Oceanographic Features Along the Kenyan Coast:
Implications for Fisheries Management and Development

by

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INTRODUCTION

Position

The Republic of Kenya is located on the east coast of Africa between Somalia in the north and Tanzania at the south. Other neighbors are Uganda on the east and Ethiopia and Sudan at the north. It has a total area of 582,650 km^2 including about 14,000 km^2 of inland waters. These consist of freshwater and alkaline lakes, rivers and several thousands of fish ponds. Its Indian Ocean coastline including islands is 880 km long (Coppola, 1982). It has a continental shelf area (to the 200 m depth) of about 6,500 km^2 (Fig. 1). The population is about 17 million and the gross domestic product per capita is about US $200.

The Kenyan coastline (Fig. 2) extends from 1°30's to 4°30'S latitude and is characterized by the presence of fringing coral reefs commonly distributed at depths between 16-40 meters. A narrow continental shelf that widens on the northern part has a rough bottom topography of coral formation. This shallow water area is broken only by the river estuaries discharging into the Indian Ocean at Vanga, Mombasa, Mtwapa, Mida Creek, the Sabaki River mouth, the Tana River and the extensive Lamu archipelagos. The continental shelf in many places along the coast is less than 4 km wide.

Nature of the Coastline

The coastline is very irregular, indented and fronted by several islands of which the larger are in the northern part; Lamu, Manda, Pate and Kiwayuu. Mombasa Island and Funzi Island are found on the southern coast of Kenya. Between the northern islands there are many reefs and shoaling coral reefs that may extend for 8-10 km offshore. The northern islands have high sandhills on their seaward sides, but elsewhere the islands are fringed with mangroves, and their mainland coast is almost entirely bordered by mangroves. In the Ras Ngomeri area (including Ungama Bay), the shore consists of sandy beaches within which are numerous creeks and swamps. Malindi and Mombasa areas have long sandy beaches and low overhanging coral cliffs associated with scrubs and bushes, fringed by coral reefs extending in some places to a maximum of 5 km offshore. The seaward coast near Mombasa area is very flat but around the island itself there are many creeks and mangrove swamps. The southern area of the Mombasa coast has overhanging cliffs, coral points and sandy beaches. Around Chala point, the coast is rocky and fringes with reefs and mangroves around Funzi Island.

Fisheries Status

The fisheries in Kenya are common property resources and entry limitations are almost negligible in contrast to agriculture, where the land must be owned by a village under customary laws, by a public corporation, or by private individuals. Only fish ponds are privately owned. The only limitation imposed on exploitation of the fishery resources are the government licenses and their use in conservation policies. Regulations have been directed towards protecting the threatened dugong, turtles, shellfish, and corals. Fisheries being a common property implies that there is no ownership of the resource and there is relatvely easy entry and a generally high demand for the fish. This means that there is a continual and definite tendency to increase the effort in terms of men, boats, and nets in the fishery. There is no policy for achieving an optimum yield or maximum sustainable yield that would being the maximum long-term benefit to the fishing community. The major implication of this is that either increases in output from the fisheries come at a rather increasing cost, or that the increases in effort may not increase the harvest.

The marine fishing industry is mainly artisanal comprising of 6,000 fishermen using 2,050 registered fishing boats. Only 10% of the boats are mechanized and fish only within the 12 mile territorial waters. Almost all of the fishing vessels are locally built and are under ten meters in length. The vessels include small one-man dugout canoes, outrigger canoes, sailing dhows, and boats powered by a small diesel engine or an outboard motor. The main fishing gears used are fixed "usio" traps, portable "malemma" traps, handlines, fixed gillnets and tangle nets, and beach seines. Lamu, Malindi, Mombasa are the main fishing ports. There are, in addition, numerous fishing villages and landing places. There are ten active trawlers, six of which fish in the Ungwana Bay area while the rest fish in deeper waters.

Kenyan Government Development Plan (1979-83) has estimated a potential sustainable fishery yield of 7,100 metric tons for the deep sea. The actual inshore landing is 10,800 metric tone. The annual average growth rate is 14.6%. The per capita human fish consumption is 3.4 kg/year and no fish are used for animal feed or other purposes. About 40,000 people are estimated to be employed in the marine fishery industry. The economic impact of the fishing industry is at present rather severely localized for subsistence. Nearly a half of the Kenyan population do not eat fish, partly due to historical reasons connected with its non-availability or superstition. The rather low average consumption figure is therefore somewhat misleading, since in one section of the community fish is a staple item in the diet and other areas it is of no significance. A small marine fish eating community and a small sea going segment of the population have been a crucial drawback in the fishing development. There has not been any significant change in the annual catches since 1967 up to date. The only change has been in the total earnings in fish products from kshs 6,696,314 in 1967 to kshs 15,278,360 in 1977 (Gulland, 1979) (Table 1).

OCEANOGRAPHY

Currents and Water Masses

The dominant feature of the surface currents in the Indian Ocean is the seasonal reveral process in the Arabian Sea and the Bay of Bengal due to changes in the monsoon wind system. The seasonal variation of the monsoons has the following pattern described by Duing (1970); SW monsoon during April to October and NE monsoon during November to February. The intermonsoon period is generally characterized by dry weather. The surface currents respond to the onset of monsoonal winds between February and August (Fig. 3 & 4). During February an area of light winds is found in the region between 3°S and 10°S latitude in the open ocean. Water carried westward by the NE monsoon winds flows southward along Somalia and subsequently forms the Equatorial Counter Current that continues into the region of light winds. At the west of the norhtern tip of Madagascar, the South Equatorial Current (SEC) branches into the southward flow of Mozambique Current and into the northward flow of East African Coastal Current (EACC). Near 2°30'S latitude, in the region off Lamu, the EACC converges with the southward weak flow of Somali Current. This zone of convergence is the root source of the Equatorial Undercurrent (Johnson et al, 1982).

During August, the area of light winds shifts about ten degrees northward with the southeast trade winds extending to about 7°S. The major portion of SEC is returned northward via the powerful Somali Current along the coast of Kenya and Somalia and then flows eastward away from the coast inducing upwelling (Smith, 1982). This current prevails in the entire northern Indian Ocean and its influence is felt south of the equator to 7°S. The Equatorial Counter Current reaches the eastward flow of the Somali Current, they cannot be distinguished as different flows.

The current pattern in the southern Indian Ocean is similar to that of the Pacific and the Atlantic Oceans when the influence of the monsoonal winds is minimal. The SEC flows westward at around 10°S and branches as it approaches the African continent into a northward and a southward flow. The West Wind Drift, a weak and rather confused northward flowing current off Western Australia, completes the counterclockwise gyre in the southern Indian Ocean. The main current off the Kenyan coast is the EACC, which flows northward parallel to the coast and is generally poor in nutrients. This current originates as a branch of the SEC which flows towards the East African coast from the general direction of the northern part of the Seychelles-Mauritius Ridge (Fig. 5 & 6). During the SW monsoon, the wind system reinforces the current which can reach velocities up to 7 knots (Swallow, 1965) and flows as a swift and narrow current crossing the equator merging with the Somali Current. During the NE monsoon, the wind system blows southward against the northward flow of the EACC and in the northern part of Kenya a southward flow stream of the Somali Current is experienced. The Somali Current converges with the EACC in the areas off Malindi and form the Equatorial Counter Current.

Seasonal semi-annual reversals in the wind direction in the monsoonal regions were traditionally used by the Greeks during the Early Roman Empire to carrying out extensive Arabian Sea trade with India and Africa. Arabian trading dhows used the monsoonal wind system to sail to Zanzibar Island off the East African coast and Mombasa. Warren (1966) has documented early records from the medieval epoch and found that semi-annual reversals of the surface currents had been used from as early as the ninth century. Despite the early discovery, the monsoonal current system within the East African coast has been the least explored current. The International Indian Ocean

Expedition between 1960-1965 and the recent observations from the Index pilot projects have provided extensive data on the physical, chemical and biological response of the current system to the monsoons.

The rapid build up of the SW monsoonal Somali Current is caused by winds over the East African coastal waters (Duing, 1977). The current flows as an intense western boundary current that differs from other western boundary currents by its reversal process annually. It flows across the equator where mean flow should be zero due to geostrophy. Bruce (1970) estimated the total volume transported by the Somali Current during the SW monsoon due to geostrophy as 48 x $10^6 m^3 s^{-1}$ for the 0-200 m depths and 74 x $10^6 m^3 s^{-1}$ for the 0-1000 m depths. Bruce and Volkmann (1969) during the NW monsoon of 1964-1965 estimated volume transport values between 20-28 x $10^6 m^3 s^{-1}$. Duing and Szekielda (1971) observed that the large annual change in transport was caused by the monsoonal reversal process from 0-60 x $10^6 m^3 s^{-1}$. Duing (1970) measured 400 m as the maximum depth influenced by the circulation due to the monsoonal mechanism. Leetmaa et al (1982), during the spring and summer of 1979 on a multiship survey studied the changes in currents along the East African coast in response to the transition from the NE to the SW monsoon and observed that southward flow of the Somali Current during NE monsoon had velocity between 50-100 cms^{-1} and transport of 3 x $10^6 m^3 s^{-1}$. The EACC along the Kenyan coast flowing northward had a velocity of about 200 cms^{-1}, and its transport in the top 100 m was 15 x $10^6 m^3 s^{-1}$ (Fig. 7 &8). During the SW monsoon Somali Current reverses and surface currents are greater than 350 cms^{-1} and transport increases from 3 to 27 x $10^6 m^3 s^{-1}$ in the top 100 m.

The characteristics of water masses in the western Indian Ocean have been thoroughly studied by Rochford (1964), Warren et al (1966), and Quadfasel and Schott (1982). The major different types of water masses during the SW monsoon are the relatively warm, saline water originating in the Arabian Sea and the Gulf of Aden (>35.6°/$_{oo}$); and the very cold rather fresh water originating from the Bay of Bengal and the deep circulation. The five intermediate water masses include the Antarctic Intermediate Water (AIW), Red Sea Water (RSW), Persian Gulf Water (PGW) and the Equatorial Water (EQ). Among these, the most distinct are the RSW and the PGW along the East African coast as undercurrents during the monsoonal circulation mechanism and play a major role as agents for salt transport from the northern into the southern Indian Ocean. They may also serve as an indicator for subsurface flow to the surface during the monsoonal periods. The northward flow of the EACC forms the whole of the surface water mass throughout the year along the Kenyan coast. The meeting point of the EACC and the Somali Current varies from the Equator to 3°S (Williams, 1963) according to the strength of the NE monsoon. At the beginning of the NE monsoon, there is a maximum salinity due to saline water being drawn into the Equatorial Current from the South Pacific. Surface temperatures of the EACC reach a maximum between 29.5°-30°C in March shortly after the maximum air temperatures has been reached. The stable water mass existing down to the first main thermocline during the SW monsoon breaks down and a series of subsidiary thermoclines appear in the body of the EACC. This layering of the EACC is not very stable and varies according to the strength of the wind. The depth range is considerably shallow during the NE monsoon than in the SW monsoon.

The subsurface water masses along the Kenyan coast at the ASW, AIW, and the Indian Ocean Deep Water (Fig. 9). Their depths are variable depending on the season and the intensity of the EACC. Along the Kenyan coast the ASW is of most interest as it is usually sinks beneath the surface EACC and has a temperature range between 15.5°- 19°C. ASW undergoes annual fluctuations reaching its maximum salinity and depth range during the NE monsoon. During the monsoon period, the East African coastline is a region where high saline water masses originating from the north interact with water masses of low salinity formed in the southern end and eastern part of the Indian Ocean. To the north of about 3-5°N salinities are generally higher than 35.1‰, and south of 5°S they seldom exceed 34.95‰. Trapped to within a few degrees of the equator there exists a vertically homogeneous water type of intermediate salinities (34.98-35.10‰) (Wyrtki, 1971).

Two sources of high-salinity water in intermediate layers exist in the western Indian Ocean. The excess evaporation over precipitation in the Red Sea and in the Persian Gulf leads to salinities of more than 40‰. The high saline waters enter the Indian Ocean and sink to the depths corresponding to their densities. In the Gulf of Aden the core layer depth of the RSW ($\sigma_\theta \simeq 27.25$) lies between 600 and 700 m, while PGW ($\sigma_\theta \simeq 26.7$) sinks to about 250-300 m. Two sources of low salinity water exist in the southern Indian Ocean. AIW forms at the Antarctic Convergence at around 50°S, sinks and flows north. The mean northern boundary of this water, which is characterized by low salinities (<34.3‰) and a high oxygen content (>5 ml L^{-1}) at its source, and has a density of $\sigma_\theta \simeq 27.4$ and is situated at about 5°S and is found in a depth range of 700-800 m (Wyrtki, 1971). The second water mass of low salinity is the SSW which originates at the subtropical convergence in the Southern Hemisphere near 40°S. It has a density range from $\sigma_\theta \simeq 26.5$ to 27.0 and lies between 300 and 400 m, with temperatures between 8 and 15°C and salinities between 34.8 and 35.5‰. Its main characteristic is the maximum oxygen content (>4 ml L^{-1}) found at temperatures of about 11°C and a salinity of 35.0‰ (Warren et al, 1966). Quadfasel and Schott (1982) have referred to the EW as a water type found along the equator between 3°N-3°S having a salinity range of 34.98-35.10‰ and is roughly bounded by the density surfaces $\sigma_\theta \approx 26.85\text{-}27.50$.

Cox (1970) developed a mathematical model to explain the anomalous currents and water masses associated with the Indian Ocean and concluded that the salinity structure was due to the excess evaporation in the Arabian Sea and the excess precipitation off the Bay of Bengal. Duing and Szekielda (1971), using satellite pictures found a time lag in temperature gradients as an indicator of the early formation of the monsoonal circulation. They suggested that the effects of local winds induced the circulation before the onset of large scale geostrophic circulation. Bruce (1973) made hydrographic measurements of the Somali Current and concluded that the general pattern of circulation considerably changes seasonally. The changes he observed were the eastward flow offshore around 12°N forming the anticyclonic gyre and temperature varying up by upto 10°C due to the upwelling that breaks the thermal structure above 200 m depth. Leetma (1972) used a parachute drogue and geomagnetic electrokinetograph for both shore and offshore measurements during the March-May 1970 SW monsoonal onset. He found that the current underwent two reversals from a southward to a northward flow.

The formation of the Somali Current takes a month after the onset of the monsoonal winds. During the SW monsoon the surface waters, because of their low salinity, can be traced from the EACC and the South Equatorial Current. Anderson and Rowlands (1976) observed the local winds blowing along the coast as a mechanism for the immediate generation of the Somali Current during the SW monsoon. The SW monsoon circulation is generated around the East Madagascar area from the trade winds belt and the south Equatorial Current (Duing 1977). The NW monsoon is generated in the Arabian and the Indian peninsula land masses with a maximum southward flow along the eastern coast of Somalia. The intensity of the NW monsoonal Somali Current is pronounced in January and February, but it never reaches the intensity of the SW monsoonal flow.

LOCAL UPWELLINGS AND THE VERTICAL MIXING BETWEEN THE WATER MASSES

There are a number of upwelling areas associated with the SW monsoon (Cushing, 1971). The northward and southward flow of the monsoonal and local winds drive the surface flows off the Kenyan coast causing localized upwellings. The alongshore stress of the equatorward winds induces an acceleration of the surface currents, which drift offshore under the influence of the coriolis force. Johnson et al (1982) postulate that the deflection of the EACC seaward at its point of convergence with the Somali Current is mainly due to topographic forcing in the North Kenyan Banks. During the SW monsoon, this circulation patterns changes and the Somali Current develops as an intense northward western boundary current. The SW monsoonal upwellings to the north of Kenya are mainly geostrophic ones caused by the tilt in the thermal structure as the current swings away from the horn of Africa (Swallow and Bruce, 1966).

The rapid northward flow of water during the SW monsoon, aided by the strong winds, causes vertical mixing of the water mass so that the EACC has similar physical and chemical properties throughout its depth to the boundary with the underlying water mass. This boundary is marked by a strong thermocline which is deepest during the NE monsoon (Smith, 1982). During the NE monsoon when there is no upwelling, the pycnocline near the East African coast is deeper than during the SW monsoon (Fig. 10). Current shearing is normally considered at vertical interfaces between water masses, but it does occur at horizontal interfaces, and in East Africa there is a marked interface between the north-flowing EACC and the Somali Current. During the SW monsoon the EACC and the ASW must cause a great deal of turbulence and mixing due to the convergence of the two water masses. During the NE monsoon this mixing will be less as the EACC slows down. The stratification of the sea off Kenya exists right up to the fringing reefs and it is possible that submarine banks, islands and promontories which stand in the path of the various water masses may cause a break-up of flow and create local eddies and wakes with resultant vertical mixing. There are some few places where turbulence is present throughout the year: near Pemba Island, near Malindi (off the Sabaki River) and in the northern part of the deeper waters off Ungama Bay. Other upwelling areas are given by Foxton (1965), Warren et al (1965), Ryther et al (1965); Ryther and Menzel (1965), Bruce (1974), Smith and Codispoti (1980), and Smith (1982).

The physical and chemical environment of the NE monsoon along the Kenyan coast is associated with low salinities, minimum current velocities and warmer waters. The SW monsoon, on the other hand, is associated with high salinities, maximum current velocities (3-5 knots) and waters that are colder but richer in nutrients (Brusher, 1974). Birkett (1979) describes the water of the EACC to be relatively poor in nutrients during the NE monsoon when it is weakened and water flows eastward as the Equatorial Counter Current. The EACC, however, is poor in nutrients, reaching the coast as the Southeast Equatorial Current after a passage of 6000 km across the Indian Ocean. This is a critical factor that limits primary productivity along the coast. SEC is characterized by low PO_4 nutrient less than 0.60 μg at l^{-1} (Thorrington, 1974).

