APPLICATION OF SATELLITE IMAGERY TO WEST AFRICAN FISHERIES

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APPLICATION OF SATELLITE IMAGERY

TO

WEST AFRICAN FISHERIES

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Executive Summary

The Assessment and Information Services Center entered into an agreement with the Agency for International Development (AID), to study the feasibility of applying satellite imagery to the management of west African fisheries.

The relatively broad and shallow west African shelf has a well-defined seasonal upwelling which is easily identified in satellite images. The upwelling cells extend to 80 kilometers off the coast. The region of the upwelling extends from Cape Bojador to below Cape Vert. The most intense upwelling occurs in the spring and is responsive to local winds along the coast.

We developed satellite imagery for January through September 1983 to determine the feasibility of analysis of upwelling or other features of the environment using NOAA AVHRR data. We compared the observational characteristics of the several satellite systems available for adequacy of coverage and resolution. We found the MEteosat was the best for temporal coverage (hourly) but the NOAA AVHRR was the best for spatial resolution (1.2km). The French are presently providing basic maps of weekly sea surface temperatures of the region based on MEteosat imagery.

The fishery of the region is dependent on the upwelling cells for nutrition and possibly life-cycle timing for reproduction. Each upwelling cell ages after being brought to the surface. The water is advected by surface flow, warmed by the sun, and has its nutrient contents depleted by the grazing zooplankton. The fish in turn feed on the abundance of plankton. Observations indicate the local abundance of fish north of Dakar may be predicted somewhat by the earlier size and intensity of upwelling cells there, as the fish appear to migrate from one aging upwelling cell to a newer one in a slow southward movement. Because fisheries of the region are strongly linked to the upwelling cells, and because the upwelling intensity is highly variable, timely satellite images showing the intensity and location of these cells is valuable to fishermen and fisheries managers.

We limited our present study to the pelagic fishery, which represents the majority of the catch from African coastal waters between Morocco and Cameroon. The fishery is near maximum exploitation, most of the catch being taken by distant water fleets. Two additional groups of fishermen compete with the large foreign vessels for the same resources: local industrial fishermen and artisanal fishermen.
Satellite data can be used in West African fisheries management. The imagery from either Meteosat or NOAA-n satellites with AVHRR data can be used to detect and quantify upwelling in the region. By alerting fishermen to where the fish are feeding, economies can be realized in the form of fuel savings, optimized catch per unit effort, decreased spoilage in the catch, and direct intervention by fisheries managers in the subject countries where the possibility of overfishing might occur.

AISC has developed recommendations in the area of basic environmental understanding, fisheries, satellite data distribution, and social impacts of change in the fishery. We strongly recommend AID continue support of CECAF (1) for study of the regional fishery, (2) for establishment of satellite receiving and image processing technology in the local countries, (3) for developing use of satellite products to reduce spoilage of the catch, (4) for development of means to redistribute the catch to the countries of West Africa, and (5) for evaluation of the relationship of upwelling off the coast of Africa to the drought cycles of the inner continent. While increased capability for monitoring of catch by distant waters fleets would be very helpful for the West African fisheries management, surveillance of any type is not within the scope of NOAA mandates and we can pass no recommendations in this area.
Dr. Kurt Hess provided valuable comments on the draft report. Ms. Marlene Stern processed satellite images for the west Africa region.
Glossary

artisanal - refers to local area fishermen.

baroclinic - state in a fluid in which surfaces of constant
pressure intersect surfaces of constant density.

chlorophyll - green pigments found in photosynthetic organisms.

curl of wind stress - can be regarded as the cause of oceanic
motion, in particular related to the vertical motion.

demersal - pertaining to bottom-dwelling organisms (fishes).

Ekman transport - a representation of the way in which wind­
driven currents vary with depth. Integrated over the depth
of wind influence, the motion is 90° to the right (Northern
Hemisphere) of the surface wind direction.

euryhaline - adaptable to a wide range of salinity.

gyre - vortex or spiral of water.

nadir - the point directly below the satellite sensing element.

navifacial - refers to temperature of sea surface directly below
satellite sensors.

oxyty - measure of the quantity of oxygen in sea water.

pelagic - pertaining to, or living in open oceans or seas.

phytoplankton - minute, floating aquatic plants.

salinity - measure of the quantity of dissolved salts in sea
water.

taxa - name applied to type groups within a subject field.

upwelling - an ascending motion, by which water from subsurface
layers is brought into the surface layer and is removed
from the area of upwelling by horizontal flow.

zooplankton - floating, often microsopic aquatic animals.
1. Introduction

The Assessment and Information Services Center (AISC), entered into an agreement with the Agency for International Development (AID), undertook to study the feasibility of applying satellite imagery to the management of west African fisheries, and to evaluate the ramifications of such application. This report is the final report for Participating Agency Service Agreement (PASA) BAF-0454-P-CC-5115-00, with extension Project Implementation Order/Technical Services (PIO/T) No. 698-0454-2-5614008. The project is part of AID support to the Committee for Eastern Central Atlantic Fisheries of the United Nations Food and Agricultural Organization.

We have divided the study into sections based on environmental background, fisheries statistics for the region, satellite data applications, and implications of the satellite data products. A short discussion of markets and users is included, followed by a brief scenario for technology transfer for these applications. A reference list is given in the last section.
Figure 2.1 Map of the west African coastal countries.
2. Environmental Background

The west African shelf region (Fig. 2.1) is one of the leading fishery areas of the world ocean. Fish are abundant nearshore as well as offshore. The region is one of those with seasonal upwelling providing nutrients to a rich plankton population, a variety of small forage fish, and thus up the food chain to larger migratory commercial species such as tuna and mackerel. Because the upwelling cells in such areas tend to be of limited spatial extent and highly variable in time, even at the peak season, we can use satellite imagery with oceanographic and meteorological data and conceptual models to evaluate the state of the environment for fishery harvest and conservation. We provide in this section brief summaries of the oceanographic and meteorological patterns known for the region.

2.1. Oceanography and Meteorology of the Region

Regions of the ocean bounding the western shelves of continents have well-developed equatorward flow patterns called eastern boundary currents. These currents are a response to the general wind-driven circulation of the oceans, a kind of return current for waters driven northward in the stronger more intense western boundary currents such as the Gulf Stream and the Kuroshio Current. The Peru Current, the California Current, and the Canary Current found off the coast of west Africa, are examples of eastern boundary currents. Any consideration of economic benefits from marine fisheries in the west African area must include consideration of the strength and location of the Canary Current flow.

The surface winds coming off the Sahara, the northeast trades, control much of the marine environment in this region. Both the strength and direction of the trade winds are important for the second major oceanographic feature of the region, coastal upwelling. The upwelling is found in most eastern boundary current areas, but in the west Africa region depends more on local winds than in other eastern boundary current regimes. Coastal fisheries of the area depend entirely upon the upwelling system for food chains, and may also follow upwelling cycles for breeding patterns. Thus the oceanography and the meteorology of the west African shelf are critical factors in the health of the fisheries resources for those countries in the region.
2.1.1. Oceanic Circulation of the Region

The ocean area off west Africa between the equator and 35°N contains two major current systems which interact to give the region a changeable and unusual circulation. In the north the (Fig. 2.2) Canary Current is part of the eastern boundary current system of the north Atlantic ocean. In the southern area the north equatorial current and the equatorial countercurrent create another circulation. Between these two major systems a semi-permanent gyre forms off the coast of Mauritania, Senegal, Dahomey, Guinea-Bissau, and Guinea. The precise size and position of the gyre changes seasonally in response to the relative positions and strengths of the two current systems.

Both of these driver current systems are associated with upwelling. The Canary current maintains permanent upwelling, though varying in strength and location from Morocco to Senegal with occasional excursions as far south as Sierra Leone. The zone of equatorial upwelling is in the Gulf of Guinea off Ivory Coast and Ghana and is seasonal.

The Eastern Boundary Current

The dynamics of eastern boundary currents (EBC) are not completely understood but several aspects of these currents have been studied for some regions. The currents arise in response to equatorward winds in the temperate and subtropical regions between 45 degrees latitude (north or south) and the equator. Upwelling is associated with the eastern boundary currents in intense cells near the coast. Although most of the EBC region comprises a general equatorward drift, an equatorward surface jet forms near the coast at a distance related to the latitude and topography called the baroclinic radius of deformation. The EBC region is usually known by the name of this coastal jet, as in the Canary Current, the California Current, the Bengucia Current, and the Peru Current.

There is normally strong variability on the time scale of days and much fine structure may be present in the form of cells of upwelled water, or fronts which form in response to either the upwelling or topography. Currents will vary from year to year or from season to season, although some form of upwelling will usually be present. The variability is a feature only of the coastal current and does not control what happens offshore.
Figure 2.2 Mean surface currents of the west African coast; a) January
b) September.
Summary aspects of EBCs can be given and are applicable directly to the Canary Current region:

1) Ekman transport (forced by local winds) is the major driving mechanism. This dependency on the wind stress is a major consideration in monitoring the region and for interpretation of satellite imagery. Changes in the winds will contribute to subsequent changes in the temperature and density fields in the region.

2) The oceanic responses to local wind forcing moves poleward and raises the thermocline poleward of the region of forcing. This response creates a poleward undercurrent.

3) If the upwelling is very intense strong surface fronts will form which may set up sub-cells of circulation, leading to local intensification of productivity.

4) Eastern boundary currents affect the climate of the regions near them since they bring water with temperatures much cooler than normal for waters of that latitude.

The Canary Current

The region of upwelling of interest to us in the West Africa project is in the area traversed by and to the south of the Canary Current. The Canary Current flows from the Moroccan coast south-southwest to the coast of Mauritania and Senegal where it turns offshore more to the southwest and eventually westward into the Sargasso Sea (Fig. 2.2). Where the Canary Current flows offshore, the north equatorial countercurrent flows eastward toward the Gulf of Guinea and the two currents form a small gyre to the west of Guinea-Bissau, Guinea, Sierra Leone, and Liberia. Along the coast of Morocco, Mauritania, Senegal, and Gambia, the southward flowing eastern boundary current and the local wind stress field create seasonal upwelling. A map of the average annual temperature variability shows the strongest upwelling and most change in position for upwelling pockets in the region between 23°N and 10°N (Fig. 2.3).

The Canary Current differs from the other eastern boundary currents in being a current which flows from a source region where evaporation exceeds precipitation, giving the surface waters in the current salinities higher than salinities in neighboring waters, (35.5-36.5ppt). Smith (1981) has compared the relative topography, density fields, and wind stress regimes of three of the major eastern boundary jets. He shows the Canary region to have weaker stratification than either the Oregon coast
Figure 2.3  Average yearly variation of surface temperature with upwelling areas shaded.
or the Peru Current region. The baroclinic radius of deformation for the west African coast is less than half that of the Peru coast. Each of these factors should make upwelling less intense and more localized than in the Peru or Oregon areas. However, the wind stress off Africa is nearly three times as strong as in either Oregon or Peru. Thus we see the strongly spread upwelling found by Barton, et al. (1977; Fig. 2.5). The cooler upwelled waters spread from the coast out to the shelf break, as much as 80 kilometers offshore. For comparison the upwelling off Peru stays generally within 50 kilometers of the coastline.

