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Research and management of competing small-scale and industrial fisheries:

A modeling study of the shrimp fisheries in Mozambique

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Abstract

The shrimp fisheries in tropical areas often present interactions between the fleets that are taking part in the fishery: industrial fleet and small-scale sector. The fisheries in the Sofala bank, Mozambique, are an excellent case study of such interactions. In this study a simulation model is used to analyze different scenarios and management issues: lack of information in the fishery, catches of artisanal fleet not taken into account in stock assessments, same management measures applied to both fleets, over-crowded fishery, and interactions through catches and by-catches. Although coarse, the model appears to model appropriately some of the main characteristics of a two-fleet two-prey fishery without biological interactions. Six-management scenarios differing mostly on the extension and timing of closed seasons in the shrimp fishery were simulated, following earlier practices and recommendations from different authors. These scenarios suggest that for maximizing yield and profit in the long term a strong reduction in the trawler fleet would be most appropriate. With large fleets present, as in the late 2000’s, increased closed seasons may, or not, be beneficial for the stocks, but seem to be little economically efficient as they don’t deal with the race to fish. .

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1. Introduction

Shrimp fisheries around the world are known for a number of technological interactions happening between small-scale and industrial fleets [1-3]. Known cases happen in Madagascar, Cambodia and Nigeria where fleets target the same shrimp species or accidently catch, and often discard the target species of other fleets. Similar interactions are well-documented in Mozambique. In this East African country a developed industrial fleet targets shallow water shrimp species (mainly *P. indicus* and *M. monoceros)* and captures, as by-catch [4] a number of fish species, including many small pelagic fish such as the shad (*Thryssa vitrirostris)* [5]. Simultaneously, a small-scale fishery in Mozambique targets i.e. small pelagic fish and takes shrimp as an accessory species [6]. This is just an example of the complexity that faces the stakeholders and authorities engaged in fishery management. Indiscriminate application of some management measures to one fleet is bound to have positive or negative repercussions in that or in all fleets, and these repercussions are seldom certain or predictable. Similarly, it can be questioned if fishery-dependent research data sampled dominantly from one of the fleets are not inherently biased. Although these are objective questions they are very difficult to answer by observation studies alone.

The present work puts large emphasis in the interacting fisheries of Mozambique as a case study. Despite the great deal of effort put into the research of the fishery in Mozambique [7-8] there are possibilities for bias in the current stock assessment of shrimp. For instance, rough estimates performed in the yearly research reports indicate that catches of the small scale fleet can be as high as 25% of the total shrimp catch. However, this volume was not accounted for in the assessment of the fishery [6, 9] as this assessment is mostly oriented towards the determination of the catch potential of the industrial fleets alone. This is done because the estimates of the catches and effort of the small-scale fleets are variable and uncertain.

Like elsewhere, much of the regulation of effort in the shrimp fishery in Mozambique is based on the implementation of increasingly longer closed seasons, as recommended by researchers [9]. These regulations are, in principle, similar for both fleets, but are often not complied with by the small-scale fleet. The small-scale (artisanal[1]) fishermen claim that

[1] In Mozambique the word *artesanal* is the official expression to describe the sub-sector, which can be of commercial or subsistence nature. An artisanal vessel has LOA<10m, and in >99% of the cases is not motorized.

shrimp are not their main target, that many of them are fishing for their subsistence, and that the timing of the closed season is strongly detrimental to their fishing activity [10].

1.1. Applicability of the study

Biological and physical interactions between fleets are a rule in world fisheries [2, 3]. The interactions between the two fleets in Mozambique are considered an excellent case-study for training in fisheries management: this is not because this shrimp fishery is an utterly important world fishery, but because the conflict of interests between fleets is relatively well defined and there is a reasonable amount of statistics and biological and social information to support the analysis. The present research builds on the implementation and improvement of a fisheries model [Sofala v3, Santos (2013)], created to explore the dynamics of the fishery in a sector-wide approach, with particular reference to the biological dynamics. The existing simulation model was developed as a management game for teaching because it is difficult to find long time-series (longitudinal studies) that address the changes brought about in a fishery by different management regimes. Although it was thoroughly inspired in the Mozambican situation the model and its predictions are not place-bound: the model attempts to represent a general situation and the conclusions should apply elsewhere too. The model implicitly defines a number of stakeholders, such as a small scale fleet, an industrial fleet (an existing semi-industrial fleet of very small size is neglected), researchers and managers. The output from the model includes biological and socio-economic indicators and is therefore suitable for scenario analyses with a diversity of goal functions.

1.2. Interactions in shrimp fisheries

(The following description of the shrimp fisheries in Nigeria, Cambodia and Madagascar relies totally heavily on the wide review performed by Gillet (2008) [3]. These countries were selected because they present similar characteristics to the shrimp fishery situation in Mozambique.)

1.2.1. Nigeria

Shrimp fisheries in Nigeria are divided between industrial shrimp trawlers, with about 225 vessels, and a large number of small scale participants that use different fishing techniques. Shrimp is the most important agricultural export of the country, and a large source of employment and subsistence in coastal areas.

Trawling for shrimp and fish started in Nigeria in the late 1950s. However 1982 can be considered an important year for development of the sector, with the introduction of 49 medium-size trawlers. By 1985, a total of 149 trawlers were already taking part in the fishery. These trawlers came from different regions to take part in a finfish fishery, and the shrimp was a by-catch product. Due to the devaluation of the Nigerian currency (Naira), the finfish became insufficient to cover the costs; therefore, the shrimp (by-catch until the date) became an important source of export due to its high commercial value. In 1987, the shrimp production rose by 82.5% to 5234 tonnes.

The industrial fleet consists today of vessels ranging length from 23 to 26m; most of them build in the United States, using a four-seam trawl with capacity to freeze on board up to -20°C. Operations take place during day and night time.

The artisanal fleet consists of three different groups: first, a fisher group using 8-12m wooden canoes with outboard engine, fishing in waters up to five kilometers from the shore. Second, an artisanal beach seine net fishery operating in shallow waters. And, third, a group operating passive conical stow nets mainly to capture submature shrimp.

Shrimps are targeted by both fleets. While the artisanal boats fish from the shoreline to five nautical miles offshore, the industrial fleet is required to operate off this line to avoid conflicts. However, they do not always they respect the reserved area, especially in periods of peak biomass. This creates physical interactions between fleets and as consequence, gear damage. The main problems affecting the shrimp fisheries in Nigeria are allegedly the physical damage caused by the industrial operations to the small-scale fisheries, and a stated overcapacity of the industrial fleet. Data regarding the shrimp fishery (catches, effort, and export) are not easily accessible, and when it is, numbers are inaccurate and conflicting.

In Nigeria, the small-scale fisheries have been traditionally blamed for the shrimp by-catch, as they catch large quantities of juveniles in the shrimp stove nets. This makes the average size of the shrimp smaller in the catches. It would probably be better to all other groups (trawlers and small-scale alike) to allow shrimp to reach a larger average size. Larger shrimp fetch better prices and contribute to a larger spawning stock, thus improving the overall quality and status of the fishery. However, Akande (2002) [11] provided additional information with respect to the problem of by-catch by the industrial fleet. While by-catch must be landed in ports it was obvious that transfer of by-catch from the industrial fleet to artisanal canoes was taking place in the high seas. While illegal, this was a good and viable source of income for the small-scale fisheries.

1.2.2. Cambodia

Shrimp fisheries in Cambodia are not as important as freshwater fisheries for local consumption. However, the catches of 3500 tonnes of shrimp per year make this fishery an important export industry.

In the 1920s, an experimental survey was performed to analyze the viability of trawling. The conclusion was that catches were too small in order to use European trawlers. During the late 1960s, however, the high increment in trawlers in Thailand, the scarcity of grounds and the rising prices for shrimp, lead to the introduction of this fishing method in Cambodia. In the 1980s, a fleet of small trawlers became well established owing to their low operational costs and ability to fish in shallow areas.

It is possible to divide this fishing fleet into two big groups, which are non-differentiable in the fishery statistics: a first group of small trawlers with engines smaller than 30HP that catch shrimp, normally close to the shore and during night time. A second group of vessels, 20m of length, fish offshore.

By decree, it is illegal to operate at depths shallower than 20m in Cambodia. This is a problem for all the small trawlers, since this minimum depth is only reached as far as ten kilometers offshore sometimes. Therefore, many of these trawls operate in illegal areas. Further, there is a clear excess of capacity with 3.4 vessels per linear km of coastline.

One of the biggest problems that Cambodia faces relates to fishery monitoring and control. Evidence of underestimation of catches [2], landings performed outside Cambodia, and generally poor information on shrimp production are rife. There is also evidence of unregulated foreign fishing activity (by Thailand and Vietnam) in Cambodian waters [12], and due to the fact that the entry costs for fishing activities are low, there is an increment of population in coastal areas.

The main problem in the interactions between the fleets, it is the destruction of the artisanal fishing gear by the industrial fleet. No compensation is given because that would be recognition by trawlers that they are fishing in illegal grounds. The fisheries regulation does not allow trawling in bottoms less than 20m deep, but the artisanal boats are small in size and are not safe in offshore areas. Therefore, there is a big concentration in shallow areas of all types of fleets. When actually considered in the Cambodian law, by-catch relates to “trash fish” defined as “fish that have a low commercial value by virtue of their low quality, small size or low consumer preference” [13]. Then, the trash fish is used as a reduction in factories. By-catch can comprise as much 60-65% of the total catch.

1.2.3. Madagascar

Shrimp fisheries in Madagascar comprise two categories: a fully undeveloped deep-water shrimp fishery possible to neglect in terms of catch (just 1 trawler operating in 2004); and a highly developed coastal shrimp fishery divided in 3 groups (industrial, traditional and artisanal).

The industrial shrimp fishery started in 1967. Nowadays all the companies are local, but they often have a large share of foreign capital. The artisanal sector is the result of an introduction by FAO, in the 1970s, of a mini-trawl with the aim of modernizing the traditional fleet.

The industrial sector accounts for two-thirds (68.6%) of the landings and is composed of 70 freezer trawlers, with engines from 250 to 500HP and length from 23 to 30 m. The fishing grounds used are situated between the seven and 25-m isobaths and the shrimp are aimed to exportation.

The artisanal sector is formed by 36 “mini-trawlers”, with a power of less than 50HP and a length of ten meters, representing a small part of the landings (4.1%). These only operate during day time and close to mangrove and estuaries. They operate in the same grounds as the industrial fleet.

The traditional fleet consists of non-motorized vessels, but their landings account for more than one fourth of the total (27.3%). Fishers participate in groups or individually, using nets, weirs or traps. The information regarding the number of people is imprecise. Coarse estimates indicate from 8000 to 10000 people taking part in the fishery, which has experienced an important increment, from 800 tonnes in the late 1970s to about 3500 tonnes in 2004. This increment is due to the migration of people to coastal areas, which is facilitated by the open access character of the fishery resources of Madagascar.

In 2004, there was a reduction in catches by 15%. Factors contributing to this situation are not clear. For the last 30 years, cycles of two, three or four years of good catches have ended with strong falls. But some other factors could have contributed, like two major cyclones, or the uncontrolled traditional fleet that targets small- and medium sized shrimps. The shrimp fishery in Madagascar presents a high seasonality, with peak of catches at the start of the open season (1st of March). About 50% of the catches are made in the three first months and then, at the end of the season (30th November).

The by-catch in the Malagasy shrimp fishery was as high as 55% in 2004. Calculations made by Kelleher (2005) [14] indicate a 72% a discard rate of the by-catch.

As the fishing ground is not delimited for one single type of fleets, there is a competition between industrial and artisanal exploiting the same resource. In the past, the main problem was the damage of the artisanal gear by the industrial fleet, but this is no longer a problem. The industrial fleet is aware of the compensation obligation to artisanal vessels in case of accident. The major conflict between fleets arises from the occurrence of 85% of the shrimp stock within a two-mile zone from the shoreline. The government is reluctant to ban the access for the industrial fleet, which may otherwise incur in large economic losses.

1.3. Mozambique

Mozambique is situated in the south east coast of Africa, facing the Indian Ocean, with maritime borders to Tanzania in the North, and South Africa in the south. The sea between Mozambique and Madagascar is called the Mozambique Channel. The coastline of Mozambique can be sectioned in three parts (from North to south), depending of ecological factors [15, 16, 34]:

- A northern coastal region 770km long with a narrow continental shelf, characterized by rocky and coral-bearing bottoms.
- The central coast (swamp coast), 980 km long, characterized by mangrove forests, estuarine areas and sandy coasts, with two important deltas (Zambezi and Save delta).
- The southern coast is 950 km long. The most common aspects are high parabolic dunes, north oriented capes, barrier lakes and sea beds with rocks and coral.

The importance of the industrial fisheries to the national economy has dramatically declined since the end of the civil war in the 1990's thanks to the emergence of alternative industries. Nowadays it still represents at least 3% to the Mozambican gross national product [8, 16, 36]. Figures are uncertain, but it has been estimated that the annual marine catches amount to about 130000 tonnes, 91% of which come from the artisanal fisheries sector and only 7% from industrial fishing. But, the industrial sub-sector represents 52% of the total first hand value, and contributes largely to the country's export income, and to the state finances (central treasury and Ministry of Fisheries) owing to the taxes, fishing licenses and catch quota fees paid. The artisanal fishing sector has major importance for employment, nutrition and income of a large group of population. It also represents a major subsistence activity for the most disadvantaged [8].

The history of the fisheries in the country can be divided in three periods [17, 18]:

- Period before independence: late development of an industrial shrimp fleet (1960's); lack of great fishery potential reflected in the absence of a fisheries development policy; fishing practiced as a subsistence activity by a minority.
- Period after independence (1976 – 1992, civil war): important contribution of the artisanal sector to the subsistence and economy of the coastal sectors, and

of the industrial shrimp fishery (mostly foreign vessels) to export economy; creation of institutions related to fisheries and its development.

- 1992 – Present days: the Mozambican Ministry of fisheries was established; legislation, monitoring, management of the fisheries became a reality.

The main law regulating the sector is the Fisheries Law [19], which defines the types of vessels and gear, general aims of the management, conservation measures and the license and surveillance systems. The principal controls used in Mozambique to manage fisheries include a total catch quota, which is divided and allocated to companies and licensed vessels, as well as technical measures and a seasonal closure of the most important fisheries. From 2013, the main control in the industrial shrimp fishery has been changed from catch quota systems to effort quota systems (foot rope based) (Lucinda Mangue, ADNAP, pers. com. August 2013), but is not clear what the total effort quota is and its consequences. One of the most evident changes is that the important operational fees paid to the State changed from a vessel-quota based fee to a foot-rope based fee.

Most of the industrial shrimp trawling in Mozambique takes part in the shallow waters of the Sofala Bank. With a maximum breadth of 60 nautical miles and a surface area off 45000 km2 up to the depth of 200m, it represents 64% of the Mozambican continental shelf, with. It is in this productive region that the largest concentrations of marine resources are found. During and right after the civil war that raged until 1992 this shrimp fishery accounted for up to 40% of the total exports of Mozambique [15]. This gave this activity a great symbolic value for the sovereignty of the nation, an image that it still partially carries, despite the loss of economic dominance. However, the Sofala bank is also home to the largest concentration of population and artisanal fisher households in Mozambique, and these number tens of thousands [7, 10, 16].

With regard to characteristics and operation areas the fleets of Mozambique can be characterized as:

- The industrial fleet composed by trawlers fishing offshore (at least three miles from the coastal line), over 20 meters length, with capacity to freeze on board and to stay away of the port, working day and night time. In 2011, the number considered to be included as industrial fleet, also included the semi-industrial vessels with capacity to freeze on board, was 50 vessels [6].

- The semi-industrial fleet, trawling offshore too, with length between 10-20 meters, using ice to preserve the catches and return to port each day. Thus these vessels tend to perform short trips from their main harbor, Beira. This fleet is composed of 14 vessels that operate only during day time.
- The artisanal fishery, which operates from the shore or in very shallow waters, with vessels up to 10 meters long, using different techniques to catch fish and shrimp: drag nets and trammel nets, and particularly beach seine. Fishing takes time only during day time. There is an estimated number of 4000 beach seines in the Sofala bank [7, 20].

The shrimp fishery is performed by two main fleets. An industrial fleet (including the semi-industrial sector) targets several species of shrimp. The by-catch consists of different types of fish, the most important being Largehead hairtail *(Trichiurus lepturus*), Sin croaker (*Johnius dussumieri*), Tiger-tooth croaker (*Otolithes ruber*), Indian pellona (*Pellona ditchela*) and the Orangemouth anchovy or shad (*Thryssa vitrirostris*) [4]*;* the artisanal fleet targets mostly these fish species but also captures shrimp. The predominant gear in terms of volume in the artisanal sub-sector is the beach-seine*,* and in this group the clupeids and anchovies are the target species and shrimp the accompanying fauna [6].

In 2011, the total catches of shrimp reached 5670 tonnes, of which 25%, or 1460 tons, originated from the artisanal fishery (although reports talk about estimations, due to the hard task of collecting information) [7]. Due to the small catches of the semi-industrial sector (102 tonnes), in the last report of fisheries from the "Instituto Nacional de Investigação Pesqueira" (IPP) [6] this catch was added to the industrial catches, giving a total industrial shrimp production of 4209 tons in 2011.

Although the industrial shrimp fishery has a large economic value it also creates a good share of externalities in the form of non-targeted catches and discards. The stated by-catch ratio varies among authors: from a 1:3 ratio in Pelgrom and Sulemane (1982) [31] up to 1:5 from Anon (1994) [32] this represents a great deal of competition for resources with the small-scale fishery, which sometimes is a subsistence fishery. A system that was once attempted in Mozambique in order to diminish wastage consists of an arrangement, whereby the artisanal fishermen can collect the by-catch form the industrial fleet, using their own boats. For that, however, the industrial vessels must be close enough to the shore to be accessible to the canoes. When the industrial shrimp vessels operate further offshore and there is no excess storage room in the freezing stores the by-catch is simply discarded [5, 16].The products that can reach the shore are processed: salted and dried or fresh; being distributed along the coast of Mozambique, however the system has shown not being reliable [33].

The main species of shrimp caught are Penaeus Indicus and Metapenaeus Monoceros, representing up to 80% of the total amount of catches of the industrial fleet. The remaining 20% of the industrial targeted catch is typically composed of three species (Penaeus japonicus, Penaeus latisulcatus and Penaeus monodon), which are captured mostly at night time [9]. While in the artisanal fishery P. indicus is captured as a secondary species, industrial and semi-industrial fleets target all shrimp species offshore up to 60 meters depth; P. indicus and M. monodon (abundant in the shore line) are exploited by the three fleets, but the important bulk from the point of view of management are P. Indicus and M. monoceros. These are mostly caught during the first semester of the year. The other three species are caught by the industrial fleet only, in deeper waters and mostly during the second semester of the year [6] when the yields of the main shallow water species decline.

1.3.1. Operational areas of the fleets and closed seasons

Management of industrial fisheries in Mozambique is a fairly developed process, including components of biological research, central management and laws regarding fishing rights, ownership and technical measures. The artisanal shrimp fishery has an exclusive zone to develop their activities, up to three nautical miles parallel to the shore line, designed with the aim of avoiding or minimizing the interactions between the industrial vessels and the artisanal boats [6]. Consequently, the industrial fleet is legally banned to trawl less than three nautical miles from the shore line. The artisanal fleet, mostly composed of frail boats powered by oars or sails, hardly ventures far from the shore and into the three-mile area. The semi-industrial fleet has also been assigned a specific area of operation south of Beira where the industrial trawlers do not seem to operate [6].

Seasonal closures are a preferred instrument of the Mozambican authorities to control effort in the industrial fishery. Until 2003, the closing season lasted for three months, from December to end February, i.e. the local warm and rainy season. Lately, to combat growth overfishing and declining annual catches the closure has been gradually extended. In 2009 the official seasonal closure lasted 164 days (five month and a half), and decreased to 147 days in 2010. The closed season for the industrial fleet extended in 2011 from September to February (Dr. Lizette Sousa, IIP, pers.com. 2011), and the closure and opening are adjusted every year according with the phase of the moon [6]. As a consequence of the increment of fuel prices and decline in shrimp prices in the export markets, particularly since 2008, the industrial sector voluntarily decreased their fishing intensity, in order to obtain better economic efficiency. Thus, the combination of the official and the un-formal closed seasons for the industrial fleets lasts nowadays for six months. It is not totally clear what the official closure for the artisanal fishery is. Documents from the early 2000s frequently mention the implementation of a closed season of one to three months for beach-seines to comply with the general protection measures for the shrimp stocks. However, this closure was only partially complied with by the artisanal sector in some districts, and totally neglected in others [21, 22].

