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The use of satellite imagery in sardinella and sardine fisheries in the Mauritanian EEZ - Annual Report 2003

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Summary

Remote sensing research missions on board Dutch freezer trawlers in the Mauritanian EEZ in 2003 have focused on the relationship between water temperature, trawling tactics, and by-catch. During the research missions, which last 8-12 days each, satellite images of sea surface temperature (SST) are received by the trawler on a daily basis and tows are planned on the basis of oceanographic information to limit search time and minimize by-catch of non-target species.

In contrast to sardines, which appear to concentrate in cold, plankton-rich water, sardinella avoids the cold water and the center of the upwelling region. The avoidance may result from cold temperature, low oxygen content of the upwelling waters (as a result of oxidation processes), and/or limited primary production. The satellite images are useful to locate these oceanic fronts and have yielded insight into the spatial distribution of temperature anomalies in the Mauritanian EEZ.

Observed seasonal sardinella behaviour appears to be related to ocean dynamics and rapid decline of sardinella stock in the Mauritanian EEZ apparent from catch data (125 ton/day in 1997 to 35 ton/day in 2002) may not be (entirely) due to fisheries pressure. Echo surveys performed by R/V Fridtjof Nansen demonstrate high stocks in the Senegalese EEZ (1999) and in the area of permanent upwelling in the Moroccan EEZ (2000-2002), while sardinella appears to avoid the warm Mauritanian region.

Comparison of monthly averaged temperature charts since 1985 shows that between Fall 1994 and Summer 2002 there were two or three warm episodes with temperature anomalies of up to +3°C in the Mauritanian EEZ. The fall of 1993 into the winter of 1994 (-2.5°C) was the last of a series of cold anomalies before a shift of the system to warm anomalies. There appears to be an inverse relationship between SST and the North Atlantic Oscillation, probably reflecting increased surface cooling during years with a strong Azores high. A strong high pressure system would result in increased surface winds, increased surface cooling, and increased upwelling. SST and sardinella abundance therefore would respond to basin scale atmospheric trends. The strong year class of 1997-1998 may reflect successful recruitment in the period 1994-1995; this would indicate that sardinella matures in approximately 3-4 years. A second warm event in 2001-2002 may thus result in increased recruitment during 2004-2005. Research therefore will focus on the effects of atmospheric and/or oceanic anomalies on recruitment, year class strength, and migration of sardinella at Northwest Africa.

In addition to the observer program and the missions related to the 'preventing by-catch' project, the RS research missions in 2003 accounted for 40% of the observations (hauls) on the by-catch of large non-target species (198 of 505 observed hauls). By-catches of large species occur predominately in tropical water (>20°C) and during trawls in shallow water (e.g. catfish and smaller, bottom dwelling sharks), especially above coral banks. To reduce repetition of by-catches when it becomes apparent that there is a large density of e.g. sharks in a region a vessel could adjust its strategy and steer to nearby cooler waters or to deeper waters with same temperature. Remote sensing thus provides a tool for 'selective fishing', more so because it
helps locate target species and limits 'random' trawling.

1. Introduction

2003 was the fourth consecutive year of remote sensing research on board Dutch freezer trawlers operating in the Mauritanian Exclusive Economic Zone (EEZ), the second year under the present contract. The remote sensing work (RIVO project 313-123000-02) is one of three projects in Mauritania that are jointly financed by the Dutch Ministry of Agriculture, Nature Management, and Food safety (LNV) and the Redersvereniging voor Zeevisserij, part of the Pelagic Freezer-Trawler Association (PFA). The project is the continuation of a study initiated in 1998 by the PFA and covers a three-year period (2002-2004). RIVO relays satellite images (.jpg) showing sea surface temperatures (SST) at least twice weekly to the Dutch freezer-trawler fleet off the northwest African coast (Fig. 1). SST-images reflect the dynamics of the ocean and thus provide an instrument to fisheries comparable with weather maps (for details see annual report 2002; Zeeberg et al. 2003). The use of satellite images helps cut search time and makes fishing more cost-effective. By reducing ‘random’-trawling it answers to demands for cleaner and more selective fisheries. The remote sensing research missions therefore entail monitoring of haul composition, including by-catch of non-target species. Sardinella (*Sardinella aurita*) is the most important target species for Dutch fisheries at Northwest Africa. It occurs in well-sorted, single species shoals. The distribution of pelagic fish (sardinella, sardines, anchovys, and herring) and the growth and survival of their larvae is strongly influenced by environmental factors such as water temperature, food abundance, current direction, and turbulence (e.g. Cury & Roy 1989; John & Zelck 1997; Rodrigues 1999; John et al. 2000; Huggett et al. 2003). The second objective of the project, therefore, is to identify whether and by how much environmental variability accounts for observed stock fluctuations.