High salinity water from the Arabian Sea, low salinity water from the Bay of Bengal and the nutrient rich waters in upwelling areas have pronounced effects on the food chain dynamics in this area. Records of oxygen content, pH, inorganic and total phosphate indicate that a seasonal phytoplankton cycle occurs in the surface flow waters. The outburst of growth would commence during the NE monsoon, the actual date being dependent upon the length and intensity of the preceding SW monsoon. Maximum phytoplankton growth appears to be in March, and the surface waters reach their minimum fertility from June to September (Williams, 1963). Total phytoplankton growth for East Africa appears to be small compared with the adjoining Arabian Sea to the northwest (Thorrington, 1971). During the NE monsoon a closed gyre circulation is prominent and nutrients would tend to be depleted faster by plankton in the area. There is a possibility of some of the nutrient rich Somali Current waters being brought into the East African circulation system. During the SW monsoon plankton accumulation would be unlikely because of the rapid dispersal of organisms both vertically and horizontally because of increased water column turbulence.

Temperature, salinity, alkalinity, pH, oxygen, phosphate, total phosphorous, silicate, nitrite and nitrate concentrations are major factors in primary production. The wind conditions of the monsoon induce upwelling and turbulence resulting in transports of organic and inorganic nutrients from below the permanent thermocline to the euphotic layer. This should increase the annual primary production by supporting a high phytoplankton growth rate in this tropical light unlimited area.. During the monsoon surface waters are well mixed and separated from the subsurface water by a stable boundary layer. Upwelling breaks this barrier and allows the transfer to new and regenerated nutrients to the surface. These nutrients are used by phytoplankton that increases phytoplankton biomass (Thorrington, 1971; Subrahmanyan et al, 1974) at boundaries where the equatorial undercurrent is elevated and when the EACC meets the ASW and the Somali Current.

At the abrupt change of temperature of the thermocline between the EACC and the ASW there is a rise in salinity, density and phosphate concentration and a fall in pH and oxygen content. The accumulated debris at this density barrier may be a source of regenerated nutrients. The organic matter is oxidized at this point and a drop in oxygen content and pH and a rise in inorganic phosphate would be expected. Currie et al (1973) observed very high PO_3^{3-}P values due to the monsoon upwelling. High concentrations were found at the point where the Somali Current left the coast and in the colder water regions where the current met the ASW.

Warren et al (1966) measured temperature, salinity and the dissolved oxygen concentration during the SW monsoon. They observed that both temperature and salinity decreased with depth, and the dissolved oxygen decreases upto a depth of 500 m then starts to increase again. Ryther and Menzel (1966) measured the same properties together with dissolved organic carbon, particulate carbon and phytoplankton pigments. Using Nansen bottle casts and carbon-14 assimilation techniques, they observed that nutrient levels increased sharply with depth beginning from the surface to within the limits of the euphotic zone 50-200 m. Dissolved oxygen dropped to 0.5 ml/l below the euphotic zone reflecting a high oxygen consumption by organisms and decay. Ryther et al (1965) mapped low and high primary production areas corresponding to the nutrient concentrations in the high and weak upwelling areas respectively. They used carbon-14 and the light and dark bottles method to measure the primary productivity. They found low productivity levels south of the equator where upwelling was weak and high productivity where upwelling was strong. Bogorov et al (1966) have defined productive and moderately productive seasons depending on phytoplankton biomass estimates they made. They identified biologically distinct seasons: SW monsoon, June-August; NW monsoon, December-February; and the intermonsoon periods of October-November and March-May.

Wickstead (1961) described the plankton distribution along the North Kenya Banks and noted the bottle green colors of inshore waters. This observed enriched coastal plankton abundance increased towards the north. George (1968) noted a red tide phenomena as a threat to fisheries in the Bay of Bengal. Foxton (1965) working on both offshore and inshore waters off the Somali coast during the SW monsoon, observed a high plankton abundance and dead and moribound fish in isolated patches. He accounted for this by the presence of an exceptionally cold front of upwelled waters from the deep with a minima of 13.2°C. Another suggestions would be due to the low dissolved oxygen saturation values that are associated with monsoonal upwelling. This may be true, but usually one would expect a very high oxygen content if there are associated phytoplankton blooms. Swallow and Bruce (1966) also observed cold water areas to be associated with some dead fish. The dead fish species were mainly sluggish families of the Diodontidae and the Balistidae. This may suggest that the commercially important species migrate to warmer water masses associated with the monsoon.

PRIMARY PRODUCTIVITY AND THE GENERAL PLANKTON

Primary production measurements estimate the rate at which phytoplankton convert inorganic matter into organic carbon. It had been the belief that tropical waters in general and the Indian Ocean in particulate are not productive compared with temperate and polar waters. It appears that this view was due to the lack of sufficient knowledge about the organic life in these waters. The distribution of primary productivity has been charted by Kabanova (1968). This study showed some productive areas in the Indian Ocean (Cushing, 1971). During the NE monsoon, areas of high production lie off northwest Madagascar up to the coast of Tanzania; there is a band of high production off Kenya and areas associated with divergence of the South Equatorial Current.

The SW monsoon period shows very high production in the Arabian Sea and scattered patches along the East African coast.

Wickstead (1962) measured plankton dry weights in the North Kenya Banks to be between 55 mgm/m^2 - 161.6 $mgm/^3$ and estimated that 32.27 kg plankton dry weight were produced beneath one oacre of water each year. Ryther et al (1966) mapped areas of low and high primary production corresponding to the nutrient concentrations and major water types during the SW monsoon. Fig. 11 shows the general level of primary production along the Kenyan coast to be between 0.51 - 1.00 $gCm^{-2}d^{-1}$. Smith and Codispoti (1980) measured primary productivity during the SW monsoon and found a higher value of 0.8 - 1.7 $gCm^{-2}d^{-1}$, compared to the NW monsoon value of 0.1 - 0.3 $gCm^{-2}d^{-1}$. These high values were associated with high concentrations of nutrients at the surface in upwelled waters. The separation of the Somali Current from the east of east Africa (Smith, 1982; Johnson et al. 1982) induces upwelling of deep water that is cold and has high nutrient concentration and hence can be associated with blooms of phytoplankton. Codispoti (1981) has attributed the nutrient variability in the area due to the local winds and monsoonal season.

The semi-annual reversal in wind direction markedly affects the chemical conditions along the Kenyan coast. Records of the oxygen content, pH, inorganic and total phosphate (Williams, 1963) indicate that a seasonal phytoplankton cycle occurs in the surface waters. The outburst of growth commences during the NW monsoon when there is very little turbulence. The actual date of growth enhancement would be dependent upon the length and intensity of the SW monsoon that fertilizes the water column. Regions of high phytoplankton abundance have been associated with environmental instability (Thorrington, 1974). The shear zone at the boundary of the Equatorial Undercurrent, where the EACC and the Somali Current converge would be an area of instability. Because of the contact and stress between the different water masses EACC, ASW and the Somali Current, there is likely to be a disruption of a consequent formation of micro-habitats. Sensitive phytoplankton species to environmental instability will not flourish and only the adaptable and opportunistic species will be able to capitalize on the situation. Smith and Codispoti (1980) identified two species of diatom Nitzschia delicattissima and Rhizosolenia styliformis as the characteristic species found in high numbers during the SW monsoon.

Seasonal variation in primary productivity during the two monsoonal periods results in a high zooplankton biomass during the height of the SW monsoon to the north of the Kenyan coast, but low biomass to the wouth were the wind system is very weak. High abundance of gastropods, amphipods, euphausids, copepods and calanoids together with empty shells of Limacina inflata has been observed off the Kenyan coast during the SW monsoon by the International Indian Ocean Expedition group. Empty shels would indicate mass mortality due to the toxic effects of high phytoplankton blooms that may lead to deoxygenated waters. The plants die off due to overcrowding and the dissolved oxygen is used by bacterial decay. Wickstead (1963) and Okera (1974b) have found high cladozeran zooplanktons between December-March with peak values that did not coincide with any period of the monsoon. Smith and Lane (1981) have documented the zooplankton collected during the SW monsoon using Bongo frames fitted with 223 and 333 μm mesh nets and T.S.K. and general oceanic flowmeters. Tables 2 and 3 represents samples taken along the Kenyan coast.

The Indian Ocean Expedition charts of the distribution of zooplankton in numbers per volume measured by hauling the Indian Ocean standard net from about

200 m has been converted into gCm^{-2} by Cushing (1971). During the NE monsoon high production of 1.95 gCm^{-2} was observed off the Kenyan coast, while during the SW monsoon lower production of less than 0.98 gCm^{-2} was recorded. Smith (1982) collected planktons in hauls from 200 m to the surface during the SW monsoon and found values from 0.82 - 6.96 gCm^{-2} with extremes in upwelling areas. General categories of zooplankton (Wickstead, 1963; Okera, 1974b; Smith and Lane, 1981; Smith, 1982) shows that total cyclopoida and chaetognatha are significantly more abundant during the NE monsoon. Other general categories are Harpacticoida, calanoida, euphausiacea and appendicularians that show no significant differences in mean abundance between the monsoons.

The feeding of zooplankton on phytoplanton is a function of both concentration of food and species compositon. Ingestion would then, increase when food concentration is increased during the SW monsoon and the zooplankton would store lipids (Smith, 1982) and thereby become independent of food supply for some period of their life cycle, when food is a limiting factor for growth. These would be used for growth and reproduction. The total biomass of zooplankton in general is significantly greater within areas of upwelling and turbulence than outside. A high frequency of reproductively active population can be explained as an annual life history strategy associated with the reversal in the monsoonal circulation.

Cushing (1971) described the distribution of fish larva and eggs in the Indian Ocean. During the NE monsoon, eggs are found inshore off the North Kenyan Banks with densities not greater than 101-200 per square meter, while during the SW monsoon dense larval concentrations occur farther north of the equator near the Somalia coast. Between April-October, SW monsoon, fish eggs number between 0-24 per haul while between October-April the number ranges between 50-100 per haul. Recruitment into prawn resources has been found to occur between February and

March (Brusher, 1974); this coincides with the time when the zooplankton are numerically abundant. Heavy rains occur along the East African coast between March-May and light rains in October, so that flow from the rivers reach a maximum from April to June. The brackish outflow from these rivers is kept close inshore by the prevailing northward flow of the EACC and hence does not explain the high occurrence of fish larvae during the NE monsoon.

FISH STOCKS AND FISHERIES

In temperate and in arctic waters, a fish stock often has a fixed spawning ground, a single cohort spawning season and a consistent migratory circuit. Here a unit stock has been defined as a group of individuals of a species that have the same biological characteristics. These are the growth rate, recruitment rate, natural mortality, catch per unit effort and fishing mortality rate. Knowledge about the nutrient availability, phytoplankton growth rates, zooplankton abundance and the fish stocks along the Kenyan coast is a vital tool for the effective utilization of the biological resources in the area. Oceanographic information is essential to understand the ecology of the major fish stocks and can be used in fishery models to plan a management strategy. The major oceanographic factors: surface temperatures of EACC, offshore transport by NEC, mean sea level, the Somali Current, ASW and the Equatorial Undercurrent influence the spawning, food availability for ichthyoplankton and settling and survival of the larval and juvenile fishes to mature.

Fish landed along the Kenyan coast have been classified as pelagic and demersal fish, crustaceans and molluscs. This classification has been adopted for convenience due to lack of trained personnel who can identify the fish landed to the species level. The data collection system in mainly market-oriented and given very little inforamtion on the biological factors of the fishery or its response to the intensity of fishing both of which are necessary for management decisions. Williams (1963), Williams (1965) and Merret (1968) have identified the following as the target species of the Japanese and Korean long-line fishing fleets operating in the area: bluefin tuna, yellowfin tuna, albacore, bigeye tuna, swordfish, black marlin, blue marlin, striped marlin, and sailfish. Incidental catches caught during their operations include sharks, wahoo, skipjack tuna, and barracuda. Catch rates for sailfish during the SW monsoon is 0.01/100 hooks and 0.31/100 hooks during the NE monsoon. Game fishery for sailfish at Malindi is restricted to the NE monsoon where about 80% of the catch is being taken from December to February. Striped marlin has high catch rates of 2.86/100 hooks during the NE monsoon. Losse (1969), Darracott (1977), Nzioka (1979), and Birkett (1979) have identified the major demersal and pelagic stocks. Pelagic fishes in order of abundance include the families Clupeidae, Scombridae, Carangidae, Mullidae, and Leiognathidae. Demersal fishes include Lutjanidae (red snappers), Lethrinidae (emperors), Sphyraenidae (barracudas), Pomadasyidae, elasmobranchs, rays, and skates. Crustaceans include the rock and spiny lobsters, prawns and shrimps, and portunid crabs. Cephalopods include squids, cuttlefish, and octopus.

Williams (1963), using morphometric differences between the yellowfin tuna caught along the East African coast and those caught in other different geographical areas, concluded that the East African yellowfin tuna was a separate stock. He based his conclusion on fin counts, gillrakers number, length and weight relationships and the highly seasonal catch rates. Yellowfin tuna is caught more frequently during the SW monsoon when the EACC is coldest and occupies its greatest depth range and is relatively isothermal from the surface to the thermocline and the boundary between the EACC and the ASW. The maximum yellowfin tuna catches during the SW monsoon in some areas along the coast can be attributed to the local enrichment of the water column initiated by the strong monsoonal winds that cause vertical mixing between the nutrient poor EACC and the nutrient rich ASW. This monsoonal mechanism should at least support a short three trophic stage involving the phytoplankton, zooplankton and small nekton fed on by the yellowfin tuna. This should explain why a high peak catch rate for the yellowfin tune has been observed in late November when the SW monsoon subsides. Spawning is between June-December along the inshore coastal waters (Darracott (1977) and very large shoals of very small tuna have been observed in February during the NW monsoon.

The biology of the demersal, pelagic and crustacean stocks are influenced by the effects of the monsoonal periods. Dominant species are found in different areas with differing levels of abundance during the two monsoons. Williams (1965) made morphometric observations on species of Carangid and Sphyaenid families and concluded that each of the species of caranx and sphyraena could be considered as a unit stock. He observed more increased catches toward the end of both the NW and SW monsoons. The uniform physico-chemical characteristic of the surface water mass of EACC should explain the availability of the stocks throughout the year. Spawning of these stocks take place throughout the year. Merrett (1968) surveyed the area between 2°N - 13°S for tuna stocks using handlining gear and found a higher mean catch per unit of effort of 2.1 pounds per hook during the NW monsoon compared to the 1.8 pounds per hook during the SW monsoon. The commercially important species were the yellowfin tuna and the striped marlin that formed the dominant species of the fishery constituting up to 65.45% by weight of the catch. The remainder of commercially exploitable stocks were in descending order: albacore, bigeye tuna, blue marlin, sailfish, black marlin, and skipjack. The 1968 Tuna Longline Survey results showed that increased NE monsoon catches were due to the increased availability in catches of the striped marlin and sailfish in the inshore waters down to the 500 fathoms from the Zanzibar Island up to the north of the Lamu archipelagos. At the same time, there was also increased catches of the bigeye tuna offshore. During the SW monsoon prevalent species are the yellowfin, albacore, and skipjack.

Decapterus spp,. Gnathodon spp., Cerangoides malabaricus and Selar sp. are some of the pelagic stocks off Kenya that produce large catches between 150-230 kg/hour (Birkett, 1979) during the SW monsoon in July caught by trawl net. The main species among the clupeidae and Engraulidae caught off Kenya are the round herring Etremeus micropus (152-244 kg/hour) in July. Rastrelliger kanagurta yields 50 kg/hour occasionally off Kenya. Other herrings important in the pelagic fishery are Herklotsichthys sp., Sardinella sp., Hilsa sp., and Pellona spp. All are neritic and fished mainly in bays and estuaries. They show the greatest fluctuations from year to year in abundance mainly in response to the rainy seasons and the NE monsoon. Sardinella longiceps studied by Losse (1966), Loose (1969), Okera (1973) show maximum abundance in the Indian Ocean in areas of upwelling and biologically rich waters. Its occurrence along the Kenyan coast may be associated with the southward inflow of the relatively nutrient rich Somali Current during the NE monsoon. Sardinella longiceps may be a useful indicator of the inflow of biologically rich waters off the Kenyan coast. The species generally avoids areas of deep thermocline and biologicall poor surface waters.. Sardinella albella is available throughout the year (Okera, 1974a). Two populations of Sardinella gibbosa have been observed by Losse (1969); one during the SW monsoon and the other during the NE monsoon. These populations differ in mean body depth, gillraker numbers and the spawning season.

CRUSTACEANS

The major crustacean fishery stocks are the lobsters, prawns and shrimps, and crabs. The spiny lobster Puerulus carinatus is a dominant species in the 200-500 m depth off the Ungwame Bay where catch rates between 20-60 kg/hour by trawl nets are frequently made during the SW monsoon. Other lobster species include Puerulus angulatus, Panalirus ornatus, P. vesicolor, and P. longipes during the NE monsoon. The deep water shrimp Heterocarpus spp. and the shallow water shrimp Parapeneus rectacutus have been observed along the Kenyan coast (Scheffers, 1982). There are five species of Penaeid prawns that are of commercial importance within the trawlable areas of the Ungwana Bay complex. In order of abundance, they are: Penaeus indicus, Metapenaeus monoceros, Peneus semisulcatus, Penaeus monodon, and Penaeus japonicus. The River shrimp, Macrobrobrachium sp. has also been observed by Brusher (1974) in the upper reaches of the Mombasa estuarine area.