1.3.2. Interactions and conflicts

The clearest interaction in the shrimp fishery is the sharing of stocks (competition) and to a less extent the physical interaction between gears. Both fleets capture shrimp, despite the lower share of the artisanal (allegedly 25% of the total amount, or 1460 tonnes from the total of 5670 tonnes). Whilst the procedure is not totally clear, it seems that the fishing effort and volume of the artisanal fishery is omitted from the scientific assessment. In the research assessment of 2006 [9], the situation is acknowledged: "the catch estimate [of the artisanal fleet] ranged from 524 to 705 t for 2000–2002; representing 13–17% of the total penaeid catch". Nevertheless, the assessment report recommended management measures only oriented towards the industrial fleet. In 2012, the situation was seemingly the same. In the annual report published by the IPP "Relatório Interno de Investigação Pesqueira" [6], the previous artisanal share of the catches of 2006 (13-17%), is updated to 25%. Still artisanal effort and catch remain excluded from the scientific assessment, most probably owing to the lack of precision, and unknown bias of the data collected in the beaches: "the quantity of shrimp landed can be significant along some areas of the coastline", "Artisanal catches accounts for 25% of the total catch and are likely to be impacting on the main industrially fished shrimp stocks" or "these artisanal estimates require some independent validation, before being accepted". The reason yielded by the reports is that "collecting information on this fishery is a difficult task, and the resulting survey based data are therefore rather uncertain". It must be borne in mind that the beach sampling program performed in Mozambique [7, 20] is one of the most ambitious and complete statistical initiatives of its kind, particularly in the developing world. Still, the quality of the resulting global statistics on catch and effort have never been, to our knowledge, formally tested (validated) and are thereby still neglected in the formal shrimp assessment.

In some areas of the Sofala bank (Moma-Nicoalada, Angoche and Dondo a Machanga), the captures of shrimp from the artisanal fleet are particularly significant compared to the captures of the industrial sector [6]. There may be an economical reason for this, as there may be a market willing to pay higher prices for shrimp in these areas. In one of these areas (Moma and Nicoalada), the catches of shrimp by the artisanal are close to represent 25% of the total capture, having a clear potential to impact in the stocks of shrimp [6].

Many of the regulations are, in principle, similar for both fleets, but the artisanal fleet often do not comply owing to reasons of subsistence, fishing being the mechanism to ensure food protein and some economic security [10, 22]. Much of the regulation of effort in the shrimp fishery is based on the implementation of increasingly longer closed seasons, as recommended by researchers. However, most of the catches and income for the artisanal fishers are secured from November to February, the rainy and productive season, which normally coincides with the targeted fishing closure (November to March). Therefore, the artisanal fishers see their livelihood options reduced [10]:

"The loss of such capture cannot be compensated. By the end of the closing season, end March beginning April; most of the shrimp have already migrated offshore, which impairs the ability to produce enough livelihoods during 4.5 months" (Focus groups and household surveys in Angoche and Moma, 2006)." [10].

Masquine (2005) [23] recommended that the closed season be moved to the period between May and June, as this option is the one that best attends to the needs of the artisanal fisheries. This would not collide with the major fishing season and would match the time of alternative income-generating activities for the rural households, such as agriculture. The current closed season is clearly oriented towards the biological control of the shrimp stocks through the industrial fleet, and offers no opportunity to combine fisheries with agricultural activities. Additionally, the artisanal fleet cannot fish offshore with their small boats, and the only shrimp remaining in their fishing grounds during the currently open season are small and less valuable shrimps. This is also problematic for the shrimp fishery as a whole that this juvenile shrimp is captured [10].

1.4. Goals

The goal of this study is to develop a set of simple and simulation scenarios that can be useful for management orientation. These scenarios should be realistic and analyze conflicts between industrial and small scale fisheries.

1.5. Research questions

Along the scenario building process, the following questions will be asked and attempted answered using simple modelling techniques:

1. Does the original model describe the current situation in a satisfactory way (validation)?
    - Do model results mimic trends observed in the fishery?
2. How uncertainty in the inputs of the model is reflected in the output, or how do the different management controls in isolation impact on the fisheries? (Sensitivity analyses).
3. What inaccuracies are brought to the stock assessment if the capture of the artisanal fleet is not taken into account?
4. Are the same controls / technical measures justified for both fleets?
    - What are the expected consequences if a measure is not complied with by one or both fleets?
5. Which management measure has more impact on the fishery in a sector-wide approach?
6. How would the small-scale fisheries benefit from a reduction in the by-catch of the industrial fleet?

These research questions are approached through a simulation model that includes two archetypal fleets (large industrial vessels and beach-seines) and two archetypal preys, a shrimp species and an anchovy, which are the target and by-catch of the two fleets.

Different hypothesis with possible applicability in the fishery field can be investigated using quantitative scenarios modeling. These scenarios can reach a high complexity owing to the diversity of inputs of the model. In this study the situations modeled will be limited to the past, present and future scenarios that have been proposed by people acknowledge with the fishery in the Sofala bank.

1.6. Modeling theory

The utilization of simulation models in fisheries management is well described in the work of Malcolm Haddon, "Modelling and Quantitative Methods in Fisheries" [24]. Models *"try to represent the real situations happening in nature"* or stating in a different way: "*models are hypotheses or theories about the structure of nature and how it operates*". Then, models are an *abstraction or simulation* of the reality. Therefore, models are never a perfect copy [24, 37, 38] of the modelled situation, but dependent on the selection of properties that are used to represent the system, in an attempt to make it as similar as the real process as possible. Models help researchers to get a better understanding of nature systems and it is the task of the modeler to decide which properties, or parameters should be included, consequently models are adapted or focused more in one particular aspect of reality [28, 37, 38].

Models can be developed to describe processes that affect a species at different levels. For example a simulation of growth in penaeid shrimp can be made to quantify the different physiological processes involved in growth [25], and these results can, in turn, be applicable in population management. Additionally, models can be developed to study the interaction between different stressors, for example to determine the long-term effects of different inputs (stressors) on coral reefs, from a ground level effect (the grazing of algae by fish), to stressors of big magnitude (like a hurricane) helping to set different fishing regulations [26]. The greatest advantage of the modeling approach is that can be used as a forecast tool in complex scenarios, as it is possible to simulate real situations with a high degree of similarity/specificity. It is, thus, possible to create realistic scenarios to assess the consequences of actions that would otherwise be impossible to forecast in reasonable time. This has immediate application in e.g. fisheries, allowing the modeler to simulate and apply management measures without having to wait many years to observe the response of a natural process [27-30].

2. Material and methods

3.1. Model

The model utilized in the present work - "Sofala v3" was developed by J. Santos [34] and is a simple two-fleet two-prey age-structured yield model that allows the researcher to experiment with a number of management policies in deterministic or stochastic environments. The model was first developed in the mid-2000's with teaching purposes, and reflects much of the situation in the Sofala bank around 2008-2009. The version used for this study is dated 15th of June 2013, but it terms of its parameters (e.g. economic) it does not reflect yet the rapid changes that have been occurring in recent years. In the development of the model some of the biological detail, such as sex-segregated growth, spatial distribution and biological interactions, had to be sacrificed to give place to management realism. Validation of the model against real data from the Sofala fishery [34] has shown, however, that the simulations are credible in normal situations, and even in extreme scenarios. The model has therefore been considered useful and reliable for experimentation for fishery management purposes. Few other two-fleet two-prey simulation models seem to be available for fisheries worldwide and in particular to realistically describe shrimp fisheries and the specific situation of Sofala.

The model represents a multi-fleet fishery capturing a mix of species (shrimp and shad). Shrimp are captured by an industrial (trawl) and a small-scale fleet (beach-seine); the shad is captured by small-scale gears and as by-catch by the industrial fleet. No biological or other trophic interactions between species are depicted. As a rule recruitment to shrimp stocks can hardly be associated to size of parental stocks [43], and in this model recruitment is a random variable with log-normal distribution. One of the purposes of the model is to investigate whether sampling of catches from only one of the fleets can result in biased perception of the state of the stock by researchers. While the determination of the age-composition was assumed to be made without error and the true natural mortality (M) known, a small "assessment error" (log-normal, CV=0.1) was included in the calculation of the perceived fishing mortality ($F_{perceived}$). These can calculate fishing mortality ($F_{perceived}$) in two-ways: by means of catch-curve analysis of pseudo-cohorts (inactive) or by simple ratios (duplets) of abundance of particular cohorts in the catch in subsequent periods (months). The calculation of $F_{perceived}$ by research can be then be compared to the F_{true} utilized to simulate the stock. One of the inputs of the model is the size of first capture (L_{50}), and the output includes the mean size (weight and length) of shrimp and shad captured monthly and annually by each fleet. The model includes economic functions for each fleet and species. In the present work the option of effort compensation was not utilized. By effort compensation of the artisanal and industrial fleets is here meant a frequently occurring monthly re-distribution of effort [0, 1] upon introduction of closed seasons. In other words, for the purposes of the present work if a closure of six-months is implemented the effective fishing effort is simply halved. Technological creep of the two fleets was considered with a 2% annual rate for the industrial and 1% for the small-scale fleet.

Attempts were made to both utilize reference scenarios that reflect the status quo of the fishery [6, 7, 9, 34] and to develop hypothetical management scenarios that are consistent with the opinions of people and organizations with good knowledge of the context of Sofala [6, 8 24]. The following management controls could be manipulated in the model:

- Industrial fleet(trawl):
    - Number of boats (boats)
    - Hours per boat (hours per boat)
    - Size first-catch shrimp (Carapace length, millimetres)
    - Size first by-catch shad (trawl net, total length, centimetres)
    - Closed season (1-12 months)
- Artisanal fleet (beach):
    - Number of boats (boats or beach seines)
    - Days (days fishing per boat)
    - Size first-catch shrimp (Carapace length, millimetres)
    - Size first by-catch shad (Total length, centimetres)
    - Closed season (1-12 months)

The reference scenario was the average shrimp yield in a year-round Sofala Bank fishery with the main variables for the fleets industrial and artisanal fleets set to the values (status quo values) shown in Table 1.

Table 1. The status quo values of the fishing intensity, pattern and efficiency increase in the two fleets operating in the Sofala bank, as used in the base case of the sensitivity analyses and scenario modeling.

Fleet variable	Industrial trawlers	Small-scale beach seines
Effort: units	60	4000
Technological creep	0.02	0.01
Selection size shrimp (CxL, mm), knife-edge	25	17.1

For the base case to run the simulations for both fleets, 60 boats were selected for the industrial fleet, corresponding to the number of vessels licensed in 2007 (rounded from 59 to 60) [20]. When it comes to the number of the artisanal fleet, the author of the model, Santos [34], made a reasonable estimation regarding to the information based on the census of 2007 [7], only considering the beach seines in the provinces of Nampula, Zambezia and Sofala (all adjacent to the Sofala Bank), obtaining a total of 4397 boats, rounded down to 4000 for modeling work. Therefore the status quo of the fishery was established as 60 trawlers x 5000h for the industrial fleet and 4000 beach-seines x 200 days for the small-scale fisheries.

Sensitivity analyses were performed to provide a ranking of the model inputs based on their relative contributions to model output variability [39-42]. The analysis was realized calculating the % of variation of the yield, profit or fish size upon a pre-determined increase/decrease of each parameter (±1%, ±5% and ±10%), one by one, against the standard obtained in status quo. In the simplest case up to 14 variables can be changed in the model. Simultaneous change of all or many of these variables would be poor experimental design [37] and fail to give unequivocal information about the importance of each input control. To avoid this, a total of six different scenarios considered to be realistic were taken into consideration [34]. The suggested scenarios are:

1. Full access. Both fleets operating year round. This was the situation occurring until 1990 and is used here as the base reference scenario [9].
2. Closed season of 3 months for both fleets: December, January and February. Months with higher seasonal recruitment parameter “r” for species. The main reason for the three months closure in this study was to mimic the closure imposed by the authorities to the industrial and other fleets fishing shrimp in 1999 onwards [9] to protect the recruitment of shrimp and avoid growth overfishing.

3. Masquine suggestion [23]. This author suggested applying different closed seasons for both fleets, since the artisanal fishery is a subsistence fishery, it is better for this sector to implement a closed season when these fishermen can work in the fields. A closed season of six months was established for the industrial (from September to February) and for the artisanal fleet, two months (May and June).
4. Closed season of six months (October to March) for industrial fleet and full access for the artisanal fleet through year. This scenario explores the management measures that can realistically be applied to both fleets
5. Closed season of six months (October to March) for the industrial fleet, and one month closure for the artisanal (January): scenario applicable to the current situation in the North Sofala Bank, Moma district (L. Mangue, Administracao Nacional das Pescas, ADNAP pers.com.)
6. Closed season of six months (October to March) for the industrial fleet, and 2 months month closure for the artisanal (January and February): scenario applicable to the current situation in the South-Sofala Bank, Sofala, Zambezia (L. Mangue, Administracao Nacional das Pescas, ADNAP pers.com.)

For each of the seasonal closure combinations, different scenarios were tested with different combinations of fleet structure. In one group of scenarios (the "industrial perspective"), simulations were performed with a full strength industrial fleet and three combinations of fishing intensity of the small-scale fleet:

- Impact on the yields of the industrial fleet with the strength of the artisanal fleet set to 50%, 100% and 150%.
- Impact on the profit average of the industrial fleet with the strength of the artisanal fleet set to 50%, 100% and 150%.
- Comparisons of sizes (length and weight of the shrimp) of catches for the industrial fleet in both the scientific sampling and true values against the real mortality with a background of different strengths for the artisanal fleet (50%, 100% and 150%).
- Comparison of perceived and true mortality levels for the industrial fleet against a number of vessels with a background of different strengths for the artisanal fleet (50%, 100% and 150%).

In addition to the "industrial perspective" that limits the intensity of the small-scale participation, simulation models were done for the "artisanal perspective". In these trials the small-scale fleet was allowed to participate at full strength and the industrial fleet was simulated at 50%, 100% and 150% intensity levels. The same goals of yield, profit and fish size as above were used for these simulations.

The main purpose of the game-model is to make to make forecasts, normally with prediction horizons of 20 years of the results (or outputs) from a possible set of management measures (inputs) applicable in a fishery. The regulations and controls to the fishery are kept constant along the prediction horizon. Outputs that are often considered are the shrimp yield and size, the profit of the fishery, as well as the yield and size of the shad captured by each fleet. Several scenarios can be compared with the current situation (best available information) [6] in terms of catch, size composition of catch, mortality and revenue. Variables such as body size can be utilized as indicators, and decreasing trends in average size or weight in the catches can be interpreted as a valid signal of increasing exploitation of a population [43].

a. Reasons to exclude the semi-industrial fleet

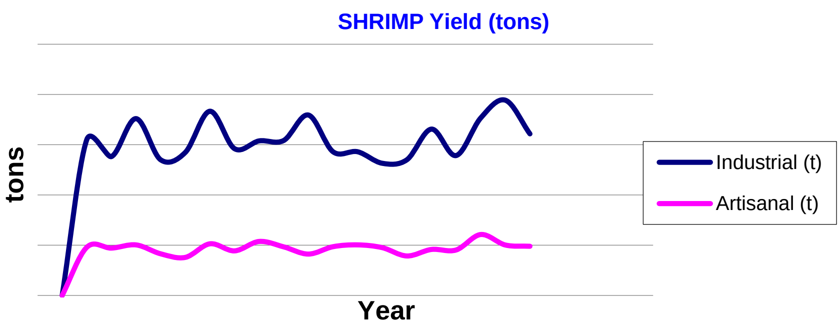
The semi-industrial fleet has not been included in this study due to reasons mostly related with the previsions made by the "*Relatório Interno de Investigação Pesqueira*": "*While artisanal fishing for shrimp continued and indicated that shrimp stocks are still available in this area, these significant catches in competition with the semi-industrial vessels suggest the recovery of this fleet is unlikely*."[6].

This fleet has never made significant catches relative to the total amount of the shrimp fishery. In the year 2005, the semi-industrial fleet achieved its highest catch ever with 400 tons, or less than 10% of the industrial fleet, and the perspectives for this sub-sector are quite negative. Due to the preservation method of the catch (cooling in ice), this product does not fulfill strict hygienic requisites and cannot be exported to the European Union. In addition, the shrimp prices have been decreasing, making this sector unprofitable. The economic irrelevancy of the sector is also reflected in the fact that even in the last reports from Mozambique, the catch of this fleet is included in that of the industrial sector. [6]; hence, this study does not deal with this fleet.

3.2. Modeling process

Simulations were executed with the six scenarios proposed for both fleets. Effort variation was simulated by removal or addition of vessels to the two fleets. While the number of vessels have little effect on the total effort (depending on the time spent fishing by each unit), it has a clear effect on the fixed costs of each fleet.

Owing to the stochastic formulation of the model a macro was designed to perform the Monte-Carlo simulations, with 1000 realizations for each scenario [24]. At the end of each realization, different outputs were collected. Normally, most output variables achieved stable values after 10 years (Figure 1), and the time period between year 11 and 20 years was considered to reflect "equilibrium" condition and be the horizon of concern for management. Output values were therefore the average values obtained from 11th year until 20th year.



Plot 1: Examples of a random 20 year forecast of shrimp yields for two fleets

The following outputs were chosen as the representative quantities routinely investigated in stock assessments by fishery scientists (references) and utilized in the formulation of management advice.

Table 2. Outputs of the modeling process

INDUSTRIAL	ARTISANAL
YIELD	YIELD
PROFIT	PROFIT
SHRIMP WEIGHT	SHRIMP WEIGHT
SHRIMP LENGTH	SHRIMP LENGTH
SHAD LENGTH	SHAD LENGTH
$F_{PERCEIVED\ (shrimp)}$	$F_{PERCEIVED\ (shrimp)}$
$F_{PERCEIVED\ (shad)}$	$F_{PERCEIVED\ (shad)}$
F_{TRUE}	
TRUE WEIGHT	
TRUE LENGTH	

These outputs were chosen as the representative quantities routinely investigated in stock assessments by fishery scientists (references) and utilized in the formulation of management advice. A minimum of 1000 realizations were performed in each simulation [24].

3. Results

3.1. Sensitivity analysis

To evaluate how the main continuous characteristics of the two fleets, in terms of fishing intensity, fishing pattern and improved efficiency, affect the output of the model several one-by-one sensitivity analyses (SA) were performed. The equilibrium yield of the shrimp trawlers was mostly affected by the size of first capture of shrimp (L_{50}), decreasing by nearly 25% with an increase of the input variable of +10%, followed by a decrease of 10.5% for an increase of +5% in the same input variables The artisanal yield relatively insensitive to most variables with the exception of the number of beach seines. The lack of sensitivity of the performance of this fleet to changes in the size of first capture can probably be a result of the lack of definition of the model. The model has one-month time steps and in these shrimp this corresponds to large changes in size that can exceed the 10% amplitude.

Table 3. Sensitivity analyses of the output variables of the model with respect to changes in the variables describing the fishing intensity and pattern of the two fleets. A color red reflects larger percentage effects (absolute values) for a combination of input and output variables than a cooler color (yellow and green, respectively).

Output variable Input changed	Δ input variables						
	-10%	-5%	-1%	0	+1%	+5%	+10%
Industrial shimp yield							
Effort : units	-2.1	-1.0	-0.2		0.2	0.9	1.7
Tech. creep	-0.6	-0.3	0.0		0.1	0.3	0.5
Size (avg CxL)	0.5	0.0	0.0		0.0	-10.5	-25.0
Small-scale shrimp yield							
Effort : units	-7.7	-3.7	-0.7		0.7	3.7	7.2
Tech. creep	-1.1	-0.5	-0.1		0.1	0.5	1.1
Size (avg CxL)	0.0	0.0	0.0		0.0	0.0	0.0

In the second sensitivity analysis, the effect of the discrete variable "closure month" on yield was evaluated. This was done by implementing a closure in January and one in June, as the model may have different sensitivities in the two periods. The change in outputs was compared with those obtained with the fishery in status quo. The January closure gave rise to higher sensitivity than the June closure, being the most affected outputs the yield of the artisanal with a decrease of -7.7% in from the status quo, followed by a decrease of -5.9% in the industrial yield.

Table 4 Sensitivity analyses of the output variables of the model with a discrete closure. The values show percentage of variation with respect to the status quo of the fishery.

Output Closure:	January	June
Ind yield shrimp	3.4	0.7
Ind profit	-5.9	-2.2
Ind avg CxL	0.4	0.8
SS yield (shrimp+shad)	-0.5	-0.8
SS profit	-7.7	-1.5
SS avg CxL	1.3	0.9

3.2. Effects of mixed fisheries on the perceptions of research

3.2.1 Does sampling of catches in either of the fleet affect the perception of fishing mortality?

The scenario of a year-round fishery by both the industrial and the small-scale fleets was used as a case to analyze whether calculation of fishing mortality from the age-composition of the monthly catches of either of the fleet affects the perception of the real fishing mortality (F_{true}). While the determination of the age-composition was assumed to be made without error and the true natural mortality (M) known, a small "assessment error" (log-normal, CV=0.1) was included in the calculation of the perceived fishing mortality ($F_{perceived}$). This fishing mortality was calculated at variable levels of fishing intensity of the reference fleet (industrial or small-scale) at discrete degrees (50%, 100% and 150%) of intensity of the other fleet operating in the background.

