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Application of satellite imagery to analyse the distribution and recruitment of sardinella - Annual Report 2002

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Summary

Remote sensing studies at the Netherlands Institute for Fisheries Research (RIVO) aim to stimulate the use of satellite images on board of Dutch freezer-trawlers in the Mauritanian Exclusive Economic Zone (MEEZ). During four research missions (5-12 July 2002, 23-30 August 2002, 13-20 October 2002, and 14-23 November 2002) NOAA-AVHRR images of sea surface temperatures (SST) and SeaWifs plankton images were used to locate the fronts at which sardinella, the target species of the Dutch fleet at West Africa, tend to concentrate. These 'RIVO-images' are transmitted biweekly with specified annotation to enable easy interpretation. Remote sensing helps locate target species and reduces by-catches associated with 'random' trawling. Satellite-derived time series are furthermore applied to analyse apparent spatial shifts of the stock in recent years.

Comparison of catch data (size, location) with associated satellite-derived oceanography yields insight into the behaviour and migration patterns of sardinella. The oceanographical situation on the Mauritanian shelf (water depths <200 m) fluctuates between a winter state and a summer state. Sardinella during summer appears to stay ahead of the advancing warm front associated with advection of tropical water (>20°C). SST increases in the Mauritanian EEZ in July and catches decrease simultaneously, probably reflecting migration of sardinella into Morocco. Between September and February, fish abundance is minimal and the region is dominated by tropical water. In contrast, pilchard are seen to seek cold waters and are caught in the very centre of the upwelling.

The research missions indicate that 'field' observations are essential for interpretation of catch data and inference of the influence of ocean climate on catches. In 2002, the sardinella was rapid (speeds up to 7 kn) and occurred in compact, relatively small shoals. As a result the sardinella were difficult to intercept, and all vessels reported declining catches. The Mauritanian EEZ was exceptionally warm between 1995 and 1999 (1 to 3°C anomaly). The rapid decline of sardinella stock during this period (c. 125 ton/day in 1997 to c. 35 ton/day in 2002) may, therefore, result from environmental changes in combination with fisheries pressure. From observations during the research missions it appears that by-catches of large species (sharks, sunfish, marlin; cf. Ter Hofstede 2003) occur in tropical water (>20°C). Vessels may use satellite images to steer to nearby cooler waters when large numbers of e.g. sharks are observed. Remote sensing thus provides a tool for 'selective fishing' without lowering total catches.

1. Introduction

RIVO project 999-00006-06 (‘Application of remote sensing data to analyse the distribution and recruitment of sardinella’) is one of three projects in Mauritania that are financed jointly by the Dutch Ministry of Agriculture, Nature Management, and Fisheries (LNV) and the Redersvereniging voor Zeevisserij, part of the Pelagic Freezer-Trawler Association (PFA). Remote sensing images provide an instrument to fisheries comparable with weather maps (Fig. 1). SST-images reflect the dynamics of the ocean, which enable a vessel to predict and locate the physical boundaries that confine fish. The use of satellite images helps cut search time and makes fishing more cost-effective, and more selective, reducing ‘random’-trawling. 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. 2). The objective of this project is to stimulate the use of remote sensing information on board of the trawlers, and to apply remote sensing techniques in biological and ecological research (Corten 2000, 2001; Troost 2002). Sardinella (*Sardinella aurita*) is the most important target species for Dutch fisheries at Northwest Africa. It occurs in well-sorted, single species shoals (see also Table 5). The distribution of pelagic fish (sardinella, sardines, anchovys, and herring) and the growth and survival of their larvae are strongly influenced by environmental factors such as water temperature, food abundance, current direction, and turbulence (e.g. Cury & Roy 1989; John & Zelck 1997; John et al. 2000).

