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Fishery trends, resource-use and management system in the Ungwana Bay fishery Kenya

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ABSTRACT

The present study assessed trends in resource-use, partitioning and management in the Ungwana Bay fishery, Kenya, using surplus production models. The fishery is one of East Africa's important marine fisheries sustaining a bottom trawl commercial fishery and a resident-migrant artisanal fishery. Two models: Schaefer (1954) and Gulland and Fox (1975) were applied to catch-effort data over a 21-year period to model maximum sustainable yield (MSY) and optimal effort (f_{MSY}) to examine the status of resource exploitation and provide reference points for sustainable management. In the artisanal fishery, model MSYs range from 392–446 t to 1283–1473 t for shrimps and fish respectively compared to mean annual landings of 60 t for shrimp and 758 t for fish. These landings represent <50% of the model MSYs suggesting under exploitation in the sub-sector. Moreover, current fishing effort applied stands at <0.5 f_{MSY}. On the other hand, mean annual landings in bottom trawl commercial fishery, at about 330 t for shrimps and 583 t and fish represent about 90% of the model MSYs of 352–391 t and 499–602 t for shrimps and fish respectively. Therefore, the bottom trawl commercial fishery is likely under full exploitation. Similarly, the current effort is estimated at >0.7 f_{MSY}. Resource management in the bay is faced with numerous problems including resource-use conflicts, poor economic conditions in artisanal fishery, poor legislation, and inadequate research augmented by poor reporting systems for catch-effort statistics. Thus, the fishery lacks clearly defined exploitation regimes. Fisheries research and assessment of the marine resources are important for sustainability of the fishery. Moreover, income diversification in the poverty ridden artisanal fishery would go a long way in addressing resource-use conflicts and use of deleterious fishing methods in the sub-sector. Borrowing from the successes of the Japanese community-based fisheries resource management (CBFRM) which has easily resolved numerous fisheries management issues in coastal small-scale commercial fisheries, and the beach management unit (BMU) system which has been applied to the artisanal fisheries of south coast Kenya with enormous benefits, it is envisaged that a hybrid CBFRM–BMU system presents the best approach to sustainable resource-use in the Ungwana Bay fishery.

1. Introduction

The Ungwana bay, Kenya, extends from Ras-Ngomeni in the south to Ras-Shaka in the north of Kipini off the East African coast. To its south lies the smaller Malindi Bay and both bays form the Malindi–Ungwana Bay complex, simply referred to as the Ungwana Bay (Fig. 1). The complex is part of the wider Western Indian Ocean and the bays are shallow with water depths averaging at 12–18 m between 1.5 and 6.0 nm, rapidly increasing to over 100 m beyond 7 nm (Alverson, 1974; Iversen, 1984). The continental shelf extends 15–60 km with rich fishing grounds both inshore and offshore. Two rivers, the Athi River in the south and the Tana River in the north, flow into the bay, thus enriching the associated fishery.

The Ungwana Bay fishery is home to Kenya's only commercial shrimp fishery and is an important source of livelihood along the Eastern coast of Africa. A resident-migrant artisanal fishery utilizes 0–5 nM inshore waters, and the grounds are designated as trawl exclusion zones (TEZs) by law (Government of Kenya, 1989a) for utilization by the small artisanal crafts. However, majority of the

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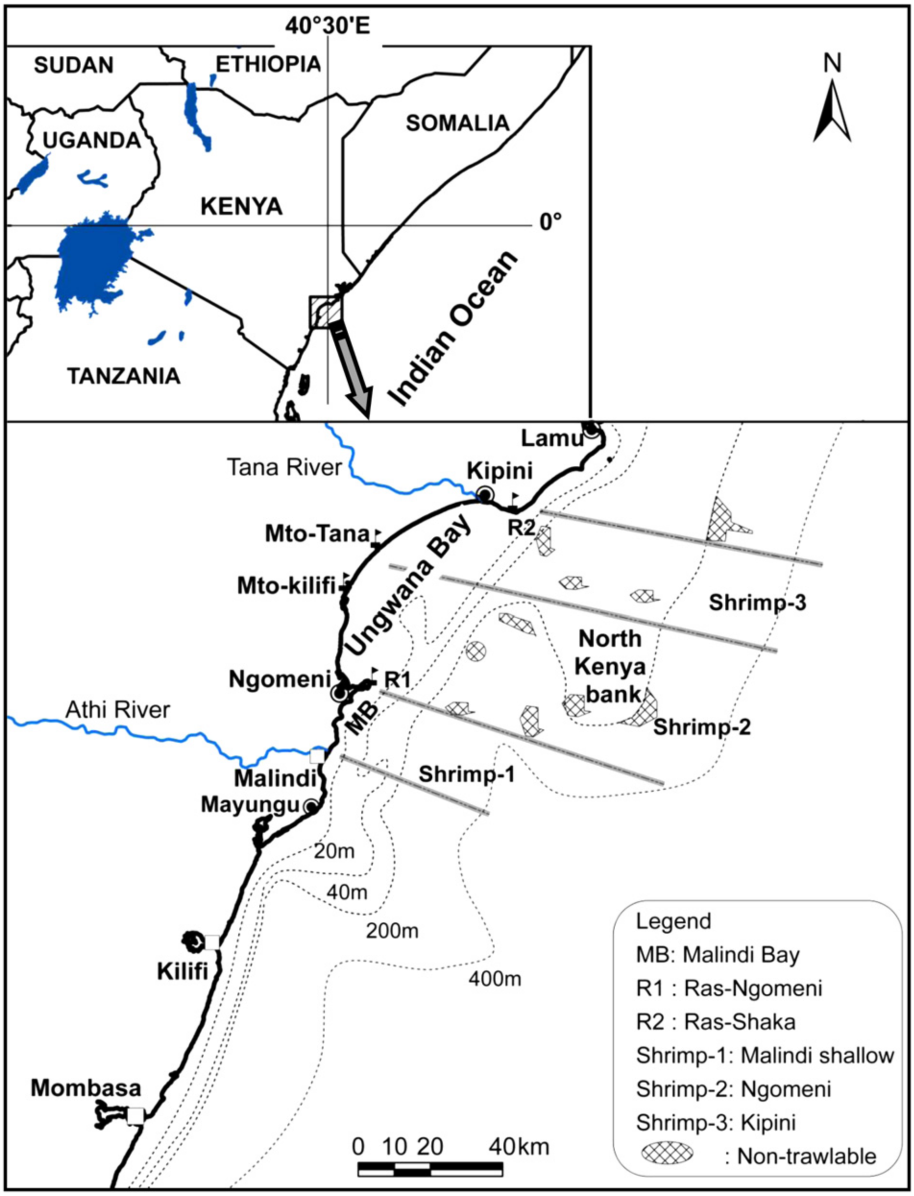

Fig. 1. A map of Kenya showing the location of the Ungwana Bay fishery and demarcation of the shrimping grounds in the commercial fishery i) Malindi shallow, ii) Ngomeni and iii) Kipini.

small artisanal crafts are technologically restricted to the inshore waters less than 3 nM. On the other hand, commercial fishery restricted to the 5–200 nM offshore fishing grounds (Government of Kenya, 1989a), setting an arbitrary area-based resource utilization system in the bay. The Ungwana Bay fishing grounds are considered to be some of the most productive and extensive shrimping areas on the East African coast (FAO, 1983; Fulanda, 2003; Mwatha, 2005). The livelihoods of thousands of coastal communities in north coast of Kenya are dependent on the fisheries resources of the Ungwana Bay (Fulanda, 2003; Mwatha, 2005; McClanahan et al., 2005). However, the numerous households in these communities are faced with uncertainty over the sustainability of Ungwana Bay fisheries resources due to escalating resource-use and partitioning conflicts augmented by undefined harvest strategies amid rise in deleterious fishing practices (Fulanda, 2003; McClanahan et al., 2005; Fulanda et al., 2009). Consequently, there is a need to assess the current status of the Ungwana Bay fishery resources, evaluate trends in the fishery, resource-use and partitioning and the sustainability of the current management systems. With a clearer understanding of the factors influencing resource-use and partitioning, and the influence of current management systems, sustainable management options can be explored based on set reference points using research data and stock assessment.

Ungwana Bay fishery is a resource with complex exploitation regimes being home to a resident and migrant artisanal fishery as well as a bottom trawl commercial fishery. In the artisanal fishery, the fishing vessels are mainly traditional crafts including *mtumbwi*, *hori*, *ngalawa* and *dau* (Table 1a) which account for more than 40% of the vessels in the artisanal fishery (Fulanda et al., 2009; Hoorweg et al., 2009). *Mtumbwi* are dug-out canoes measuring about 4 m long with curved bottom. The *hori* is canoe made of plankwood and canoes fitted with outriggers and small sails are called *ngalawa*. The *dau* is a flat bottom-vessel built from plankwood and propelled by small sails. Some crafts employ dual modes of propulsion including inbuilt engines and lateen sails. Typical examples include *mashua*

Table 1a
Fishing crafts recorded from the Ungwana Bay artisanal fishery during the present study 1985–2005.

Fishing craft	Total length (m)	Clearance	Construction	Primary propulsion	Center pole for sale	Steering mode	Crew size
Mtumbwi	3	Low	Dug-out	Paddles/poles/few sails	None	Paddles/poles	5–6
Hori	3	Low	Plank	Sail	Removeable	Rudder with shoulder rope	2–3
Ngalawa[a]	5–6	Higher than *dau*	Dug-out	Sail	Permanent	Rudder with stick	4
Dau[b]	5	Low[e]	Plank	Sail	Removeable	Rudder with stick	2–3
Mashua	10	High[d] Talbisi[f]	Plank	Sail	Permanent	Rudder with stick	4–6
Jahazi[c,d]	20	High[d] Talbisi	Plank	Sail	Permanent	Rudder with stick/wheel	10+

Source: Classification and definition adapted from Hoorweg et al. (2009) (eds.)

[a] *Ngalawa* come from the islands off mainland Tanzania including Pemba and Mafia and are mostly associated with the migrant fishery.

[b] *Hori* and *dau* are very similar but the latter are wider inside, have flat bottom and are longer with a curved silhouette.