In general the average monthly, $F_{perceived}$, tended to be larger than the true monthly fishing mortality. There were however different trends in the systematic error depending on whether the $F_{perceived}$ was estimated with basis on the catches from the industrial fleet or from the catches of the artisanal fleet. With the age-composition of the industrial fleet the estimate of F tended to over-estimate the true F by a relatively constant proportion giving rise to two divergent lines (Figure 1). In the status quo situation the $F_{perceived}$ from the industrial data overestimated the true fishing mortality by 10%. This happens because the industrial fleet exploits just a sub-group of the cohorts exploited by the small-scale fleet. If the fishing mortality is calculated from the artisanal data alone the slopes of the F_{true} and $F_{perceived}$ lines are parallel, meaning that the error is additive rather than multiplicative. These lines are shown in Figure 2 where a situation of increased (150%) fishing intensity by the industrial fleet was simulated in the background. In general the effect of increasing the fishing mortality of the fleet in the background (either the industrial or the small-scale fleet) was to increase the over-estimation of the true fishing mortality calculated with the data from the other fleet. The simulations of $F_{perceived}$ performed for other scenarios of effort management are shown in appendix (I - XII), but reflect consistently the trends described for the reference scenario: the stronger the restrictions in effort by means of e.g. seasonal closures, the lower the $F_{perceived}$ and the lower the overestimation of the true F.

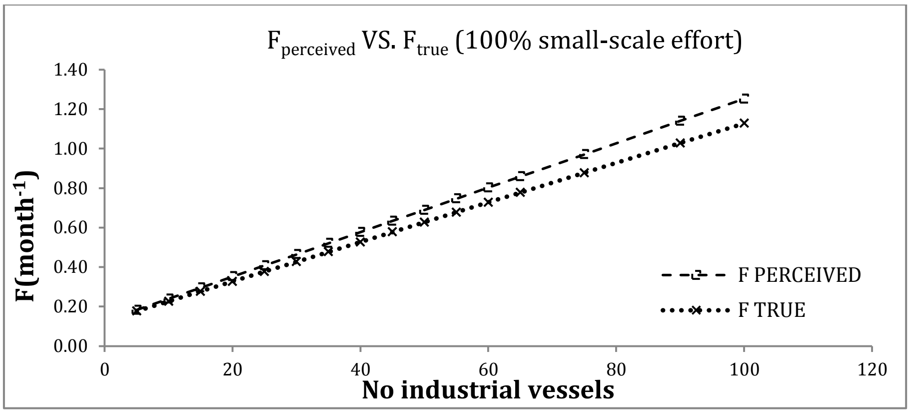


Figure 1 True average monthly fishing mortality and perceived fishing mortality from size composition analysis of the industrial data at different levels of industrial effort. In this scenario no seasonal closures are implemented and the fishing intensity of the small-scale fleet was kept constant at status quo levels (100%). The small-scale fishing mortality at this intensity is the intercept of the lines on the y-axis.

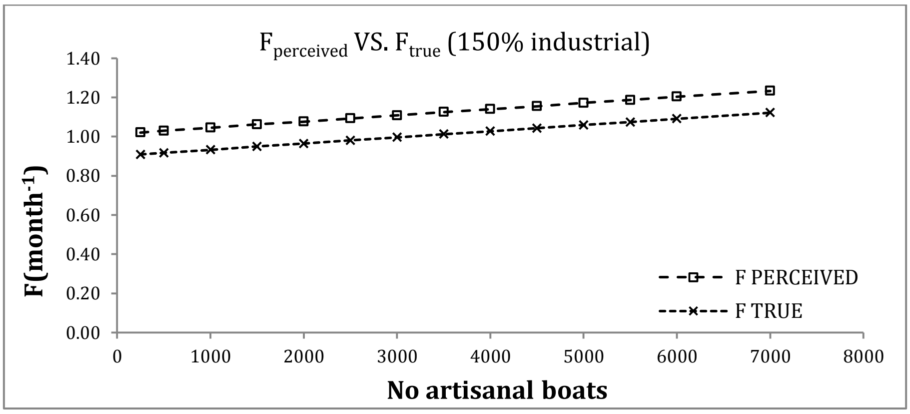


Figure 2. True average monthly fishing mortality and perceived mortality from size composition analysis of the small-scale data at different levels of effort of this fleet. In this scenario no seasonal closures are implemented and the fishing intensity of the industrial fleet was kept constant above status quo levels (150%).

3.2.2 Does the average size in catches reflect the size trends in the stock?

The trends in the average sizes of the catch can be used as indicators of the exploitation state of the stocks. Thus, the relationships between the average weight and length (perceived and true) against the real fishing mortality (F_{true}) are relevant for research. Although the sizes perceived in the catches of the industrial and the artisanal are probably different from the true mean sizes, it is important that the trends in average size are similar. The fisheries are selective, so the true sizes, which include non-recruited shrimp (1 month old), will always be smaller. The average sizes of shrimp was calculated with based in various levels of fishing mortality of the fleet with varying degrees (50%, 100% and 150%) of the intensity of the other fleet operating in the background.

Overall the simulations indicated that the perceived changes in size correspond to the trends in the stock. As expected the average perceived sizes tended to be larger than the true sizes in the simulations, and this was particularly clear in the industrial data, which is most selective (Figure 3). More importantly, the trend of decreasing true sizes with increasing F_{true} was relatively well represented in the perceived sizes too. A small divergence between the lines was observed for the industrial data at low levels of fishing mortality, and this was particularly evident when size was described as body weight. This reflects the non-linear relationship between body length and weight. In this sense, decrease in body mass is more responsive to exploitation, and probably more easily detected, than changes in body length. The same nearly parallel (decreasing) trend between true and perceived sizes at increasing levels of exploitation was observed in the artisanal catch samples (Figure 4). Increasing (or decreasing) the fishing intensity by the fleet in the background resulted in consistent trends of decreasing (or increasing) mean monthly size in the catches.

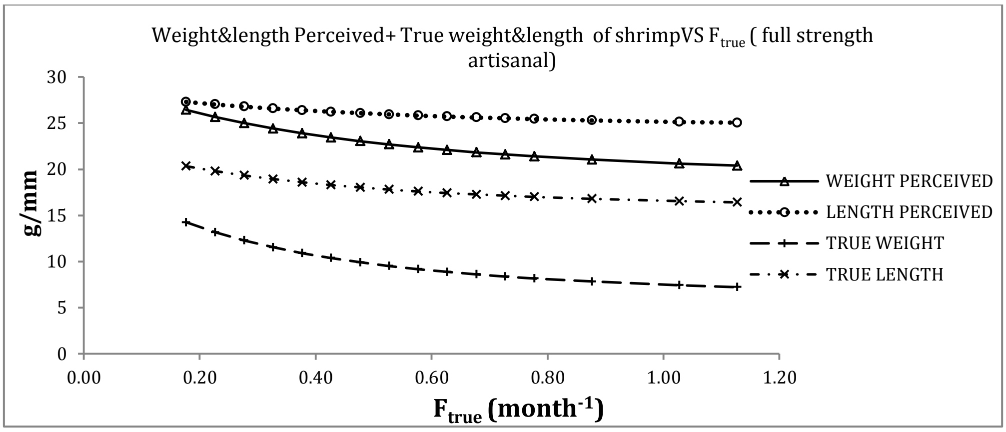


Figure 3: Perceived and true sizes from size composition analysis of the industrial data at different levels of real fishing mortality of this fleet. In this scenario no seasonal closures are implemented and the artisanal background was set a 100%.

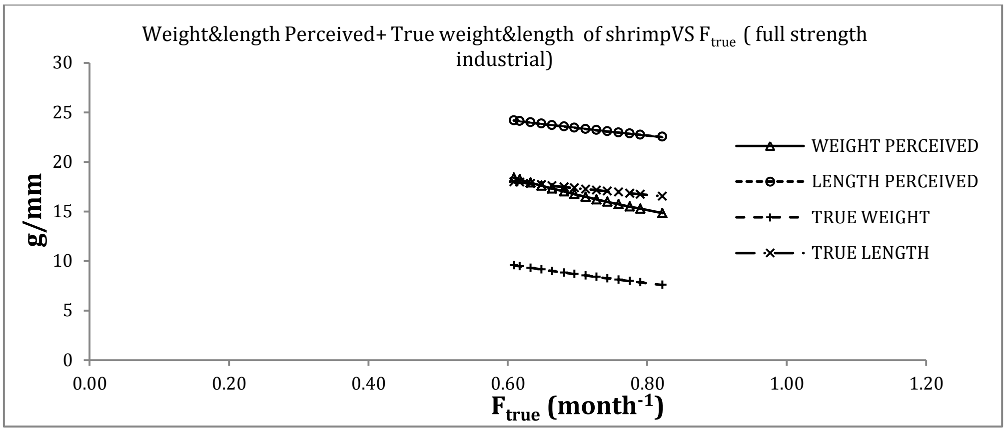


Figure 4: Perceived and true sizes from size composition analysis of the artisanal data at different levels of real fishing mortality of this fleet. In this scenario no seasonal closures are implemented and the industrial background was set a 100%.

3.3. Scenarios

3.3.1. Scenario 1: Non-restricted fisheries.

The first scenario is a reference situation, and coarsely represents the fishery taking place until about 1990 [9] when there were no restrictions on fleet sizes and operation time. In the first set of simulations the industrial effort was varied continuously at three background levels of the small-scale fishing intensity. In this case the yield curve for the industrial fleet was monotonically rising (non-asymptotically) with increasing effort (number of vessels), a reflection of the constant recruitment approach of the model. Under status quo (60 trawlers x 5000h; 4000 beach-seines x 200 days) the yield of the industrial fleet approached 6000 tons and that of the artisanal fleet 1500 tons (Figures 5.1 and 5.3). With this number of vessels the industrial fishery is largely unprofitable (annual deficit about $21 million) (Figure 5.2); reduction of effort to 30 trawlers would reduce the total yield by only about 1000 tons, but bring this fleet to a break-even of costs and revenues. Reduction of the small-scale fleet by 50% would increase the yields of the industrial fleet by about 1300 tons but still not make it profitable in the long run (average deficit $ 12.5 million). The maximum economic yield of the industrial fleet is achieved with a drastic reduction to about 12 trawlers. At status quo the total fishing mortality (F_{true}) reaches $0.73.month^{-1}$, and the average carapace length (CxL) in the industrial catches is 25.5 mm. Reduction of the small-scale effort by 50% would bring the F slightly down to 0.66 and have negligible influence on the size of the shrimp caught by the industrial fleet (25.6 mm).

In the second set of simulations the small-scale effort was varied continuously at discrete levels of the industrial fleet, representing a strong control on the later fleet. The patterns observed followed largely a non-asymptotic curve as that observed for the industrial fleet with regards to yield. At status quo the small-scale fleet was somewhat unprofitable (- $ 6.7 million, divided by 4000 units) (Figure 5.4). It must be borne in mind that this figure disregards the revenues brought by fish other than shrimps and small pelagics. Break-even could be achieved by either reducing the small-scale fleet to 3400 beach-seines or bringing the industrial fleet down by 50%, which would shoot the yield of shrimp of the small-scale fleet to 2450 tons. The maximum economic yield for the small-scale fleet is achieved at about 1000 beach-seines, a drastic reduction as well. This represents the loss of many thousand full-time and part-time jobs associated with the excess 3000 fishing units. At status quo the average size of shrimps is 23.2 mm CxL and that of shad 11.0 cm TL. Also in the status quo situation the average annual catch of small pelagics by the small-scale fleet is about 48150 tons, and the corresponding by-catch by the industrial fleet 3315 tons.

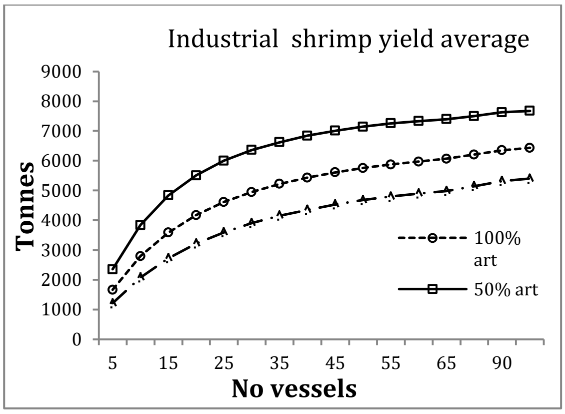


Figure 5.1

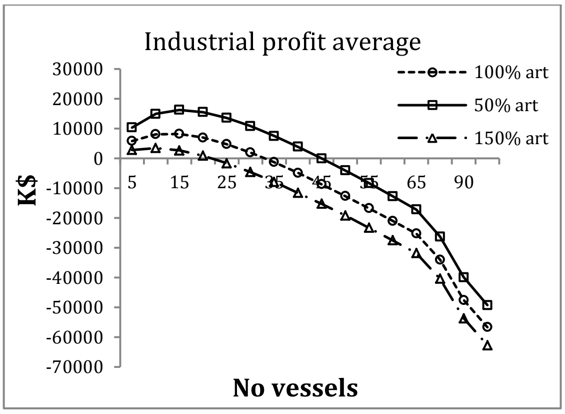


Figure 5.2

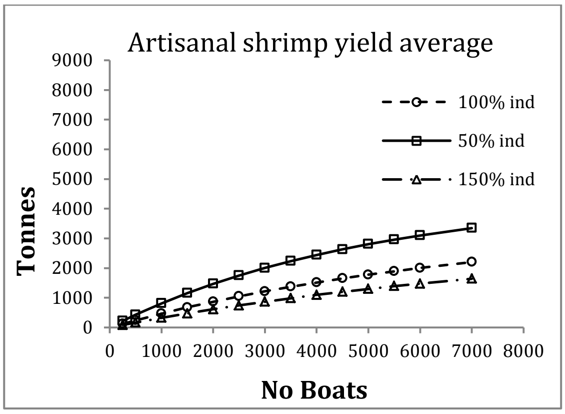


Figure 5.3

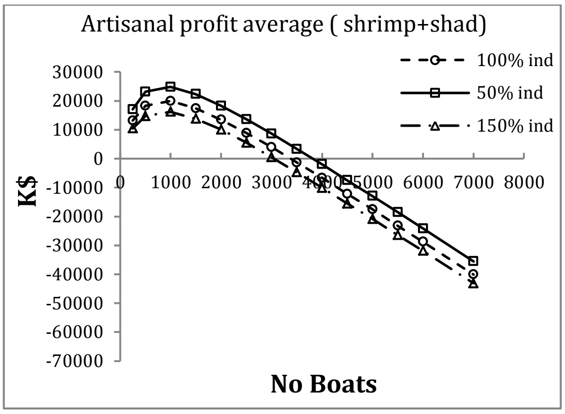


Figure 5.4

Figure 5. Scenario 1

3.3.2. Scenario 2: 3 months closed season both fleets.

The second scenario represents a closed season of 3 months (December, January and February) for both fleets. The main reason for the three months closure in this study was to mimic the closure imposed by the authorities to the industrial and other fleets fishing shrimp in 1999 onwards [9] to protect the recruitment of shrimp and avoid growth overfishing The industrial yield curve (Figure 2.1) presents the same pattern as for scenario 1. Under status quo the industrial yield approached 6550 tons and the artisanal fleet 1480 tons (Figures 6.1 and 6.3), i.e. a 10% increase and a 2.5% decrease, respectively, in relation to the base case. With 60 vessels the industrial fishery remains unprofitable (deficit about $17million) (Figure 6.2). With a further reduction to 30 industrial trawlers the yield is reduced by 1200 tons, but the fleet becomes profitable ($4.7 million). Reduction of the artisanal background by 50% would increase the industrial yields by 1000 tons, but it still would not be profitable under the status quo (deficit about $10.5 million). Despite the closure, the MEY of the industrial is again only achieved at 15 vessels. In status quo the F_{true} reaches 0.55 month^{-1}, the average carapace length of shrimp (CxL) is 26.0 mm, which are both relative improvements to the base case (no closures). If the small-scale fishing in the background is reduced by 50%, the F goes down to 0.50, but this has negligible influence on the size of the shrimp caught by the industrial fleet (26.1 mm).

When the case is made for the small-scale fleet with a strongly regulated industrial fleet the patterns observed were similar to those describe earlier for the industrial fleet. At status quo, the artisanal fleet is unprofitable (-$3.9 million) (Figure 6.4). A break-even situation could be achieved with a fleet of 3700 beach-seines, which is a small reduction in the fleet. With a reduction of 50% in the industrial background, a yield about 2400 tons is achieved, close to a break-even situation in terms of profit. The MEY is achieved at about 1100 beach seines, a still dramatic reduction of the small-scale fleet. At status quo the average size of shrimps is 24.2 mm, and that of shad 11.5 cm TL. At status quo the average annual catch of small pelagics by the small-scale fleet is about 51500 tons, a nearly 10% increase from the base case, and the by-catch of the industrial fleet 3270 tons for the, still a negligible decline.

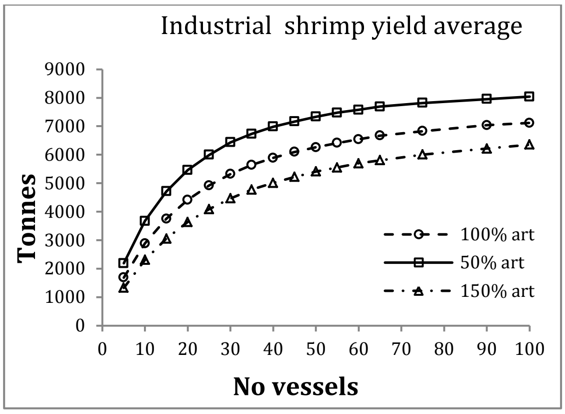


Figure 6.1

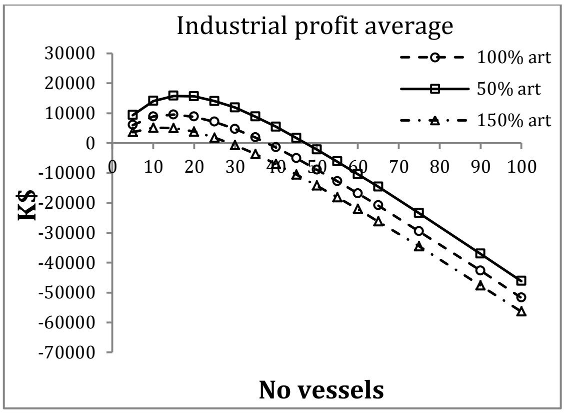


Figure 6.2

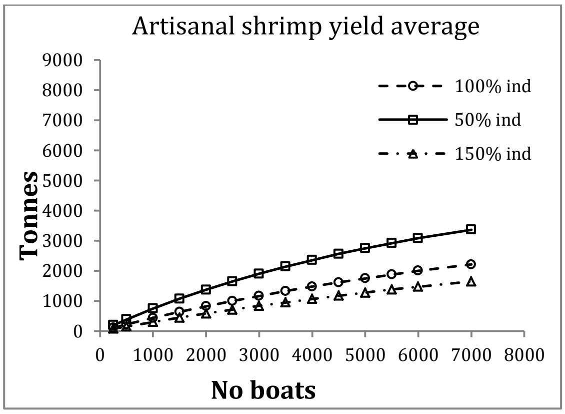


Figure 6.3

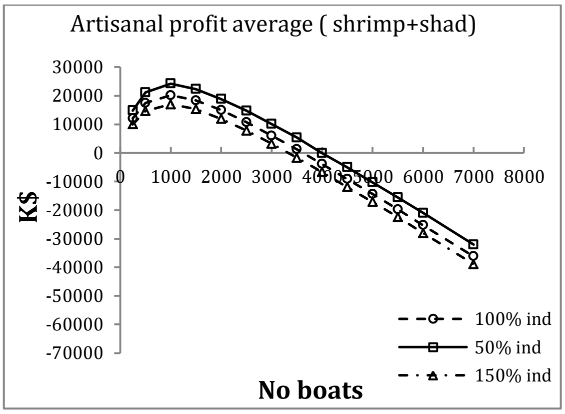


Figure 6.4

Figure 6. Scenario 2

3.3.3. Scenario 3: six months closed season for the industrial fleet, two months for artisanal fleet.

In this scenario, the recommendations of Masquine [23] were taken into account. A closure from September to February for the industrial fleet was established, and for the artisanal fleet from May and June. This author suggested adapting the closures of the artisanal fleet to the rainy seasons, which it would allow for a combination of fishing and agriculture. The industrial yield showed the same pattern as in earlier scenarios, i.e. a monotonically rising curve with increasing the effort. Under the status quo, the yield obtained was close to 5600t, while the artisanal reached 2250t (Figure 7.1 and 7.3), a decrease of 6.5% and an increase of 50% over the base cases, respectively. In this scenario, the industrial fleet shows to be highly unprofitable (deficit close to \$23 million) (Figure 7.2). With a reduction of the effort up to 30 trawlers, the total yield would reduce to 4400t, and the fleet would be close to break-even (deficit of \$1 million). When a reduction of 50% is applied to the small-scale fleet in the background, the total industrial yield gains 1200t, but the fleet is still non-profitable (deficit of \$15 million). The MEY for the industrial fleet is obtained with 12 vessels, a dramatic reduction of the fleet. A total fishing mortality of 0.41month^{-1} is achieved at the status quo, which is a marked reduction, and the CxL in the industrial catches rises 26.0 mm. This is a larger shrimp size in the present model (L_∞= 31 mm CxL), close to the modeled spawning size (L_{50}=26.7 mm CxL). The reduction by 50% of the artisanal fleet would reduce the value of F_{true} to 0.35month^{-1} and the size of shrimp would be 26.2mm, a negligible influence.

