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AN ASSESSMENT OF THE RELIABILITY OF FOSSIL PILCHARD AND ANCHOVY SCALES AS FISH POPULATION INDICATORS OFF NAMIBIA

by

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A thesis submitted in fulfilment of the requirements of the degree of Master of Science

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ABSTRACT

Fossil fish scales hold potential for ellucidating past fish population fluctuations. A system of classification for scales from the pilchard, Sardinops ocellata, and the anchovy, Engraulis capensis, is presented. Both species show an unexpected range of scale types. The classifications reduce errors in distinguishing between the scales of the two species to ±2,5%.

Scale loss from these fish is quantified under laboratory conditions. Pilchard lose 1,56 scales/fish/day due to death and 1,50 scales/fish/day due to deciduousness over their expected lifetimes. For anchovy the figures are 2,42 scales/fish/day (death) and 0,48 scales/fish/day (deciduousness). Application of these scale-loss studies to scales preserved in the anaerobic sediments off Walvis Bay, Namibia, shows that deciduousness is the dominant process contributing scales to the sediments.

This basic information on pilchard and anchovy scale loss is used to interpret counts of scales in the laminated interval of a core taken from the diatomaceous muds off Walvis Bay. This pilot study shows that: i) the Namibian Fishery was dominated by pilchard in the past as it was prior to the collapse in the early 1970's and, because of this, is distinctly different from the anchovy/anchovetta-dominated east Pacific systems; and ii) major pre-fishery stock fluctuations do appear to be reflected in the sedimentary record. Further scale studies on larger sediment samples are recommended to ellucidate the Namibian fish stock fluctuations.

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CHAPTER I

INTRODUCTION

"Fisheries scientists have been intrigued with the boom and bust phenomenon that characterizes many fisheries, but is particularly exemplified by the clupeoid fisheries" (Lasker and MacCall 1983, p 110).

This thesis presents a critical assessment of the application of fossil fish scale studies to gain an insight into these population fluctuations.

I.1. BACKGROUND

Clupeoid fish - pilchard, sardine, anchovy, herring, etc, achieve huge populations with biomasses of millions of tons which have been heavily exploited. Figure I.1 shows the catches of clupeoid fish in different parts of the world. Rapid declines in these fish populations have occurred (see Figure I.1, Peruvian anchovetta, North American Pacific coast sardine, Japanese sardine, North Atlantic herring, Namibian pilchard). These declines have been attributed to overfishing, but this has not yet been proven. Just as collapses of fish stocks have occurred, so have rapid recoveries been documented (see Figure I.1 the Japanese pilchard and the Chilean sardine for example). An enormous amount of fisheries research effort all over the world has gone into trying to understand these fluctuations. The studies have been hampered by the short data sets available and the virtual lack of data from the period before fishing commenced.

In 1967 Andrew Soutar, stimulated by Prof John D Isaacs, at Scripps Institution of Oceanography broke through the barrier of the limited historical data sets. He reported on the downcore distribution of fish scales in certain Californian coastal sediments. The main purpose of his paper (Soutar 1967, p 136) was "to point out the existence of material which could allow the introduction of a relatively long time-perspective into the character of the fisheries and oceanographic conditions off California".

In this first paper he describes the unusual anoxic conditions at the bottom of the Santa Barbara Basin which allow fish debris to accumulate undisturbed by benthic burrowing organisms and unaffected by aerobic bacterial decomposition. He points out that the slowly accumulating sediments form an excellent framework for the study of ocean history and presents plots of the numbers of Pacific sardine, northern anchovy and Pacific hake scales found in 1 cm slices of his cores. Hake scales were by far the most abundant and Pacific sardine the least abundant. The sardine scales were concentrated at certain levels of the core. Soutar took this to be a reflection of periodic changes in abundance of the sardine. The hake and anchovy populations, as inferred by scale counts, remained more constant.

The ideas presented in the 1967 paper were further developed in 1969 in a paper entitled "History of fish populations inferred from fish scales in anaerobic sediments off California" by Soutar and Isaacs. In considering the unique oceanographic environment which encourages the preservation of fish debris, they point out the link between regions of upwelling and the accumulation of anaerobic sediments. Nutrient-rich upwelled waters support vast blooms of plankton. The decompositon of this organic matter depletes the bottom water of oxygen and anaerobic, often highly stratified sediments accumulate. The authors analyze in detail a 2,5 m long, 7,6 cm diameter piston core taken at a depth of 585 m in the central Santa Barbara Basin. They derive estimates of numbers of sardine, anchovy and hake over the last 2000 years. They found cyclic occurrences of sardine with peaks occurring at about 80 year intervals (but ranging from 20 to 200 years). Anchovy fish numbers were consistently higher and non-cyclic, but showed an overall decrease over the last 1 500 years.

In a paper in 1971 Soutar considered the sedimentology and micropalaeontology of these anaerobic sediments, emphasizing their value as repositories of a wealth of information about the past which has relevance to the present and future. In his paper with Crill (Soutar and Crill 1977) he developed this theme, integrating all available environmental and palaeontological information to achieve a greater understanding of these valuable marine sediments.

The most significant paper published on the use of scales in the sediment as past fish population indicators is the 1974 paper by Soutar and Isaacs, "Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment off the Californias". Described by Lasker and MacCall (1983, p 112) as "an elegant palaeoecological investigation" this study actually provides biomass estimates of sardine, anchovy and hake for the past 200 years. They compare the character of the pelagic fish abundance in two regions, the Santa Barbara Basin and the Soledad Basin. The former shows a cyclical variation and the Soledad Basin a unique event distribution. Overall they estimate that major pelagic fish productivity declined markedly after 1925.

Following on the pioneering research of Soutar and Isaacs, De Vries and Pearcy (1982) used fish debris preserved in laminated sediments on the upper continental slope off Peru to reconstruct a history of Holocene fishes. As off the Californias, they found anchovy/anchovetta dominating the system. Hake were common and sardine present only sporadically. They associated periods of sardine abundance with incursions of warmer water (as determined from the microfossils). Unexpectedly these occurred during periods of glacial and neoglacial advance indicating a complex response of the upwelling to glacial cooling. They estimated that prior to exploitation the anchovetta standing stock off Peru was about five times that of the northern anchovy off California.

In 1980 Thomas at the Sea Fisheries Research Institute proposed that a fish-scale study be attempted in the diatomaceous muds off Walvis Bay. He collected 30 short cores and although he found scales in them, he did not find evidence that the sediments represented an undisturbed sedimentary sequence. He concluded that "our sediments unfortunately do not lend themselves to the determining of pelagic fish cycles" (Thomas 1980, p 3) and Thomas (1982). Meanwhile, as a result of Bremner's comprehensive thesis on the sediments on the continental margin off South West Africa (1978), interest in the anaerobic diatomaceous muds off Walvis Bay was growing amongst the geo-scientists at the University of Cape Town. Evidence for the existence of undisturbed laminated sequences was coming to the fore (Diester-Haas 1978) and, in 1983, Dr R Johnson of the Marine Geoscience Unit proposed that another attempt be made to determine a history of both marine productivity and climate from the sediments off Namibia (Johnson et al 1983).

I.2 THE WALVIS SHELF AREA

Comprehensive descriptions of the geological, physical and chemical environment of the study area (see Figure I.2) have been made by, among others, Bremner (1978), Shannon (1985) and Chapman and Shannon (1985). (Detailed references are to be found in these review articles).

I.2.a The geological environment

The continental shelf off central South West Africa/Namibia is wide and shallow, typically 140 km wide with the shelf break at a depth of 350 m on average. In the Walvis Bay area there are pronounced inner and outer shelf breaks at 140 and 400 m respectively (Siesser, Scrutton and Simpson 1974). Sediments on the Walvis shelf are dominated by an elongated deposit of diatomaceous mud parallel to the coast (Bremner 1978). The western edge of the mud belt is diluted by calcium carbonate and organic matter and inshore there is an increase in terrigenous material, but, over a width of up to 50 km and a length of over 500 km, the muds contain over 88% opal by weight (Bremner 1978). They are thought to have been accumulating since the Flandrian

Transgression after the last lowering of sea level during the Warm II pleni-glacial and have attained a maximum thickness of 15 m (Bremner 1983) over the past 5000 years.

I.2.b The physical environment

The major features of the physical environment of the northern Benguela region are summarized in Figure I.3. Shannon believes that the broad inner shelf in the Walvis Bay region plays an important role in the dynamics of the central Namibian region (Shannon 1985). The interaction of the meteorology, the circulation of the South Atlantic water masses and the topography result in the Namibian shelf being one of the most dynamic upwelling areas in the world. The main upwelling centre is off Luderitz, south of the present study area where the upwelling rate can reach 20-30 m/day (Bremner 1978). Frictional interaction of the south east trade winds causes Ekman transport of the surface waters offshore. Cold, South Atlantic Central Water upwells near to the coast in a zone whose width is dependent on the seasonal variation of the wind. Upwelling reaches a maximum in late winter and spring (Stander 1964) when 16°C water can extend up to 300 km offshore. During summer and autumn the zone of cold, upwelled water contracts and there is an incursion of warm, saline, Angolan and oceanic water which can reach as far south as Walvis Bay (Boyd and Agenbag 1984). During the maximum upwelling season the upper 50 m of water is well mixed and the surface currents are predominantly longshore. Below this is a deep compensation current with perennial southward movement of water periodically characterized by low oxygen concentrations (Shannon 1985).

I.2.c The productivity of the area

The uplifting of the cold, nutrient-rich South Atlantic Central Water into the euphotic zone results in massive plankton blooms (Brongersma-Sanders 1957, Hart and Currie 1960, Eisma 1969). The chemistry of the upwelled water shows it to be oxygen depleted but rich in nitrate, phosphate and silicate (Bailey 1979). These nutrients result in the Walvis Bay area having an extremely high productivity. The phytoplankton rapidly depletes the surface waters of nutrients but re-enriches the waters below the thermocline as decay takes place. Bottom waters are concurrently depleted of oxygen as this rain of organic matter is decomposed and settles on the sea floor to form the organic rich diatomaceous muds described by Bremner (1978, 1983).The resultant near-permanent anoxic conditions near the sea floor render it devoid of any benthic life other than anaerobic bacteria (Eisma 1969)

I.2.d Fish stocks

Not only does this extraordinarily high productivity result in the accumulation of anaerobic organic sediments but it also supports one of the largest fish stocks in the world. A complex food web has grown up as a result of the productivity. This web is summarized by a matrix of important predator/prey interactions in the Benguela ecosystem drawn up by Bergh (1983) (see Table I.1). The small schooling pelagic fish - pilchard (Sardinops ocellata), anchovy (Engraulis japonicus) and maasbanker (Trachurus trachurus) are central in the system, preying upon phyto- and zooplankton, and in turn being eaten by the larger demersal and pisciverous fish.