[c] A *Jahazi* is technically for cargo, not for fishing; however the terms are loosely used and large *mashua* are sometimes called *jahazi*.

[d] Sometimes *jahazi* carry a smaller *mashua* inside as a lifeboat or landing craft.

[e] *Dau* clearance is low because it is used for collected traps.

[f] *Talbisi* are matting used to increase clearance above the water.

and *jahazi*, which account for about 10–16% of the artisanal crafts (Fulanda et al., 2009). On the other hand, *Mashua* are large vessels made from plankwood measuring about 10 m long, and used for out-of-reef fishing. They use sails as the main mode of propulsion. They are the fishing crafts of choice for the night fishers who employ long lines and drifting nets (Hoorweg et al., 2009). On the other hand, *Jahazi* are basically large dhows depending on inbuilt engines for propulsion. They are mainly and are preferred for open-sea fishing and transportation of cargo. The *mtumbwi*, *hori*, *ngalawa* and *dau* are technologically restricted to the inshore waters <3 nM. Therefore, only *mashua*, *jahazi* and *motaboti* (modern boats with outboard engines) are capable of venturing into the open sea, and are therefore the common fishing crafts in coastal migrant fishery in addition to *ngalawa* (Fulanda et al., 2009). However, smaller boats also venture out into near shore open waters especially during the calm North East Monsoon (NEM) season which runs from December through March.

Fishing gears used in artisanal fishery are mainly traditional homemade traps including portable basket traps (*malema*), intertidal fixed weir (*uzio*) traps made of sticks, spear-guns (*bunduki*), made from wood and some rubber band resembling sport-fishing guns, and wooden spears (*ngovya*) for octopus and crab fishing (Fulanda et al., 2009). Modern gears used in the fishery include all types of nylon nets (gill nets, floating nets, beach seines) and lines (long lines and hand lines) accounting for about 65% of the gears (Fulanda et al., 2009). Floating gill nets (*jarife*) with mesh size <10 cm were used to target pelagic species mainly outside the reef. Smaller gill nets, *mpweke*, which measure slightly >5 cm mesh size are used within lagoons far from corals to avoid entanglement (Hoorweg et al., 2009). Sardine nets (*kimia*) measure <5 cm mesh sizes and are used to target smaller fish including sardines while fine meshed beach seines (*juya*), which are prohibited by law (Government of Kenya, 1989a), are often used, capturing fish of all sizes and destroying juveniles and larval stages (Fulanda, 2003; Hoorweg et al., 2009). In addition *juya* nets scrape the feeding and breeding grounds with physical destruction of corals (Fulanda, 2003; Hoorweg et al., 2009). Generally, gill nets and hand lines are the preferred gears by majority of the fishers.

Beyond the 5nM boundary to the 200nM Exclusive Economic Zone (EEZ) lies the bottom trawl commercial fishery. In this fishery, the fishing fleet is mainly comprised of industrial double-rigg and outrigger steel trawlers (Fulanda, 2003). The outriggers (or booms) are made of steel and measure about 10 m long with the side booms, center boom, and center mast located at the mid-ship. The vessels range in size from 25 to 40 m long and all are equipped with blast freezers and freezing holds (Table 1b). The vessels range from 115 to 1500 hp while the storage is between 30 and 350 t and smaller vessels or non-mechanized crafts are virtually absent in this sub-sector. All vessels lack shrimp sorting machines and the entire catch is sorted manually onboard. The fleet homebases are located around the Kilindini marine port in Mombasa.

The trawlers employ double-rigged, stern or outrigger trawling as the predominant method of fishing (Table 1b). The trawl gears are funnel-shaped otter trawls mostly towed behind the vessels. The trawl nets are mostly made of polypropylene with 50–55 mm and <40 mm mesh sizes at body and codend respectively (Mutagyera, 1984; FAO, 1986; Fulanda, 2003). Majority of the trawlers use rectangular, flat, wooden otter boards directly attached to the wings (Haule, 2001; Fulanda, 2003) and four chain bridles are then used to attach the otter board to a wire bridle

Table 1b
Fishing vessels recorded from the Ungwana Bay bottom trawl commercial fishery during the present study 1985–2005.

Fishing vessel	Total length (m)	Tonnage (t)	Horsepower	Crew size	Gear type
Kuvuna-22[a]	24.0	131	390	n.d	Beam trawl
Kusi[a]	41.0	352	1400	n.d	Beam/stern trawl
Aegina[b]	79.0	250	1500	80	Multi-gear
Alfa Challenger[b]	27.0	197	650	32	Beam trawl
Alfa Commander[b]	25.0	106	225	32	Beam trawl
Shoka[b]	18.0	50	350	n.d	Beam trawl
Kuvuna-369[b]	16.0	37	240	15	Beam trawl
Kuvuna-888[b]	16.0	37	240	n.d	Beam trawl
Shoka ndogo[b]	12.0	35	115	n.d	Beam trawl
Venture-II[c]	37.0	100	970	72	Beam trawl
Bahari-I[c]	27.0	197	800	n.d	Beam trawl
Alpha Amboseli[c]	27.0	197	624	24	Beam trawl
Alpha Tsavo[c]	27.0	197	624	24	Beam trawl
Alpha Serengeti[c]	27.0	197	800	24	Beam trawl
Alpha Manyara[c]	27.0	166	624	24	Beam trawl
Alpha Marine-7[c]	27.0	152	550	24	Beam trawl
Alpha Kilimanjaro[c]	27.0	165	510	24	Beam trawl
Venture[c]	26.0	131	390	n.d	Beam trawl
Andrea[c]	26.0	n.d	n.d	n.d	Beam trawl
Hamko-I[c]	24.0	115	550	n.d	Beam trawl
Albaraka-II[c]	24.0	119	365	n.d	Beam trawl
Vega[c]	24.0	100	500	18	Beam trawl
Kuvuna-138[c]	13.5	176	550	n.d	Beam trawl
Kuvuna-169[c]	13.5	176	550	n.d	Beam trawl
Kuvuna-777[c]	13.5	176	550	15	Beam trawl
Almadad[c]	n.d	n.d	n.d	n.d	Beam trawl
Roberto[d]	18.0	117	295	18	Beam/stern trawl

[a] Fishing vessels entered the fishery in the early 1970s, but no data and statistics are available (except for licensing details) due to lack of proper reporting arrangements.

[b] Vessels entered the fishery in 1984–1985.

[c] Vessels entered the fishery in 1990–1993.

[d] Vessels entered the fishery in 2003.

extending to the towing warps. Generally, the bridles measure 60–70 m long while the warps are 18–20 mm diameter wires.

In the management of marine resources, maximization of catch over an infinite time horizon under sustainable yield levels is a key traditional default objective, focusing on mean catches while ignoring year to year variations (Sparre et al., 1989; Hilborn and Walters, 1992; Quinn and Deriso, 1999). Notwithstanding, the maximum sustainable yield (MSY) index is a simple operational principle for stock assessment and fisheries management considerations (Hilborn and Walters, 1992; Quinn and Deriso, 1999). However, MSY has no intrinsic biological justification (Hilborn and Walters, 1992; Sparre et al., 1989; Quinn and Deriso, 1999). Studies show that examining the transient behavior of fisheries during period of imbalance is an important step to understanding its dynamics. Moreover, changes occurring during the development of a fishery offer fundamental sources of information on the dynamics of both the stock and fishing effort (Ricker, 1975; Hilborn and Walters, 1992). Two types of models have been used to compute MSY and optimal effort f_{MSY}: analytical models which require the age composition data, including the Beverton and Holt Yield-Per-Recruit analysis and Thompson and Bell Yield and Biomass prediction models (Sparre et al., 1989), and holistic models which consider fish stock as a homogenous biomass ignoring length or age structure of the stock. These models include surplus production models (SPMs) such as the Schaefer (1954) and Gulland and Fox (1975) models. The SPMs are the models of choice especially where only an index of abundance, such as catch per unit effort (CPUE) is available. This is because majority of the model parameters of these SPMs can easily be estimated using catch-effort and CPUE analysis.

2. Materials and methods

2.1. Study area

Geographically, the East African coast lies within one of the most dynamically varying large marine ecosystems in the world; the Western Indian Ocean (WIO) eco-region (McClanahan, 1988; Richmond, 1997). The coast experiences a tropical humid to subhumid climate with two distinct seasons influenced by two monsoons winds, running April–June (South East Monsoons, SEMs), and the Dec–March North East Monsoons (NEMs) (McClanahan, 1988). These monsoon winds have greatly shaped the fishing patterns within the artisanal fisheries of the East African coast (Datoo, 1974; McClanahan, 1988; Fulanda et al., 2009).

The Ungwana Bay extends along a coastal stretch of about 210 km from Ras-Ngomeni to Ras-Shaka in the north of the Kipini (Fig. 1). It is demarcated into a 0–5 nM artisanal fishery trawl exclusion zone (TEZ), and an offshore bottom trawl commercial fishery running from 5 nM to the 200 nM Exclusive Economic Zone (EEZ). The TEZ is amorphously demarcated based on accessibility and technological limitation of the artisanal fishing craft, with smaller vessels operating below 3 nM inshore, while the bigger artisanal fishery vessels operate up to the TEZ boundary. The 5–200 nM bottom trawl commercial fishery grounds are also amorphously divided into three main areas with anchoring points for the fishing vessels: i) Malindi shallow, lying off the Malindi Bay, ii) Ngomeni, running from Ras-Ngomeni and the waters off Mto-Tana, and ii) Kipini, covering the shrimping grounds north off Mto-Tana through Kipini to the waters of Ras-Shaka. The Ngomeni area has a more extensive continental shelf and provides better sheltering areas and is main anchoring point within the bay especially during the rough April–June SEM season.

The Ungwana Bay fishing grounds cover an estimated 35,300 km^2 (Iversen, 1984; Fulanda, 2003; Mwatha, 2005). The coastline has is characterized by fringing reefs with occasional outcrops limiting the effective trawlerable grounds to about 20,000 km^2 (Birkett, 1979; Iversen, 1984; Fulanda, 2003). Most trawling is done in trawl grounds shallower than 70 m and the areas deeper than 70 m are not favored by the trawlers due to patchy coral growths augmented by the problem of the steep continental slope (Iversen, 1984; Fulanda, 2003). Several studies reported that the richest grounds for the target shrimp species lie within 3–7 nm (Garcia and Le Reste, 1981; Mutagyera, 1984) creating potential conflicts in the partitioning of the fishing grounds. Moreover, the area where deep-sea Crustacea occur lies beyond 200 m in an area of turbulence where two currents meet: the East African Coastal Current and the Somali Current (Brusher, 1974; Mutagyera, 1981).