The current project is the continuation of a study initiated in 1998 by the Redersvereniging voor Zeevisserij and covers a three-year period (2002-2004). This report presents observations and progress made during the first year. In line with the contract, four research missions have been performed in 2002: 5-12 July 2002 (SCH 118_*Johanna Maria*, Jaczon); 23-30 August 2002 (KW 171 *Maartje Theodora*, P&P); 13-20 October 2002 (SCH 54 *Franziska*, WZ); and 14-23 November 2002 (SCH 302 *Willem v/d Zwan*, WZ). The technicalities and skippers of this fleet are summarized in Table 8; observations during particular research missions are reported in Zeeberg et al. (2003). Images are obtained from the Universidad de Las Palmas de Gran Canaria (ULPGC), and are derived from United States NOAA "Advanced Very High Resolution Radiometer" (AVHRR)-satellites. ULPGC also provides radar-scatterometry, and plankton images (Fig. 1), and has developed algorithms to derive SST from AVHRR measurements (Ramos et al. 1996). 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; MacKenzie 2000); (3) opportunities for ‘selective fishing’.

Table 1. Use of remote sensing by the European trawler fleet at Africa

Vessel	Receives	Use
Johanna Maria (Jaczon)	OrbMap + RIVO	always
Afrika (Jaczon)	OrbMap + RIVO	often
Maartje Theadora (PP)	OrbMap + RIVO	often
Willem van der Zwan (WZ)	Orbmap + RIVO	sometimes
Oceaan IV (WZ)	Orbmap + RIVO	often
Franziska (WZ)	OrbMap	sometimes
Carolien (Vrolijk)	RIVO	often
Frank Bonefaas (Vrolijk)	RIVO	always
Veronica (via via)	RIVO	often
Atlantic Dawn (via via)	OrbMap + RIVO	often
Helen Mary	RIVO	sometimes

2. Research methods

2.1. Sea surface temperature (SST)

Satellite-derived ocean temperature measurements are used to infer ocean dynamics, specifically current directions and strengths, 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. These temperatures agree ±0.3°C, but may be off by 2.5°C (SCH302, Zeeberg et al. 2003). Linear regression demonstrates correlation (r=0.86) of recorded water temperatures and SST derived from AVHRR images (Troost 2002).

Plotting catch per hour with SST (Fig. 3) demonstrates that there is no relation between catch (sardinella abundance) and water temperature. Sardinella are caught in water 15 to 29°C, and apparently are tolerant to rapid temperature changes, moving from tropical SACW (22°C) to upwelling water (18°C). Yearly sardinella migration is possibly timed by seasonal warming and cooling of the region. Analysis of the oceanographic situation in relation to catch data may provide insight into the environmental factors that regulate migration and determine the route chosen by the fish.

SST is measured by a series of meteorological satellites launched by NASA and operated by the American National Oceanic and Atmospheric Administration (NOAA). Two such satellites are kept operational at any time (currently they are NOAA-10 and NOAA-11). The satellites are in a polar orbit, which puts them on a north-south track with a period of about 102 minutes and an altitude of about 860 kilometres. The Resolution Radiometer (AVHRR) on board the spacecraft is a scanning radiometer that looks at a swath nearly 3000 km wide, centred on, and perpendicular to, the satellite track. Each sensor in this instrument measures the radiation coming up from earth in a narrow section (band) of the spectrum. A ground station within the satellite-footprint is able to receive the transmissions without cost. Two versions of the AVHRR instrument have been flown in the NOAA satellites: one with 4 bands and one with 5 bands. One of the bands is in the visible part of the spectrum, one is in the near infrared, one is in the reflected infrared and the remaining one or two bands are in the thermal infrared. The visible and near infrared bands are mostly used for terrestrial work and cloud discrimination and the thermal infrared bands are used for temperature estimation. The resolution of the sensors is 0.1°C but the accuracy of the final temperature estimate is less than that.