The Walvis Bay region is where both juvenile pilchard and juvenile anchovy recruit to the fishery. Anchovy spawn inshore along most of the coast of Namibia during the winter. Most of the larvae are found in the warmer waters to the north of Walvis Bay but large shoals of juveniles accumulate in the Walvis Bay area from May onwards. The adults then move northwards out of the area. Although pilchard now appear to spawn off northern Namibia, Walvis Bay was their traditional spawning ground. Larvae would disperse northward towards the Namibian/ Angolan border, but juvenile pilchards recruited to the fishery near Walvis Bay. Adult fish are caught in the vicinity of Walvis Bay (Alant 1983, Thomas 1985). Juvenile maasbanker tend to school with the juvenile pilchard and anchovy, but move offshore as they grow larger (Kompowski and Slosarszyk 1976).

The pilchard catch off Namibia peaked at 1 386,6 thousand metric tons in 1968, thereafter declining rapidly to below 50 thousand metric tons in 1978 (Crawford and Shelton 1978, Alant 1983). To compensate for the loss of pilchard, anchovy were exploited from the early 1970's. The maasbanker catch (and population) has also increased nearly fourfold over this period. Alerted by the collapse of the pilchard (and other clupeoid collapses elsewhere) management advice to the fishery has sought to limit over-exploitation of both the anchovy and the pilchard. Scientists are trying to understand the processes which led to the decline of the pilchard in the expectation that this will contribute towards improving the basis for rational management of the anchovy, and pilchard, if and when it recovers.

I.3 THIS STUDY

Placing these recent drastic pelagic fish stock fluctuations off Namibia into an historical perspective is highly desirable. This has been attempted by analyzing the link between sea-bird guano and pilchard biomass (Crawford and Shelton 1978), but the potential of a Soutar and Isaacs-type fossil scale analysis seems to far exceed what can be extracted from the guano data.

Over the period 1967-1974 the original idea of assuming that fish population fluctuations were reflected in variations in scale abundances in the sediment was developed by Soutar and Isaacs to enable them to give actual biomass estimates for pre-fishery periods. De Vries and Pearcy (1982) also suggested that biomasses be calculated from scale numbers. But how valid are these extrapolations? Coring procedures are such as to limit sample sizes. With pilchard and anchovy scale densities of 10 scales/ 100 ml of sediment (from Soutar 1976) and a 10 cm by 10 cm corer whole populations are being resurrected on the basis of very few scales! Clearly any biases introduced, such as incorrect scale identification or differential scale preservation, will dramatically affect the final biomass estimates.

In the present study area I consider the validity of using a Soutar and Isaacs-type analysis to gain an insight into the past fish populations off Walvis Way. This is approached in two ways:

(i) the processes governing scale loss from the fish and accumulation in the sediment are quantified by means of laboratory experiments in order to make the back calculations from scale counts to fish populations with more confidence;

(ii) the information obtained is applied to scales accumulating in the surface sediments off Walvis Bay (grab samples) and in the laminated section of a core taken in the area.

The basic scale study initially centres around the problem of the correct identification of the scales and a detailed analysis is made of the different types of scales found on different parts of the bodies of both pilchard and anchovy (Chapter II). A flux of scales to the sediment from the death of the fish is calculated but in so doing another process of significant scale loss is discovered (Chapter III). The validity of the findings in Chapters II and III is tested by applying them to scales found in grab samples taken from the diatomaceous muds off Walvis Bay (Chapter IV). However, relating scale count fluctuations to different time periods is only possible when the sediments in which they have accumulated are undisturbed and hence Chapter V looks in more detail at the laminations which have been found in the anaerobic sediments. In Chapter VI a detailed analysis is made of the scale counts over a 27 cm laminated interval in a core taken off Walvis Bay. This gives a fascinating glimpse into pre-fishery pilchard and anchovy population fluctuations. The contribution of the basic scale studies to the application of the Soutar and Isaacs technique is summarized in the final chapter. From the application of the technique (with the relevant corrections applied) to even a small sediment sample several significant facts about the fish stocks off Walvis Bay have emerged. We are now nearer to providing the fisheries scientists with the data sets they require to understand the clupeoid "boom and bust" phenomenon.

	1. Phytoplankton	2. Bacteria	3. Zooplankton	4. Pilchard	5. Anchovy	6. Mackerel	7. Maasbanker	8. Other shoaling fish	9. Squid	10. Hake	11. Pisciverous fish	12. Seals	13. Marine mammals	14. Sea birds
1. Phytoplankton		X	X	X	X									
2. Bacteria		X	X											
3. Zooplankton		X	X	X	X	X	X	X	X	X	X			
4. Pilchard		X				X			X		X	X	X	X
5. Anchovy		X				X			X		X	X	X	X
6. Mackerel		X				X			X	X	X	X	X	X
7. Maasbanker		X				X			X	X	X	X	X	X
8. Other shoaling fish		X				X			X	X	X	X	X	X
9. Squid		X				X			X	X	X	X	X	X
10. Hake		X				X			X	X	X	X	X	X
11. Pisciverous fish		X									X	X	X	X
12. Seals		X									X			
13. Marine mammals		X												
14. Sea birds		X												

Table I.1 A matrix of important predator - prey interactions in the Benguela Ecosystem (after Bergh 1983)

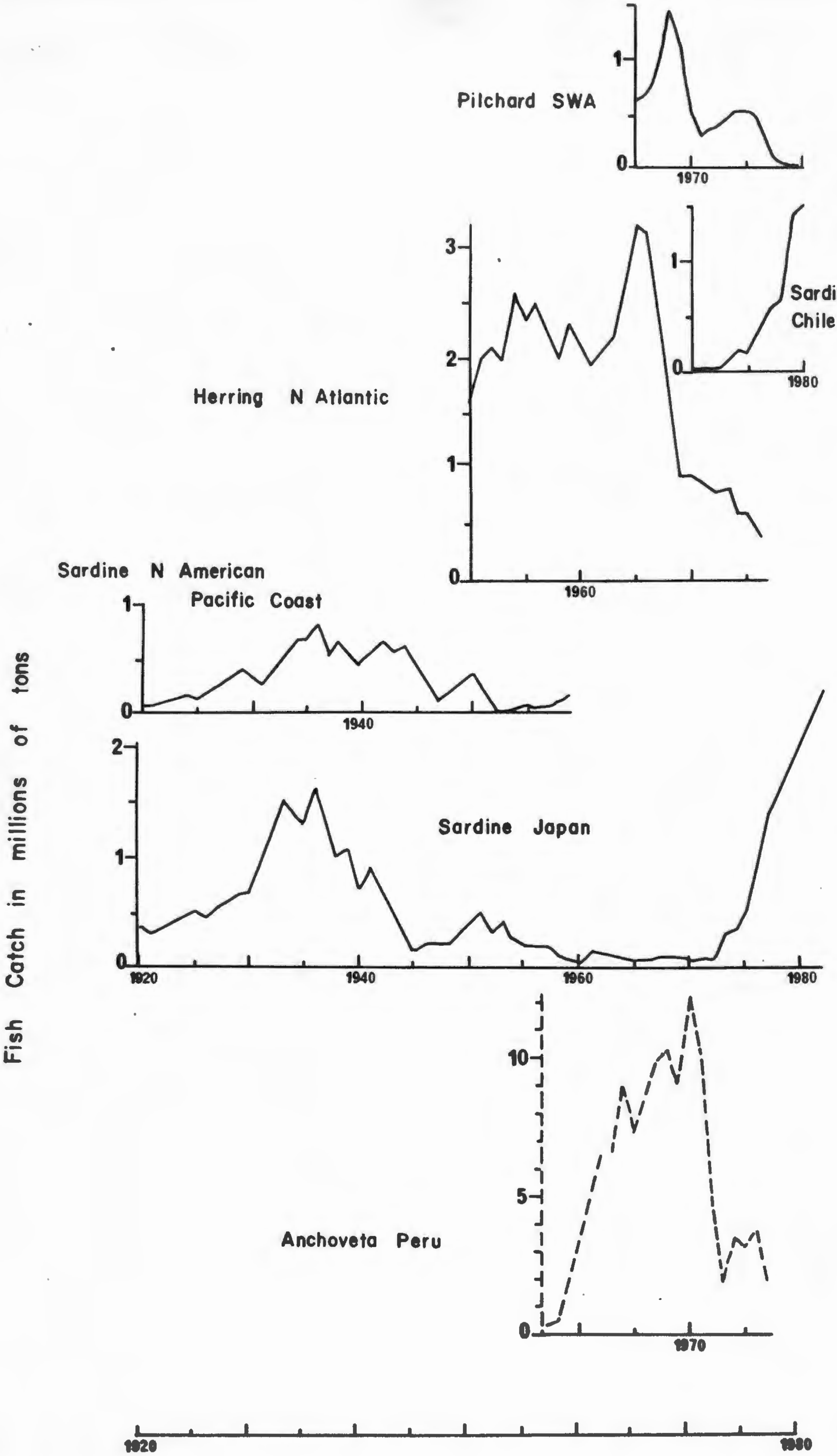

Figure I.1 Clupeoid fish catches in different parts of the world (after Lasker and MacCall 1983). The SWA data was obtained from Alant 1983.