2.2. The fisheries and their characteristics

2.2.1. The artisanal fishery

The development of a coastal artisanal fishery in Kenya dates back to the 9th century coinciding with the rise of the East African Indian Ocean trade that linked this coast to Arabia, Persia and India (Fulanda, 2003; Stearns, 2001). The period before the 19th century witnessed the emergency and dominance of the Indian Ocean coastal Swahili community and fishing villages (Stearns, 2001). However, legislation of Kenya's fisheries dates back recently to the period after independence in 1963, and the enactment of fisheries laws; the Fish Industry Act Cap. 378 in 1983 and Fisheries Act Cap. 378 in 1989.

As described, artisanal fishery refers to the small-scale fishery employing non-mechanized or small mechanized crafts which are technologically limited to the inshore waters. About 87% of the vessels in the artisanal fishery sub-sector are non-mechanized and some are part of a local migrant fishery which runs along the coastal stretch from Kilifi, through the Ungwana Bay to Lamu in the north (Fulanda, 2003). The fishing vessels vary widely in design and the number of fishers per vessel, and gear types and quantity per vessel among other factors. Thus, the effective fishing effort exerted by each vessel varies widely. For the purpose of this study, a standard craft in the artisanal fishery was defined as a non-mechanized boat measuring approximately 7 m long. The effort exerted by all other vessels in the artisanal fishery was then calibrated to the 7-m standard vessel taking into account the crew size, types and size of gears used, and the mode of propulsion. On average, the artisanal fishers operate for 5–6 days/week over a 10–11 month fishing season every year, and are dry docked for 1–3 months for repairs, shelter from adverse monsoon winds and/or festive seasons including Ramadan, Christmas and Easter. Fishing effort was therefore calculated from consolidated monthly data taking into account the numbers of registered, active and non-active vessels at the landing sites each day. A fishing season lasting 200 days/year was used, and the fishing effort expressed as boat-days. The CPUE was then expressed as kg/boat-day.

The main landing beaches for the artisanal fisheries include Mayungu on the southern tip of the Ungwana Bay fishing grounds, Malindi, Ngomeni, Mto-Kilifi and Mto-Tana and Kipini on the Tana River mouth. However, the Malindi, Ngomeni and Kipini creeks are the favored sheltering sites during the rough April–June SEM season. However, the fishers' daily choice of landing sites is dependent on seasons and the monsoon winds and traditional fishing migration routes strongly influence the preference for landing sites (Fulanda et al., 2009). During the April–June SEM season, the landings are directed to the sites on the coasts of the North Kenya bank including Kipini. During the Dec–March NEM season, northward navigation is difficult, and the landing sites south of the North Kenya Bank are the preferred shelters. During this period, most of catch from the North Kenya bank were diverted to Malindi (Fulanda, 2003). Prior to the construction of an all weather road linking Malindi and the areas north of the bay in 1999, most of the catch from the North Kenya bank was transported to target markets in Malindi and Mombasa by sea using the stronger *mashua* and *jahazi* vessels (Fulanda, 2003; Mwatha, 2005). However, after 1999, the new road link realigned the marketing channels within the artisanal fishery, and today, most of the catch is transported to markets by road (Fulanda, 2003).

2.2.2. The bottom trawl commercial fishery

Further offshore beyond the 5 nM TEZ, lies the bottom trawl commercial fishery, extending to the 200 nM EEZ. This fishery is relatively young, dating back to Kenya's post independence period. During the late 1960s, the Kenya government initiated deep-sea fisheries development (FAO/UN, 1966). However, the fishery has been faced with various problems and the objectives for sustainable development have remained elusive (Fulanda, 2003). Catch data in the fishery is still scarce and unreliable and only available only from the mid 1980s. Some authors have documented the early history of this fishery (FAO/UN, 1966; Brusher, 1974; VNIRO, 1978; Mutagyera, 1981; Fulanda, 2003; Mwatha, 2005).

The fishing vessels of the commercial fishery comprise industrial double-rigg beam and outrigger steel trawlers owned by venture companies in the seafood export sector (Fulanda, 2003). The vessels range in size from 25 to 40 m long (Table 1b). Notably, smaller vessels and/or non-mechanized crafts, and vessels owned by individual fishers are virtually absent in the Ungwana Bay bottom trawl commercial fishery. The pioneer shrimping vessels were mainly double-rigg beam trawlers with homebases at the old Mombasa port of Kibokoni, and included four vessels ranging in size from 16 to 27 m long equipped <250 hp engines. However, realization of the richness of the shrimp resources in the bay saw the number of venture companies and size of fleet reach a peak of 17 vessels belonging to seven different companies in 1989. To date, the venture companies have their homebases near the modern Mombasa port of Kilindini for ease of shipping and export (Fulanda, 2003; Mwatha, 2005).

The fishing gears are funnel-shaped otter trawls towed behind the vessels or on the sides, in vessels employing 2–4 trawl nets. The twine diameter of the nets is diamond mesh shaped, measuring about 1.4–1.6 mm in the body and 1.9 mm or more at the codend. Majority of the vessels use combination wires for their ground ropes while the rest use steel wires covered by PP rope. There are no bycatch reduction devices on the trawls and only a few of the trawlers employ turtle excluder devices (TEDs) on trial basis (Fulanda, 2003; Mwatha, 2005). The fishing fleet varies widely both in terms of sizes of vessels used and numbers of vessels operating each season. Therefore, fishing effort in this fishery was expressed in trawler-days and a standard trawler defined as fishing craft of about 490 hp equipped with a 25 m headrope. In this fishery, a typical trip lasts 16–32 days/month over an 8–10 months fishing season depending on catch levels, weather and vessel storage capacity (Fulanda, 2003; Mwatha, 2005). Therefore, for the present analysis, 26 days was used as the average length of a standard fishing trip.

The development of the bottom trawl commercial fishery has been slow since its initiation in the 1980s but resource-use conflicts pitting the artisanal against the bottom trawl commercial fishery have continued to escalate yearly. However, the management of the fishery has been based on unclear policies or guidelines augmented by lack of research and stakeholder involvement (Fulanda, 2003; Mwatha, 2005; Fulanda et al., 2009).

2.3. Data sources

In order to assess the fishery trends, resource-use and management system of the Ungwana Bay fishery, the present study consolidated catch-effort data over a 21-year period, from 1985 through 2005. To synchronize both the artisanal and bottom trawl commercial fisheries of the bay, 1985, the year of available data on the commercial fleet, was chosen as the starting year for the analysis of the fishery. Three main sources of data were available for this study; i) Fisheries department archived data, ii) field data collected at the landing beaches and onboard the commercial trawlers and, iii) statistical and market data provided by the venture companies. The 1985–1994 utilized archived data at the Ngomeni, Malindi and Mombasa offices of the Fisheries Department - Kenya for the data on both the artisanal and bottom trawl commercial fishery. Consequently, the 1985–1994 early data from the bottom trawl commercial fishery lacked detailed information on fishing activities owing to lack of suitable arrangements in the reporting system during the early periods of the fishery.

In the artisanal fishery, 1995–2005 fisheries data was collected using Fisheries staff at the designated landing sites of Ungwana Bay. The landing sites incorporated in the present study include Mayungu, Malindi, Ngomeni, Mto-Kilifi, Mto-Tana and Kipini. Data recorded at the landing sites included; i) total number and weight by species, ii) number and type of fishing gears, iii) type, size and number of fishers per fishing craft and, iv) landing site and fishing grounds. On the other hand, bottom trawl commercial fishery 1995–2005 statistical data was obtained from the venture companies while active data collection was conducted onboard the vessels for clarification of archived statistics. In this sub-sector, data collected included i) vessel size by length, horsepower and tonnage, ii) fishing gears used, iii) fishing grounds and expanse, iv) duration and number of hauls per day, and duration of each fishing trip and, v) catch data by species and weight.

Further, information related to marine resource exploitation and policy management was obtained from government status including the Fisheries Act (Government of Kenya, 1989a), the Kenya Wildlife Conservation and Management Act (Government of Kenya, 1989b) and the Maritime Zones Act (Government of Kenya, 1989c). Interviews with the fishers and fisher groups including fisheries cooperatives, community conservation groups and beach management units was further conducted to get an history of the existing fishery management systems, resource-use, types and sources of conflicts and fisher views on existing fishery management systems. To assess options available for sustainable management of Ungwana Bay fishery, data and information on similar fisheries and their management systems was obtained from literature review, with particular focus on traditional fisheries management systems worldwide. Coastal fisheries-based management systems, case studying the Kagoshima Bay, southern Japan, were explored in preference to other fisheries in other parts of the world due to its successes in resource-use and management. Moreover, despite the technological advancement of Japan as country, the coastal fisheries including the Kagoshima Bay have largely remained traditional based, with community fisheries resource management systems similar to Kenya's beach management units employed in the artisanal fisheries.

2.4. The surplus production models

Fish stock assessment of exploited stocks is aimed at estimating exploitation rate to predict future yields and sustainability in terms of biomass levels at varied levels of fishing effort (Sparre et al., 1989). Surplus production models are used for stock assessment purposes and the surplus production is the biomass that can be harvested each year from a population without affecting abundance. The models assume population density will not change if the stock is harvested at the same rate as the population's capacity to increase, considering fish stock as a homogeneous biomass (Jensen, 2005). Therefore, surplus production models the preferred option in data limited conditions such as the Ungwana Bay fishery.