This report presents observations and progress made during the second year of the project. To relate oceanographic changes with catch statistics the project includes observation on board freezer-trawlers during 'research missions'. Three of such missions with a total of 33 research days have been made in 2003: 17-27 June 2003 (KW 171 *Maartje Theodora*, P&P); 19-29 September 2003 (SCH 302 *Willem van der Zwan*, WZ); and 20 November-6 December 2003 (SCH 81 *Carolien*, Vrolijk). This is 2% of the total effort of Dutch trawlers in the Mauritanian EEZ (1590 fishing days). During the mission, daily images are received by the researcher on board of the trawler and discussed with skipper and pilots to analyse fishing operations. These are the same 'temperature charts' normally forwarded by RIVO. The images are acquired by United States NOAA "Advanced Very High Resolution Radiometer" (AVHRR)-satellites (Fig. 1a-c). Data from these satellites is received by the Universidad de Las Palmas de Gran Canaria (ULPGC) or ordered from the Jet Propulsion Laboratory (Pasadena, USA). ULPGC has developed algorithms to derive SST from AVHRR measurements (Ramos et al. 1996). Continuing from 2002, this research applies satellite images to study (1) the distribution of sardinella in relation to ocean dynamics (e.g. Binet 1997; Demarcq & Faure 2000; Roy & Reason 2001); (2) possible covariation between anomalous SST patterns and sardinella recruitment (e.g. Cury & Roy 1989; Cole & McGlade 1998; Demarcq & Faure 2000; (3) opportunities for ‘selective fishing’.

2. Research methods

2.1. Sea surface temperature (SST)

Satellite-derived ocean temperature measurements are used to infer ocean dynamics, specifically current directions, and the extent of upwelling (Van Camp et al. 1991; Nykjær & Van Camp 1994). Freezer-trawlers in the Mauritanian EEZ monitor SST to locate the temperature fronts at which sardinella tend to concentrate. Sensors in the engine cooling-water intake (water depth >1 m) and the net-probe measure SSTs. Linear regression demonstrates correlation (r=0.86) of recorded water temperatures and SST derived from AVHRR images (Troost 2002).

The AVHRR instrument measures radiation emitted by a 1 mm-thick surface layer. An algorithm (formula) converts the measurements to sea surface temperatures representative of the conditions below the surface (Casey & Cornillon 1999). The data are downloaded into Erdas-Imagine software, which has preset parameters to correct the image for satellite motion and deformation resulting from the angle of viewing. The software furthermore georeferences the image, i.e. connects the image footprint with existing coordinate grids. A coastline and bathymetry (200 m depth line) are plotted and land is masked. Finally, data intervals are categorized according to a 0.5ºC colour coding designed by ULPGC (Fig. 2).

2.2. Trawling strategies and application of satellite data

Sardinella are caught in water 15 to 29°C and appear to be tolerant to rapid temperature changes, moving from tropical water (22°C) into upwelling water and *vice versa* (18°C). Plots of catch per hour with SST demonstrate that there is no relation between catch (sardinella abundance) and water temperature. Yearly sardinella migration is possibly timed by seasonal warming and cooling of the region. Analysis of the oceanographic situation in relation to catches may provide insight into the environmental factors that regulate migration and determine the route chosen by the fish. A trawling vessel circles to intercept a shoal with a speed of 5-6 kn, resulting in a 'spaghetti' trajectory with a length of ca. 15 km. A circle with a ca. 15 pixel width plotted in the satellite image, therefore, roughly covers the trawling area (Figure 1). Because the oceanographic environment is influenced by to the topography of the shelf margin, fisheries are primarily related to depth. Vessels concentrate searches along depth-related search lines and based on sonar-observations. Incidentally RIVO satellite images are consulted to seek a temperature front.

Chartworx Quodfish in 2003 has developed a module for its plotter software that enables the RIVO-jpegs to be opened in the standard plotter software. This system is currently being tested aboard the fleet. The fishermen consider the Quodfish plotter to be more efficient than other systems because it is user friendly and allows quick comparison between archived tows from previous years. The RIVO charts because of high resolution (1 km) have distinct advantage in the Mauritanian situation over comparable systems such as Orbmap (for particulars see Zeeberg et al. 2003). The catch size plotted in the satellite images is estimated from the number of reservoirs ('tanken') that are filled (full, half full, one quarter full) following a trawl. One reservoir holds 300 (SCH118) to 700 (SCH81) 'kantjes', equivalent to ca. 27-63 tons.

Tabel 1. <u>Terminology catch statistics</u>

Pak	1 pak is 20-22 kg (depending on species)
Froster	1 freezer unit with 52 'pak'
Kantje	~90 kg
Zak	± 8 ton

2.3. Application of remote sensing information

2.3.1. General principles

The oceanographic situation on the Mauritanian shelf (water depths <200 m) fluctuates between a winter state and a summer state. The summer situation is characterized by a strong front along the shelf edge (Fig. 1b) between advected South Atlantic Central Water (SACW) of the warm (>20°C) Guinnee Current and cold water of the Canary Current and upwelling region (Tomczak 1977; Mittelstaedt 1991; Nykjær & Van Camp 1994; Barton 1998; Hagen 2001). This situation is commonly established late June and lasts until February. The shelf warms in August as a result of the advection and solar heating.

Advection takes place in the form of eddies. Eddies are circular currents or whirls, with anticyclonic (clockwise) rotation in the northern hemisphere. Anticyclonic rotation causes convergence of surface water in the centre of the eddy and downward movement in the water column (see examples in Zeeberg *et al.* 2003). Upwelling is permanent north of Cape Blanc. Between February and (late) June, trade winds increase and upwelling dominates the entire Mauritanian EEZ.

