regulation stations located in two different states: one is in Khartoum at Jebel Aulia station and three are in the White Nile state. These stations are understaffed and specialised fishery competencies are absent from them (FAO, 1999b). As in all Sudan fisheries, JAR is regulated as an open access regime. Fisheries Administration in the MAA&WR, based in Khartoum state, is in charge of enforcing regulations and monitoring violations through its regulation office at JAR next to the dam site.

[3]Mandasha is smoked fish, shaped into small balls and sundried, then stored and used in farming camps and is very popular in southern Sudan.

The Fisheries Department of the MAA&WR recommends a mesh size of 100 mm. However some of the commonly used gillnets in the region have mesh sizes ranging from 60 to 160 mm especially designed for catching Tilapia (*Oreochromis* spp.). Another type of gillnet known as the Bee-Bee has mesh sizes ranging from 30 to 40 mm. These are over 100–500 m long and can be 1.5 to 2 m deep (FAO, 1999b). They are used at night in open waters, targeting small species such as *kawara* and *kass* (Tables 2.8 and 2.9), which are mainly used to make the popular *fasiekh* food. Beach seines are another type of gillnet that is either made to a length of 500 m (*umsura*) or as large-sized beach seines (*umkubuk*) consisting of nets with a large mesh size hanging in the middle and smaller meshes along the aisles. To increase the catch, fishers often spread sorghum grain (*durra*) as bait along the targeted shoreline two to three hours before the actual operation (FAO, 1999b).

Despite JAR fishing regulations, fishers are reported to violate regulations especially by using small mesh size (Jebel Aulia Regulation Office, 2004). A study conducted by Fisheries Research Centre (1985) in the northern part of JAR revealed that half of the fish catch was made up of undersize fish (Table 2.8). The differences in sizes (measured by length) between fish caught illegally and prescribed sizes are clearly large. Since 1985, the situation has worsened and over-fishing has been cited as the main cause of the undersized catch. Many factors are reported to be the reasons behind over-fishing in JAR. Among these reasons are the increased use of illegal fishing gear, such as mesh below prescribe size, deficiencies in law enforcement, loss of species diversity, heavy fishing pressure on the remaining breeding grounds and reduction of natural regeneration (FAO, 1999b).

Table 2.8 shows results of a survey conducted in the area where the size of commercial species caught was measured. The difference between caught and prescribed sizes is very large and hence a matter of serious concern. Fish above first maturity age were scarcely found in the experimental and commercial catches (FAO, 1999b). This suggests that noncompliance with prescribed mesh size is clearly a major issue in the northern part of JAR.

More than 56 fish species are found in JAR, from which the endangered species *kass* and *kawara* are processed as wet and salted fish. The other commercially important fish species in JAR are *shilbya*, *dabis* and *bulty* (Table 2.9). The first four species in Table 2.9 are mostly used for making fish products, while others are sold fresh (FAO, 1999b).

Table 2.8: Prescribed and actual length of species' size in 2004 (average)

Targeted species	Prescribed species sizes in (cm)	Actual fish length (cm)
Bayad	55	31
Bulty	20	8
Dabis	45	17
Kass	30	20
Kawara	20	10

Source: MAAWR (1997)

Table 2.9: White Nile catches composition of selected commercial species in JAR, 1986

Scientific name	Local names	% of total catch
Hydrocyonus forkhali	Kass	10
Chrysichthys auratus	abuRial	5.2
Labeo horie	Dabis	5
Alestes dentex	Kawara	4.8
Eutropius niloticus	Shilbya	4.6
Telapia zillei-oreochronus	Bulty	4.6
Hydrocyonus lineatus	Kass	4.4

Source: Rahaman (1985)

JAR fishers use canoes for catching fish and two types of boats are common in the area: *sharook* and *moorkab*. Both have a life expectancy of 8 to 10 years. The maximum capacity of the *sharook* is two nets and it is usually fitted with an outboard engine. These canoes are usually used in the southern part of JAR. The *moorkab* is 4 to 6 metres long and not motorised, with a maximum capacity of five men and five nets. Canoes made from local wood (*Acacia nilotica*) are common in the northern part of the reservoir. Canoe motorisation levels are rather low among *moorkabs*. A 500-metre net lands a catch of 100-150kg in JAR, while that from a 100-metre net ranges from 50 to 60 kg (FAO, 1999b).

Fishing seasonality is very important to explain for two reasons first, JAR fish species are characterised by varied spawning seasons (late winter and autumn). Second, it identifies which type of gear fishers will use to get a catch. For instance, in JAR there are three different seasons. The first extends from November to February and considered to be the main fishing season when mature fish is relatively abundant. The second season extends from March to July when fishes are rare and fishers tend to use illegal nets. The third season coincides with the rain and flood season, when some fishers shift to agriculture, some continue fishing in a very hard situation and others stop fishing altogether (FAO, 1999b).

As seen above illegal fishing and over-fishing are clearly the main source of pressure on the fishery of the JAR. Unfortunately, apart from isolated reports on inland fish catch and their value in Sudan, reliable information on status of the fishery hardly exists. Illegal fishing, especially catches of smaller than prescribed size, is very common as fishers, who are mostly poor, are interested more in bigger catches for survival than commercially desirable fish size. Local inhabitants as well as fishing companies are both involved in over-fishing in the White Nile area. Companies and fish brokers transport fish to the marketing areas in insulated trucks or chilled ice boxes (FAO, 1999b). Gillnets are the most dominant gear in this region because they are certain to catch all the fish behind the gill cover (FAO, 2000). The probability of capture or escape from the net after contact depends totally on the fish size, which is why size selectivity is distinctive for gill nets (Potter and Pawson, 1991). The use of silk is particularly dangerous (very thin and sharp) because it kills all enmeshed creatures and has especial large catch capacity because it is invisible and it is therefore highly deceptive (Osman, 2009). Use of gillnets made from monofilament (silk) thread, unlicensed fishing and fishing during reproductive seasons are reported to be common violations in the JAR area (Fisheries Department, 2004)**.**

The use of illegal techniques, such as undersize gillnets to catch immature fish (i.e. catching species for fish processing of 20 mm instead of 40 mm or commercial species under 100 mm), is considered the main source of the fishing pressure in JAR (Jebel Aulia Regulation Office, 2004). Food processing in the area is also becoming a good business, which adds a financial incentive that increases the existing tension between production and enforcement agencies, which are under-resourced, and this result in continuous, routine violation. The fact that many fishers wish to migrate from the area, arguing that it is difficult for them to find an easy catch due to the large number of fishers is one good indicator of over-fishing pressure (Jebel Aulia Regulation Office, 2004).

It is clear that serious efforts and significant investments in generating better information and research on the status of the fishery and good understanding of fishers' behaviour towards regulation are badly needed to improve the management of the JAR fish resources. Fisheries Departments clearly require major investments to upgrade their financial and human resource capacities for more effective monitoring and enforcement. It is necessary for all that to conduct more comprehensive and in depth scientific investigation and analysis of fishery crime and its economic, social and political determinants. The purpose of this research is therefore to contribute to this need.

2.5 Summary

About 5 % of the total area of Sudan is covered by water and the fresh water fishery is an important resource for the country and its people, especially the landless poor. Fresh waters resources of Sudan are characterised by rich biodiversity of fish, which is a valuable food source with high protein content and calorific value. It also offers employment to many who depend totally on fishing for their livelihoods. Sudan also has good prospects for prosperous development of aquaculture.

About 88.3 % of the total fish production is from inland waters, of which 70 % is consumed fresh. Generally, the fishery sector in Sudan is characterised by its traditional technology and poor performance attributed to many factors such as weak enforcement of fishery regulations, lack of effective institutional structures and the little support from other law enforcement and natural resource management institutions. As a consequence of these difficulties in managing the resource, illegal fishing practices are spreading, placing serious pressure on an already over-fished resource, especially in recent years.

JAR (White Nile state) is the main supplier of fresh and processed fish. The most common gear used for fishing are gillnets, and non-motorised *moorkab* canoes are common in the northern part of the reservoir. The larger segment of the population in JAR is poor, comprised of local landless fishermen with limited income and employment opportunities other than fishing. Apart from the main fish market in Khartoum, some small fish markets exist on site next to the dam and transactions are carried through middlemen.

The excessive population of fishers at this reservoir leads to over-fishing, which directly affects species biodiversity and reduces their sizes. Fishers cope with this by reducing mesh net sizes and hence confounding pressure on the fishery particularly in the northern part of JAR. Other factors such as deficiencies in law enforcement, heavy fishing pressure in the reproduction season and reduced natural regeneration are also causes of the pressure. Illegal fishing especially use of small mesh size is therefore considered the main challenge facing this important fishery resource.

The JAR Regulation Unit lacks resources and specialised personnel. Failure to control illegal fishing due to inability to enforce regulations is also attributed to lack of proper means, deficiencies in formulating rules, and costly and weak enforcement and monitoring of compliance with laws and regulations.

The present study intends to analyse causes of the problem of noncompliance with mesh size regulations in the north of JAR and identify reasons behind the failure of current management and policy regimes to promote sustainable management and exploitation of fishery in this reservoir.

CHAPTER THREE

RELEVANT LITERATURE ON MEASURING NONCOMPLIANCE WITH FISHERY REGULATIONS

3.1 Introduction

Future viability and benefits from fisheries have been negatively affected by the practicing of illegal fishing and noncompliance with fishery regulations. This has become a global problem, presenting serious threats to fish stock rebuilding (MEA, 2005; Sumaila *et al*. 2006). Serious decline in inland water stocks has been reported in developing countries; the number of un-harvested inland fish stocks has been steadily decreasing; from 40 % in 1990 to 23 % in 2004. Despite the existence of fisheries management policies, fisheries in developing countries are encountering a serious threat of over-fishing (Allan *et al*. 2005). Many factors are believed to contribute to this problem; among them are difficulties in enforcing regulations and inefficient institutions to handle the problem.

The lack of effective enforcement and monitoring mechanisms also encourages corruption and creates a good environment for illegal fishing (Eggert and Lokina, 2010). Thus, fisheries' sustainability has been far more difficult to achieve in developing countries although many efforts have been made to rebuild fish stocks. For instance, official limits on the size of fishing nets and harvests, as well as other management measures, have been used to help stock recovery and reduce over-fishing and consequently illegal fishing (FAO, 2003). It is also believed that Africa's fisheries crisis and steady decreases in fish stocks are attributed to the use of destructive gear and the practice of illegal fishing (MEA, 2005).

Despite its major role in the failure of fishery management, illegal fishing has received little attention in the past (Anderson, 1989, Sutinen and Hennessey 1986), particularly in the field of fishery economics and policy making studies (Charles *et al*. 1999). However, illegal fishing behaviour has gained considerable attention recently in both fields because of the increasing recognition of the damage and loss associated with this problem (Sumaila *et al*. 2006). Many studies have argued that fishery regulation failure is attributed to costly and weak enforcement and monitoring of compliance with laws and regulations, in addition to tolerance to corruption and cheating (Charles *et al*. 1999 and MEA, 2005).

Many theoretical and empirical studies have been conducted to analyse reasons for noncompliance with fishery regulations by adapting different static, dynamic and policy oriented approaches. Different types of noncompliance with fishery regulations are cited in the literature such as: fishing in closed areas, catching with non-prescribed mesh size or fishing in a prohibited zone or any behaviour against the law (Akpalu, 2008a; Charles *et al*., 1999; Srinivasa, 2005; Furlong, 1991; Hatcher *et al*. 2000 and Sumaila *et al*. 2006). However, noncompliance with mesh size regulations is found to be the most common and biggest problem in Africa (Atta-mills *et al*, 2004; Akpalu, 2008a, 2008b; 2009; Eggert and Lokina, 2010).

This chapter provides a study of the relevant literature on noncompliance with fishery regulations. The next section reviews the approaches for analysis of determinants of noncompliance with fishery regulations under static and dynamic formulations. Empirical approaches used to analyse factors influencing violation rate are reviewed in section three and the chapter concludes with a summary.

3.2 Approaches and methods used in compliance analysis

Noncompliance with fishery regulations has important implications for the welfare of fishing communities. The framework schema of Figure 3.1 is adapted from Sutinen and Kuperan (1999) and extended to include determinants of noncompliance with fishery regulations in dynamic approaches. The following sections present a review of the various components of the compliance modelling framework presented in Figure 3.1.

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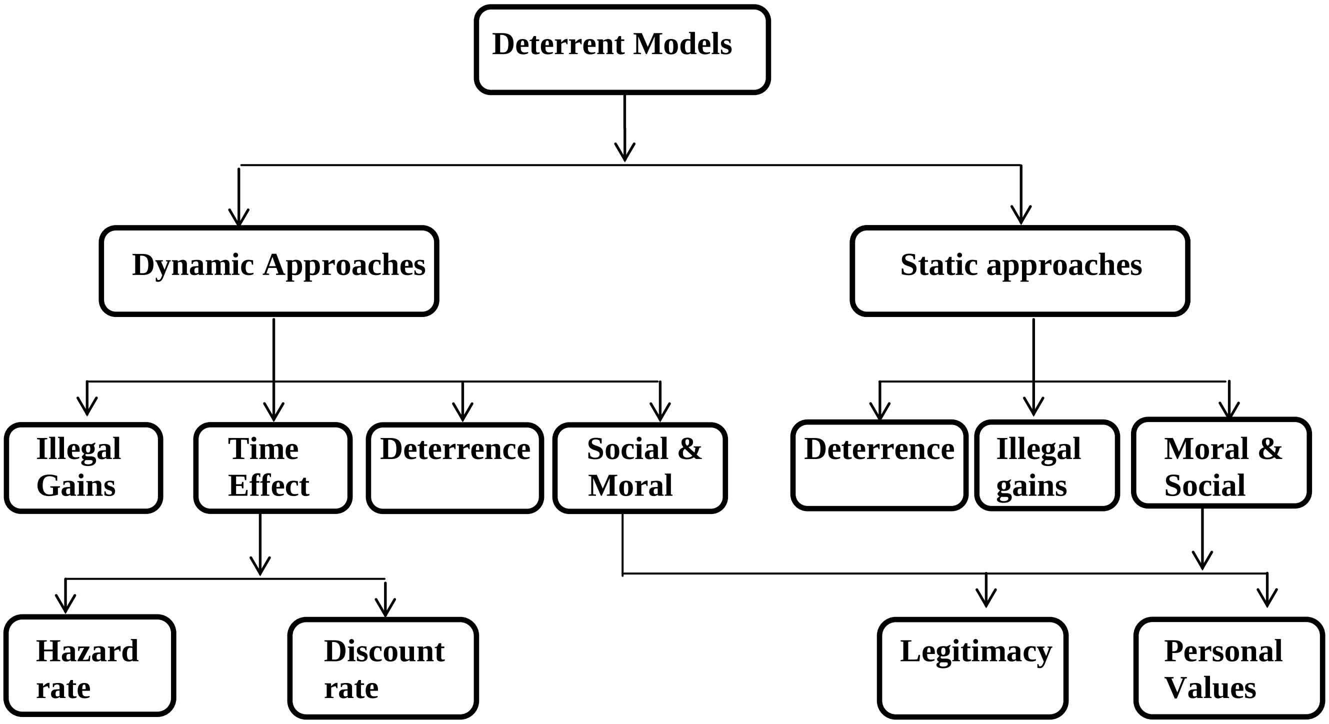

Figure 3.1: Approaches and factors considered in analyses of determinants of noncompliance with fishery regulations
Source: Modified/extended from Sutinen and Kuperan (1999)

3.2.1 Static approach to study noncompliance with fishery regulations

Becker (1968) was the first to study the behaviour of law breakers. He developed the first theoretical deterrence model to analyse the choice between legal and illegal options for a criminal to maximise his/her utility from illegal activities. Static deterrence models assume that a violator faces a single time period decision problem of maximising expected utility from illegal fishing, i.e. the choice of either to follow fishery regulations or not. The model's implicit assumption is that a fisher has a fixed amount of time to be allocated to both legal and illegal fishing. The gain from violation is not guaranteed because of the probability of enforcement leading to detection and consequent punishment. This motivated the use of expected utility in deterrence models.

In the static context, the main determinants of the choice of an illegal option are the profit that an offender gains from the illegal practice and the low probability of detection combined with a small fine (punishment). Many studies have followed Becker's model of the economics of crime and punishment under static formulations (Charles *et al.* 1999; Furlong, 1991; Hatcher and Gordon, 2005; Kuperan and Sutinen, 1998; Sutinen and Kuperan, 1999; Sumaila *et al.* 2006).