To examine the status of resource exploitation in the fishery, surplus production models were applied to the 1985–2005 catch-effort data to model maximum sustainable yield (MSY) and optimal effort (f_{MSY}). In the models, the artisanal and bottom trawl commercial fishery sectors are treated as two distinct fisheries. The overall objective was to provide a clearer understanding of the transient behavior of the separate fishery sectors in the Ungwana Bay and provide reference points for design of separate and/or joint sustainable management regimes for these fisheries. Two SPM models were selected for estimation of MSY and f_{MSY} using the surplus production and the catch-effort data fitted using MS Excel. In the analysis, population parameters including growth, recruitment and natural mortality were assumed to be constant. The models used were:

(i) Schaefer (1954) logistic model assuming non-equilibrium conditions and
(ii) Gulland and Fox (1975) exponential model using a predictive regression of ln(CPUE) against fishing effort, f

The Schaefer (1954) logistic model is a simple, useful and convenient method for assessing fish stocks. Generally, the direct measures of biomass are rarely available in marine populations and indices of stock-size including CPUE are the frequent data collected. The Schaefer (1954) model assumes that these indices are proportional to the stock-size and that increase in biomass conforms to a logistic curve where yield and effort are symmetrically related. The production term in the Schaefer (1954) model is given by:

$$B_t = rB_t(1 - B_t/K) \quad \text{(i)}$$

Therefore the surplus production is given by: $dB_t/B_tdt = r(1 - (B_t/K))$, where B_t = biomass at time t, r = intrinsic growth rate, K = carrying capacity. Assuming a linear relationship between CPUE and biomass:

$$\text{CPUE}_t = C_t/E_t = U_t = qB_t \quad \text{(ii)}$$

where q is the catchability. Integrating Eq. (i) gives:

$$B_t = KB_0e^{rt}/K + B_0(e^{n} - 1) \quad \text{(iii)}$$

Under fishing, the equation is expressed as:

$$dB_t/B_tdt = r(1 - (B_t/K)) - F_t \quad \text{(iv)}$$

where F_t = fishing mortality rate at time t, hence the annual catch Y_i can be expressed as:

$$Y_i = F_iK\left[1 + (1/r)^*\ln\left(B_{i,t}/B_{i,t+1}\right) - (F_i/r)\right] \quad \text{(v)}$$

where $B_{i,t}$ = initial biomass at year = 0, $B_{i,t+1}$ = biomass at end of year = 1, F_i = initial fishing mortality, K = carrying capacity, r = intrinsic growth rate.

Rewriting the equation, the yield becomes: $Y = af + bf^2$ and a graphical plot of CPUE against effort, f, gives a linear relationship: CPUE = $Y/f = a - b\,(f)$ where a is the y-intercept, b is the slope of the line, and f is fishing effort. These parameters are then used to calculate the fishery performance indicators of MSY and optimal effort f_{MSY} as follows:

$$\text{Maximum sustainable yield, MSY} = a^2/4b \quad \text{(vi)}$$

$$\text{Optimal fishing effort at MSY, } f_{MSY} = a/2b \quad \text{(vii)}$$

However, the relationship between CPUE and effort is generally non-linear in nature, especially in exploited fisheries (Hilborn and Walters, 1992). Fox (1970) introduced a modification to the Schaefer (1954) model to give a curved line when CPUE is plotted directly on fishing effort, f, but a straight line when log-transformed CPUE data is plotted against f:

$$\ln(Y_i/f_i) = a' + b'^*f(i), \text{ rewritten as } Y_i/f_i = \exp\left(a' + b'^*f_i\right) \quad \text{(viii)}$$

where a' and b' are the intercept and slope respectively.

Gulland (1971) suggested that in the Schaefer (1954) model, biomass at MSY is equal to half the virgin biomass (B_0), i.e. $B_{MSY} = 0.5\ B_0$, and fishing mortality at MSY is roughly equal to natural mortality rate (M), and proposed estimation of MSY = 0.5 MB_0 of a virgin stock where the estimators of M and B_0 are available. Considering that the ratios B_0:B_{MSY} and M:f_{MSY} are often different for different species groups, Gulland proposed a generalized equation for MSY = xMB_0, where x could be estimated from the Beverton and Holt yield tables (Beverton and Holt, 1964). However, fishing effort f_{MSY} is often lower than natural mortality M and hence Gulland's initial equation: MSY = 0.5 MB_0, was likely to overestimate MSY especially where the virgin biomass is unknown (Hilborn and Walters, 1992; Quinn and Deriso, 1999). A correction is given in the Gulland and Fox (1975) model based on asymmetric parabolic relationship exponential relationship between yield and effort. The model is more appropriate when effort in previous years is thought to affect current yield and when yield is expressed in biomass (Ricker, 1975) and was therefore chosen for comparison with the Schaefer (1954) logistic model. The Gulland and Fox (1975) model is mathematically summarized as:

$$Y_i = f_i^*\text{CPUE}_\infty{}^*(\exp(-bf_i)) \quad \text{(ix)}$$

where Y_i is the annual yield, f_i is effort and CPUE$_\infty$ is the catch rate corresponding to the virgin stock. If the catchability coefficient q and natural mortality coefficient M are considered constant, then $f_i = (Z_i - M)/q$ and the effort can be transformed into analytical mortality rates:

$$Y_i = [(Z_i - M)/q]4\ CPUE_\infty{}^*\exp(-b\ ((Z_i - M)/q)) \quad \text{(x)}$$

If $b' = b/q$, then $U_\infty/q = B_\infty$ and the yield Y_i can be expressed as:

$$Y_i = F_i^*q^*B_i = \exp\left(a' + b'^*F_i\right) \quad \text{(xi)}$$

and

$$\ln(Y(i)/f(i)) = a' + b'^*f(i) \quad \text{(xii)}$$

From Eqs. (xi) and (xii), Gulland and Fox (1975) model, the MSY and f_{MSY} are given by:

$$\text{Maximum sustainable yield, MSY} = -\left(1/b'\right)(\exp(a' - 1)) \quad \text{(xiii)}$$

$$\text{Optimal fishing effort at MSY, } f_{MSY} = -\left(1/b'\right) \quad \text{(xiv)}$$

where a' is the y-intercept and b' is the slope of the line of the graphical plot of ln(CPUE) and fishing effort f.

A comparison of the MSY and f_{MSY} indices estimated from the 21-year catch-effort data from the Ungwana Bay fishery were compared to establish reference points for sustainable management of the Ungwana Bay fishery.

2.5. Resource-use and management system in the Ungwana Bay fishery

The management of the Ungwana Bay fishery is based on government limitation of fishing effort using licensing and closed seasons implemented by the Fisheries department basically in a typical top-down approach. Such an approach leaves the fishing communities out of the management process (Yamamoto, 1995; Pomeroy and Berkes, 1997; Fulanda, 2003). Moreover, the approach builds up barriers between the fisheries administration and fishing communities and is a main reason for the lack of success in the management of many fisheries including the Ungwana Bay.

Community-based fisheries resource management (CBFRM) on the other hand, increases the commitment of fisher folks to the management system and is heralded worldwide as a success to the management of marine resources. Therefore, top-down approaches to fisheries management have been replaced with CBFRM in many of the most successful fisheries management systems including Japan (Yamamoto, 1995; Pomeroy and Berkes, 1997; Fulanda, 2003). Based on the success of Japanese fishery management, CBFRM is defined as system of fisheries management created at the initiative of the fishermen (Yamamoto, 1995) defined. The system encompasses the management of fisheries resources, fishing effort and fishing grounds. In the management of fisheries resources, conservation of resources is done by establishment of catch limit while propagation encompasses marine ranching. Although Japan's fisheries are very advanced technologically, the management of fisheries resources has remained traditional based employing the CBFRM with enormous success. Further, majority of the vessels used within the coastal fisheries are still owned by individual fishers; a scenario common in the artisanal fisheries of many developing countries including the Kenya. Therefore, the CBFRM systems employed in Japan and the Pacific region are fairly easy to implement in resource poor countries compared to systems borrowed from other developed countries especially in the Atlantic Ocean. Therefore, this present study explores management of the Ungwana Bay fishery, borrowing from the CBFRM and traditional fishery rights based management systems using Kagoshima Bay fishery and other coastal fisheries in Japan as a reference. This traditional introduction of fishery regulations by fishers themselves in a cordial "bottom-up management" to ensure optimal regulations on the fisheries resources, effort, and fishing grounds is presented as a solution to the management of the Ungwana Bay fishery. It is hoped that the success of the fisheries management in the small-scale fisheries in Japan will showcase a more sustainable alternative to the current management system employed in the Ungwana Bay fishery.

Further, the present study used results of the surplus production models and information from the fishery to examine the status of resource-use and consolidates early data in the fishery. Key issues in the development and management of the fishery are highlighted to provide guidelines to future assessment and identification of alternative management options.

3. Results and discussion

3.1. Species of the Ungwana Bay fishery

Analysis of catch-effort data over the 21-year period shows that the Ungwana Bay is a species rich ecosystem within the WIO. The crustacean catch is dominated by decapods of the family Penaeidae (Table 2a). Shallow water species are most abundant, comprising *Fenneropenaeus indicus* accounting for 55–70% of the shrimp species, *Metapenaeus monoceros* (10–15%), *Penaeus semisulcatus* (<10%), *Penaeus monodon* (<10%) and *Penaeus japonicus* (<5%). Spiny lobsters of the family Palinuridae caught in the shallow water fishing grounds include *Panulirus ornatus*, *Panulirus longipes longipes*, *Panulirus versicolor*, *Panulirus homarus*, *Panulirus dasypus* and *Panulirus penicillatus*. In the fishing grounds beyond 100 m water depth, the deep-sea shrimp *Heterocarpus woodmasoni*, and lobster *Puerulus angulatus*, *Metarephrops andamanicus* and *Thenus orientalis* were the main species recorded. Additionally, several commercially important species of fish also inhabit the bay and are target catch for both the commercial and artisanal fisheries were also recorded in the bay (Fulanda, 2003; Mwatha, 2005). In the present study, the most populous families were Lutjanidae, Carangidae, Carcharhinidae, Squalidae, Rajidae, Scombridae, Dasyatidae, Sphyraenidae and leiognathidae (Table 2b). The most dominant species are *Carcharhinus sealei*, *Siganus* spp., *Lethrinus* spp., *Mugil* spp. and *Callyodon guttatus*.

Table 2a
Major crustacean and mollusca species recorded in the Ungwana Bay fishery during 1985–2005.