2.2. Temperature estimation and validation

The AVHRR instrument converts counts from a sensor with a rotating mirror to albedos and brightness temperatures. These brightness temperatures do not give the exact temperature of the viewed object because some radiation is absorbed by water vapour along the path from the object to the sensor. Temperature estimates are corrected either by looking at an area twice using different optical paths or by looking at an area in bands 4 and 5 simultaneously (called a split-window technique). The algorithm (formula) relating temperature to brightness temperatures in the two bands can be summarized to (Casey & Cornillon 1999):

$$SST = a + b*T4 + c*T5$$

T4: brightness temperature in band 4
T5: brightness temperature in band 5
a, b, c are constants provided by comparison with ship data and buoys

Cloud-affected pixels can be eliminated by combining images from a number of satellite passes over an area (composites). The sensors measure radiation emitted by a 1 mm-thick surface layer. These to some extend reflect the conditions below the surface. On calm afternoons solar heating can create a stable layer of warm water on the surface of the ocean, which can be misleading ('skin' effects). The data are downloaded into Erdas-Imagine software, which has buttonized 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 is plotted and land is masked. Finally, data intervals are categorized according to a 0.5ºC colour coding designed by ULPGC (Fig. 2).

2.3. Catch data and 'sampling' strategies

Comparison of catch data (size, location) with associated satellite-derived oceanography yields insight into the behaviour and migration patterns of sardinella. To achieve this, catches are classified and plotted as circles in the satellite images (Figs. 4 and 5). A trawling vessel circles with a speed of 5-6 kn, resulting in a 'corkscrew' trajectory. One circle roughly covers the trawling area. Following a successful catch in water of a certain temperature, a vessel continues to search in that water, using temperature as indicator. When fish cannot be found, a vessel will return to the *QuodFish 510* log archive to study previous locations for that particular day or season. Because the oceanographic situation and fish migration depend on the season, such experience-based decision is often consistent with a decision based on temperature images.

The catch data provide a *first order* indication of the amount of fish in the migrating population, sampled while it crosses through the Mauritanian EEZ. Because sardinella also migrate within the coastal fishing limit (13 mile offshore and roughly the 50 m isobath) that is off-limit to Dutch trawlers, a large part of the population may pass unseen. Fish abundance is better represented by echo surveys, i.e. those performed yearly by R/V Fridtjof Nansen, although here too, a large part of the population may pass unseen. For this reason, the acoustic estimations from this vessel are potentially are off by 30% (FAO, 2001). The catch size 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 2. Terminology

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

Fish abundance is estimated by dividing the catch by the trawling hours (a measure of effort). When comparing between vessels, catch per unit of effort should be standardized, e.g. by multiplying hours with an index of engine power (engine power/average engine power, ~10,000 hp). The catch-per-hour estimate incorporates the effects of trawler tactics. While searching for fish, the vessels stay close together to systematically cover an area with sonar. There is constant exchange of observations over the VHF-radio ('Sputnik'). Catches thus concentrate in the area's where fish have been located prior. A vessel will lower the nets when in a particular region one or more compact shoals are seen (cph>60). Alternatively, a haul may last several hours, resulting in a lower catch per hour. During the night, sardinella forages and is spread out, while during early morning hours and in daytime, the fish group in compact shoals. Depending on freezing capacity, captures of less than 8.3 ton/hour are unprofitable, because a vessel must trawl six hours for 50 tons. During hauls longer than six hours, friction forces may damage the fish; sardinella falls apart after eight hours. Most trawls therefore last 4 to 5 hours.

3. Evaluation of the remote sensing services provided by Orbimage and RIVO

AVHRR-Sea Surface Temperature images comparable to the RIVO-images have been widely applied in oceanography and fisheries since the 1980s. In the past years, user-friendly software (OrbMap) has been developed and commercially exploited by the SeaStar Fisheries Information Service (Dulles, Virginia, USA). This corporation, a major US provider of satellite data, has also equipped and serviced ULPGC. OrbMap is a user-friendly, Windows-based program distributed since 1997 by the Orbital Imaging Corporation (Orbimage). The worldwide application of the program is obvious from the available language options: English, French, Spanish, Japanese, Chinese, and Korean. Weather charts, surface currents & surface height (radar satellite images), and AVHRR-SST are distributed by e-mail on a daily basis. Because plankton concentrations change gradually, SeaWifs Ocean Color Maps are produced twice weekly. The software by automated combination of overlays, produces a 'Fish Finding Map'.