Offshore prawn stocks are concentrated seasonally within specific depth zones (Brusher, 1974). During the NE monsoon, prawn populations were located in a 0-30 m depth zone with average catch per unit effort (CPUE) of 23.8 kg/hour while the 30-100 m depth zone areas had a CPUE of 4.2 kg/hour in the same monsoon period. During the SW monsoon, the prawn CPUE in the 0-30 m depth areas was 4.6 Kg/hour and catch at the 30-100 m depth areas was 67.4 kg/hour. This apparent prawn movement between depths within the Ungwana Bay complex may be due to the low salinities of the SW monsoon oceanic environment in May plus the large influx of fresh water discharge from the Sabaki river during the rainy seasons.

SPAWNING, BREEDING AND RECRUITMENT ACTIVITY

Okera (1969) noticed that some species of sardines are single spawners with a spawning season towards the end of the SW monsoon. Recruitment into the fishery occurred during September and a high fat content in the sardines has been observed at the beginning of the SW monsoon in April (Okera, 1974a) when zooplankton abundance is very high. The largest gonad sizes for both sexes of *Sardinella gibbosa* and *S. albella* are found between August to September when the SW monsoon subsides. Williams (1965) has observed that the major pelagic stocks spawn between July to March with a peak during the NE monsoon and an increased high juvenile catch is observed between February and March. Kamanyi (1975) found that the abundance of the Indian mackerel *Rastrelliger kanagurta* during the NE monsoon coincided with its spawning season. The spawning season is between September to December when the majority of the female catches have gonads showing advanced stages of gonad development (stage IV and V).

Williams (1963) saw a sex differential ratio of a 1:1.30 between males and females albacore tuna during the SW monsoon. Spawning period of the fish is between July and December. The presence of spent and recently spent fish in July and November, and ripe and running females in December has been used to estimate the spawning period along the Kenyan coast. Darracott (1977) observed an increased availability of demersal stocks during the SW monsoon prior to the short rains in October-November when a pronouced feeding and spawning activity occurred in the inshore waters along the East African coast. Nzioka (1979) examined maturity stages of the commercially important reef fishes and found ripe gonads and a breeding peak towards the end of the SW monsoon.

Mutagyera (1975) examined breeding females of the spiny lobster *Panulirus ornatus* and found that a breeding peak occur towards the end of the SW monsoon. Brusher (1974) observed the offshore movement of the dominant prawn species *Penaeus indicus* from the estuarine nursery areas within the Ungwana Bay complex during the NE monsoon, and ripe females are observed in December before the NE monsoon. One hypothesis is that during the NE monsoon, the emigration period of post-larval prawns, the stocks follow the southward flow of the Somali Current, ASW and their convergence with the EACC.

Changes in fish availability and breeding activity can be due to migration for reproductive purposes or to variation in food supply. In exploited stocks it can be due to overfishing. Zooplankton abundance and primary productivity along the Kenyan coast are determined by the monsoonal periods and the rainy seasons. The cold waters of the SW monsoon and the increased river volume discharge into the estuarine areas may act as a trigger mechanism for spawning. Commerically important species will come inshore in greater numbers towards the end of the monsoonal periods when the rainy seasons begin to give birth in shallow sheltered depths. Results of primary productivity studies so far reported for the Kenyan coast (Kabanova, 1968; Smith and Codispoti, 1980; Smith, 1982) conclude that the period of maximum productivity is during the SW monsoon. A conclusion from the above studies is that most of the stocks maintain a level of breeding throughout the year with peaks at the ends of both monsoons and that the rainy season is an important factor for the spawning of some species. The North Kenya Banks area is a feeding and spawning ground for most of the major stocks.

STOCK ASSESSMENT

A variety of models are available for the assessment of the status of a fishery. The more elaborate analytical models require statistics on a number of variables such as catch, effort, growth rate, stock size, recruitment, age of entry into a fishery and fishing mortality rate. The traditional techniques of stock assessment and the study of the dynamics of exploited fish populations around the temperate waters of the North Atlantic and North Pacific rely to a large extent on information on the ages of the fish. In these waters this can be obtained for most species from the examination of otoliths or scales. In tropical waters this has not proved easy. The absence of big seasonal differences means that there are few clear markings at annual intervals on otoliths or scales that can be used to determine age or growth rates that are essential in stock assessment models.

Other biological properties of tropical stocks have been discussed by Munro (1980) and Pauly (1980b). There are a large number of species being exploited in one single fishing ground. This leads to extensive lumping of species in the fisheries statistics, resulting in an absence of data, one of the basic items required for analysis of the individual species as a basic unit for stock assessment. Biological interactions between the species, that is how one species affects the growth, death and birth rates of other species is unknown. Component species are generally small sized and mainly in shallow waters. Migratory movements of the fish assemblages are unknown. The main controlling growth factors for fishes in the tropics are the temperature, light and amount of radiation, nutrients and primary productivity.

In tropical areas the average daily incident illumination shows little variation as compared with high latitudes despite short lived changes due, for example, to thunderstorms and cloud cover. The light available for primary productivity reach depths greater than 100 m and productivity is only limited by nutrient availability. This means that there is a constant phytoplankton crop throughout the year except during the rainy season when river inflows into the oceans may enrich the water column, and seasonal variation of the phytoplankton crop is also due to the monsoonal mechanism. The short lived increase in food supply for fish would mean a faster growth rate and small size to take opportunity of the temporary rainy season or upwelling in warm waters. This would mean that most fishes would devote more energy to reproduction in contrast to larger fishes in temperate waters that grow slowly but are able to carry greater energy reserves through periods when food is virtually absent, as in winter. Natural mortality caused by predation and diseases in fishes is a function of both size, growth rate and the environmental temperature. Pauly (1980c) has demonstrated this relationship on the basis of literature on 175 fish stocks and found that natural mortality in tropical fishes, other things being equal, is twice as high in tropical as in temperate waters. Seasonal spawning and recruitment of the major stocks along the East African coast has been studied by Darracott (1977) and Nzioka (1979). Both observed that spawning and breeding activity occurred throughout the year with two peaks corresponding to the periods of the weakest winds and currents at the end of the NE and SW monsoons.

Gulland (1979) reviewed the major methods used in the assessment of fish stocks. A list of these methods in decreasing order of demands on data requirements are:

a. Analytic methods (Beverton and Holt or Ricker models). These take into account the growth of the individual species and the mortality rates caused by fishing and by natural causes. These methods require information on the age and growth of individual fish and have not been used along the East African coast.

b. Production models (Schaefer type models). These methods require reliable data on total catch and total fishing effort (CPUE) covering a period during which there has been big changes in total fishing. This method has been used for tuna longlining survey by Williams (1963; 1968); and crustaceans fisheries on the North Kenya Banks by Brusher (1974).

c. Estimation from biomass data obtained from surveys. This is the method most widely used and has been used by Birkett (1979) and Scheffers (1982). Several assumptions have to be made when using this method: area covered by gear must be known and the proportion of fish caught in a gear is a representative of the community, catch rates and fishing intensity per unit area must be constant, and the different areas fished are also assumed to be ecologially similar (Munro, 1980) and to support fish communities of similar composition and biomass.

The notion that methods developed in the temperate regions could not be applied in tropical waters and whether things were essentially the same everywhere and that methods were universal was a philosophical question for sometimes. Many fish stocks in tropical waters consist of annual fishes, hence allowing one to follow the growth and decay of a cohort within a period of twelve months. This can further allow one, when there are well defined spawning seasons to determine the growth from length-frequency data and neglect time lag effects when fitting Schaefer-type models to catch and effort data. Estimation of recuirt numbers from yield-per-recruit can also be done including age in days or months.

The most important technical development for tropical fish stocks are the length-frequency based methods for fish stock assessment. These methods have their origin in the equation developed by Beverton and Holt (1956) which state that:

$$Z = K\,(L_\infty - \overline{L})/(\overline{L} - L')$$

where Z is the coefficient of mortality, K is the coefficient of growth, L_∞ is asymptotic length, L' is the smallest length of fish that is fully represented in the catch, and $\overline{L}$ is the average length of all fishes lying between L' and L_∞. Fig. 12-14 from Pauly (1980a) show how estimation of growth parameters can be done from length-frequency data and growth parameters. With problems of population parameter estimation partially solved, the challenge for fish stock assessment would be whether the effects of selective or non-selective exploitation patterns by the use of dugout canoes, motorized boats, gillnets, traps, hooks, harpoons, poisons, modern trawls, and bench seines can give a meaningful estimate of maximum sustainable yield.

MAXIMUM SUSTAINABLE YIELD (MSY) CALCULATIONS ALONG THE KENYAN COAST FROM THE SURPLUS PRODUCTION MODEL

In an unexploited fish population natural mortality usually equals the birth rate so that the population persists. If the natural mortality was very high, then the stock would eventually become extinct. In exploited fisheries two responses allow fisheries managers to maintain fisheries at a desirable level. The first response in that environmental variability such as upwelling may favor increased productivity such that birth rates will be higher than death rates. A fishery can then operate by harvesting off the surplus production. The second type of stock response is compensatory density dependence where natural regulation takes place so that production fluctuates around the carrying capacity. These changes in productivity can be expressed as yield estimates for the stock by estimating the equilibrum stock size or the carrying capacity. The difference between birth and death rates is the source of increase for the stock and is called "surplus production." It is available for harvest without depleting the size of the stock.

Most fisheries are conducted on a weight basis rather than by numbers. The algebra for yield calculations for the surplus production model is therefore expressed in biomass terms. A graphical presentation of the model is given in Tyler and Gallucci (1980). The rate of change of the stock biomass (ΔB) depends on the size of the stock itself and also on the distance between the biomass and the maximum equilibrum stock size, B_∞. This can be expressed algebraically as:

$$\Delta B = \frac{kB_E(B_\infty - B_E)}{B_\infty}$$

where the difference between B_E and B_∞ is written as a proportion.

k = intrinsic rate of population growth

ΔB = surplus production that may be taken in a unit time as equilibrum yield Y_E

B_E = biomass of a stock when it is in an equilibrum condition

If the surplus production curve is symmetrical, then the stock size produces maximum sustainable yield, B_s, is one half B_∞,

$$B_s = \frac{B_\infty}{2}$$

Hence from above

$$Y_E = k\ B_E - \left(\frac{k}{B_\infty}\right) B_E^2$$

To find the maximum sustainable yield in terms of B, we substitute B_s in place of B_E

$$Y_s = k\ \frac{B_\infty}{2} - \left(\frac{k}{B_\infty}\right)\left(\frac{B_\infty}{2}\right)\left(\frac{B_\infty}{2}\right)$$

$$Y_s = k\ \frac{B_\infty}{4}$$

The annual maximum sustainable yield represents removal of one quarter of the maximum stock size each year, multiplied by the rate of increase.

The above relationship has been used in a modified form (Gulland, 1974) as

$$Y_s = 0.5\ MB_o$$

where

Y_s = maximum potential yield

M = natural mortality coefficient of the stock.

B_o = unexploited virgin biomass (stock size)

When fishing mortality and natural mortality are known then

$$Y_s = 0.52B$$

where Z = total mortality = F + M, F = fishing mortality

B_1 = biomass at the time a survey is done.

The model $Y_s = 0.5MB_o$ is twice the model $Y_s = \frac{kB_\infty}{4}$

The explanation for this is that in the tropical situation growth rates tend to be higher because of high stable annual temperatures when compared to temperate ecosystems where the original method was developed for use. The model MSY = $0.5MB_o$ has been used by Gulland (1979), Birkett (1979) and Scheffers (1981) to calculate potential yields, biomass, fishing mortality and natural mortality of groups of fishes (stocks) along the Kenyan coast.

Birkett (1979) and Scheffers (1981) estimated potential yield of different groups of fishes from catch and effort from exploratory trawling surveys along the Kenyan coast. Each trawl haul was assumed to be representative of the biomass of fishes present in the area of water swept by the trawl net. Where the biomass

$$\underset{(mt)}{\text{biomass}} = \underset{(mt\ n\ mi^{-2})}{\text{mean density of fish}} \times \underset{(n\ mi^{-2})}{\text{area swept by trawl net}}$$

mt = metric tons, n mi = nautical miles

$$\underset{(mt\ n\ mi^{-2})}{\text{density of fish}} = \frac{1}{0.035} \times kgh^{-1}x10^{-3} = 0.28\ kgh^{-1}$$

where $0.035\ n\ mi^2h^{-1}$ is the average area swept by a 16.4 m wing-end to wing-end length trawl at the average towing speed of four knots.

There are several assumptions for the applicability of the surplus production model along the Kenyan coast. Assessment for fish stocks is based upon treating the multispecies caught in a trawl into species groups, that is, a community and then defined as a single stock. Scheffers (1981), because of the large heterogenity of fishes along the coast found it impracticable to calculate the biomass and potential yield for every single species. He grouped the fishes into fifteen groups taking into account their economic value and estimated natural mortality. The mean growth rate and natural mortality are considered to be representative. The relationship between year class strength, recruitment and spawning stock is also assumed to be constant. The biomass estimates are realistic and that there is a slow change in fishing effort, that is fishing is mainly artisanal. Fig. 19 shows on aerial distribution of the artisanal sector of the fishing industry.

MANAGEMENT

Fishery management is an integrated discipline of science, and social, ecological, economic and political factors with no set weighting but with consideration for the realization of an institution's goals and objectives. The idea that a stock of fish should be harvested to provide a maximum sustainable yield has been used to manage most fisheries around the world (Larkin, 1977). Regulations are used to achieve it by regulating the minimum mesh size used in a fishery, annual catch, quota sex and species caught. How the fish is caught is determined by the fishing vessels, gear used, fishing seasons and fishing grounds. At a large effort the fish population gets depleted and fish becomes hard to catch. A shrewd fisherman would want to establish a level of fishing effort to realize the MSY. Fisheries managers always recommend a lower fishing effort because of the difficulties in realizing the MSY or the best fishing effort that realizes it. The stock assessment results done along the Kenyan coast left no room for environmental variation and no knowledge was available for yields at very large fishing effort. Therefore, the simple models used in the region do not produce reliable estimated sustainable yield.

Knowledge about the fish stocks, zooplankton distribution and abundance, and phytoplankton growth rates is a vital tool for the effective utilization of the biological resources along the Kenyan coast. The interacttion between the biota and the progressive changes in the chemical and physical characteristics of the water column resulting from the monsoonal phenomena may determine the destiny of a significant part of the world population. A fishery manager here would have to find functional relationships between the oceanographic conditions of: winds, nutrient concentrations, temperature, salinity and currents; to the supply of food for recruitment patterns and regulate fishing by monsoonal seasons.

The climatic regime with its strongly contrasted monsoon periods is a major determinant of the periodicity and intensity of biotic processes. The incidence of strong winds during the SW monsoon must be allowed for deciding upon the timing of fishing seasons. The distribution of commercial species has been found to be related in various ways to the monsoon regime (Williams, 1963; Merret, 1968; Cushing, 1971; Okera, 1974a; Kamanyi, 1975; Mutagyera, 1975; Darracott, 1977; Nzioka, 1979; Scheffers, 1981). Major concentrations of the fish stocks are associated with areas of turbulence and currents convergence. During the NE monsoon a narrow coastal zone of fairly high production is maintained along the coast of Kenya. The entire area is tropical with strong heating from radiation, and high evaporation, resulting in high temperatures and high salinity in the surface layers. There is a biomodal temperature cycle with a maxima in March and December (Williams, 1965; Okera, 1974b). Observations of primary production from the Indian Ocean Expedition has shown very high production during the SW monsoon around the North Kenyan Banks. This is the major fishing ground. Fig. 20-25 show that most of the commercial stocks are concentrated between Malindi, Ungama Bay and North Kenya Banks. The SW monsoon has a higher density of most of the groups of species than the NE monsoon.

Estimates of the maximum yields for the demersal, pelagic and crustacean fisheries are now available. The maximum sustainable yield from the inshore coastal fishery is not known exactly, only the fishing activity has been estimated by Coppola (1982). Estimated catches from the Indian Ocean areas and the adjacent seas is about two million tonnes per year. On the basis of yields this is approximately 20% of the total world yields and the Kenyan contribution is ranked at 2% (Gulland, 1979). Yield is based mainly on coastal inshore species which make up 80% of the entire catch (Kambona, 1980). Low yields can be attributed to simple gear and effort which has a greater impact on the subsistence level rather than the industrial fishing that the government has a keen interest.

POSSIBLE MANAGEMENT STRATEGIES

Fish stocks off the Kenyan coast are now at least moderately being exploited. The question of management of the available resources depend upon the ability to predict alterations in species composition and yields under different possible management strategies. Regulation of inshore demersal fisheries began in the 1950's by limiting mesh sizes, although the sizes chosen were based from experience in temperate waters. The diversity that includes fish of a wide variety of shapes, makes it difficult to decide upon a single mesh size. Tyler et al (1982) have suggested the use of an assemblage production unit of a group of fishes that occur together to be managed as one unit instead of the traditional management of fisheries on a species by species basis. This would allow the use of the mixed multispecies catch grouped together as a unit shock and the application of yield models to determine the maximum yields of the commonly landed fish groups for a given area.

The management of tropical fisheries on a multispecies basis have three pronounced attributes which lead to the difficulty in their biological management; a large number of species being exploited, biological interactions between species and the fishing mortality imposed on the fishery is not equal for all species and is influenced by fishermen's behavior. This means that the species are so evenly mixed on the fishing grounds and in the catches no preference for one species can be implemented for a fisherman. The scientific analyses can be made for each species, yield curves for each species can be calculated and added together to give the total yield. From this, the management target quota can be determined. The current available methods have been criticized by Munro (1980) and Pauly (1980) to be inadequate to resolve many of the questions arising from management questions requiring prediction of the species mix under widely differing fishing regimes. Research directions should be directed to assess the impact of fishing techniques generally used (small meshes, high effort) on the various stocks of the Kenyan coast.