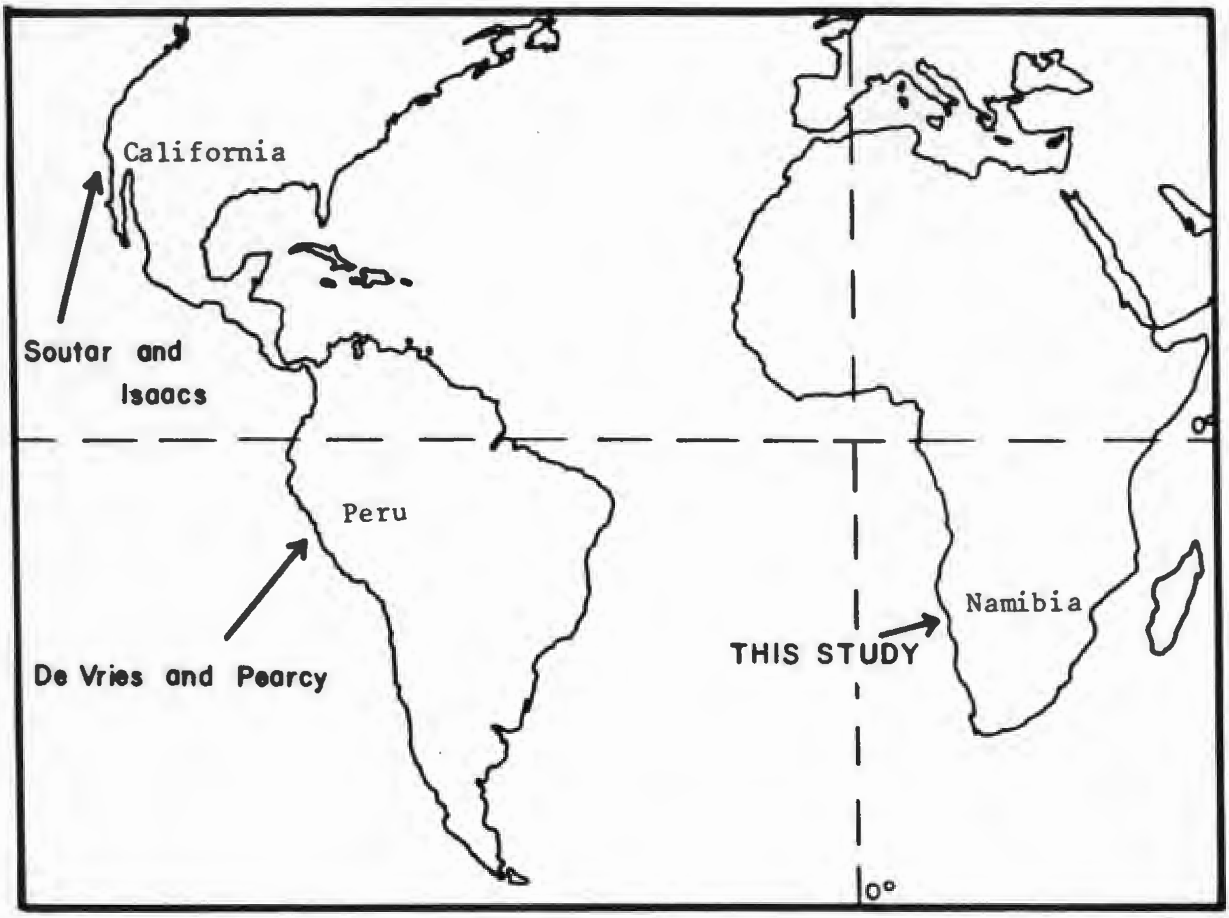

Figure I.2 **The location of the present study area.** The areas in which previous fossil scale studies have been carried out are also indicated

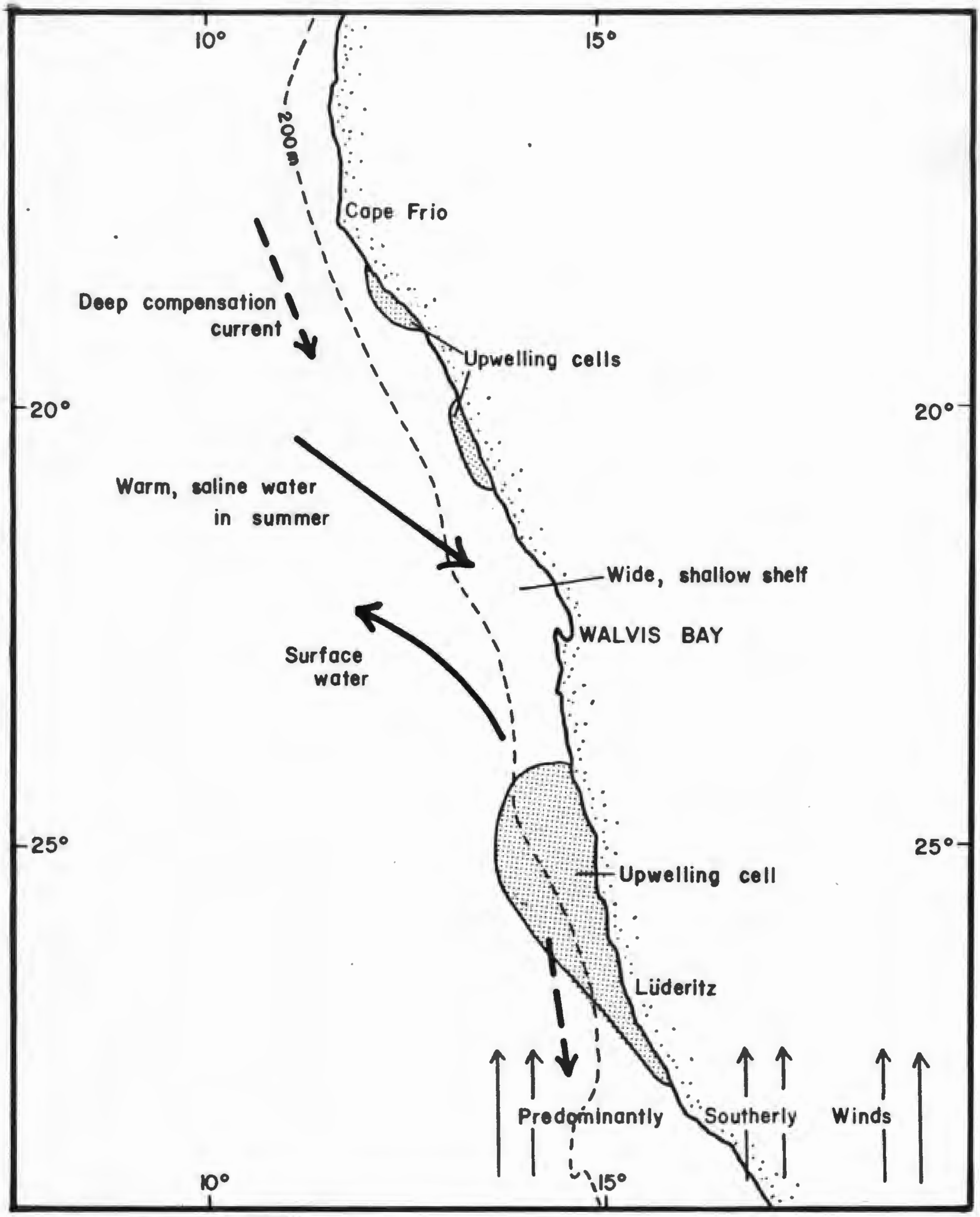

Figure I.3 Summary of the major features of the Northern Benguela region (after Shannon 1985)

CHAPTER II

SCALE IDENTIFICATION

II.1. INTRODUCTION

References to fish scales in the literature concentrate on their application to ageing techniques. Scales are assumed to be species specific and cursorarily there appears to be little problem in identifying the fish from which the scales found in the sediment off Namibia come.

Of major interest to this study is the occurrence of pilchard and anchovy scales in the sediment and the relationship, if any, they bear to each other. Soutar (1966) identified his scales by comparison with a reference collection. De Vries and Pearcy (1982) refer to this same reference collection. In neither case is there any suggestion that there might be a problem with identification. Photographs of pilchard and anchovy scales are to be found in the literature, eg Soutar (1971), Miller (1955), Nawratil (1961) and Davies (1958). These show the typical scales depicted in Figure II.1. Verbal communication with fisheries scientists indicated that there was no problem in distinguishing between pilchard and anchovy scales. Pilchard scales were recognized to be rectangular with deep, regular radii and a straight wing join. Anchovy scales on the other hand were more rounded, irregularly cracked and had a curved wing join. (Figure II.2 shows the terms I have used in describing clupeoid scales).

Initially I based my scale identification on these typical scales. However, experience showed that these two apparently distinct types of scales were the two extremes of a gradation. Identifying any other than the very characteristic scales with any reasonable degree of certainty was impossible. A half to a third of the scales could not be positively identified. Before the study could proceed further it was essential to obtain a more rigorous method of scale identification.

I attempted to determine distinguishing features under a low-power binocular microscope and, at the other extreme, under the electron microscope. Both methods only showed up the overlapping wide variety of scales within each species. Handling the scales gave a distinct impression that they differed in thickness and this was used as a basis for determining methods of differentiating between them. Use of transmitted light highlighted and intensified structures on the scales and indicated that a further detailed microscope study might be valuable. A reference set of photographs of all the scales from one side of both an anchovy and a pilchard were compiled and analysis of these has led to an acceptable way of identifying the scales.

II.2. METHODS

Pilchard and anchovy were obtained from the fish-rearing tanks at the Sea Fisheries Research Institute. Dead fish were preserved in formalin and scales taken from them were stored in a solution of 50% distilled water and 50% absolute alcohol.

II.2.a. Thickness

Initial experience indicated that pilchard and anchovy scales might be distinguished on a basis of thickness, pilchard scales seeming sturdier than the more flimsy anchovy scales. I chose scales from each type of fish at random and, when wet, measured their thickness using a micrometer screw gauge.

II.2.b. Settling velocity

An experiment was carried out to determine whether the difference in settling velocity between the two types of scales could be used as a means of distinguishing between them. (Figure II.3).

Well wetted scales were released below the surface of water at constant temperature in a large graduated measuring cylinder. Care was taken that all turbulence in the cylinder had ceased before releasing each scale. Once a sinking scale had reached a steady terminal velocity I recorded the time taken for it to drift through a measured distance. The longest dimension and that at right angles to it were measured using a centimetre rule.

II.2.c. Reference photographs

A system of rapid visual identification seemed preferable to the above finicky and time-consuming methods of distinguishing between the two types of scales. 'Typical' pilchard and 'typical' anchovy scales could already easily be identified on sight. By illuminating the scales with transmitted rather than reflected light much greater detail became evident. I now attempted to determine what proportion of the total scales were 'typical' and whether there was any way of distinguishing between the atypical scales of each species.

Scales were systematically pulled off one side of both an anchovy and a pilchard, row by row, head to tail. These scales were mounted between strips of acrylic sheet 20 cm long and 2,5 cm wide. The scales had to be kept moist during the mounting to prevent curling on drying, but dried out flat after being pressed between the strips for about 24 hours. The strips were then glued together for permanence and ease of handling. Each scale was then photographed in order using a Nikon 35 mm camera mounted on a microscope. Limited aperture back lighting was used and distinctive features of the scales were found to show up best when the aperture of the light was just smaller than the scale itself. The black and white contact prints made from the 35 mm film strips were numbered and formed an easily accessed reference set of photographs for analysis.

II.3. RESULTS

II.3.a. Thickness

The measured thicknesses of the pilchard and anchovy scales are plotted on the histograms in Figure II.4.

Thickness was measured to an accuracy of 0,005 mm for 22 randomly chosen pilchard and 20 anchovy scales of different sizes. All the anchovy scales were thinner than 0,4 mm whereas only 22% of the pilchard scales measured were. Pilchard scales showed a greater variety of thicknesses, ranging from 0,24 - 0,89 mm but with a mean of 0,53 mm. 85% of the anchovy scales on the other hand were between 0,15 and 0,29 mm thick.

II.3.b. Settling velocity

Within falling 4 cm after being released in the settling tube the scales adjusted to moving smoothly through the water presenting their flat surface to the direction of motion. I first assessed the repeatability of the method by timing the same scale falling through the measured distance 13 times. The results are presented in Figure II.3.b.

All the measurements were evenly distributed within a four second range over an average time of 21,5 sec giving a maximum error from the average as ±2,5 seconds. Over the distance this translates to a velocity error of ±0,15 cm/sec. The results obtained from timing the fall of seven anchovy and seven pilchard scales of different sizes through 31,8 cm are listed in Table II.1. Spot checks were made on repeatability and the results for these scales are averaged to give a single reading on the table.