The RIVO charts that are sent to the fleet at least twice a week provide detail to plan a trawl-haul. Oceanographic conditions may change rapidly within few miles. RIVO charts are annotated to show individual currents and the precise extent of upwelling water. Disadvantage of the RIVO-service is the rather large size of the image (30-80 kb). It takes a vessel about ten minutes to download a RIVO-image by e-mail and the providers of several vessels (SCH54, SCH302) block files larger than 20 kb. The images can also be faxed, but during the research missions it was found that this results in unacceptable loss of detail (Zeeberg et al. 2003). File size may be limited while preserving image detail by preparation of cut-to-size images of <20 kb when fishing operations are concentrated in e.g. the north. Images are distributed in .jpeg format, which is an image compression format. Zipping the images does not achieve much more compression: commonly less than 10 bytes. In comparison, OrbMap-files are smaller and better suited for daily updating.

Table 3. <u>OrbMap Files</u>

Regional SST	.sst	11 kb	7 d
Quadrant SST	.sst	25 kb	7 d
Weather (incl. 2 d forecast)		15-20 kb	7 d
Wind	.bin, .bix	4 kb	
Front	.nat	2 kb	
Swell	.bin	5 kb	
Wave	.bin	4 kb	
Movement	.nat	0.3 kb	
Currents	.cur	8 kb	7 d
Sea surface height anomaly	.ssh	10-20 kb	2 wks
Plankton	.bu2	28 kb	mo, th
Frontal analysis	.fab	2-10 kb	we
Fishing recommendations	.frb	3 kb	we

OrbMap with a combination of weather maps, SST, regional currents, and plankton is a valuable program for vessels in the open ocean. RIVO-images however are well suited for the Mauritanian EEZ, in which the search area is well delimited and wind directions are commonly NNE. OrbMap for 'Sardine-like fishes' recommends to '*Search for sardinella along the strong coincident plankton and temperature fronts adjacent to the western coast of Africa. Sardinella prefer the medium plankton concentration sides of strong medium/high plankton concentration fronts*'. From the positions of Dutch trawlers it appears that the vessels in Mauritanian waters always work on the margins of the plankton area, because plankton forms in upwelling regions above the shelf (<200 m depth) and is transported by offshore currents. In the Mauritanian EEZ the RIVO maps with accurate representation of temperature fronts, coastline and bathymetry are as suitable for fish finding as the Orbmap files.

4. Application of remote sensing during the research missions

4.1. 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 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 (Fig. 3). 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 (Fig. 4). The accumulation of water in the centre of the eddy can be seen in Sea Surface Height charts. An SSH-anomaly (SSHa) indicates the difference between two surface elevation measurements. An SSHa of –3 cm, reported for the core of the approaching eddy during the research mission of 10-11 July (Fig. 4) indicates decreasing SSH, likely because the eddy loses energy, cools, and slows. Upwelling is permanent north of Cape Blanc. Between February and (late) June, trade winds increase and upwelling dominates the entire Mauritanian EEZ.

4.2. 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 (Fig. 4). Net loss of surface water from the upwelling region results in a lowered sea surface. An SSHa of +3 such as reported for the centre of the upwelling region on 10-11 July indicates a rising surface, hence decrease of upwelling intensity. 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). Sardinella during summer (July, SCH118) was in spawning condition and appeared 'trapped' between upwelling water and SACW, searching for a path to spawning areas. Spawning areas, however, are unknown, and possibly include the Banc d'Arguin and coastal areas of Morocco.