2.3.2. Upwelling

Upwelling of deep (50->200 m) water across the continental shelf is caused by the permanent NNE-wind ('trade winds') parallel to the Northwest African coast (Michelchen 1981; Mittelstaedt 1991; Nykjær & Van Camp 1994; Hagen 2001). As a result of these winds and under the influence of the Coriolis force, net transport of surface water is away from the coast (Ekman spiral). Upwelling of deep water compensates this flow. 'Ekman pumping' also occurs when water masses diverge, i.e. in the centre of cyclonic (anticlockwise) eddies, which appear to form north of the oceanic front across the Mauritanian shelf. Net loss of surface water from the upwelling region results in a lowered sea surface. The upwelling water is transported away from the coast as 'filaments'; narrow strips of water extending tens to hundreds of kilometres and often rich in plankton (e.g. Barton et al. 1998).

3. Results

3.1. Oceanographic situation during the missions in 2003

KW 171 *Maartje Theadora* 17-27 June 2003

During the second week of June 2003, upwelling intensity decreased and the Mauritanian EEZ warmed. The image of 12 June shows a warm (>20°C) Banq d'Arguin and upwelling filaments still extending towards the ocean throughout the region, from northern Mauritana to Senegal. On June 18 upwelling is strong and extensive around Cap Blanc but warm water can be seen moving in from the south with a front at 18º30N. The upwelling extends along the shelf on June 19 (Fig. 1a). In the next days, tropical water (>24°C) is seen moving in from the south and the front of warm water (>20°C) has shifted north to 18º45N. By the end of the month, tropical water has reached 20°N and the 'summer season' has begun.

KW171 has been trawling in the Mauritanian EEZ since 10 January. Half of total catches is sardines (> 8000 ton until June) and only a quarter sardinella, one-eight mackerel. The large quantity of sardines caught until now probably relates to low spring-time water temperatures (-1.5ºC anomaly in February), because sardines prefer cold waters (Chavez et al. 2003; Boyer et al. 2001; Schwartzlose et al. 1999; Lluch-Belda et al. 1992). In the last week of May between 16ºN and 19ºN hauls consisted of mackerel, many >1,5 kg. During the remote sensing mission KW 171 caught sardinella (60%) in maturity stage 4, i.e. ripe-close to spawning. First of these sardinella were observed early June over the 2000 m isoline at 20º44'N-17º52'W.

Observations during this mission indicate sardinella abundance in cold plankton-rich water (green water) with hauls of 120 and even 300 ton (18-19 and 21-22 June), whereas in clear, blue water catches are less. By-catches were minimal in cold water but when trawling in proximity of tropical water and temperatures rose >19°C on 25 June large sharks were by-caught.

SCH 302 *Willem van der Zwan* 19-29 September 2003

The Mauritanian EEZ warmed in the last week of July. A cold area with upwelling continued to exist around Cap Blanc in August. In September the upwelling extended to 20°15'N (Fig. 1b). During the mission with SCH 302 fisheries concentrated on three areas: the edge of the upwelling (20-23/9), over the 'canyons' (23-25/9), and 'south' along the Limit (26-29/9).

Sardinella catches were declining in September and much time was devoted to searching. SCH 302 set out from the roadstead of Nouadhibou and began its search on the border of the upwelling region. Radar images showed about 30 trawlers (Russian, Dutch) lined up along the temperature front of 22ºC but catches are low.

Sardinellas that were caught were large (30-35 cm fork), rapid (6-7 kn), and in maturity stage 3 ('late developing'). However according to the logs registering catch statistics about 60% is by-catch, including a dozen small 0.5-1 m hammerhead sharks each haul. During fishing in the south at water depths of circa 50 m and water temperature of 28-29°C, sardinella catches remained low. Permanent trawling in shallow waters resulted in high by-catch rates of bottom dwelling species, notably catfish and milk sharks (Table 2).

SCH 81 *Carolien* 20 November- 6 December 2003

August and September appeared to be relatively warm with SSTs exceeding 29ºC. The region cooled during October and upwelling extended across the continental shelf in the first two weeks of November until ca. 17ºN. This situation was stable during the mission with SCH 81 (Fig. 1c). Fisheries concentrated on sardines at the margin of an intense upwelling (15-18°C, pinkish in the satellite images), which established on 26-27 November.

Sardine catches concentrated in water of circa 19°C immediately outside the center of upwelling at water depths of 50-70 m. Sardines appear to concentrate on the margin of the upwelling where according to the chlorophyll image primary production is greatest. Hauls are 'clean' and consist of 90-95% pilchards. In 63 hauls by-catch of just ten large animals was recorded, most of which occurred in vicinity of tropical water around 19°C (including one sea turtle), and two sharks in waters of 17°C.

4. Discussion

4.1 Are the remote sensing images useful in sardinella fisheries?

During the missions of 2002 and 2003 research concentrated on the relation between water temperature and sardinella abundance. There is no obvious relation because sardinella traverses water with temperature 15° to 29°C. However the oceanographic changes that are observed in the satellite images may influence sardinella migration, spawning time, and the success of recruitment.

The remote sensing missions have demonstrated that sardinella during the summer tends to concentrate around the upwelling in the northern part of the Mauritanian EEZ. Probably the sardinella avoid the center of the upwelling because it is void of plankton as compared to the surrounding region. In comparison with predatory species such as tuna, which actively seek spots of warm temperature and concentrated plankton, sardinella is an opportunistic species. Sardinella cruises at high speeds filtering planktonic organisms from the water column, often targeting specific zooplankton, including juvenile shoals of their own. The metabolism and energy-use efficiency of these fish is optimal in warm water, which thus facilitates high-speed swimming, although dissolved oxygen is lower in warmer than in colder water. Sardinella appears to avoid the upwelled waters, possibly due to low oxygen content of these waters (as a result of oxidation processes), cold temperature, and/or limited primary production. The satellite images are useful to locate these oceanic fronts. The satellite images have yielded insight into the spatial distribution of temperature anomalies in the Mauritanian EEZ and the relation with SST in the eastern subtropical Atlantic. Research in 2004 will focus on the description of this relationship and analysis of regional trends (Figs 2 and 3).