Pilchard and anchovy scales were clearly seen to settle at different velocities. Consideration of the physics involved shows that this is another reflection of their differing thicknesses.

Consider a scale with a surface area 'a' and density 'ρ' falling at a constant settling velocity, V, through water with a density 'ρ_ω' and a viscosity 'μ_ω'. Let t be the thickness of the scale parallel to the direction of movement.

As there is no acceleration the forces on the scale balance and

. Drag + buoyancy = weight of scale

$$D + at\rho_\omega g = at\rho g \qquad \text{(Eqn i)}$$

where D is drag
g is gravitational constant

From Binder (1955), Chapter II,

$$D = C_D \tfrac{1}{2} \rho_\omega V^2 a \qquad \text{(Eqn ii)}$$

where C is drag coefficient

For small Reynold's numbers (R_n less than 10^2)

$$C_D = \frac{24}{R_n} \qquad \text{(Binder 1955 Chapter 11)}$$

But the Reynold's number for a scale falling through water can be calculated

$$R_n = \frac{\rho_\omega V d}{\mu_\omega}$$

For water $\rho_\omega = 1$ gm.cm^{-3}
$\mu_\omega = 0{,}012$ gm.cm^{-1}.sec^{-1}
d = cross-flow diameter of disc

(Binder 1955)

Taking two extremes from the results in Table II.1,

Case 1	Case 2
Settling velocity:	
$V = 0{,}5$ cm.sec^{-1}	$V = 1{,}5$ cm.sec^{-1}
Diameter:	
$d = 0{,}4$ cm	$d = 0{,}6$ cm
$Rn = \frac{1 \times .5 \times .4}{0{,}012}$	$Rn = \frac{1 \times 1.5 \times .6}{,012}$
$= 16{,}6$	$= 75$

The Reynold's number for falling scales is low enough for Stokes Law to apply (Binder 1955)

So from Eqn ii above

$$D = \frac{24}{\rho_\omega Vd} \cdot \mu_\omega \cdot \tfrac{1}{2} \rho_\omega V^2 a$$

$$= 12 \mu_\omega V \cdot \frac{a}{d}$$

$$= atg(\rho - \rho_\omega) \qquad \text{(from Eqn i)}$$

$$V = \frac{tdg(\rho - \rho_\omega)}{12 \mu_\omega} \qquad \text{(Eqn iii)}$$

ie for scales of the same diameter perpendicular to the direction of motion,

$$V \propto t(\rho - \rho_\omega)$$

The thickness of pilchard and anchovy scales has been experimentally determined and by substituting these thicknesses in Eqn ii values for the density of pilchard and anchovy scales can be calculated and seen to be almost identical (to within 0,003 gm/cm^3). The difference in thickness between the pilchard and anchovy scales thus accounts for the difference in the settling velocities of scales with the same area perpendicular to the direction of motion.

A plot of scale 'diameter' (determined by halving the sum of the length of the scale and the width perpendicular to this length) against settling velocity for pilchard and anchovy scales is given in Figure II.5. The lines for pilchard and anchovy both theoretically go through the origin but have different slopes dependent on the scale thickness.

II.3.c. Reference photographs

A total of 567 pilchard and 354 anchovy scales were photographed. This was as close to the full complement of scales on one side of each fish as was possible to obtain - small scales near the tails of the fishes were almost certainly missing. (The fish were assumed to be bilaterally similar). A detailed analysis could now be made of the appearance of the scales and the relationship between type of scale and its position on the fish. Properties which were considered were:

- size
- shape
- wing join
- position of cracks/radii
- appearance of cracks/radii
- number of cracks
- scale margin
- apparent thickness as determined by translucence and apparent depth of cracks.

An initial attempt was made to find features common to all the photographed pilchard scales yet distinct from the anchovy scales. The pilchard scales seemed to transmit less light, giving a general impression of being thicker than anchovy scales but this property was difficult to quantify on the photographs. Only one feature seemed common to almost all the pilchard scales and not the anchovy scales - the outer margin of the scale wing was crenulated whereas the margin of the rest of the scale was smooth. Distinctive as this is, its application is limited to scales with wings still attached. Wings are easily detached when the scale is subjected to mechanical abrasion in the sediment or the laboratory.

Detailed analysis of the photographs of pilchard and anchovy scales are considered separately below.

i) Pilchard

With as much precision as possible scales were removed from 12 lateral rows, head to tail on one side of the pilchard. A breakdown of the number of scales per row provided a check on the success of sampling one row at a time.

	Dorsal											Ventral
Row	1	2	3	4	5	6	7	8	9	10	11	12
No. of scales	52	44	41	38	57	45	54	53	55	51	35	42

The low count in row 11 is indicative of difficulty in separating out the scales from the ventral rows.

Six major distinctive types of scale were identified.

1. <u>T-scales</u> (Figure II.6.a)

   These are 'typical' pilchard scales having a regular rectangular shape and deep regular radii radiating out from the axis of the scale. The wing join is a straight line. Size can vary from 2 mm - 7 mm long on same fish.

2. <u>C-scales</u> (Figure II.6.b.)

   These are similar to T-type scales but less perfect in some or all respects. Shape varies from rectangular to more square, the radii are less regular and do not radiate as clearly from the axis. The wing join is curved on one or both sides of the axis. Size is variable.

3. <u>S-scales</u> (Figure II.6.c)

   These are square in shape or elongated at 90° to the usual pilchard scale long elongation. Their most distinctive feature is deep cracks pseudo-parallel to the axis of the scale but seeming to radiate from the centre of the wing join. Size is variable.

4. T/S or C/S-scales (Figure II.6.d)

One half of these scales resembles a C or T scale, the other half an S-scale. On one side of the scale the cracks are parallel to the axis, on the other they are regular, radiating pilchard cracks. Size is variable.

5. t-scales (Figure II.6.e)

These are tiny scales, < 3 mm long and are anomalously shaped and cracked.

6. x-scales

These are anomalous scales not fitting into any of the above categories.

Finally, distinctive variations of the above types were found at specific locations on the fish, seemingly so as to form a neat fit against fins or along the central line. These variations represent ½ and 3/4 scales of the types listed above.

Sizes of the T, C, S and T/S scales on a pilchard of caudal length 16,0 cm varied from 3 mm - 7,5 mm. Smaller scales are found near the tail.

The relative proportions of the different types of scale on the pilchard are summarized below:

Pilchard scale type	Percentage of total scales
T	34
C	20
S	19
T/S, C/S	11
t	10
x	4

ii) Anchovy

354 scales were removed from one side of an anchovy along nine rows.

Dorsal Ventral

Row	1	2	3	4	5	6	7	8	9
No. of scales	52	16	44	39	38	40	38	40	47

The paucity of scales in row 2 is due to their being mistakenly sampled as row 1. Small scales from near the tail in rows 1 and 2 were missing.

A study of the photographs showed that although anchovy scales varied with respect to size, shape and cracks, on the whole they appeared to be more uniform than pilchard scales. Sizes of scales from a 12,4 cm caudal length anchovy varied from less than 2 mm to 7 mm, but the majority were between 5 and 7 mm long. (Miller (1955) noted a similar lack of range of sizes of Engraulis mordax scales in comparison with those of the Pacific sardine). Seven main categories of scales were recognized.

1. Y-scales (Figure II.7.a)

These are oval to rectangular and cut by deep cracks down the axis. Some cracks are present near the wing join and on the wing, but the 'shoulders' of the scales are uncracked. They are usually 5-7 mm long.

2. X-scales (Figure II.7.b)

These are rounded to square in shape with deep cracks down the centre and cracks coming in from the margin all around the scale. They are 5-6 mm in size.

3. S-scales (Figure II.7.c)

These are usually elongated at 90° to the normal anchovy scale elongation. They are cut through by unbroken, wiggly cracks semi-parallel to the axis of the scale. The size is variable.

4. R-scales (Figure II.7.d).

These vary in shape and size but have a marked ring parallel to the margin within the scale. This ring often forms the limit of cracks radiating in from the edge of the scale.

5. L-scales (Figure II.7.e).

These scales are usually small and are latticed with intersecting cracks. The shape is variable.

6. t-scales (Figure II.7.f).

These are tiny scales, 3 mm long, anomalously shaped and cracked.

7. x-scales

These are anomalous scales not fitting into any of the above categories.

The relative proportions of these types of scales are summarized below:.

Anchovy scale type	Percentage of total scales
X	29
Y	18
R	17
S	14
L	13
t	5
x	4

II.4. DISCUSSION

Pilchard and anchovy scales are easily distinguished from the other scales likely to be found in the sediments off Namibia. However, distinction between the scales of these two species is not as straightforward as originally assumed. Different methods of distinguishing between the scales are compared below and a detailed analysis of the recommended method follows.

II.4.a Comparison of methods

Identification based on shape and radii was inconclusive for a large number of scales studied under a low-power binocular microscope. Use of transmitted rather than reflected lighting showed up two properties that could possibly be used to distinguish between pilchard and anchovy scales. The first was dependent on the scale wing being present and therefore was of limited application. The second, evident both in handling the scales and by their transmission of light, was an apparent difference in the thickness of the scales of the two species.

Direct measurement of the thickness of scales provides a reasonable means of distinguishing between scales. Anchovy scales were all thinner than 0,4 mm, having an average thickness of 0,21 mm. Pilchard scales showed a wider range of thicknesses, but over 78% of the pilchard scales measured were thicker than 0,4 mm. Some confusion is still possible for scales in the 0,3 - 0,4 mm thick range, and this, combined with the fact that the method was finicky and potentially liable to crack the more brittle and phosphatized scales found in the sediment led to my discarding it as the principal way of identifying scales.

Distinction on the basis of settling velocity has potential. Mixed pilchard and anchovy scales could first be divided into two size categories to separate the large anchovy scales from the small pilchard scales which fall at similar velocities.

The velocity V' above which all falling scales in a given size category are pilchard can be read off the experimentally determined graph in Figure II.8 and converted to time over a suitable distance. Similarly V" can be used for distinguishing between smaller pilchard and anchovy scales.

The major problem with this method is the rapid determination of 'diameter'. Direct measurement is time-consuming, but a sieve-based sorting method is complicated by the presence of elongated scales with one short and one much longer axis.

The detailed photographic study of the scales of pilchard and anchovy in transmitted light has given sufficient information about the different types of scales on each species to enable the majority of scales to be correctly identified. Familiarity with all the types of scales on the fish combined with reference to the photographs seems to be the best method for distinguishing between the scales of the two species. This recommended method is analyzed in more detail.

II.4.b Reference photographs

Both pilchard and anchovy have a certain proportion of unequivocally distinctive scales. On the pilchard these are the T-type scales and on the anchovy the Y-type scales. T-scales account for 34% of pilchard scales and Y-scales for 18% of anchovy scales. Their distribution on the fishes and the relation to the other types of scales is shown in Figures II.9 and II.10.