4.3 Plankton/chlorophyll

The upwellingwater transports detritus from the slope of the continental shelf and thus is nutrient (nitrate NO_3^- and phosphate PO_4^-) rich. The process of photosynthesis in plants converts light and carbon dioxide to carbon in the cell. Primary productivity can be estimated by remote sensing by measuring ocean color, which reflects phytoplankton pigment from chlorophyll (mg/m^3). Ocean color images (SeaWifs sensor) show that chlorophyll at Northwest Africa is concentrated along the Mauritanian shelf (Hoepffner et al. 1999). Primary production is maximum in spring, probably in connection with increasing winds and associated upwelling. Primary production peaks in spring (April, May, June), when upwelling is maximum as a result of strengthening winds. Primary production is minimal during summer (July, August, September, October), due to advection of SACW south of Cap Blanc, and decreasing upwelling intensity (calculated from winds measured at coastal stations; Barton et al. 1998; Ould-Dedah et al. 1999). In autumn, advection of SACW ceases and a zone with high plankton extends with upwelling filaments to Cape Verde, approximately 400 km. Plankton concentrates in 'filaments' (John & Zelck 1997; Rodriguez et al. 1999). Indeed according to echoegrammes recorded by trawlers this water includes much 'seed', i.e. zooplankton, fish larvae, and anchovies. The use of ocean colour images is limited because the view is often obstructed by dust, water vapor (clouds), and reflection of the sun on the ocean surface (sun glint), blinding the sensor. The timeseries since 1997 is therefore fragmented.

4.4. Situation during the missions in 2002

SCH 118 *Johanna Maria* 5-12 July 2002

During the first remote sensing research mission, a strong front developed along the shelf edge between South Atlantic Central Water (SACW) of the warm (>20°C) Guinnee Current and cold water of the Canary Current and upwelling region. Permanent strong winds (N4-6) sustained the upwelling and a cold wedge over the southern shelf. Along the temperature front several eddies can be distinguished. Anticyclonic rotation of advected eddies can be seen in the image of 11 July, notably of the large (300 km, 1 degree latitude is 225 km) structure of 24-26°C. Fisheries were successful (trawl sets of 50-100 ton) in small eddies spun off across the shelf from the coastal jet (Fig. 4).

KW 171 *Maartje Theodora* 23-30 August 2002

Anomalously strong upwelling around Cap Blanc and into Morocco dominates fisheries in August (Fig. 5). During the second remote sensing research mission, searches concentrated along the shelf edge (water depth 200 m) in the boundary waters of the upwelling (19-22°C).

SCH 54 *Franziska* 13-20 October 2002

Satellite images for the third week of October were partly clouded, but the images of 21 and 22 October demonstrate turbulent advection of warm (24-27°C) SACW along the shelf edge (Fig. 5). A line of cool (20-22°C) upwelled water is wedged into the warm waters along the shelf edge, consistent with hard wind documented on 19 October (Zeeberg et al. 2003). Fish abundance was extremely low during this mission, which is common during the fall and winter seasons. Several small shoals were spotted within upwelling water, close to and within the (13 mile) fishing limit (largest catch 180 ton).

SCH 302 *Willem v/d Zwan* 14-23 November 2002

Sardinella appears to be absent in the Mauritanian EEZ, which is cooled by anomalously strong upwelling. Pilchards are caught in the cold center of the upwelling (15-19°C) region (Fig. 5).

5. Discussion

The research missions have been instrumental in testing whether remote sensing analysis, stock assessments, and discard monitoring are consistent with direct fisheries observations (Zeeberg et al. 2003). The research missions indicate that 'field' observations are essential for interpretation of catch data and inference of the influence of ocean climate on catches. In 2002, the sardinella was rapid (speeds up to 7 kn) and occurred in compact, relatively small shoals. As a result the sardinella were increasingly difficult to intercept, and all vessels reported declining catches. In spring and summer, the sardinella are easier to catch when they concentrate in shoals along the temperature front on the shelf break north of 19ºN (cf. Binet et al. 2001). This situation was established in 2002 in the last week of June, which explains low catches in prior months.