ISSUES FOR INTERNATIONAL FISHERY MANAGEMENT

The four major areas where international fishery management in the Indian Ocean are of a major concern are the tuna-like fisheries; areas where rivalries between neighboring states exist; migratory species and the activities of non-Indian Ocean states. Clement (1971) has identified some commonalities among the Indian Ocean countries that may be critical in the fisheries management issures. These are: some of the countries have the lowest per capita in the world and hence are economically undeveloped and the majority of the people live in rural areas and gain their livelihood from agricultural or normadic pursuits. Critical shortages of capital, an industrially skilled labor force, and technical and managerial know-how, all hamper the exploitation of fishery resources (Marr and Olson, 1974).

Most of the stocks in the Indian Ocean have been divided into demersal, crustacean and pelagic fisheries. Significant international problems to be expected regarding the demersal fisheries shared among neighboring states, where the fishermen of one country are able to fish just outside the territorial waters or exclusive fisheries zone of another. Contentions have mainly arisen over the incursion of an adjacent country's boats into the territorial waters of its neighbors rather than the depletion of high seas resources by fleets of more than one nation. Instances of rivalry have been reported along the East African coast, the Gulf between Iran and the Arabian Peninsula, Upper Bay of Bengal and the Red Sea and the Gulf of Aden. At least in principle, most such problems can be resolved through bilateral negotiations. Crustaceans and pelagic fisheries stocks may migrate through territorial waters or the exclusive fishery zones of more than one state and hence a problem concern for international fishery management. In such a case, efficiency of harvesting and even the integrity of the stocks may require early international cooperation.

The following are the target species of Japanese, Taiwanese and Korean Long Distance Trawler fleets operating in the area of the Indian Ocean: bluefin tuna, albacore, yellowfin tuna, bigeye tuna, swordfish, black marlin, blue marlin, striped marlin and sailfish. Incidental catches caught during their longlining operations include: sharks, wahoo, skipjack tuna and barracuda. There is little prospect for successful management of the tuna stocks under any regime that is confined to the Indian Ocean (Gulland, 1974). Many of these species spend most of their life cycle far outside the areas of national jurisdiction and range widely on high seas. Most stocks migrate between the Western Pacific to waters off southern Africa and hence their extensive migratory span of several thousands of kilometers is beyond a national management strategy.

Although the Indian Ocean tunas are now exploited by mainly a very few nations outside the region, several others are considering entry, and the inevitable rise of tuna prices will attract more participants from Indian Ocean countries. Controls of fishing effort now being established in the Pacific and Atlantic areas are displacing fishing activity and further stimulating fishing entry into the Indian Ocean where fishing limitations does not exist. The main fishing method for catching tunas and tuna-like fishes is by longlining in the waters of the Indian Ocean (Klawe, 1980). The basic unit of deployed longline gear is called a basket and it consists of a main horizontal line which is buoyed to the surface by float lines. Four to six hooks are suspended from branch lines which are attached to the main line. The baskets of gear are fastened to each other end to end so that the fishing gear extends over as many miles as 75 nautical miles with over 2000 hooks in some cases, and fishes at depths of about 50 and 250 meters. This deep longline has proven to be effective in cathcing tunas (Klawe, 1980) and is a potential method for over-exploitation.

The 200 miles economic zones as well as maritime boundaries between the adjacent countries (Fig. 26) within the Indian Ocean are not well delineated.

These boundaries for each country or dependency have been arbitrarily drawn and there are no national laws governing their use except the Law of the Sea. The sovereignty of several of the geographical entities such as Diego Garcia and the British Indian Ocean Territory are under dispute. Most of the Indian Ocean countries are party to all four of the 1958 Geneva Conventions on the Territorial Sea and the Contiguous Zone, on the Continental Shelf, on High Seas, and on fishing and the Conservation of the Living Resources of the High Seas. The first of these treaties recognizes coastal state sovereignty over the 12 mile coastal state territorial sea and establish it for specified purposes. The Continental Shelf Convention recognizes coastal state sovereignty over the continental shelf 'for the purpose of exploring it and exploiting its natural resources'. The Convention on Fishing and Conservation recognizes coastal state sovereignty over the continental shelf 'for the purpose of exploring it and exploiting its natural resources'. The Convention of the High Seas includes "freedom of fishing" among the freedoms of the high seas. Although not sanctioned by the Geneva Conventions, a state practice of exclusive fishing zones beyond the limits of the territorial sea has become increasingly common.

Rivalries among neighboring states for both overfishing and international conflict, among the middle distance fisheries of two or more neighboring states fishing for pelagic or demersal stocks on nearby shelf or slope areas on the high seas may exist. Bilaterial agreements between Kenya and Tanzania, (Christy, 1979), is an example where a delimited territorial and extended jurisdiction boundary between the two countries is being used to solve disputes. The two neighbors agreed to harmonize their fisheries legislation and to grant reciprocally tolerant treatment to traditional vessels from the other country. Most Indian Ocean countries ambitions for developing distant water trawlers or becoming middle-distance fishing powers, Tussing (1974) mainly because exploitable resources lies outside the present limits of territorial waters or exclusive fishery zones. The additions of the new fishing capacities are likely to lead to overfishing and eventually outstrip the fishery resource stocks on the high seas.

The final issue concerns the role of non-Indian Ocean fishing nations in the Indian Ocean with respect to the coastal species both pelagic and demersal. International rivalry over fish stocks, or their depletion as a result of such rivalry is still rare in the Indian Ocean. The only notable instance is the deep-water fishery of tunas. The region has not observed any 'pulse fishing' by distant-water fleets, that is, the massive concentration of fishing power upon particular stocks which rapidly depleted certain fisheries in the North Atlantic and North Pacific Oceans leading to the FCMA.

DEVELOPMENTS

Kenya, like any other African countries close to the coastal upwelling region, does not derive a large benefit from the productive oceanic waters in her doorstep (Glantz, 1978). The major reasons for this are mainly the fluctuating environmental conditions, lack of scientific information; lack of appropriate technology for exploitation; artisanal fishing methods and the social attitude of the local community. Over half of the Kenyan population do not eat fish for reasons of either non-availability or superstition. There has been a great publicity campaign where posters and the public media have been used to encourge consumption of fish. Fishery development has been geared towards generating additional employment opportunities; increase income levels and the availability of animal protein. This is in contrast to other major fishing nations that produce maximum exploitation on a sustainable basis and stimulate the national economy by foreign exchange earnings from the sale of fish exports.

Confined fishing along the coastal reefs is being replaced by trawling fleets that can go beyond the 200 m contour depth. Outboard and inboard engines on motorized boats are just beginning to replace the dogout canoes and dhowsails that have dominated Kenyan fishery since time immemorial. There have not been any significant changes in the annual catches since 1967 up to date. The only major changes have been the total earnings that have risen from Kshs. 6,696,314 in 1967 to Kshs. 15,279,360 in 1977. The tourist industry has boosted the demands for crustaceans which are highly priced.

Major problems in fishery development in Kenya mainly arise from the different diverse cultures. A small fish eating community and a small sea going segment of the population has been a crucial drawback. The other major drawback is that the fisheries operate without the assistance of a unified or intergrated distribution and market organization. Fishery cooperatives mainly collect levies and lack qualified personnel. The fishermen operate rather on subsistence level rather than to supply their catch to the cooperatives. More often a fisherman retains a portion of his catch for his own use and sells the remainder directly to the consumers or to a fishmonger. Fishermen are sometimes provided with loans in the form of material supply rather than cash. Fishermen operate on individual basis and often fishing is not the only occupation. Most fishermen abandon fishing when weather conditions make fishing unproductive or when they need to practice agriculture. Other problems that we must overcome in the near future include among others: the lack of ice in remote landing depots, fishing technology, managerial skills, import restrictions and poor communications from the fishing villages to the cities.

INDUSTRIAL AND FOREIGN FISHING

The small dugout canoe and simple gear such as beach seines have not been able to compete with the capital intensive and technologically specialized fleets of foreign governments in exploiting the offshore stocks. Long distant trawlers of Southern Europe, Japan and the Koreans have been able to trawl in the Kenyan waters under bilateral agreements (Pease, 1974). Japanese tuna long-liners operating in the Indian Ocean, in conjunction with Taiwanese and South Korean fishermen, began using Mombasa as a tuna transhipment port in 1969 when the Taiyo Gyogyo of Japan sent a 1,500 gross tonnage reefer to the port. They have also started joint ventures with Maritime Co. of East Africa Ltd. and the Industrial and Commercial Development Cooperation of the Government of Kenya for the constru-ction of a cold storage facility in Mombasa. The new firm, Kenya Fishing Industries Ltd. now operates 10 large commercial trawlers of its own and operates the cold storage. The facility has a storage capacity of 2,000 tons of fish at -31°C. The complex includes handling and weighing rooms, ships stores, a warehouse, pier and a fixed conveyor belt system that can move 30 tons of fish per hour from the dock to the weighing room. There is also a bunkering facility and a ship repair workshop. South Korean and Taiwanese tuna longliners fish for the plant in Mombasa.

In conclusion, the mainstay of the Kenyan local fishing effort is the dugout canoe and the beach seine which is limited to the immediate vicinity of the shore. Apart from the cultural problems and the oceanographic conditions; the narrow continental shelf, a rich profusion of coral growth in all but the sub-estuarine areas precludes the industrial fishing methods such as trawling. Bilaterial agreements with foreign fishing fleets have provided employment in the storage facilities, freezing depots, handling and maintenance of related fishing vessels operations. Large scale fishery development in Kenya has the primary objectives that are socially and economically oriented. Fishery development has been centered on gear improvement, facilities and increased exploitation of the fishery resource.

RECOMMENDATIONS

1. Research should be directed towards the study of the physical and chemical characteristics of the sea water throughout the year. Surface currents under the influence of winds and tides should be traced, temperature, salinity, nutrient concentrations and density gradients at various times of the year should be studied. A knowledge of these would allow for the correct advice to future coastal developments such as industrial discharges into the ocean from urban sewage or river runoffs from agricultural lands. These may adversely affect the marine community and destroy inshore fisheries.

2. New techniques for production, preservation and marketing of fish products in a developing nation like Kenya must be developed step by step. Introduction of modern fishing techniques such as trawling will take considerable time since the old and established, but inefficient, methods must be replaced with new and improved methods. Use of outboard engines or small diesel engines and the development of new methods of smoking, salting and drying fish should be considered.

3. To improve the national fishery statistics for use in tropical multi-species model for stock assessment, the Kenyan fisheries agency for research should have access to the records of the fishing companies, landing and production cooperatives. Fishing companies records should have total landings for the month,

each commercial species groups, vessels unloading fish at a port during the month and the size composition of the catch. A Fishermen's Logbook system should be introduced to obtain detailed catch and effort data. The logbook should be designed to provide information on catch by species groups, time away from port, operation time and area of operation along with basic information on the size of the vessel, the gear used, time spent fishing or searching for school of fish and fishing ground based on a latitude/longitude location.

4. Kenya proclaimed a 200-mile Exclusive Economic Zone (EEZ) on 28 February 1979. This proclamation gave her the responsibility to manage the exploitation of living resources inhabiting the small continental shelf and the deep sea. Matters arising from extended fisheries jurisdiction could be solved by signing bilateral agreements with foreign nations and our neighbors Somalia and Tanzania. An agreement with our neighbors should harmonize fisheries legislation and grant reciprocally tolerant treatment to traditional vessels from the other countries.

5. Kenya's most pressing need in fisheries legislation is for basic regulation of its local marine fishery. At the same time, provision should be made for regulation of foreign fishing, which is already being conducted in the area now included in the EEZ. Some local vessels will venture beyond the 12-mile territorial limit and some foreign vessels may be permitted to fish within territorial waters, so it is hardly possible to distinguish separate management regimes for local and foreign vessels that may be fishing in the same areas using the same gear.

6. The logical basis for management measures and licensing decisions for the Kenyan Fishery Agency is to develop a management plan. At its simplest the plan can be a comparison of estimated resources and estimated catches; a knowledge of

these would help in allocating areas for foreign fishing. Heavily fished areas such as the Ungwana Bay and the North Kenyan Banks should be subject to closer scrutiny and effects of measures such as closed seasons or restricted gear should be projected and tested. Registration of fishing vessels has been used for preventing and detecting the theft of boats. This was a worthwhile service but served no fishery management function. Licensing would facilitate the control of fishing effort, as well as of methods and areas of fishing.

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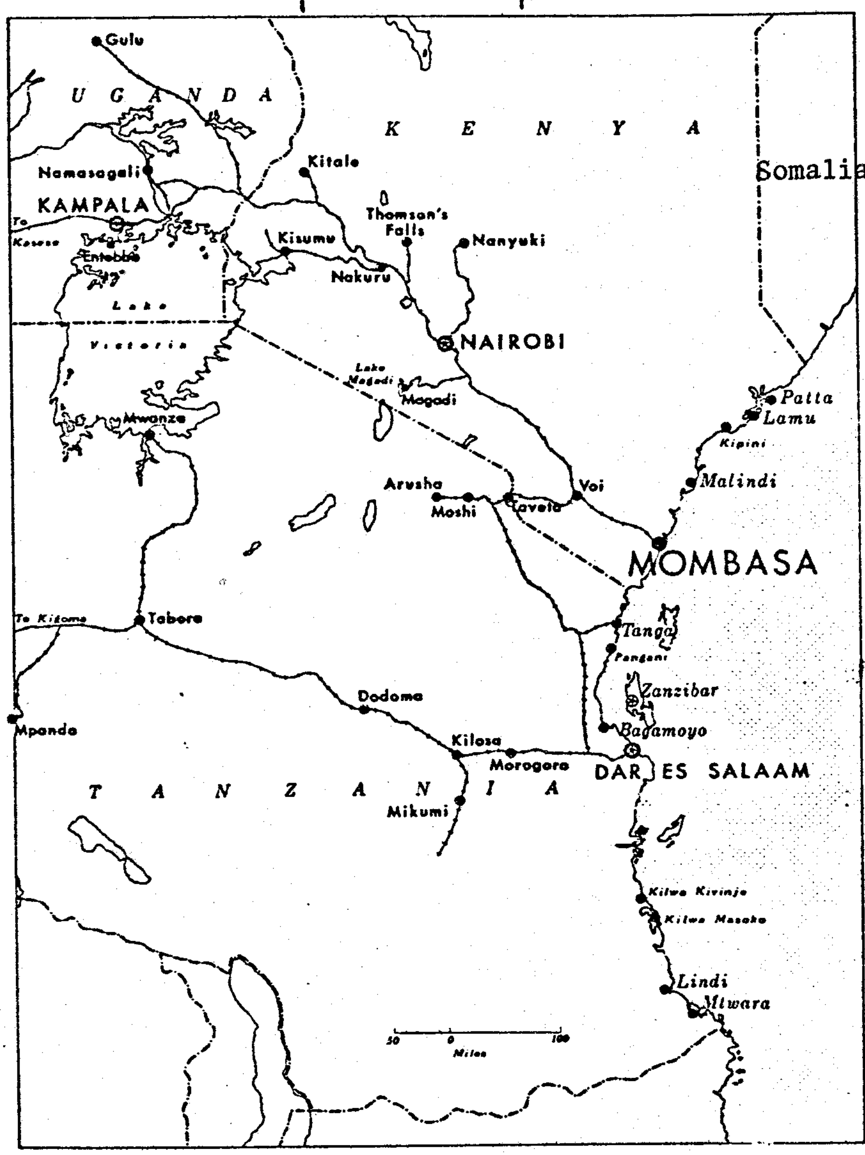


MAP 1

Fig. 1. Kenya and its neighbors.