When the situation is analyzed from the artisanal perspective, at status quo the fishery showed to be close to a break-even situation, with a deficit of only \$2 million (Figure 7.4). With a small reduction of 300 beach-seines the break-even situation is achieved. This can also be achieved by reduction of the industrial strength by 50%, which would also result in an increase of the artisanal shrimp yield of 800t. The MEY for this fleet is obtained at 1000 beach-seines, a dramatic change. At status quo, the CxL of shrimps caught by the small-scale fleet is 22.8mm. and the length of shad is 11.4 cm TL. In this situation the catches of shad would be situated around 52300t and the by catch by the industrial fleet at 2590t. These are more favorable situations for both fleets.

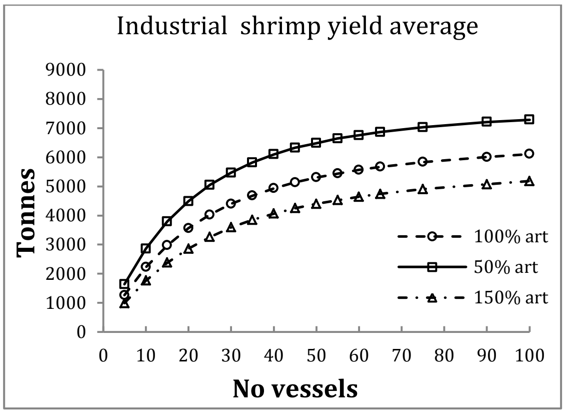
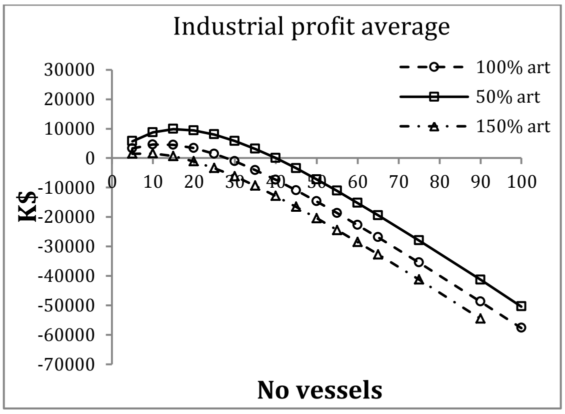


Figure 7.1



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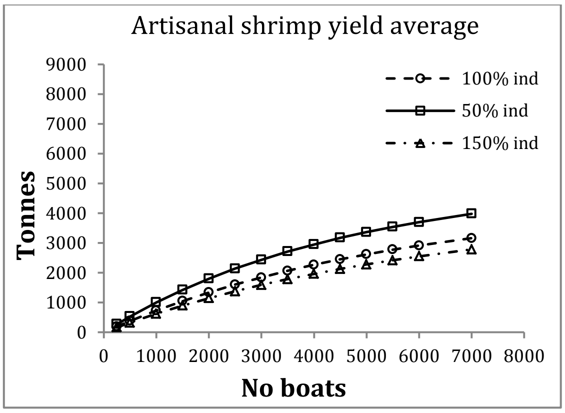

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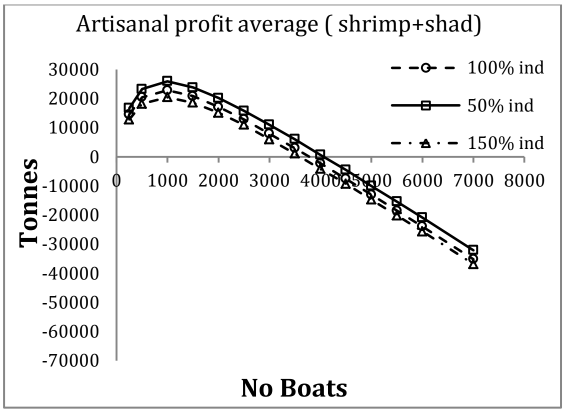


Figure 7.4

Figure 7. Scenario 3

3.3.4. Scenario 4: Six months closed season for the industrial fleet and non-restricted fishery for the artisanal fleet.

This scenario explores the management measures that can realistically be applied to both fleets. Under status quo this scenario penalizes the industrial fleet that sees the shrimp yield reduced to 5000t, but greatly benefit the small-scale fleet, which achieves a shrimp yield of 2800t (Figures 8.1 and 8.3). The industrial fleet becomes highly unprofitable, with a deficit of about $26 million (Figure 8.2). With a reduction of the industrial fleet to 30 vessels it would still remain unprofitable (deficit $4 million), with their total yield reduced by 1100t. The estimated point for a break-even is situated in 21 trawlers, which is a number lower than obtained under previous scenarios. If the artisanal background is reduced by 50%, total industrial yields would increase in 1400t, but the fleet would still remain unprofitable (deficit of $17 million). Under this regime the MEY for the industrial fleet is achieved with 10 vessels, a tremendous reduction in effort. At status quo the total fishing mortality reduces to a reasonable value of 0.43month^{-1}, and the average carapace length increases to 26.3mm CxL in the industrial catches. If a reduction of 50% is imposed on the artisanal fishery background, the F_{true} is further reduced to 0.36 and the average length in the industrial catches increases to 26.5 mm, very close to the maturation size.

From the artisanal fleet point of view the status quo is only slightly unprofitable (deficit $0.5 million) (Figure 8.4). The break-even situation could be achieved reducing less than 100 beach-seines. With a reduction by 50% of the industrial background, the total yield of shrimp obtained by the artisanal could greatly increase to above 3550t. The MEY is achieved at 1000 beach seines, still a drastic reduction of the fleet. At status quo the average size of the shrimps in the beach seines is 23.0mm of carapace length, still far below the maturation size of shrimp and that of the shad is 11.3 cm TL. Under this restrictive scenario for the industrial fishery the annual catches of small pelagics by the small-scale fleet would rise to about 52800t and the by-catch by the industrial fleet decline to 1350t.

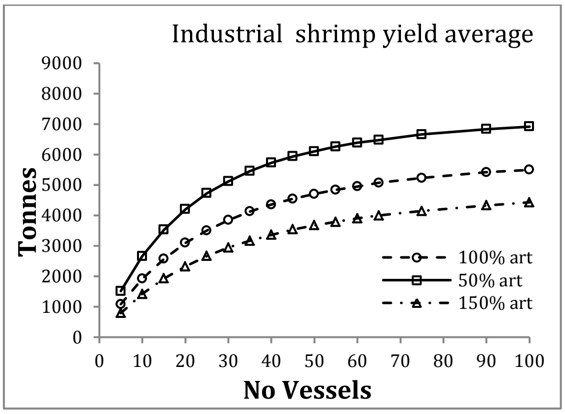
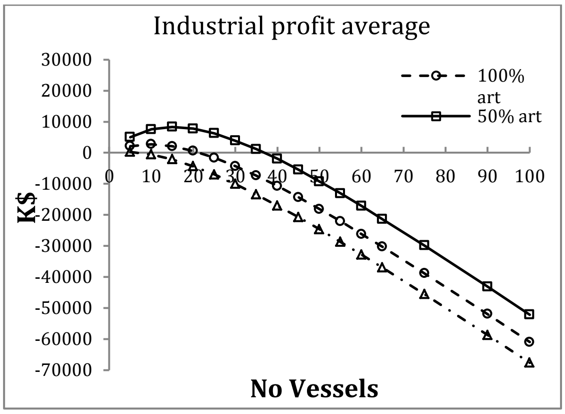


Figure 8.1



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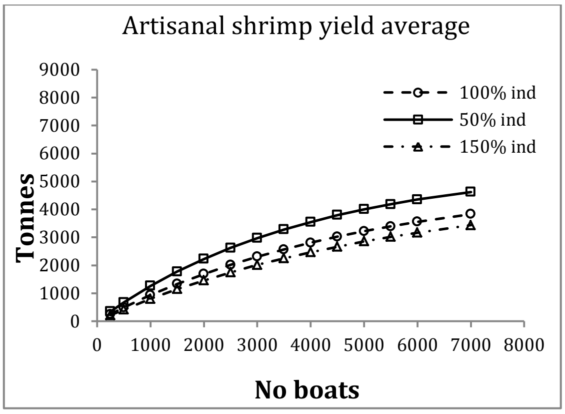

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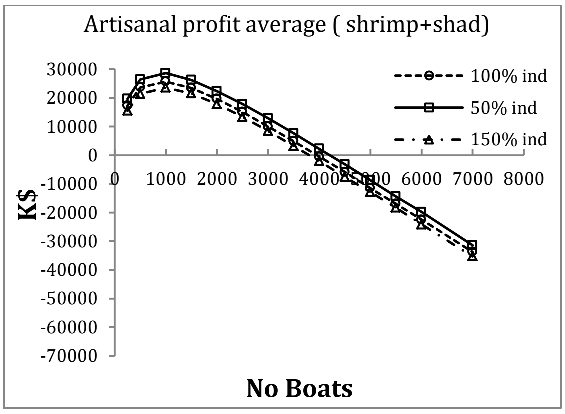


Figure 8.4

Figure 8. Scenario 4

3.3.5. Scenario 5: Closed season of six months for industrial fleet, and one month for artisanal fleet.

The fifth scenario analyzed mimics the current situation in the North Sofala bank, where a closed season from October to March is applied to the industrial fleet and a closure of one month, January, is applied to the artisanal fleet. The yield curve for the industrial fleet follows previous patterns, and status quo the total industrial yield declines to 5200t, with an increase for the artisanal fleet to above 2600t (Figures 9.1 and 9.3). This situation is still highly unprofitable for the industrial fleet (deficit about $24.5 million) (Figure 9.2). A one-sided reduction of industrial effort to 30 vessels would reduce this deficit to an annual average of $3 million in the long run. The yield would also decrease to 4000t. The MEY of the industrial fleet with unchanged artisanal fleet in the background is achieved with 12 trawlers, a drastic reduction once more. At status quo the F_{true} reaches 0.42month^{-1} and the shrimp average CxL is 26.4 mm. If a reduction by 50% in the artisanal background is realized, this would bring the total fishing mortality to 0.36month^{-1}, almost a negligible influence, but the size of shrimp caught by the industrial fleet (26.5 CxL mm) would approach the maturation size in this model.

At status quo the artisanal fleet is close to a break-even situation (deficit $0.3 million) (Figure 9.4). The break-even situation can be achieved with a soft reduction of 100 beach-seines, or bringing down the industrial fleet by 50%, which would result on an increase of catches by the artisanal fleet of 700t. Otherwise, the MEY is achieved at about 1000 beach-seines, a high and drastic reduction of the fleet. At status quo, the average size of shrimps is 23.3mm and the shad is 11.3 cm TL in the catches of the beach-seines. Also in status quo, the catches of small pelagics by the artisanal fleet are 54000t and the by-catch by the industrial fleet is further reduced to 1450t.

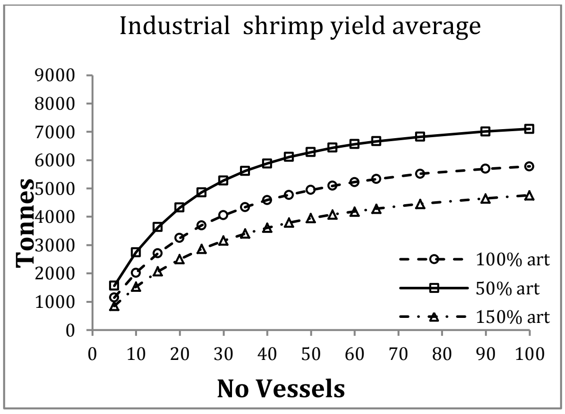
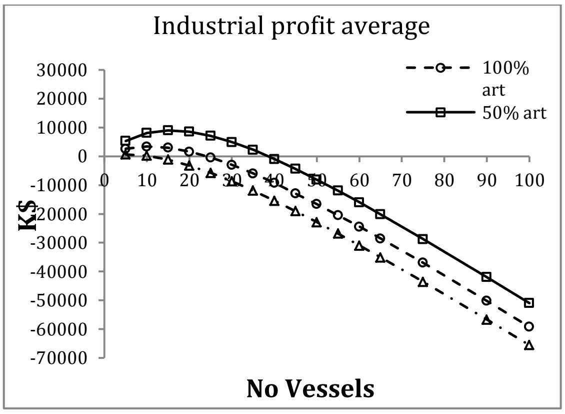


Figure 9.1



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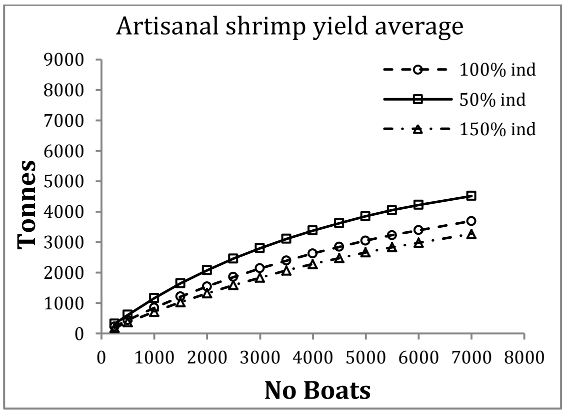

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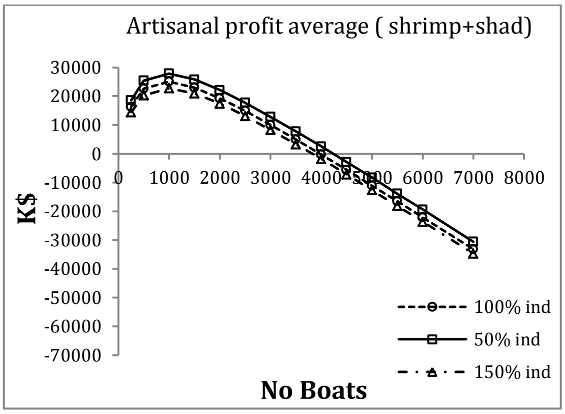


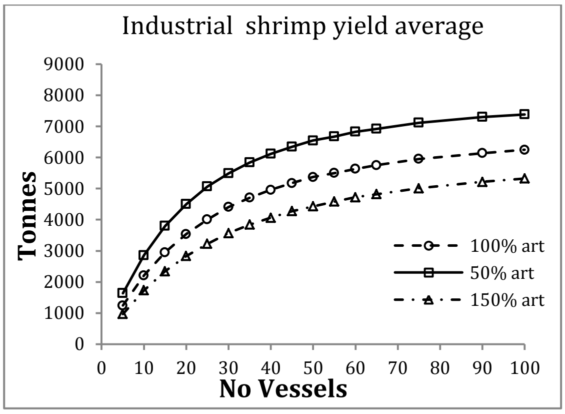
Figure 9.4

Figure 9. Scenario 5

3.3.6. Scenario 6: Closed season of six months for industrial fleet, and two month for artisanal fleet.

The sixth scenario analyzed mimics the current situation in the South Sofala bank, where, in addition to the usual closed season from October to March for the industrial fleet, a closure in January and February is applied to the artisanal fleet. The yield curve for the industrial fleet presents a recurrent pattern, and in status quo the yield achieved by the industrial fleet is above 5600t and that of the artisanal fleet is 2300t (Figures 10.1 and 10.3). With 60 vessels, the industrial fleet is largely unprofitable (deficit close to $22 million) (Figure 10.2); a reduction of 50% of the industrial fleet would reduce the total yield by 1200t, but bring this fleet to an almost break-even situation (deficit $0.7 million). If a reduction by 50% in the artisanal background is implemented the industrial yields increase by 1200t, but would still remain far from profitable (deficit of $14 million). The MEY of the industrial fleet is achieved at 12 vessels, a dramatic reduction of the fleet. At status quo the total fishing mortality is 0.41month^{-1} and the shrimp average length catches by the industrial fleet is 26.4mm. The reduction of 50% in the artisanal background has negligible influence in the (0.35month^{-1}) and average length (26.5) of shrimp.

Despite the imposition of a two month closure, at status quo the small-scale sector is close to a break-even situation (deficit of $0.4 million) (Figure 10.4). The break-even could be achieved with just a reduction of 100 beach-seines, or reducing the industrial strength by 50%. This would boost the yield of the shrimp of the artisanal fleet to 3100t. The MEY is achieved at about 1000 beach-seines, again a drastic reduction, that represents the loss of many jobs associated with the excess of 3000 fishing units. At status quo, the shrimp size is 23.8 mm and the shad 11.6 cm TL in the beach-seines. Also at status quo, the average annual catch of small pelagics is 54400t and the industrial by-catch is 1800t, which are still very favorable situations for both fleets.



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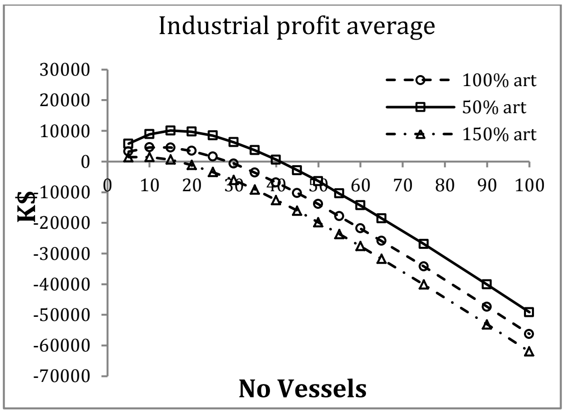

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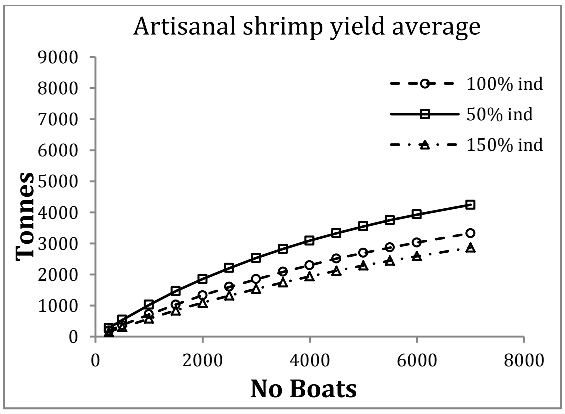

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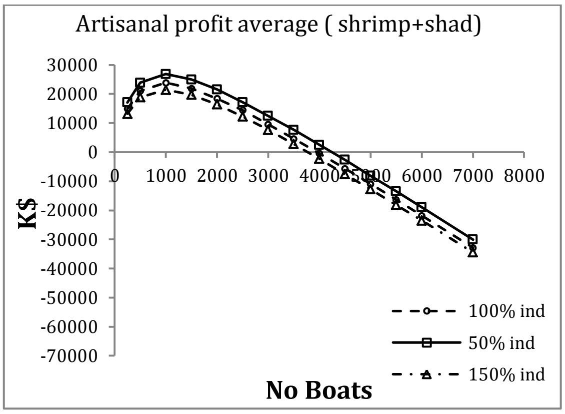

Figure 10.4

Figure 10. scenario 6

4. Discussion

This is one of the first attempts to apply two-fleet two-prey fishery models for management purposes. The model itself is still under development, and there is ample room for improvement. Further modifications of the model aim to achieve higher ecological detail. The present version contemplates, however, a very large spectrum of possibilities with regard to the fish biology and ecology, fleet operation, economics and management measures. This version of model was considered sufficiently flexible to address the main research questions raised with an acceptable degree of detail and robustness. An additional challenge was to populate the model with appropriate statistics and parameters to describe the real situation in the Sofala Bank. Again, the values utilized were those that could be estimated from the literature or Mozambican statistics, and often from very limited field surveys, or otherwise figures that seemed to be appropriate by the authors. A major limitation is the difficulty to simulate fisher's behaviour. For instance, it is a known fact that industrial enterprises in Mozambique tend (or attempt) nowadays to concentrate their fishing effort at the start of the fishing season because of high catch rates. However, it is impossible to say whether that behaviour is a cause for the present closure regulation or a consequence of it. Would fishers still behave like that if the resource was abundant and there were no closures? Considerations of fishers' behaviour are for similar reasons seldom dealt with in system models like the present one, rather investigated in agent-based models.

4.1. Does the original model describe the current situation in a satisfactory way? Do the model result mimic trends observed in the fishery?

As it was stated in the introduction "*the goal of this study is to develop a set of simple and simulation scenarios that can be useful for management orientation. These scenarios should be realistic and investigate conflicts between industrial and small scale fisheries*".

There are only few points of reference to judge whether or not the present simulations have a realistic grounding. An obvious benchmark is the total yield obtained by the two fleets under the different management regimes. The 1st scenario designed to be used as a reference was a non-restricted fishery tries to mimic the situation in the Sofala Bank until the 1990 [9]. The official reports [9] reported an industrial catches of shrimp about 6000 tonnes, while the results obtained in the model for status quo showed a catches identical, about 6000 tonnes.

Reports of catches from the 90's of the small-scale fisheries are inexistent, but this problem it is still present in the last reports [6], where the official information talks about "estimation of catches from the artisanal fleet". With these limitations in mind, and assuming that the reports of industrial catch correspond to their actual catches, it seems that this scenario can be appropriately utilized as a reference.