Comparison with the California Current System

We can compare the structure of the water column with key properties in Figure 2.5. The thermocline stratification off west Africa is less intense than that in California waters. Off west Africa the temperature changes from 25°C at the surface to 20°C at the base of the thermocline. The upwelling source water lies between 15m and 100m depth which is near the top of the thermocline and should yield nearshore surface temperatures of that value for the time of year we have the measurements. Similarly the upwelling water from offshore depths between 45m and 65m yields water from the top to middle of the thermocline, or about 21° or 22°C.

Comparison of the salinities of the two regions reveals the much higher salinities of the source waters for the Canary Current. Values of 37 ppt appear off Africa, higher than the ambient salinities of 36 ppt; while the California Current region reveals a core salinity (33.2 ppt) lower than its surrounding environment (34.0 ppt). These relative salinity analyses indicate the source region of the Canary Current is a region where evaporation exceeds precipitation.

The oxyty field shown for the two regions indicates the California Current has higher surface values of oxyty than the Canary Current regime; but values drop off to less than 1.0 ml/l at a depth of 500m near the coast. Off the coast of Africa the levels of oxyty are not as high at the surface, but remain overall higher throughout the water column. Nowhere in the upper 1000m do values fall below 2.0 ml/l. This should provide excellent conditions in the ecosystem for the plankton which grow in or around the upwelled waters.

Phosphorus does not appear to be a limiting factor in either environment, although the concentrations available at depth in the California Current system are greater than those available in the Canary Current region at depth.
Figure 2.4 Spreading upwelling cells as shown by the zonal distribution of surface temperature. (After Barton, et al, 1977.)
Figure 2.5 Comparison of water properties between California Current region and Canary Current region.
2.1.2. General Meteorology of the Region

The climatological winds for the Committee for Eastern and Central Atlantic Fisheries (CECAF) region are dependent on the interplay between the North Atlantic Subtropical High (NASH), the South Atlantic Subtropical High (SASH), the Intertropical Convergence Zone (ITCZ) which is the near-equatorial trough of low pressure. During the northern hemisphere summer the Sahara Thermal Low (STL) figures prominently in weather for the region. The shifting of these large scale atmospheric systems changes the regional wind induced sea surface mass transports, the potential for favorable upwelling winds along the coast of Northwest Africa, and the Equatorial divergence upwelling in the Gulf of Guinea.

Figure 2.6 is a schematic of the climatological latitudinal distribution of high and low pressure systems and resultant winds. The clockwise circulation of the NASH results in the Northeast trade winds from approximately the equator to 30°N latitude. The counter clockwise circulation of the SASH results in the southeast trade winds from approximately the equator to 30°N latitude. Separating those two systems is the ITCZ and its associated light and variable winds and heavy precipitation, also called the doldrums. The location of the ITCZ is generally north of the equator due in part to the configuration of the coastlines of the Americas and Africa. Thus, the equatorial area is under the influence of the SASH or the ITCZ for the majority of the year.

The wind-induced vertical transport of water is proportional to the curl of the wind stress (Fig. 2.7). Along the Northwest African coast positive values of wind stress curl signify seaward increase in the equatorward wind stress. Thus, the offshore wind-induced transport increases in the offshore direction. To balance this increasing flow of water offshore upwelling of subsurface waters is required. If the equatorial wind stress decreases in the offshore direction the result is a negative wind stress curl value. This results in convergence in the wind induced surface drift which could result in the formation of oceanic fronts and downwelling offshore of the coastal upwelling region.

Northern hemisphere spring is a time of transition. The NASH begins to intensify and move northward filling in some of the region being vacated by the Icelandic Low which is now weakening in intensity. The SASH also moves northward being pushed northward by the intensifying Antarctic sub-polar low in the Southern Ocean. The ITCZ moves northward and runs southwest from the African coast.

Figures 2.7 through 2.9 show the gradual changing wind and upwelling potential in spring in the equatorial Atlantic. The winds of the SASH cross the equator from the Gulf of Guinea to approximately 25°W longitude. Alongshore winds are dominant in this April picture (Fig. 2.8). The triangular region of the doldrums expands westward across the Atlantic.
Figure 2.6 Map of equatorial Atlantic showing climatological atmospheric circulation features.
Figure 2.7 Curl of the wind stress (in $10^{-8}$ dynes cm$^{-3}$) for April. (After Hastenrath and Lamb, 1977.)
Figure 2.8 Resultant wind directions for April. (After Hastenrath and Lamb, 1977.)
Figure 2.9 Wind steadiness (in percent) for April. (After Hastenrath and Lamb, 1977.)
2.1.3. Upwelling Dynamics

What is upwelling? No strict definition for upwelling exists, but one that is generally accepted is given by Smith (1968) as "an ascending motion, of some minimum duration and extent, by which water from subsurface layers is brought into the surface layer and is removed from the area of upwelling by horizontal flow." The upward vertical motion of water from below the sea surface (on the order of tens to several hundreds of meters) toward the surface of the ocean is upwelling. Once at the surface, this water is then advected (moved horizontally) away from its source location.

Why is upwelling important for fisheries? The majority of the production of phytoplankton (grasses of the sea) occur in the surface waters of the oceans. Phytoplankton are the primary producers of the ocean, converting sunlight and nutrients into living plant tissue. Animals at higher trophic levels, from zooplankton to tunas, then consume these phytoplankton. Abundance of nutrients is generally the limiting factor in the amount, duration, and location of phytoplankton in large quantities. Upwelling brings to the surface waters that are generally enriched in nutrients, deficient in oxygen, and of cooler temperatures. The increased availability of nutrients allows for increased production of phytoplankton which in turn means more food for the higher trophic levels (fishes). Thus, upwelling regions have increased potential for fisheries exploitation. The water upwelled along the northwest African coast is north Atlantic central water (NACW) which is not as enriched in nutrients as the upwelled waters found off the west coast of the United States. Thus phytoplankton productivity will not be as high for the CECAF region as for the area of the California Current.

2.1.3.1. Causes of Upwelling in the CECAF Region

There are three different types of upwelling which we need to consider for the CECAF region: 1) northerly winds parallel to the coast, 2) eastern boundary current upwelling, and 3) equatorial divergence upwelling. The equatorial upwelling occurs only in the Gulf of Guinea. However, both type 1 and type 2 upwelling occur off the coast of west Africa.

Winds Parallel to Coast

The first type of upwelling occurs when winds are flowing parallel to the coast with the coastline on the left(right) in the northern(southern) hemisphere (divergent flow along a boundary). The surface waters are advected offshore and are replaced by subsurface convergence along the coastal shelf.
**Eastern Boundary Current Upwelling**

The second type of upwelling results from the surfacing of the Eastern Boundary Current (Canary Current) flowing over a sloping bottom (Cruzoado and Salat, 1981). The effect of the winds inducing this type of upwelling is indirect since the winds drive the Eastern Boundary Current.

The dependence of upwelling on surface winds implies variability of the upwelling at time and space scales similar to the meteorological scales of variability. Thus, the seasonal shifting of the North Atlantic Sub-Tropical High results in a seasonal variability in the coastal upwelling off northwest Africa. Temporal variability is intensified by the effects of storms which transverse the area. Finally, interannual variations due to changes in the hemispheric distributions of high and low pressure systems in the atmosphere result in a two to five year sustained variability of upwelling.

Coastal topography and bathymetry are very important for the west African upwelling. These geologic features help to locate regions favorable for upwelling. The gentle sloping shelf is important for type 2 upwelling. The head of submerged canyons and the lees of capes are prime locations for type I coastal upwelling. The width of the coastal shelf also influences upwelling allowing the zone of upwelled water to widen across the shelf.

2.1.3.2. Observations of Upwelling

Detection of Upwelling

Waters from depths of the order of tens to several hundred meters are much cooler than surface waters. Temperature measurements alone can be used to define the region of upwelling. Upwelling has various spatial scales and temporal scales, from tens to hundreds of kilometers, and from days to weeks. A synoptic picture of the sea surface temperature field gives the best detail of the spatial variability, while daily synoptic pictures will display temporal variability. Collection of synoptic data over the northwest African coast by in-situ ship sampling is not possible except in large experiments. However, satellite thermal data can be used to detail sea surface temperature (SST) fields over large geographic regions with accuracies of better than 1°C. Satellite data can be used in the generation of synoptic scale imagery of sea surface temperature, revealing where upwelling is occurring.
Aging of Upwelling Cells

Following a parcel of upwelled water from its original cool nutrient-rich subsurface location to a later time when it is indistinguishable from the waters normally found at the surface, depleted of nutrients and warm, a series of events has occurred. First, the local phytoplankton species start to reproduce when sunlight becomes available. The water parcel is advected by surface currents away from its source location. As the parcel moves it warms due to solar insulation and phytoplankton use the nutrients. Zooplankton feed on the new phytoplankton crop and reproduce rapidly. When the nutrients are depleted to a low level, phytoplankton production is greatly reduced while zooplankton production continues and these animals continue grazing on the phytoplankton crop.

Upper trophic levels in the oceanic food chain respond to increased availability of food by feeding on the zooplankton. Higher trophic animals (tuna) feed on lower trophic animals (squid). Thus, the local enrichment of the surface waters by upwelling produces a positive impact throughout the food chain, even to the economically important species.

In the west African coastal region, the Canary Current carries parcels of upwelled water southward along the coast. As the parcel drifts the nutrients are depleted by the phytoplankton and the older cells are found southward of the points of origin. Scientists have observed the higher trophic level fish migrating southward from one pool of upwelled water to another, following the fresher upwelled cells for better grazing.

Time and Space Scales of the Upwelling

In most of the eastern boundary upwelling systems, the pattern of upwelled water is noted as highly variable with organization into small cells of upwelling. Guillen and Rondan (1973) documented chlorophyll-a concentrations in pockets along the Peruvian coast. The sizes of these pockets were up to 100 km in length but less than 50 km wide. Blasco and Estrada (1980) show the temporal variations of the upwelling off the west African coast to be on the order of a few days and have shown further the dynamic variability in the temperature, salinity, and flow fields is reflected in the density of plankton populations along the shelf and through time. In just a few days or in the space of a few kilometers, the concentrations of plankton can vary from less than 1000 cells/liter to more than 100,000 cells/liter during an upwelling event.
2.2. Pelagic Fisheries

The pelagic (in the water column) fishery represents the majority of the total fish catch between Morocco and Cameroon. We have, therefore, limited our study to pelagic fish only. While there are several demersal species available in the area which are harvested commercially, data available are not suitable for detailed analysis, and satellite imagery is not likely to aid the search for bottom dwelling species.

2.2.1. Species and Volume of Catch

There are reporting problems in studying both volume and catch for this region. We summarize the statistical reporting problems for the entire catch and discuss the pertinent life characteristics and harvest patterns for the economically important taxa.