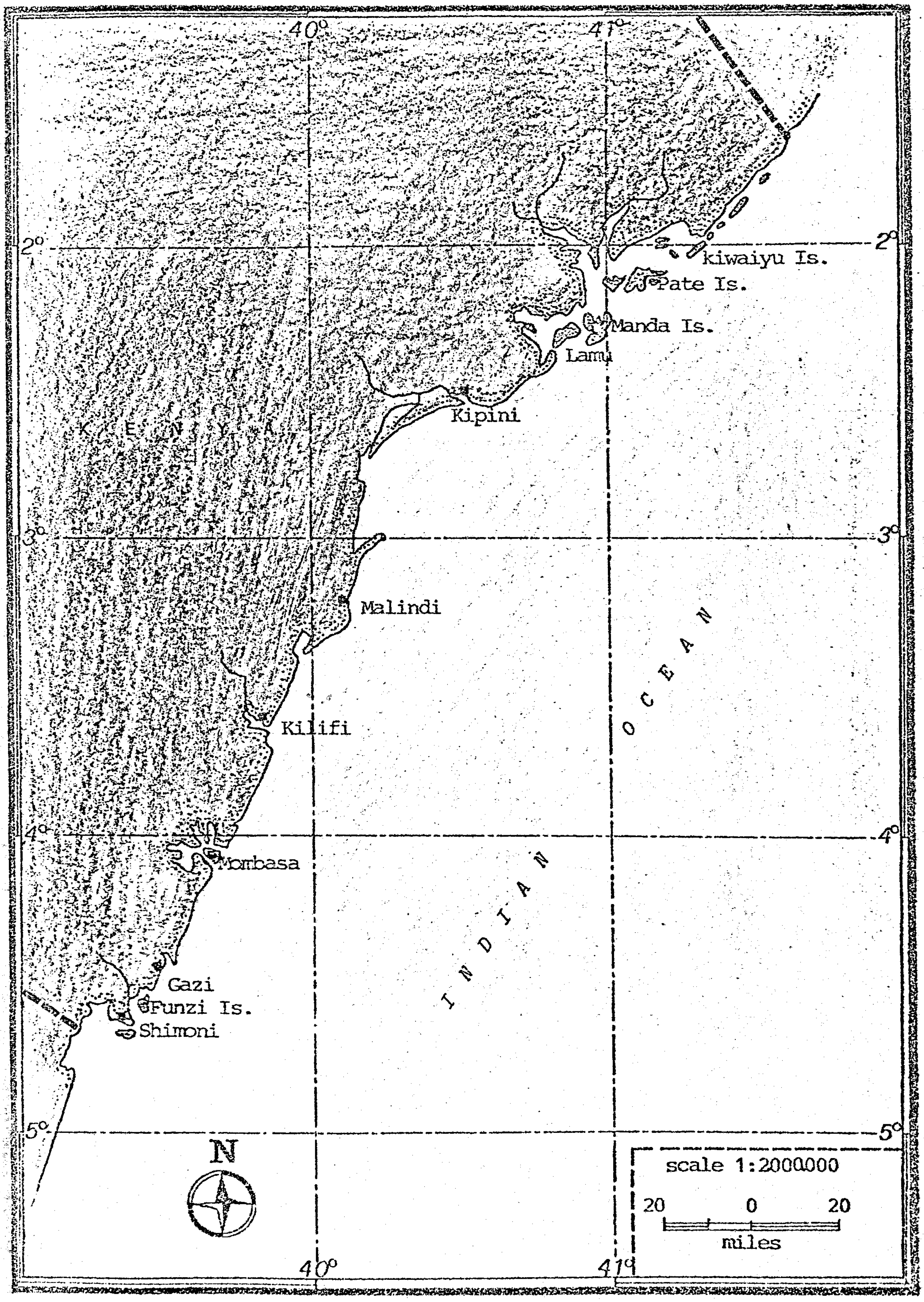


Fig. 2. Kenyan coastline from Coppola (1982).

KENYA'S MARINE FISH PRODUCTION FOR 1967 - 1977

Species	Demersal		Pelagic		Sharks		Mixed Fish		No. Accounted for		Crustacea		TOTAL	
Years	tons	Shs.	tons	Shs.	tons	Shs.	tons	Shs.	tons	Shs.	tons	Shs.	tons	Shs.
1967	5 758	6 304 878	-	-							120	391 436	5 878	6 696 314
1968	2 499	3 337 059	-	-	815	980 988	2 401	1 797 316	-	-	162	470 512	5 877	6 696 314
1969	2 673	-	-	-	720	-	2 207	-	-	-	167	649 656	5 767	
1970	3 437	4 840 708	-	-	527	348 356	2 495	317 642	-	-	163	683 232	6 622	6 189 938
1971	3 919	11 217 817	517	1 195 070	790	686 641	1 231	1 309 319	-	-	284	1 402 640	6 742	15 811 487
1972	3 484	5 712 451	2 017	1 458 287	638	677 416	1 172	911 125	-	-	185	1 100 328	7 496	9 859 607
1973	2 505	3 768 409	291	213 188	267	305 663	339	598 301	-	-	208	1 212 374	3 610	6 097 935
1974	2 132	4 970 208	301	1 113 643	230	385 148	371	666 811	504	1 037 586	209	1 134 387	3 747	9 307 783
1975	2 137.4	5 258 300	369.2	1 687 162	293.6	538 413	493.5	971 376	859.7	2 030 331	223.2	1 809 348	4 376.6	12 297 930
1976	2 298.0	6 297 189	564.5	2 154 608	446.1	887 979	547.1	1 184 884	617.8	2 171 007	233.1	2 034 020	4 706.6	14 729 687
1977	2 078.1	6 506 772	520.7	2 224 785	365.5	727 696	600.4	1 397 807	363.8	2 019 343	252.8	2 401 957	4 181.3	15 278 360

These data exclude fish landed by foreign trawlers.

Table 1. Kenya marine fisheries catch from 1967-77 from Gulland (1979).

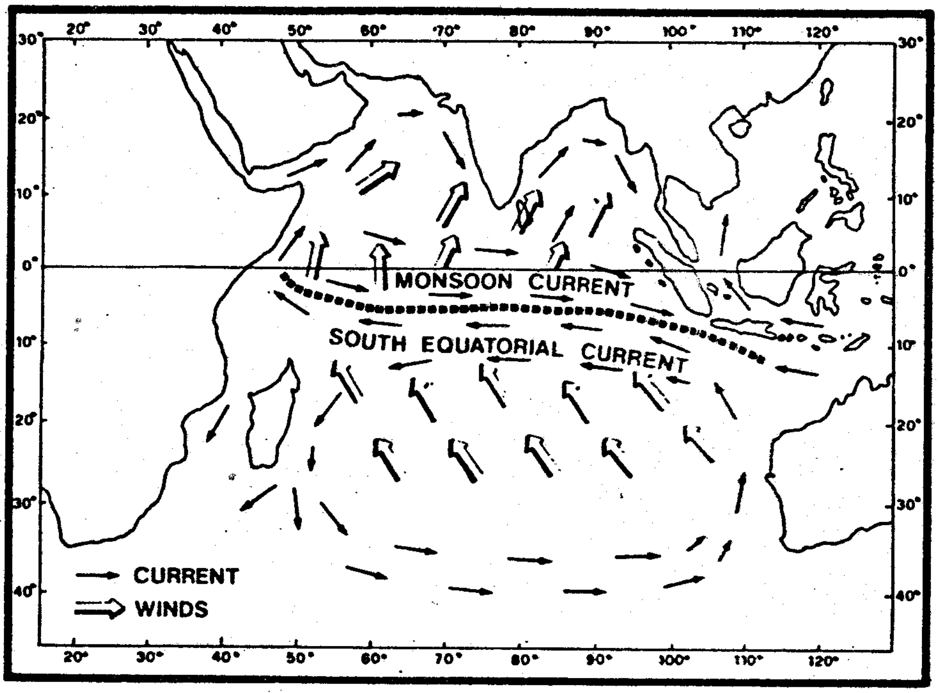


Fig. 3. SW monsoon surface circulation (April-October)
(After Wyrtki 1971)

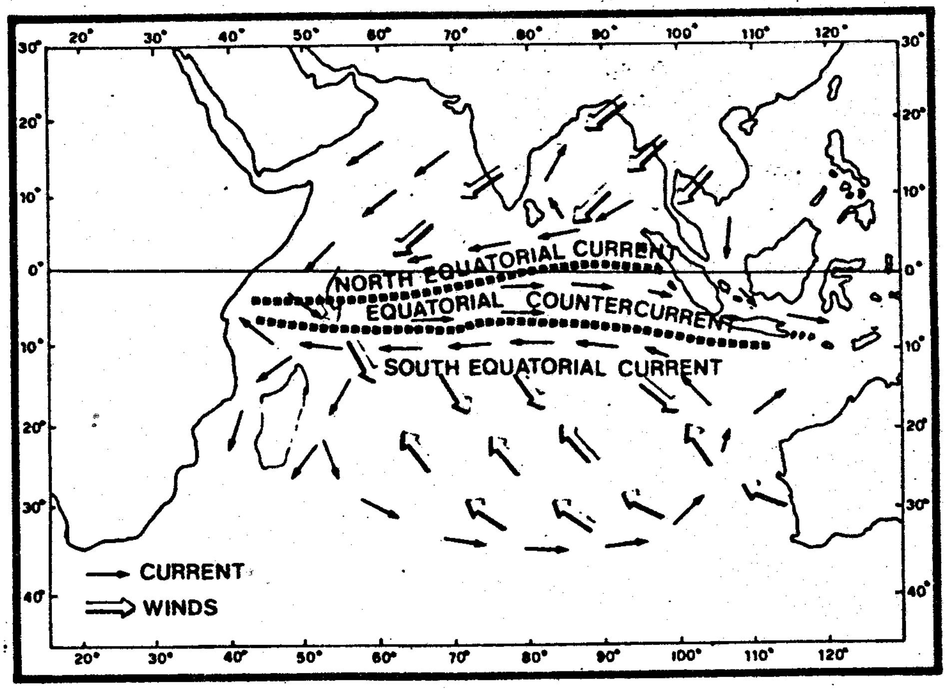


Fig. 4. NE monsoon surface circulation (October-March)
(After Wyrtki 1971)

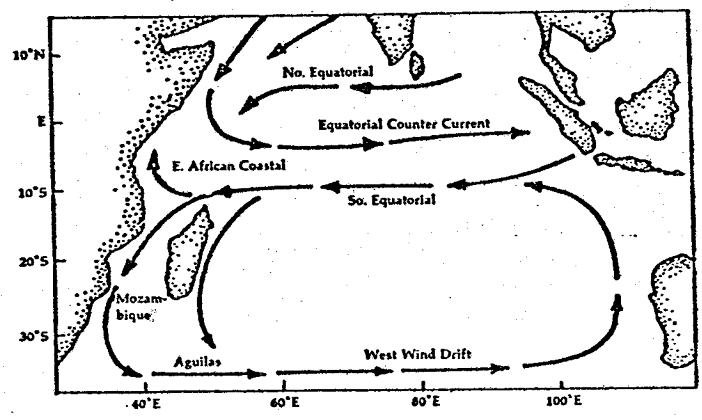


Fig. 5. Surface currents during the SW monsoon in the Indian Ocean.

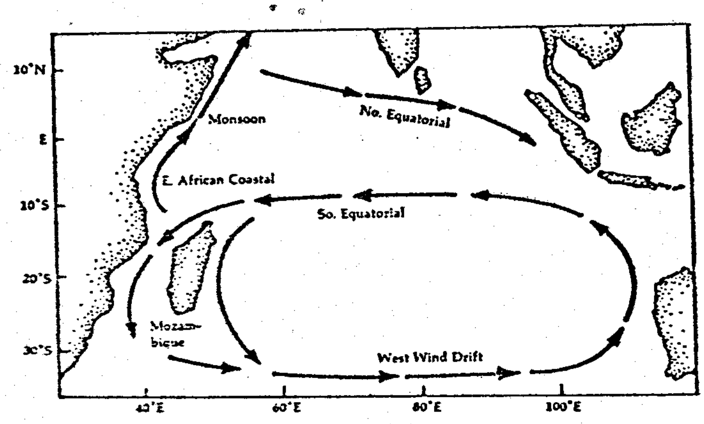
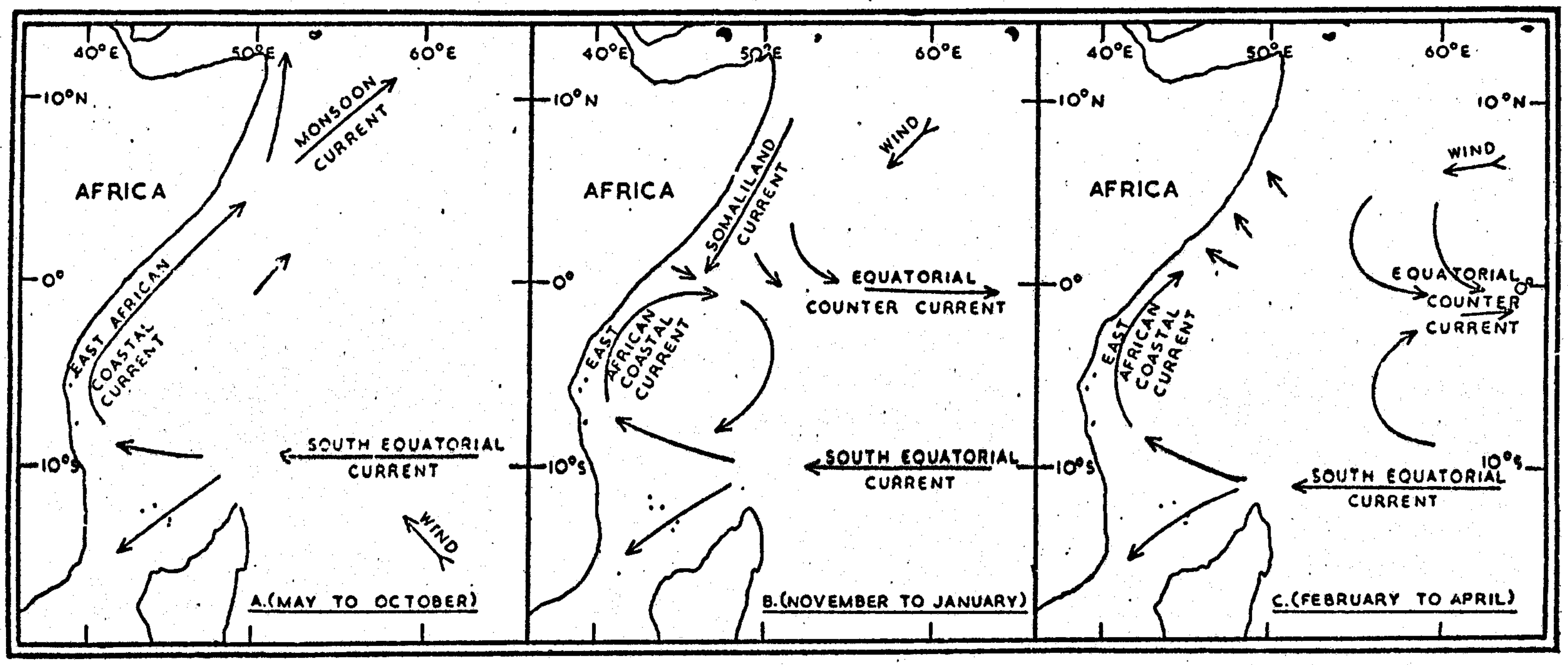


Fig. 6. Surface currents during the NE monsoon in the Indian Ocean.

Fig. 7. The seasonal surface current changes along the East African coast (from Williams 1963).



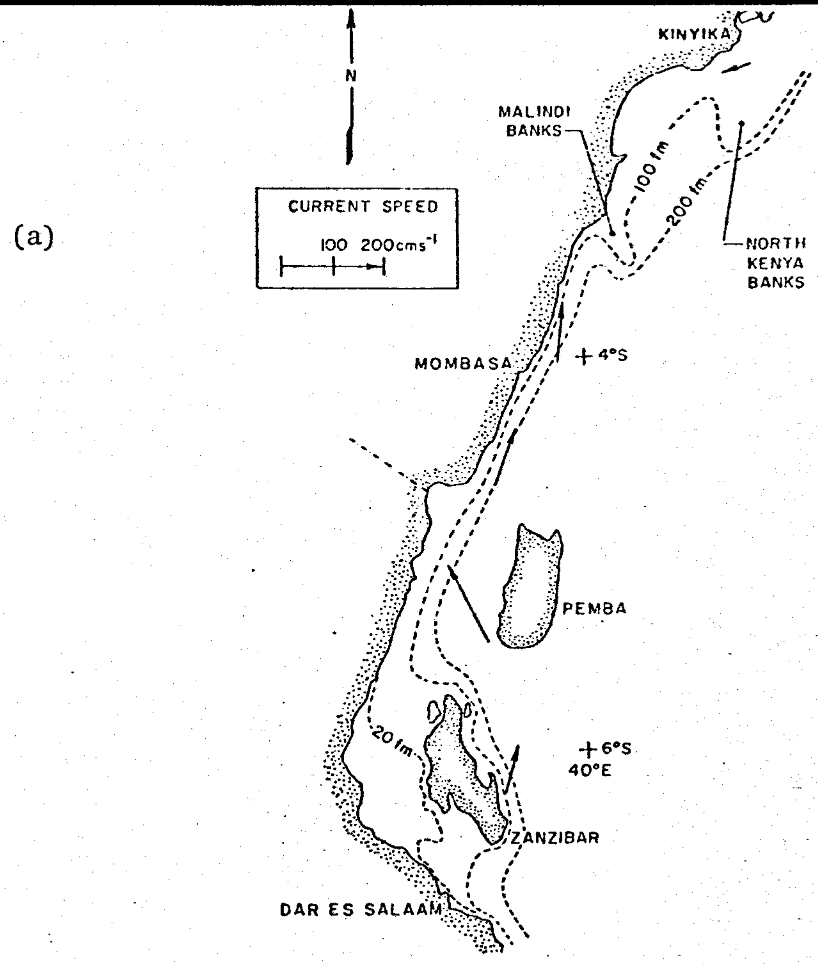
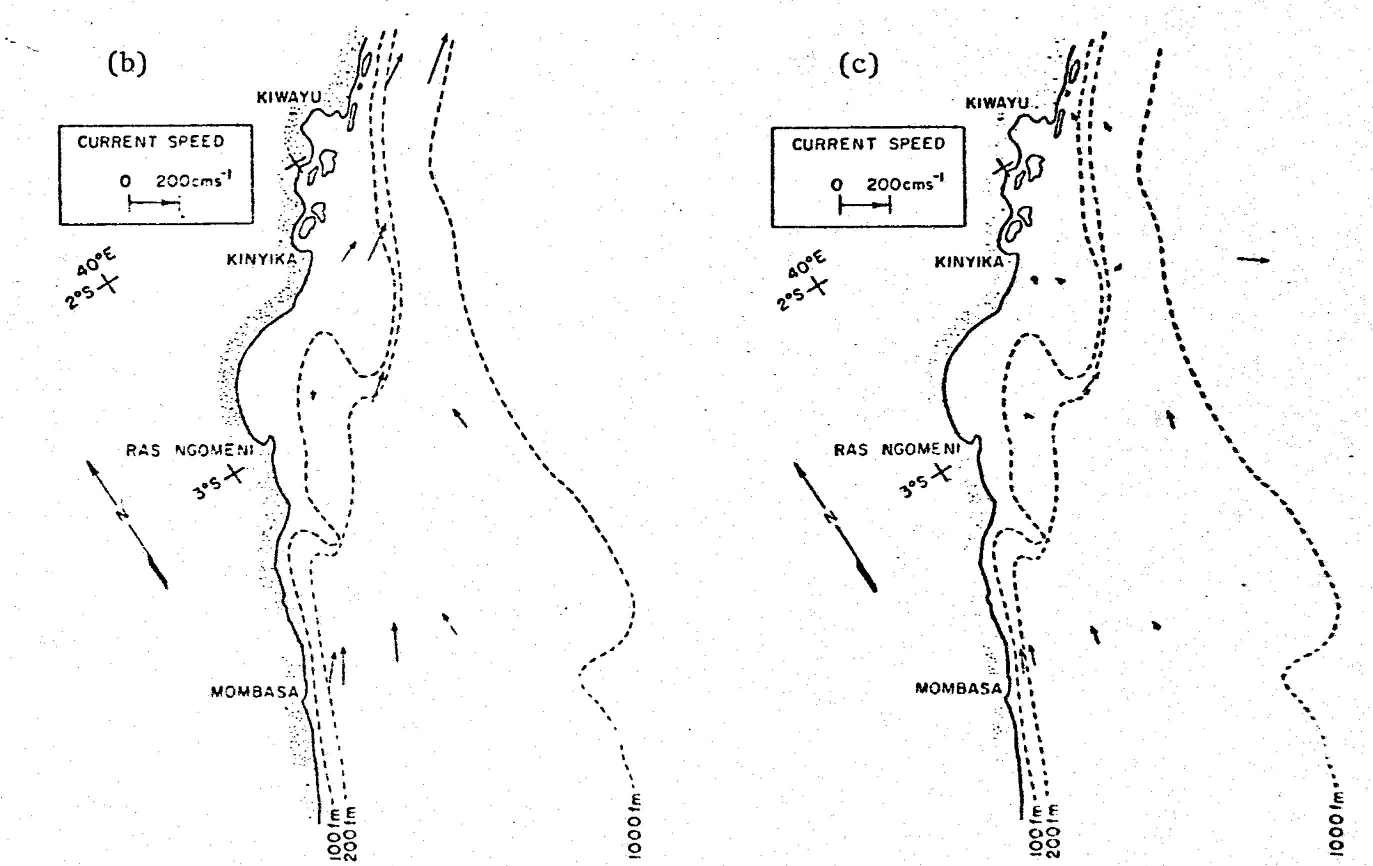


Fig. 8. Current vectors in (a) January and February, (b) July and (c) December (From Johnson et al. 1982).