With the exception of the R-scales, the different scale types plot on clearly defined areas of the fish. R-scales are randomly scattered over the body of the anchovy. Because of this they are not considered to be a distinctive type of scale such as the other categories are, but a product of the experimental procedure. Some scales proved difficult to pull off the fish. Scales are attached to the dermis of the fish by two different structures, denticles and collagen fibres, located on the upper surface of the scale (Zylberberg and Meunier 1981). (The denticles can be seen on the electron micrograph of the surface of an anchovy scale (Figure II.11).)

Pulling at a firmly attached scale could result in bending and cracking of the unattached part of a thin scale. In this way an X or Y-type anchovy scale would become a superficial R-type. R-scales should not be found in the sediment as a result of death or natural deciduousness* and so will be corrected for in the data collected on anchovy scales. (The correction has been applied with reference to Figure II.10, replacing R-scales by the type of scale expected in that location). The percentage of different scale types on the anchovy then becomes:

Anchovy scale type	Percentage of total scales
X	38
Y	24
S	15
L	13
x	5
t	5

Y- and T-scales

These scales represent the 'typical' scales on each species and make up 34% and 24% of the total scales respectively. Their identification presents no problems.

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*None have been found in the course of this study

S-scales

Very similar S-type scales are found on both species. In the pilchard these account for 19% of the scales and are found mainly along the dorsal part of the fish, posterior to the dorsal fin and near the tail. On the anchovy they are found near the dorsal and ventral fins and account for 15% of the scales. Comparison between the S-scales on each type of fish enables them to be distinguished on the basis of the uninterrupted continuation of the parallel cracks over the wing join. The cracks on the pilchard scales tend to focus in and become discontinuous over the wing join whereas those on the anchovy might be funnelled together slightly over the join, but carry on unbroken.

Combined with assessing the quality of the cracks, anchovy cracks being finer and wigglier than pilchard, this virtually eliminates the error in distinguishing between the S-scales from each species.

t-scales, x-scales

The t-scales from each fish, ie those less than 3 mm in length are often indistinguishable. 10% of pilchard scales counted and 5% of anchovy scales fitted into this group (although in reality they probably form a greater proportion on a healthy fish as these are the scales found nearest the tail and the scales shown by experience to be most easily shed). The x-type scales on each fish are similarly indistinctive and impossible to assign to any type or species. They form a further 5% on the anchovy and 4% on th pilchard.

T/S, C/S ½ and 3/4 scales

These are all found exclusively on the pilchard and should be identified with reference to the photographs if necessary.

L-scales

These scales with an intersecting lattice work of cracks are found on both species. On the pilchard they are all tiny, less than 3 mm and are grouped with the t-scales. About half of those counted on the anchovy were larger than 3 mm and as such form a distinctive group.

C-and X-scales

The C-type and X-type scales have probably resulted in the most significant confusion between the scales of the two species. As stated in section II.3.c, the C-type scales range from relatively minor variations on T-scales to scales which could easily be identified as anchovy X-type. In deciding between them the most indicative features are the wiggliness of the cracks and the presence of a marked group of central cracks typical to X scales. Figure II.12 shows the similarity between certain pilchard and anchovy scales.

Despite comparison with the reference photographs an error in identification of 5% of pilchard C-scales for anchovy scales and 5% of anchovy X-scales for pilchard scales should be expected.

This discussion is summarized in Table II.2 which considers the identification of the scales from two fish, one a pilchard and the other an anchovy.

An 80% correct identification of all the scales is now possible. The major error is due to the difficulty in identifying the small scales ($<$ 3 mm long). If the small scales are not used for identification purposes, the error is reduced to ±2,5%. (The small scales can be corrected for later to obtain a better absolute count of scale numbers).

The significance of having achieved this degree of accuracy in distinguishing between pilchard and anchovy scales becomes evident when the possible consequences of a less rigorous classification are looked at. Indications from the literature are that previous identifications were based on 'typical' looking pilchard scales. All other scales would be considered to be anchovy. Table II.3 quantifies the possible errors.

Scale identification would only be 60% accurate with a heavy bias towards anchovy. 45% of pilchard scales would be identified as anchovy scales. This error is compounded - pilchard are underestimated by 45% and anchovy overestimated by 70% (anchovy have fewer scales). This could possibly be a contributing factor to the predominance of anchovy scales found in the sediments by Soutar (1967), Soutar and Isaacs (1969, 1974) and de Vries and Pearcy (1982).

Pilchard			
Size	'Diameter'	Time	Velocity
cm	cm	sec	cm/sec
*.65x.59	0.62	21	1.48
.61x.60	0.60	22	1.45
*.57x.55	0.56	21	1.52
.60x.50	0.65	22	1.45
.50x.55	0.52	22	1.45
.40x.49	0.44	32	1.00
.35x.28	0.31	40	0.80

Anchovy			
Size	'Diameter'	Time	Velocity
cm	cm	sec	cm/sec
.67x.65	0.66	36	0.88
.71x.60	0.65	35	0.91
*.70x.60	0.65	32	1.00
.65x.63	0.64	37	0.86
*.61x.60	0.60	45	0.71
*.50x.41	0.45	52	0.61
.40x.40	0.40	58	0.55

*These measurements represent means for multiple readings on the same scale

Table II.1. **Results of settling velocity experiment**

	Scale type	No. of scales correctly identified	No. of scales unidentifiable	Estimated error
	T	374	-	
	C	209	-	11
Pilchard	S	209	-	
Total 1100	T/S	121	-	
	t	-	110	
	x	-	44	
	Y	168	-	
	X	253	-	13
Anchovy	S	105	-	
Total 700	L	46	45	
	t	-	35	
	x	-	36	
100%		82,5%	15,0%	2,5%

Table 11.2. Best possible identification (based on reference photographs) of all the scales from an anchovy and a pilchard

	Scale type	No. of scales correctly identified	No. of scales unidentifiable	Estimated Error
Pilchard Total 1100 scales	T	374	-	
	C	100	-	120
	T/S	-	-	121
	S	-	-	209
	t	-	110	
	x	-		44
Anchovy Total 700	Y	168	-	
	X	266	-	13
	S	105	-	
	L	46	45	
	t	-	35	
	x	35		
		61%	10%	29%

Table II.3. **Quantification of errors in identifying the scales from an anchovy and a pilchard if identification of pilchard scales is based on "typical" scales only**