4.2. Do the research missions add to understanding of sardinella behaviour?

The research missions support interpretation of catch data and inference of the influence of ocean climate on catches. The spatial distribution and relative size of the catches do provide a useful approximation of the size of the migrating sardinella population, location of the fish with respect to surface water masses, and the diurnal variation. Much of the observations on sardinella behaviour are anecdotal and unsystematic, in contrast to e.g. observations during an echo survey. During the day sardinella occurs in compact, relatively small shoals that may reach speeds of 7 kn. Sardinella does not shoal during the night and hence seems to ‘disappear’ to shallow water according to some skippers.

Foraging behaviour like migration is probably connected with the spawning cycle. Spawning occurs throughout the years with July-October being the peak spawning period and secondary spawning during January-February (Mantingh 2003). In June-October when the fish concentrate in shoals along the temperature front on the shelf break north of 19ºN they are easier to catch than in other seasons or years when upwelling is less localized (cf. Binet et al. 2001). Sardinella do not necessarily seek plankton rich water but rather appear to follow migratory paths according to season and maturity. Sampling of stomach content during the summer missions revealed empty stomachs indicating that the animals even in plankton-rich water are not necessarily foraging. Building and restoring energy reserves also seem to be seasonally timed.

Catches are largest in spring (June-July) and after that fish abundance decreases until August-September, when secondary migration or back-migration of (parts of) the main population results in increased catches. Between September and February, fish abundance is minimal and the region is dominated by tropical SACW. Probably sardinella around this time are spread along the permanent upwelling in Morocco. In contrast, pilchard (*S. pilchardus*) appear to seek cold waters and are caught in the centre of the upwelling (Fig. 1c).

Observed seasonal sardinella behaviour appears to be related to ocean dynamics and rapid decline of sardinella stock in the Mauritanian EEZ apparent from catch data (125 ton/day in 1997 to 35 ton/day in 2002) may not be (entirely) due to fisheries pressure (cf. Binet 1997; Binet et al. 2001; Boyer et al. 2001). Echo surveys performed by R/V Fridtjof Nansen demonstrate high stocks in the Senegalese EEZ (1999) and in the area of permanent upwelling in the Moroccan EEZ (2000-2002), while sardinella appears to avoid the warm Mauritanian region.

Comparison of monthly averaged temperature charts since 1985 shows that between Fall 1994 and Summer 2002 there were two or three warm episodes with temperature anomalies of up to +3°C in the Mauritanian EEZ (Figs. 2 and 3). The fall of 1993 into the winter of 1994 (-2.5ºC) was the last of a series of cold anomalies before a shift of the system to warm anomalies. The first pulse between ca. April 1995 until May 1997 was 1 to 2.5ºC above average, followed by a large recurring warm event from July 2001 to July 2002 with temperatures in November 2001-February 2002 of +3ºC above average (Fig. 3). There appears to be an inverse relationship between SST and the North Atlantic Oscillation, probably reflecting increased surface cooling during years with a strong Azores high. A strong high-pressure system would result in increased surface winds, increased surface cooling, and increased upwelling. SST and sardinella abundance therefore would respond to basin scale atmospheric trends. The strong year class of 1997-1998 may reflect successful recruitment in the period 1994-1995; this would indicate that sardinella matures in approximately 3-4 years. A second warm event in 2001-2002 may thus result in increased recruitment during 2004-2005. Research therefore will focus on the effects of atmospheric and/or oceanic anomalies on recruitment, year class strength, and migration of sardinella at Northwest Africa (cf. Roy & Reason 2001; Czaja & Frankignoul 2002; Czaja et al. 2002). We will analyse the timing of maximum catches from 1997-2004 catch statistics in relation to previous winter-spring spatial anomalies to find whether these anomalies had effect on sardinella migration.

4.3. Is there a relationship between SST and by-catch of large predators?

In addition to the observer program and the missions related to the ‘preventing by-catch’ project, the RS research missions in 2003 accounted for 40% of the observations (hauls) on the by-catch of large non-target species (198 of 505 observed hauls; for details see Ter Hofstede et al. 2004). During the RS missions 80-90% of the hauls are observed. By-catches of large species occur predominately in tropical water (>20ºC) and during trawls in shallow water (e.g. catfish and smaller, bottom dwelling sharks), especially above coral banks.

During the research missions in 2003 a much lower number of by-catch was registered than in 2002, except for sharks due to the timing of the September mission, when trawls were concentrated in shallow waters along the Fishing Limit. In August SCH 302 registered large numbers of dolphins and pilot whales in the vicinity of the vessel but none were caught. During the same journey a ‘giant’ turtle was caught, but not registered in catch lists. RIVO-assistant Ronald Bol in October (no RS mission) registered one by-caught dolphin and one sea turtle. During the RS-mission in November-December SCH 81 concentrated on sardines in the centre of the upwelling. In these cold waters RIVO-assistant Martien Warmerdam during 63 hauls observed by-catch of one sea turtle, a manta ray, and six large sharks. Dolphins, hammerhead, and tropical species such as sunfish are not regularly observed in colder waters. Ship crew on SCH 302 and SCH 81 report a decline in the number and size of by-caught sharks and sunfish.