The 2nd scenario, with a closed season of 3 months mimics the situation from 1990 onwards [9] until the late 2000's. The industrial catches from the official reports showed a range of yields from 6500 to 8500t (1990-2002). The model obtained 6500 for the status quo, but it must be borne in mind that, according to official statistics, 80 industrial vessels were operative on average in that period. The same unresolved situation applies in this period with regard to artisanal statistics. The situation occurring from the late 2000's to the present is probably depicted more approximately in scenario 4, with a 6 months closure for the industrial fleet. This would bring their predicted long-term yield down to about 5000 tons, against the reported 4200 tons in 2011, reflecting the expected trend. So, it seems that in general there is some correspondence between the yields expected from the model and those obtained historically in similar management regimes.

The profitability of the industrial fishery could also be a means to benchmark the model. After all, a capitalized fishery would not tolerate to operate in deficit conditions for a long time, so what we observe in status quo can be an industrial fleet in breakeven conditions, a probable long-term equilibrium. In this sense the model does not seem to perform well as it indicates an industrial fishery in recurrent deficit. At least two reasons can explain this. First, the information about the first-hand prices of shrimp is largely contradictory. Immediately after the western financial crisis in 2008, and partially owing to great competition from aquaculture, the price of Mozambican wild shrimp plunged to about $6 / kg according to many independent sources [44] following the trend in the world markets. This is the kind of price level that was used in the present simulations (although with a correction for shrimp size). But, as late as in 2012 the Institute of Fisheries Research in Mozambique (IIP) was still using a base price of $9 /kg in their bio-economic simulations. This difference alone would bring the profitability curves of the fishery (e.g. Figure 2.2 or 4.2) upwards at status quo by $15 million, which is close to break-even conditions. Secondly, in the present simulation the current street prices for diesel ($1/l) were utilized. The IIP uses instead a price of ($0.75/l) that reflects the fuel exemption given by the State to the industrial fleet. In the present model fuel costs are taken to represent 60% of the variable costs of the trawlers, so that the fuel subsidy decreases total variable costs by 15%. The consequence of this is to push the profitability curves upwards and the MEY point further to the right, towards higher fishing intensity (e.g. more vessels). Lastly, after a lasting shock to the industry the trawler fleet in Mozambique seems to be operating in 2013 with about 30 vessels. This corresponds approximately to the break-even situation predicted in the present model at status quo (Figure 2.2), and gives an indirect indication that the present predictions may indeed be realistic, but more so in the present times than in 2008-2009.

4.2. How do the different management controls in isolation impact on the fisheries?

Sensitivity analyses were utilized to understand the isolated effect of different controls on yield, profit and size of the shrimp on each fleet at the time. The management control that presented a higher impact was the size of shrimp at first catch (L_{50}) for the industrial yield, with a reduction of 25% of the yield when size is increased by 10%. Otherwise, the same control did not affect, or in a very small proportion the artisanal yield. The measure that affected the most the artisanal fisheries was the reduction of the effort, with a 7% decrease in the artisanal yield for a change of -10% in effort. All these trends suggest that at status quo the shrimp fishery is tightly connected between the two fishing fleets. Decrease in fishing pressure in one fleet leads to loss in that fleet, with compensatory gain in the other fleet, a competitive situation. Introduction of simultaneous closures for the two fleets had some expected and some unexpected effects: the average size of shrimp in the catches increased, the yields of the industrial fleet increased, but the yields of the small-fleet decreased. Both fleets became less profitable, and this was particularly evident for the small-scale fleet, if the closure took place in January, which is in their more productive season. Thus, and as expected, the introduction of closures has some biological effects, somewhat more pronounced in January, but its main result is making the fleets less profitable.

4.3. What inaccuracies are brought to the stock assessment if the capture of the artisanal fleet is not taken into account?

4.3.1. Perception by research: Fishing mortality

There are two major reasons to explain the difference between F_{true} from $F_{perceived}$ at any fishing intensity of one of the fleets, with the $F_{perceived}$ overestimating F_{true}. One reason is sampling bias and the other is stochasticity. Estimations of the average F across age groups from industrial catch data alone would in principle correctly provide the full F (small-scale + industrial), but only for the older age groups. The estimates from the industrial data omit the lower F inflicted by the small scale fleet on the younger age groups. Thus, even if the average F_{true} is lower than the $F_{perceived}$ in the older cohorts it applies cumulatively along a longer part of the life-cycle and becomes dominant. Experiments with the model showed that when the small-scale fleet exploits three age groups more than the industrial fleet the cumulative F_{true} is on average 11% larger than the cumulative $F_{perceived}$ from the industrial data; along a full life of a cohort this can lead to a 33% overestimate of the number of survivors in a cohort reaching the last age-group in the fishery (i.e. the sequential fishery). This error affects the data obtained from the industrial fleet, but not so seriously the data from the small-scale fleet, which (in this model) operates un-selectively, catching big and small shrimp. Another consequence of this fishing pattern is that the deviation between $F_{perceived}$ in the industrial data and F_{true} increases with the fishing intensity of the industrial fleet (Figure 1).

The second source of error, which superimposes on the first one, is the error introduced by uncertainty (stochasticity) in the model. In an experiment with model the log-normal nature of the assessment error (CV=10%) alone increased the $F_{perceived}$ by about 4% in relation to the F_{true}. Unlike the first source of error, this over-estimation of $F_{perceived}$ in the data from the small-scale fleet seems to be additive along the range of F_{true} as the two lines run parallel (Figure 2). In conclusion, sampling only the size-composition of shrimp captured by the industrial fleet bias the estimates the fishing mortality. The error induced by sampling the size/age distribution of the industrial catch alone may be partially compensated by the inherent error in assessment, at least in the conditions utilized in the present model. As the sampling bias dominates the error, this calls for good sampling of catches of both fleets. However, the over-estimation of recruit survival in real conditions does not seem to be exceedingly serious.

4.3.2. Perception in size of capture shrimp

The values of sizes presented for the shrimp captures, true and perceived values, showed to be different, although following the same pattern among all the scenarios. There were not changes in the trends described in sizes among scenarios of the industrial fleet and the small-scale fisheries. The difference between perceived and true values at any fishing intensity of one of the fleets it is due to the sampling method used. In fact, the values use for the official assessments are taking only into account the perceived values , that means the data comes only from the catches of the industrial fleet. The trawlers are only exploiting one part of the total stock, it can be said somehow that they are selective, fishing the bigger shrimps of the stock; meanwhile, the small-scale fisheries are not selective, and therefore are catching any size of shrimp. Therefore, this difference is depicted in the appendix I-XII, where the perceived size trends present higher values than the true size trends. In conclusion, using the average size of the shrimp from the catches of the industrial fleet (perceived sizes) as indicator of the state of the stock can be slightly bias, because the size of the stock is declining faster what it is observed in the catches of the true values, but they don't see to be extremely differences (average of 7mm CxL for industrial fleet and 6mm for the small-scale fisheries). That would bring inaccuracies to the stock assessment. One possible point of concern is that the industrial trawlers, being more selective and mobile, can be un-proportionally targeting the females, which grow faster and larger and are, thereby, more valuable. This means that an increased fishing mortality may deplete faster the spawning stock by two processes: selective catch of faster growing females at the beginning of the season, closer to shore, and selective search for large shrimp (females) offshore later in the season. The present model is too coarse to investigate the consequences of these patterns.

4.4. Are the same controls / technical measures justified for both fleets?

Analysing the overall of all the scenarios, at the status quo, the industrial fleet is never profitable, and with a large deficit. Even reducing by 50% the artisanal background, still keeps under deficit. Four out of six scenarios for the small-scale fisheries present at status quo fisheries close to a break-even situation or with profits, and when the background is reduced by 50%, these artisanal scenarios become in profits. Interestingly, and despite the coarseness of the model, the present simulations repeatedly suggest that the best overall economic efficiency can be achieved by regulating (decommissioning) strongly the industrial fleet. At lower levels of effort than status quo the small-scale fleet, despite its primitive character, could become very profitable, and compensate for the lost profit in the industrial fleet. At present, however, the fisheries are working for different targets: the artisanal is mostly a subsistence fishery (although it seems that for the last years the increase in catches would mean that there is a market for them), and the industrial is exportation-oriented market.

4.5. Which management measure has more impact on the fishery in a sector–wide approach?

All this different scenarios, working with closed seasons as a main management control measure, are pulling towards a reduction in the effort, since the results have shown that the fishery is not profitable for the industrial in the levels that is working now. The results obtained can be perceived as expected, since the reports from the last years [7, 8, 9 and 10] showed a tendency to decrease inside the industrial fleet, but it is still complicated to give a proper assessment due to the lack of official information to introduce the proper values in the model. The change in the management strategy from scenario to scenario (different closed seasons) does not result in large differences among them, but in terms of protection of stock (mortality levels) has a large influence and it must be considered if that is the target (biological approach). Reduction of effort in the both fleets will produce an increase in profits, therefore in economic terms. But, dramatic reductions in the industrial fleet must just to get a break-even situation, and in both fleets to achieved maximum economic yield. As mentioned above, this may not be an interesting objective for the small-scale fleet.

4.6. How would the small-scale fisheries benefit from a reduction in the by-catch of the industrial fleet?

In general lines, there is a direct relation between the increase of shad yields and management measures reducing the activity of the industrial fleet. The scenarios applying closed seasons depicted in average a 10% more of yield in the artisanal catches of shad than in the 1st scenario, and therefore a higher profit. Always that the industrial fleet is reduced somehow (fleet number or background), the yields for the artisanal shad catches increase and consequently also decreases the by-catch of the industrial. But the shad does not represent all the species of fish that can be found in the by-catch and in the gears of the small-scale fisheries. The other species presents higher commercial values than the shad, and there it is where the importance of the by-catch in terms of profit for the artisanal can make the difference. The model does not contemplate these other species inside the parameters mostly because there is a lack of biological information of them, but there is more information about the shad. The aim of the model is to mimic the fishery in an easy way, trying to do not get really complex and with the inclusion of these other fishes in the model, it should be included also trophic chains, due to some of these species use the shad as feeding, and therefore the model would acquire a complexity far from what it is intended in the development of this model. For that reason, this study did not study in a deep way the shad situation.

5. Conclusions

- The shrimp fishery in the Sofala bank offers a general and interesting case-study of physical interactions between two fleets. A model was utilized to develop scenarios similar to the real fishery, with a reasonable accuracy, despite some uncertainty about prices and costs in the real fishery. Therefore an update of parameters may be required, to represent the real situation in Sofala.
- The fishing mortality and average size of shrimp perceived by research in the industrial fishery alone are somewhat, but not dramatically, biased. Researchers must be careful and check what it is happening in terms of shrimp size in the artisanal as well to perform adequate assessments of the state of the stocks.
- There is a direct competition between fleets: when effort is reduced in one fleet, the other fleet obtains improved yield and profit. It is, thus, inappropriate to manage the fleets separately. The fleets serve different people, markets and objectives. This can be taken account in a preliminary design of management measures to the two fleets.
- The timing and extension of the closed seasons, a preferred technical measured in Sofala, influences the levels of yields and profits. Closed seasons can be adapted separately for each fleet and goal.
- All the scenarios indicated that in order to maximize yield and profit in the whole fishery in the long term, a strong reduction of fishing effort, must be realized in the industrial fleet. The costs of decommissioning a great part of the fleet must be analyzed, and can be introduced in a model of this type.
- Seasonal closures achieve different levels of protection of the stock, but probably do not address the economic problem of an oversized industrial fleet.

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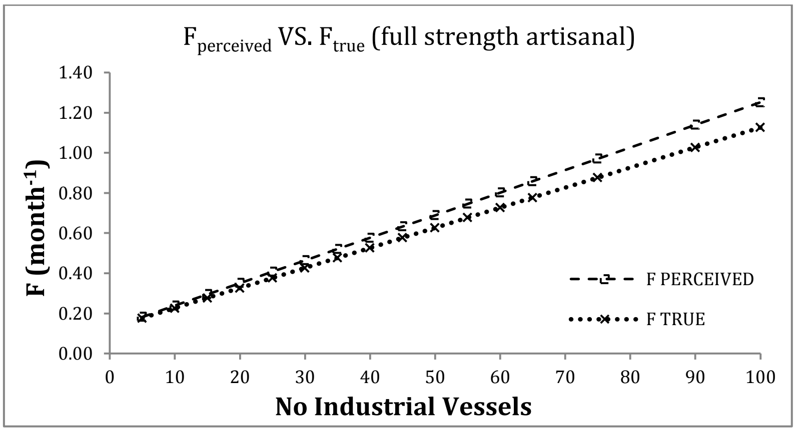
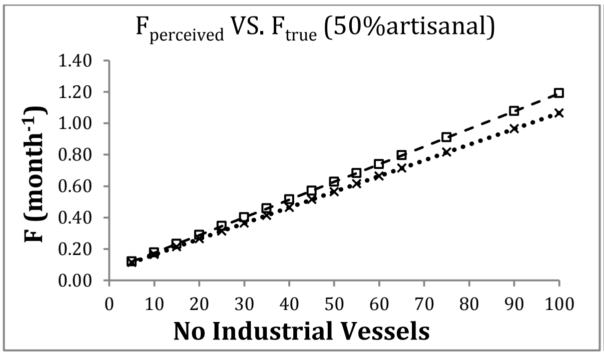
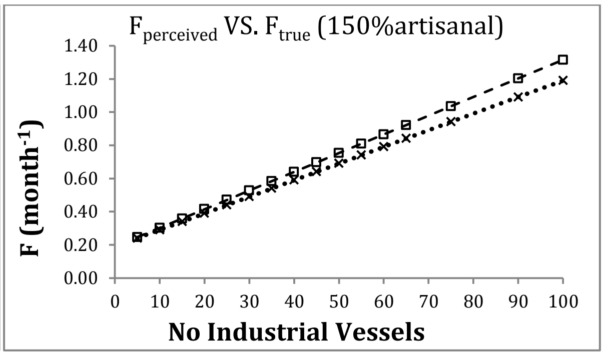
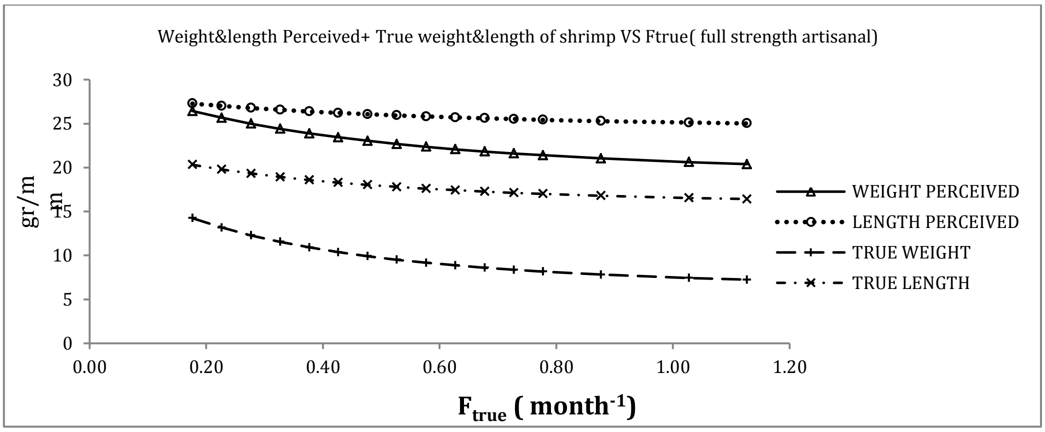
Appendix

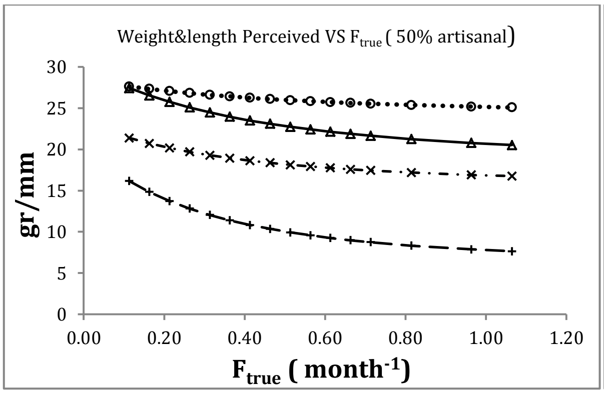
Scenario 1: Non-restricted fishery. INDUSTRIAL

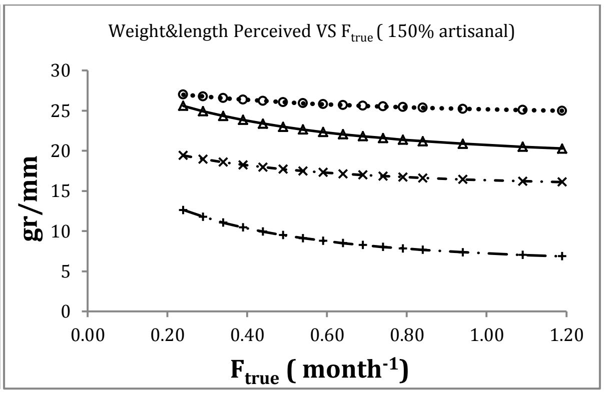




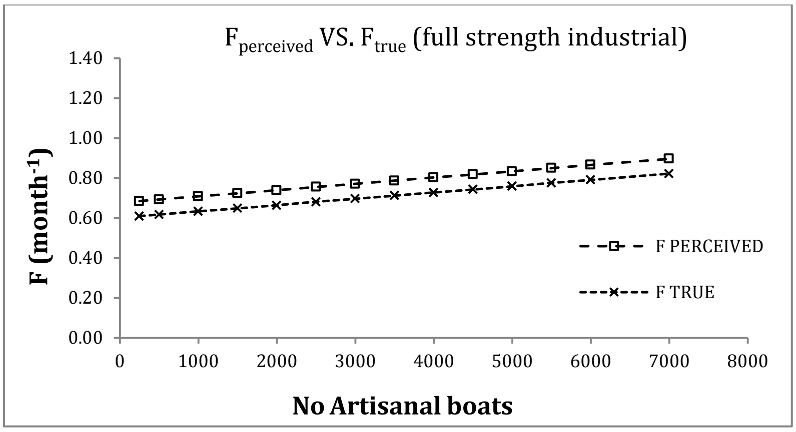


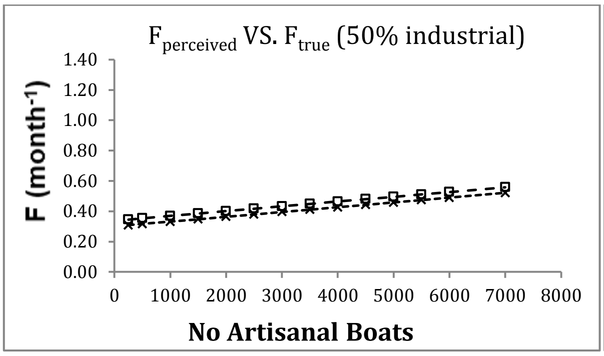


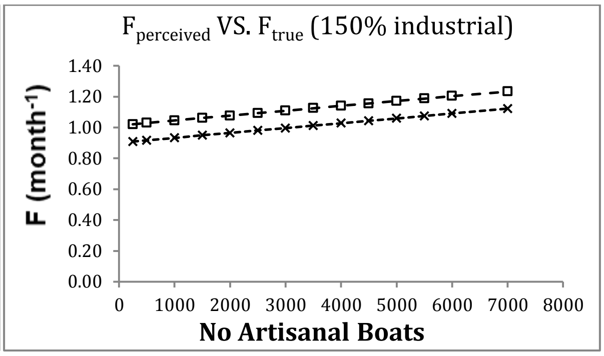


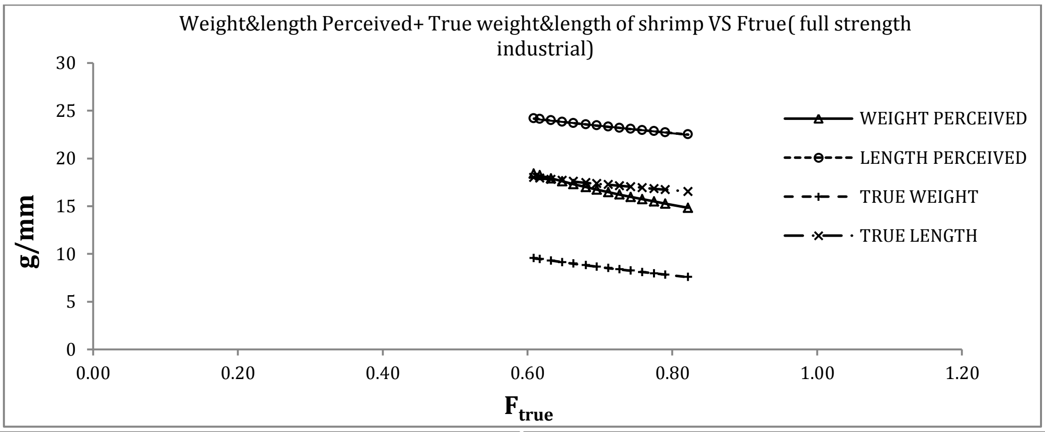


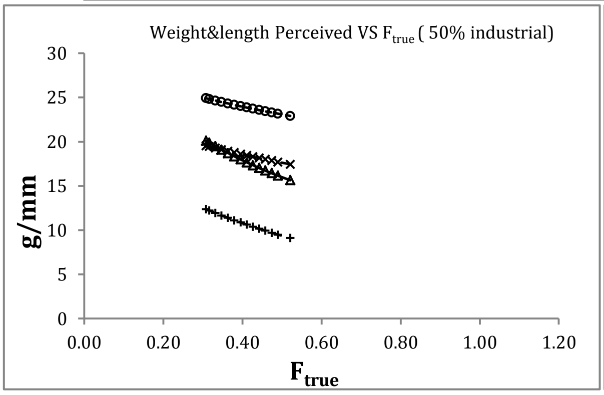
Scenario 1: Non-restricted fishery. ARTISANAL