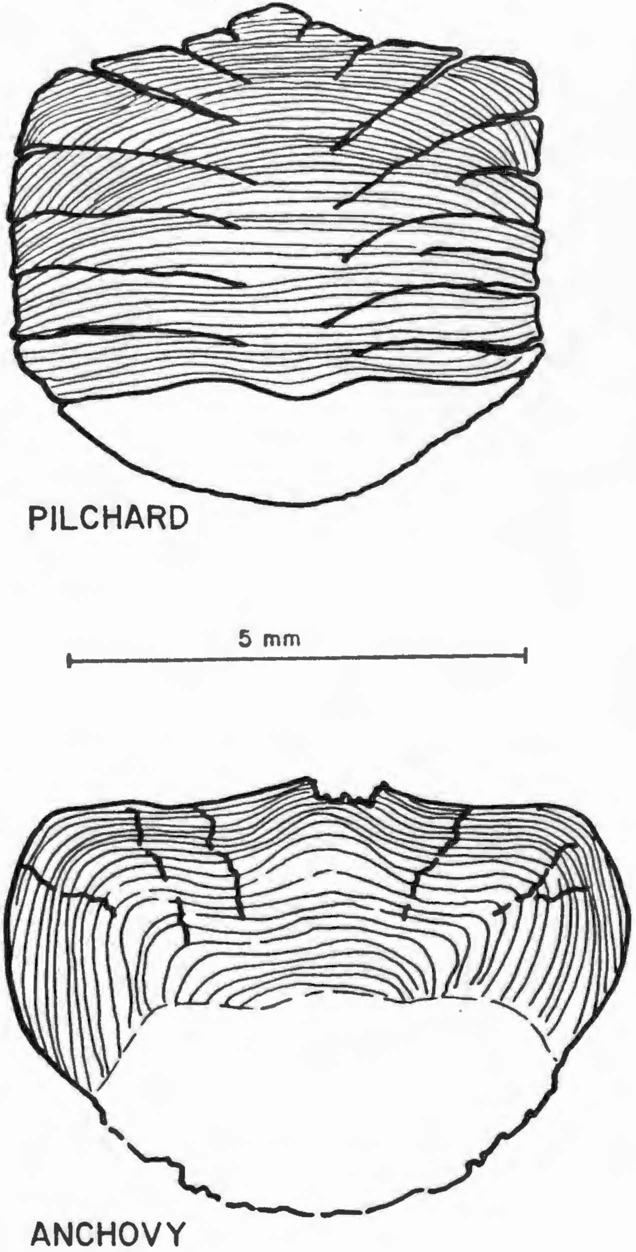


Figure II.1 Sketches of typical pilchard and anchovy scales

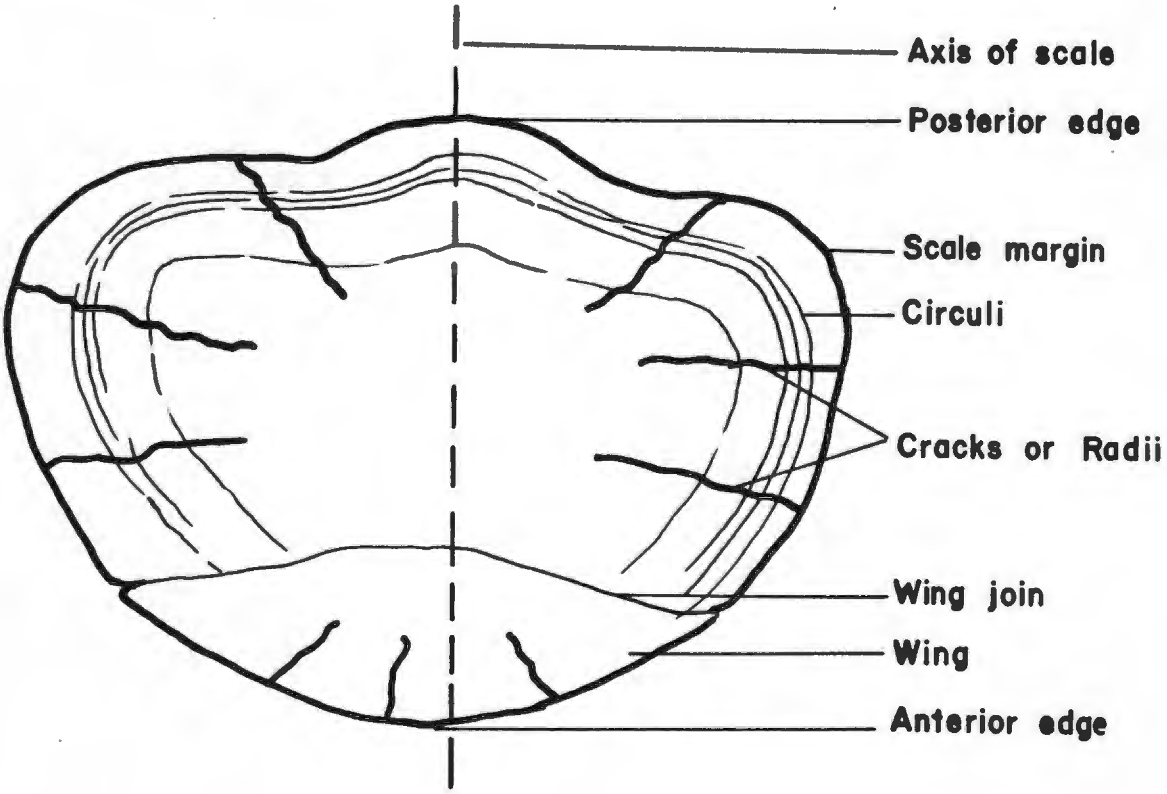


Figure II.2 Terms used in describing clupeoid fish scales

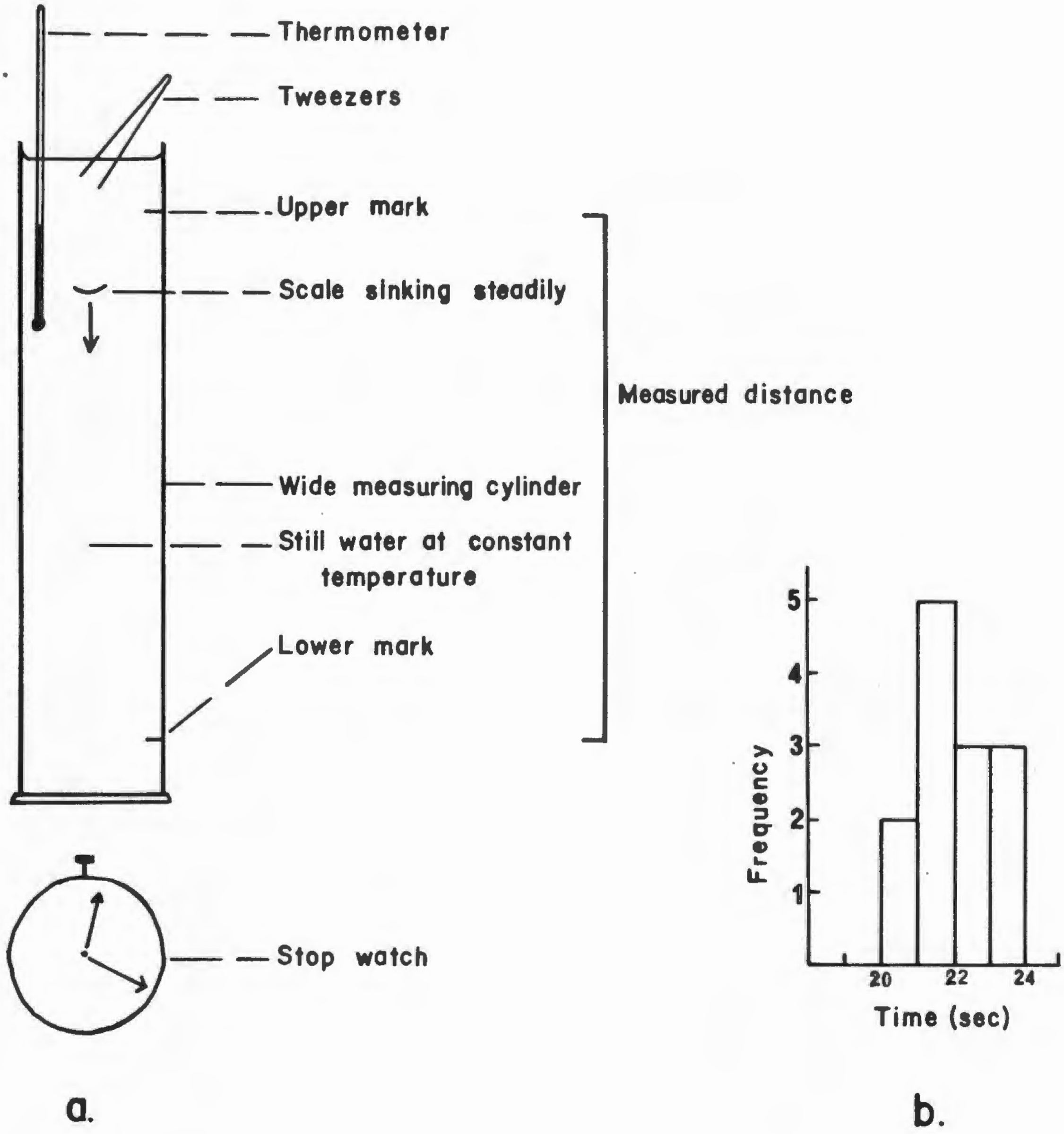


Figure II.3 Settling velocity experiment. a) The apparatus used. b) Histogram showing the repeatability of the method

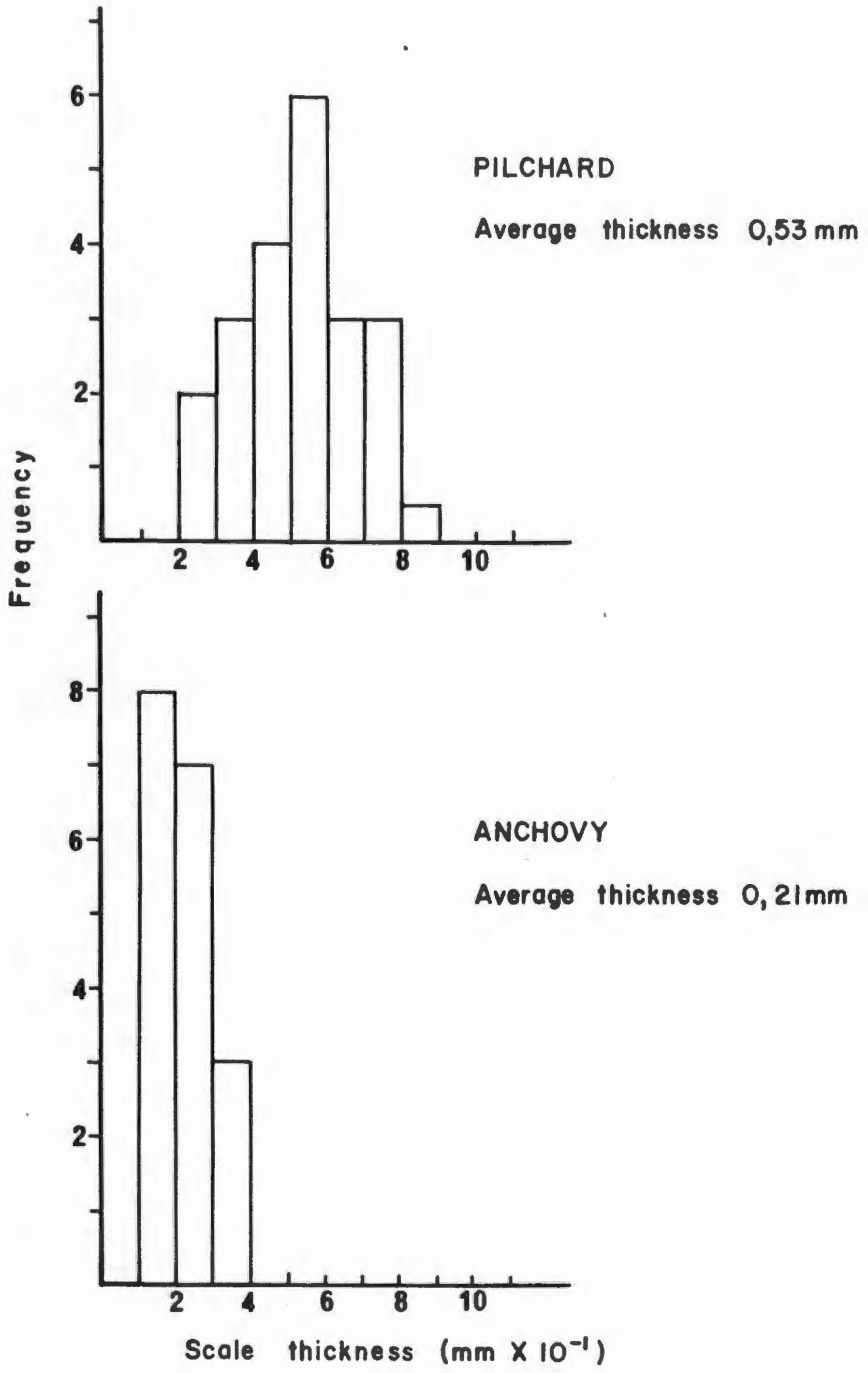


Figure II.4 Histograms showing the measured thickness of pilchard and anchovy scales using a micrometer screw guage

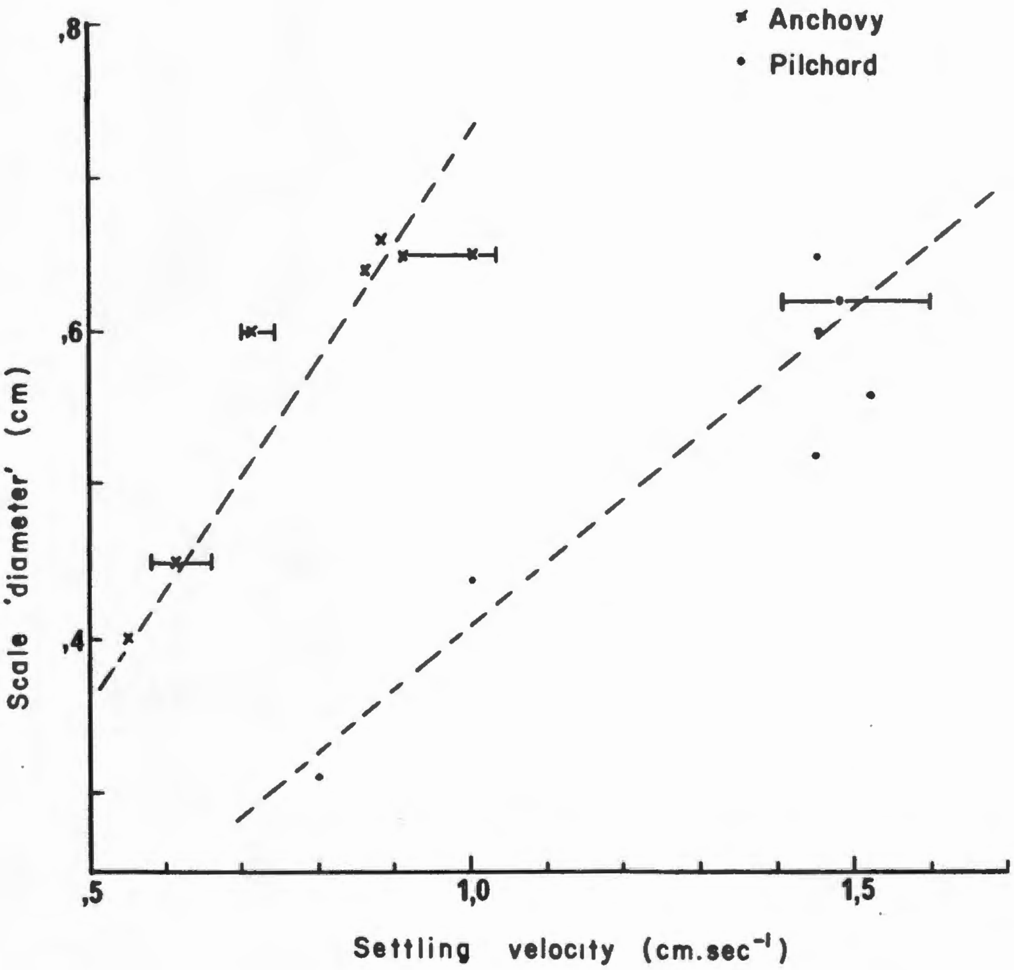


Figure II.5 Plot of scale 'diameter' against settling velocity for pilchard and anchovy scales