The high profit that fishers gain by violating national laws is the main incentive for noncompliance (Charles *et al*. 1999; Hatcher and Gordon, 2005; King and Sutinen, 2010 and Sumaila *et al*. 2006). Sumaila *et al*. (2006) estimate gains from illegal fishing by a set of apprehended illegal fishing vessels to amount to about 24 times the fine paid as a punishment. King and Sutinen (2010) estimate it to be 5 times the penalty paid.

One major extension of the static model is the attempt by Charles *et al.* (1999) and subsequently Sumaila *et al.* (2006) to consider effects of avoidance activities. Charles *et al*. (1999) applied a micro-economic static model to determine the level of enforcement a policy maker should allocate in the presence of evasion activities for optimal management of a fishery. The study showed that fishers react to enforcement by focusing more on avoidance behaviour than reducing violation rates. This means that improvement of law enforcement in fisheries needs to be grounded in a good understanding of avoidance behaviour.

The recommendation from the pure deterrence model is that detection should be increased and that penalties should be high to offset gains from violation. On the other hand, Furlong (1991) conducted a self-reported survey among Canadian fishers and found that fishers are more sensitive to increases in likelihood of detection than increases in penalties. Some studies have argued that the policies suggested by the purely traditional deterrence model cannot be applied to real life and also do not give a complete explanation of compliant behaviour. Kuperan and Sutinen (1998) pointed out that profit from and cost of illegal behaviour, are not enough to describe fishers' decisions.

Based on this last argument, some studies have extended the traditional deterrence model to account for moral, social and legitimate dimensions, known as normative factors that are believed to be important in determining violation among fishers (Akpalu, 2008a/2008b; Eggert and Lokina, 2010; Hatcher *et al.*, 2000; and Kuperan and Sutinen, 1998). These factors measure a fisher's behaviour and beliefs towards his peer violators and how these influence his values. It also measures a fisher's perception of the violation itself and his perception of regulations as effective or fair.

The influences of social and moral factors have been accounted for in theoretical and empirical applications to examine their impact on compliance. Results of empirical investigations revealed that such factors can have either positive or negative influences. Positive influence implies supporting or encouraging compliance and considering violation of regulations to be bad behaviour. On the other hand, negative influence result from the perception that violation is not wrong, which is an attitude making noncompliance dominant and a normal part of their regular job. However, the normative effect was found to be smaller in comparison to the deterrence effect in a study by Hatcher and Gordon (2005).

One of the shortcomings of the static model is the assumption that two different agents have an equal set of constraints and the only factor that differentiates them is their affinity for taking risks. This distinction was argued to be immeasurable by Davis (1988), which makes the static model limited. The static model also does not account for the effect of discounting future benefits, i.e. discount rates (Davis, 1988). Static models by nature cannot measure the optimal rate of violation over time.

3.2.2 Dynamic compliance modelling approaches

Dynamic models have been developed to consider allocation of resources over time (i.e. to study inter-temporal allocation decisions). In dynamic formulations, the fisher will be optimising his gains over time until he gets caught, because the crime is committed repeatedly. The two periods dynamic deterrence model (DDM), as developed by Davis (1988), postulates that violators seek to maximise expected discounted profit over both periods. In the first period, offenders gain from illegal activities until the time they get caught and pay a fine. Violators will then comply and engage only in legal activities thereafter, concluding the model' second period.
Justifications for using a dynamic model for illegal fishing analysis are motivated by many legitimate considerations, most important of which are the repeated nature of the crime (i.e.

violation occurs repeatedly), the change in the danger of getting caught over time (detection time evolves), and differences on fishers extraction rate of the resource. These factors imply a temporal objective of not analysing single period gains but rather maximising the sum of the stream of net benefits over time (at least over two periods). It also motivates inclusion of evasion efforts with the aim of prolonging the time before getting caught.

The difference in skippers' time preference is also a very important factor in deterrence analysis since it gives information about their patience (choice between consumption now or in the future). A study by Akpalu (2008a) found that impatient fishers have higher violation rates. It also provides information on skippers' poverty levels, given the fact that that poorer fishers are found to have higher discount rates.

Conclusions from the current dynamic model with constant probability of detection reveal that noncompliance is more likely to be deterred by increasing the probability of being caught than by raising the fine (Akpalu, 2008a; Davis, 1988). The DDM adds the effect of the discount rate and modifies probability of detection from being subjective in the static model to a conditional probability that explains the fact that the profit from violation is conditional on the violator's survival.

Although the standard DDM represents the most advanced analytical framework widely used for analysis of compliance with fishery regulation, it suffers from some deficiencies. For instance, violation rates in the DDM have so far been mainly specified only as "intensity of violation" (Akpalu, 2008a), whereas "frequency of violation" has been used only in static deterrence models (Eggert and Lokina, 2010; Furlong, 1991 and Sutinen and Kuperan, 1999). No study has yet used frequency as a measure of violation rate in a dynamic formulation, in spite of the proven advantages of using frequency in static deterrence models. This is an important gap in the existing theoretical and empirical literature.

First, intensity of violation, which is measured by the value of juvenile fish in an illegal catch per day averaged over the past week's catch, may fit developed countries but is highly unlikely to work well in developing countries where property rights are less well defined and it is relatively easier for fishers to escape being caught. This makes it very hard to estimate the total catch per day that includes violating harvests, and hence presents a data problem. Second, by not employing frequency as a measure of violation rate, one misses the opportunity of capturing the direct link between violation rates and opportune time periods for illegal fishing (seasonality). This is due to the fact that, during months of active breeding the quantities of small fish are high, which encourages illegal fishing compared to months of no breeding. Thirdly, the use of frequency also helps to classify fishers into categories of violators, a typology that will help policy makers and managers design policy measures and instruments suited for each group. Finally illegal catches are not sold on formal fishing markets, but are rather concealed and sold out of monitors' notice, outside formal channels. Therefore this study intends to extend the current DDM by introducing frequency of violation and hence identify typologies of violators.

Standard DDM formulations have also been limited to the case of probability of detection that doesn't depend on time assumptions. The present study intends to fill these gaps by extending the current DDM to relax these assumptions and derive analytical results under alternative specifications allowing for probability of detection that depends on time and measuring the rate of violation by distinguishing different typologies of violators according to their violation rates measured by frequency of noncompliance.

3.2.3 Empirical studies based on static and dynamic approaches

To design more effective deterrence mechanisms, more research is needed to gain better understanding of fishers' noncompliant behaviour. Illegal fishing is difficult to observe, however, and information about it cannot be obtained from government and fisheries departments' statistics but is mostly based on surveys and interviews (King and Sutinen 2010). Generally, there is little published research on empirical regulatory compliance. Some empirical studies of noncompliance with fishery regulations have been conducted in many parts of the world, generating results that differ across countries. Some studies analysed the extent of violation by looking at how frequently fishers violate (Sutinen and Kuperan 1999; Furlong 1991; Eggert and Lokina 2010; King and Sutinen 2010) and hence provide information on violators' degrees of violation.

Frequency of violation has been measured in different ways in studies conducted in different countries. A study of fishers in Lake Victoria measured violation of minimum mesh size regulations by the number of months when such illegal fishing was practiced within the year (Eggert and Lokina 2010). Furlong (1991) used proportion of violation (proportion of regulatory regimes violated) in a typical fishing trip in a specific season as a measure of frequency of violation. Hatcher and Gordon (2005) measured violation rate as the percentage of landings over quota in the previous year, whereas Kuperan and Sutinen (1998) measured violation rate by the number of days a fisher has fished in a prohibited zone.

In analysing factors affecting compliance with output restrictions (quotas) among fishermen in the United Kingdom, Hatcher *et al. (*2000) measured violation rate by a fisher's decision to violate or comply. On the other hand, in a dynamic formulation Akpalu (2008a) measured the rate of violation of fishers in Ghana by looking at the intensity of violation, calculated as the value of juvenile fish in an illegal catch per day averaged over the past week's catch.

Different econometric models have been employed to suit the different ways in which violation rates are measured. Eggert and Lokina (2010) and Hatcher and Gordon (2005) used ordered Probit models to analyse determinants of violation of fishery regulation because of the ordered nature of the latent dependent variable. In both above cited studies, the ordered likelihood function was used to predict changes in the probability of violation in response to changes in considered determining factors. Eggert and Lokina (2010) further measured the extent of violation within one fishers' typology (occasional violators) by truncating the data to exclude both non-violators and chronic violators.

Hatcher *et al.* (2000), Kuperan and Sutinen (1998) and Akpalu (2008a) all investigated fishers' decision on whether to violate or comply using binary Probit models. Kuperan and Sutinen (1998) and Akpalu (2008a) subsequently used the Tobit model because their dependant variables were censored at zero. Furlong (1991) also used Tobit models to estimate the violation supply function. The Tobit models are used to avoid the problem caused by censored data if the dependent variable is continuous but sensored at zero, as some fishers do not violate for reasons other than their moral standing, like high cost of illegal nets (Long, 1996).

Studies that classify violators according to their violation rate believe that classification will help managers understand each group and hence formulate policy accordingly. Generally, non-violators are found to be significant in numbers in many countries, which supports the positive influence of normative factors (Eggert and Lokina 2010; Furlong, 1991; Kuperan and Sutinen, 1998; Sutinen and Kuperan 1999; King and Sutinen, 2010).

The typology of violators also differs across countries. For example, Eggert and Lokina (2010) found that about half of the surveyed fishers in Tanzania were violators. On the other hand, Furlong's (1991) surveys reported that about two thirds of fishers violate while Kuperan and Sutinen (1998) reported 75 % violation rates among fishers in Malaysia. In Ghana, however, violation (the use of light attraction equipment) was found to be 46.9 % (Akpalu, 2011).

Other studies suggested that some personal characteristics are important in compliance analysis. Furlong (1991) for example, conducted a survey of Canadian fishers and included age, and income from fishing and other employment as variables. In his estimation, although these variables had the expected sign, age was the only variable with statistical significance. On the other hand, Sutinen and Gauvin (1989) found, in their estimation of compliance in the lobster fishery of Massachusetts, that the effect of all three (i.e. age, experience and fishing as source of income) on noncompliance to be statistically significant.

There has been a lot of debate in literature about the probability of detection and the way it enters the model and how to measure it. Probabilities of detection are either estimated separately or jointly in an econometric model. The leading work by Kuperan and Sutinen (1998) explains this very well. They considered probability of detection to be a salient issue of compliance and hence better understanding of how this variable behaves is very important. Probability of detection itself is the joint estimation of probabilities, which include probability of detection, the probability of an arrest given detection, the probability of being taken to court given arrest, and the probability of being found guilty given that the fisherman is taken to court (Akpalu, 2008; Eggert and Lokina, 2010; Furlong, 1991; Kuperan and Sutinen, 1998; Hatcher *et al.*, 2000; Sutinen and Kuperan, 1999).

This implies that probability of detection by itself is a function of a number of factors. Kuperan and Sutinen (1998) suggested measuring the overall probability of detection variable in three different ways. They firstly proposed an exogenously determined probability of detection, which makes the overall probability of detection not included in the main violation model directly. Instead, exogenous determinants such as enforcement and avoidance activity enter the deterrence model. This method is adapted by this study for the development of the modified DDM which will be explained in details in chapter five.

The second way is to jointly estimate probability of detection as part of the violation model. For example, the overall probability of detection is treated as an explanatory variable and used in the main deterrence function. In a study by Furlong (1991), the probability of detection was jointly determined in the model and divided into four stages, probability of detection, prosecution, conviction and punishment in the function. The said study encountered both problems of co-linearity and simultaneity due to the joint estimation of the overall probability of detection and violation function.

The third method entails an estimation of the probability of detection by one variable measuring the number of times the violator has been seen by the police landing an illegal catch or using unauthorised gear or by the perceptions of fishers about the chances of detection as increasing or decreasing. Our study chooses this method, which helps overcome the endogenity problem. In a study by Hatcher and Gordon (2005), the probability of detection is measured by including the subjective probabilities as a regressor in the violation function.

Almost all these studies (except Hatcher and Gordon, 2005) faced the problem of endogenity due to reasons explained in the preceding paragraphs (Akpalu, 2008a; Eggert and Lokina, 2010; Furlong, 1991; Hatcher *et al.*, 2000; Kuperan and Sutinen, 1998; Sutinen and Gauvin, 1989). Hatcher and Gordon (2005) argued that the reason for not having endogenity is due to the fact that the violation rate and probabilities of detections were not estimated in the same time period (fishers were asked about their previous year's violations). This is based on the assumption that the perceived risk has not changed significantly within the time under consideration. Hence, the simultaneity problem falls away. In some studies, instrumental variables have been used (Akpalu, 2008a) to solve this problem, but Hatcher *et al*. (2000) used a two-stage simultaneous equation system.

Kuperan and Sutinen (1998) argued that there is an inconsistency in the performance of variables measuring the probability of detection. This inconsistency stems from the fact that the probabilities are subjective and are difficult to analyse because of the lack of knowledge about the factors affecting their generation. Furthermore, the respondents may not understand the concept of probabilities.

Another problem related to compliance analysis is the strong correlation between variables measuring normative factors. The close link and interdependency between social, moral and legitimate factors usually create this type of problem (Akpalu, 2008a/2008b; Hatcher *et al*., 2000; Hatcher and Gordon, 2005).

Some factors in the empirical model cannot be measured directly and hence proxies are used. For instance, probability of detection is measured by asking respondents about their perception of probability of detection, ranking on a five-point scale ranging from very high to very low (Hatcher *et al*. 2000). Akpalu (2008a) for example, measured the discount rate using experimental choice design. The skippers were asked to choose between two hypothetical fishery projects: Project A, which was supposed to increase skipper's income once by an amount at the end of the month in which the data were collected, and Project B, which increased it once by twice the amount in six months' time. After the choice was made, the respondent was asked to indicate the value for Project B that would make him indifferent between the two projects. Depending on the fisher's choice, the discount rate is calculated as the amount quoted by the skipper over the amount that the project offers.

Enforcement is measured by asking fishers whether they perceive the current enforcement to be adequate and fair (Sutinen and Kuperan, 1999). The moral variables refer to the fisher's beliefs about violation given the fact that some people are impressionable and act according to others' standards (Tyran and Feld 2002). Moral variables are also measured by the fisher's moral standing in the community, that is, when fishers are keen about their moral standing in the fishing community and how it might psychologically impact on them (Sumaila *et al*. 2006). Moral aspects such as acceptance of bribes by police when violators are arrested have been found to be very significant in Tanzanian fisheries, where corruption and poverty make it difficult for fishers to comply with regulations (Eggert and Lokina, 2010).

The different measurement of the social and moral factors as explain above makes the effect of normative factors differ or may have both negative and positive effects on compliance with fishery regulations**.** The measure of the normative factors that one should choose in the model depends on the current fisheries environment in terms of the social relations within the fishing community under study and how fishers value violation and the way regulations are enforced, considering their fairness and effectiveness.

Empirical results from compliance studies are different. Some papers found that to deter violation, deterrent variables are the most important factors (Hatcher and Gordon 2005), while others found both deterrence and non-monetary variables such as social and moral standards to be equally important (Akpalu, 2008; Hatcher *et al*. 2000, Eggert and Lokina 2010; Kuperan and Sutinen 1998). For instance, Eggert and Lokina (2010) tested for exclusion of either the deterrence or normative factors from the model and the results showed that both deterrence and normative factors are very important in explaining violation behaviour.

It may also happen that the regulation officer could be socially excluded from the community in his or her efforts to enforce the regulations. This creates an incentive for a regulator to accept bribes in order to continue keeping social ties with his community and avoid shame-based sanction (Akpalu *et al*, 2009).

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Empirical studies generally suffer from data accuracy and difficulties in obtaining quality and reliable information. This may refer to misreporting, not understanding concepts and giving misleading answers since reporting own violation is not an easy task. The concepts of probabilities and perceptions are new to fishers, who are most likely to have only primary education. In addition, some variables in compliance analysis cannot be measured directly; hence proxies are used, which may also have some effect on model parameters' estimates.