Maximum catches were close to the fishing limit and during the night, when the sardinella appears to move away from the coast. According to the skippers, the fish retreats at high speed after ca. 2 a.m. Possibly the behaviour of the fish to retreat within the limit reflects a learning pattern. Sampling of stomach content during the summer missions revealed empty stomachs indicating that the animals even in plankton-rich water were not foraging. Logs of the research missions (Annex I) furthermore demonstrate that current monitoring of discards and large by-catches is incomplete (cf. Ter Hofstede 2003). By-catches of e.g. sharks, sunfish, turtles, and marlin occur predominately in tropical water (>20ºC). Vessels may use satellite images to steer to nearby cooler waters when large numbers of e.g. sharks are observed (cf. Baum et al. 2003). Remote sensing thus provides a tool for 'selective fishing', more so because it helps locate target species and limits 'random' trawling.

Sardinella is a filter feeding species that cruises at high speeds to intercept planktonic organisms. 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 fish appear to concentrate on the limits of the upwelling region, where temperature and dissolved oxygen are more favourable, and primary production is high. 'Mesoscale' (20-100 km) oceanographic features such as filaments may concentrate primary and secondary production (zooplankton, krill, larvae) and thus attract predatory species such as tuna, which are able to distinguish warm temperatures associated with anticyclonic eddies (Ramos et al. 1996; Barton 1998). Less selective species such as sardinella probably locate the sharp boundaries provided by these features. Sardinella during summer appears to stay ahead of the advancing warm front associated with advection of SACW. SST increases in the Mauritanian EEZ in July and catches decrease simultaneously, probably reflecting migration of sardinella into Morocco.

Fish abundance increases in August, reflecting secondary migration or back-migration of (parts of) the main population. Between September and February, fish abundance is minimal and the region is dominated by tropical SACW. In contrast, pilchard (*S. pilchardus*) appear to seek cold waters and are caught in the very centre of the upwelling (Fig. 5c). Sardinella catches are maximum between May and July when the Mauritanian EEZ is in a 'winter state' with SST between 16 and 21°C (FAO 2001). Observed seasonal sardinella behaviour appears to be related to oceanographic dynamics and, likewise, 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 result from environmental changes in combination with fisheries pressure (cf. Binet 1997; Binet et al. 2001; Boyer et al. 2001). Echo surveys performed by R/V Fridtjof Nansen demonstrate a similar trend as the catch data but also show high stocks in the Senegalese EEZ (1999) and the Moroccan EEZ (2000-2002). These spatial shifts of the stock may result from changes in the ocean climate, because the Mauritanian EEZ was exceptionally warm from April 1995 until May 1997 (1 to 2.5ºC anomaly), and remained warm (1ºC anomaly) until August 2000. Future 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).

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Table 4. Sardinella almanac

Sun – more sardinella, cloudy – less sardinella
New and full moon – disturbances; strong currents at full moon
Day – compact shoals, night – fish are spread out and forage
Some wind – sardinella, strong wind or no wind – no sardinella
Clear blue water – no sardinella; green ('thick') water – sardinella.

Table 5. Species in one haul on 28 Augustus 2002

Merk	**# pak**
Sardinella	4004
Horsemackerel	104
Mackerel	196
Vadigo	71
bonito (*Sarda sarda*)	516
Tonijn – bullet tuna	34
Lintvis – hairtail	450
Totaal pak	5375

Table 6. Minimal length for small pelagics in the Mauritanian Exclusive Economic Zone (MEEZ) per 1 October 2002

Sardinella (*S. aurita, S. maderensis)*	18 cm
Sardine (*Sardina pilchardus*)	16 cm
Horsmackerel (*Trachurus Spp.)*	19 cm
Mackerel (*Scomber japonicus*)	25 cm

Table 7. Waypoints 13 Mile Zone ('Fishing Limit')

Wpoint	**North**	**West**
1	20°46'30"	017°03'00"
2	20°36'00"	017°11'00"
3	20°36'00"	017°24'10"
4	19°57'00"	017°24'10"
5	19°45'70"	017°03'00"
6	19°29'00"	016°51'50"
7	19°21'00"	016°45'00"
8	19°21'00"	016°46'60"
9	19°06'60"	016°39'20"
10	19°00'00"	016°29'30"
11	18°55'00"	016°25'60"
12	18°36'40"	016°22'00"
13	18°24'80"	016°17'00"
14	18°00'00"	016°15'00"
15	17°50'00"	016°16'00"
16	17°50'00"	016°15'00"
17	17°42'30"	016°16'00"
18	17°25'60"	016°20'60"
19	17°00'00"	016°31'40"
20	16°34'10"	016°39'30"
21	16°17'50"	016°43'30"
22	16°04'00"	016°42'40"