2.2.1.1. Problems with Fishery Statistics

Interpretations of the catch statistics reported for the CECAF region (FAO fisheries region 34) require caution. Countries do not report catch statistics according to uniform standards. For example, some countries follow FAO geographical subdivisions of the CECAF region, others do not. The Soviet Union reports its catch only for the entire CECAF region. Secondly, the catch statistics for species are frequently inaccurate. The two species of sardinella, and sometimes even the sardine are reported as one species, even though the distributions and exploitation rates differ among these three fisheries.

Catches are not usually reported by gear type or even by fishery type (e.g., industrial or artisanal), although these data are essential for estimating fishing effort. Finally, the catch estimated for the artisanal fishery is crude, because of the logistical problems associated with the large numbers of artisanal fishermen and their dispersion along the coast.

As a result of these collective problems, we commonly find conflicting catch statistics, and major revisions of previously published data. Often the data cannot be tabulated by the categories of interest for this type of analysis. We therefore have based our analysis on published FAO catch statistics with revisions through 1983 (FAO, 1979; 1981; 1983).
2.2.1.2. Volume of Catch

In the west African region between Morocco (26°N) and Cameroon (6°N), the pelagic fishery represents the majority of the total fish catch (Boe and Fréon, 1982). The pelagic catch in that region grew by a factor of six between 1966 and 1976 (Fig. 2.10), with the majority of the increase occurring in the region from Cape Bojador (26°N) to Guinea (9°N). During that decade in the 26°-9°N region, the catch reported for carangids (jacks) increased by a factor of nine and the catch reported for clupeids (sardines) increased by a factor of 20. Catches in the Gulf of Guinea (9°N-6°S) also increased during this period, but only by a factor of two. Now less than 20 percent of the catches of pelagic fish for the CECAF region are taken from Gulf of Guinea waters.

2.2.1.3. Taxa of Catch

Although many taxa comprise the pelagic catch, the taxa listed in Table 2-1 are the most important by landed weight (FAO, 1979; 1981; 1983). The following discussion centers on the local species that comprise these taxa, although the catch statistics for some species are lumped together in fisheries reports for the region. The tunas are subtropical and tropical oceanic species found throughout the world. The cunene horse mackerel (Trachurus treace), yellow horse mackerel (Caranx rhonchus), sardinellas (Sardinella aurita and S. maderensis), bonga (Ethmaloa fimbrata), and Chub mackerel (Scomber japonicus) are found throughout the study region (Boe and Fréon, 1980). Three temperate species, European sardine (Sardina pilchardus), blue fish (Pomatomus saltatrix), and Atlantic horse mackerel (Trachurus trachurus), extend only into the more northern parts of the study area.

**Tunas**

The most abundant tunas in this region are the Skipjack (Katsuwonus pelamis), Yellowfin (Tunnus albacares), and Bigeye (T. obesus). All three species are common in tropical and subtropical seas, and are found throughout the entire west Africa region. The Skipjack tuna is generally found in oceanic waters, above the thermocline, and near the shelf break. It is caught using poles and line, or with purse seines. The yellowfin tuna is found in somewhat cooler waters and may be below the thermocline. This species is caught with purse seines or longlines. The Bigeye tuna is found in oceanic waters to 250m depth. This species is caught with longlines and occasionally purse seines.
Figure 2.10 Total pelagic catch for west Africa (FAO CECAF Region) for 1964-1983. (From FAO, 1979; 1981; 1983)
Table 2.1. Catch of pelagic fishes in West African waters. Catch is reported in thousands of metric tons. Adapted from FAO Yearbook of Fishery Statistics (1979, 1981, 1983).

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<td>Trachurus spp.</td>
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<td>Caranx spp.</td>
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<tr>
<td>Sardinellas</td>
<td>327</td>
<td>438</td>
<td>350</td>
<td>544</td>
<td>556</td>
<td>521</td>
<td>504</td>
<td>427</td>
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<tr>
<td>Sardinella spp.</td>
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<td></td>
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<tr>
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<td>63</td>
<td>59</td>
<td>56</td>
<td>65</td>
<td>73</td>
<td>68</td>
<td>81</td>
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<td>81</td>
<td>88</td>
</tr>
<tr>
<td>Ethmalosa fimbriata</td>
<td></td>
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<tr>
<td>European Sardine</td>
<td>683</td>
<td>718</td>
<td>983</td>
<td>778</td>
<td>436</td>
<td>390</td>
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<tr>
<td>Skipjack Tuna</td>
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<td>73</td>
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<tr>
<td>Katsuwonus pelamis</td>
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<tr>
<td>Yellowfin Tuna</td>
<td>95</td>
<td>110</td>
<td>107</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Bigeye Tuna</td>
<td>35</td>
<td>34</td>
<td>21</td>
<td>25</td>
<td>30</td>
<td>21</td>
<td>31</td>
<td>23</td>
<td>28</td>
<td>29</td>
</tr>
<tr>
<td>Thunnus obesus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chub Mackerel</td>
<td>149</td>
<td>177</td>
<td>160</td>
<td>174</td>
<td>87</td>
<td>109</td>
<td>135</td>
<td>115</td>
<td>200</td>
<td>177</td>
</tr>
<tr>
<td>Scomber japonicus</td>
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<td></td>
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<td></td>
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</tr>
</tbody>
</table>
Mackerel

The Atlantic horse mackerel is captured as far south as Cape Verde Peninsula (13°N) (Fig. 2.11a). The cunene horse mackerel is more tropical and is found from the vicinity of Cape Barbas (23°N) to Angola (Dias, 1974) (Fig. 2.11b). The largest concentrations of each species are found from 50m depth to the shelf break in the areas of upwelling. The adults migrate along the coast in apparent conjunction with shifts in the inter-tropical front, with the cunene horse mackerel located somewhat south of the Atlantic horse mackerel. From November to January, the Atlantic horse mackerel breeds offshore between 20°N and 26°N; consequently young fish are commonly caught in that region. The main breeding area of the cunene horse mackerel is further south between capes Tmiris and Verde. In February and March T. trachurus is abundant near Cape Verde, whereas T. treciae is abundant near the Gambia river. Both species are fished off Mauritania and Senegal only by large-scale, mostly foreign, fleets.

The yellow horse mackerel (Caranx rhonchus) is found between Cape Barbas (23°N) and the Bissagos Islands (11°N), migrating along the coast also in apparent conjunction with the inter-tropical front (Fig. 2.11c). The adults are found on the outer shelf, while juveniles are more coastal. The main breeding season extends from April to July, and from Cape Roxo (12°N) to Nouakchott (18°N). The largest catches by the large-scale fisheries are composed of pre-breeding adults caught near the shelf break. The seiners catch these fish south of the Cape Verde Peninsula from January to April and the trawlers catch northward-migrating fish from April to July, between Cape Verde (15°N) and Cape Tmiris (19°N) (Boely and Fréon, 1973). In Senegal, these fish are caught by local seiners and the artisanal fishermen, but the total catch by these two groups in Senegal and Mauritania is less than 5000 MT (Fréon et al., 1979).

Sardines

The European sardine (Sardina pilchardus) is a temperate species that until recently was not abundant below Cape Bojador (26°N) (Fig. 2.11d). Since 1970 this species has been both increasingly abundant, and distributed further south, 26°-19°N (Boely and Fréon, 1980). Catch-per-unit-effort (CPUE) statistics reported by the Polish large-scale fleet suggest that the increased catch was due to increased abundance, and not by switching effort to a previously under utilized stock (Boely and Fréon, 1980). However, since 1976, catches of this species have declined (FAO, 1981; 1983; c.f., Figure 4.1d).
Figure 2.11a,b Major fishing areas within the northern CECAF area; a) Atlantic Horse Mackerel, b) Cunene Horse Mackerel. Cross-shelf axis of fishing area not to scale. (After Garcia, 1982.)
Figure 2.11c,d  Major fishing areas within the northern CECAF area; c) Yellow Horse Mackerel, d) European Sardine. Cross-shelf axis of fishing area not to scale. (After Garcia, 1982.)
The Sardinella Species

The round sardinella (Sardinella aurita) ranges all along the west African coast from Gibraltar (36°N) to Cape Frio (18°S) (Fig. 2.11e). It prefers clear, saline (35 ppt) shelf waters with temperatures less than 24°C. Thus, in this region it is only abundant in the upwelling zones. Each upwelling zone may have a different population of sardinella, because fish are not generally caught outside the upwelling zones, and the ocean currents do not favor population exchange (FAO, 1973). The major spawning period is during May and June, from Senegal to Cape Timiris (19°N) and continues through July and August off Mauritania (Boely and Fréon, 1980). Deep sea trawlers catch the adults north of 20°N during the entire upwelling period in 50 to 500 m of water (Elwertowski and Boely, 1971). The young are fished by local and large-scale seiners in 10-50m of water (Boely and Fréon, 1980).

The flat sardinella (S. madeensis) has a latitudinal distribution similar to the round sardinella (Fig. 2.11f); however, it is euryhaline and is found in shallower coastal waters, frequently near river mouths (Boely and Fréon, 1980). Like the round sardinella, it is also found in the relatively clear waters of upwelling zones, but it prefers waters warmer than 24°C (ibid.). The flat sardinella has two major nursery areas in this region: between Dakar and the Bissagos Islands, and from the Arguin Bank to south of Cape Timiris. The young spawners found on the seaward edge of these nursery areas form the bulk of the catch for the coastal fleets and occasionally form part of the catch of the long-distance seiners (Boely and Østvedt, 1976). The adults are most abundant north of Cape Verde and are mainly caught by the artisanal fishery.

Other Species

The bonga (Ethmalosa fimbriata) is euryhaline and is common in estuarine, lagoonal and coastal waters (Scheffers, 1973; Scheffers and Conand, 1976). It is rarely found at depths greater than 20m. Because the bonga is found in warm and turbid waters and therefore not common in upwelling zones, there is little overlap with the local distribution of the sardinellas. The bonga is caught mainly by the artisanal fishery using beach seines and gill nets, between Mauritania and the Congo river (Boely and Fréon, 1980).

The chub mackerel (Scomber japonicus) is caught in this region (26°N-9°N) during the cold season, and then north of Cape
Figure 2.1e,f  Major fishing areas within the northern CECAF area; e) Round Sardinella, f) Flat Sardinella. Cross-shelf axis of fishing area not to scale. (After Garcia, 1982.)
Figure 2.11g,h  Major fishing areas within the northern CECAF area; g) Chub Mackerel, h) Blue Fish. Cross-shelf axis of fishing area not to scale. (After Garcia, 1982.)
Timiris (19°N) during the hot season (Elwertowski and Boely, 1971; Chabanne and Elwertowski, 1973). This species is most abundant near the shelf break in upwelling areas (Fig. 2.11g).

The blue fish (*Pomatomus saltatrix*) migrates between Senegal and Morocco (Fig. 2.11h). In Senegal (Dakar to St. Louis), it is caught by artisanal fishermen from December to June. In June and July, the large-scale fishery takes pre-spawning fish near Cape Timiris (19°N) (Boely and Fréon, 1980). Blue fish are typically not abundant between Dakar and the equator.

### 2.2.2. Harvest Patterns

There are three major harvest groups for West Africa: artisanal fishermen, local industrial fleets, and large-scale, mostly foreign, fleets.