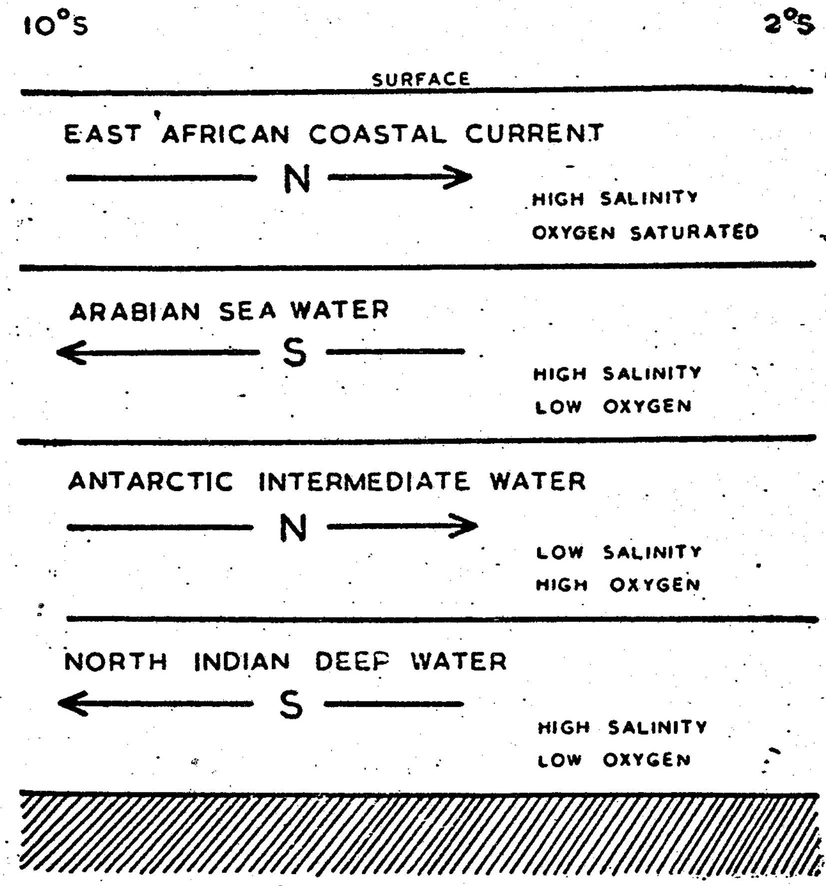


Fig. 9. Water masses along the Kenyan coast (After Williams 1963).

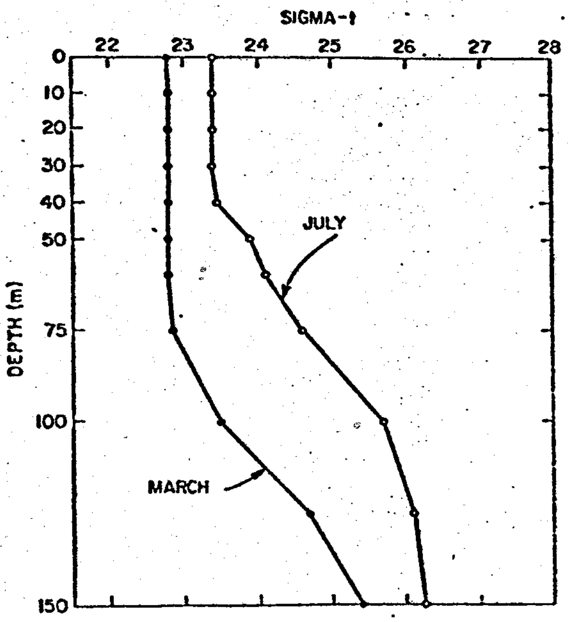


Fig. 10. SW monsoon pycnocline (July) is shallower than the NE monsoon (March) (After Smith 1982).

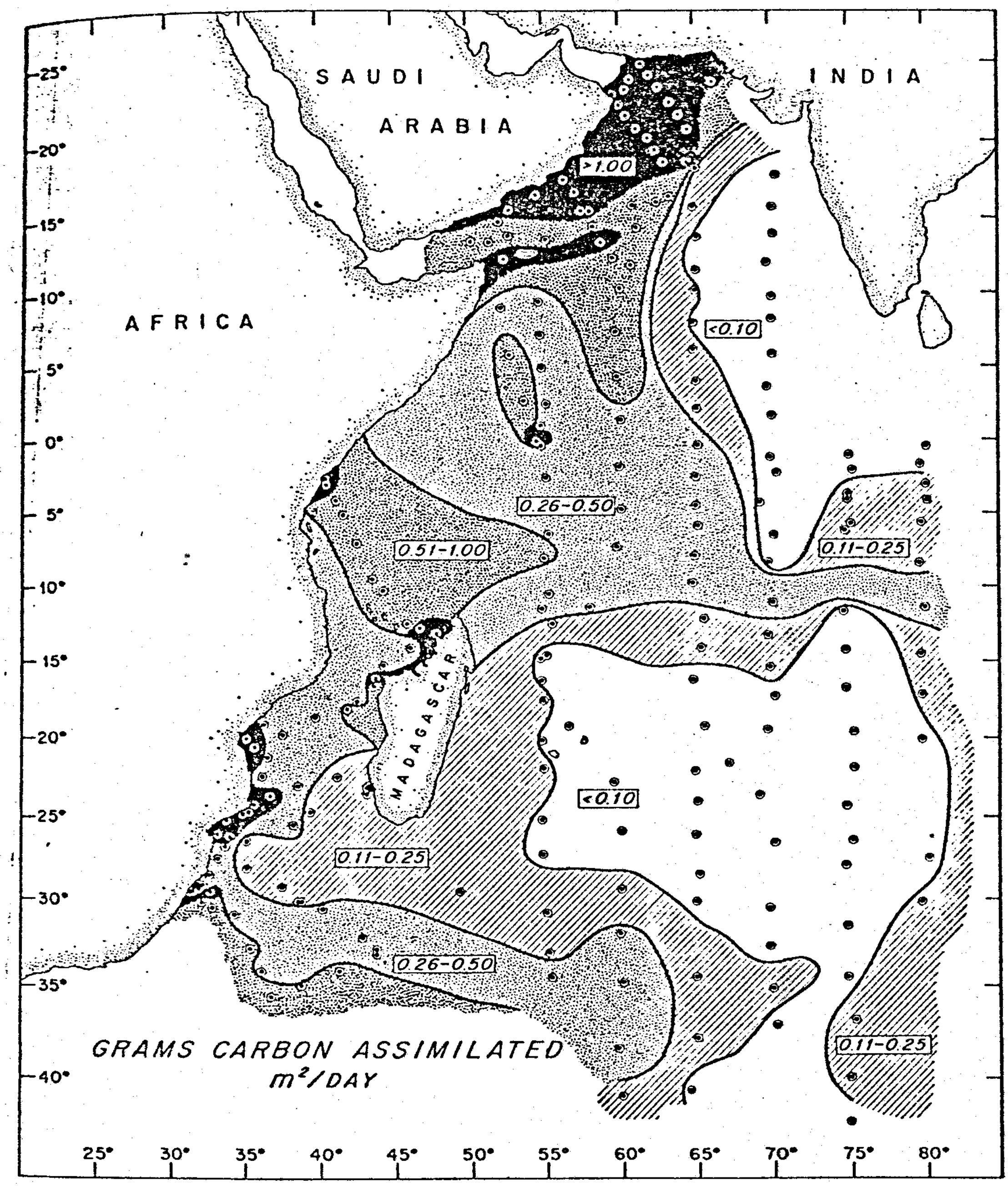


Fig. 11. Primary organic production of the Western Indian Ocean, the Kenyan coast is between 0.51-1.00 $gCm^{-2}d^{-1}$.

Cruise	CI 7901	Latitude	2°14.2'S	Sunrise	0550
Station	1-021	Longitude	41°23.3'E	Sunset	1745
Date	14 March 1979	Sonic Depth (m)	900	Integrated Carbon Fixation (g/m^2/day)	0.4
Local Time	1405				
Secchi Depth (m)	22				

Light (%)	Depth (m)	Initial Chlorophyll (mg/m^3)	Final Chlorophyll (mg/m^3)	Initial Phaeophytin (mg/m^3)	Final Phaeophytin (mg/m^3)	Carbon Fixation (mg/m^3/day)
100	1					5.86
50	9					10.10
30	16					12.39
15	25					6.11
5	39					2.54
1	60					2.71

Table 2. (From Smith and Lane 1981)

STATION	DATE	TIME	LATITUDE	LONGITUDE
1021	14 MAR 79	13:03:00	2 14.2 S	41 23.3 E

SONIC DEPTH	NET MESH	NET MOUTH AREA
840.0	223	0.2827

NET TOW DEPTH	VOLUME SAMPLE	FRACTION COUNT	VOLUME COUNT
280	248.58	0.013	3.107

SPECIES	RANK	COUNTS	%	NO./M3	NO./M2
ONCAEA SPP. ALL	1.0	158	13.50	50.85	14335.
CALANOID COPEPODIDS, UNIDENTIFIED	2.5	142	12.14	45.70	12883.
APPENDICULARIA	2.5	142	12.14	45.70	12883.
OITHONA SPP. ALL	4.0	130	11.11	41.84	11794.
CORYCAEUS SPP. ALL	5.0	120	10.26	38.62	10887.
CALANOID ADULTS, UNIDENTIFIED	6.0	71	6.07	22.85	6441.
CHAETOGNATH	7.0	43	3.68	13.84	3901.
CLAUSOCALANUS FURCATUS AF	8.0	35	2.99	11.26	3175.
PARACALANUS SPP. C	9.0	28	2.39	9.01	2540.
CLAUSOCALANUS SPP. C	10.5	27	2.31	8.69	2450.
OSTRACOD	10.5	27	2.31	8.69	2450.
ACARTIA NEGLIGENS AF	12.0	22	1.88	7.08	1996.
EUCALANUS SPP. C	13.5	20	1.71	6.44	1815.
CLAUSOCALANUS MINOR AF	13.5	20	1.71	6.44	1815.
CALOCALANUS SPP	15.0	19	1.62	6.11	1724.
ACARTIA SPP. C	16.0	16	1.37	5.15	1452.
ACROCALANUS SPP. A	17.5	15	1.28	4.83	1361.
PARACALANUS DENUDATUS AF	17.5	15	1.28	4.83	1361.
EUPHAUSIID CALYPTOPIS	19.0	14	1.20	4.51	1270.
ACROCALANUS SPP. C	20.0	12	1.03	3.86	1089.
DECAPOD LARVAE	21.0	11	0.94	3.54	998.
HARPACTICOID	22.0	10	0.85	3.22	907.
CLAUSOCALANUS FARRANI AF	23.0	9	0.77	2.90	817.
CLAUSOCALANUS SPP. AM	24.5	8	0.68	2.57	726.
PLEUROMAMMA SPP. C	24.5	8	0.68	2.57	726.
EUPHAUSIID FURCILIA-ADULT	26.0	7	0.60	2.25	635.
PARACALANUS ACULEATUS AF	28.0	6	0.51	1.93	544.
CYCLOPOIDS, UNIDENTIFIED	28.0	6	0.51	1.93	544.
PARACALANUS SPP. AM	28.0	6	0.51	1.93	544.
PARACALANUS PARVUS AF	31.0	5	0.43	1.61	454.
EUCALANUS SPP AF	31.0	5	0.43	1.61	454.
ACARTIA DANAE	31.0	5	0.43	1.61	454.
ACARTIA NEGLIGENS AM	33.5	2	0.17	0.64	181.
EUCALANUS SPP AM	33.5	2	0.17	0.64	181.
CLAUSOCALANUS ARCUICORNIS AF	36.5	1	0.09	0.32	91.
PLEUROMAMMA BOREALIS A	36.5	1	0.09	0.32	91.
PARACALANUS SPP. A	36.5	1	0.09	0.32	91.
CLAUSOCALANUS PARAPERGENS AF	36.5	1	0.09	0.32	91.
TOTALS	38	1170	100	376.5	106148.

Table 3. (From Smith and Lane 1981)

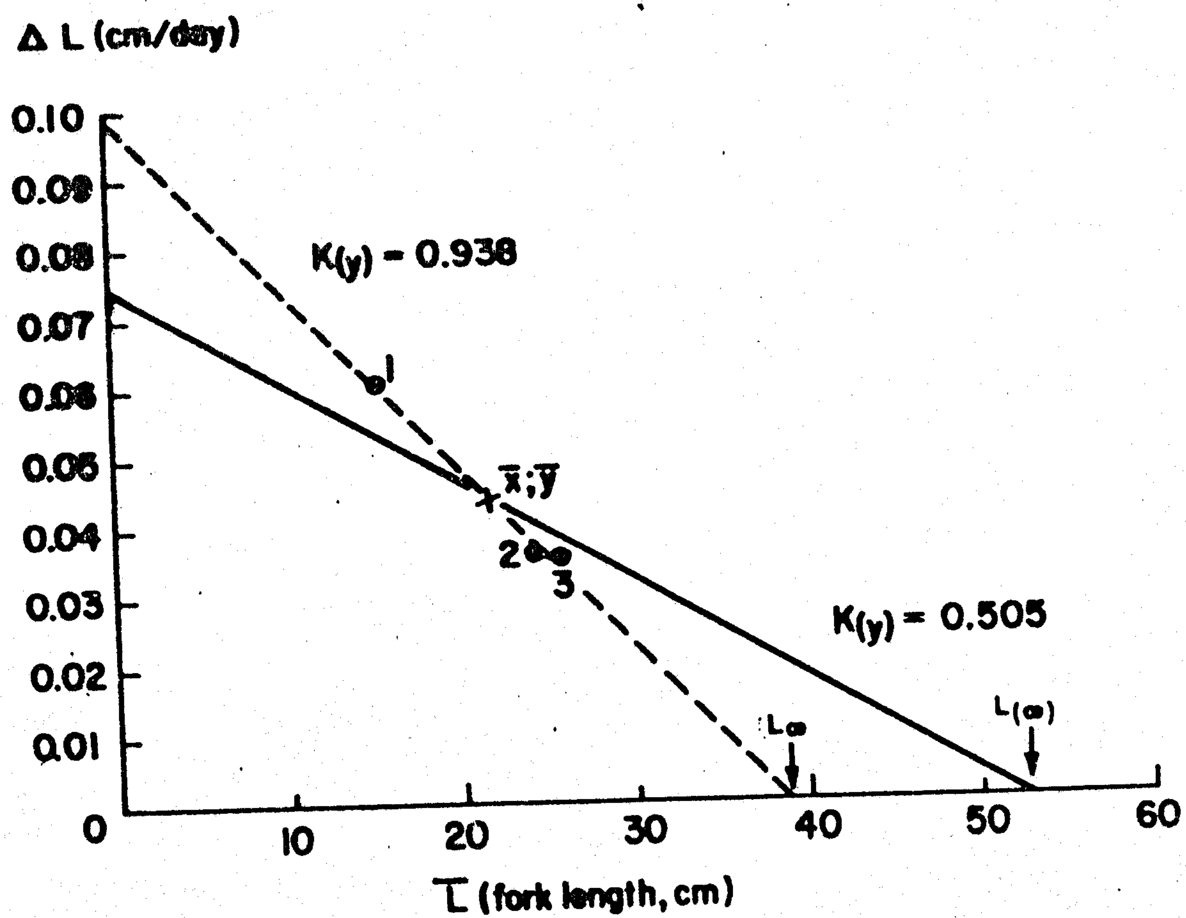


Fig. 12. Total length vs. fork length can be used to estimate parameters for stock characteristics for a given fishery.