The remote sensing images demonstrate that tropical water arrived in the Mauritanian EEZ at latitude 18ºN between 15 and 20 May 2003 and ten days later the ‘World Conservation Union’ UICN by referral of the Mauritanian government reported that ca. 200 dolphins and several large sea turtles had washed ashore between 16,5 and 18º N. The animals had damages sustained by nettings and were probably by-caught in the international fishing fleet. Dutch trawlers on 16-17 May operated on 16,5-17ºN. This indicates that trawlers and predators both target the migrating fish shoals ahead of the advecting tropical water.

To reduce repetition of by-catches when it becomes apparent that there is a large density of e.g. sharks in a region a vessel could adjust its strategy and steer to nearby cooler waters or to deeper waters with same temperature. Remote sensing thus provides a tool for 'selective fishing', more so because it helps locate target species and limits 'random' trawling (Zeeberg et al. 2003).

Table 2. By-catch of large animals observed during the RS missions

	2002	2003
common and white-sided dolphins	20	0
long-finned pilot whale	0	0
sharks and rays (various species)	62	121
sea turtles	1	1
swordfish, marlin, ocean sunfish	30	5

Table 3. Observed by-caught species (other than in Table 2)

little tuny (*Euthynnus alleteratus)*
skipjack tuna (*Katsuwonus pelamis)*
Atlantic bonito (*Sarda sarda)*
bream, pomfret, japuta (*Brama brama)*
bream, Sparidae, pargo (*Pagrus pagrus)*
bass, bluefish (*Pomatomus saltator)*
black king fish (*Rachycentron or Acanthocybium?*)
black scabbardfish (*Aphanopus carbo)*
silver scabbardfish (*Lepidopus caudatus*)
hairtail (*Trichiurus lepturus)*
butterfish (*Stromatus fiatola)*
longfin pompano, Carangidae (*Trachinotus ovatus*)
pompano, dolphinfish, dorado, (*Coryphaena equisetis)*
dorade, dolphinfish, golden mackerel (*Coryphaena hippurus)*
eel (*Ophichtidae*, serpentons)
catfish
anchovy (*Engraulis*)
smooth hound shark (*Mustelus mustelus)*
milk shark (*Rhizoprionodron acutus*)

5. Outline for 2004

For 2004 a minimum of three RS missions will be scheduled: in Spring (April-June), Summer (June-September), and Fall (September-December) to collect further observations on fish distribution in the Mauritanian EEZ and oceanographic changes. Research questions are:

- What has been the effect of the warm winter of 2001 and the warm summer of 2003?
- Is there a connection between catch size in the past five years and changing SST?
- Did the Mauritanian EEZ warm in the past three years and if so did warming cause the sardinella to migrate farther north into Morocco?
- What is the nature of the warming that occurred between 1994 and 1999? Are there any 'teleconnections', e.g. with transport in the Canary Current and/or atmospheric fluctuations associated with the Azores High pressure cell?
- Can the periodicities that are observed (Figs. 2b and 3) be used to predict sardinella recruitment?

In 2004 we will apply satellite-derived scatterometer (altitude) and chlorophyll (plankton) data to support present, SST related observations. Do currents observed in SST images represent real currents and advection or do temperature changes reflect differential heating? Analysis of trawling positions from catch statistics 1997-2004 can decipher whether or not there is a systematic shift in trawling activities, possibly in connection with shifting oceanic regimes.

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Figure captions

Figure 1. From left to right the satellite images of 20 June (a), 28 September (b), and 27 November (c) with latitude and longitude on the axes. Plotted are the remote sensing missions of KW 171 (17-27 June 2003), SCH 302 (19-29 September 2003), and SCH 81 (20 November-6 December 2003, sardines). Each circle represents a haul and circle widths vary according to catch size (tables 4-6).

Figure 2a. Satellite-derived monthly SST for 19.5°N, 17°W and anomalies for the same location (below).

Figure 2b. SST anomalies and the North Atlantic Oscillation (NAO)-index (monthly). SST anomalies are derived by subtracting the composite image for each monthly average from the composit image that shows the monthly average for 1985-2003 (see also Fig. 3). Thick black line is the 7-month moving average; bar graph shows the monthly values of the NAO, which are dominated by the strength of the Azores High. There appears to be an inverse but nonlinear relationship between the NAO and the SST in the Mauritanian EEZ. The positive-negative NAO shift in Spring 1995 is probably related to the disturbance of prior regularity in the SST anomaly pattern.

Figure 3. Anomaly charts of extreme warm months (top) and extreme cold months (bottom). Anomalies are derived by subtracting the composit for the monthly average from the monthly average composite for 1985-2003 (see also Fig 2).