There is a strong view in the empirical literature that for compliance to be applied in a proper way, a good management system should be designed and put into effect since the management regime has a direct influence on compliance (Hardin, 1968). A quite divergent view on which management system is most effective for better compliance with regulations exists in literature, however. For instance, many authors agree that the most suitable management system to ensure compliance is a properly implemented co-management system (Ostram, 1990; Eggert and Ellegård**,** 2003; Jentoft, 2000; Nilsen, 2003, Hanna, 2003; Nielsen and Mathiesen, 2003). Jentoft (2000) attributed perfect compliance under this regime to the improvement of the legitimacy of fisheries management system such as sharing decisions, creating a feeling of fairness and justice and greater understanding of regulations. He further indicated, though, that if co-management is not handled carefully it may lead to loss of legitimacy. Nilsen (2003) ascribed the success of compliance to the fact that managers and decision makers lack knowledge about the factors that affect compliance and legitimacy within the fishers' communities. Legitimacy is defined as the perception of the fishers about regulations. He concluded that if there are large numbers of fishers involved in regulation formulation, legitimacy is more easily achieved.

Hatcher *et al*. (2000), on the other hand, argued that co-management as a fishery management system is unlikely to result in high levels of compliance as long as output controls are concerned. They pointed out that it is not co-management *per se* but the flexibility in the management system that brings about efficient fishery management in many regulatory regimes. The management approaches that are currently applied in most developing countries are based on centralised government intervention and have proven inadequate to deal with the issue of compliance with fisheries regulations.

3. 3 Summary

This chapter reviews the literature on measuring noncompliance with fishery regulations and its determinants. Several deterrence models have been developed to study noncompliance with fishery regulations in static and dynamic decision frameworks. The static approach assumes violators maximise expected utility from fishing illegally and the gain from violation is not guaranteed because violators might get caught. This model was developed by Becker (1968) and was widely used and one main conclusion from this approach is that higher fine rather than probability of detection is more effective deterrent.

On the other hand, Davis (1988) argues that by taking certain factors into account, like discounting of future profits and the perceived risk of detection, which change over time, deterrence analysis is more realistically modelled as a dynamic decision process. This implied changing the expected gain from "not guaranteed" in the static model to "conditional upon fisher's survival" in the DDM. The DDM has also been applied to noncompliance in fishery deriving results that suggest violation of regulations is more likely to be deterred by increased probability of detection than by increases in fines. Very few studies apply this model, which emphasizes the importance of including discounting in measuring violation, as it has direct effect on policy formulation regarding current and future distribution of resources.

Different econometric models have been specified to conduct empirical deterrence analysis on determinants and extent of the decision to violate. Binary models, ordered choice models and Tobit models are among those used in the empirical literature. Determinants of noncompliance include purely deterrence factors and normative factors. Some econometric problems, such as multi-collinearity among factors that measure normative effects and biased data on self-reporting of violation, are common in empirical estimations of noncompliance with regulations. Co-management has been found to be the most successful regime for compliance with regulations as widely mentioned in the literature.

Existing literature using DDM, is found limited to the case of constant probability of detection and intensity of violation as a measure of violation rate. This study attempts to relax these assumptions by extending and modifying the standard model aiming for a more flexible model as explained in following chapter. First the study will adapt the standard DDM using frequency instead of intensity of violation rates, which allows analysis of factors that determine compliance by typology of violators. Second, the study will adapt the DDM to allow for probability of detection that depends on time. The adapted models will then be empirically estimated using data from a survey of fishers in the JAR of Sudan.

CHAPTER FOUR

DYNAMIC DETERRENCE OF NONCOMPLIANCE WITH FISHERY REGULATIONS: THE ADAPTED ANALYTICAL FRAMEWORK AND RESULTS WITH FREQUENCY AS THE MEASURE OF VIOLATION

4.1 Introduction

As discussed earlier in the literature study of chapter three the DDM is commonly used for analysis of non-compliance with fishery regulations. This study adapted the DDM to deal with some of the existing gaps in the application of the model to situations representing artisanal fishery circumstances in developing countries. The DDM adapted for the use of frequency rather than intensity of violation as the measure of noncompliance is presented in the following section. Section three employs the extended DDM to perform comparative static on the sensitivity of optimal violation to a number of key factors of high relevance to compliance with regulations. Analytical results obtained from this modified DDM are then compared with findings of earlier empirical studies employing alternative static and dynamic formulations. The chapter concludes with a summary in section four.

4.2 Dynamic deterrence with frequency measures of violation rate

In the literature, noncompliance is measured by either intensity or frequency of violation. Some empirical studies used frequency of violation to measure violation rate in static deterrence models (Eggert and Lokina, 2010; Hatcher and Gordon, 2005; Sutinen and Kuperan, 1999). Furlong (1991) and Sutinen and Kuperan (1999) assumed that a fisher has a fixed amount of time, part of which he spends fishing illegally but did not explicitly classify violators by type. On the other hand, Eggert and Lokina (2010) adopted a typology of violators but did not account for the dynamic nature of violation, i.e. alternate periods of violation and non-violation for the same fisher, continued repeatedly over time. The said studies revealed that using frequency measures has the advantage of enabling classification of violators by type which is of significant value for effective policy design and targeting.

Fishing in African lakes and rivers is characterised by its seasonal nature. For instance, three seasons of fishing are observed, the abundant catch season, when fishers are able to use their normal techniques of catching fish; scarcity season, when it is hard to obtain a catch by authorised means; and the flood season, when fishing is hard to practice. Fishers cope with this seasonality by changing techniques to suit different seasons' circumstances, which in most cases involve violation. It is therefore important to consider fishing seasonality in analysing compliance with regulation. Eggert and Lokina (2010) explained it implicitly by measuring the rate of violation among artisanal fishers in Tanzania by how frequently fishers violate regulations in terms of months.

Three types of fishermen have been observed in developing countries (Eggert and Lokina, 2010; Kuperan and Sutinen, 1998). The first is the non-violators' group, who always follow regulations (e.g. use prescribed nets) and tend to be mostly well-off fishermen who have alternative sources of income for survival. For this group, using small-sized nets is usually time consuming and the small fish caught with these nets command low prices. The second group can be described as chronic violators, who only own illegal nets because they cannot afford to buy both types of nets. For this relatively poor group, the small-sized fish, though not commercially profitable, guarantees a subsistence catch necessary for survival, especially during seasons of low stocks of large size fish. The opportunity cost of labour of the relatively poor fishers "chronic violator" is almost zero. Their higher dependency on fishing, increases violation and hence make them significantly contributes to the sock decline in JAR.The third group consists of alternate violators who own both types of net using the prescribed nets during fish abundance seasons and illegal sized nets during seasons of scarcity. In addition to enabling use of fishers' typology, frequency measures are less problematic with data. This is because illegal catches are not sold in formal markets as most of the time fishers hide them to avoid being caught and that makes it very hard to find data necessary for deriving intensity measures (e.g. share of illegal catches in total harvest per day).

Despite its revealed usefulness for policy design frequency of noncompliance has not been used yet as a measure of violation rate in dynamic formulations and only intensity has so far been used with DDMs. This study adapted the two periods DDM (Davis, 1988; Leung, 1991; Akpalu, 2008), which postulates that violators seek to maximise their expected discounted profit over two periods. In the first period, offenders gain from illegal activities until the time they get caught and pay a fine. Violators will then engage only in legal activities thereafter, concluding the second period choice problem (as explained in chapter three). In this study the DDM is adapted for use of frequency as the measure of violation rate.

In the following frequency of violation is defined in terms of the number of months during the year a fisher uses under-sized nets. According to that, three groups of violators are defined as follows. Non-violators (NV) referring to those who never violate; occasional violators (OV) are those who alternate between not violating and violating at least once (e.g. one month per year). The last group is the chronic violators (CV) who violate all the time. Eggert and Lokina (2010)
In order to measure frequency of violation, the two periods DDM is specified to suit the middle group (OV). Due to the seasonality of the catch, fishers alternate between fishing legally and illegally in the first period (they own two types of nets). When they get caught, the illegal nets will be seized and fishers will continue using legal nets thereafter. Kuperan and Sutinen (1998) noted that most fishers in developing countries are alternate violators.

NV only use a legal net throughout the two seasons while CV use an illegal net in both periods until they are caught. On the other hand OV might refrain from fishing for a certain time until they manage to buy another illegal net because it is costly to comply with regulations. That causes those who own two nets to alternate between illegal –legal nets in the first period and only legal nets in the second period.

We assume that m is the frequency of illegal fishing measured by the number of sub-periods of fishing per unit time considered (i.e. it could be number of months/days or years of illegal fishing). If in any period the fisher uses a small (illegal) mesh size, he targets both mature and immature fish (i.e. m> 0) and his profit $\pi(m)$ from violation is:

$$\pi\left(m, c, p_a, Q_{m,} E_{m,} s, x\right) = m(p_a Q_m\,(E_{m,} s) - c(E_m)) = m\left(p_a Q_m - c(E_m)\right) \tag{4.1}$$

Where m is the frequency of illegal fishing before detection, $p_{a,}$ refers to the average price of fish caught (mature and immature)[4], Q_m is quantity of the mixed catch of mature and immature fish using illegal net per period of violation, and (c) measures total cost of fishing illegally per period, including a fixed (e.g. sunk cost of the illegal net) and variable (e.g. effort) cost components. The cost variable *(c)* might also include corruption cost (paying a bribe) as an attempt of not being caught, if detected. E_m, refers to the effort used to catch this quantity per unit period of illegal fishing time, and *s* is the stock of mixed catch (mature and immature).

It is assumed that the time of the entire planning horizon is T, which extends to infinity and *(t)* is measured by years; within each year there are months of violation (m) and months of compliance (n). After being caught at the end of the first period and the illegal net is being seized, the fisher will be left with only one option which is to continue to maximise his profit[5] from only legal catches thereafter. The fisher's second period profit $\pi(n)$ is therefore:

$$\pi(n, b, p_n, Q_n, E_n, x) = n(p_n Q_n(E_{n,} x) - b(E_n)) \tag{4.2}$$

Where *(n)* measures the frequency of legal fishing, p_n is the price of normal catch, $Q_{n,}$ is the quantity of normal catch and *(b)* is the total cost (including fixed and variable components) per period of no violation (time of normal fishing). E_n is the effort per time period of legal fishing and *(x)* is the stock of mature fish. Then the sum of the two profits gives the total profit of the violator over the two-time periods planning horizon as:

$$\pi(m) + \pi(m) = m\left(p_{a.} Q_m - c(E_m)\right) + n(p_n Q_n(E_{n,} x) - b(E_n)) \tag{4.3}$$

[4] Average price is used because of the fact that the catch from illegal net include both catches mature and immature and fishers usually sell their catch of mixed sizes to middlemen in weight units (kg).

[5] Though DDM assumes fishers violate in order to maximise profits, in developing countries where rivers and lakes are over-fished, fishers violate for survival and to sustain life (Sterner, 2003).

Given that the assumption of the DDM holds, the violator lacks knowledge about the exact time of detection. However, he has some information about the distribution of the time of detection (Davis, 1988). Thus, we assume a continuous distribution of time of detection (*t*) with the probability density function (pdf) given by $g(t)$ and the cumulative density function (cdf) given by $G(t)$ so that $g(t) = dG(t)/dt$. Then, the probability of being caught at time (*t*) is $G(t)$ and the probability of not being caught at time *t* is $1 - G(t)$.

It is also assumed that if the fisher is caught, he pays a fine *F*, which is a fixed amount of money plus the cost of the seized illegal catch. According to Davis (1988), the probability of paying the fine is *R*[6] and the expected present value of the fine is:

$$R \int_0^\infty Fg(t)e^{-\delta t}\, dt \qquad (4.4)$$

The following value function (equation 4.5) states that the fisherman is maximising his expected discounted profit *v* (.) over an infinite time horizon (the two periods) and the fisher is alternate violator who uses both nets in the first period and when caught , the illegal net will be sized then he will continue fishing legally in the second period. The value function of the fisher is therefore,

$$v(p_{a.}Q_m, E_{m,}, s, c, m, n, b, x, Q_n, E_n, p_{n,})$$

$$v(.) = \int_0^\infty e^{-\delta t} \left\{ \begin{matrix} [m\, p_{a.}Q_m\,(E_{m,}s) - m\,c(E_m) + n\,p_{n.}Q_n\,(E_{n,}x) - n\,b(E_n)](1 - G(t)) \\ +[n\,p_{n.}Q_n\,(E_{n,}x) - n\,b(E_n)]\,G(t) - RFg(t) \end{matrix} \right\} dt \qquad (4.5)$$

Where $v(.)$ is the value function, δ is the discount rate. Equation (4.5) states that the fisher's expected discounted net profit is equal to the expected discounted profit from illegal fishing (the first and second terms) plus the expected discounted profit from legal fishing (the third term) minus the expected fine from violation (last term). The justification for using two period model that, with an infinite time horizon, as made by Akpalu, (2008) is that due to abject poverty, the illegal net may be transferred over generation.

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[6] The use of R is due to considerations such as corruption, as some fishers may escape paying a fine even if they are caught.

The probability of detection is modelled as a hazard rate, which is the conditional probability of having a spell length of exactly t, conditional on survival up to time t (Jenkins, 2005). Following Davis (1988), the probability of detection is equated to the hazard rate and set to be independent of time. Used in this context, the hazard rate is the probability that a law-breaking fisher be caught at time *t*, given that he escaped the police until time *t*. This probability is given by:

$$\Pr(E, m) = \frac{g(t)}{1 - G(t)} \tag{4.6}$$

Pr(.) is the probability of detection of a violator given that he/she has not been detected before;
E is the constant enforcement effort of the regulator, *m*, as defined earlier is the rate of violation (e.g. number of months per year that the fisher fishes illegally). The survival function is
$\left(1 - G(t)\right)$ and *E* and *m* are time-invariant. Then, we assume that the hazard rate increases with *m* at an increasing rate (i.e. $\frac{dPr}{dm} > 0\ \frac{d^2Pr}{d^2m} > 0)$. This assumption of a convex relationship between probability of detection and violation rate is made following the standard DDM of Davis (1988). Furthermore, we assume that no fisher will be falsely detected, that is $Pr(0) = 0$.

$$\Pr(m) = \frac{g(t)}{1 - G(t)} = \frac{-d(1 - G(t)/dt}{1 - G(t)} \tag{4.7}$$

$$\Pr(m) = \frac{-dln(1 - G(t)/dt}{d(t)} \tag{4.8}$$

Integrating both sides, we reach:

$$\int_0^{t} \Pr(m)\, dt - ln(1 - G(t)) \tag{4.9}$$

$$\ln\{1 - \mathrm{G(t)}\} = -\int_0^{t} \Pr(m)\, dt\ hence \{1 - \mathrm{G(t)}\} = \exp - \int_0^{t} \Pr(m)\, dt \tag{4.10}$$

Although regulated open access is the current management regime of JAR with no limit in catch or seasonal closure, the model assumes that the frequency of violation (*m*) is constant over time.