#### 2.2.2.1. Artisanal Fishing

The artisanal fishermen generally fish from canoes with simple gear, typically cast nets, gill nets, seines, or handlines. The artisanal canoes have recently become motorized, which has permitted the fishermen to follow the fish migrations, increase their CPUE, and to land more of their catch at port facilities (Boely and Fréon, 1980). In Senegal, artisanal fisheries are estimated to land more than twice as much fish as the local-industrial fleets, but the numerous and diverse canoe landings in numerous villages along the coast makes for only crude estimates of the catch. In 1977 the Senegalese artisanal fishery reportedly took 80,000 MT. Of that figure, 71 percent were sardinellas, 7.5 percent blue fish, 7.5 percent bonga, 4 percent yellow horse mackerel (Fréon et al., 1979). No data are available on the catch of the artisanal fishery in Mauritania. In fact, many of the artisanal fishermen in Mauritania are from Senegal.

#### 2.2.2.2. Local Industrial Fishing

The local industrial fishery refers to vessels with a typical length of 13-25 meters that are better equipped than the artisanal canoes. These vessels typically have acoustic detection equipment (fish finders) and power winches. Unlike the artisanal fishery, the catch is preserved on ice or in refrigerated seawater. Most of the countries of this region have at least a few vessels of this type, but Senegal, Ivory Coast and Ghana have fleets. These vessels use purse seines for a coastal fishery (\(<50m\) depth) that takes mainly sardinellas, on trips
lasting less than three days (Boely and Fréon, 1980).

2.2.2.3. Large-Scale Industrial Fishing

The term large-scale fishery refers to the use of ships (mainly foreign) with the capability of staying at sea for weeks or months. The vessels range in size from 35 m Scandinavian and Soviet seiners supplying a mother ship, to 85 m eastern European trawler-processors. For the coastal pelagic fishes, this fishery is mainly confined to the richest upwelling areas (Cape Bojador - Sierre Leone) 26°-9°N.
2.3. Economic and Historical Perspective

The northwest coast of Africa from the Canary Islands to the Gambia River is rich in fish resources but in terms of per capita Gross National Product (GNP) Mauritania ($470), Senegal ($490), and Morocco ($870) rank in the lower-middle income group of world nations (World Development Report, 1984). Thus, the fishery resources known to exist in the marine waters off the coasts of the nations in this area have seemed to be a promising area for economic development. Economic benefits would fall into several categories: nourishment of the population, employment, and commercial-industrial development. Within the scope of this report, it is therefore important to understand how the development of fishery resources historically have related to economic development and what could be anticipated in the future.

2.3.1. Development of Exclusive Economic Zones

The impetus for West African nations to look at fisheries as a positive resource in their economic development came with the evolution of the concept of the exclusive economic zone in international law in the 1970's. Because of the abundance of fish in West African waters, they were among the first areas of the world to be intensively fished by the so-called "distant water" fishing fleets of the more highly industrialized nations. Senegal was the first nation of the area to announce the extension of its territorial sea limit from 12 miles. In April 1976 this nation extended it to 150 miles and in July declared a 200-mile fishing zone within which it would manage and maintain control of fishing activities. Table 2.2 lists the limits of the territorial sea, declared fishing zones, and exclusive economic zones for the nations of our study area.

Establishment of EEZ's was followed by the signing of the United Nations Law of the Sea Convention in December 1982. A key element of the Convention deals with the concept of coastal states jurisdiction over fisheries resources out to a 200-mile limit and the responsibility to manage these resources. However, while any nation can establish authority in a region by decree, its ability and/or will to exercise this authority is another question. Where states establish laws and regulations regarding foreign fishing in their zones, these laws may not be enforced uniformly. Increased monitoring of fish catch is highly desirable, but outside the scope of this report.
Table 2.2. Territorial seas, fishing zones, and exclusive economic zones established by West African nations in nautical miles with year of establishment. Source: Resources Development Associates, 1985.

<table>
<thead>
<tr>
<th>Country</th>
<th>Territorial Sea</th>
<th>Fishing Zone</th>
<th>EEZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morocco</td>
<td>12 nmi (1973)</td>
<td>not available</td>
<td>200 nmi (1981)</td>
</tr>
<tr>
<td>Mauritania</td>
<td>70 nmi (1978)</td>
<td>not available</td>
<td>200 nmi (1978)</td>
</tr>
<tr>
<td>Gambia</td>
<td>12 nmi (1969)</td>
<td>200 nmi (1978)</td>
<td>not available</td>
</tr>
<tr>
<td>Guinea-Bissau</td>
<td>12 nmi (1978)</td>
<td>not available</td>
<td>200 nmi (1978)</td>
</tr>
<tr>
<td>Cape Verde</td>
<td>12 nmi (1978)</td>
<td>not available</td>
<td>200 nmi (1978)</td>
</tr>
</tbody>
</table>
2.3.2. Development of the Fisheries Committee for the Eastern Atlantic (CECAF)

CECAF was established by the Food and Agriculture Organization (FAO) of the United Nations (UN) in 1967. CECAF became operational in 1975 with headquarters in Dakar, Senegal. The area of interest extends from the Straits of Gibraltar to the mouth of the Congo River. CECAF functions are "to promote, coordinate, and assist national and regional programs of research and development leading to the rational utilization of marine resources and to formulate management measures aimed at the conservation and improvement of these resources" (Resources Development Associates, 1985). Of the 20 coastal nations lying in the CECAF area, all but Equatorial Guinea were members of the Committee at the end of 1983. Several distant-water fishing nations were also members, among them the United States. Members meet periodically to discuss issues pertinent to the purposes of the organization.

CECAF is most reliable source for statistical data on the regional and local fisheries of Northwest Africa. In order to evaluate the fisheries of the area, CECAF has established several divisions within its jurisdiction. For the study area of this report, three of these areas are of significance although it must be noted they do not correspond to any political boundaries. The first area, referred to as the Cape Verde Coastal division, extends from 9°N latitude to 19°N. The Sahara Coastal division extends from 19°N to 26°N, and the Morocco Coastal division lies above 26°N.

The coincidental timing of the operational phase of CECAF and the establishment of EEZ's by Northwest African nations is significant. CECAF gave these nations a statistical base for understanding the economic significance of their fisheries resources and a forum for discussing common interests. In particular, it gave them the means to fully evaluate their policies toward national fisheries development and foreign fishing in their waters.

2.3.3. Fishery Resources and National Policy

The nations of Northwest Africa may each individually decide on the goals of national economic policy development and the means to reach these goals. These goals are molded by past experiences of the population; the religious, ethnic, social, and cultural makeup of this population; variety and distribution of resources; climate; and current stage of economic development and income distribution.
2.3.3.1. Options for Fishery Management

Three options are available for managing fishery resources to attain economic and social goals:

1) To encourage the development of primarily local small scale fishermen (generally referred to as artisanal fishermen) who use fishing as either a primary or supplemental source of income and who operate in canoes or small motorized boats (known as piroques). In this option, the village economy is enriched. Processing of fish is done on a small-scale basis locally and the distribution is within a limited area. There has been a tendency in recent years to have catch of artisanal fishermen landed in port areas.

2) To encourage the development of a commercial fishing fleet, operating larger boats or ships, requiring a good deal of investment, and docked generally in a major port (urban) area. In this option, another goal is the development of medium-to-large-scale processing facilities. Distribution for the export market would proceed from these port areas and domestic distribution would be in the port and within the region serviced by local roads. Development of service industries related to port activities is also targeted in this option.

3) To license and monitor, or to operate joint ventures with foreign nations to exploit the African nation's fish resources. Under the license option, the goal is the collection of fees from foreign nations based on catch in the EEZ. The goal in joint ventures is shared profits and perhaps other agreements as to where fish are to be landed and processed. If some of the catch is processed in the African nation or if the African nation receives part of the catch, then the development of processing and distribution industries is also part of the goal. As in (2), above, this scenario is usually urban in nature.

In any of these options, other objectives usually include the better nutrition of national populations and the better management of fishery resources. Any nation may employ one or all of these options to varying degrees.

2.3.3.2. Comparison of Fishery Management Strategies

The varying strategies of the countries of Northwest Africa may be seen by comparing the development strategies of Senegal and Mauritania.
Senegal. Fisheries are an important part of the Senegalese economy contributing almost as much as to Senegal's GNP as the peanut crop. In 1982, Senegalese exports of fish and shellfish were about 20 percent of its total export volume of about $642 million. Senegal's fishery is also very important to local employment. Artisanal fishermen accounted for about 70 percent of the catch in Senegalese waters in 1982 (Resources Development Associates, 1985). The heavy employment of artisanal fishermen should be considered a plus for the Senegalese economy and a bright spot among West African nations. A healthy industrial fishery also exists. Dakar has become a major fishing port. In addition to freezing, processing, and distribution industries located in Dakar, there is a ship repair and servicing facility which reportedly serves 200 ships. In 1983, Senegal landed 212,895 mt of fish in marine waters.

Figure 2.12 shows the share of total catch in the CECAF Cape Verde Subregion in 1982 taken by Senegal and other nations. Figure 2.13 indicates the share of total catch by value. For Senegal catch share was 39 percent and value share 38 percent. Both constitute a good share of the catch by a local nation.

Mauritania. Mauritania has become heavily involved with joint ventures with other nations, particularly Eastern bloc nations, as a means of profiting from the fishery resources in its jurisdiction. Catch statistics in the area are sketchy for both the foreign nations and Mauritania. However, in 1983 Mauritania reported a total marine catch of 42,849 mt. Mauritania is one of the world's principal exporters of fish and fishery commodities probably as a result of onshore processing of foreign nations' catches for transshipment. In 1983 the value of such exports in U.S. dollars was $159.6 million. Fish exports were half of the total exports for the country in that year. The government is making an attempt to establish Noadibou as a landing and processing facility. While Mauritania has emphasized joint ventures, it has also encouraged farmers and herders to pursue artisanal fishing, particularly because of the impacts of drought on their traditional occupations.

Figure 2.14 shows the share of total catch in the CECAF Coastal Sahara Subregion in 1982 taken by Mauritania and other nations and Figure 2.15 indicates the share of total catch by value. For Mauritania the catch share was three percent and the value share five percent. By contrast, the Soviet Union and Eastern Europe took 89 percent of the catch by volume and 85 percent of the catch by value. These statistics do not indicate to what degree Mauritania profited by the joint venture arrangements. However, the figures stand in sharp contrast to those of Senegal in the Cape Verde Subregion.
Figure 2.12 Share of reported total catch by volume, Cape Verde Subregion, CECAF, 1982. Note: Spain did not report catch in 1982. Source: Resources Development Associates, 1985.

Figure 2.13 Share of reported catch by value, Cape Verde Subregion, CECAF, 1982. Note: Spain did not report catch in 1982. Source: Resources Development Associates, 1985.