Table 4. Tow list for KW 171, 17-27 June 2003

Maartje Theadora				17 June 2003 until 27 June 2003							
tow	**date**	**shoot-haul**		**duration**		**position**		**water**		**catch**	
						N	W	depth (m)	SST	(ton)	composition
1	18-jun	10:40	13:55	3	15	2012	1736	100	17.0	120	saa 50%, saa small 50%
2	18-jun	19:30	22:30	3	0	1928	1700	200+	20.2	100	saa 90%, mkr 5%, rest 5%
3	19-jun	5:05	6:40	1	35	1856	1652	500+	20.4	10	mkr 100%
4	19-jun	8:30	10:40	2	10	1858	1645	160	20.6	0	-
5	19-jun	12:45	14:00	1	15	1850	1655	500+	22.4	120	saa 98%
6	19-jun	15:30	16:30	1	0	1854	1654	500	22.0	0	-
7	19-jun	17:35	22:35	5	0	1855	1658	1000	22.5	120	saa 98%
8	20-jun	2:20	7:40	5	20	1902	1652	500+	21.3	30	mas
9	20-jun	21:15	23:15	2	0	1757	1631	200	22.5	50	saa, hm, mkr
10	21-jun	0:15	3:45	3	30	1752	1633	200	22.5	100	mkr 90%, hm 10%
11	21-jun	5:10	9:30	4	20	1749	1630	170	22.5	50	-
12	21-jun	15:25	20:30	5	5	1755	1630	190	22.5	30	saa 65%, hm 20 mkr 10%
13	22-jun	13:10	15:15	2	5	1947	1731	1500+	18.1	300	saa 90%, mkr 10%
14	22-jun	17:30	22:00	4	30	1945	1726	1100+	19.0	70	mkr 90%, saa 10%
15	23-jun	1:30	5:15	3	45	1957	1725	100+	17.1	160	saa 98%
16	23-jun	7:00	10:00	3	0	2003	1730	100+	17.6	50	saa 98%
17	23-jun	11:30	13:30	2	0	2001	1728	50+	16.9	110	saa 98%
18	23-jun	14:50	19:30	4	40	2012	1727	50	14.9	20	sardine, saa
19	23-jun	22:30	23:45	1	15	2006	1733	50	16.8	5	saa
20	24-jun	1:15	3:15	2	0	2002	1727	40	16.9	0	-
21	24-jun	6:25	8:30	2	5	1940	1734	85	16.8	25	mix
22	24-jun	13:00	16:45	3	45	1935	1714	500	18.4	120	saa 90%, mkr 10%
23	24-jun	18:00	22:15	4	15	1940	1712	500	18.4	40	saa, mkr
24	25-jun	0:30	3:15	2	45	1942	1704	100	19.8	65	-
25	25-jun	4:35	7:35	3	0	1944	1704	100	19.8	25	mix hm, mkr, saa
26	25-jun	9:30	12:10	2	40	1950	1720	300+	17.3	70	saa
27	25-jun	14:50	18:30	3	40	1949	1739	1300	18.1	80	saa 70%, mkr 30%
28	25-jun	19:45	0:15	4	30	1950	1739	1000	18.1	80	saa 90%, mkr 10%
29	26-jun	12:00	17:20	5	20	1945	1735	1000	18.3	70	saa 80%, mkr 20%
30	26-jun	18:20	22:00	3	40	1951	1747	1500	17.9	200	saa 95%, mkr 5%
31	26-jun	23:45	3:25	3	40	1956	1747	1500	17.9	150	mkr 40%, hm 40, saa 20%

Table 5. Tow list for SCH 302, 20-29 September 2003

Willem van der Zwan						20 September 2003 until 29 September 2003					
tow	**date**	**shoot**	**haul**	**duration**		**position**		**water**		**catch**	
						N	W	depth	sst	ton	composition
1	200903	8.15	11.30	3	15	2041	1721	60	21,1	0	
2	200903	12.50	17.20	4	30	1952	1728		24,1	15	
3	200903	18.30	22.30	4		2004	1733		23,4	50	
4	200903	23.30	4	4	30	2000	1731		23,6	30	sar, mkr
5	210903	6.30	10.30	4		1957	1728		23,4	15	1 zak mix
6	210903	12	1500	3		2017	1728	50	21,6	30	sardine, ansjovis, bonitos
7	210903	22.00	2.00	4		2026	1739		21,2	20	sar
8	220903	5.30	10	4	30	2026	1739	250	21,9	60	sar, brama
9	220903	15.30	19.00	3	30	2006	1732		23	30	
10	220903	20.30	01.15	4	45	2006	1731		22,7	40	60% shit
11	230903	2.45	8.15	5	30	2011	1740	660	22,4	30	sar 80, bon 20
12	230903	11.00	14.00	3		1951	1723		23,4	15	dotje sar
13	230903	15.45	19.00	3	15	1939	1701		24	10	
14	230903	20.00	23.45	3	45	1936	1703		23,2	10	
15	240903	1.45	6.45	5		1939	1701	235	25,1	75	95 sar, 5 scabbard
16	240903	10.00	14.00	4		1935	1701		24,8	30	sar, lint
17	240903	16.45	22.00	5	15	1945	1706	161	23,5	10	
18	250903	00.15	5	4	45	1942	1706		24	60	sar, lint
19	250903	8.50	12.50	4		1941	1703	300	25	15	
20	250903			3	40	1943	1703		24,3	10	
21	250903			0	20	1942	1703		24,8	0	panne winch
22	260903	18.00	22.00	4		1756	1630		28	10	sar, bonito
23	270903	00.00	3.15	3	15	1809	1620		28	60	sar, jax
24	270903			4	30	1807	1616	40	28	15	25 sar, 50 hm, 25 demersal
25	270903	11.00	14.45	3	45	1815	1624		27,6	20	50 sar, 50 lint
26	280903	6.30	10.30	4		1815	1630		27	10	too small
27	280903	20.00	1.15	5	15	1835	1623	40	27,3	20	sar, sax
28	290903	6.30	10.30	4		1752	1619	37	27,8	10	50 sar, 20 hm, 30 demersal