Table 8. Technical details freezer-trawlers used in this study

SCH 118 '*Johanna Maria*'

Rederij	Jaczon
Schipper	Mart van der Meij
Bouwjaar	1994
Lengte en vermog	120 m, 11.000 hp
Net	6300 mazen (55 mm)

SCH 81 '*Carolien*'

Rederij	Vrolijk
Schipper	Koos van Rijn, Sjaak van der Zwan
Bouwjaar	1998
Lengte en vermog	126 m, 12.000 hp
Net	6300 mazen (55 mm)

SCH 54 '*Franziska*'

Rederij	Willem van der Zwan (WZ)
Schipper	Willem Jonker
Bouwjaar	1989
Lengte en vermog	120 m, 12.000 hp
Net	6300 mazen (55 mm)

SCH 302 '*Willem van der Zwan*'

Rederij	WZ
Schipper	Piet Haasnoot, Aad Jonker
Bouwjaar	1999
Lengte en vermog	142 m, 16.500 hp
Net	6300 mazen (55 mm)

KW171 '*Maartje Theodora*'

Rederij	Parlevliet & Van der Plas (PP)
Schipper	Gerrit Plug
Bouwjaar	2000
Lengte en vermog	141 m, 16.000 hp
Net	6300 mazen (55 mm)

Annex I. Catch Lists

SCH118

	N	W	dur	temp	ton	cph	cat	by-catch
4-jul-02	1948	1717	3,5	20	30	8,6	2	-
5-jul-02	1934	1708	4,5	22,1	90	20,0	2	yes
5-jul-02	1931	1714	4	22,9	60	15,0	2	-
6-jul-02	1945	1726	6,5	22	180	27,7	2	yes
6-jul-02	1943	1731	1,3	22,8	230	176,9	1	-
6-jul-02	1951	1746	1,5	22,2	100	66,7	1	yes
7-jul-02	1946	1746	16	21,2	100	6,3	3	yes
7-jul-02	2004	1742	4,5	18,8	45	10,0	2	yes
8-jul-02	1952	1737	4,5	19	95	21,1	2	yes
8-jul-02	1935	1725	5,5	22,1	130	23,6	2	yes
9-jul-02	1956	1736	3	19	15	5,0	3	-
10-jul-02	1938	1715	5,3	21,5	15	2,8	3	yes
10-jul-02	1941	1729	3,5	21	120	34,3	2	yes
10-jul-02	1943	1741	6	20,5	50	8,3	3	yes
11-jul-02	1943	1721	5	20	70	14,0	2	yes
11-jul-02	1951	1741	6,5	20,5	75	11,5	2	yes

KW171

	N	W	dur	temp	ton	CPH	cat	by-catch
23-aug-03	2010	1727	2,5	21.2	40	16,0	2	-
24-aug-03	2018	1743	2,5	21.7	100	40,0	2	-
24-aug-03	2019	1747	6	23.0	120	20,0	2	yes
24-aug-03	2032	1803	6	22.1	5	0,8	3	yes
25-aug-03	2044	1802	2,5	19.6	0	0,0	..	-
26-aug-03	2038	1750	5,5	23.5	5	0,9	3	yes
26-aug-03	2039	1725	2	21.4	30	15,0	2	-
26-aug-03	2033	1732	3	21.2	45	15,0	2	-
26-aug-03	2009	1724	1	23.1	0	0,0	..	-
27-aug-03	2043	1725	4	20.7	110	27,5	2	-
27-aug-03	2038	1727	3	21.0	5	1,7	3	-
27-aug-03	2046	1737	5,5	21.9	95	17,3	2	-
28-aug-03	2040	1727	5,5	20.5	30	5,5	3	-
28-aug-03	2016	1734	4	19.8	5	1,3	3	-
28-aug-03	2031	1729	5,5	19.9	0	0,0	..	-
29-aug-03	2029	1731	4,5	19.6	10	2,2	3	-
29-aug-03	1845	1721	4,5	23.8	50	11,1	2	-
29-aug-03	1945	1717	6,5	23.8	90	13,8	2	yes
30-aug-03	1939	1710	6	24.4	15	2,5	3	yes
30-aug-03	1926	1712	3,5	25.4	200	57,1	2	-
30-aug-03	1923	1711	3,5	25.5	10	2,9	3	-
31-aug-03	1954	1731	5	22.3	70	14,0	2	-