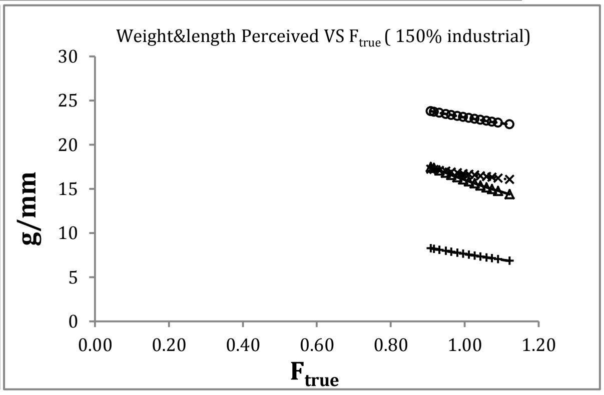




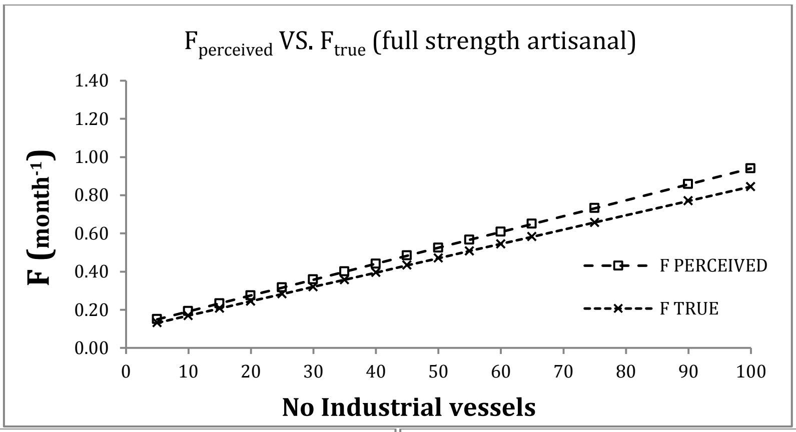


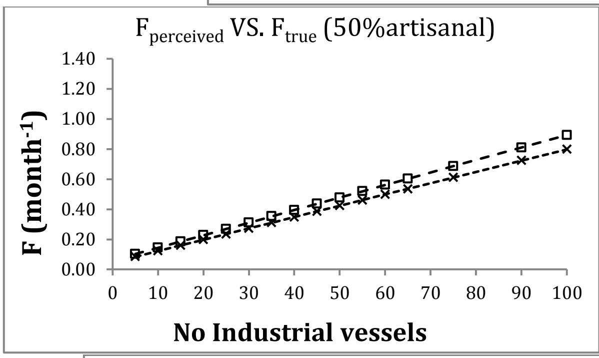


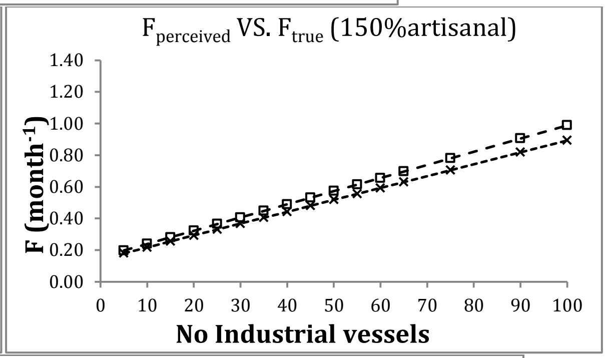


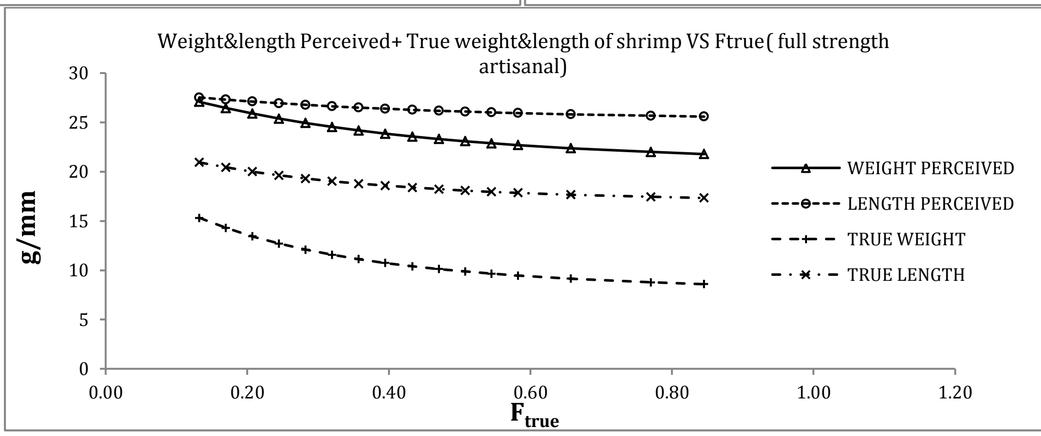


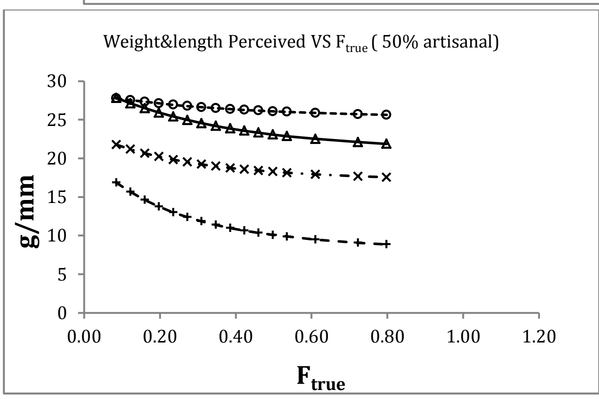
Scenario 2: Closed season of 3 months for both fleets. INDUSTRIAL

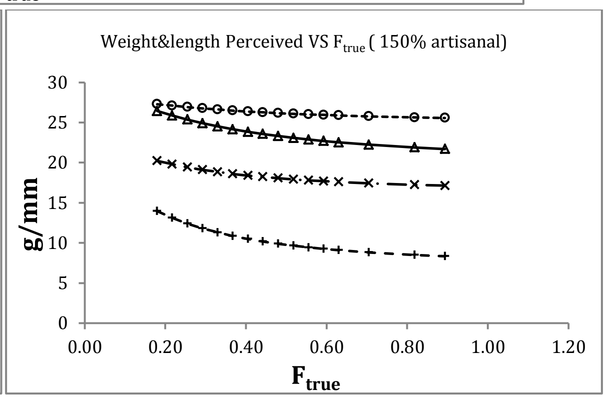




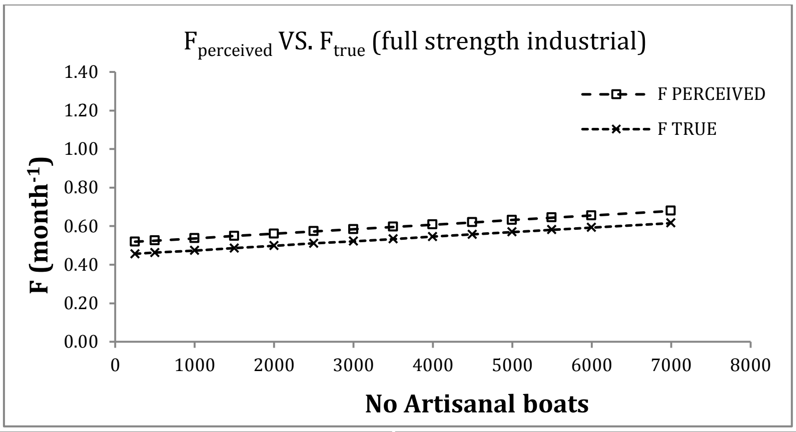


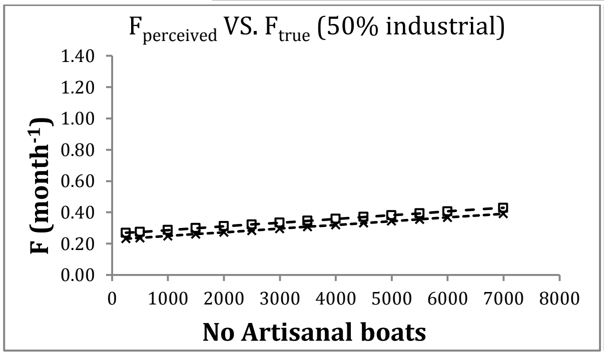


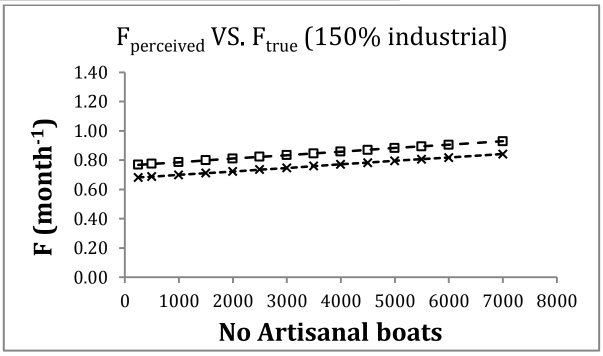


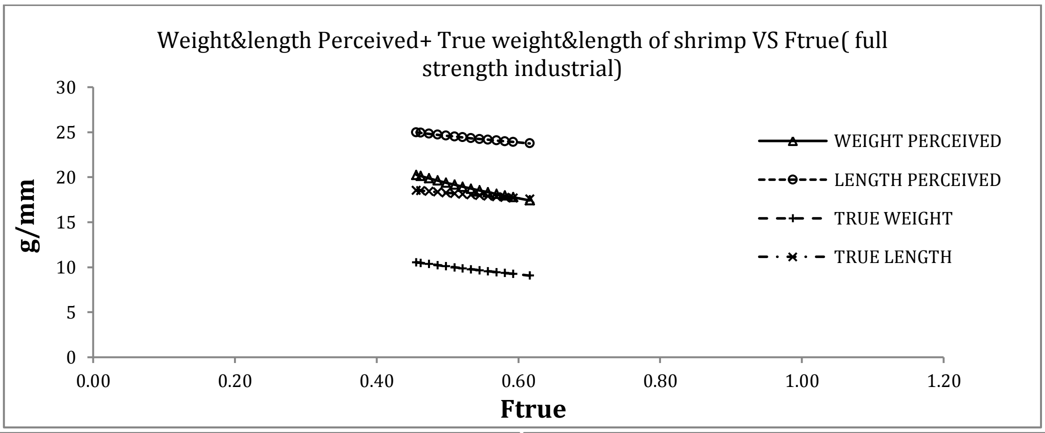


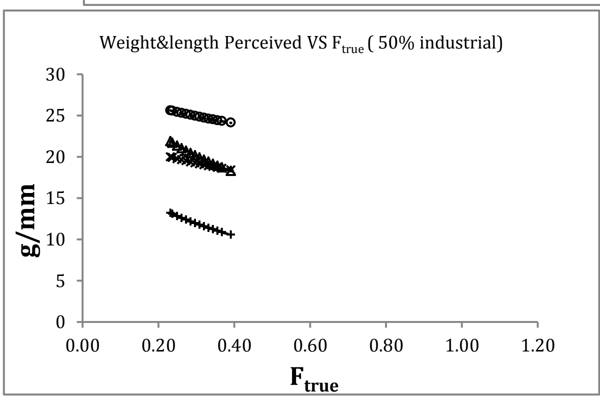
Scenario 2: Closed season of 3 months for both fleets ARTISANAL

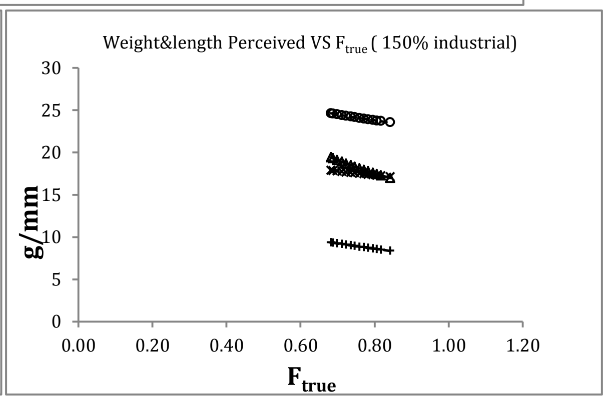




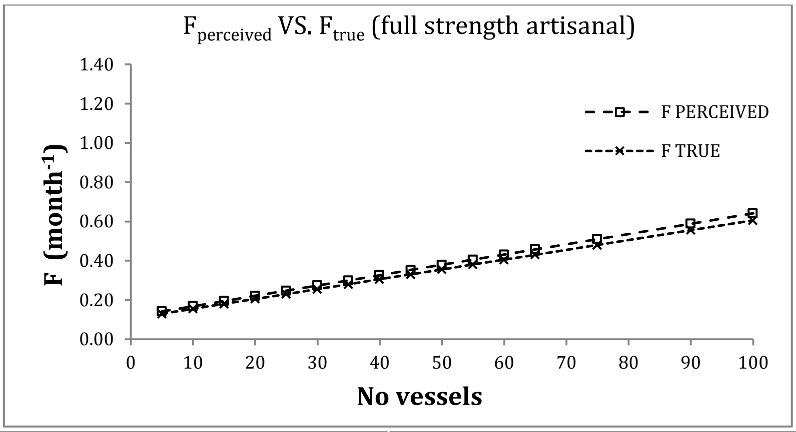


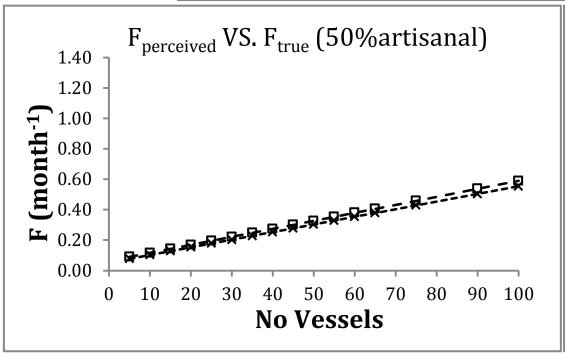


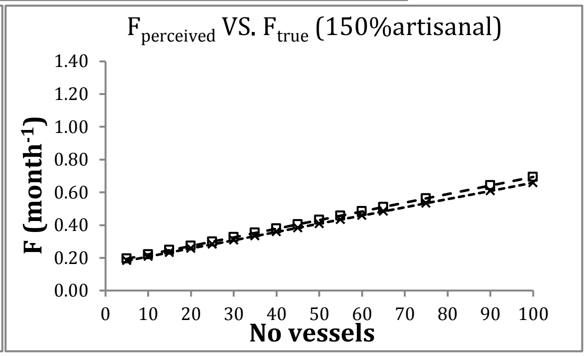


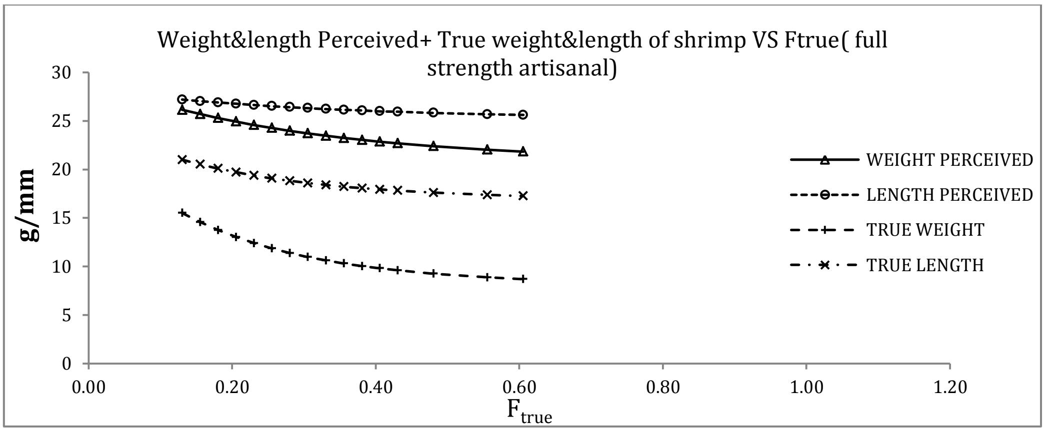


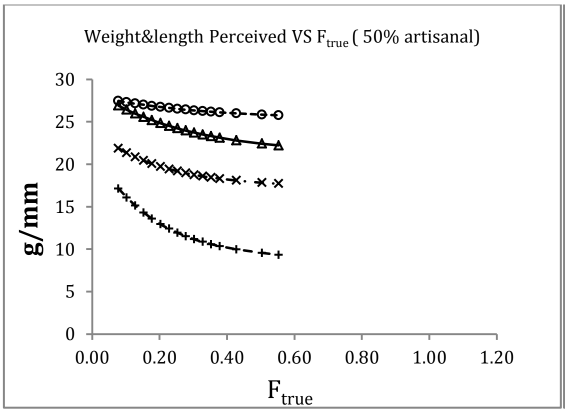
Scenario 3: Masquine assumption. Six months closed season industrial (Sep-Feb), two months closed season artisanal (May-June). INDUSTRIAL

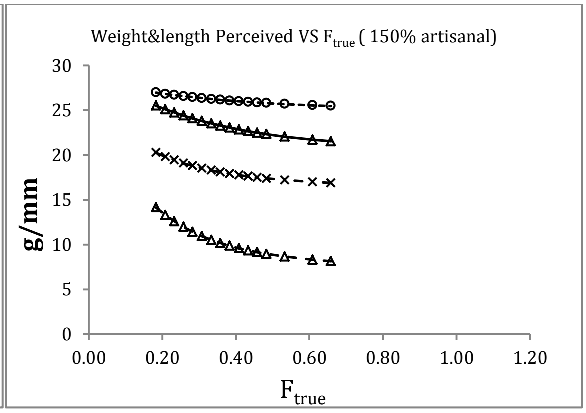




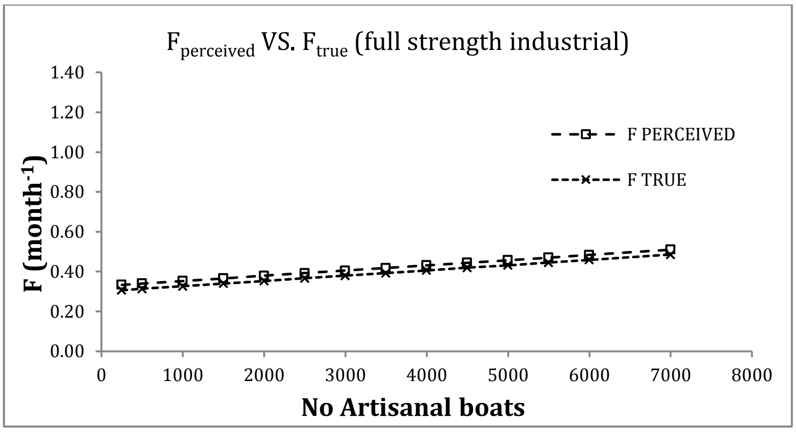


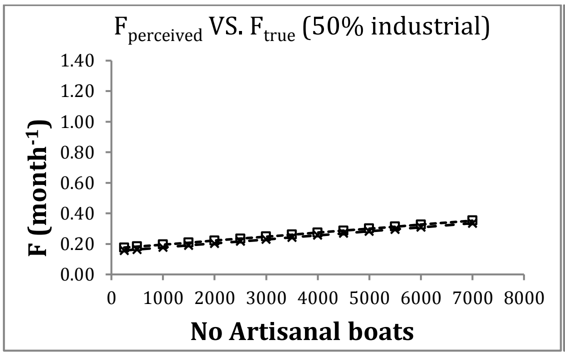


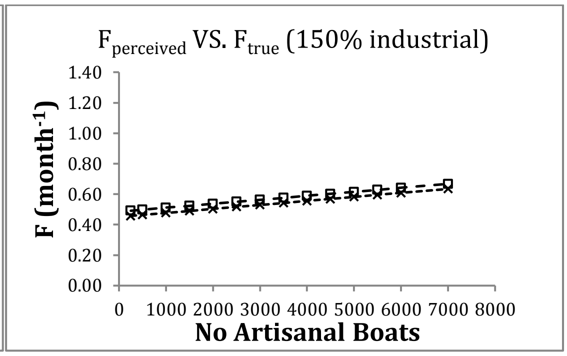


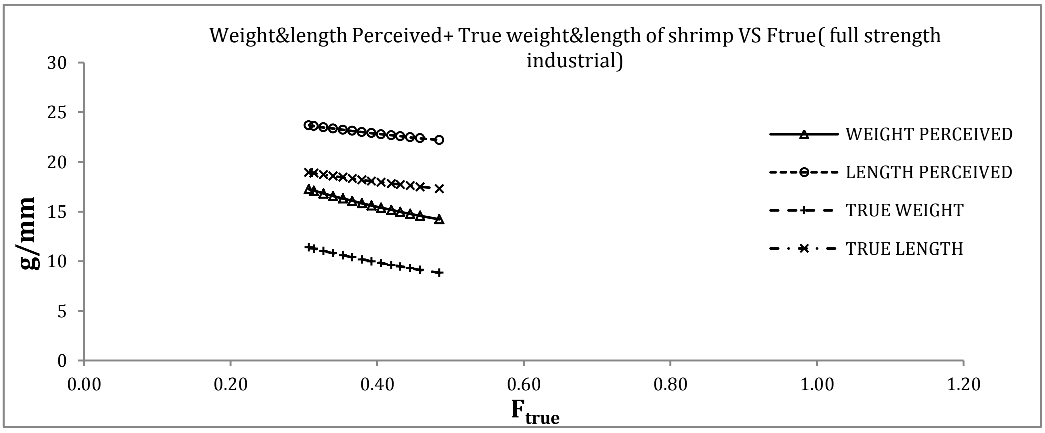


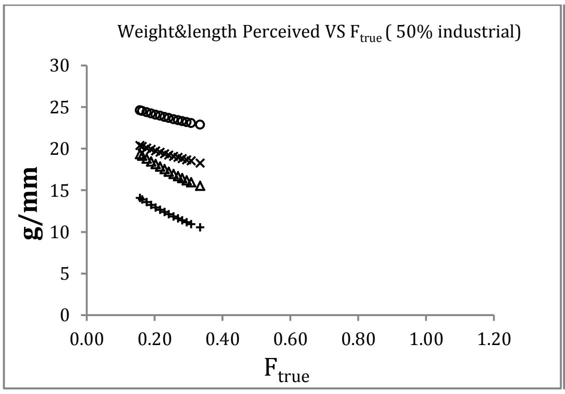
Scenario 3: Masquine assumption. Six months closed season industrial (Sep-Feb), two months closed season artisanal (May-June). ARTISANAL