Family	Species
Penaeidae	*Fenneropenaeus indicus*
	Metapenaeus monoceros
	Penaeus monodon
	P. semisulcatus
	Marsupenaeus japonicus
Pandalidae	*Heterocarpus woodmasoni*
Palinuridae	*Panulirus ornatus*
	P. homarus
	P. dasypus
	P. versicolor
	P. longipes longipes
	P. penicillatus
	Puerulus angulatus
	Linuparus somniosus
	Puerulus angulatus
	Palinustus mossambicus
Scyllaridae	*Scyllarides squamosus*
	S. tridacnophaga
	Ibacus incisus
	Thenus orientalis
Nephropidae	*Metanephrops andamanicus*
Octopodidae	*Octopus cyanea*
	O. macropus
	O. vulgaris
	O. aegina
Sepiidae	*Sepia latimanus*
	S. pharaonis
	S. prashadi
	S. australis
Loliginidae	*Loligo duvauceli*
	L. forbesi
Onychoteuthidae	*Onychoteuthis banksii*
Ommastrephidae	*Ommastrephes bartrami*
	Symplectoteuthis oualaniensis
Thysanoteuthidae	*Thysanoteusis rhombus*
Turbinidae	*Turbo marmoratus*
Tonnidae	*Cypraecassis rufa*
Cypraeidae	*Cypraea tigris*
	C. moneta
	C. mauritiana
Architeuthidae	*Architeuthis Steenstrup*
Argonautidae	*Argonauta argo*
Portunidae	*Scylla serrata*
	Portunus pelagicus
	P. sanguinotentus
	Charybdis spp.
	Thalamita crenata

3.2. Trends in catch and effort in the artisanal fishery

In the artisanal fishery, annual landings showed no discernible trends during the present study but fluctuations are evident (Fig. 2). Peak harvests were recorded around 1987, 1992, 1995 and 2005 and steady increases in annual catch were recorded during 1990–1995 and 2001–2005. Sharp declines in are noted in 1989 and 1998. The fluctuations in total catch appear to rhyme with fishing effort, except during the periods of slumps in total catch.

Table 2b
Major commercially important fish species recorded in the Ungwana Bay fishery during 1985–2005.

Family	Species
Carcharhinidae	*Carcharhinus sealei*
	Eridacris redcliffei
	Hypogaleus hyugaensis
	Mustelus manazo
	Rhizoprionodon sp.
	Hemigaleus sp.
Scyliorhinidae	*Halaelurus hispidus*
	Halaelurus lutarius
	Holohalaelurus granulosus
Squalidae	*Centrophorus lusitanicus*
	Centrophorus scalpratus
	Etmopterus sentosus
	Squalus blainvillei
	Squalus megalops
Dasyatidae	*Dasyatis favus*
	Dasyatis sephen
	Dasyatis uarnak
	Urotrygon daviesi
Myllobatidae	*Myliobatis cervus*
	Stoasodon narinari
Rajidae	*Raja alba*
	Raja miraletus
	Raja ocellifera
	Raja springeri
	Raja stenorhynchus
Torpodinidae	*Heteronarce garmani*
	Torpedo fuscomaculata
	Torpedo marmoratus
Lutjanidae	*Lutajanus argentimaculatus*
	Lutjanus bohar
	Lutjanus rivulatus
	Lutjanus sanguineus
	Lutjanus sebae
	Aprion virescens
	Etelis carbunculus
	Etelis oculatus
	Paracaesio xanthurus
	Pinjalo pinjalo
	Pristipomoides argyrogrammicus
	Pristipomoides types
Carangidae	*Alectis indicus*
	Alepes sp.
	Atropus atropus
	Carangoides chgysophrys
	carangoides cocruleopinnatus
	Carangoides equula
	Carangoides malabaricus
	Decapterus lalang
	Decapterus macrosoma
	Decapterus kurroides
	Decapterus maruadsi
Clupeidae	*Etrumens teres*
	Dussumieria sp.
	Peliona ditchela
	Sardinella gibbossa
Pristidae	*Pristis pectinatus*
Pentapodidae	*Gymnocranius griseus*
	Gymnocranius robinsoni
Schombridae	*Auxis thazard*
	Euthynnus affinis
	Sards orientalis
	Scomber australascius
	Scomberomonus commersoni
	Scomberomonus guttatus
	Thunnus obesus
Sphyraenidae	*Sphyraena barracuda*
	Sphyraena flavicauda
	Sphyraena japonica
	Sphyraena jello
	Sphyraena obtusata
Gymnuridae	*Gymnura natalensis*
Rhinobatidae	*Rhinobatos holoorhynchus*
Engraulidae	*Thryssa satirostris*
	Thryssa vitritostris
Synodontidae	*Saurida undosquamis*
	Synodus indicus
Chimaeridae	*Hyrdolagus africanus*
Orectolobidae	*Chisoscyllium indicum*
Pristiophoridae	*Pliotrema warreni*
Leiognathidae	*Leiognathus bindus*
	leiognathus equula
	leiognathus fasciatus
	Gazza minuta
	Secutor insidiator

During the El-nino weather in 1997–1998, there was high influx of sediment deposit within rich fishing grounds around river mouths making them difficult to exploit. Hence the recorded decline in catches during 1997–2000 may be due to the El-nino effects. The El-nino weather also destroyed the road network hence most of catch was transported directly to the target markets in Mombasa by the bigger *jahazi* vessels. During 2000–2002, a second decline in effort was observed. During this period, escalating resource-use conflicts and destruction of artisanal fishing gear by the trawlers within the TEZ may have triggered the exit of smaller fishing crafts out of the Ungwana Bay fishery. During 1985–2005, annual landings averaged at 800 t with shrimp landings contributing only 35–60 t.

Generally, fishing effort in the artisanal fishery shows an upward trend from 1985 to 2005 except for a decline in 1997–1998 El-nino. During this period, fishing operations as well as fishers' choice of landing sites were adversely affected in the ill-equipped artisanal fishery (Fulanda, 2003; Mwatha, 2005; Fulanda et al., 2009). Moreover, after the El-nino weather cut off road links between Malindi and the landing sites of the bay, stronger artisanal fishing crafts including *mashua* and *jahazi* were diverted from active fishing ferrying people and cargo between the fishing villages of the bay. Generally, fishing effort varied from year to year and averaged at 46,000 boat-days or about 230 boats (Fig. 2). During the 1997–2005, the fishing effort varied greatly, ranging 32,000–52,000 boat-days. The highest level of fishing effort was recorded in 2004 at over 66,000 boat-days, probably due to entry of artisanal craft from fisheries outside the bay following the decline in the numbers of trawlers just before the 2005 trawl ban.

3.3. *Trends in catch and effort in the bottom trawl commercial fishery*

The trends in annual catch and effort in the Ungwana Bay bottom trawl commercial fishery during 1995–2005 are shown in Fig. 3. In the fishery, annual total catch was fairly stable averaging at 650 t, although both total catch and effort in the bottom trawl commercial fishery show marked inter-annual variations. The highest increase in annual catch was recorded in 1992 due to very high bycatch of demersal fish species, at slightly over 2100 t. Highest landings of the target shrimp species were recorded during 1998–2001 at 430–640 t while 1985, 1993 and 1995 reported less than 200 t. of shrimp catch annually. The 1993 decline is due to excessive effort applied in 1992 when 17 trawlers were in operation. Similarly, the bycatch species also dropped by more than 90%, from over 2100 t in 1992 to <270 t in 1993. Inter-annual variations in total catch rhyme well with the fishing activity and effective fishing effort applied year after year. However, the 1985–1991 period was characterized by marked variations in fishing effort but total catches remained stable but from 1992 to 1995, fishing effort

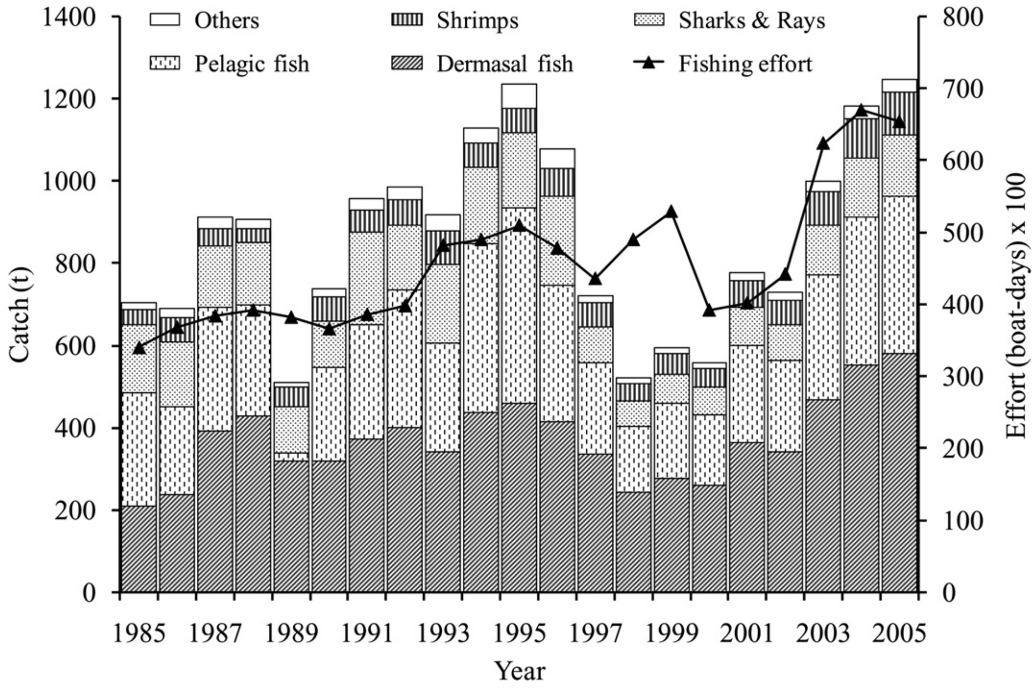

Fig. 2. Annual trends in catch and effort in the Ungwana Bay artisanal fishery during 1985–2005. The group "Others" includes species of minor commercial importance mainly in the family Apogonidae, Labridae, Macrouridae, Mullidae, Serranidae, Mugilidae and Scorpaenidae.

shows a general downward trend. Fishing effort at the start of the analysis was about 1100 trawler-days by 5 trawlers. However, with realization of the profitability of shrimping ventures, the fishing effort rose to more 3000 trawler-days by 1992. Generally, fishing effort in this fishery fluctuated between 750 and 1800 trawler-days, depending on the catches, fishing season and level of resource-use conflicts within the fishery. On average, only about five vessels were active during 1998–2005 with fishing effort averaging at about 900 trawler-days. After the excessive effort applied in 1992 with sharp declines in catches, some fishing vessels modified for diversification into the long-line fisheries. Additionally, some vessels also exited the fishery into neighboring shrimp fisheries of the WIO including Tanzania and Mozambique.