SCH54

	N	W	dur	temp	ton	CPH	cat	by-catch
13-okt-02	2043	1738	1,75	19,9	70	40,0	2	-
13-okt-02	2041	1741	4,00	20	35	8,8	2	yes
13-okt-02	2032	1734	3,75	19,3	30	8,0	3	-
13-okt-02	2029	1739	4,00	.	0	0,0	3	yes
14-okt-02	2022	1738	4,58	19,4	35	7,6	3	-
15-okt-02	1915	1653	6,00	21,4	35	5,8	3	yes
15-okt-02	1854	1624	8,50	21,9	15	1,8	3	yes
15-okt-02	1813	1619	2,00	24,4	0	0,0	3	yes
16-okt-02	1713	1628	4,50	24,6	75	16,7	2	-
16-okt-02	1711	1631	13,00	24,5	0	0,0	3	-
16-okt-02	1709	1628	4,17	25	30	7,2	3	-
17-okt-02	1729	1620	3,42	23,9	0	0,0	3	-
17-okt-02	1839	1629	7,58	23,8	30	4,0	3	yes
18-okt-02	1838	1628	7,75	23,7	20	2,6	3	-
18-okt-02	1810	1634	9,33	23,8	2	0,2	3	-
19-okt-02	1914	1647	5,00	22,4	40	8,0	3	-
19-okt-02	1915	1649	8,83	21,4	40	4,5	3	yes
19-okt-02	1916	1647	5,00	21,1	60	12,0	2	-
20-okt-02	1912	1644	1,58	21,1	180	113,7	1	-
20-okt-02	1921	1649	4,75	20,8	50	10,5	2	-

SCH302

	N	W	dur	temp	ton	CPH	cat	by-catch
14-nov-02	2043	1739	3	21.3	3	1,0	hm 3	-
15-nov-02	1847	1641	3,25	-	16	4,9	hm 3	-
15-nov-02	1858	1647	6	-	10	1,7	hm 3	yes
16-nov-02	1858	1648	5	24	8	1,6	hm 3	yes
17-nov-02	1842	1643	5,25	20.0	8	1,5	hm 3	-
17-nov-02	1843	1637	4,5	21	25	5,6	hm 3	yes
18-nov-02	1845	1634	4	21.1	3	0,8	hm 3	yes
18-nov-02	1841	1634	3,75	21.7	3	0,8	hm 3	-
18-nov-02	1841	1639	3,75	22.4	6	1,6	hm 3	-
19-nov-02	1844	1634	3,75	22.4	3	0,8	hm 3	-
20-nov-02	2044	1731	5	18.3	50	10,0	pe 2	-
20-nov-02	2034	1733	3	18.3	45	15,0	pe 2	-
21-nov-02	2043	1730	1,5	17.6	40	26,7	pe 2	-
21-nov-02	2040	1730	3,25	18.3	1,5	0,5	pe 3	-
21-nov-02	2038	1724	2,25	18.0	40	17,8	pe 2	-
21-nov-02	2040	1724	1,75	17.8	25	14,3	pe 2	-
22-nov-02	2044	1726	2	18.1	60	30,0	pe 2	-
22-nov-02	2043	1722	1	17.2	40	40,0	pe 2	-