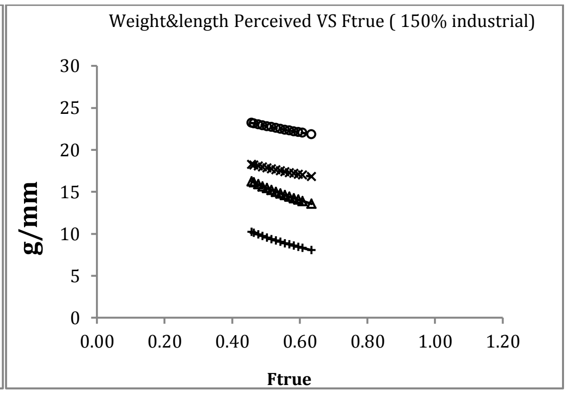




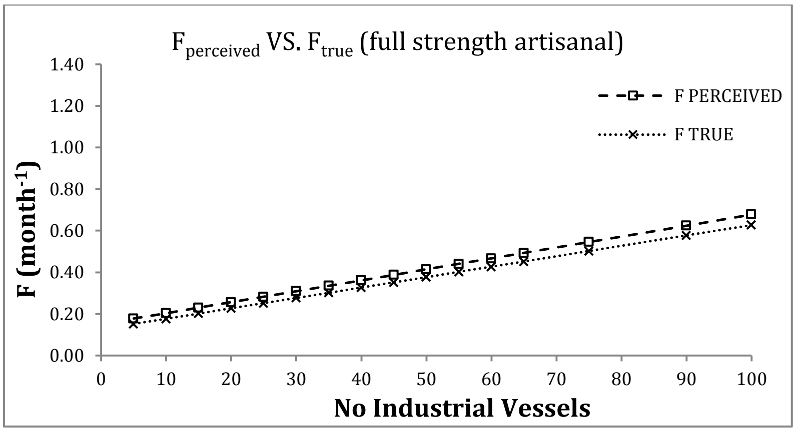


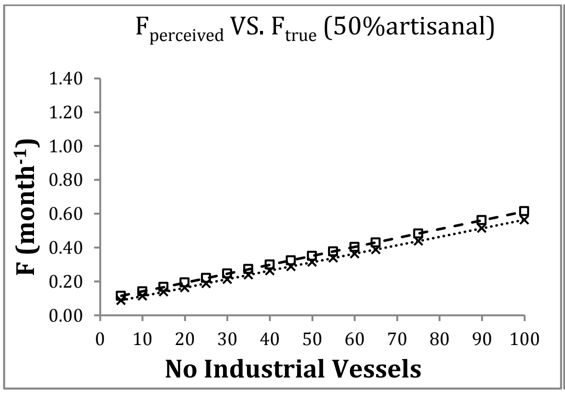


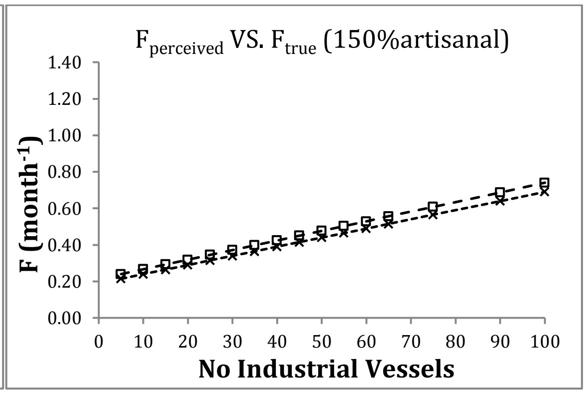


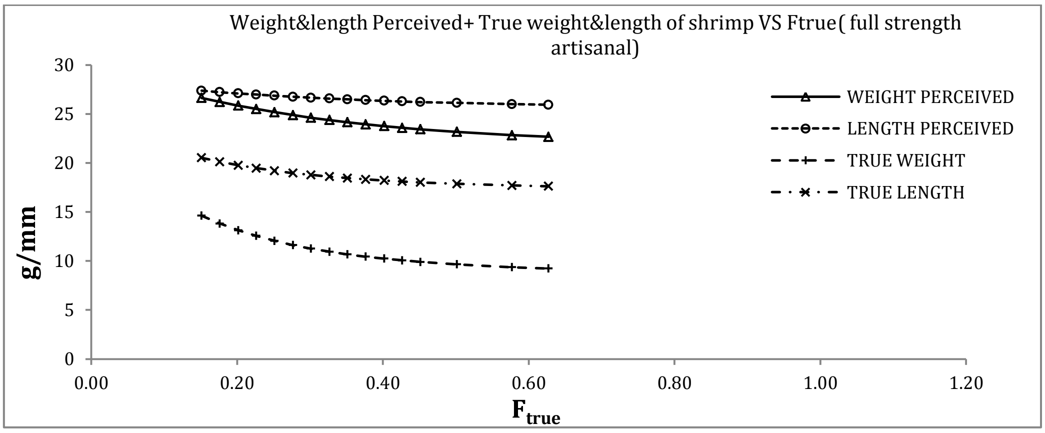


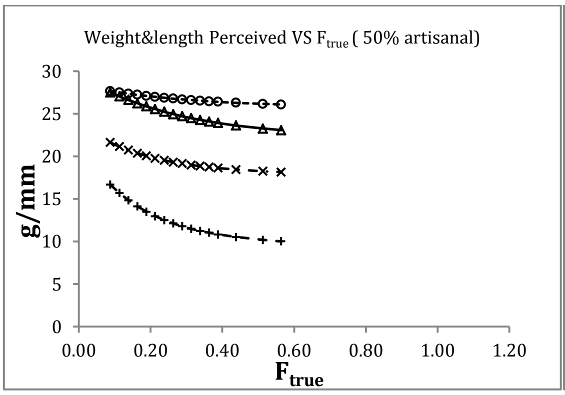
Scenario 4: six months closed season for industrial fleet. Non-restrictive fishery for artisanal fleet. INDUSTRIAL

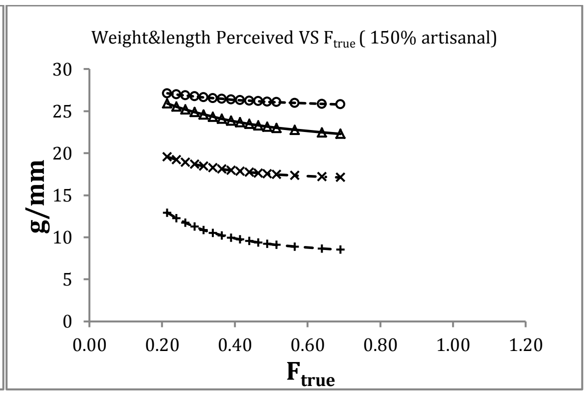




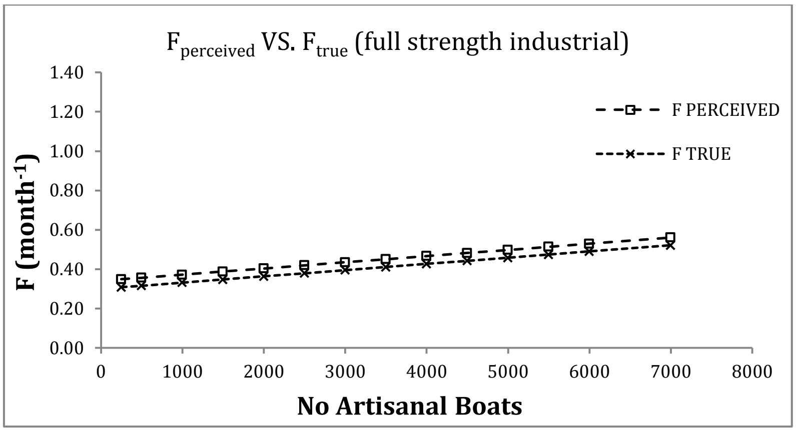


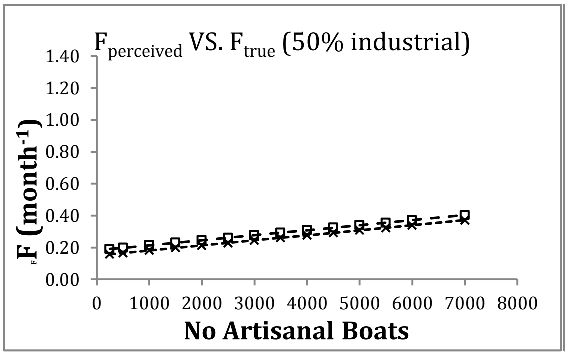


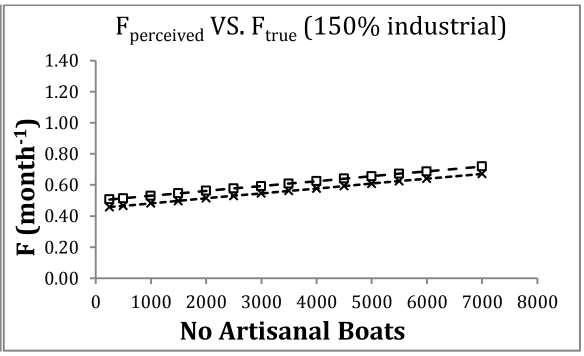


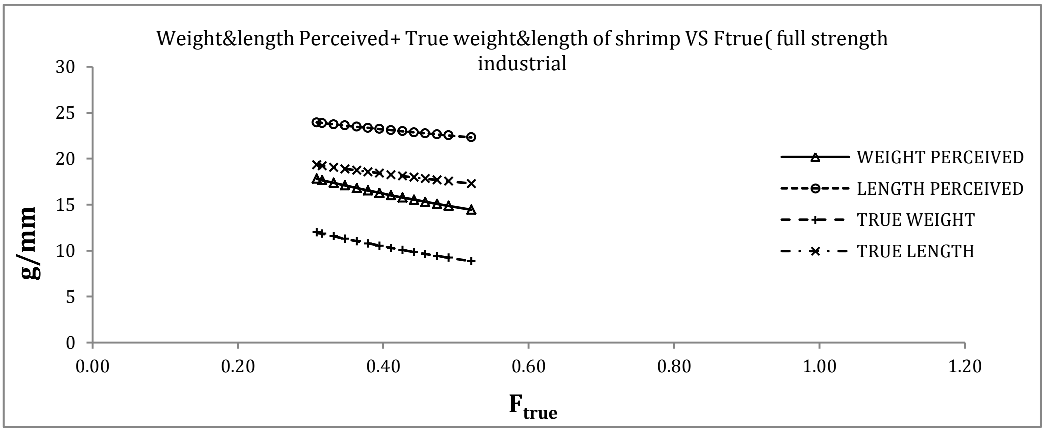


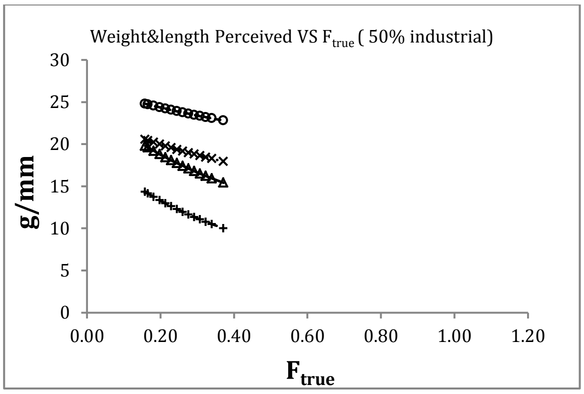
Scenario 4: six months closed season for industrial fleet. Non-restrictive fishery for artisanal fleet. ARTISANAL

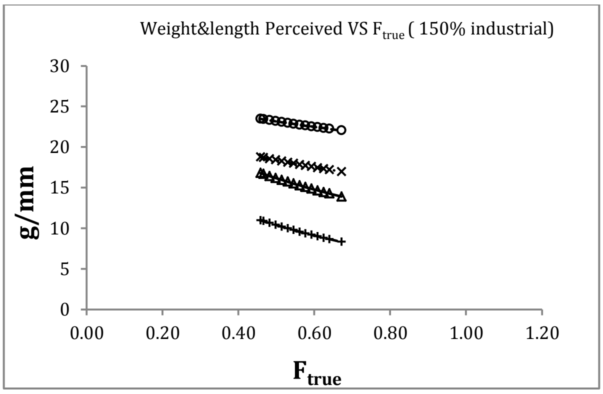




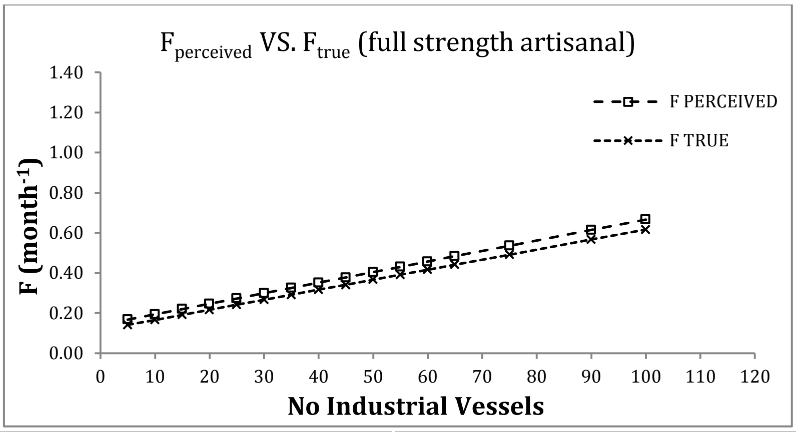


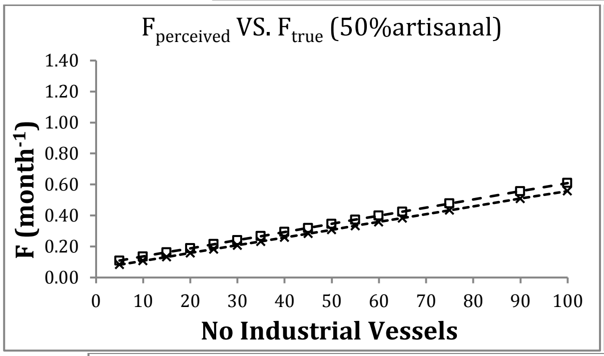


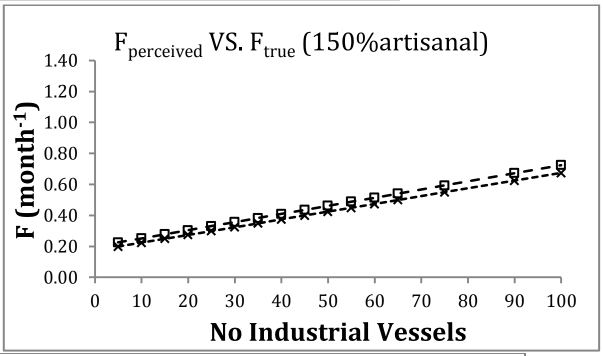


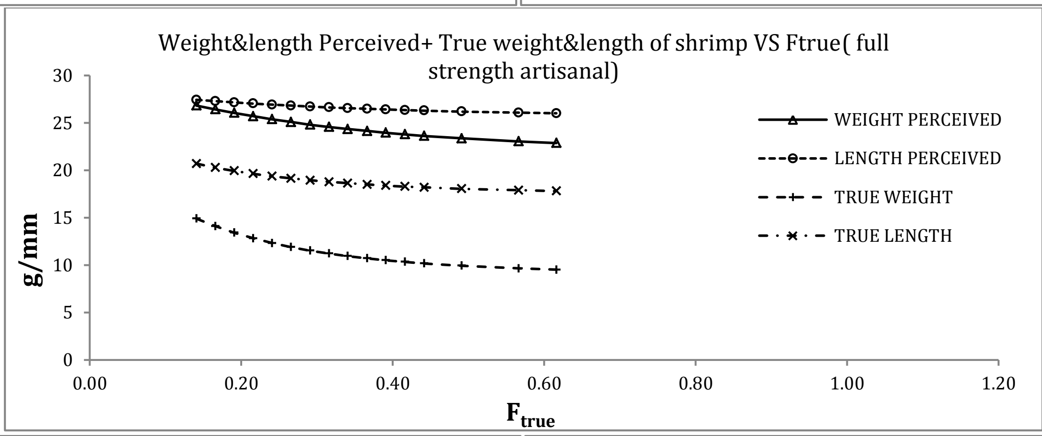


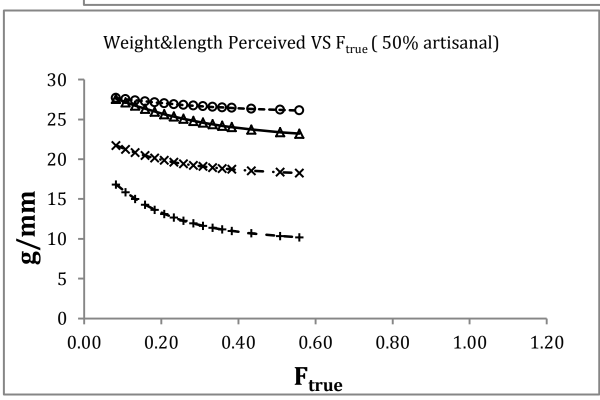
Scenario 5: Closed season of six months (Oct - Mar) for the industrial fleet, and one month closure for the artisanal (Jan). INDUSTRIAL