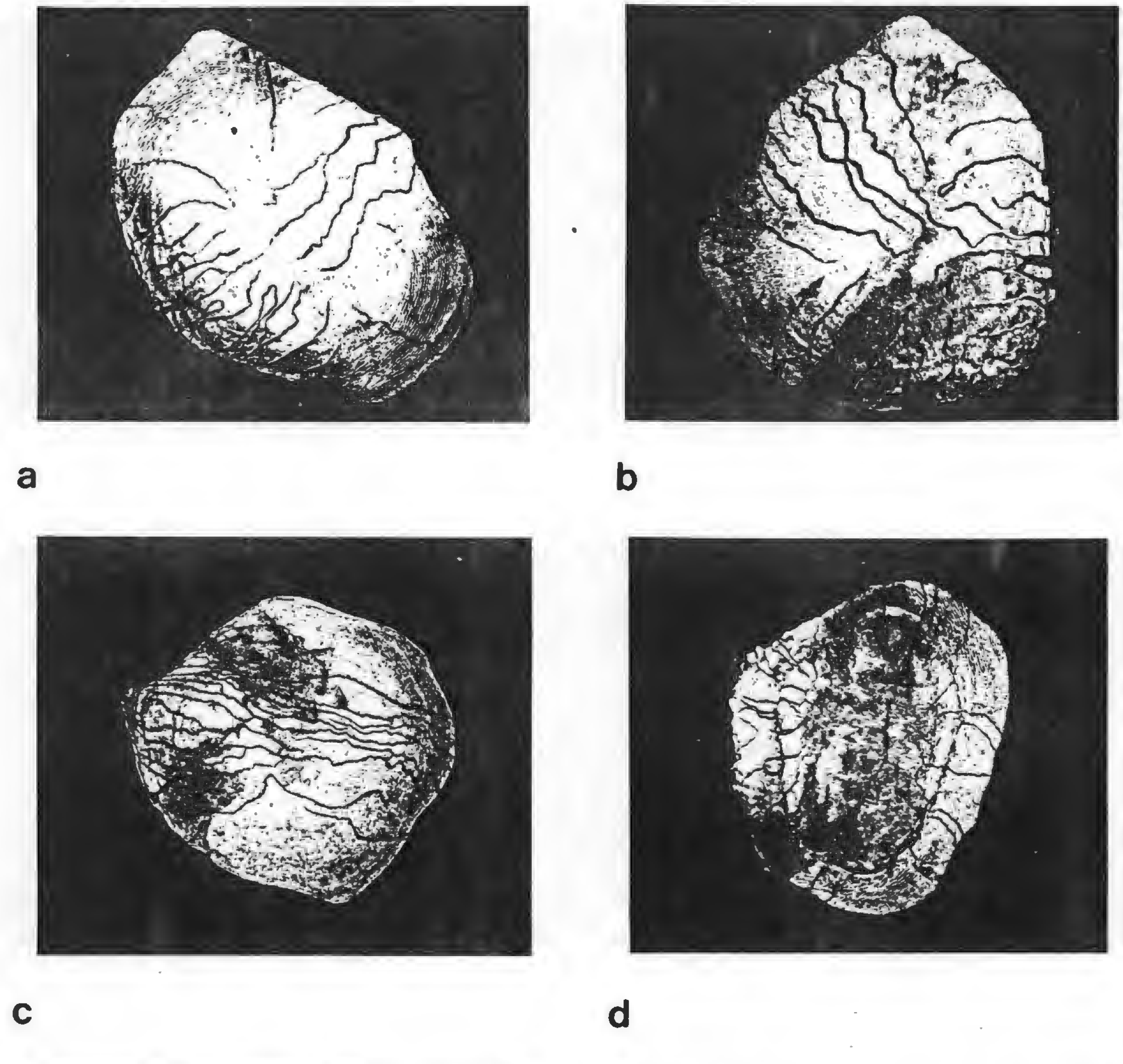


Figure II.7 Anchovy scales. a) Y-scale, b) X-scale, c) S-scale, d) R-scale, e) L-scale, f) t-scale

Head dorsal Tail
1 c c c c c c c c c c c c c c t S S S S S S S S S S S S S t t S S S S S S S S S S S S S S S S S S S S
2 c c c c c c c c c c c c S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S
3 c c c c c c c c c c c c c c c c S S S S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S T/S
4 c c T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T S T T T/S T T T/S T T t t t
5 T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T
6 T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T t t
7 T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T T/S T/S T/S T/S T/S t t t t t
8 c T T T T T T T T T T T T T T T T T T T T T T T T c T T T/S T/S S S S S
9 ½c ½c ½c ¾c ¾c ¾c ¾c c c c c c c c c c c c c c c c c c c c c c c c c T/S T/S T/S T/S S S S S S S T/S/2 T/S/2 T/S T/S S S S S S t t t
10 c c c c c c c c c c c c c c c c c ¾c ¾c ¾c ¾c ¾c c c c c c c T/S T/S T/S S S T/S/2 T/S/2 T/S/2 T/S/2
11 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 α α α T/S T/S T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 T/S/2 S S S t t t t
ventral

PILCHARD

Figure II.9 The row by row distribution of the different types of scale found on a pilchard

Head **dorsal** **Tail**

1 t x x x Y Y Y Y Y Y Y Y Y Y R R t S S S S S S S S S S S Y Y Y Y Y Y Y Y Y Y Y R X X X L t L S S S S S S
2 X X X X X X X X X X X X X X X X
3 x t t R R x R Y Y Y Y Y R Y Y Y R X X X X X X X X X R X X X X X X X X X X X X X X L t
4 x Y Y Y Y Y Y R R R Y Y Y Y Y Y X X R R X X X R X X X X X X X X X X X X X X L t
5 x Y Y Y Y Y Y R R R Y Y X Y Y X X X R R X X X R X X X X X X X X X X X X X L
6 Y Y Y Y Y Y Y Y Y Y Y R R Y X X R R R R R X R X R X X X X X R X R X R L L L L x
7 x x Y Y Y Y Y R Y Y Y Y R R R R X R R R R R R X X X X X X L L L L L L L L L
8 Y x Y Y Y R Y Y Y R Y x R R Y R R x R L S S S S S L S S S L L L L L L L L L t t
9 x x R L L t L x S x x x S S S S x x x L x S S R S S S R L L L L L t L t t t t t L L x.x t x t t

ventral

ANCHOVY

Figure II.10 The row by row distribution of the different types of scale found on an anchovy

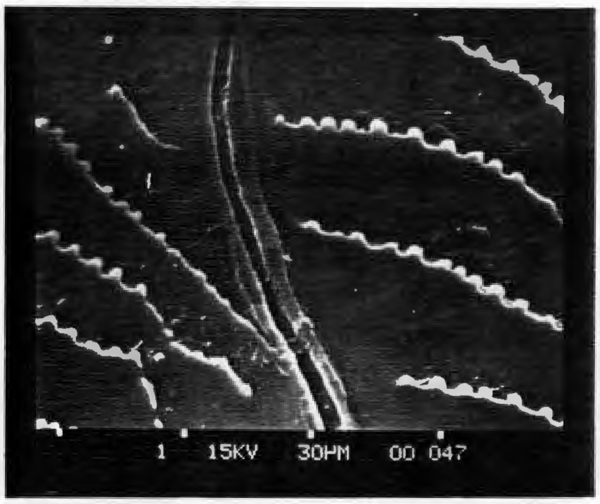


Figure II.11 Electron micrograph of anchovy scale (x926) showing denticles

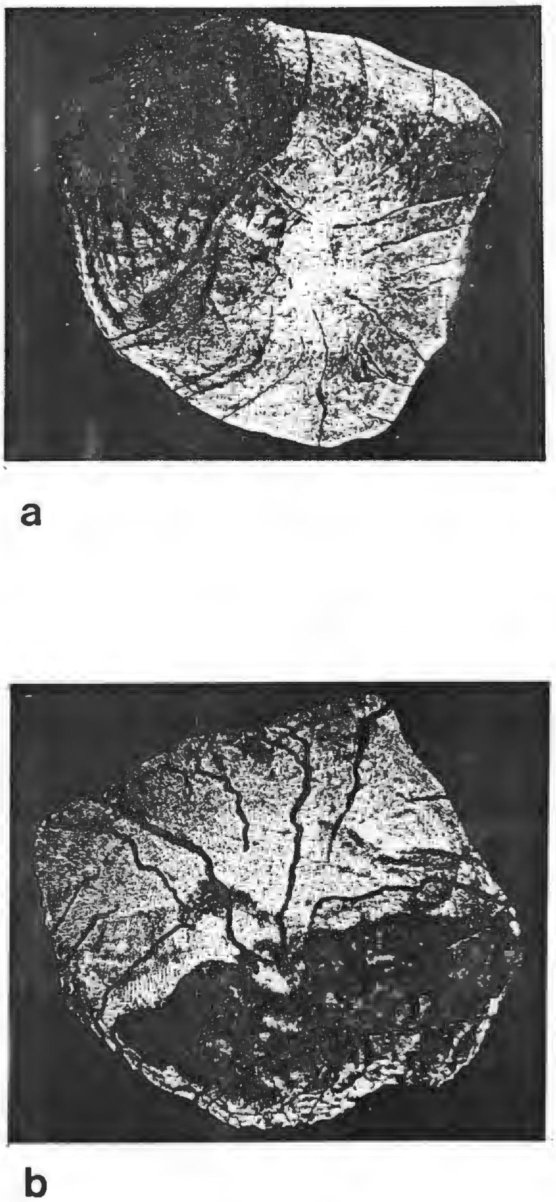


Figure II.12 (a) Pilchard and (b) anchovy scales showing the similarity between them

CHAPTER III

DECIDUOUSNESS VS DEATH

III.1 INTRODUCTION

Earlier studies of fossil scales in the sediments have either not considered the process of scale transfer from the fish to the sediment (Soutar and Isaacs), or have assumed that the scales accumulating are there as a result of the death of the fish (De Vries and Pearcy). I was alerted to the possibility of another process of scale loss when I experienced difficulty in finding dead pilchard and anchovy with a full complement of scales. Further investigation showed that this "deciduousness" of pilchard and anchovy has been noted by Davies (1958), Miller (1955) and Nawratil (1961) and is well known amongst pelagic fishermen.