Then the values of the density and cumulative functions are:

$$\{1 - G(t)\} = e^{-Pr(m)t}; \;\; G(t) = 1 - e^{-Pr(m)t} \; and g(t) = \Pr(m)\, e^{-Pr(m)t} \qquad (4.11)$$

Substituting the values of $g(t)$ and $G(t)$ in equation (4.5) and assuming that all other variables are constant over time, we get the value function of each violator (integrating and rearranging of terms that results in (4.12) is explained in heading 1-Annexure A):

$$v(.) = \frac{(m\, p_{a.} Q_m\left(E_{m,} s\right) - m\, c(E_m) - RFPr(m)}{\delta + \Pr(m)} + \frac{n\, p_{n.} Q_n\left(E_{n,} x\right) - n\, b(E_n)}{\delta} \qquad (4.12)$$

The first term is the discounted profit from illegal fishing, while the second term is the discounted profit from legal fishing. Since the second term doesn't include illegal profit that depends on the rate of violation *(m)*, it will be dropped. Thus, the objective of the fisher will be to maximise the discounted illegal profit as follows:

$$v(.) = \frac{(m\, p_{a.} Q_m\left(E_{m,} s\right) - m\, c(E_m) - RFPr(m)}{\delta + \Pr(m)} \qquad (4.13)$$

Then, the optimal level of violation for each fisher is given by:

$$m^* = \arg max \;\; \frac{(m\, p_{a.} Q_m\left(E_{m,} s\right) - m\, c(E_m) - RFPr(m)}{\delta + \Pr(m)} \qquad (4.14)$$

Assuming an interior solution, the first order condition is given by:

$$\frac{dV}{dm} = \frac{[p_{a.} Q_m(.) - \; c(E_m) - RFPr_m](\delta + \Pr(m)) - Pr_m[m\, p_{a.} Q_m(.) - \; mc(E_m) - RFPr(m)]}{(\delta + \Pr)^2} = 0 \quad (4.15)$$

Where (Pr_m) is the differential of (*Pr*) with respect to (*m*). Condition (4.16) suggests that illegal fishing will be attractive up to the point where:

$$p_{a.}Q_m\,(.) - c(.) - RFPr_m = \frac{Pr_m[m\,p_{a.}Q_m\,(.) - mc(.) - RFPr(m)]}{(\delta + Pr)} \qquad (4.16)$$

Which is the point where the optimal level of illegal fishing is reached and beyond which net expected marginal benefits (left hand side) will be less than the discounted net marginal cost (right hand side) of illegal fishing. The fisher will never fish illegally (i.e. *m*=0) if:

$$p_{a.}Q_m\,(E_{m,}s) - c(E_m) - RFPr_m < 0 \qquad (4.17)$$

This condition is fulfilled for those who never violate (NV). This equation could only be positive if (*m)* becomes positive, i.e. the fisher starts to violate and thereby earns more money. The question becomes: why are fishers not willing to violate? There are two justifications for making such an inquiry. Firstly; it can be attributed to the influence of some other important non-monetary reasons preventing fishers from violating regulations (i.e. normative factors) such as moral beliefs. Secondly, fishing is not likely to be the main source of income for this group.

Note that the condition in equation (4.17) is independent of the discount rate, but depends on the expected marginal fine. However, in a poor institutional environment with weak enforcement, condition (4.17) is highly likely to be positive. For instance, in a community of chronic violators, we can deduce from equation (4.17) that violators will totally switch to illegal fishing if:

$$p_{a.}Q_m\,(.) - c(.) - RFPr_m \geq \frac{Pr_m[m\,p_{a.}Q_m\,(.) - mc(.) - RFPr(m)]}{(\delta + Pr)} \qquad (4.18)$$

This condition is fulfilled for those who are full-time violators (CV).

4.3 The effect of key determining factors on the optimal violation rate

This section employs the method of comparative static to explore direction of the effect of each factor on the rate of violation. The first order equilibrium condition is calculated to derive comparative static results on the effects of various factors on the frequency of violation using the implicit differential rules in equilibrium (Chiang, 1984). These results will help to understand the nature of determining effects of some factors of policy relevance on the optimum value of violation, i.e. frequency of violation.

Let the first order conditions of equation (4.15) be denoted by K and use it to derive the comparative static of the model with respect to its parameters (See detailed derivation of results in Heading 2-Annexure A).

(1) Effect of probability paying the fine (enforcement)

$$\frac{dK}{dR} = -\delta F Pr_m < 0 \qquad (4.19)$$

There is no doubt that equation (4.19) has a negative value, given the fact that Pr_m , F and δ are all positive. This result implies that violation rate/frequency m^* decreases with an increase in the probability of paying the fine R.

(2) Effect of level of fine F

$$\frac{dK}{dF} = -\delta R Pr_m < 0 \qquad (4.20)$$

The same argument used in equation (4.19) applies to equation (4.20) suggesting that frequency of violation m^* decreases with an increase in the amount of fine (F).

(3) Effect of probability of detection Pr(m)

$$\frac{dK}{dPr(m)} = [p_{a.}Q_m\,(.) - \; c(E_m) - RFPr_m\,] + RFPr_m = \pi(.)_m + RFPr_m = 0 \qquad (4.21)$$

For condition (4.21) to give the expected negative sign (negative impact of probability of detection on violation rate), the expected marginal fine for the violation has to be greater than the discounted marginal gain from violation. This will hold true for larger values of the expected penalty, implying that the higher the probability of detection, the lower is the frequency of violation.

(4) Effect of discounting the future δ

$$\frac{dK}{d\delta} = \; p_{a.}Q_m\,(.) - \; c(E_m) - RFPr_m > 0 \qquad (4.22)$$

The positive result of the specification in (4.22) is implied by the condition of optimality derived in equation (4.16) for violating fishers, e.g. for $m > 0$. Accordingly, this result suggests that violation rate increases with higher discount rates. That means the less important the future is for the violators, who prefer a given amount of money today than to having the same amount in the future.

(5) Effect of price of / returns to illegal catch P_a

$$\frac{dK}{dP_a} = Q_m\,(E_{m,}s)(\delta + \mathrm{Pr} - \mathrm{Pr_m}) \geq 0 \qquad (4.23)$$

For equation (4.15) to be optimal the following condition must be hold:

$$\delta + \mathrm{Pr} > \mathrm{Pr_m}$$

This implies non-negativity of result (4.23) suggesting that frequency of violation increases with higher prices of (returns from) illegal (mixed) catch.

(6) Effect of fixed cost of the illegal net c

$$\frac{dK}{dc(.)} = -\delta - \mathrm{Pr} + \mathrm{mPr_m} = ? \qquad (4.24)$$

Result (4.24) is indeterminate and would give the expected negative effect of a rise in the cost of acquiring the illegal net if the following must hold:

$$\mathrm{Pr_m} < \frac{\delta + \mathrm{Pr(m)}}{\mathrm{m}} \qquad (4.25)$$

Condition (4.25) simply requires that the incremental risk of being caught (marginal chance of detection) should be less than the average expected gains from not violating (opportunity cost of waiting for next period plus probability/opportunity of being caught) per violation attempt.

The analytical results of this extended DDM using frequency measures are compared with the results of earlier empirical studies in Table 4.1. It is clear that dynamic formulations have important advantages over static models as they could control for the effects of key factors such as discounting the future, costs and prices. Analytical results derived with the extended DDM, which uses frequency measures, confirm the findings of the empirical DDM using intensity measures for the effects of key factors. These factors are probability of fining (enforcement), level of fine and discount rate.

The conclusion from the static model of Becker (1968) and other studies that used static formulations is that a penalty (fine) should be high to deter violation. On the other hand, studies that applied the dynamic deterrence model suggest that crime is more likely to be deterred by increasing the probability of detection than by raising the fine (Akpalu, 2008; Davis, 1988; Lueng, 1991). In this study for probability of detection to deter violation expected marginal fine should outweight expected discounted gain from violation.

Table (4.1): Summary of the comparative static' analyses for different models

Determinants of compliance/violation using intensity or frequency measures	Static models using frequency measures A	Dynamic models using intensity measures C	Dynamic models using frequency measures (this study)
Probability of fining (R)	Negative	Negative	Negative
Level of fine (F)	Negative	Negative	Negative
Probability of detection	Must be less than the fine [B]	Expected marginal fine must be higher than marginal profit from violation	Expected marginal fine must be higher than marginal profit from violation
Discount rate (δ)	Not included	Positive	Positive
Price of / income from illegal catch	Not included	Undetermined	Positive
Fixed cost of illegal fishing	Not included	Undetermined	Undetermined
Normative factors	Positive/negative	Positive	Not included

A. This group includes Furlong (1991), Kuperan and Sutinen (1994 and 1999), Hatcher et al. (2000) , Hatcher and Gordon (2005), Kuperan and Sutinen (1998), King and Sutinen (2010).
B. Except for Furlong (1991).
C. This group includes Lueng (1994), Davis (1988), and Akpalu (2008).

4.4 Summary

This chapter presented the DDM analytical framework adapted in the study to investigate the importance of choosing the suitable method of measuring violation rates. It suggests that due to a number of factors related to institutional and market failure, frequency rather than intensity measures are more feasible and policy relevant measures of noncompliance with regulations, particularly in artisanal fisheries of developing countries. Using frequency as a measure of violation rate provides the opportunity of capturing the direct link between violation rates and seasonality of illegal fishing (e.g. months of active breeding when quantities of small fish are high, which encourages illegal fishing). Use of frequency helps to classify fishers into categories of violators. These categories will help policy makers and managers design policy measures and instruments suited for each group. In spite of these apparent advantages frequency has been used only in static deterrence models and studies that employed DDM have so far only used intensity of violation measures to analyse noncompliance with fishery regulations.

Accordingly, this chapter extends the two periods dynamic deterrence model (DDM) to use frequency instead of intensity of noncompliance as a measure of violation rate. The method of comparative static is employed to derive analytical results on the sensitivity of optimal violation to a number of key factors of high relevance to compliance with regulations designed to protect against over-fishing. Analytical results obtained with this extended DDM confirm the findings of earlier empirical studies employing alternative static and dynamic formulations and reveal more interesting economic meaning of modelled relations. The study shows that in the artisanal fishery industry in developing countries, violation rates are bound to be high. This is the case, given that probability of detection, enforcement and levels of fine are typically low and poverty levels lead to high impatience about the future (social discounting). Nevertheless, the relative magnitude of the effects of each of these factors on compliance with regulations remains an important empirical question that requires further investigation for prioritisation of policy actions. The chapter however, provides a general theoretical model that could be valid and potentially applicable to developing countries with similar fishing circumstances of regulated open access such as the one modelled here.

CHAPTER FIVE

DETERMINANTS OF NONCOMPLIANCE WITH FISHERY REGULATIONS IN SUDAN'S ARTISANAL FISHERY

5.1 Introduction

The standard DDM described in chapter four is extended in this chapter to introduce broader and more flexible formulations for analysis of the problem of noncompliance with fishery regulations. The main extension of the model is to allow for probability of detection that depends on time. Another feature of the adapted analytical framework is introducing time of detection as a random variable to the model and employing the Cox hazard model instead of the survival hazard function previously used in the literature. The predictions of the adapted analytical model are tested on data collected from cross-section survey of artisanal fishers in the Jebel Aulia Reservoir of Sudan. Factors that determine the probability of violation as well as the extent of violation were analysed, employing the ordered Probit model and count data model, respectively. The econometric model specification, study area and data sources are presented and discussion of findings and results and policy implications of the conducted empirical analyses are provided in this chapter.

5.2 Extensions introduced to the standard DDM framework

In this chapter we introduce two extensions to the DDM of Chapter four. Firstly, although the DDM calculates profits from violation into two periods, namely, before and after getting caught, all previous literature using this model formulates the choice problem to be optimised over an infinite time horizon. The transition between the two periods is therefore not clear. This study assumes that time of detection is a random variable that defines the end of the first period and the start of the second period, which then extends to infinity in period two. Splitting the two periods would then result in an easier distinction between the violation and compliance periods within the time horizon.

Secondly, we adapt the DDM to allow for non-constancy (depend on time) of probability of detection by employing the Cox proportional hazard function, which defines probability of detection to be a function of the multiple of two terms, a constant individual characteristics' function and a time-variant hazard function.

Suppose that the goal of an individual fisher who violates regulations is to maximise his profit from two periods before and after being caught. If the fisher violates specific regulations, we observe a positive rate of violation (i.e. m > 0). According to the DDM adapted in Chapter 4, the profit from fishing illegally in the first period is defined by $\pi(m)$ (illegal profit), where m is the violation rate which increases the gain from violation at a decreasing rate, i.e. $\frac{d\pi_m}{dm} > 0 \& \frac{d^2\pi_m}{dm^2} < 0$. Also as defined in Chapter 4, violation rate is measured by frequency of violation, which is how frequently fishers violate in terms of weeks, months or years. The model assumes that after being caught, the fisher will only fish legally (i.e. m=0) and gets a constant profit net of the fine F and that his profit in the second period is π_0 (legal profit or compliance profit)

Moreover, assume that in absolute terms, illegal fishing is more profitable than legal fishing.

$$\pi(m) > \pi(0) \tag{5.1}$$

As stated earlier, we assume that, in the first period the violator will fish until getting caught at a random time variable τ in the future, given that he has never been caught before. The second period starts from the random time τ when the fisher is caught and required to pay the fine (F).

Here we have two important assumptions to take into consideration. First we assume perfect selectivity i.e. nets with the legal mesh size can harvest only mature stock, and the one with the illegal mesh size can harvest both mature and immature stock. Second, although violators do generally recidivate because of poverty and difficulty in buying an illegal net (expensive for the fisher to buy another net given his poverty suitation), we assume that the fisher is highly unlikely to recidivate following literature (Akpalu 2008). Not as in chapter 4, in this model we assume that the fisher own only one illegal net. Taking into consideration the same specifications of the profit functions that explained in details in chapter 4.

The fisher's inter-temporal expected profit is accordingly given by:

$$J(.) = max\, E\left\{\int_0^{\tau} e^{-\delta\tau}\ \pi(m)dt + \int_{\tau}^{\infty} e^{-\delta\tau}\, \pi(0)\ dt\ - e^{-\delta\tau}F\ \right\} \qquad (5.2)$$

Where, *J(.)* is the value function, *E* is the integral expectation, δ is the discount rate, *m* is the violation rate, τ is the random time when the second period starts i.e. the time the fisher is caught and required to pay the fine *F*. we assume that the violator does not know the exact time of detection, but has information about the probability distribution of time of detection. As in Chapter 4, we specify a continuous distribution of time of detection τ with a probability density function pdf (g(τ)) and cumulative density function cdf (G(τ)) such that g(τ) = dG(τ)/dτ, where $0 \le \tau \prec \infty$. However in this chapter we assume that the fisher is not a pure-maximising agent, but drives disutility (for example, feeling guilty) that incurs a psychological cost, from harvesting stocks, *s* and x with cost functions *k(s)* and *d(x)* respectively, following Akpalu, (2008). This will make the profit function to be re-specified as:

$$u(m) = \pi(m) - k(s) - d(x) \qquad (5.3)$$

Where *k>0*, *d>0* and *d*(0)*=0*, and if the fisher doesn't violate his utility is $u(0, b, p_n, Q_n, E_n, x)$.Under the above assumptions, if the fisher is caught, he pays a fine *F*, which is a fixed amount of money plus the cost of the illegal catch which will be seized immediately. The expected present value of the fine is $\int_0^{\infty} Fg(t)\, e^{-\delta t} dt$

We now assume that the fisherman is maximising expected utility over two periods as follows:

$$J(.) = max\, E\{\int_0^{\tau} e^{-\delta\tau}\ u(m)dt + \int_{\tau}^{\infty} e^{-\delta\tau}\, u(0)dt - e^{-\delta\tau}F\ \} \qquad (5.4)$$

Where $J(.)$ is the value function, *E* is the mathematical expectation, δ is the discount rate of each skipper and, τ is the random time of detection. Then, the fisher's objective function is to maximise the expected discounted utility from fishing illegally in the first period and legally after getting caught, subject to the survival time (the details of in between calculations from 5.4 to 5. 5 are presented in Heading 1. Annexure B).

$$J(m) = \left\{\frac{u(m)}{\delta} - \left[\frac{u(m) - u(0)}{\delta} + F\right] Ee^{-\delta\tau}\right\} \quad (5.5)$$

The interpretation of this equation is important. The first term of equation (5.5) is the discounted expected benefits of illegal fishing for an infinite time horizon, and the second part (between the brackets) illustrates the penalty that the violator should pay when getting caught, including the illegal gain plus the fine and the disutility the fisher gains by committing the violation. The last term ($e^{-\delta\tau}$) stand for the proportion of time spent fishing legally. That means that if the fisher gets caught, he will end up benefiting only from legal gains.

Then the goal of a violator is to maximise the value function (equation (5.5)) subject to survival time or the probability of detection. While the previous literature assumes a constant probability of detection (doesn't depends on time), this study adds a new formula for the survival time that makes it non-constant, as explained in detail in the following section.

5.2.1 Specification of probability of detection function

Probability of detection is very important and has been limited so far to situations where independence of length of time to detection is assumed and with lack of clarity on factors that determined the probability of detection in the main deterrence model. In this chapter these assumptions are relaxed to allow for a more flexible model. There are plausible reasons to believe that the probability of detection varies over time. Non-constancy of probability of detection could be due to factors beyond the control of violators. For instance, the probability of the violator being caught is small in an artisanal setting but higher when the fishing industry is highly commercialised. Other sources of non-constancy of probability of detection include violator's attitude towards the risk of arrest that varies over time because of age or simply luck or any factor that is assumed to make the hazard rate change over time.