Table 6. Tow list for SCH 81, 20 November-6 December 2003

SCH 81 Carolien				20 November 2003 until 6 December 2003							
tow	**date**	**time**		**duration**		**position**		**water**		**catch**	
		shoot	haul			N	W	depth (m)	sst	(ton)	composition
1	20-11-2003	06,30	08,00	1	30	2043	1725	58	19,0	40	pels 45% lg 45% sm 10 % discard
2	20-11-2003	09,45	12,00	2	15	2039	1727	58	18,9	55	pels 55% lg 30% sm 15 % discard
3	20-11-2003	13,45	15,00	1	15	2037	1726	58	18,6	10	pels 55% lg 30% sm 15 % discard
4	20-11-2003	18,10	20,50	2	40	2042	1725	58	19,3	40	95% pelser (= pilchard), 5% disc
5	20-11-2003	22,30	01,00	3	30	2042	1732	40	19,4	50	95% pelser 5% discards
6	21-11-2003	02,50	06,00	3	10	2041	1732	54	19,5	30	95% pelser 5% discards
7	21-11-2003	08,10	12,40	4	30	2029	1730	50	19,9	1	Span mkr 95% bonito 2 mkr 3%
8	21-11-2003	17,10	17,20	0	10	2043	1727	74	19,0	0	-
9	21-11-2003	20,00	22,30	2	30	2044	1737	83	19,5	40	75% pels 25% discard
10	22-11-2003	00,15	02,20	2	0,5	2038	1730	65	19,2	25	80% pels 20% discard
11	22-11-2003	04,15	06,30	2	15	2042	1730	54	18,9	35	75% pels 25% discard
12	22-11-2003	08,10	10,00	1	50	2042	1725	60	18,9	75	95% pelser 5% discard
13	22-11-2003	11,50	14,35	2	45	2034	1729	57	19,2	35	90% pelser 10% discards
14	22-11-2003	16,15	18,00	1	45	2040	1728	58	18,8	50	95% pelser 5% discards
15	22-11-2003	19,30	21,50	2	20	2033	1731	65	19,0	45	60% pels, 25 mkr, 15% disc
16	22-11-2003	23,35	02,15	2	40	2042	1729	70	18,9	20	85% pelser, 15% discard
17	23-11-2003	04,45	08,30	3	45	2028	1736	102	19,2	2	15% hm, 15% mkr, 70% disc
18	23-11-2003	12,00	14,00	2		2021	1731	54	19,6	25	95% mkr, 5% disc
19	23-11-2003	17,15	19,39	2	15	2044	1726	53	18,9	15	90% pelser, 10% discards
20	23-11-2003	23,00	01,10	2	10	2026	1724	53	19,6	65	85% pelser, 15% makreel
21	24-11-2003	04,00	07,00	3	-	2026	1728	50	19,1	30	85% pelser, 15% mkr, 5% disc
22	24-11-2003	08,30	11,15	2	45	2024	1727	45	19,1	20	87% pels, 10% makr, 3% disc
23	24-11-2003	13,45	16,45	3	-	2022	1727	60	19,2	25	35% mkr, 15 mkr sm, 25 pels, 25% disc
24	24-11-2003	18,30	20,45	2	15	2019	1735	42	19,7	60	70% pelser, 25 mkr, 5% discards
25	24-11-2003	22,15	00,15	2	-	2024	1726	40	19,3	70	97% pelser, 3% discards
26	25-11-2003	02,00	05,00	3	-	2032	1727	39	19,2	65	45% pelser, 45 mkr, 10% discards
27	25-11-2003	06,45	08,10	1	25	2017	1725	38	19,3	100	85% pels, 8 mkr, 4 harders, 3% disc
28	25-11-2003	11,30	14,30	3		2016	1736	44	19,3	5	100% makreel
29	25-11-2003	17,00	19,10	2	10	2032	1725	40	19,3	85	85% pelsers, 15% discards
30	25-11-2003	21,00	23,35	2	35	2036	1727	42	19,3	55	98% pelsers, 2% discards
31	26-11-2003	01,15	04,15	3	-	2024	1726	37	19,1	35	85% pelsers, 5% mkr, 10% discards
32	26-11-2003	07,30	10,30	3	-	2030	1725	37	18,9	45	85% pelsers 15% discards
33	26-11-2003	12,00	14,20	2	20	2036	1729	55	19,1	65	90% pelser, 10% discards
34	26-11-2003	15,45	18,45	3	-	2038	1729	58	19,1	50	80% pelser, 20% discards
35	26-11-2003	20,30	21,45	1	15	2038	1726	50	18,3	50	70% pelsers 30% discards