3.4. CPUE in the Ungwana Bay fishery

Assuming variant species the estimated CPUE for the different groups catch within the artisanal and bottom trawl commercial fisheries of the Ungwana Bay during 1985–2005 are shown in Table 3. Treating the fisheries as dependent on all the harvested species, the overall CPUE and fishing effort are also estimated.

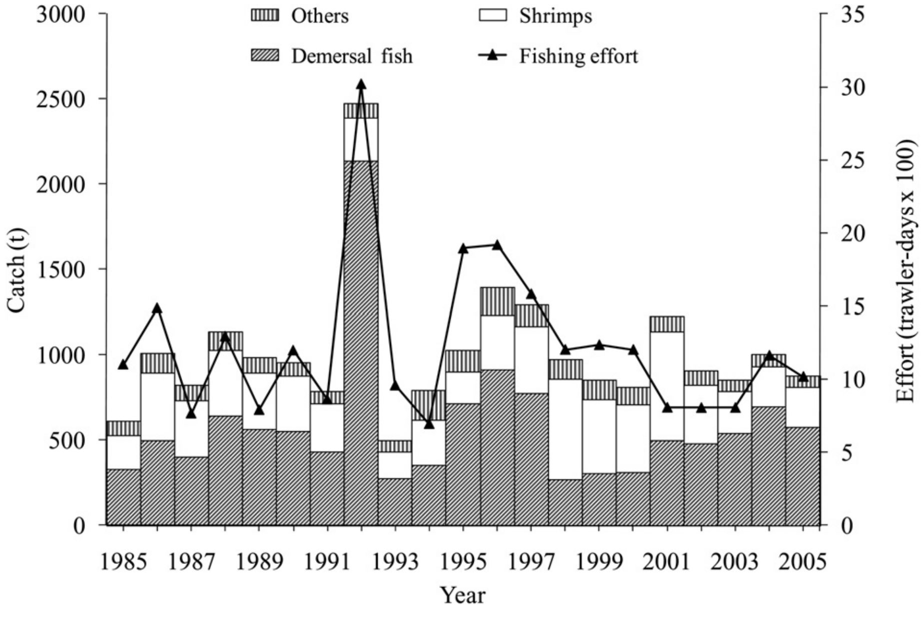

Fig. 3. Annual trends in catch and effort in the Ungwana Bay bottom trawl commercial fishery during 1985–2005. "Others" includes species of minor commercial importance mainly in the family Apogonidae, Labridae, Macrouridae, Mullidae, Serranidae, Mugilidae and Scorpaenidae.

Table 3
Annual variations in overall catch per unit effort (CPUE) in the Ungwana Bay (i) artisanal and (ii) bottom trawl commercial fisheries during 1985–2005.

Year	Artisal fishery							Bottom trawl commercial fishery					
	No. of boats	Fishing effort (Boat-days)	CPUE (kg/boat-day)					No. of trawlers	Fishing effort (trawler-days)	CPUE (kg/trawler- r-day)			
			Shrimp	Fish (Demersal)	Fish (Pelagic)	Others (Mollusca)	Overall			Shrimp	Fish (Demersal)	Others (Mollusca)	Overall
1985	170	34,000	1.0	11.1	8.1	0.5	20.7	5	1104	176	300	78	553
1986	184	36,800	1.6	10.8	5.8	0.5	18.7	6	1488	267	333	77	677
1987	192	38,400	1.1	14.1	7.8	0.7	23.7	11	768	434	521	120	1074
1988	196	39,200	<1.0	14.8	6.9	0.6	23.2	12	1296	298	495	82	874
1989	191	38,200	1.3	11.3	0.5	<0.5	13.4	17	792	423	708	110	1241
1990	183	36,600	1.7	11.8	6.2	0.5	20.1	11	1200	272	458	68	798
1991	193	38,600	1.4	15.5	7.2	0.7	24.8	12	864	326	501	84	912
1992	199	39,800	1.6	5.0	8.4	0.7	15.7	17	3024	84	71	27	817
1993	241	48,200	1.7	11.1	5.4	0.8	19.1	7	960	160	289	67	516
1994	245	49,000	1.2	12.7	8.4	0.7	23.0	12	696	384	506	102	991
1995	255	51,000	1.1	12.6	9.3	1.1	24.2	9	1896	97	378	57	532
1996	239	47,800	1.4	13.2	7.0	1.0	22.6	9	1920	165	477	84	726
1997	218	43,600	1.4	9.7	5.1	<0.5	16.6	12	1584	248	487	80	816
1998	245	49,000	<1.0	6.2	3.3	<0.5	10.6	6	1205	487	225	96	808
1999	265	52,920	<1.0	6.6	3.4	<0.5	11.2	6	1237	347	248	79	674
2000	196	39,200	1.2	8.4	4.4	<0.5	14.2	6	1204	329	260	45	634
2001	201	40,200	1.6	11.4	5.9	0.5	19.3	4	808	788	615	113	1516
2002	221	44,200	1.4	9.7	5.0	<0.5	16.5	4	806	427	593	107	1126
2003	312	62,400	1.3	9.4	4.9	<0.5	16.0	4	807	309	667	84	1060
2004	335	67,000	1.4	10.4	5.4	<0.5	17.6	5	1165	203	595	65	864
2005	327	65,400	1.6	11.2	5.8	0.5	19.1	5	1020	231	566	61	858

In the artisanal fishery, CPUE varied widely. Demersal fish averages at 5–16 kg/boat-day, 1–9 kg/boat-day for pelagic fish, 1–2 kg/boat-day for shrimps and <1.2 kg/boat-day for molluscs including octopus and squids. Overall CPUE ranges from 10 to 25 kg/boat-day. From 1985, overall CPUE showed an upward trend reaching about 23 kg/boat-day but a more than 40% decline was recorded in 1989. The highest overall CPUE was recorded in 1991 and the lowest in 1998. The decline in CPUE in 1992 appears to coincide with an increase in the number of fishing vessels to 17 trawlers, although the reported fishing effort is lower. Similar decline was recorded in 1998–1999 with CPUE of 10–11 kg/boat-day attributed to the peak of the El-nino, which affected fishing patterns within the artisanal fishery. Moreover, the El-nino weather resulted in huge post harvest losses due to the poor road network augmented by lack of refrigeration facilities both at sea and at the artisanal fishery landing sites. During 2000–2005, continuous trawler encroachment into the TEZ during, discarding of low value bycatch and increased resource-use conflicts is reflected in wide variations in CPUE during this period (Fulanda, 2003; Mwatha, 2005).

On the other hand, the bottom trawl commercial fishery, the CPUE for the target shrimp species was relatively lower than that of non-target species throughout present analysis, 1985–2005. From 1985, the lowest CPUE recorded was 84 kg/trawler-day in 1992 when a fishing effort, of 3024 trawler-days was applied, compared to a 10 fold increase in 2001, at 788 kg/trawler-day with fishing effort at 808 trawler-days. The target species CPUE however declined to 200–430 kg/trawler-day during 2002–2005. The decline is due to the escalation of resource-use conflicts with the artisanal fishery during this period (Fulanda, 2003; Mwatha, 2005). The highest CPUE of non-target species including fish and molluscs was recorded in 1989 at 818 kg/trawler-day when an effort of 792 trawler-days was applied. Similarly, 1992, recorded the very high CPUE for the non-target species, at 733 kg/trawler-day when the highest fishing effort was in effect. Evidently, the fishing effort of 3024 trawler-days is too high and unsustainable for this fishery and the low CPUEs for both target and non-target species signal a clear case of overfishing. After reduction in the fishing effort to 960 trawler-days in 1993, CPUE of the target shrimp species increased to 160 kg/trawler-day while a fourfold increase was estimated for non-target species, at >350 kg/trawler-day. Variations in the CPUE for the target shrimp species are partly attributed to differences in efficiencies of the shrimping vessels operating during different seasons and years. Some of the vessels reportedly landed relatively higher amounts of bycatch and debris compared to vessels of same size using similar (Mdodo, pers. comm.). Moreover, poor legislation for the enforcement of the TEZ law resulted in serious encroachment of the artisanal fishery waters by the trawling fleet especially in the Malindi and Kipini areas (Fulanda, 2003; Mwatha, 2005). Thus, some of the apparently high CPUEs of target shrimp species were partly due to catch harvested within the artisanal fishery grounds. Spatio-temporal variations in the distribution of the species within the bay also influenced the seasonal and year to year landings. On the other hand, the CPUE for non-target species showed a relatively steady increase with increase in fishing effort. From the present analysis, economic viability of an all-shrimp bottom trawl commercial fishery is doubtful and the bycatch species present an important supplement to the dwindling shrimp stocks of the Ungwana Bay. Therefore, the bottom trawl fishery was considered as dependent on both target shrimp and bycatch species and overall CPUEs estimated at 516–1500 kg/trawler-day (Table 3).

The year to year variations in CPUE in the entire fishery signal some negative impacts of trawl gear on the ecosystem and fishery stocks, augmented by deleterious fishing methods in the artisanal fishery. Such impacts on the ecosystem and the fishery as a whole are often widespread and cannot, therefore be ignored in the management of the Ungwana Bay.

3.5. Parameter estimations and comparison of the surplus production models

The results of the estimated parameters for MSY and f_{MSY} determined using the logistic and exponential models are shown in Table 4.

In the artisanal fishery, all the species caught were considered as target catch and of importance are the overall MSY and f_{MSY}. The Schaefer (1954) model estimated overall MSY is 1601 t at an

Table 4
Estimations of surplus production parameters; maximum sustainable yield (MSY) and optimal effort (number of vessels and vessel-days) in the Ungwana Bay artisanal and bottom shrimp commercial fishery by the Schaefer (1954) logistic and Gulland and Fox (1975) exponential models using catch-effort data from 1985 through 2005.