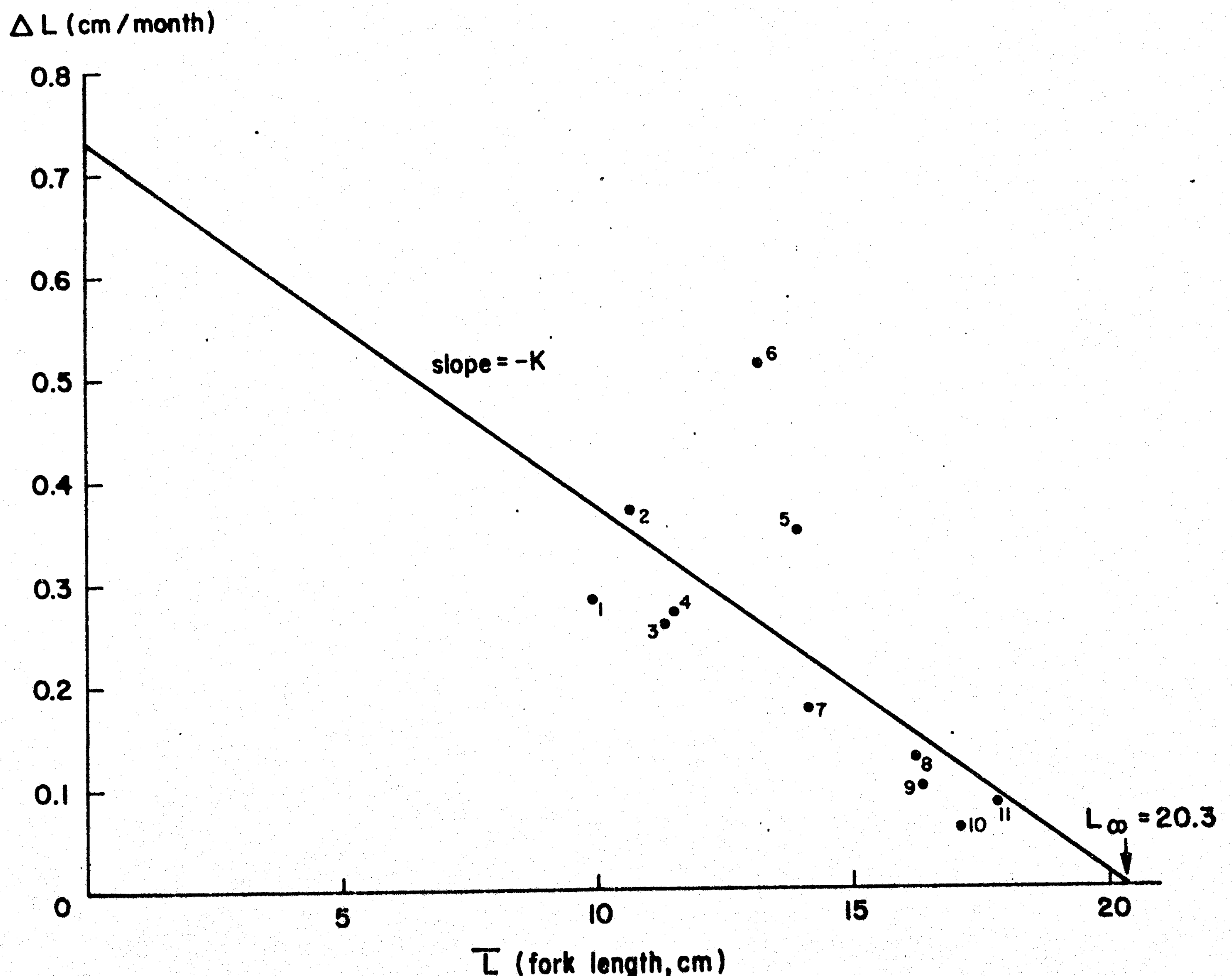


Fig. 17. The functional relationship between ΔL and $L\infty$ can be used to age fish.

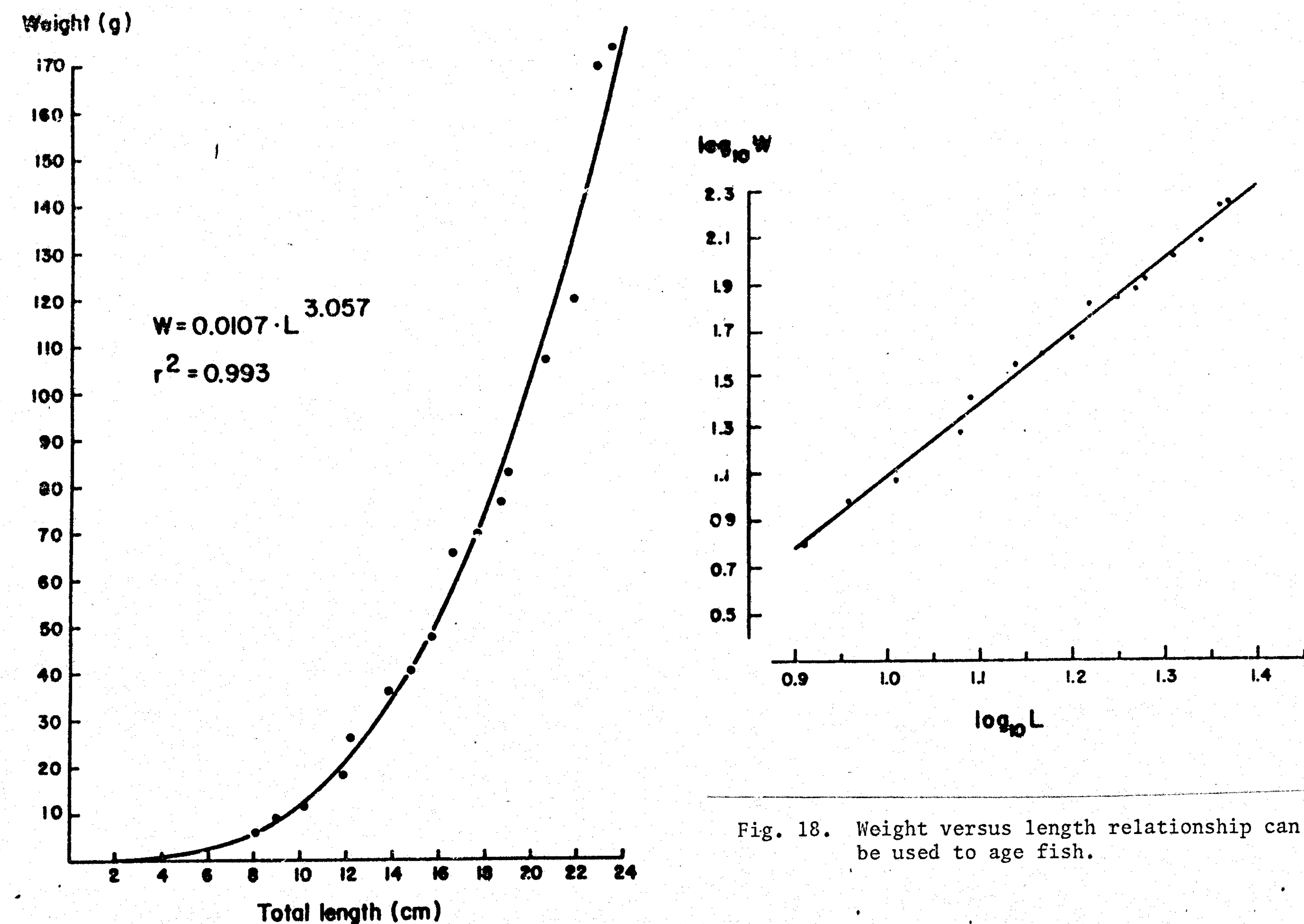


Fig. 18. Weight versus length relationship can be used to age fish.

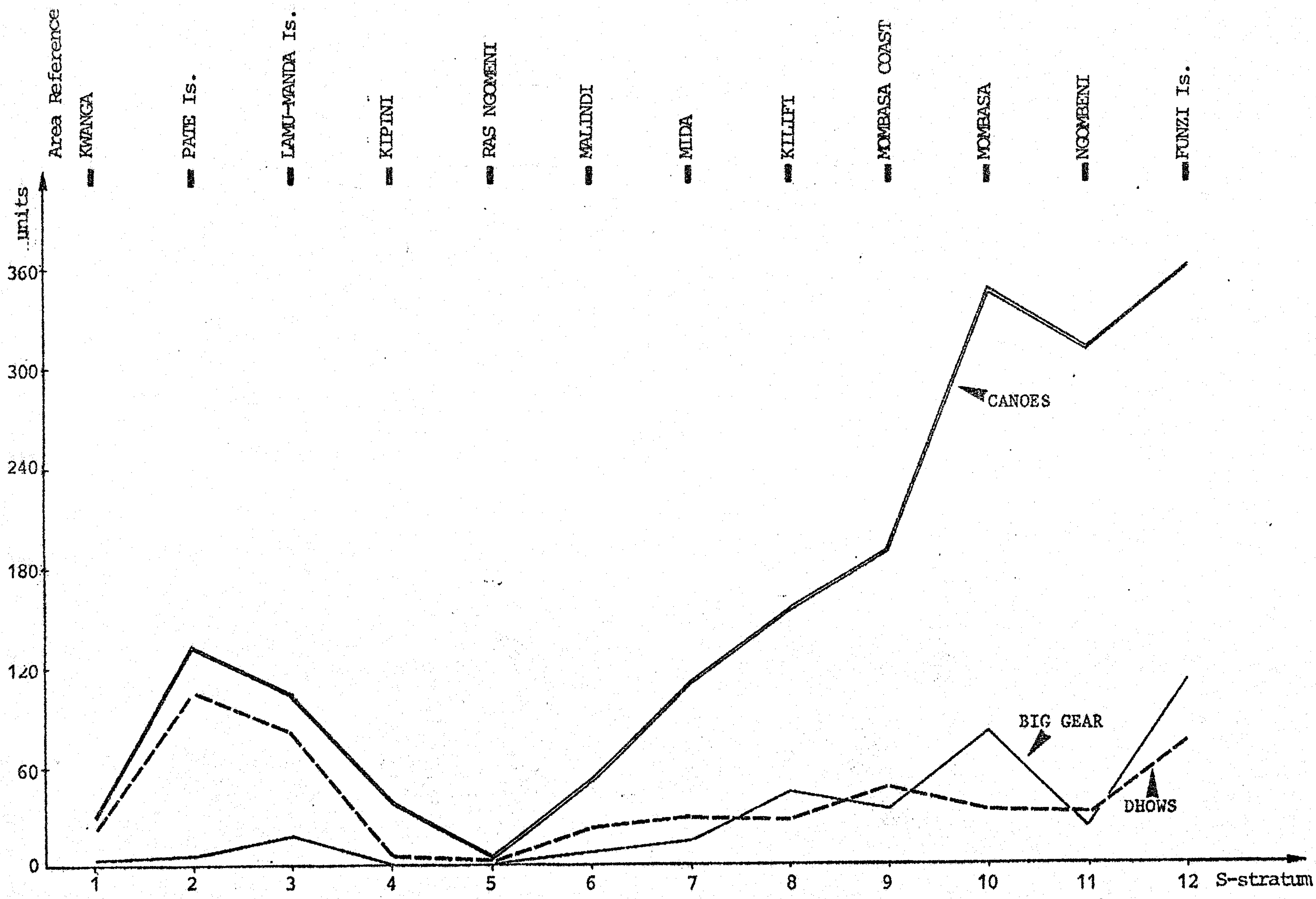


Fig. 15. Localization pattern of big gear, canoes and dhows seen along the coast of Kenya by sub-stratum (Results of Aerial Frame Survey, November 1981).

From Coppola 1982.

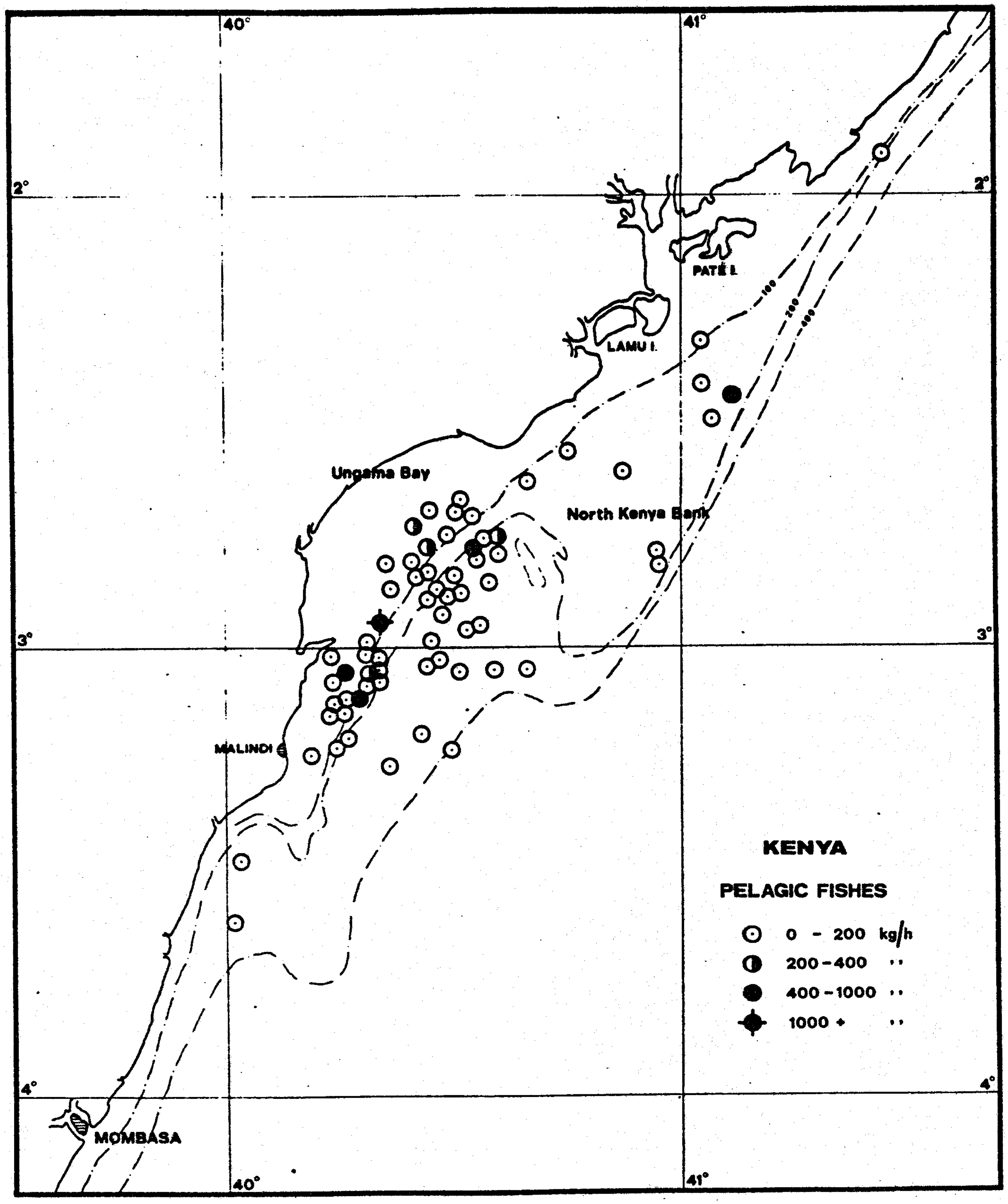


Fig. 16. Most pelagic fishes are concentrated where the SW monsoon current converges with the EACC.