Figure 2.15 Share of reported total catch by value, Coastal Sahara Subregion, CECAF, 1982. Note: Spain did not report catch in 1982. Source: Resources Development Associates, 1985.
2.3.4. Issues in the Future Development of National Policy on Fishery Resources by West African Nations

Several major issues now confront West African nations in their search for the most productive ways to handle their resources. A major social and cultural issue is the expansion of domestic fish consumption. Protein intake from meat is the preferred dietary pattern, particularly in areas away from the coast. However, other than in Mauritania, there appears to be some willingness to substitute fish for meat, particularly where price is a significant factor (Sutinen, 1981). In 1980 the fish contribution to total protein intake (including through fish products fed to animals) was 12.3 percent in Gambia, 14.3 percent in Senegal, and 7.6 percent in Mauritania (CECAF, 1984). Some effort by the governments of West African nations to expand fish consumption could lead to improved nutrition, relief of hunger, and the expansion of the fishing industry in these nations.

In regard to other issues relating to national fisheries policy, available satellite technology may be able to provide valuable tools to assist the implementation goals. These issues are:

**Improvement of fish catch by West African nations.**
Table 2.3 gives the number of locally based fishing vessels by type for Gambia, Mauritania, and Senegal. While the Senegalese statistics are overwhelmingly artisanal, it is also clear that an industrial capacity exists. For example, Senegal has at least 128 small trawlers/shrimpers. Mauritania's fishing fleet is dominated by its considerable number of freezer trawlers. Expansion of fish catches by these nations is therefore feasible. Technical data that would support such expansion would be useful. The necessity to expand processing and distributing facilities as a result of the improved

**Maximization of profit from licensing/joint ventures.**
Considerably sketchy reporting (with the impression of under-reporting) of foreign catches in the EEZ's of West African nations is known to exist. Unauthorized intrusion into these EEZ's also occurs. Some West African nations may wish secure technical means of surveillance in these two matters, leaving the question of enforcement to later decision-making. Economic benefits to West African nations could be enhanced through enforcement of agreements in their EEZ's.

**Fisheries management.** Major fish stocks along the northwest coast of Africa have been extensively exploited for some time. If West African nations wish to maintain or expand their own catches in their areas and preserve their economic interest in licensing other nations to fish in them, then the resources must be preserved through management. Technical data in support of assessing the condition of stocks in order to better manage them would be valuable.
Table 2.3. Preliminary and indicative number of locally based vessels by type in selected nations of CECAF.  
Source: CECAF/TECH/84/58.

<table>
<thead>
<tr>
<th>Country</th>
<th>Tuna Freezer Trawler</th>
<th>Small Trawler/ Shrimper</th>
<th>Purse Seiner</th>
<th>Gillnet-ter/Hand-liner</th>
<th>Canoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gambia</td>
<td></td>
<td>4A</td>
<td>4</td>
<td></td>
<td>350</td>
</tr>
<tr>
<td>Mauritania</td>
<td>57A</td>
<td>15A</td>
<td>10</td>
<td>10</td>
<td>132</td>
</tr>
<tr>
<td>Senegal</td>
<td>4</td>
<td>6</td>
<td>128A</td>
<td>14</td>
<td>9111</td>
</tr>
</tbody>
</table>

A = substantial increase in recent years
3. Satellite Technology Applicable to West African Fisheries

Cloud cover and dust storms make precise (within 1°C) determination of navifacial temperature difficult. The area of consideration off northwest Africa has minimum cloud cover and only occasional dust storms extending over the ocean. These conditions make satellite remote sensing a more reliable proposition for operations than in the regions farther into the tropics.

Several environmental satellites are available to produce imagery for the region. Not all of these satellites are equally useful for applications to marine resource management. We discuss the primary satellites, their channels of imagery and the relevant utility to the problem of marine fisheries.

3.1. Satellite Platforms and Sensors

Two U.S. satellite sensors can provide information that can help in developing a coastal fishery, the Coastal Zone Color Scanner (CZCS) on NASA's NIMBUS-7 satellite, and the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-n polar-orbiting weather satellites (Table 3.1). Other satellites such as Landsat and the French SPOT satellite were designed specifically for use over land. Thus, they can provide information suitable for studying land use, vegetation, wetlands, geologic features, and some turbid lakes and waters. However, their sensors lack the sensitivity for studying ocean water, and they provide limited temporal coverage—only a few images a month at best—which is unsuitable for analyzing dynamic ocean features. The geostationary satellites, particularly the European Space Agency's METEOSAT, although designed to monitor large-scale weather patterns, can provide excellent data on upwelling. The METEOSAT will be discussed in detail in section 3.5.

3.1.1. NOAA-n Polar Orbiters

The AVHRR collects data in bands that can provide accurate information on temperatures (Table 3.2). Because the sensor imagery is used in weather forecasting, the two polar-orbiting satellites can provide 2 to 4 images per day. AVHRR sensors are particularly useful in fisheries applications because they can provide initial data routinely within one day and will be operational for many years.

41
### Table 3.1. Satellite-Sensor Systems

<table>
<thead>
<tr>
<th></th>
<th>SPOT</th>
<th>Landsat</th>
<th>CZCS</th>
<th>AVHRR</th>
<th>Meteosat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TM*</td>
<td>MSS*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channels recorded</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>visible</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>thermal</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td>2-3</td>
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<tr>
<td>Cost per scene($)</td>
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<td>3300</td>
<td>660</td>
<td>(cost depends on source)</td>
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</tr>
<tr>
<td>Resolution(m)</td>
<td>10,20</td>
<td>30</td>
<td>80</td>
<td>830</td>
<td>1100</td>
</tr>
<tr>
<td>Image width(km)</td>
<td>60</td>
<td>180</td>
<td>180</td>
<td>1500</td>
<td>2000</td>
</tr>
<tr>
<td>Image Repeated (days)</td>
<td>26</td>
<td>16</td>
<td>16</td>
<td>3-5</td>
<td>.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.1</td>
</tr>
</tbody>
</table>

*TM=thematic mapper, MSS=multi-spectral scanner

### Table 3.2. Spectral Bands of the Advanced Very High Resolution Radiometer

<table>
<thead>
<tr>
<th>Band</th>
<th>Visible</th>
<th>Near-IR</th>
<th>Middle-IR</th>
<th>Thermal-IR</th>
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</thead>
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<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Wavelength</td>
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<td>.72-1.0</td>
<td>3.5-3.9</td>
<td>10.5-11.5</td>
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<td>cloud</td>
<td>nighttime</td>
<td>day and night</td>
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<tr>
<td></td>
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<td>detection</td>
<td>temperature</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

42
3.1.2. Nimbus

The CZCS provides sensitive measurements of ocean color and brightness. Variations in ocean color tend to indicate the presence of phytoplankton, therefore the potential food for various fishes. Ocean brightness indicates water clarity, which can also indicate the location of various fish species.

The CZCS has operated for an impressive eight years (it had a design life of 1 year). However, it has begun to fail and is expected to cease working within a few months. In addition, although it can provide historical data on various parts of the world, the CZCS was designed as an experimental sensor, therefore it cannot generally provide routine or timely coverage. In selected parts of the world, particularly off the coast of California, special efforts were made to process the data immediately and provide data maps to fishermen within a day of acquisition (see section 3.4). In other parts of the world, this rapid processing is not practical. No provisions have been made for replacing the CZCS, thus the data will be of historical interest only.

3.1.3. Landsat

Landsat can provide high resolution data as often as twice per month. The Landsat thematic mapper has a thermal band, therefore estimates of nearshore temperatures are possible. The visible and near-infrared bands do not have the sensitivity to provide data on coastal upwelling or offshore turbidity. They can be of use in turbid nearshore and estuarine waters. Given the long period between overpasses, Landsat is poorly suited for looking at dynamic marine events. It is most commonly used to look at land features in small areas (180x180 km). It has been used to identify wetlands and water bodies and can provide data on land-use, geologic features and agriculture. Because the images are infrequent, it is more difficult to find cloud-free data from this satellite.

3.1.4. SPOT

The System Probatoire d'Observation de la Terre (SPOT) of France has virtually identical uses as Landsat. However, the SPOT satellite does not have a thermal band. The SPOT multispectral sensor has slightly higher resolution than the thematic mapper (20 m vs. 30 m) and the satellite has a panchromatic (black and white) band with 10 m resolution. The sensor can also be aimed at a specific target area, allowing that area to be imaged 5 times a month. The SPOT also has the unique capability of providing stereo imagery from the single satellite. The areal coverage for SPOT is 60x117 km, limiting imagery uses to
local scale features such as embayments, rivers and small areas on land.

3.1.5. METEOSAT

The Meteosat is a geostationary satellite positioned over the equator at the Greenwich meridian. It provides one visible and thermal infrared channel, each having about 5 km resolution. It can provide useful climatological and sea surface temperature data, as will be discussed in section 3.2.5.1.
3.2. Imagery Available and Derived Products

The AVHRR collects data by scanning in a line across the orbital track of the satellite. It collects 2048 radiance measurements along each scan line, extending 55.4° from nadir. Each measurement is called a pixel, i.e., picture element. Each pixel covers 1.1km on the ground at nadir. The distance increases to more than 2km toward the ends of the scanlines, owing to the large scan angle and the curvature of the earth. The pixel size determines resolution, therefore objects smaller than 1.1km across cannot be distinguished. The standard scene width is about 2000km.

The accumulation of scanlines as the satellite progresses in its orbit results in the image. This occurs at a rate of 360 lines (ca. 400km) per minute. The satellite is polar orbiting, i.e., it crosses near both poles, and the orbit is sun-synchronous, meaning that the satellite crosses the equator at the same solar-time. Therefore, areas at the same latitude are always imaged at the same local time.

Satellite Applications in the Region

For monitoring the coastal conditions appropriate for both the commercial fishing and artisanal efforts the scales of the NOAA/NESDIS Global Ocean Sea Surface Temperature maps (GOSSTCOMP) lack sufficient resolution. Application of the AISC methods to the region show the ability to identify specific regions of upwelling even to the extent of only 10 kilometer widths. The wide extent of the Canary Current upwelling shows up readily and the relatively cloud-free conditions through much of the year allow frequent monitoring. The high resolution in AISC images provides information on the detailed structure of the flow and the pockets of upwelling.

3.2.1. Receiving Stations

At present there are no receiving stations for high resolution AVHRR data in West Africa. A station is under construction in the Canary Islands and one is proposed for Niamey, Niger. A Landsat processing laboratory exists in Burkina Faso. The Canary Islands station would collect data along the coast as far south as Dakar. A station in Niamey would provide good coverage of the Gulf of Guinea, however, the Atlantic coast is far enough to the west to limit data to 2 to 3 scenes per week.

Prompt receipt of data from these stations by the West African coastal countries would require special agreements and close relations. Obviously, satisfactory coverage of the coast...
from Mauritania to the Ivory Coast would require a receiving station in one of those coastal countries.

3.2.2. Processing Requirements

The satellite provides data in different formats. When the satellite lies within line of sight of a ground receiving station the data can be transmitted directly. In this case the data are identified as either APT (automatic picture transmission) or HRPT (high resolution picture transmission). APT is an analog transmission of the channel 2 and channel 4 images at about 4 km resolution. HRPT consists of direct digital transmission of all 5 channels. APT stations are common and inexpensive; there are several thousand scattered over the world. HRPT stations are about an order of magnitude more expensive (about $250K), making them considerably rarer.