Fishery	Group	Schaefer (1954) Model			Gulland–Fox (1975) Model		
		MSY (t)	Fishing effort (no. of vessels)*	f_{MSY} (vessel-days)*	MSY (t)	Fishing effort (no. of vessels)*	f_{MSY} (vessel-days)*
Artisanal	Fish	1283	633	126,638	1474	1000	200,000
	Shrimps	392	3132	626,400	446	5000	1,000,000
	Overall	1601	633	126,535	1312	714	142,857
Commercial	Fish	602	9	1785	499	7	1429
	Shrimps	391	8	1507	352	7	1429
	Overall	1549	14	2815	1966	24	5000

NB: In the fishing effort (no. of vessels)* and optimal effort f_{MSY} (vessel-days)*, vessels refer to boats in the artisanal and trawlers in the bottom trawl commercial fisheries respectively.

optimal effort fMSY of about 126,500 boat-days compared to1312 t and 142,857 boat-days in Gulland and Fox (1975) model respectively. However, considering the individual categories of catch, Schaefer (1954) model MSY for shrimps is 392 t requiring about 626,000 boats-days Gulland and Fox (1975) MSY is 446 t at 1,000,000 boat-days or about 5000 boats. The MSY for fish is 1283 t requiring f_{MSY} of 126,600 boat-days in Schaefer (1954) model and 1474 t requiring 200,000 boat-days. The estimations for shrimp MSY and optimal effort are highly doubtful owing to the lack specific gears and fishing methods targeting the shallow water shrimp species in the artisanal fishery. Moreover, the shrimps may be considered as bycatch in the fine meshed nets of the artisanal fishery.

On the other hand, the bottom trawl commercial fishery analysis was conducted assuming a variant species system targeting shrimps only and the MSY and f_{MSY} for target and non-target species expressed separately. In the Schaefer (1954) model, estimated MSY for the target shrimp species is at 391 t requiring an effort f_{MSY} of 1507 trawler-days while MSY for fish is 602 t requiring 1785 boat-days. Therefore, fishing effort in terms number of vessels is estimated at 8–9 trawlers. On the other hand, the Gulland and Fox (1975) model MSY estimation the target shrimp species is 352 t, and 499 t for the non-target species including fish, other crustaceans and molluscs. For both MSYs, the estimated effort f_{MSY} is 1429 trawler-days or a total of 7 vessels. Therefore, the both SPM models estimated the f_{MSY} at about 7–9 vessels. Treating the fishery as a non-variant system depending on all species for economic breakeven, the overall MSY is estimated at 1967 t requiring optimal effort f_{MSY} of 5000 trawler-days or a total of about 24 trawlers.

Comparing the parameter estimations from the Schaefer (1954) and Gulland and Fox (1975) models, results show that in the artisanal fishery, the overall MSYs (1601 and 1312 t) and optimal effort f_{MSY} (126,535 and 142,857 boat-days) respectively by both SPM models, are not statistically different ($p = 0.9$). During the 21-year period in analysis, highest landings in artisanal fishery 1246 t recorded in 2005, by a fishing effort of 65,400 boat-days. Therefore, based on both SPM models, the overall MSY and optimal effort f_{MSY} have not been attained. Furthermore, the highest recorded catch of shrimp species in this fishery was 102 t during the same year, and presents about 25% of the model estimated MSYs of 392 and 446 t by the Schaefer (1954) and Gulland and Fox (1975) models respectively. Catch-effort analysis showed positive correlation between CPUE and fishing effort in this fishery, but the correlation coefficients were very low for both models ($r^2 < 0.07$), further confirming that the fishery is currently under-exploited. Consequently, there is a need to improve the technological aspects of the artisanal fishery if its full potential is to be realized.

On the other hand, the bottom trawl commercial fishery Schaefer (1954) estimations for MSY of the target shrimp species is 391 t requiring 1507 trawler-days. The Gulland and Fox (1975) estimation is 352 t requiring 1429 trawler-days. The shrimp catch data shows that annual landing ranged 154–637 t during the 21-year period under analysis and the model MSY was surpassed during several years: 1986 (397 t), 1988 (386 t) and 1997–2001 at 393–637 t. These years of effort beyond the f_{MSY} are followed by sharp declines in annual catches as recorded in 1987, 1989–1996 and 2002–2005, signaling cases of overfishing. Lowest catches of the target shrimp species were recorded in 1993, 1995 and 2004–2005 at <250 t per year. On the other hand, the MSY and f_{MSY} estimations for the non-target species by the Schaefer (1954) and Gulland and Fox (1975) models are 602 t and 499 t requiring f_{MSY} of 1785 and 1429 trawler-days respectively. The estimations for MSY and f_{MSY} from both SPM models are not statistically different ($p = 0.19$). Generally, the annual landings of the non-target fish species show that over 1985–2005, the catches have oscillated around the estimated MSYs, averaging at about 510 t annually. Further, the overall MSY and f_{MSY} were estimations at 1549 and 1966 t requiring 2815 and 5000 trawler-days by the Schaefer (1954) and Gulland and Fox (1975) models respectively. These estimations from both models for overall MSY and f_{MSY} are statistically different ($p < 0.05$). Based on the recorded annual catch of 2470 t in 1992 when a fishing effort of 3024 trawler-days was applied, a drastic drop in the target shrimp catch was noted and therefore, the optimal effort f_{MSY} of 5000 and overall MSY of 1967 t estimated by the Gulland and Fox (1975) model is evidently exaggerated and should be received with caution. Moreover, both SPM models estimated negative correlation between CPUE and fishing effort in the bottom trawl commercial fishery in contrast to correlation values in the artisanal fishery. The correlation coefficients in the bottom trawl commercial fishery are also relatively high: (Schaefer (1954) model, $r^2 = 0.35$; Gulland and Fox (1975) model, $r^2 = 0.53$). This indicates that during 1985–2005, the Ungwana Bay bottom trawl commercial fishery has already attained full realization of the MSY, and focus should be shifted to sustainable management to avoid overfishing and resource degradation, since the fishing effort has been mostly on the edge of over-exploiting the fishery. High catches recorded during some years suggesting an apparent recovery of the fishery are evidently due to encroachment overfishing in the TEZ waters, and is partly to blame for fluctuations in artisanal fishery catches during the same year. Consequently, there is a need to divert part of the extra fishing effort in the bottom trawl commercial fishery into other types of fisheries to avoid a potential collapse of the bottom trawl fishery and safeguard the livelihoods of the artisanal fishery. Furthermore, discarding of low value bycatch by bottom trawl fishery negatively impacts the foraging grounds of grazer-fish species and benthic feeders including Siganidae and Lethrinidae which form the bulk of the target species of the artisanal fishery (Fulanda, 2003; Mwatha, 2005). The fishing effort in the bottom trawl commercial fishery should be maintained below the model estimated f_{MSY} of 1429–1785 trawler-days equivalent to about 7–9 trawlers under a variant species system. Moreover, research has shown that most fisheries can only be optimized for one species at a time and in multi-species fisheries, some are often over-exploited while others remain under-utilized (Jensen, 1981). Therefore, diversion of the excess fishing effort to other fisheries should be done with caution to the overfishing of one species among several in the multi-species fishery. Furthermore, the usefulness of the model estimations for MSY and f_{MSY} indices may be limited by their imprecision due to the explicit and implicit assumptions and limitations underlying the model. For example, the assumption that fishing effort is distributed fairly uniformly over the fishing grounds, may not hold. If intense fishing is conducted in localized areas, as is often the case, it will likely constitute overfishing, and the population risks collapsing in the areas of effort concentration. Therefore, current ban on trawling should only be lifted setting fishing effort at about half the model estimated f_{MSY} of about 1500 trawlers-days to allow for experimental trawling and research for stock assessment of the fisheries resources in the bay. Future studies should also assess the impacts of the bottom trawl gear on reproduction and other biological aspects of the individual species of the Ungwana Bay fishery.

3.6. Japan's community-based fishery resource management: key elements of relevance for the Ungwana Bay fishery

To evaluate available options for sustainable management of the Ungwana Bay fishery, an assessment of Japanese system was conducted to highlight some key elements of relevance to the fishery. The Japanese fisheries have been exploited over centuries and unlike the Ungwana Bay fishery, their MSYs have been attained in majority of the fisheries. However, resource utilization in these systems presents a sustainable approach to exploitation of marine resources while employing traditional fisheries management. Moreover, despite the evolution of the resource management system in the Japanese system over centuries, the fisheries still retain a traditional community-based bottom-up approach to resource management. Therefore, the Japanese fisheries management system presents a good approach to the management of the Ungwana Bay fishery, while retaining the traditional community-based approach to fisheries management.

In the Japanese fishery management systems, CBFRM is regarded as system of fisheries management created at the initiative of the fishermen. The system encompasses management of fisheries resources, effort and fishing grounds (Asada et al., 1983; Yamamoto, 1995; Pomeroy, 1995). Despite the technological advancement of Japan as a country, fisheries management has remained traditionally based on the CBFRM approach with enormous success. Majority of the fishing vessels are owned by individual fishers; a scenario common in the artisanal fisheries of many developing countries including the Ungwana Bay, Kenya. Traditionally, fishery management in Japan has been based on the first fishery law: "*Ura*" law and partly by "*Osumi-tsuki*" or fishing rights, where fishing rights were granted to fishing villages dating back to the feudal era (1743–1867). Later, the government embarked on modernization of the fishery, borrowing from fisheries of the North Atlantic. However, it took 32 years to get a new law in place, since none of the European laws suited the Japanese system (Asada et al., 1983; Yamamoto, 1995), during a period characterized by numerous resource-use conflicts. The new law enacted in 1901, classified fishing rights into, among others, exclusive fishing rights, which were granted only to fishery societies (FS). Consequently, all fishermen had either to organize their own FS, or risk being left out. The law incorporated maintenance of the "*Osumi-tsuki*" fishing traditions and rights, which were later, converted into traditional coastal fishing rights (Asada et al., 1983; Yamamoto, 1995). The government also introduced a new coastal fishing rights system which allowed for expansion to cover migratory resources as a result of the ongoing mechanization of small boats. The operation of mechanized boats, and trawl nets and Danish seines near shore resulted in conflicts with coastal fishermen forcing the government to introduce no-trawl zones along the coast (Asada et al., 1983; Yamamoto, 1995). After 1949, the government enacted a new law which saw FSs replaced by Fisheries cooperative associations (FCAs). These new democratically established FCAs were granted with reformed fishing rights, under the prefectural governments giving the fishermen a sense of ownership over the fisheries resources. Thus, the community-based coastal fisheries management system is created with area-based fishing rights (Christy, 1992; Yamamoto, 1995; Pomeroy, 1995). The CBFRMs have three basic components including management of i) fishery resources, ii) fishing effort and iii) fishing grounds. The FCAs, together with prefecture governments establish their own fishery regulations, assess fish stocks, set catch limits and monitor the fishing grounds, and have the authority to fine or suspend violators (Asada et al., 1983; Yamamoto, 1995). Consequently, the CBFRM systems have reduced competition for resources and resource-use conflicts among fishermen.