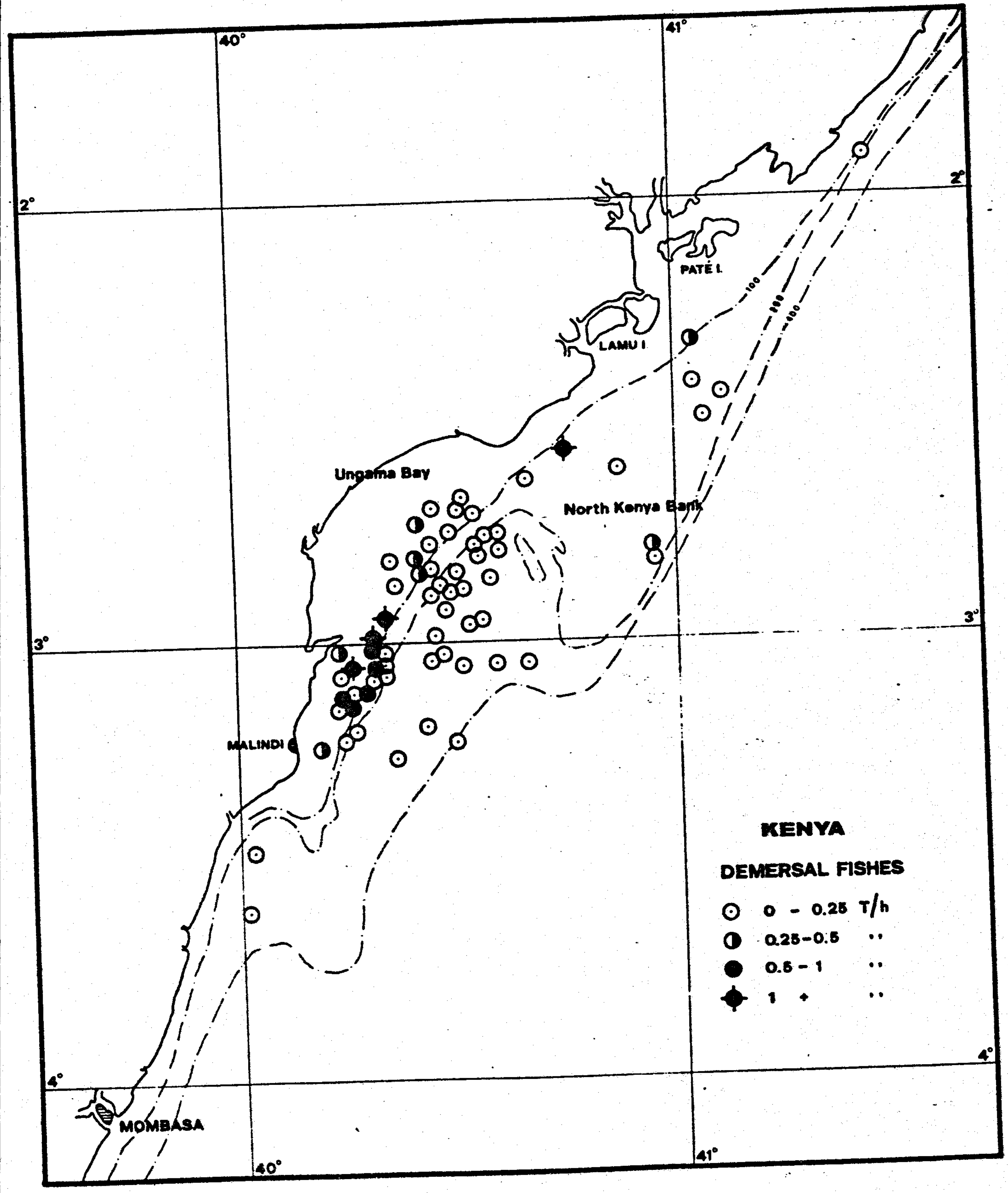


Fig. 17. Demersal fishes are concentrated in the North Kenya Banks and Ungama Bay.

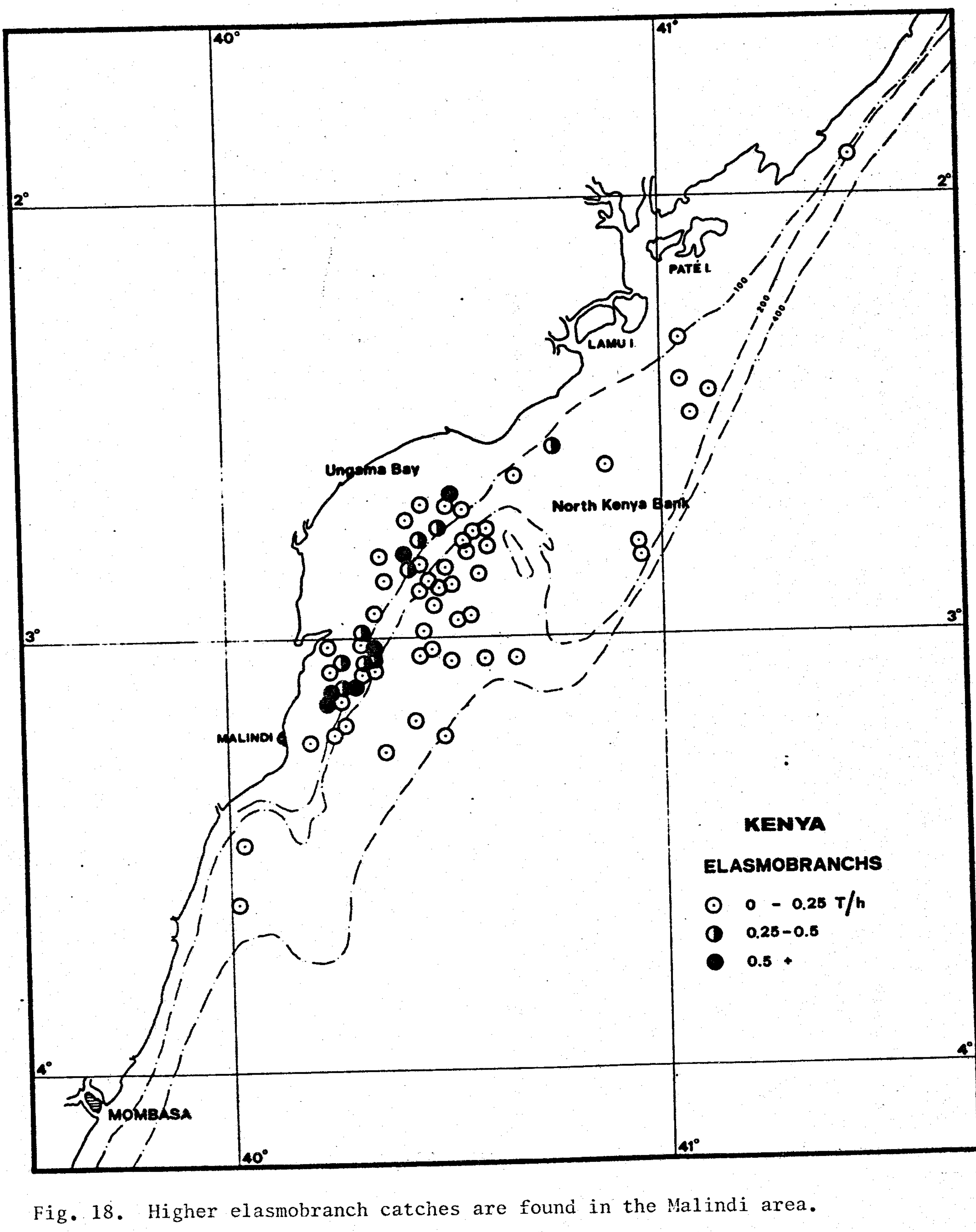


Fig. 18. Higher elasmobranch catches are found in the Malindi area.

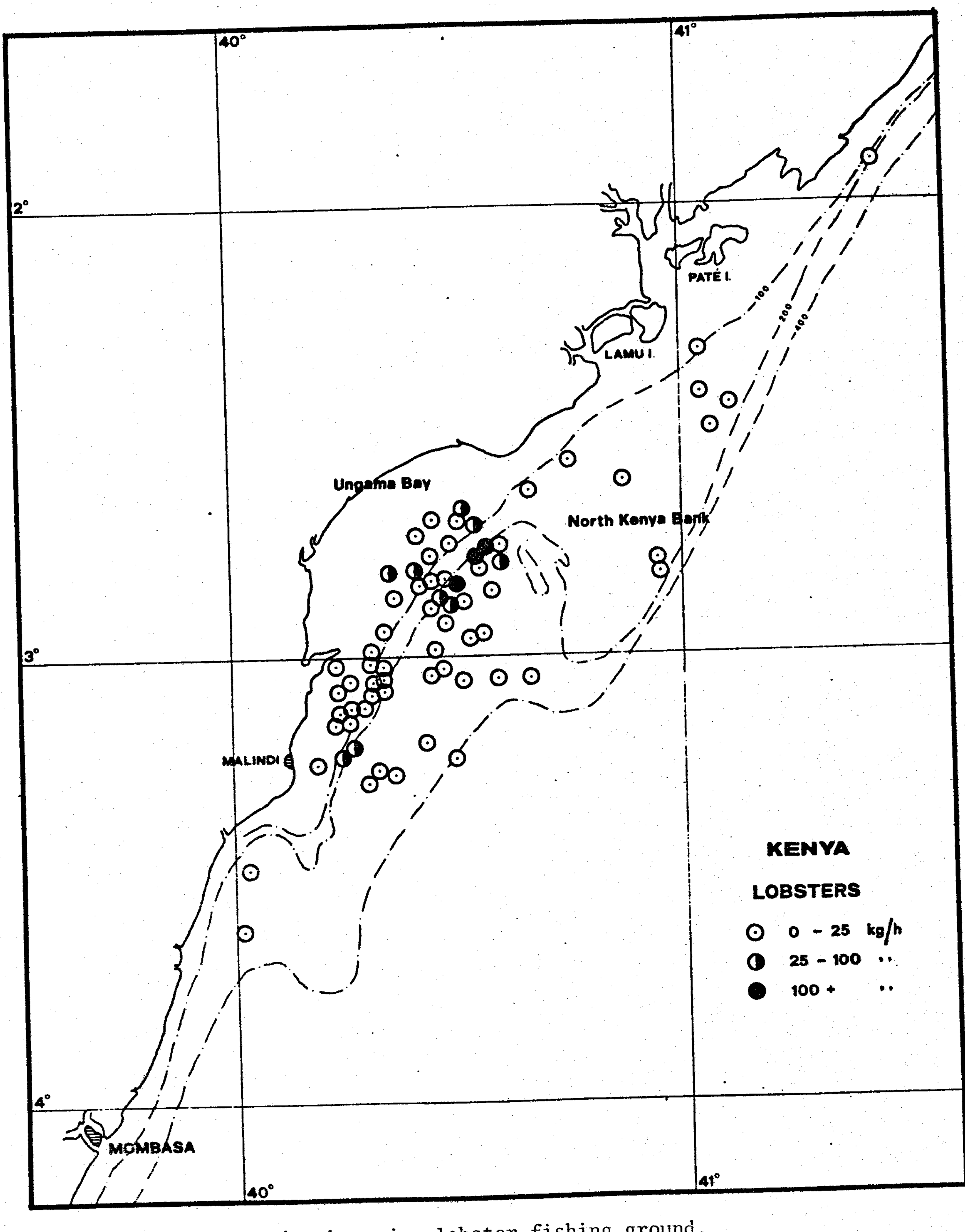


Fig. 19. Ungama Bay is the major lobster fishing ground.

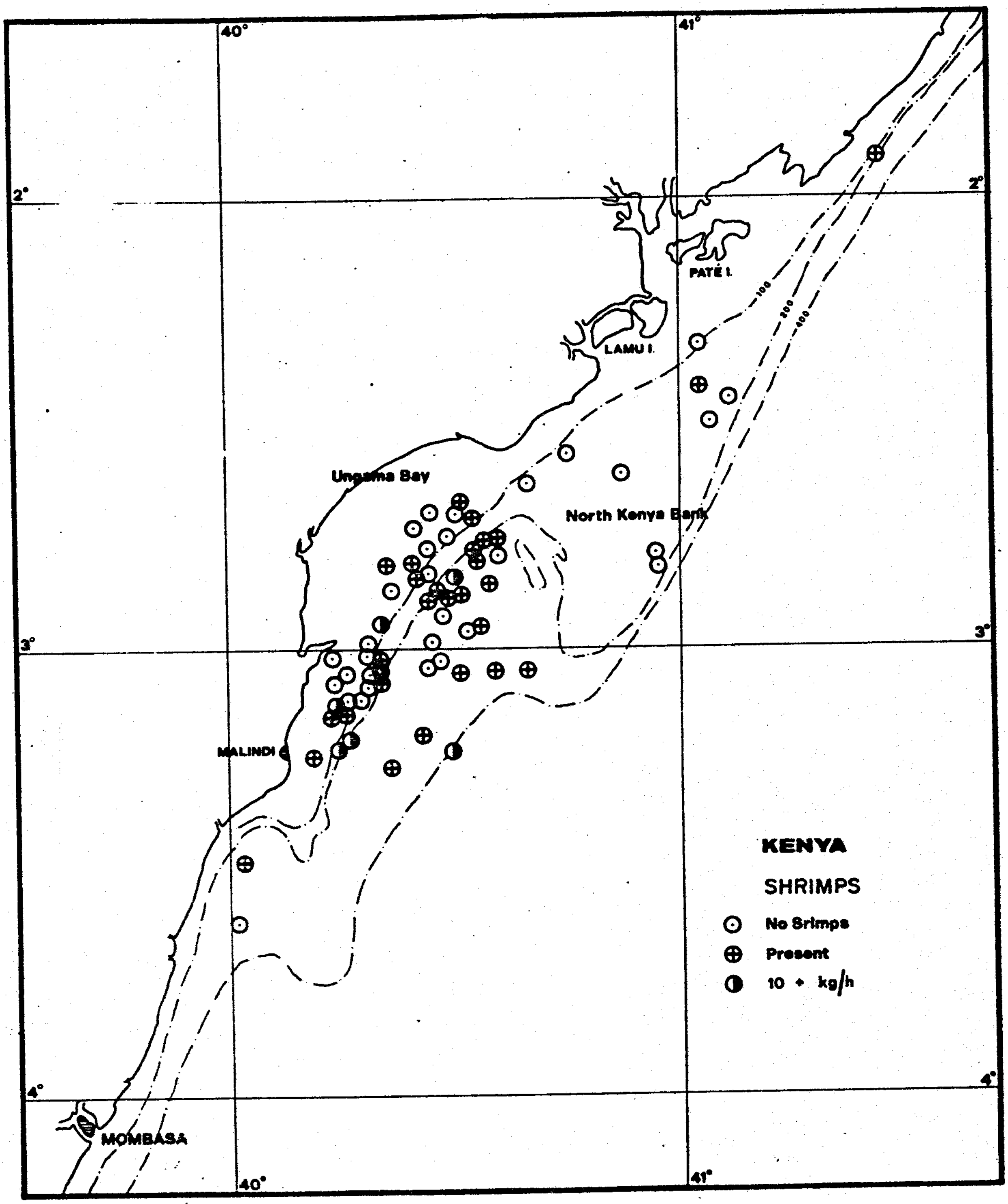


Fig. 20. Shrimps are found in the Ungama Bay complex and North Kenya Banks.

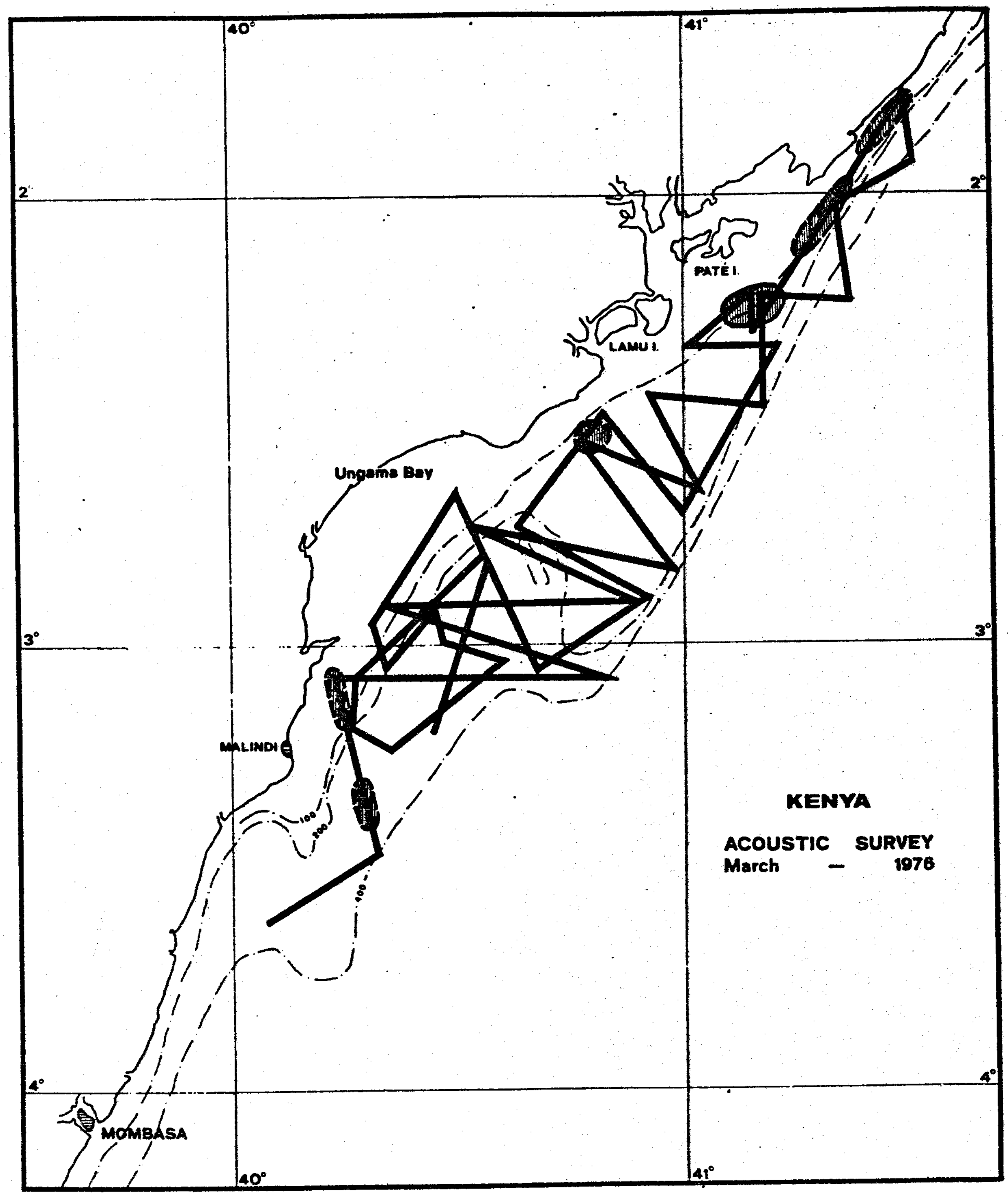


Fig. 21. Fish tracks by hydroacoustic sonar show even distribution along the Kenyan coast at the cessation of the NE monsoon.