While some attempts have considered influences of probability of detection to vary with the violation rate m but still independent of time (Leung, 1991), so far in the literature, the probability of detection function has been modelled as constant over time. Accordingly influences of important factors were not explicitly entered in the supply of offences function of the deterrence model. This study modifies previous specifications of the hazard function to allow for better understanding of influences of factors determining noncompliance by relaxing key assumptions.

To relax the assumption of constancy of probability of detection, we adopt the Cox's proportional hazard model (CXPHM). This model is mostly used in survival analysis (Cox, 1972) commonly applied to analysis of data in different fields of sciences such as medicine, environmental health, criminology, and marketing (Jenkins, 2005; Lee and Go 1997). The said model is particularly popular in medical sciences when measuring the survival of patients who encounter serious diseases. This study used the CXPHM to define probability of detection (equation 5.6).

$$\mathrm{H}(\mathcal{T}, m, v, n) = \mathcal{B}(m, v, n) h(\mathcal{T})$$

$$\Pr(\mathcal{T}, m, v, n) = \mathcal{B}(m, v, n) h(\mathcal{T}) \qquad 0 \leq \mathcal{B} \leq 1 \; and \;\; \frac{d\beta}{dm} > 0 \qquad (5.6)$$

The right-hand side includes two hazard functions, the first $\beta(.)$ is the individual-specific hazard function, which does not depend on τ , whereas the second $h(\tau)$, which depends on time but not on β factors, is the baseline hazard function. The latter function is the one which determines if the hazard rate is constant, decreasing or increasing (if we use a Weibull distribution for example) as will be explained more in the following sections. The individual hazard function $\beta(.)$ is linearly related to the probability of detection and increases with violation (the crime rate m) and decreases with the enforcement (n) and evasion activities (v) as cited in the literature (Charles *et al*., 1999). This is a special important implication is associated with the Cox proportional hazard because the baseline hazard function can accommodate constant and inconstant time, while the individual hazard function is linearly related to probability of detection. The proportional hazard rate is specified as: $h(.) = \frac{g(m,v,n,\mathcal{T})}{1-G(m,v,n,\mathcal{T})}$ then, we linked this proportional hazard rate with probability of detection specified in equation 5.6 (CXPHM) in order to define the density function with the following general expression (see Heading 2-Annexure B for more details):

$$g(\tau, m, n, v) = \mathcal{B}(m, v, n)h(\mathcal{T})\mathrm{e}^{-\mathcal{B}(m,v,n)h(\mathcal{T})} \tag{5.7}$$

Most of the literature in survival analysis that uses the Cox proportional hazard rate uses exponential distribution because it is easy to implement and interpret. However, according to Bender *et al.* (2005) this assumption does not generate realistic survival time in real life. The most frequently used distribution for survival time is the Weibull distribution (Lee and Go, 1997). Using this type of distribution will make the baseline hazard decrease or increase over time according to the factors mentioned previously (Bender *et al.*, 2005). This modified modelling of probability of detection also makes the previous specification to represent one of the three versions of this formulation, since the new model accommodates situations of constant and non-constant probability of detection

The introduction of the time of detection in equation (5.5) into the value function, gives the following violator's maximisation problem that depends on time:

$$J(m) = \left\{\frac{u(m)}{\delta} - \left[\frac{u(m) - u(0)}{\delta} + F\right]\int_0^\infty g(\mathcal{T}, m, v, n)\ e^{-\delta\mathcal{T}}\,dt\right\} \tag{5.8}$$

So the net gain from violation is the expected discounted illegal fishing minus the discounted expected penalty. The last term represents the discounted density of time of detection which is the function of explanatory variables (m, v, n).

For simplicity, the last term of equation (5.8) will be replaced by the following formula throughout the text.

$$D(\tau, m, n, v) = \int_0^\infty g(\mathcal{T}, m, v, n)\ e^{-\delta\mathcal{T}}\,dt \tag{5.9}$$

D is the discounted density of the detection time. The discounted density function that is used as the probability of detection in this model can take different distribution functions that give the flexibility of addressing the three possibilities of constant, increasing and decreasing probability of detection by using a Weibull distribution, as example.

Based on literature the following hypotheses are advanced (see Heading 3 Annexure B for the effect of the discount rate)

$$\frac{dD}{dm} > 0; \ \frac{dD}{dv} < 0; \ \frac{dD}{dn} > 0; \ \frac{dD}{d\delta} < 0 \tag{5.10}$$

Substituting equation (5.9) into the value function, gives the final specification as follows:

$$J(m) = \left[\frac{u(m)}{\delta}\right] - \left[\frac{u(m) - u(0) + F}{\delta}\right] D(\tau, m, n, v) \tag{5.11}$$

The optimal level of violation is obtained from the first order conditions by differentiating the objective function with respect to *m* to decide on the optimal amount of *m* that maximises the profit through the optimal path. Then the supply of offences function is given by:

$$m^* = m(F, \delta, n. v, B) \tag{5.12}$$

Where *n* stands for enforcement, *F* is the fine, δ is the discount rate, *v* is evasion activities and the perception variables that affect disutility from violation and socioeconomic characteristics of the fishers, such as years of experience and number of crew per boat directly affects the profits and costs of harvest are included in the vector *B*. Other variables include normative factors such as peer pressure which is measured by the perception of the number of violators in the community. This pressure is believed to motivate fishers to increase the rate of violation, following the findings of a number of studies revealing the importance of normative factors for enforcement of regulations (Akpalu 2008; Eggert and Lokina 2010; Hatcher and Gordon 2005; Sumaila *et al*. 2006; King and Sutinen 2010). However some parameters such as prices and cost are incorporated in the constant term of the regression model since they are common for all the skippers (Akpalu 2008).

This extended model is believed to be more flexible as the new specification of probability of detection function introduces to the DDM new variables for the supply of offences function. These are evasion activity and enforcement that have not been included in this model before. This implies that the model can be reformulated to have two control variables m and v. In such case the violator will seek to choose the optimal combination of these two variables. Thus, a useful extension of the DDM is to consider the trade-off between these two choices and possibilities of substitution.

The modified DDM can be used to empirically simulate influences of key determinants of compliance under alternative formulations. For example, the discounted density function that is used to model probability of detection in this study can assume different distribution functions, which allows for the three possibilities of constant, increasing and decreasing probability of detection employing the Weibull distribution. Therefore, simulation and sensitivity analyses can be performed and outcomes compared under the three situations. This may be implemented through maximising the deterrence model in equation (5.11) subject to the proportional hazard equation (5.6) on any optimization algorithm.

Moreover, regression analysis can be employed to empirically measure influences of identified determinants of probability of detection as demonstrated in medical and criminology fields applications of the Weibull proportional hazard regression model (Bender *et al*., 2005; Lee and Go, 1997; Bodenhorn and Price, 2009; Brempong and Price, 2006; Maddan *et al.*, 2008). Applications of the model developed in this study are not limited to the fishery case but can be generalised to management and regulation of other natural resources such exploitation of common property forest, water and grazing lands and hunting of wildlife.

The following section explains the empirical application of the model based on data from a survey of artisanal fishers in JAR of Sudan.

5.3 Empirical applications of the adapted model to non-compliance with regulations in Sudan

The above model is specified and empirically estimated to analyse noncompliance with fishery regulations among Sudan's artisanal fishers. The empirical analysis intends to achieve two objectives. The first purpose is to study factors that influence the choice between violation categories (which type of violator groups to belong to) and the second is to analyse determinants of the rate of violation (intensity) among violators. This is expected to provide useful information on the number of violators, classified into violation groups (NV, OV, CV), and to further determine why fishers choose to belong to different violation categories and to specify the determinants of extent of violation within violators.

Various models have been used to pursue such objectives. Binary Logit and Probit models have been employed to study determinants of the decision to violate or not. However these models have been criticised in the literature as giving limited information about violators (King and Sutinen, 2010). Moreover, binary specifications such as the Heckman selection and hurdle models are not suitable for this study because our sample does not support efficient estimation and the dependent variable is specified as a discrete variable (Kennedy, 2003). Ordered choice models are more suitable when the dependent variable is measured with data of ordered nature.

However, ordered models are not relevant when estimating the extent/intensity of violation within violators. To analyse extent of violation, we choose to employ count data models, which measure how frequently an event happens within an interval of time, as most relevant for the case of this study. Since in this case we are interested in violators only, the Zero Truncated Poisson (ZTP) distribution is employed as the most suitable among commonly used count models. Nevertheless, this model is known to violate the over-dispersion assumption that characterises count data (variance of occurrences exceeds their mean). A generalised version of this model, the Zero Truncated Negative Binomial model (ZTNB) was developed to overcome this problem and is known to give more accurate results over the famous Poisson model (Kennedy, 2003; Long, 1997 and Wooldridge, 2000; Cameron and Trivedi 2005/2009).

Two empirical models are accordingly employed to implement the intended empirical analysis. The ordered Probit model is used to achieve the first objective and the negative binomial model is employed to analyse determinants of the intensity of violation among violating fishers (second objective).

5.3.2 Estimating the determinants of the choice to belong to one of the violator groups

This chapter follows Eggert and Lokina (2010) typology of fishers which distinguishes three groups of fishers; non violators, occasional violators and chronic violators, and our approach also follows the work by Hatcher and Gordon (2005). The dependent variable *Y** is the latent variable measuring the degree of violation, and which has an ordered nature that justifies the use of ordered maximum likelihood for estimating model parameters, and hence our choice of the ordered Probit model (OPM) for analysing determinants of the choice to belong to one of these three fishers' typologies. The general form of the OPM is specified as:

$$Y^{*} = X'\beta + \mu \qquad (5.13)$$

Where *Y** is the non-observable latent variable and *Y* is its observed counterpart; *X* is a vector of explanatory variables assumed to influence the choice to belong to one of the three violator categories; β is the vector of parameters to be estimated; and the error term *u* is distributed as standard normal (Long 1997; Green 2000). *Y* is only observed when the latent variable *Y** takes only three values $(0,1,2)$. These values range from *Y= 0* for non-violators (NV), *Y= 1* for occasional violators (OV), and *Y= 2* for chronic violators (CV).

Eggert and Lokina (2010) employed a frequency of violation index based on number of months a fisher has violated to classify fishers into the said three categories of fishers' typology. To implement this, cut-off point to separate violators into OC (1-10 months of violation) and CV (11-12 months of violation) are specified according to the information provided on numbers of months of using legal and illegal nets. We also followed the more behavioural choice variable of type of fishing equipment owned/used the previous year as suggested by Eggert and Lokina

(2010). Fishers are accordingly classified into NV, OV and CV based on their initial choice to use only legal nets (NV), only illegal nets (CV) or in both legal and illegal nets (OV)[7]. Though we expected the skippers to give information about violation rate in continuous time, they argued that it is easier for them to answer in discrete time (number of months).

We assume that the latent variable $Y*$ can be described by a normal distribution, so that

$$\Pr(Y = z) = \Phi(-\beta' X) \quad (5.14)$$

z = 0 if fisher owns only legal nets (NV)
= 1 if fisher owns both legal and illegal nets (OV)
= 2 if fisher owns only illegal nets (CV)

The latent variable is related to the observed variable as follows:

$$Y = 0 \text{ if } Y^* \leq 1$$
$$= 1 \text{ if } 1 < Y^* < 11 \quad (5.15)$$
$$= 2 \text{ if } Y^* \geq 11$$

For interpreting model results marginal effects are calculated as given by:

$$\frac{d\Pr(Y=z|x)}{dX_k} \quad (5.16)$$

The marginal effect of factor k is then the slope of the curve relating X_k to $\Pr(Y = z|x)$, holding all other variables constant. In other words, for a unit increase in explanatory variables, the

[7] These numbers are not specified arbitrarily, however, we have cross-checked this behavioural rule criteria of classification with a similar typology, based on data we collected on frequency of violation in months, as in Eggert and Lokina (2010). The two classification systems produced perfectly matched typologies of fishers.

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probability of the dependent variable can increase or decrease according to the sign of the coefficient β (Cameron and Trivedi 2005/2009; Kennedy, 2003). We found that, the fishers' situations including fishery typology, socio economic and normative factors in Sudan hardly change due to inefficient institutions. Therefore, we assume that these factors will remain the same over time. This supports the idea of asking about the previous year violation's violations to be reported for the current year.

5.3.3 Estimating the determinants of the extent of violation within violators

To estimate how frequently violation occurs within the year, the ZTNB model is estimated, where the dependent variable *y* assumes a range of values of between 1 to 12 months of violation. This means that the model is truncated at zero. Then the conditional probability of observing *y* events given that *y* > 0 i.e. the probability that fisher violated given that NV are not part of the sample is computed with the law of conditional probability is:

$$\Pr(y_i \mid y_i > 0, x) = \frac{\exp(-u_i)u_i^{y_i}}{y_i![1-\exp(-u_i)]}, \qquad y = 1, 2, \ldots, 12 \tag{5.17}$$

Since zero counts are excluded, value is increased by the inverse of the probability of a positive count (Long 1997):

$$E(y_i \mid y_i > 0, x) = \frac{u_i}{[1-\exp(-u_i)]} \tag{5.18}$$

u_i is the predicted number of months the fisher violates (probability of given number of months of violation, u_i = 1, 2,..., 12), conditional on explanatory variables (covariates) X_i. A truncated negative binomial model is estimated by modifying the likelihood function (Long 1997) as follows:

$$L(\beta, \propto \mid y_i, x) = \prod_{i=1}^{N} \Pr(y_i \mid y_i > 0, x_i) \tag{5.19}$$

Generally, the model is estimated by the discrete effect method holding variables at their mean. This model estimates the influence of determining factors on the frequency of violation among violators. The results of this model will be compared with the factors that determine the choice to belong to the middle category since this is the only group that has a great rate of variation.

5.4 Study area and sources of data

To conduct the intended analysis, data were collected through a survey of fishermen from JAR, on the White Nile south of the Jebel Aulia Dam in Khartoum State (Figure 2.3 in chapter 2). Fishers in the study area use mesh sizes as small as 2 cm, targeting small catch that is sold fresh or dried for further processing for own subsistence use later. The population included all skippers in Khartoum state who use gillnets. From this population, a random sample of 241 skippers, constituting approximately 30 % of the total number of boats in the area, were surveyed between February and May 2010. Samples were selected from five survey sites with adequate spatial spread across all landing sites on the White Nile between Khartoum city and the dam. Sampling fractions were allocated to the different survey sites proportional to size of population in the site and then randomly selected from a prepared sampling frame showing lists of fishers willing to be interviewed compiled by the site chief.

The sample was collected randomly from five landing sites because of the high homogeneity of the population in all landing sites. The sample was initially 250 and after data cleaning, we managed to get 241 valid questionnaires. These landing sites are, namely, Kalaklat, El Fiteh, Taweel, El Marsa and south of the Dam.

A structured questionnaire was developed and pre-tested on the different sample of population before administering the main survey. Surveyed fishers were assured of the academic nature of the study being part of a PhD degree research at the University of Pretoria and that the survey has nothing to do with the government or the fishery department in Sudan. The final questionnaire was administered to each of the skippers separately in direct face-to-face interviews. The questionnaire collected information on demographic characteristics (e.g. education and experience) of fishing households, types of fishing nets used and number of fishing crew, skipper's perception of the mesh size regulations, violation rates, and how frequently nets were used during previous year. Other questions covered fishers' opinions on current regulations, whether they experienced any arrests, their interaction with the police and managers, and what evasion measures they used to avoid being caught. Respondents were asked about the previous year to maximise accuracy and minimise an expected bias of caution against providing the current year's information on using unlicensed nets.

The questionnaires were administered by post-graduate students from the University of Juba and chief fishermen from the area who are highly trusted by all the fishers. Each fisher was interviewed alone and a meal (equivalent to 4 US$) was provided to the fisher to compensate for their time. They were asked about previous years' violations to maximise the accuracy and reduce the bias that might occur if they were asked to tell the truth about their own current violation rates.

5.5 Model variables and econometric estimation

To establish fishers' typologies, the surveyed population were asked about the type of net they own/use. Those who indicated that they own only legal net sizes were classified as non-violators and those who only owned illegal nets as chronic violators. Occasional violators are those fishers who owned both legal and illegal nets. Violation rates were measured by asking fishers about how frequently they have used an illegal size net in the past year in number of months (a frequency of between zero and 12 months, where zero indicates no violation and 12 stands for violating the whole year). This information was used to classify fishers into categories of violators. The produced typologies corresponded perfectly to the classification of fishers into NV, OV and CV based on type of net owned (used) information. We found that it is easier for the fisher to give information in number of months rather than days, which implies discrete distribution of the months of using different types of nets.