On the other hand, the management of the Ungwana Bay fishery is based on control of fishing effort by regulations set up by the government in a top-down approach. This system leaves the fishing communities out of the management process and is to blame for the failure of many fisheries worldwide. Further, the system builds barriers between the fishers and the fishery managers making data collection and reporting difficult. It is the above approaches which are partly to blame for the problems facing the Ungwana Bay fishery. Considering CBFRM, the system is heralded as an important factor in successful fisheries management, since it increases the commitment of fisher folks to the system. Consequently, top-down approaches to fisheries management have been replaced with CBFRM in many of the most successful fisheries management systems in marine fisheries (Asada et al., 1983; Yamamoto, 1995; Pomeroy, 1995; Pomeroy and Berkes, 1997). Earlier studies have suggested the application of CBFRM as a viable option to solve the Ungwana Bay fishery (Fulanda, 2003; Mwatha, 2005). The top-down approach to manage the Ungwana Bay fishery has witnessed numerous resource-use conflicts, which threaten the livelihood of many coastal fisher folks. Evidently, unlike in the Japanese system, there is a lack of feeling of ownership over the coastal resources among the artisanal fishers. The feeling of being isolated by government regulations due to lack of involvement, and the apparent lack of government control over the bottom trawl commercial fleet has further aggravated the conflicts in the fishery. The open-access nature of the fishery instills a common property attitude among bottom trawl fishers. Consequently, their target is to reap maximum profits within the shortest time period possible and this has further isolated the coastal communities in Ungwana Bay artisanal fishery. This sense of isolation has triggered the use of deleterious fishing methods by the artisanal fishers in an effort to sustain their threatened livelihood. Evidently, these problems facing the Ungwana Bay are not peculiar, and are characteristic of many multi-species fisheries where there is little stakeholder involvement. Therefore, CBFRM is viewed as an easy to adopt viable option to the sustainable management of the Ungwana bay fishery, resolution of the resource conflicts and a cost effective way of enhancing legislation of the laws governing the utilization of the resources of the bay by the coastal communities themselves.

Secondly, with limited fishery data and lack of stakeholder involvement, the main regulatory factor in the fishery has been profitability of the fishing ventures. Thus, the wide impacts of fishing on marine ecosystems, which comprise impacts on stock abundance, size and species composition and population parameters, trophic shifts and habitat disturbance acting in short and long-term temporal scales, are totally ignored (Kaiser et al., 2002; Pauly et al., 1998). Therefore, to realize the benefits of CBFRM, the fishers must conceive the resources as their own and thus the revival and strengthening of the collapsed FCAs along the fishing villages of the Ungwana Bay are crucial to sustainable fishery management. The fishers are likely to adopt a more positive attitude toward conservation and management measures. Thus, the Japan fishery law, which strengthens fishing rights systems for marine and coastal fisheries, presents numerous lessons for successfully managing the Ungwana Bay resources.

Thirdly, the stock-size and the socio-economic conditions of the Ungwana Bay fishery remain largely unstudied. Resource-use conflicts and feeling of isolation among the fishers of the artisanal fishery, have further made data collection and research an uphill task. This is because due to lack of dissemination of research results to the stakeholders, the fishers fail to appreciate the importance of the catch-effort statistics collected over years, while the socio-economic conditions in the fishery continue to deteriorate (Fulanda, 2003; Mwatha, 2005; Fulanda et al., 2009). The open-access and dispersed nature of the fishing grounds and scattered landings sites further increases the costs of data collection and law enforcement. Therefore, the revival of FCAs and strengthening of the fisher ownership of resources through CBFRM presents a low cost approach to data collection and assessment of the stock-size and socio-economic conditions within the fishery. The dissemination of research results, regulatory policies and management decisions across the FCAs, and across various government agencies and research institutions should be strengthened for full stakeholder involvement in managing the Ungwana Bay fishery. This way the fisher will appreciate the importance of the fisheries statistics in the management of the fishery. The fishers understanding of the role of Marine protected areas which have continuously cushioned the artisanal fishery against overfishing (IUCN, 2003; McClanahan et al., 2005; Muthiga, 2009) would also reduce conflicts with conservation agencies allowing for smooth enactment of measures to protect other delicate ecosystems at the river draining into the bay.

In the commercial fishery, the otter trawls used by majority of the vessels act like plows increasing turbidity and extensively damaging the benthic ecosystems (Schwinghamer et al., 1998; Fulanda, 2003) which impacts kelp and coral reproduction negatively (Palanques et al., 2001). The sediments act as ocean sediment sinks of persistent organic compounds and their re-suspension back into the plankton ecology also triggers potential bioaccumulation in seafood. During periods of overfishing and increased resource-use conflicts in the fishery, the commercial fishing fleets switch between bottom shrimping, purse seining and long-lining depending on the profitability of the fishing ventures. Consequently, replacement of the current otter trawls in the fishery with lighter gears such as Danish seines employed in fisheries around Japan including the Kagoshima Bay, southern Japan should be explored to reduce negative impacts on fisheries resources and the ecosystem. The profitability and sustainability associated with fisheries exploitation based on more environmentally sound gears such as the Danish seines, would entice the venture companies to change the fishing gears despite the additional costs that may be involved. Furthermore, the shift from the current top-down approach to a bottom-up community-based fisheries resource management still presents a cheaper option to the management of the Ungwana Bay fishery without the need for extensive law enforcement and surveillance patrols. A shift from a fisheries-based to ecosystem approach to resource management would further add resilience to the Ungwana Bay.

In the artisanal fishery, poor socio-economic conditions are evident and current management measures including licensing, fishing gear regulation and closed seasons have shown little success. Focus should be shifted to maximizing employment through marginal economic benefits to individuals with the entire fishery output at stake including government support for technological improvement of the fishery. The Japanese government's push for modernization of the traditional fishing vessels and retention of a CBFRM should be emulated for development of the Ungwana artisanal fishery.

The current legislation demarcating a TEZ at 5 nm appears to ignore the natural distribution of the target shrimp species. Several studies have reported higher shrimp abundance in the 3–5 nM area (Garcia and Le Reste, 1981; Fulanda, 2003; Mwatha, 2005) and may explain continuous trawler encroachment of the TEZ. On the other hand, artisanal fisheries within lagoons often employ undersized nets, while the reef fisheries are faced with poisons and dynamite blast fishing. Resource-use conflicts negatively impact on the sustainability of the fisheries resources. Therefore, encroachment of the TEZ should be monitored to reduce resource-use conflicts while ensuring that conflict management is initiated at early stages. The use of vessel monitoring systems (VMSs) in combination with community-based fisheries resource management systems present an easy way to manage the commercial fishing fleet of the Ungwana Bay. Moreover, the VMS facility has already been installed at the Assistant Director of Fisheries, Mombasa since 2008.

To date, the old assumption management regulations can be used to control fishers and fishing effort at will, and that fishing is a communal, cooperative and altruistic process is invalid (Hilborn and Walters, 1992). An integrated approach to management of the Ungwana Bay fishery resources together with associated ecosystems and anthropogenic activities along the coast should therefore be implemented.

In the south coast of Kenya, beach management unit (BMU) systems grouping fishers along fishing villages, similar to the CBFRM, have been employed with enormous success (King, 2003; Mangi and McClanahan, 2003; Alidina, 2005). However, the villages have no fishing rights as enshrined in the Japanese systems. Consequently, due to the presence of a coastal migrant fishery along the East African coast, conflicts between the resident and migrant fisheries sectors are frequent (Fulanda et al., 2009). However, the BMU system still presents an opportunity for initial localized management of fishing villages in the Ungwana Bay. Assessing the benefits, successes and weakness of both the CBFRM, the BMU system and the current top-down approach employed in the Ungwana bay, it is envisaged that a hybrid system borrowing from both the south coast beach management system and the Japanese coastal fishery rights systems presents the best option for a successful CBFRM tailored to the Ungwana Bay. The overall result is a revitalization of traditional fishing practices and empowerment of fishing communities of the Ungwana Bay under a new CBFRM system. This system will reduce conflicts in resource-use in the fishery, and the FCAs will enhance legislation of the existing management regulations on fishing methods, gears, species, fishing grounds and seasons at minimal cost to the government.

Some schools of thought attribute the success of coastal fisheries management in Japan to the long history of the fishing rights system. Consequently, it argued that in countries with no history of fishing rights, fishermen may not accept such a system and CBFRM development has little chance. However, the system can be employed successfully even where the fishermen do not have legally endorsed fishing rights, but conceive ownership of resources near their villages in a system similar to the BMU system (Asada et al., 1983; Yamamoto, 1995; Pomeroy, 1995). In Kenya, though there is no history of fishing rights, the conception of community belonging has facilitated implementation of the BMU system and the Japanese CBFRM would reduce conflicts between resident fishers and migrant fishers encroaching on their coastal resources. Consequently, the coastal rights fisheries management systems would be easy to implement in Kenya under a Japanese CBFRM - Kenya BMU hybrid system. It is hoped that the solutions to better regulation of fisheries resources, effort, and fishing grounds and reduced resource-use conflicts lie in an hybrid CBFRM with a cordial “bottom-up management” system.

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