To collect data outside the United States, NOAA can also program the satellite to record up to 10 minutes (about 4000 km) per orbit of full-resolution data on tape onboard the satellite. When the satellite overflies a NOAA receiving station, usually at Gilmore Creek, Alaska, these recorded data are then transmitted to the ground. This is referred to as LAC (local area coverage). LAC data and HRPT data are identical except for the transmittal procedure. One can request collection of this data from NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). Because of the great demand for LAC data and the limited recording capacity of the satellite, only 1 to 2 scenes per week can usually be obtained for any given area.

NOAA does obtain complete daily coverage of the globe through a reduction of resolution into GAC (global area coverage) format. Every third scanline is saved and 4 of every 5 pixels on that line are averaged into one. Hence, GAC has an effective resolution of 5.5 x 3.5 km. A typical GAC scene has 409 of the reduced resolution pixels on about 700 lines. Because of the reduced resolution, GAC can show large areas, but it cannot provide information on small-scale features.

3.2.4. Derived Products Available

NOAA also produces weekly maps of global sea surface temperatures. These are produced by reduction of the GAC data together with available data from ships. The spatial resolution, however, is only 1 degree (100 km). As the upwelling region is typically less than 50 km wide, the GOSSTCOMP maps can rarely detect the presence of upwelling.
3.2.5. Existing Satellite-Derived Products for West African Fisheries

European countries, France in particular, have a great interest in the West African countries and the offshore fishery. As a result, the French Centre National d'Etudes Spatiales (CNES) and the European Economic Community's Joint Research Centre in Ispra, Italy, process and evaluate satellite imagery from the west African area.

3.2.5.1. Analysis of Sea Surface Temperatures (SST)

In 1981 France, working with Senegal and the Ivory Coast established a program for climatic monitoring of West Africa using satellite. The program includes rainfall estimation, study of the seasonal movement in the inter-tropical convergence zone (ITCZ) and weekly estimates of sea surface temperatures of the West African coast including the Gulf of Guinea. In 1984, estimates of SST for delivery to West African countries become an operational program of the French Meteorologie Nationale.

Much of the data used in the SST project derives from the Meteosat geostationary satellite (Citeau et al., 1985). Meteosat has about a 4-5 km resolution. It has 2 bands, a visible band and a thermal-infrared band (10-12 um). It provides 8-bit (512 brightness levels) data and 0.5°C resolution. This project uses Meteosat data collected 2-3 times daily at Lannion, France to create weekly SST maps, sometimes referred to as skipjack maps.

Because METEOSAT has only a single thermal channel, the data is calibrated against in situ data in order to provide accurate temperatures. Using the Global Transmission System, meteorological and oceanographic data can be received at Lannion in real-time from ships off West Africa. As many as 400 observations per week derive from the region from Mauritania to Liberia, and only some 120 per week originate in the Gulf of Guinea.

All of the week's satellite images are geometrically corrected to the same projection. A composite is created to eliminate clouds and the data are calibrated against the in situ observations.

The weekly SST maps are made using data collected from Thursday to the following Wednesday. On Friday at 830 UT (0730 in Dakar) the final maps are sent via facsimile to ASECNA (Agence pour la Securite de la Navigation Aerienne) in Dakar and by telecopy to Abidjan. These maps are then made available to ships by radio-facsimile from Dakar at 19.750 kHz and from Sainte-Assise at 12.305 kHz. When the system was first developed, the quality of transmission and accuracy of the maps were verified using the research vessel Capricorne.
Researchers with Organization des Recherches Scientifiques et Technologiques d'Outre-Mers (ORSTOM) and Centre de Recherches Oceanographiques de Dakar-Thiaroye (CRODT) have been using the data and trying to establish relationships between environmental conditions and fisheries. CRODT has established a remote sensing laboratory as has the Department of Geography in the University of Dakar. The Senegalese have also submitted a proposal for a NOAA AVHRR receiving station.

3.2.5.2. Chlorophyll Analyses

The Joint Research Centre (JRC) of the European Economic Community investigated the west African upwelling using CZCS data (Sturm and Schlittenhardt, 1984). This project was conducted jointly with the European Space Agency (ESA), ORSTOM, and CRODT. The CZCS data was collected by ESA and processed by JRC into maps of chlorophyll-like pigments and relative temperature.

Scientists examined the upwelling from January to April, 1983, and found a correlation between low water temperature and high chlorophyll concentration. In some images high chlorophyll concentrations were found to correspond with warm water far offshore (200-300 km).

3.2.6. ARGOS Data Collection System

The ARGOS data collection system was designed to collect environmental data throughout the world. It is operated through a cooperative agreement between NOAA and the French Centre National des Etudes Spatiales (CNES). The system uses small transmitters that send data from a sensor or microprocessor as a signal that can be detected by the NOAA-n satellite, when it is within view. The signal is then transmitted to CNES, which reconstructs the data and determines the location of the sensor and makes this information available to the owner of the transmitter. The information can become available at CNES within 3-4 hours of collection time and may be supplied to the user by mail, telex, magnetic tape, or other medium.

Alternatively, a user can own and operate a local user terminal that can receive the signal directly from the satellite. In this case the operator must be within the field of view of the satellite at the same time as the transmitter.

The transmitters can be quite small, 5-10 cm on a side, making them quite mobile. They are used in weather stations, buoys, for animal tracking, and in collecting geophysical data from remote areas. A transmitter can provide a means of obtaining air and water temperatures and wind speeds. The system
is specifically intended for environmental data collection, therefore collecting data using the ARGOS system for surveillance of fishing vessels would be illegal.

The transmitter costs about $2500 and needs an external power source (about 10 volts). Using the system costs about $3300 per platform-year. A local user terminal can cost about $40,000. A typical simple transmitter contains an internal temperature sensor. The system can determine locations to within about 1 kilometer.
3.3 Sea Surface Temperature

As upwelling characteristically produces reduced sea surface temperatures, the measurement of temperature by satellite provides an excellent means to identify and monitor upwelling. Temperature, being a fairly conservative property, provides a good tag of water masses and a tracer for circulation.

Satellite measurements of temperature have been used to identify and track eddies from the Gulf Stream and to view variability and identify fronts in other parts of the ocean.

Ideally, sea surface temperature could be determined directly from the radiance in the thermal infrared channels. Absorption and emittance by the atmosphere distort the radiance, usually producing a lower calculated temperature at the satellite than exists at the ground. To correct for the atmospheric interference, NOAA/NESDIS has developed equations for calculating the temperature using data from channels 3, 4, and 5 (Strong and McClain, 1984). The resultant temperatures are considered accurate within $1^\circ$C and can be calculated to $0.25^\circ$C intervals. This correction is valid over most of the image, except near the ends of the scanlines. There, owing to the large viewing angle, the amount of atmosphere through which the signal must pass is too great to allow proper correction. Generally, the incorrect temperatures occur at the outer 100-200 pixels of a full HRPT/LAC scene or the outer 50 pixels of a GAC scene.

Fog, dust, mist, and clouds also distort the temperatures. However, these can often be identified and masked using the visible and near-infrared channels.

3.3.1. Satellite Data Processing

The Assessment and Information Services Center obtains the AVHRR digital data from NOAA/NESDIS in Suitland, Maryland. The Center uses a VAX-750 computer for preprocessing of the data and a Log/E image processing system, which included a DEC LSI-11 computer with an array processor, for display, enhancement, and photography.

Preprocessing entails calculation of sea surface temperatures, truncation of the visible and near-infrared data from the original 1023 (10 bit) brightness levels to the lowest 255 (8 bit) brightness levels, and placing the data on a Mercator projection. The Log/E (and most personal computers) store data in 8 bit units, making the truncation necessary. The temperature and brightness data are placed on tape and transferred to the image processor.
Figure 3.1 Sea surface temperature off the north western African coast (in black and white). Dotted line following the coast identifies the edge of the shelf.
On the image processor, the land and clouds are masked using the near-infrared (channel 2) data. Water is an extremely effective absorber of near-IR radiation. Unless exceptionally turbid, it appears much darker in channel 2 than does land, clouds, or haze. Therefore, using a threshold brightness for channel 2, one can designate as water those pixels having a lower radiance than the threshold, and denote as land and clouds those that are brighter. This designation is superimposed on the sea surface temperature image to produce a mask over the land and cloud pixels. Although effective, this filter may not exclude light haze and thin or sub-pixel clouds. These features can usually be identified by both elevated brightnesses on channel 2 images and lowered temperatures, particularly around some masked areas on the SST images. After masking, the sea surface temperature images are colored in $1^\circ$C intervals.

AISC can potentially receive and process the AVHRR data within 4 days of the actual collection. However, as we must receive the data on computer tape, it more commonly takes one or two weeks. The resultant SST images may be displayed with contour lines, black and white brightnesses, or color-coded displays.

Figure 3.1 shows a black and white image of a scene that has been fitted to a Mercator projection and the actual temperatures have been calculated. The cooler waters appear white, thus the upwelling off Senegal is quite evident. A color version appears in Figure 3.6. In the color image, warm water is red and cool water is dark blue and purple. Temperatures can be discriminated more easily using color than black and white.
3.4 Fisheries Applications of Satellite Data

Before the advent of environmental satellites, aerial reconnaissance of ocean features provided fishermen with information which assisted them to identify and locate areas with high potential as productive fishing grounds. However, aircraft monitoring could not offer the broad spatial coverage and the routine repeatability of coverage that is afforded by satellites. Development of narrow band, multi-channel infrared radiometers for the NOAA series of polar orbiting environmental satellites (POES) provided the means for large scale synoptic monitoring of sea surface temperatures with a spatial resolution of nearly 1 km and repeatability of coverage of twice a day.

Use of satellite remotely sensed environmental data for fisheries purposes began experimentally in 1975 in the United States (Breaker 1981). The initial study provided west coast albacore tuna and salmon fishermen with twice weekly sea surface temperature maps for coastal and ocean waters off California. Because these species have known temperature preferences and tend to aggregate along strong thermal boundaries, indirect indicators of food availability, the fishermen could use the SST maps to identify and locate the best fishing areas. Results of this experiment clearly demonstrated the utility of the satellite data to the fishermen. Substantial savings in fuel and increased harvests were proven financial benefits (Table 3.3). Salmon fishermen who use the satellite SST data were able to increase the productivity of their vessels by as much as 30 percent. Since 1975 the use of satellite-derived ocean data products by coast, ranging from northern Alaska to south of the Baja Peninsula, the Gulf of Mexico, and the Atlantic Ocean off the eastern seaboard. The Advanced Very High Resolution Radiometer (AVHRR) with 5 channels, three of which are in the infrared portions of the electromagnetic spectrum, provide SST accuracies of 0.5°C.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>TOTAL BENEFIT</th>
<th>AVERAGE PER BOAT</th>
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</thead>
<tbody>
<tr>
<td>Fuel Savings ($)</td>
<td>580,000</td>
<td>29,000</td>
</tr>
<tr>
<td>Increased Harvest ($)</td>
<td>1,600,000</td>
<td>2,000-14,000</td>
</tr>
</tbody>
</table>

Table 3.3. Economic benefits of satellite remotely sensed ocean data to commercial tuna and salmon fishermen from California. Dollar values are for the 1975 fishing season. (Based on data in Hussey, 1985).
3.4.1. Fisheries-oriented satellite applications in the United States

Operational use of satellite remotely sensed oceanographic data by the fishing industry is commonplace in the United States. Mapping of ocean color boundaries and sea surface temperature fields from data sensed by the Coastal Zone Color Scanner (CZCS) satellite and the Advanced Very High Resolution Radiometers (AVHRR) onboard NOAA's POES, respectively, provide fishermen with valuable information for identifying and locating promising fishing areas. This allows them to make more efficient use of fuel and other expendables in searching for oceanographic conditions favorable for the target species. Based on estimates, the fuel savings alone amount to several millions of dollars each year. In addition, increased harvests and catch-per-unit-effort further improve the economic productivity of the vessels.