Although the majority of the fishers belong to the middle group, the number of chronic violators is found to be very significant, unlike in the available literature. The mean age of the skippers is 47 years, with a minimum of 17 years and a maximum of 80 years. The age variable is divided into four categories according to respondents' ages, and results show that younger skippers are more likely to violate. It seems that violators have a higher number of dependents, since 63.1 % of OV and 73 % belong to the household category of 7–12 individuals per family. It is also found that 85.2 % of CV and 68.6 % of OV are not able to buy nets in cash. Results also show higher dependency on fishing as a source of income since 86 % of OV and 94.3 % and only 42 % of NV depend totally on fishing.

Very high violation rates were observed, as only 12.5 % of the respondents reported that they have never violated mesh size regulations (Table 5.1), with 37 % of the violators using illegal small nets all year round (CV) and the remaining 50.5 % alternating between small and prescribed size nets during the year (OV). Although the percentage of violation is high (87.5 %), only 28 % of the violators had been arrested but only 8.5 % of those caught had to pay a fine. It is clear that fishers in the study area have high chances of avoiding a fine, with 3.7 % admitting to bribing as an evasion means. The main evasion measure, practiced by 97 % of violating fishers, is to tie the illegal net to a big stone and let it sink deep when the police is seen, and to try to recover it later when feeling secure. In spite of that, loss of illegal nets remains the biggest cost to violators, as about 70 % of them suffered seizure of nets within the past three years (see questionnaire in annexure C)

The survey gathered information on four categories of noncompliance determinants (Table 5.1). Information on socio-economic attributes such as education level, experience, source of income and number of skipper/boat represented one category of explanatory variables. There is strong evidence in the literature of the significance of socio-economic factors on noncompliance. Information was also collected about a second category of explanatory variables associated with enforcement efficacy and deterrence measures such as: number of times violators met regulation enforcing agents when landing an illegal catch (Agent). This variable assumes to measure probability of detection, followed the suggestion of Kuperan and Sutinen (1998) of estimating probability of detection by one variable measuring the number of times the violator has been seen by the police landing small sized catches or using small meshed nets**.** We coded information recorded in a three-scale measure, ranging from always to seldom and never seen.

To estimate the probability of being fined when caught, fishers were asked about the action taken against them when caught. However, it was not possible to find information in this variable within the current year or last year, so we were forced to ask them if they experienced net seizure in the past three years. If the answer was only net seizure (Action) then paying the fine is bypassed. This category also included information on incentives to violate, such as whether or not a fisher used some evasion mechanism to avoid seizure of net or paying a fine (Evasion). Fishers were also asked if they believe a small mesh net is more profitable than the prescribed size nets (e.g. Advantage on profit from violation) and if they could buy illegal nets on credit or only on cash basis (Credit). This variable is believed to reflect violators' poverty level and hence their discount rate (i.e the discount rate is therefore measured by the ability to pay in cash or credit for their nets). Those who pay cash for their nets were considered to be relatively well-off and hence have a lower discount rate (less concerned about the present).

The third category of explanatory variables included influences of social (ethical) factors on noncompliant behaviour. Information on one such factor was sought by asking fishers whether they perceive their peers' attitude towards violation to be wrong or not (Unethical). A fourth category of noncompliance factors represents fishers' perception of the legitimacy and efficacy of the regulations. Information was collected on four legitimacy variables: if fishers' views were considered in formulating the regulations (Unjust), if small mesh prohibition is fair (Unfairness), if the enforcement in JAR is adequate (Inadequacy), and if a violator can skip detection even if they violate (Ineffective). Previous studies revealed that such factors are important determinants of noncompliance (Eggert and Lokina, 2010; King and Sutinen, 2010 and Sutinen and Kuperan, 1999). Some of these variables had to be dropped (Unfairness and Ineffective) from subsequent analyses due to high correlation with other explanatory variables. Correlation between the remaining explanatory variables (multi-co-linearity) was estimated to be less than 0.54.

Table 5.1: Descriptive statistics of variables included in the estimations

Name	Variable description	Mean/%
Violation rate		
NV	Non-violators (Zero frequency)	12.5%
OV	Occasional violators (1–10 months)	50.5%
CV	Chronic violators (11-12 months)	37.0%
Education	Level of education	2.82
Experience	Years of fishing experience	27.63
Crew	Number of crew per boat	3.14
Income	If fishing is the main source of income (Yes = 1 and No = 0)	77.5%
Agent	Number of time seen by agent when landing illegal catch (0/1)	15.1%
Action	Net seized (No=0, Yes=1)	24.5%
Credit	Ability to pay in credit or cash (Yes = 1, No = 0)	72.9%
Evasion	Net sinking 1/0	80.1%
Advantage	Small net profitable (Yes=1, No=0)	77.6%
Unethical	Peer violation is not wrong (Yes=1, No=0)	56.4%
Unjust	Fishers' views considered in regulation design (No = 1, Yes = 0)	75.1%
Adequate	Enforcement in fishing area is adequate (Yes = 1, No = 0)	70.1%

5.6 Discussion of empirical results

This section shows the results of the econometrics estimation of determinants of violation rate in two sections. First, the model includes all fishers in general and then the marginal effect is estimated to show the determinants for each fisher typology.

The OPM specified above was fitted to the data described in Table 5.1 and estimation results are presented in Table 5.2. As mentioned earlier, our dependent variable is an ordered variable classifying fishers into three typologies: NV, OV, and CV. Error statistics indicate a good statistical fit of the model. Deterrence variables have the expected signs and together with the socioeconomic factors their influences have high statistical significance.

Table5. 2: Estimation results of the ordered Probit model of the probability of violation category

Variable	Coefficient	Standard error
Socioeconomic variables		
Education	-0.220*	0.127
Experience	-0.038***	0.011
Crew	-0.298***	0.115
Income	1.43 7**	0.577
Deterrence variables		
Agent	-0.807*	0.473
Credit	0.734**	0.376
Action	0.982**	0.411
Evasion	5.836***	1.162
Advantage	2.167***	0.601
Ethical variables		
Unethical	0.239	0.327
Legitimacy variables		
Unjust	0.239*	0.327
Adequate	-0.791**	0.360
*Significant at 10 % ;** Significant at 5 % ; *** Significant at 1 %.		
Prob> Chi^2 = 0.0000; Log likelihood = 133.27 No of observations = 241; Pseudo R^2 = 0.431		

On the other hand, except for the social ethical variable (Unethical), influences of enforcement and legitimacy variables were significant. Results suggest that the probability of noncompliance decreases with education level, years of experience, and number of crew employed, and increase with increased reliance on fishing as the only source of income. Results also show that using evasion activity to hide the quantities of illegal catch encourages violation, and violation increases if the perception of fishers that illegal net is more profitable than the legal net.

To measure the effects of influencing factors on the probability of belonging to any of the ordered fishers' categories, we derive measures of marginal effects of one unit change (increase/decrease) in explanatory variables, holding all other variables at their mean levels (Table 5.3). A negative sign indicates willingness of a fisher to leave the group (i.e. discouraging factors) and the reverse holds for a positive sign (i.e. incentive to remain in the same group or increased association with the current position/choice).

The effect of deterrence variables on non-violators is irrelevant since they don’t interact with regulators and have not experienced arrests before. However, the only variable of significance that appears to be highly correlated with the probability of compliance is the fact that members of this category of fishers do not use illegal nets and hence do not need to use evasion measures (large negative effect of 48 % of odds).

Among the socioeconomic factors, better education and more years of experience tend to encourage moving to lower violation categories (OV and NV), e.g. discourage chronic violation. High reliance on fishing income has the opposite effect. This is an indication that with better education and more experience fishers are able to diversify their income sources and hence have less dependence on fishing for living. More crew members on same boat seem to discourage chronic violation. This could be due to the relatively higher risk of being caught and fined for a large number of crew and the fact that they can pool resources to afford alternating between legal and illegal nets.

While some deterrence factors have the expected sign for all violating categories (i.e. prevalence of regulation agents and use of evasion measures) effects of others vary between OV and CV. For example, poor violators (access to credit) and higher profitability of illegal fishing seem to encourage higher violation (move from occasional to chronic violators’ category).

Table 5.3: Marginal effects of determinants of decision to violate

	Non-violators		Occasional violators		Chronic violators	
Variable	dy/dx	*t stat*	dy/dx	*T stat*	dy/dx	*t stat*
Socioeconomic						
Education	0.0019	0.94	0.321*	1.67	-0.0341*	-1.68
Experience	0.0003	1.08	0.0052***	3.32	-0.0055 ***	-3.38
Crew	0.0028	1.07	0.04670***	2.72	-0.0496***	-2.77
Income	-0.0309	-1.01	-0.1427***	-4.34	0.7136***	3.65
Deterrence						
Agent	0.0049	0.98	-0.1395	1.48	-0.1445	-1.50
Credit	-0.0093	-0.96	-0.9940**	-2.24	0.1088**	2.18
Action	-0.0061	-1.01	-0.1757**	-2.11	0.1818**	2.15
Evasion	-0.4701***	-3.48	0.1329	1.02	0.3372***	8.53
Advantage	-0.0556	-1.37	-0.1925***	-4.71	0.2482***	5.63
Ethical variables						
Unethical	0.0025	0.65	0.038	0.80	0.0412	0.80
Legitimacy						
Unjust	-0.0084	-0.91	-0.0922**	-2.08	0.1007* *	2.01
Adequate	0.0059	0.99	0.2155*	1.93	-0.1314*	-1.95
*Significant at 10 % ;** Significant at 5 % ; *** Significant at 1 %.						

On the other hand, while the act of seizing illegal nets discourages OVs, it seems to unexpectedly encourage CVs. That may be because it is better for them to give up the net than to pay the fine (no cash) or it may be that their nets are rarely seized due to effective evasion. It might also refer to the fact that seizure of illegal nets has actually been internalised by the fishermen who do not comply and counted as part of the cost of over-fishing. Thus they have taken this into account in their optimization problem. Another factor with an unexpected effect on CV is the ethical factor (i.e. believing that peer violation is not wrong). Not considering fishers' views in designing regulations encourages higher violation (from OV to CV), and the belief that enforcement is Adequate provides an incentive for the flexible strategy of moving to less violation categories for both OV and CV i.e decrease frequency of violation.

In order to achieve the second objective of determining the factors that influence the frequency of violation among violators only, the zero truncated negative binomial (ZTNB) model was employed. Results from this model are presented in table 5.4 and are compared to those from the OPM. Some variables (income, credit, advantage, action, and fairness/unjust) share high statistical significance in both models and their signs confirm our OPM results that they all encourage moving from the OV to the CV category, i.e. increasing degree (frequency) of violation (+ve effect in the ZTNB model - Table 5.4).

Table5.4: Determinants of extent of violation within violators.

Variable	Coefficient	T stat
Socioeconomic variables		
Education	0.023	1.30
Experience	0.005	0.40
Crew	-0.001	-0.12
Income	0.43 7***	4.50
Deterrence variables		
Agent	-0.075	1.00
Credit	0.167***	2.85
Action	0.118**	2.04
Evasion	1.78***	7.56
Advantage	0.1231***	2.89
Ethical variables		
Unethical	0.087*	1.79
Legitimacy variables		
Unjust	0.149***	2.61
Adequate	-0.050	-0.94
* Significant at 10 %; ** Significant at 5 %; *** Significant at 1 %.		
Prob > Chi^2 = 0.0000; Log likelihood = -514.38423 No. of observations = 211; Wald chi2(12) = 9443.51		

Similarly the variable Evasion seems to motivate higher violation rates (increased frequency) both within OV category (from 1 to 11) moving to CV status. While not showing statistical significance in affecting the choice to belong to violator categories, ethical beliefs have a significant, positive effect on frequency of violation. That means the community's ethical beliefs have important influences on degree of violation, especially if violation is a common behaviour in the community. This positive influence is expected among the fishing populations especially where poverty is high and violation is very common.

Interestingly, both models show low statistical significance of the effect of an agent factor (measuring probability of detection). This is consistent with other studies' findings, confirming the problem of low probability of detection in developing countries due to the high cost of enforcement and monitoring. In addition, the effectiveness of this measure is also a function of other factors such as evasion activities. Socio-economic factors such as education and experience while having significant influences on the choice to belong to violator groups do not seem to be of significance for how intensive violation is.

5.7 Summary

The standard DDM explained in chapter 4 was modified in an attempt to introduce a broader and flexible model that allows analysing noncompliance with fishery regulations problem by modelling probability of detection as a Cox hazard model instead of the survival hazard used in the literature which in turn implies probability of detection that depends on time. The new modelling of probability of detection introduces to the DDM new variables for the supply of offences such as evasion activity and enforcement that have not been applied by this model before.

The developed model was parameterised and used to analyse determinants of noncompliance with mesh size regulations among artisanal fishers in JAR of Sudan. The studied determinants include both deterrence (detecting and fining) and normative (ethical) factors. High violation rates were observed (87.5 %) with 58 % OV and 42 % CV. Two models were employed in the analysis: the OPM to examine effects of factors influencing the choice of what fishers' category to belong to (NV, OV or CV), and the ZTNM analysed determinants of how frequently violation occurs (extent).

Results show that evasion activities attract NV to violate; education and experience discourage chronic violation; while access to credit and high profitability encourage chronic violation. On the other hand, believing that enforcement is inadequate provides an incentive for the flexible strategy of being OV. More crew numbers on the same boat also discourages violation.

In both choice and extent of violation models, probability of detection (being seen by an agent) was not important as a deterrent. The study results suggest that fishers care more about penalty (seizure of net) than presence of an agent as a deterrent. This is mainly due to corruption and weak enforcement mechanisms, and effective evasion by fishers. This is consistent with widely observed phenomena in developing countries. Efforts to increase efficacy of detection, monitoring and enforcement of regulations and reduce evasion are some of the policy measures to consider for fighting noncompliance.

The study suggests that unless there is better understanding of violators' behaviour and enforcement of severe penalties on violators' noncompliance with mesh size regulations, violation is expected to increase to the extent that fish stocks may collapse in the JAR. It is therefore recommended that future empirical research on fisheries crimes in Sudan and developing countries should incorporate important factors like the discount rate, bribing and evasion activities.

The study also suggests that investment in better education of fishermen, provision of alternative income and employment opportunities outside fishing, access to credit for ownership of legal nets, effective regulation on importation of illegal nets will be necessary for enhancing compliance with mesh size regulations in Sudan. It is also necessary to promote community level organisation and awareness campaigns among fishers about the dangers for future fish stocks of eroding small fish quantities through the use of illegal nets and consequently endangering the social welfare of all.

CHAPTER SIX

SUMMARY, CONCLUSIONS, AND IMPLICATIONS FOR RESEARCH AND POLICY

Though Sudan is considered to be endowed with good fishery resources, the fishery sector contribution to national economy is marginal. The sector nevertheless supports livelihoods of some of the poorest segments of the population in the country in providing food and income and employment opportunities. Like other developing countries the fishery resources in Sudan are over-fished and the situation is bound to worsen with mounting population growth, fast urbanization, and predicted climate change pressures in addition to the increased health awareness of the nutritional value of fish building increased demand for fish in the future.

Inland waters of Sudan contribute 88.3 % of total fish potential production. The fishery sector however is believed to perform poorly. The sector poor performance is attributed to lack of strategic planning, serious institutional and governance weaknesses due to low commitment of financial and human resources, and high poverty levels among small producers.

Jebel Aulia reservoir is the main supplier of fresh and processed fish in Sudan, contributing 52 % of the total inland catch in northern Sudan. This reservoir is endowed with ecological factors that enable it to produce high sustainable yield of fish for the coming future. Proximity to the capital city Khartoum, the major urban concentration and centre of consumption, gives this area an economic advantage. The area is believed to face a pressure of over-fishing, however. A number of factors have been reported to be behind this over-fishing pressure. Among cited reasons are: increased use of illegal fishing gear, smaller than prescribed mesh sizes, deficiencies in law enforcement, leading to loss of species diversity and heavy pressure on remaining breeding grounds and reduction of natural regeneration. Noncompliance with fishery regulations especially the use of small mesh sizes, which hinders fish reproduction, is expected to increase in the future.