36	26-11-2003	23,45	01,45	2	30	2018	1725	48	18,4	120	95% pelsers 5% discards
37	27-11-2003	04,15	07,40	3	25	2014	1727	44	18,2	25	95% pelsers 5% discards
38	27-11-2003	11,00	13,45	2	45	2042	1728	67	18,5	3	pelsers (pilchards) and mackerel
39	27-11-2003	20,00	20,50	-	50	2014	1726	40	18,5	120	92% pelsers, 5% mkr, 3% disc
40	27-11-2003	22,45	01,10	2	25	2017	1724	37	18,0	90	88% pelsers, 5 mkr, 7% discards
41	28-11-2003	03,00	06,45	3	45	2019	1724	65	18,0	25	50% pels, 25 mkr, 5% discards
42	28-11-2003	08,15	10,00	1	45	2013	1732	71	19,3	5	pelsers (pilchards) and mackerel
43	28-11-2003	12,30	14,45	2	15	2037	1723	43	18,0	10	80% pels, 10 mkr, 10% discards
44	28-11-2003	17,30	20,30	3	-	2027	1730	35	18,9	110	70% pels, 20 mkr, 10% discards
45	28-11-2003	23,30	02,00	2	30	2021	1725	40	18,2	30	80% pels, 15 mkr, 5% discards
46	29-11-2003	03,30	05,45	2	15	2011	1724	42	18,4	95	92% pels, 5 mkr, 3% discards
47	29-11-2003	07,30	10,45	3	15	2010	1730	43	19,2	50	85% pels, 10 mkr, 5% discards
48	29-11-2003	15,50	18,30	2	40	2011	1726	39	18,9	90	95% pels, 3 mkr, 2% discards
49	29-11-2003	20,00	21,10	1	10	2019	1726	45	19,2	75	80% pels, 10 mkr, 10% discards
50	29-11-2003	22,45	01,30	2	45	2019	1728	42	18,9	90	90% pels, 5 mkr, 5% discards
51	30-11-2003	03,50	06,40	2	50	2007	1729	45	18,0	100	90% pels, 5 mkr, 5% discards
52	30-11-2003	15,50	19,00	3	10	2015	1724	60	17,7	20	90% blue Fish 10% discards
53	30-11-2003	20,30	23,00	2	30	2014	1726	65	18,0	15	20% leer, 35 pels, 35 hm, 10% disc
54	1-12-2003	01,30	04,45	3	15	2028	1727	55	17,4	30	15% pels, 80 mkr, 5% discards
55	1-12-2003	06,40	09,50	2	40	2015	1728	65	17,9	10	mackerel and pelsers (pilchards)
56	1-12-2003	15,30	18,45	3	15	2036	1725	44	17,0	15	60% pels, 37 mkr, 3% discards
57	1-12-2003	20,30	23,30	3	-	2029	1724	55	17,0	60	80% pels, 18 mkr, 2% discards
58	2-12-2003	01,10	04,40	3	30	2022	1725	50	17,0	45	49% pels, 49 mkr, 2% discards
59	2-12-2003	06,15	08,30	2	15	2011	1726	44	17,0	100	40% pels, 55 mkr, 5% discards
60	2-12-2003	10,15	12,05	1	50	2005	1729	40	17,4	25	98% pelsers, 25% discards
61	2-12-2003	12,50	15,45	2	55	2012	1730	40	17,0	100	40% pels, 45 mkr, 5% discards
62	2-12-2003	17,30	19,45	2	15	2010	1729	45	18,0	90	5% pels, 80 mkr, 15% discards
63	2-12-2003	21,30	23,50	2	20	2016	1728	35	18,0	70	85% pels, 10 mkr, 5% discards
64	3-12-2003	04,30	07,30	3	-	2015	1725	40	17,0	45	discarded
65	3-12-2003	09,50	12,30	2	40	2009	1730	44	17,0	20	45% pels, 45 mkr, 10% discards
66	3-12-2003	14,00	17,15	3	15	2011	1728	42	17,0	90	90% pels, 5 mkr, 5% discards
67	3-12-2003	19,30	20,20	-	50	2010	1727	40	17,0	80	95% pelsers 5% discards
68	3-12-2003	22,15	01,00	2	45	2013	1726	44	17,0	70	85% pels, 10 mkr, 5% discards
69	4-12-2003	03,50	06,30	2	40	2018	1725	43	17,0	70	40% pels, 50 mkr, 10% discards
70	4-12-2003	08,00	11,00	2	-	2018	1725	44	17,0	45	45% pels, 45 mkr, 10% discards
71	4-12-2003	12,30	16,30	4	-	2014	1729	43	17,0	45	mackerel and pelsers
72	4-12-2003	18,00	20,40	2	40	2013	1728	45	17,0	65	75% pels, 15 mkr, 10% discards
73	4-12-2003	22,15	00,30	2	15	2010	1725	50	17,0	20	85% pels, 10 mkr, 5%

											discards
74	5-12-2003	02,00	03,15	1	15	2018	1730	60	17,0	75	15% pels, 83 mkr, 2% discards
75	5-12-2003	04,50	08,30	3	30	2013	1732	72	16,9	50	35% pels, 55 mkr, 10% discards
76	5-12-2003	10,45	13,30	2	45	2023	1740	65	17,9	70	35% pels, 55 mkr, 10% discards
77	5-12-2003	15,15	17,30	2	15	2024	1738	70	18,1	130	90% pels, 5 mkr, 5% discards
78	5-12-2003	02,10	05,30	3	20	2028	1734	60	18,1	25	60% mkr, 40% discard pelsers
79	6-12-2003	07,15	10,00	2	45	2026	1726	42	18,2	75	30% pels, 60 mkr, 10% discards
80	6-12-2003	12,00	24,00	12	-	2020	1748	100	18,0	15	- panne winch