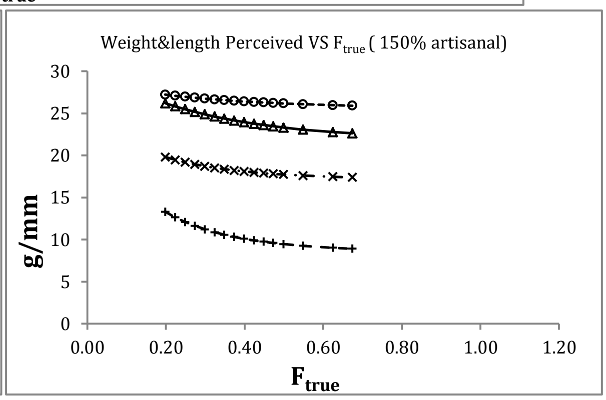




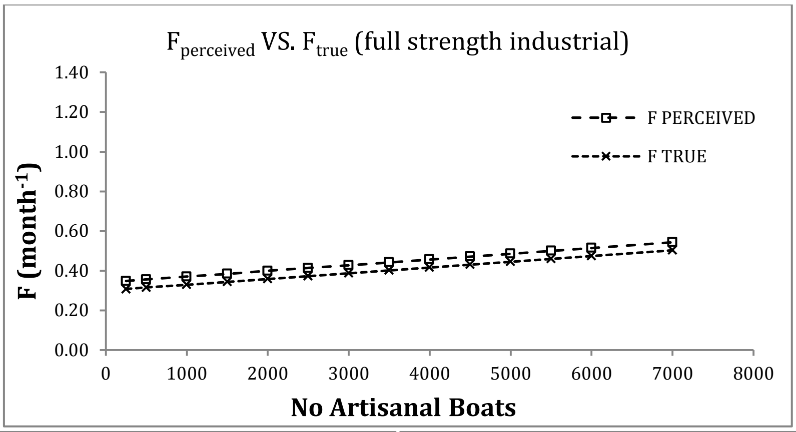


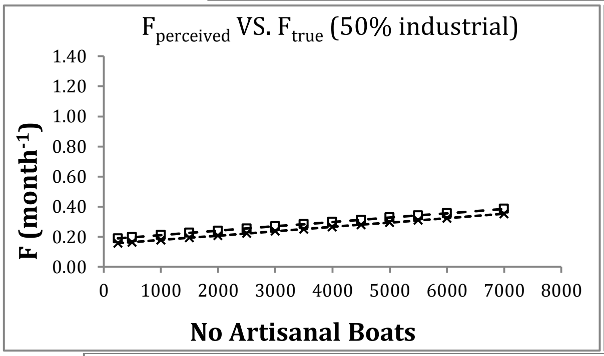


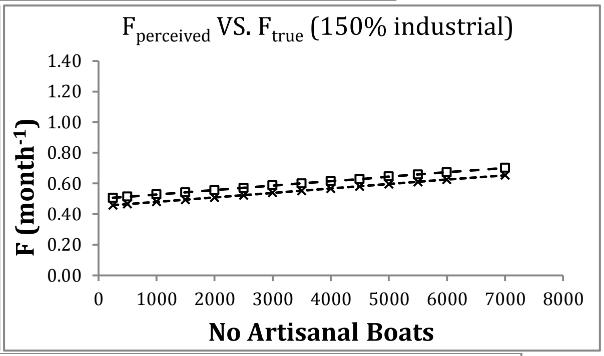


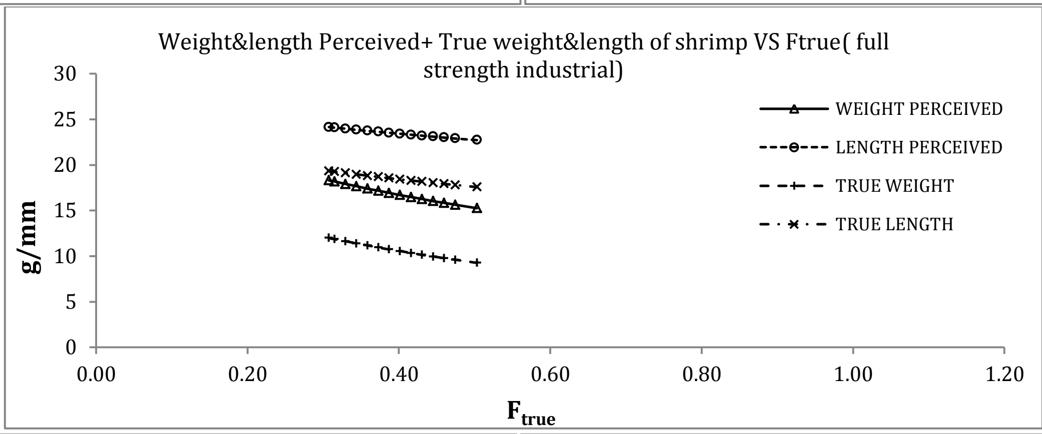


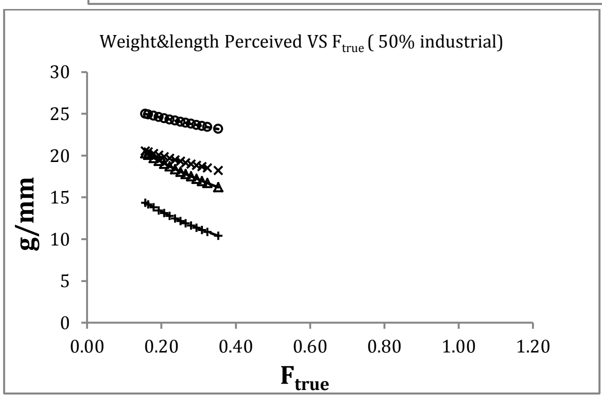
Scenario 5: Closed season of six months (Oct - Mar) for the industrial fleet, and one month closure for the artisanal (Jan). ARTISANAL

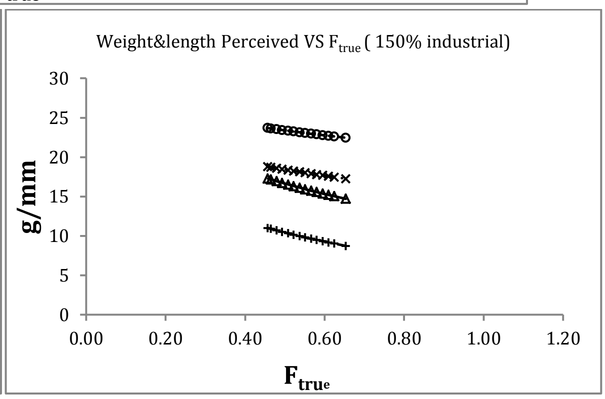




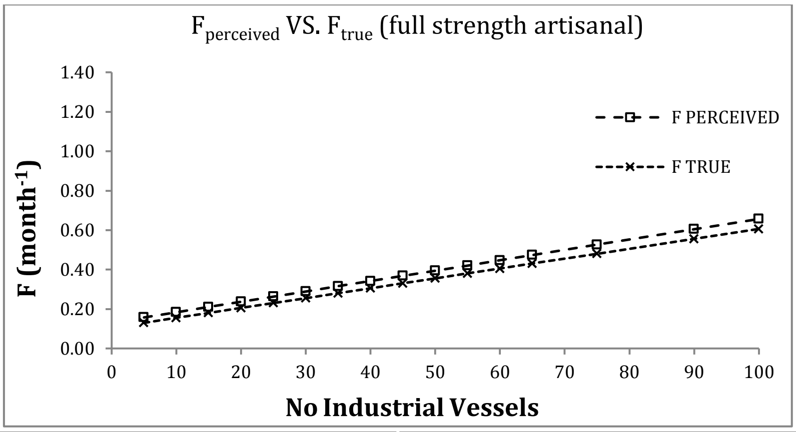


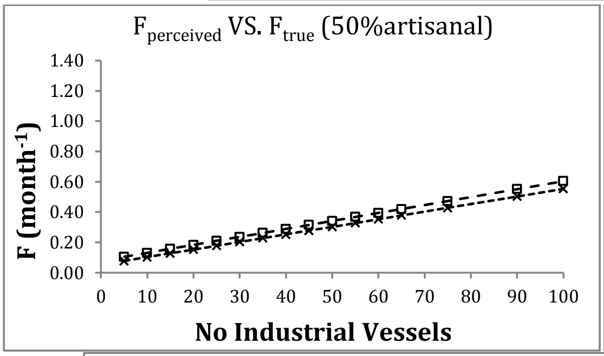


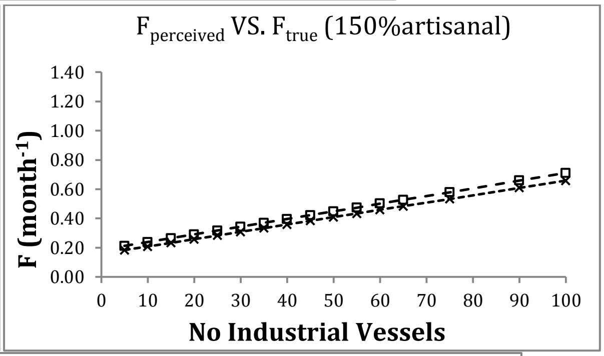


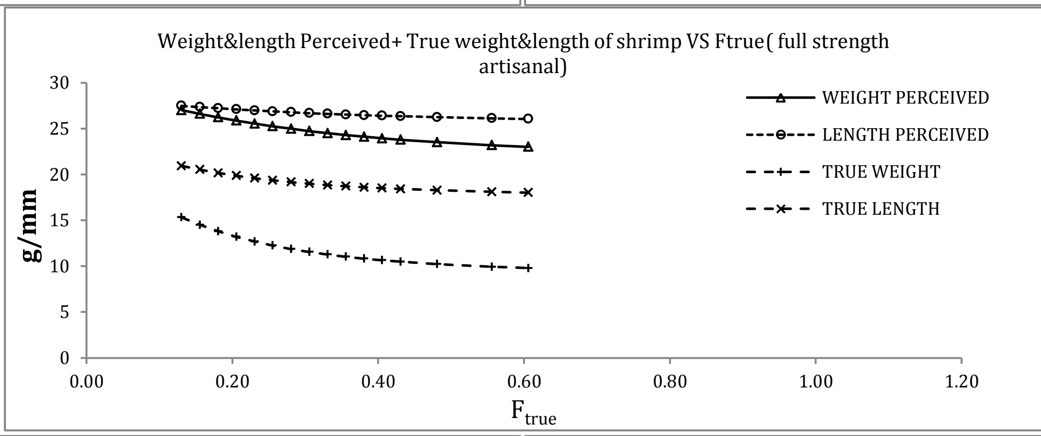


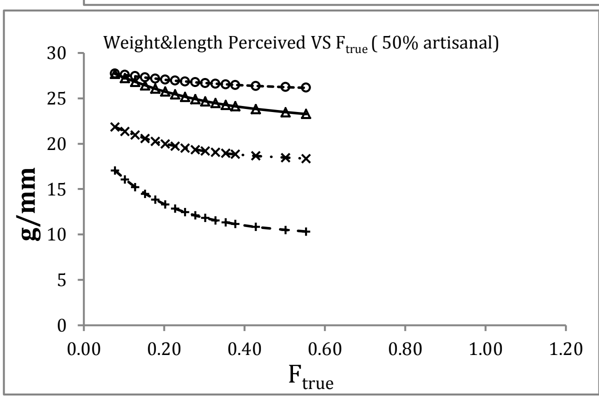
Scenario 6: Closed season of six months (Oct - Mar) for the industrial fleet, and two months closure for the artisanal (Jan-Feb). INDUSTRIAL

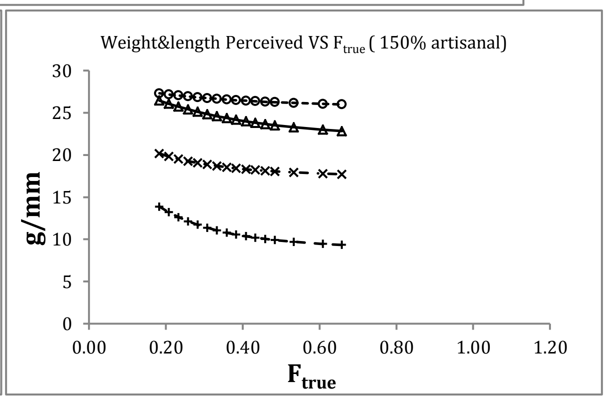




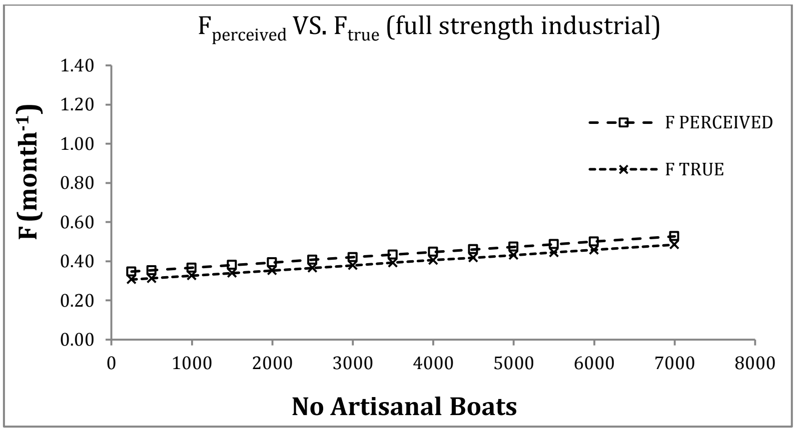


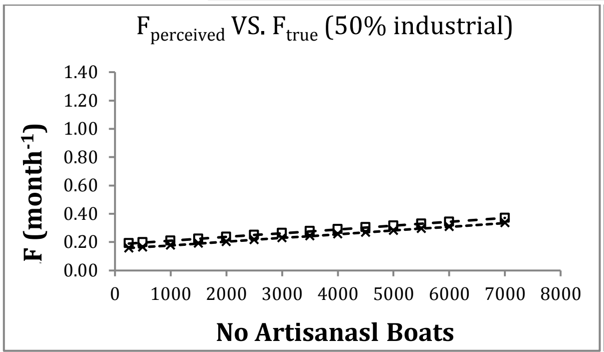


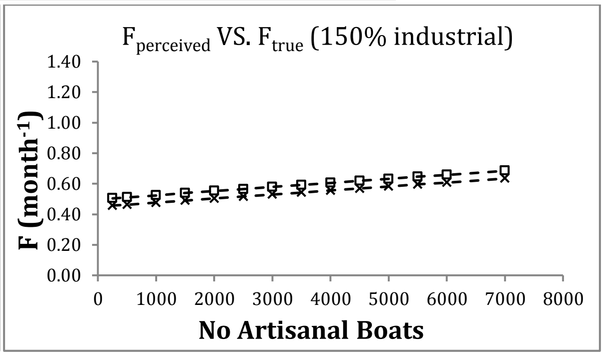


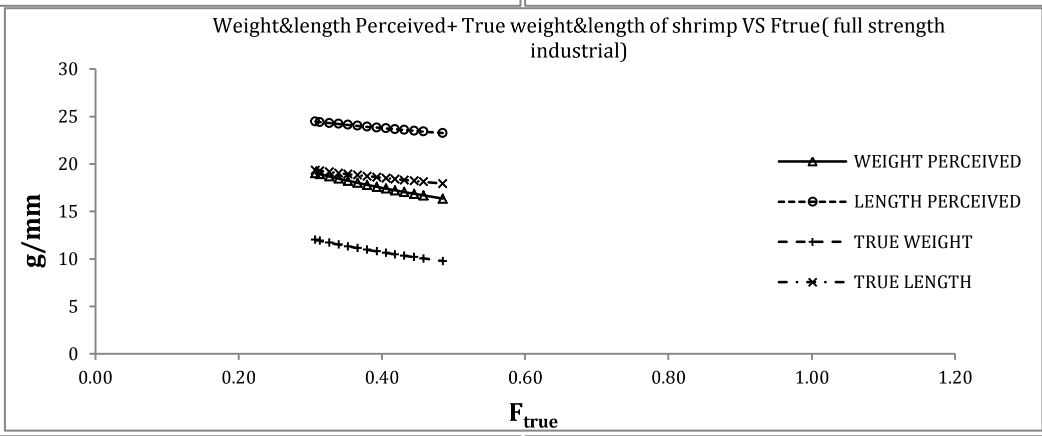


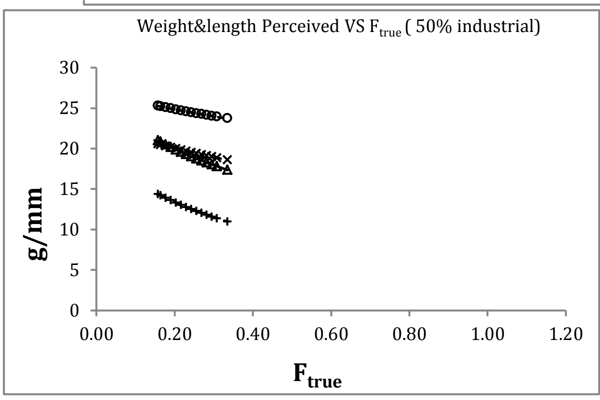
Scenario 6: Closed season of six months (Oct - Mar) for the industrial fleet, and two months closure for the artisanal (Jan-Feb). ARTISANAL











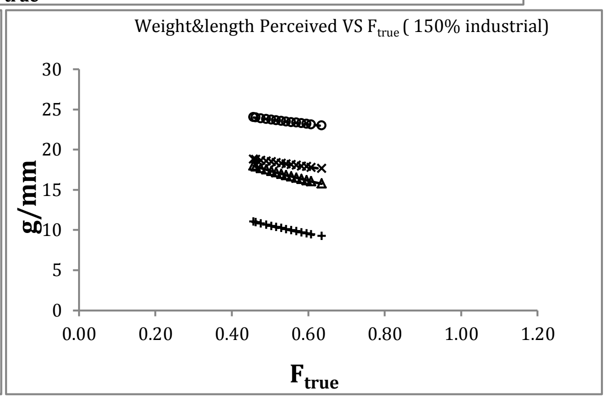


Table 1: 1st scenario values obtained at status quo of both fleets at different levels of background strengths.

	YIELD(t)	PROFIT($K)	MEY (vessels)	F_{TRUE} (month^{-1})	SHRIMP LENGTH(mm)	SHAD YIELD(t)	BY-CATCH (t)
				INDUSTRIAL			
50%	7330	-12680	17	0.66	25.62	46700	6300
100%	5968	-20966	12	0.73	25.52	48150	3315
150%	4896	-27459	10	0.79	25.43	48100	2240
				ARTISANAL			
50%	2443	-1973	1000	0.43	23.72	51800	1700
100%	1515	-6687	1000	0.73	23.19	48150	3315
150%	1096	-10079	1000	1.03	22.90	45000	4800

Table 2: 2nd scenario values obtained at status quo of both fleets at different levels of background strengths.

	YIELD(t)	PROFIT($K)	MEY (vessels)	F_{TRUE} (month^{-1})	SHRIMP LENGTH(mm)	SHAD YIELD(t)	BY-CATCH (t)
				INDUSTRIAL			
50%	7574	-10425	17	0.50	26.09	47800	6000
100%	6542	-16832	15	0.55	26.01	51500	3270
150%	5699	-22039	11	0.59	25.94	52100	2220
				ARTISANAL			
50%	2357	-93	1300	0.32	24.72	54200	1700
100%	1478	-3905	1200	0.55	24.24	51500	3270
150%	1067	-6687	1100	0.77	23.98	49000	4700

Table 3: 3rd scenario values obtained at status quo of both fleets at different levels of background strengths.

	YIELD(t)	PROFIT($K)	MEY (vessels)	F_{TRUE} (month^{-1})	SHRIMP LENGTH(mm)	SHAD YIELD(t)	BY-CATCH (t)
				INDUSTRIAL			
50%	6752	-15274	17	0.35	26.17	49700	4600
100%	5565	-22742	12	0.41	26.01	52300	2590
150%	4642	-28509	7	0.46	25.86	52400	1800
				ARTISANAL			
50%	2955	643	1000	0.26	23.54	54300	1350
100%	2267	-2250	1000	0.41	22.78	52300	2590
150%	1963	-4143	1000	0.56	22.39	50500	3700

Table 4: 4th scenario values obtained at status quo of both fleets at different levels of background strengths.

	YIELD(t)	PROFIT($K)	MEY (vessels)	F_{TRUE} (month^{-1})	SHRIMP LENGTH(mm)	SHAD YIELD(t)	BY-CATCH (t)
INDUSTRIAL							
50%	6390	-17110	15	0.36	26.46	51600	3050
100%	4955	-26169	10	0.43	26.28	52800	1350
150%	3903	-32767	6	0.49	26.11	53100	800
ARTISANAL							
50%	3544	2257	1000	0.28	23.60	53600	700
100%	2806	-472	1000	0.43	22.98	52800	1350
150%	2469	-1975	1000	0.58	22.63	51800	2000

Table 5: 5th scenario values obtained at status quo of both fleets at different levels of background strengths.

	YIELD(t)	PROFIT($K)	MEY (vessels)	F_{TRUE} (month^{-1})	SHRIMP LENGTH(mm)	SHAD YIELD(t)	BY-CATCH (t)
INDUSTRIAL							
50%	6563	-15985	17	0.36	26.50	52000	3300
100%	5224	-24438	12	0.42	26.35	54000	1450
150%	4183	-30962	10	0.47	26.22	53600	900
ARTISANAL							
50%	3381	2516	1000	0.27	23.91	55000	750
100%	2630	-311	1100	0.42	23.31	54000	1450
150%	2284	-1823	1000	0.57	22.96	52600	2100

Table 6: 6th scenario values obtained at status quo of both different fleets at different levels of background strengths.

	YIELD(t)	PROFIT($K)	MEY (vessels)	F_{TRUE} (month^{-1})	SHRIMP LENGTH(mm)	SHAD YIELD(t)	BY-CATCH (t)
INDUSTRIAL							
50%	6830	-14287	17	0.35	26.53	51300	3900
100%	5636	-21836	13	0.41	26.41	54400	1800
150%	4724	-27575	7	0.46	26.30	54300	1050
ARTISANAL							
50%	3091	2490	1300	0.26	24.35	56100	900
100%	2300	-412	1100	0.41	23.74	54400	1800
150%	1941	-2272	1000	0.56	23.39	52500	2600