Ocean color boundary maps are very useful to west coast tuna fishermen. The pelagic tuna (in this case albacore tuna) prefer clear ocean water but tend to concentrate along fronts which separate the clearer ocean water from the more turbid coastal/shelf water. Tuna, which are sight feeders, feed at these fronts as schools of coastal prey species (sardines, anchovies) move back and forth across the fronts. NOAA's National Marine Fisheries Service (NMFS) provides the tuna fishermen with ocean color boundary maps derived from the satellite data. The maps can be obtained before the vessel leaves port or, if the vessel is equipped with a facsimile machine, it can receive the information at sea. Figure 3.2 is a sample of the ocean color boundary maps provided by NMFS to the west coast tuna fishermen. The validity of the information as being important to the commercial harvesting of albacore tuna has been demonstrated. Fishermen who concentrate their efforts in the clear water at the edge of a turbidity front consistently have the highest reported catches.

Maps of satellite-derived sea surface temperatures are also important to commercial fishermen, perhaps more important than the ocean color maps. The reason for this is that the CZCS coverage is limited to a small portion of the total U.S. EEZ and the instrument, which is in its ninth year of operation, has degraded to the point where it will cease functioning altogether in the very near future. In comparison, the AVHRR is NOAA-launched on a regular basis to replace those which degrade or burn out. Because of the twice-a-day coverage provided by the AVHRR, sea surface temperature (SST) information is updated and made available to U.S. fishermen every three to four days.
Figure 3.2 Satellite-derived ocean color boundary map for waters off the coast of California.
3.5 Satellite Temperature Imagery for West Africa Project

The sequence of Figure 3.3 through Figure 3.8 shows the variation in upwelling off West Africa from January to September, 1983. GAC data were used for most of these, except those in March and July.

The imagery shows the two upwelling cells, one off Senegal and Mauritania, the other along Western Sahara and Morocco. The cell to the north persisted through the year; the one to the south was present only in the spring. This behavior is consistent with observations made from ship.

In January (Figure 3.3), strong upwelling (purple 15°C) extended south to Cape Blanc. Warm 24°C water was found to the south of Guinea-Bissau. Some dust had blown offshore from Mauritania. Upwelling began off Mauritania in February and by early March (Figure 3.4), upwelling had developed along the coasts of both Mauritania and Senegal. By the end of the month it had become quite strong (purple) south of and off Cape Blanc. The strong upwelling limited warm water to the shore and to areas far offshore.

The March and April images show the variability in the strength of the southern cell. Upwelling increased throughout March, diminished somewhat in early April (Figure 3.6), and increased again at the end of the month. The April image also shows that the outer edge of the upwelling zone corresponds to the shelf break (dotted line). In mid-June and July (Figure 3.7) upwelling ceased along Mauritania and Senegal. The coastal water temperature increased dramatically along the coast to Cape Blanc. Upwelling continued off Western Sahara. These conditions persisted into the fall (Figure 3.8): the water off Mauritania and Senegal became continuously warmer, the upwelling persisted off Western Sahara down to Cape Blanc.

The higher (1.1 km) resolution image in Figure 3.5 shows the detail of the upwelling along Mauritania and Senegal in March. Extremely strong fronts exist along the upwelling area south of Dakar. The gradients in places reach 1°C/km. Some cool water veers offshore at Dakar, producing a spike of cooler water that extends 50-100km west of Dakar.

This satellite imagery shows seasonal and weekly variability in the sea surface temperatures. It can reveal the the onset and cessation of upwelling, and the movement and strength of the upwelling cells and fronts.
Figure 3.3 Sea surface temperature off the north western African coast showing upwelling off Western Sahara.
Figure 3.4 Sea surface temperature display for 07 March and 31 March 1983, local area coverage (LAC) data at 2.5 km resolution.
Figure 3.5 Sea surface temperature display for 31 March 1983, local area coverage (LAC) data at full (1.1 km) resolution.
Figure 3.6  Sea surface temperature display for 07 April 1983, global area coverage (GAC) temperature data.
Figure 3.7 Sea surface temperature display for 16 July 1983, global area coverage (GAC) temperature data.
Figure 3.8 Sea surface temperature display for 02 September 1983, global area coverage (GAC) temperature data.
4. Economic Implications

4.1. Fisheries Expansion

Application of satellite data to fisheries of the west Africa coast can produce fishery expansion in two ways. The catch-per-unit-effort may improve with more precise guidance of where to fish for presently harvested species and whether to fish at a given time based on estimates of stress to the population. Secondly alternate species may be harvested based on satellite tracking of known environmental preferences.

4.1.1. Increased catch-per-unit-effort for present species

An estimate of fishing effort is a necessary prerequisite to our analysis of maximum sustainable yield (MSY) for west African fish and a concurrent consideration of the possibility of decreasing the fishing effort. In the simplest case, a fishery would use only one type of fishing gear that caught only one species of fish and the analyst should have catch records for all the fishermen. Of course, these conditions do not exist for fisheries in general and certainly not for west Africa. The problems are compounded in west Africa by incomplete catch records, multispecies catches, many types of fishing gear, variations in the use and efficiency of the gear, and variation in the vulnerability of the stock. Thus, fisheries scientists have devoted much ingenuity to a determination of fishing effort.

In west Africa, fishing statistics are summarized annually and occasionally monthly for only certain fleets, but typically without sufficient detail to evaluate fishing effort. In the northern upwelling region where fishing is most productive, the fishing statistics are least reliable, and therefore, estimates of effort, abundance, and maximum sustainable yield are tenuous. Boely and Fréon (1980) have estimated the fishing effort and the maximum sustainable yield (MSY) for the four most productive taxa of the west Africa region (mackerel, horse mackerel, sardinellas, and sardines). They identified three major phases in overall fishing effort in this region. A gradual increase in fishing effort by large-scale trawlers, taking mainly mackerel and horse mackerel, occurred until 1969. Then an abrupt increase in effort occurred as deep-sea seiners first began exploiting sardines north of Mauritania. Since the mid-seventies, this peak in effort has been followed by an overall decline by the large scale fleet in fishing effort first for mackerel and sardinellas, and later, for horse mackerel. At this writing, no more recent data concerning fishing effort and stock abundance were available for this region.
Boely and Fréon (1980) estimate the MSY of sardinellas as 400,000 to 600,000 MT per year, which corresponds with the upper range of the catch record (Figure 4.1a). They also estimated that the sardinella catch could withstand increased fishing pressure; however, recently the sardinella catch has sharply declined. Their estimate of the total MSY for the horse mackerels (*Trachurus trachurus*, *T. trecae*, *Caranx*) is approximately 450,000 MT per year, which also corresponds to the upper limits of the catch record (Figure 4.1b). The mackerels (*Scomber* sp.) were estimated to have a MSY of 170,000 MT per year (Elwertowski et al., 1972). The catch has only once exceeded this amount by more than 5 percent (Figure 4.1c). The MSY for the sardine was probability near the level of the 1977 catch (Boely and Fréon, 1980) (Figure 4.1d).

### 4.1.2. Extension of harvest to other species

Considering the pelagic resources of west Africa have been exploited for a long time, it is highly unlikely that any unexploited stocks of commercially important species exist. However, there are several coastal species that are not presently sought commercially (Boley and Fréon, 1980). These include some populations of the carangids (*Volmer*, *Chloroscombrus*) and the grunt (*Brachydeuterus auritus*). The grunt is a demersal fish that nevertheless is seasonally caught by seines and mid-water trawls. They are discarded in Senegal because there is no market for the catch. In 1974, the biomass was estimated as 170,000 MT, and the grunt's potential yield was estimated as 50,000 MT (Domain, 1980). Fully exploiting any or all of these under-utilized species would not cause a large increase in the total annual catch for west Africa, but could impact local economies.
Figure 4.1a Annual catch of sardinellas for west Africa (FAO region 34) for the years 1974-1983 (FAO, 1979; 1981; 1983).

Figure 4.1b Annual catch of the Horse Mackerels for west Africa (FAO region 34) for the years 1974-1983 (FAO, 1979; 1981; 1983).
Figure 4.1c  Annual catch of the Chub Mackerel for west Africa (FAO region 34) for the years 1974-1983 (FAO, 1979; 1981; 1983). Note this species accounts for 95 percent of the catch for this genus.

Figure 4.1d  Annual catch of the European sardine for west Africa (FAO region 34) for the years 1974-1983 (FAO, 1979; 1981; 1983).
4.2 Savings Associated with Fishing Costs

By using satellite imagery to identify potentially productive fishing areas, the search for fish is both more efficient and cheaper. When productive areas are identified, the fishermen also naturally disperse over larger areas thus reducing the possibility of overfishing. Pilot programs in the U.S. have been so successful that each program has been greatly expanded.

When the use of satellite information as a U.S. fisheries aid was first surveyed in 1975, the captains of 200 albacore and salmon fishing vessels identified a total of $568,000 in fuel savings (Hussey, 1985). The NOAA's National Marine Fishery Service conservatively estimates a 10 percent savings on the fuel bill for each vessel operating off the U.S. west coast (Hussey, 1985). For the albacore fishery this fuel savings may be translated to an additional two tons of fish per vessel.

Satellite products can also provide information on the migratory timing of various commercial species, thus reducing fishing effort. Using information on the movements of the 11°C isotherm off southeast Alaska, the average salmon catch increased from 50 to 200 salmon per day while fuel and equipment costs were reduced (Hussey, 1985).

We cannot estimate fuel savings for any west African fishery, because we were not able to collect any local data on fishing effort. However, if west Africa used fishery oriented satellite products, the fishing economy would clearly benefit.
4.3 Improved Fisheries Management

Satellite remote sensing often has an obvious and direct application to fisheries management, although in some cases the connection may be subtle. We briefly review here some examples, published for other fishing areas, that are relevant to west African fisheries.

By providing detailed sea surface temperature data to fisheries managers, the satellite can aid the interpretation of stock abundance survey data. The northern anchovy stock located off southern California supports an important U.S. fishery. Field concentrations of anchovy eggs have been surveyed since 1980 to estimate spawning biomass. Concurrent satellite imagery of sea surface temperature has shown that no anchovy eggs were found in waters cooler than 14°C, north of San Diego. South of there, eggs were most highly concentrated near the coast in waters with high plant pigment concentrations (Lasker et al., 1981; Fielder, 1983). Because the spatial coverage of ship surveys was limited, and because plant pigment concentrations were not measured in situ, the environmental constraints to the distribution of anchovy eggs could not be deduced from the ship data alone.