Poor enforcement of fishery regulations is attributed to lack of effective institutional structures to carry out this task**.** The Fisheries Department responsible for enforcing fishery regulations faces significant difficulties for administering the wide spread of a large number of fishers along the very extensive banks of the White Nile River, making it hard to monitor these fishing activities. It also receives little support from other related institutions such as the police and the judiciary**.** These difficulties in managing the resource encourage illegal fishing, especially the use of undersized meshes, which is spreading rapidly throughout the inland waters of Sudan.

Accordingly, policy makers need to evaluate the extent of violation, understand and give more attention to fishers' behaviour and reasons for not complying with mesh size regulations in order to achieve an adequate level of compliance and save this important renewable source from collapse.

Some studies have been undertaken on the problem of over-fishing in the study area but haven't provided adequate information on how to deal with the problem. Few Food and Agriculture Organisation (FAO) and governmental reports agree that the resource is over-fished and it is time for the government to intervene. However, none of the studies have attempted to look at the problem of illegal fishing and incentives for noncompliance with mesh size regulation.

This presents an important limitation as a deep understanding of how fishers behave and their reactions to regulations is very crucial to tackle the problem. In addition, none of the studies applied a fishery economics approach to explain noncompliance in fishery management. Most of the studies have focused on the biological aspects and limited socio-economic information about fishers, food processing and other aspects of fishing. This is a clear indication of a serious neglect of the fishery sector that might result in huge losses to the country and livelihoods of fishers.

Other studies show that noncompliance with small mesh sizes is very common in Africa. For example, Akpalu (2008 and 2009) and Eggert and Lokina (2010) found that the use of small mesh size seriously affected the fishery resources in Ghana and Tanzania, respectively. However the study by Eggert and Lokina (2010) was limited to the application of static deterrence model. On the other hand Akpalu (2008), though takes into consideration the dynamic nature of the problem, has not addressed the importance of measuring extent of violation which would improve our understanding of the severity of the violation. The later study is also limited to probability of detection that dosnt depend on time assumptions of the dynamic deterrence model (DDM).

Many studies employed deterrence models either in static or dynamic formulations. The static deterrence model assumes that the violator faces a one-period decision problem of maximising expected utility. The static model assumes that fisher has a fixed amount of time on which he spent some amount on violation. The fisher faces one-period binary decision of either to obey or violate specific regulations. This ignores the dynamic nature of the detection time, the repeated nature of the crime and discounting the future benefits. It also ignores the fact that violators might get away from being detected and therefore wants to know how much money will accumulates through time from violation. On the other hand, the two periods dynamic deterrence model assumes that violators enjoy incremental profit in the first period from fishing illegally, get caught at random time, punished and forced to behave legally thereafter. However so far the DDM measures violation rate by intensity (measured by composite index of the small mesh size) rather than frequency of violation (measured by number of months fishers violate in the time horizon). No study has yet used frequency as a measure of violation rate in a dynamic formulation in spite of the proven advantages of using frequency. Another important gap is that, the DDM has been limited to the case of a constant hazard rate case, which assumes that the probability of detection is independent of the length of time to detection.

The present study attempted to address these gaps in a two ways. First, the standard DDM was adapted to use frequency rather than intensity measures to represent violation rates in analysing determinants of noncompliance with fishery regulations. The study then compared analytical results from the adapted model with findings of static and dynamic models using intensity rather than frequency measures of violation. Second, this study extended the DDM to allow for inconstancy of the detection time, which in turn implies inconstancy of the discount rate.

Introducing frequency as a measure of the violation rate allowed construction of a typology of fishers based on their level of violation as: non-violators (NV), occasional violators (OV) and chronic violators (CV). Further, the factors that influence compliance with mesh size regulations were identified and included in the offence supply function. We further applied the method of comparative static to explore the effects of various factors on the frequency of violation using the implicit function theorem differential rules. The model allowed analysis of the influences of determining factors such as the size of fine, probability of paying the fine and the discount rate, cost of illegal net and average price of the mixed catch on the noncompliant behaviour of violating fishers.

Findings from this model reveal that a greater expected fine and probability of paying the fine discourage violation whereas a higher discount rate is a motive for violation. Regarding the effect of increase in the cost of illegal nets, an interesting result shows that in order for this policy to deter violation the incremental risk of being caught should be less than the average expected gains from not violating per violation attempt. Higher prices of illegal mixed catch, increases and attract more frequency of violation.

Analytical results derived from our adapted model were compared with findings of other studies employing both static and dynamic formulations. Dynamic formulations have important advantages over static models as they could control for the effects of key factors such as discounting the future, costs and prices. Analytical results derived with the extended DDM that uses frequency measures confirm findings of empirical DDM employing intensity measures for effects of key factors such as probability of paying fine (enforcement), level of fine and discount rate. Employing frequency instead of intensity could also sign the indeterminate effects of price of and income from illegal fishing and change in probability of detection.

Until now, the standard DDM has been limited to the case of a constant probability of detection which assumes that the probability of detection is independent of the length of time to detection and the factors that determined the probability of detection lacked clarity in explanation. As probability of detection is considered to be a salient issue of compliance, better understanding of how this function behaves is very important. The second important contribution of our study is extending the standard DDM to relax the assumption of fixed probability of detection. This is because there are good reasons to believe that probability of detection depends on time. Inconstancy of probability of detection could be influenced by factors beyond the control of violators. For instance, the probability of the violator being caught is small in an artisanal setting but higher when the fishing industry is highly commercialised. Other sources of inconstancy of probability of detection include violator's attitude towards the risk of arrest that varies over time because of age or simply luck or any factor that is assumed to make the hazard rate change over time.

Employing the Cox's proportional hazard function to our model accommodated the hypothesis of inconstant probability of detection and the results provided better explanations of factors influencing probability of detection. Extended model findings confirm those of earlier studies and introduce, for the first time, two important variables to the supply of offence function, namely evasion and enforcement efforts. The new modelling of probability of detection makes the previous specification to be only one version of the three versions of the adapted model, since it accommodates situations of constant and inconstant probability of detection (if we use a Weibull distribution).

Applications of the modified model developed in this study is not limited to the fishery case but can be generalised to management and regulation of other natural resources such exploitation of common property forest, water and grazing lands and hunting of wildlife. Regression analysis can be employed to empirically measure and test hypotheses on influences of identified determinants of probability of detection as demonstrated in medical and criminology fields applications of the Weibull proportional hazard regression model.

The present study tested the extended DDM using data from a survey of 241 fishers in the JAR area in Sudan. Study results showed that the majority of fishers in the northern part of JAR are violators (50.5 % occasional and 37 % chronic) and only 12.5 % do not violate. The high violation rate especially the high number of chronic violators indicates severity of the problem. Data was collected on different socioeconomic categories, such as education and source of income, as well as deterrence factors explaining the interaction between violators and regulators. Social and legitimacy aspects were also included, as well as the community's opinion about violation and their perception of regulations

The extended model was applied to examine influences of both deterrence factors (e.g. detection and fining) and normative factors (e.g. peer pressure) on violation by fisher typology. It further identified the factors that influence extent of violation by measuring how frequently violation occurs among violators. The model was empirically estimated as an Ordered Probit model, which enabled analysis of factors that affect the decision to belong to each group of violators: NV, OV or CV. The study further employed the zero truncated negative binomial model to specify the determinants of extent of violation among violators.

All the factors mentioned (deterrents, demographic and legitimacy variables) were found to be significant determinants of the choice to be an occasional or chronic violator, with the exception of social and probability of detection variables. The implication of no significance of probability of detection is that when fishers decide to violate, they put more value on the gain from violation than the penalty paid as punishment of the violation if caught. Higher levels of education appear to discourage violation because it increases the chances of getting employment and hence another source of income other than fishing. If fishing is the only source of income and if fishers' perception about enforcement and regulations is not good, these could encourage violation.

The zero truncated negative binomial model was employed to analyse and measure effects of determinants of the degree of violation within the group of violators. Results from this model are compared to those from the Ordered Probit Model. The results suggest that fishers care more about penalty (seizure of net) than the presence of an agent as a deterrent. This is mainly due to corruption and weak enforcement mechanisms and effective evasion by fishers, a result consistent with widely observed phenomena in developing countries. Efforts to increase efficacy of detection, monitoring and enforcement of regulations and reduce evasion are some of the policy measures to consider for fighting noncompliance.

The study suggests that unless there is better understanding of violators' behaviour and enforcement of severe penalties on violators, non–compliance with net size regulations is expected to increase to the extent that fish stocks may collapse in the JAR. It is clear that immediate government intervention is crucial and important policy reforms are urgent to save the fisheries of JAR from collapse. It is therefore, important that future research on fishery crimes in

Sudan and the developing world must incorporate and study the effects of important factors like social discount rate that gives information about the extraction rate of the resource, in addition to bribe and evasion activities factors.

The study also suggests that investment in better education of fishermen, provision of alternative income and employment opportunities other than fishing, improvement of the credit market for ownership of legal net and effective regulation of importation of illegal nets will be necessary for enhancing compliance with mesh size regulation in Sudan. It is also necessary to promote community level organisation and awareness campaigns among fishers about the dangers for future fish stocks of eroding small fish quantities through the use of illegal nets and consequently endangering the social welfare of all fishers.

Among the limitations of the study is the focus on only the northern part of the JAR in Khartoum state. As stated earlier the effects of other important explanatory variables need to be analysed. Fishers' difficulties with understanding some concepts like probabilities and perceptions about their opinion on regulations and enforcement measurements forced their exclusion from the model. Information about the study area and fishery in general in Sudan is based on few and unpublished sources due to unavailable data and limited publications.

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Annexure A

1. The dynamic deterrence with frequency of violation specification

By taking into consideration the definitions of illegal profits $\pi(m, c, p_{a,} Q_{m,} E_{m,} s, x) = m(p_{a.} Q_m\,(E_{m,} s) - c(E_m)) = m(p_{a.} Q_m\; - c(E_m))$ in the first period and the legal profit $\pi(n, b, p_{n,} Q_{n,} E_n\,, x) = n(p_{n.} Q_n\,(E_{n,} x) - b(E_n)) = n(p_{n.} Q_n\; - b(E_n)$ in the second period, Illegal profits will be denoted by $\pi(m)$ and the legal profit, by $\pi(n)$ and also $v(p_{a.} Q_m\,, E_{m,}, s, c, m, n, b, x, Q_n\,, E_n\,, p_{n,})$ by $v\,(.)$ and $Pr(m)$ by B for simplicity; then the value function for each violator is:

$$v(.) = \int_0^{\infty} e^{-\delta t}(\pi(m) + \pi(n))\;(1 - G(t)) + \pi(n)G(t) - RFg(t)dt \qquad (1.1)$$

$$v(.) = \int_0^{\infty} e^{-\delta t}\left(\pi(m) + \pi(n) - \pi(m)G(t)\right) - RFg(t)dt \qquad (1.2)$$

The values of the density and cumulative functions are derived in equation (4.11) in the text (chapter 4) as follow: G(t) = 1-e^{-Bt} and g(t) = B e^{Bt} and B=Pr(m) . Substituting these values in (1.2) above gives:

$$v(.) = \int_0^{\infty} e^{-\delta t}\pi(m) + \pi(n) - (\pi(m)(1 - e^{-Bt})) - RFBe^{-Bt}\,dt \qquad (1.3)$$

$+\pi(m) and - \pi(m)$ will simplify as follow:

$$v(.) = \int_0^{\infty} e^{-\delta t}\pi(n) + \pi(m)e^{-Bt} - RFBe^{-Bt}\,dt \qquad (1.4)$$

$$v(.) = \int_0^{\infty} e^{-\delta t}\pi(n) + (\pi(m) - RFB)e^{-Bt})\,dt \qquad (1.5)$$

$$\pi(m)\frac{e^{-(Pr+\delta)t}}{-(Pr+\delta)}\;\Big|_{t=0}^{t\to\infty} - FRPr\frac{e^{-(Pr+\delta)t}}{-(Pr+\delta)}\;\Big|_{t=0}^{t\to\infty} + \pi(n)\frac{e^{-\delta t}}{-\delta}\;\Big|_{t=0}^{t\to\infty}$$

$$v(.) = \frac{\pi_n}{\delta} + \frac{\pi_m - RFB}{B+\delta} \qquad (1.6)$$

Which is in the expanded form (substituting for B and π) is:

$$v(.) = \frac{(m\, p_{a.} Q_m\left(E_{m,} s\right) - m\, c(E_m) - RFPr(m)}{\delta + \Pr(m)} + \frac{n\, p_{n.} Q_n\left(E_{n,} x\right) - n\, b(E_n)}{\delta} \qquad (1.7)$$

This will give the value function for each violator as:

$$v(.) = \frac{(m\, p_{a.} Q_m\left(E_{m,} s\right) - RFPr(m)}{\delta + \Pr(m)} \qquad (1.8)$$

The second term in equation 1.7 is excluded since doesn't include (m)

2. Derivation of comparative static's properties

Invoking the Implicit Function Theorem for function K (m*(α), α), where α is a vector of the set of arguments in the model and *m* is at its optimal level *m** (hence omitting the * for simplicity), the following holds for each argument α_j at the optimum (Chiang, 1984):

$$\frac{dk}{d\alpha} = \frac{dk}{dm} * \frac{dm}{d\alpha} + \frac{dk}{d\alpha} = 0 \; such\; that\; \frac{dm}{d\alpha} = -\frac{dk}{d\alpha} / \frac{dk}{dm} \qquad (2.1)$$

Employing the first-order conditions' equation (2.1), which determine the optimal frequency of violation (i.e. m^*), we can derive the comparative static' (CS) properties of m* with respect to its parameters $p_{a.}, F, R, C, b, Pr, \delta$. Let *K* be

$$\mathrm{K} = \frac{dV}{dm} = \frac{[p_{a.} Q_m\,(.) - c(E_m) - RFPr_m](\delta + \Pr(m)) - Pr_m[m\, p_{a.} Q_m\,(.) - mc(E_m) - RFPr(m)]}{(\delta + \Pr)^2} = 0 \quad (2.2)$$

The first derivative of equation (1.8) with respect to *m* is taken, and the result set to zero, to determine the optimal frequency of violation (this implies that the denominator must be different from zero). Thus

$$\frac{dV}{dm} = K = \left[p_{a.}Q_m(.) - c(E_m) - RFPr_m\right](\delta + \Pr(m)) - Pr_m\left[m\,p_{a.}Q_m(.) - mc(E_m) - RFPr(m)\right] = 0$$

(2.3)

Note that for m to be optimal, it is required that the numerator of equation (1.8) to be >0. Equation (2.3) shows that $\delta + \Pr(m) > Pr_{m.}$ using the concavity condition of the profit function. Since m is implicit in equation (2.2), we derive the comparative static of m with respect to F, R, Pr, C, $p_{a.}$ and δ

2.1 Probability of paying the fine R (enforcement)

$$\frac{dK}{dR} = (-FPr_m)(\delta + \Pr(m)) + Pr_m\, FPr(m) = FPr_m(-\delta - Pr + Pr)$$

$$= -FPr_m\,\delta < 0 \qquad (2.4)$$

Equation (2.4) has to yield a negative value since the denominator is +ve and F, $Pr_m(m)$ and δ are all +ve values , e.g. hazard rate is increasing in frequency of violation m). This result $\frac{dK}{dR} < 0$ together with the satisfaction of the second order conditions of value function $v(.)$,

$\frac{dK}{dR} < 0$ which implies that, $\frac{dm}{dR} = \frac{dk}{dr} / \frac{dk}{dm} < 0$

Result 2.4 implies that violation rate – frequency (optimal m) decreases with an increase in the probability of paying a fine (R) if detected.

2.2 Level of fine

$$\frac{dK}{dF} = (-RPr_m)(\delta + \Pr(m)) + Pr_m\, RPr(m) = RPr_m(-\delta - Pr + Pr)$$

$$= -RPr_m\,\delta < 0 \qquad (2.5)$$

Following the same argument as above (denominator is +ve and R, Pr_m and δ are all +ve values) it is clear that $\frac{dK}{dF} < 0$, which implies that $\frac{dm}{dF} = \frac{dk}{dF} / \frac{dk}{dm} < 0$ frequency of violation (optimal *m*) decreases with an increase in the amount of the fine (F).