An important additional use of the satellite data is to determine the geographic limits to the sampling range. To accurately estimate egg distributions, the anchovy egg survey off southern California must cover the entire range of the spawning stock. As suggested by satellite imagery, the 1983 survey of the northern anchovy was modified to reflect the geographic shift in the spawning stock due to the influence of El Niño (Fielder et al., 1984). As a consequence of that change, anchovy eggs were found much further north than in previous samplings. If the normal sampling routine had been followed, this shift in the spawning range would not have been detected, and the spawning stock would have been underestimated.

Satellite remote sensing can also provide information on the distribution of pelagic fish, provided that the fish's environmental preferences are known. The Albacore (Tunno alalunga) is an oceanic tuna that supports another important U.S. fishery. These fish are visual predators that prefer warm and clear oceanic waters near fronts with coastal waters in which their prey are more common. Satellite imagery of sea surface temperature and plant pigment concentrations are routinely interpreted by fisheries oceanographers to determine favorable fishing areas (Breaker, 1981). The benefits to the fisherman include, decreased search time, and thus more efficient fuel use,
increased fishing time, and increased catch-per-unit-effort. Even though many of the stocks of west Africa are estimated to be fully or over-exploited (Trodece and Garcia, 1980), an increased CPUE by west African fishermen could be compensated by lower foreign allotments. The benefits to the fisheries manager in this instance are improvements in the estimation of fish distributions and migrations.
5. Products and Services

Satellite data may be made available to potential West African users in a variety of ways. These include (a) using products/services supplied by technical organizations like the National Environmental Satellite, Data, and Information Service; (b) having such an organization develop more detailed products or services; (c) training technical personnel in the nations involved to process and use satellite data themselves; and (d) actually aiding in the development and installation of a high resolution picture receiving station in one of the African nations in the study area. This section of this report will outline the options under each of these scenarios and will define both short- and long-range products available under them.

5.1. Products and Services Currently Available

Products/services that could now be made available by the National Environmental Satellite, Data, and Information Service; Assessment and Information Services Center (AISC) to West African nations are:

1. **Contoured sea-surface temperature maps.** Processing tape transmissions from the NOAA-n satellites through a communication satellite from Gilchrist, AK and Wallops Island, VA, and received in Suitland, MD; AISC could produce contoured sea-surface temperature maps and send them by facsimile machines to West African nations within 3 days of the initial transmission (Figure 5.1). These maps could then be distributed by West African governments to fishing boats equipped with devices (Loran and others) that would make it possible to locate fish using these temperature maps.

2. **Regional mass transport maps.** Using methodology already established, AISC could produce from data obtained from the National Weather Service's global wind models, maps showing the regional contours of upwelling and then distribute to scientists and government officials of West African nations who could utilize these maps.

3. **Upwelling indices.** Using wind models and methodology developed by Bakun (1973, 1975), AISC could produce maps of offshore transport that would be useful to west African scientists and fisheries officials (Figure 5.2).
Figure 5.1 Polar satellite communication links to processing center.
Figure 5.2 Sample map of wind-induced mass transports.
4. **Technical assistance in the collection of catch statistics.** Species-specific catch statistics are necessary to better understand the West African fisheries both in terms of promoting better fishing and better management of fish stocks. Providing technical assistance to West African government on how this has been accomplished by other nations and guidance on how they might establish such reporting systems could be useful.
5.2 Products and Services to be Developed

Assuming the four above products/services proceed, in the future AISC might provide the following more detailed products that could aid West African fisheries:

1. **Fishing efficiency indicators.** Employing species-specific catch data, sea surface temperature maps indicating upwelling areas, and knowledge of current marketing data, maps could be provided which would detail the area of greatest potential fishing profitability.

2. **Species distribution maps.** Employing species-specific catch data, sea surface temperature maps indicating upwelling, and the expertise of fishery biologists, AISC could produce species distribution maps for the study area. This would aid fisheries managers.

3. **Maps of the depth of upwelling.** Using sea surface temperature data from satellites and employing in situ measurements from expendable bathythermographs, AISC could depict the depth of upwelling zones which, when considered with species-specific catch data, could provide insight into the areas of optimum catch conditions.

4. **Technical guidance on the marketing of fish.** The West African nations could profit from an understanding of world market conditions for fishery products. Fish that are currently discarded might have market value. Regular bulletins providing information on this subject would be useful to West African fisheries officials.

5. **Guidebooks.** Since fishermen who fish from canoes or pirogues do not carry the kind of equipment that could help them locate fish using satellite data, methods need to be developed to make it possible to use such methods employing expertise they already possess in understanding the oceans. Guidebooks and other methods could be developed toward this objective.
5.3. Assistance to West African Nations in Developing Their Own Products

Another option is to provide technical materials and guidance to West African nations to process their own satellite data tapes and produce products. This option is not feasible for products like current sea surface temperature maps for fishermen because of potential time lags in getting the tapes to Africa. For processing historical archive satellite data leading to technical study of the ocean, this option may be feasible. AISC could assist in all phases of the project including providing tapes and training materials.

5.4 Assistance in Building and Learning to Use a High Resolution Picture Transmission (HRPT) Receiving Station in Africa

Since no HRPT receiving station currently exists which could receive images spanning the area covered in this study, a potential source of development would be the building of such a station in one of the nations. Dakar, Senegal would be a possible site considering the location of UN Food and Agriculture CECAF offices in this location. AISC could provide a variety of technical assistance in locating and building the station and training West Africans in operating it. Technical assistance might also be provided in the development of satellite products.
6. Conclusions and Recommendations

The study has led to an appreciation of the need for satellite applications in west African fisheries, but with a view toward the social ramifications of the expansion of local industrial fishing. Overall understanding of the environment of the upwelling systems off the coast of Africa could lead to applications of satellite data for early diagnostics of drought or other climate anomalies over the continent. More detailed understanding of the local species breeding habits and capacity, improved catch statistics, and increased investment in technology are required for better fishery management.

6.1 Conclusions

The upwelling areas off west Africa extend along the Coast from Cape Bojador to below Dakar in spring. This upwelling is dependent on the local winds. We note there may be a 2-4 year cycle in the upwelling strengths, based on findings in similar eastern boundary current upwelling regions.

Advanced Very High Resolution Radiometer data from the NOAA satellites shows clearly the upwelling strength and variability off the coast of west Africa. The upwelling areas are large enough in this region to be detected in GAC scenes, eliminating the need to process LAC except for special purposes. The west African countries presently receive satellite derived sea surface temperature maps weekly from the French, having a resolution of between four and five kilometers. The time resolution of the scenes available from METEOSAT is superior (hourly) to the data available from NOAA satellites (semi-daily). However, the 1.2km resolution of the AVHRR is superior to the resolution of METEOSAT for applications which require finer spatial detail.

Four groups of pelagic fish form the majority of the commercial catch in the west African waters: mackerel, horse mackerel, sardines, sardinella. Three distinct fishing communities are identifiable in the region: distant waters fishing fleet, local industrial fleet, and artisanal fishermen. The means of developing and disseminating satellite data to help each of these fishing groups are quite different.

The west African fisheries are presently exploited to near the maximum extent supportable by the stock and the environment. Artisanal fishermen are the sector most to be affected by a depletion of the stocks. There appears to be little likelihood for exploitation of new species in the region, since edible species are already exploited quite fully.
6.2. Recommendations

AISC has developed recommendations in their specific area of study and we have grouped them in this report appropriately.

General Understanding of the Environment

We recommend development of a network of wind observing stations along the coast. A regular observing system for winds might eliminate the need for quick turnaround satellite processing, since the upwelling strength and location is strongly dependent on the local offshore winds.

We recommend AID support development of an upwelling index, analogous to that available off the west coast of the United States (another eastern boundary current system), and study of the relation of that upwelling index to fish catch in specific localities and for selected species.

We recommend concomitantly that AID support establishment of more accurate, more complete, and more timely reporting of fish catch statistics.

Finally since the upwelling system is so dependent on local winds, which in turn depend upon the regional atmospheric circulation, we recommend AID support study of this particular upwelling system and the four other upwelling systems around the continent of Africa for the relationships which may exist between the upwelling indicators offshore and the climatic patterns inland, such as drought or desertification.

Recommendations for Fisheries

We recommend AID support exploration of satellite products directed toward specific fisheries and specific industry groups. The tuna, mackerel, sardines, and sardinella species appear to be key species for application of satellite data to improve the resource management. The target group for satellite data products should initially be the local industrial fishing. Products to be explored are maps of economic efficiency of fishing drawn from combined functions of sea surface temperature related to fish migration and economic value of the species; indices or maps of species spawning efficiency based on environmental factors; or, maps of fuel economy zones for fishing vessels based on combinations of SST, fish locations, fuel consumption, market price of fish species, and spoilage rates.
We recommend AID support studies in the area of redistribution of the west African fish catch to the west African nationals. Since the total catch for the region cannot likely be increased, primary effort at improvement of the resource management might be directed toward redistribution of the catch to the African nationals to improve their economies. The problem must be addressed from a political economic view, not simply from the environmental resource position. However, without knowing the expected consequences of repossessing of their marine resources, west African nations cannot make entirely rational decisions on fishery treaties and appropriate foreign exchange for their resources.

We recommend extension of the project to explore means of supporting the artisanal fishermen in the countries. Helping the artisanal fishermen requires more work with creative product design and distribution, possibly in the form of a guide ship or other means of locating the fishing zones for maximum catch.

We recommend AID support study of the social implications of supplying satellite data to the users. Application of satellite data to fisheries in the region implies social decisions for the governments involved, i.e., there is a tradeoff between artisanal fishermen and large scale fisheries, whether they be local industrial fleets or distant water fleets. Provision of regular satellite fisheries products to the industrial fleet will give strong advantages to the industrials over the artisanal fishermen. And as stated earlier, any overfishing of the stocks hurts the artisanal fishermen more than the industrial fleets, since the larger fleets can move to more fertile catch areas, while the artisanal fisherman must limit his range to his boat's capability.

We recommend AID support study by experts on means to reduce spoilage of the west African catch. Serious losses (estimated up to 40 percent of the total catch) are observed in the fisheries of the region. At that rate we are seriously depleting a natural resource and essentially wasting a very large part of the resource which we are harvesting. Reduction of spoilage would be one of the most effective means of improving the management of the west African fishery.

Finally we recommend AID support life cycle studies for the major commercial species of the region through regional consortia in the countries. Familiarity with and specific knowledge of their own marine resources will best enable the countries to deal with fishery management internally.
Recommendations for Satellite Reception in West African Countries

The Senegalese have requested funding support from France to establish an AVHRR receiving station in Dakar. We recommend AID support this effort with the French. After establishment of the receiving station and all processing of the raw satellite data, AISC could provide expert training to Senegalese or other West African nationals in marine image processing and interpretation if supported by AID.
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