2.3 Probability of detection *Pr(m)*

$$\frac{dK}{dPr(m)} = \left[p_{a.}Q_m(.) - c(E_m) - RFPr_m\right] + RFPr_m = \pi(m)_m + RFPr_m < 0 \qquad (2.6)$$

For result (2.6) to yield the expected negative sign (negative impact of probability of detection on violation rate) expected marginal fine should be greater than the discounted marginal gain from violation. This will hold true for larger values of *Pr(m)* implying that the higher the probability of detection, the lower is frequency of violation.

2.4 Discount rate

$$\frac{dK}{d\delta} = p_{a.}Q_m(.) - c(E_m) - RFPr_m > 0 \qquad (2.7)$$

The non-negativity of Result 2.7 is implied by the condition of optimality derived in equation 4.15 for violating fishers (e.g. for $m > 0$). Result 2.7 accordingly suggests that violation rate increases with higher discount rates, i.e. less important is the future.

2.5 Return from violation (price of illegal catch)

$$\frac{dK}{dP_a} = Q_m\left(E_{m,}s\right)(\delta + \mathrm{Pr} - \mathrm{Pr_m}) \geq 0 \qquad (2.8)$$

As we mentioned before, at optimal levels of *m* the adjusted probability of detection is greater than the marginal risk of detection (equation 2.3), which implies non-negativity of Result 2.8, which suggests that frequency of violation increases with higher prices of (returns from) illegal (mixed) catch.

2.6 Fixed cost of illegal net – c

$$\frac{dK}{dc(.)} = -\delta - \mathrm{Pr} + \mathrm{mPr_m} = ? \qquad (2.9)$$

Result 2.9 is indeterminate. For this to yield the expected negative effect of cost of acquiring the illegal net, the following must hold:

$$\mathrm{Pr_m} < \frac{\delta + \mathrm{Pr(m)}}{\mathrm{m}} \qquad (2.10)$$

Condition 2.10 simply requires that the incremental risk of being caught (marginal chance of detection) should be less than the average expected gains from not violating (opportunity cost of waiting for next period plus probability/opportunity of being caught) per violation attempt.

Annexure B

1. Calculation of the modified model

Annexure B1 shows all the steps for the integration to calculate the expected net present value of illegal gain using the modified two times dynamic deterrence model. As noted in the text
$u(m) = \pi(m) - z(s) - d(x)$, $u(0) = \pi(0)$, substituting for $u(m)$; $u(0)$ in the value function and integrating gives the followings:

$$J(m) = E\int_0^{\mathcal{T}} e^{-\delta t}\, u(m)dt + E\int_{\mathcal{T}}^{\infty} e^{-\delta t}\, u(0)\ dt - e^{-\delta\mathcal{T}}\, F \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

$$= E\left[u(m)\left(\frac{-e^{-\delta\tau}}{\delta} + \frac{1}{\delta}\right) + u(0)\frac{e^{-\delta\tau}}{\delta} - e^{-\delta\tau}F\right]$$

$$= E\left\{\frac{u(m)}{\delta} - \left(\frac{u(m)-u(0)}{\delta}\right)e^{-\delta\mathcal{T}} - e^{-\delta\mathcal{T}}\, F\right\}$$

$$= E\left\{\frac{u(m)}{\delta} - \left(\frac{u(m)-u(0)}{\delta} + \mathrm{F}\right)\ e^{-\delta\mathcal{T}}\right\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2$$

$$= \left\{\frac{u(m)}{\delta} - \left(\frac{u(m)-u(0)+F}{\delta}\right)\int_0^{\infty} g(\tau, m, N, v)e^{-\delta\mathcal{T}}\right\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3$$

Equation (1.1) is the discounted net present value of a fisher who violates the first period (first term) plus the gain from the second period (second term). After in between calculation and integration, we reached equation (1.2), which give us the exact expected discount profit from violation, the first term is the gain from violation (discounted expected profit from violation) and the second term is the amount of penalty that the fisher gets after being caught (immature catch plus fine) the outcome will be the pure gain from violation.

In equations (1.3), we insert the value of the expectation parameter, which is the net present value of the time of detection.

2. Calculating the Probability density (the relations between the density function and proportional hazard rate)

This is straightforward calculation to get the proportional density function g(.) from the hazard formula and inserts the final results in the maximisation equation.

$$\Pr(\mathcal{T}, m, v, n) = \mathcal{B}(m, v, n)h(\mathcal{T}) \qquad 2.1$$

With the survival function given by:

$$h(\tau) = \frac{g(\tau, m, n, v)}{1 - G(\tau, m, n, v)} \qquad 2.2$$

$$= \frac{\frac{dG(\tau, m, n, v)}{d\tau}}{1 - G(\tau, m, n, v)} \qquad 2.3$$

$$= \frac{-d(1 - G(\tau, m, n, v))/d\tau}{1 - G(\tau, m, n, v)} \qquad 2.4$$

$$= \frac{-dln(1 - G(\tau, m, n, v))/d\tau}{d\tau} \qquad 2.5$$

Integrating both sides we get

$$\int_0^{\mathcal{T}} \mathrm{h}(\tau, m, n, v)\, d\tau = -ln\{1 - G(\tau, m, n, v)\} \qquad 2.6$$

$$-\int_0^{\mathcal{T}} \mathrm{h}(\tau, m, n, v)\, d\tau = ln\{1 - G(\tau, m, n, v)\} \qquad 2.7$$

Hence

$$1 - G(\tau, m, n, v) = \exp\left(-\int_0^t h(\tau, m, n, v)\, d\tau\right) \qquad 2.8a$$

Which can written as

$$1 - G(\tau, m, n, v) = \mathrm{e}^{\left(-\int_0^t \mathrm{h}(\tau, m, n, v) d\tau\right)} \qquad 2.8b$$

If the periodic harvest in this model is assumed to be constant overtime then

$$1 - G(\tau, m, n, v) = \mathrm{e}^{(-\int_0^t \mathrm{h}(\tau, m, n, v) d\tau)} \qquad 2.9$$

$$1 - G(\tau, m, n, v) = \mathrm{e}^{-\mathcal{B}(m,v,n)h(\mathcal{T})} \quad 2.10$$

$$G(\tau, m, n, v) = 1 - \mathrm{e}^{-\mathcal{B}(m,v,n)h(\mathcal{T})} \quad 2.11$$

And,

$$g(\tau, m, n, v) = \mathcal{B}(m, v, n)h(\mathcal{T})\mathrm{e}^{-\mathcal{B}(m,v,n)h(\mathcal{T})} \quad 2.12$$

Substituting fro $g(\tau, m, n, v)$ in the value function we obtain:

$$\left\{\frac{u(m)}{\delta} - \left(\frac{u(m)-u(0)+F}{\delta}\right)\int_0^\infty g(\tau, m, N, v)e^{-\delta\mathcal{T}}\right\} \quad 2.13$$

3. Relation between probability of detection and the discount rate

The relation between, probability of detection and the discount rate calculated as follows:

$$\frac{dD}{d\delta} = -\delta \int_0^\infty \mathrm{g}(\tau, m, n, v)e^{-\delta t}\, d\tau) \quad (3.1)$$

Annexure C

1. Selected socio-economic factors that influence noncompliance with mesh size regulation

Table 1.1: Fishers' typology in Sudan

Violation rate	Frequency	Percent
NV	30	12.45
OV	122	50.62
CV	89	36.93
Total	241	100.00

Table 1.2: Violation rate and age categories

Violation rate	17-37	37-58	58-79	79-100
NV	3	16	11	0
OV	35	54	29	4
CV	36	31	16	6
Total	74	101	56	10

Table 1.3: Fishers' preference about management regimes

Violation rate	Government only	Fishers themselves	Co-management
NV	0	9	21
OV	2	33	87
CV	3	13	73
Total	5	55	181

Table 1.4: Perception of fishers towards peer violators

Violation rate	Fishers used small mesh size	Never use small mesh size
NV	29	1
OV	122	0
CV	89	0
Total	240	1

Table 1.5: Fishers' perception about net type's profits

Violation rate	Small	Normal	No difference	Total
NV	0	30	0	30
OV	103	18	1	122
CV	84	5	0	89
Total	187	53	1	241

Table 1.6: Fishers' typology and education level

VR	Uneducated	Khalwa	Primary	Secondary	Hi-secondary	university
NV	6	3	9	10	2	0
OV	32	14	39	4	15	4
CV	21	4	49	2	4	2
Total	59	21	97	16	21	6

Note: VR is violation rate

Table 1.7: Fishers' typology and household size

Violation rate	1—6	7—12	13—18
NV	7	21	2
OV	30	77	15
CV	20	65	4
Total	57	163	21

NOTE: hh size measured by the numbers of individuals within the family

Table 1.8: Fishers' typology and years of experience

Violation rate	1--20	21—42	43--63	64--84
NV	6	3	9	10
OV	32	14	39	4
CV	21	4	49	2
Total	59	21	97	6

Table 1.9: Fishers' typology and no of crew per boat

Violation rate	1—4	5—8	9—13
NV	28	2	0
OV	101	18	3
CV	84	5	0
Total	213	25	3

Table 1.10: Fishers' typology and source of income

Violation rate	Fishing only	Other sources
NV	14	16
OV	109	13
CV	84	5
Total	207	34

Table 1.11: Fishers' typology and Cash versus credit preference

Violation rate	Pay in cash	Credit
NV	11	19
OV	38	84
CV	14	75
Total	63	178

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2. Questionnaire: Fishermen Compliance Behaviour to mesh size regulation measures in Sudan

Greeting, I am a fisheries researcher working at a research institute in Khartoum and I am here to administer a questionnaire on behalf of a PhD student at university of Pretoria South Africa. You have been randomly selected to participate in the fisheries science and research. Please note that all your answers and responses will be taken seriously with great confident. your participations to the questions are one of many answers by other fishers so no one can distinguishes what you are answered among all other answers .we will compensate you for the time that you spend with us by giving you 10,000 SP . Your interview will be taken with you alone to avoid interruption. Through this interview if you don't understand any question please, ask for more explanation. If you agree about that then let us start.

Section 0: Identification

	Name	Code
Q1. State		
Q2. Village		
Q3. Questionnaire number		
Q4. Enumerator		

Section1: Socio-economic Information

	Date	Month	Year
Q5. Date of the interview			2010

	Hour	Minute
Q6. Time of start		
Q7. Time of end		

Q8. Fisher name (optional) ______

Q9. Age (year)

Q10. Sex

Male	1
Female	2

Q11. Education Level:
Only one answer is possible

Uneducated	1
Khalwa (Religious Education)	2
Primary	3
Secondary	4
high Secondary	5
University	6
Post-graduate	7

Q12. How Many members in the household (number)

Q13. How many years have you been fishing (number)?

Section 2: Background Information.
Please provide the following information regarding your fishing activities

Q14. Which fishing activities of these do you use?
Multiple answer is possible

Net	1
Vessel	2

Q15. Which fishing equipment do you own?
Multiple answers are possible

Net	1
Vessel	2

Q17. Number of the crew?

Q18. Number of trips per month

Q19. Are you always fishing (tick correct answer/s)?

Yes (→ Q21)	1
No	2

Q20. If no what were you doing?

Farming	1
employed in Government/private sector	2

	Fishing gears maintenance	3
	not applicable	0

Q21. What was the percent of income that you got from fishing?	Less than 50 %	1
	50 %	2
	More than 50 %	3

Section 3: Status of the fisheries

Q22. How do you find the trend of the fish catch now compared to the last five to ten years?	Catch has been declining	1
	Catch has been increasing	2
	There is no change	3
	Seasonal variation	4

Q23. What is the impact of the following factor on the fish stock in this area?

Use these codes:

1= Positive impact

2=No impact

3=Negative impact

4=Do not know

5=both positive and Negative impact

Factors	Code impacts
(1). Excessive number of fishermen	
(2). Excessive number of fishing gears/boats	
(3). The use of small mesh size	

Q24. Were you a member of the fishers' association in the past 12 months?	Yes	1
	No	2

Section 4: Knowledge on Laws and Regulations

Q25. Do you think other fishers use small mesh size for fishing?	Yes	1
	No (→ Q27)	2

Q26. IF YES indicate why? Multiple answer is possible	Poor enforcement mechanism	1
	Majority of fishermen are poor and not getting enough catch	2
	Corruption	3
	The level of penalty is low for the first and	4

	second offence	
	Easy marketing because people prefer the small sizes fish	5

Q27. Which type of net/nets were you using (considering mesh size) in the last 12 months?

Nets with small mesh size		1
Nets with prescribe mesh size		2
Both types of nets		3

Q28. If the answer is (3) in previous question how frequency in the previous year do you use both of them?

Q29. In which season(s) fishers like to use nets with small mesh size?

Multiple answer is possible

Winter time	1
Autumn	2
Summer	3
other (to specify)	4

Q30. Which net is more profitable?

The net with small size		1
The net with normal size		2
They are the same		3

Q31. If we offer you two choices to buy net that catch large amount of fish will you be able to pay in credit or cash?

pay in cash	1
pay it in credit	2

Section 5: Now we want to get your views about different regulations that are in place. The principal features of this regulation is mesh size regulation

Q32. For each of the following statements please indicate your level of agreement or disagreement

Use these codes:

1= Strongly agree

2=Partly agree

3=Strongly disagree

4=Partly disagree

Regulation	Code
Gill nets (mesh less than 10 cm)	

The principal reason for the following regulations (ban of gill nets of 10 cm or smaller) is to protect the fishery resources.

Q33. Indicate whether you think the above mentioned are just/fair regulations. Indicate your answer for each of the regulation in the table below

Use these codes:

1= Unfair

2=fair

Regulation	Code
Gill nets (mesh less than 10 cm)	

Please indicate whether you agree or disagree with the following statements

State your answer in the table below.

Use these codes:

1= Strongly agree

2=Partly agree

3=Strongly disagree

4=Partly disagree

Questions	Code
Q34. The mesh size regulations, closed areas licenses and other measures are aimed at improving the long term well being of ALL fishermen	
Q35. Views of fishermen are taken into account in the formulation of fisheries regulations.	
Q36. (Mesh size Regulation) is not enforced consistently	
Q37. Do fishers who violate these regulations getting away with it (i.e. not detected or penalized)	

Section 6: We would like you to tell us about your experience with enforcement authorities during the past 24 months

Q38. How often do you see the fisheries officers in the Reservoir when you were fishing during the last 12 months?

Only one answer is possible

Always	1
Often	2
Seldom	3
I have not seen them for almost a year now	4

Q39. What do you usually do to avoid being caught fishing with small mesh size net?	cell phone	1
	tie the net with small mesh to big stone and allow to sink	2
	destroy the nets	3
	Other (to specify)	4

	Code
Q40. Enforcement in the fishing areas is adequate	

Use these codes:
1= Strongly agree
2=Partly agree
3=Strongly disagree
4=Partly disagree

Q41. Please estimate to the best of your ability the percentage of fishers who usually or always comply with any of the regulation listed in the table

Regulation	Percentages
Gill nets (less than 10 cm)	
Gillnet (monofilament)	
Closed areas	
No license	

Q42. Have you been arrested for violating mesh size regulations over the last 12 months?	Yes	1
	No (→ Q44)	2

Q43. If YES, how many times?

Q44. What action did you take to avoid been taken to court	Bribe	1
	Discuss with policy friends	2
	relative in the government Protect	3
	Other (to specify)	4

Q45. What enforcement actions were taken against you for violation of the regulation over the last 3 years?	Verbal warning	1
	Written warning	2
	Fine	3
	Convicted	4

	Confiscated/sizing the net	5
Q46. Do you think that enforcement action was right given what you did?	Yes	1
	No	2
Q47. What were the total losses to you over the past 12 months as results of the enforcement action (cost of illegal fishing)?		
Q48. Compare to the previous years the chance that violator will be caught violating mesh size regulation is:	Increasing	1
	Decreasing	2
	Constant	3
	Fluctuated	4
Q49. The fisher has violated regulations because he is very poor with big family and small children should the fisherman have done that?	Yes	1
	No	2
Q50. Why?		
Q51. In your judgment what is the view of the other fishers towards those who are violating the mesh regulation.	Is wrong to do	1
	Not wrong	2
Q52. What is your judgment on the view that regulations should be complied with even if they are not fair	Agree	1
	Disagree	2
Q53. What is your judgment on the view that fishermen should comply with the regulation set by the government even if the regulations are not effective in managing the fisheries	Agree	1
	Disagree	2
Q54. In your opinion which one is good for managing	The government	1

the mesh size regulation? Multiple answers are possible	Fishers among themselves	2