In this Chapter scale loss due to both death and deciduousness are quantified for pilchard and anchovy under laboratory conditions. Some of the possible implications of deciduous scale loss being a significant factor in population extrapolations from scale counts in the sediment are considered.

III.2 SCALE LOSS DUE TO DEATH

III.2.a Causes of death

This study is essentially concerned with the pre-fishery period when fish mortality is entirely due to natural causes. Predation is the main cause of natural mortality (Bailey 1983, Brongersma-Sanders 1957, BEP Report No 1, 1982) with disease and other factors playing a minor role (Davies 1957, BEP report No 6, 1983). The stocks of pelagic fish off Namibia support most of the larger life-forms in the area. Pilchard and anchovy are preyed upon extensively by piscivorous fish, mammals, squid and to a lesser extent by birds (Davies 1957, BEP Report No 5, 1983, BEP Report No 6 1983).

Another cause of death that has attracted attention in the Walvis Bay area is the mass mortality of pelagic fish resulting from blooms of toxic dinoflagellates (Copenhagen 1953) combined with incursions of low oxygen water (Brongersma-Sanders 1957). Although these are high-profile events with spectacular reports of dead fish washed up on beaches, it seems unlikely that they contribute significantly to the overall reduction of fish stocks. Predation remains the major cause of natural death of the pelagic fish.

III.2.b Determination of scale flux due to death

To determine the maximum contribution of scales to the sediment from the death of the fish it is necessary to know both the number of scales on the fish and the expected lifetime of the fish.

(i) Number of scales on the fish

Scales form on pilchard and anchovy when they are very small (less than 3 cm long for anchovy) and are thought to remain constant over the lifetime of the fish (Miller 1955). Assuming bilateral similarity, scales were pulled off one side of eight dead fish, four anchovy and four pilchard, and counted. The scales removed were stored in a solution of 50% distilled water and 50% absolute alcohol for further studies.

The counts obtained exhibited a surprisingly wide range.

Fish	No. of scales
Pilchard	462
Pilchard	862
Pilchard	1 064
Pilchard	1 134*
Anchovy	290
Anchovy	604
Anchovy	622
Anchovy	708*

The reason for this variation appeared to be the ease with which these fish shed scales on handling. The maximum counts (marked *) were obtained from specimens which had been handled with great care and, even then, small scales were probably missing from near the tails.

As the number of scales on fish of a specific species can reasonably be expected to be constant from fish to fish and does not vary over its lifetime (Miller 1955), deciduous shedding appears to be the correct explanation for the variation in the counts of the number of scales. The best estimate of typical numbers of scales on a pilchard and anchovy are given by the maximum counts (*) which will be used in the calculations.

(ii) Calculation of expected lifetimes

Quantification of the flux of scales lost by a fish due to its death depends on the estimated expected lifetime of the fish. Pilchard are known to live longer than anchovy, and an attempt can be made to estimate their expected lifetimes using a statistical approach to fish populations, where the usual relevant statistic is an estimate of M, the instantaneous rate of natural mortality. From M, an average age at death can be calculated. In a pre-fishing population M accounts for the total mortality and the annual survival rate, S, is equal to e^{-M} (Ricker 1975). At any time the death rate is assumed to be proportional to the number of fish present, N, ie:

$$\frac{dN}{dt} = -MN$$

Using Ricker's definitions, the average age at death for a given species is found to be equal to

$$\frac{1}{M}$$

Estimates of M are difficult to obtain as they depend on the accuracy of population estimates (Bailey, 1983). Newman (1970) gave a preliminary estimate of the natural mortality for sardine species as being between 0,3 and 0,7. Butterworth (BEP Report No 6, 1983) gives a best estimate of M for the pilchard as 0,5 and 1,1 for the anchovy. This gives an expected lifetime of 2 years for pilchard and 0,8 years for anchovy.

(iii) Death fluxes

Using expected lifetimes of 2 years for pilchard and 0,8 years for anchovy, and scale counts of 1 100 for pilchard and 700 for anchovy, scale fluxes resulting from the death of a fish can now be calculated. These are expressed as scales/fish/ day and are 1,56 for pilchard and 2,42 for anchovy. A detailed breakdown of the fluxes of each of the major scale types is given in Table III.1.

III.3 SCALE LOSS DUE TO DECIDUOUSNESS

The range of values obtained when attempting to count the number of scales on pilchard and anchovy indicated the ease with which these fish lose scales. In order to quantify this "deciduous" scale loss I designed an experiment with the cooperation of Dr C L Brownell at SFRI.

III.3.a Methods

To overcome the problems inherent in handling pilchard and anchovy in the marine environment I used nine month old fish reared by Dr Brownell which schooled in tanks 3 m in diameter and containing 5 m^3 seawater. Two tanks were selected for monitoring. Tank 54 contained 7 anchovy and 45 pilchard and Tank 58 28 anchovy and 36 pilchard. The fish were fed daily on trout food (Brownell 1983) and, at approximately 7 day intervals, the floors of the tanks were vacuumed to remove uneaten food and faecal pellets.

The tanks were monitored for a period of 80 days. The debris vacuumed from the bottom of the tanks was stored in sea water in labelled jars. The fish scales were separated from the uneaten food and faecal pellets by wet sieving through a 1,4 mm sieve. The scales were stored in a distilled water/absolute alcohol solution for counting.

Initially the scales were counted wet, each scale being manually picked from the sample, identified under a low power microscope and transferred to another storage jar. This method was found to be unsuitable for accurate identification of any but the typical scales of each species (see Chapter II) and later identifications were made under a microscope using transmitted light. The scales were mounted on acrylic strips as described in section II.2.c and identified using the reference photographs.

III.3.b Results

Significant numbers of scales were found in the debris accumulating at the bottom of the tanks. The counts are summarized in Table III.2.

The total scale flux per day varied from 18 to 142. I selected four periods, A, B, C and D for a more detailed breakdown of scale counts. (The periods were chosen to give a reasonable cover of the range of scale fluxes). See Table III.3. Figure III.1

summarizes these results. Deciduousness flux defined as the number of scales lost per fish per day, is listed in Table III.4. for each scale type.

III.4 DISCUSSION

III.4.a A comparison of death and deciduousness fluxes

In past studies death has been assumed to be the major process contributing scales to the sediment. Assuming all the scales from a dead fish find their way to the sediment, a maximum value for the scale flux due to death has been calculated. An estimate of scale loss due to deciduousness over the lifetime of the fish is more difficult to obtain. However, by monitoring pilchard and anchovy schooling together in laboratory tanks, I have been able to calculate a range of values for the deciduousness flux of pilchard and anchovy under laboratory conditions (see Table III.4). (Here, although the fish were sheltered from predators, they were subjected to the trauma of human contact.) A closer look at these values is informative. Estimates of pilchard flux vary between 0,45 and 2,50 scales/fish/day and those for anchovy between 0,13 and 0,82 scales/fish/day. Table III.5 shows the anchovy flux/pilchard flux ratios and the Pilchard T-scale/Total scale ratios for the four different periods monitored.

The anchovy flux/pilchard flux ratio only varies between 0,25 and 0,58. From this I conclude that, although absolute deciduous scale loss varies, probably in response to external stimuli, pilchard and anchovy subjected to the same stimuli react in a similar way. Circumstances likely to cause greater scale loss in anchovy also cause greater scale loss in pilchard. This tight anchovy flux/pilchard flux ratio is based on counts of over 2 000 scales. It indicates the high degree of confidence with which the ratio can be used in relative fish population calculations.

Also of interest is the unexpectedly high proportion the T-scales form of the total scale loss. T-scales appear to be preferentially lost by deciduousness, and they dominate the accumulating scales forming a remarkably constant proportion of the total scales. This constancy over periods of greater and lesser scale loss suggests that deciduous scale loss follows a set pattern regardless of the number of scales lost.

The scale fluxes expected from death and deciduousness over the expected lifetime of the fish can now be compared (see Table III.6 and Figure III.2).

Expressed in terms of actual scale loss per fish over its expected lifetime, this becomes:

	Loss from deciduousness	Loss from death
Pilchard	328-1 825 scales	1 100 scales
Anchovy	38- 239 scales	700 scales

It is evident that scale loss by deciduousness is significant in comparison with scale loss due to death for the pilchard, but less so for the anchovy. Up to 62% of the pilchard scales lost could be the result of deciduousness, whereas the maximum for anchovy is 25%.

This biases the proportions of the scales found in the sediment from the proportions that would be expected based on scale counts on fish. This can be seen in Table III.7 where the total scale losses expected over the lifetime and death of both a pilchard and anchovy are listed. (Deciduous scale loss is calculated using mean values for deciduousness flux).

III.4.b Population calculations

Recognition of the significance of deciduous scale loss affects both relative population comparisons based on scale counts and absolute population calculations. Pilchards are preferentially deciduous in comparison with anchovy, thus biasing scale counts towards pilchard.

A simple population calculation shows the effect of this bias in comparative studies. Consider an area 'a' over a time 't'. During this time sediment and scales will accumulate at the bottom of a water column of area 'a' as a result of a number of fish 'F' in the water column. The number of scales 'S' accumulating is proportional to the number of Fish 'F' and the scale flux 'ϕ'.

$$S = F\phi t$$

$$\text{or } F = \frac{S}{\phi t}$$

Using deciduousness fluxes, for Pilchard this becomes

$$\text{No of Pilchard} = \frac{1}{1{,}5t} \times \text{Pilchard scales}$$

For Anchovy

$$\text{No of Anchovy} = \frac{1}{0{,}48t} \times \text{Anchovy scales}$$

Thus, over the same area, for the same time 't':

$$\frac{\text{No of Pilchard}}{\text{No of Anchovy}} = 0{,}32 \; \frac{\text{Pilchard scales}}{\text{Anchovy scales}}$$

If the calculation is based on death fluxes the relationship becomes

$$\frac{\text{No of Pilchard}}{\text{No of Anchovy}} = 1{,}55 \; \frac{\text{Pilchard scales}}{\text{Anchovy scales}}$$

From the laboratory experiments described in this chapter, theoretical contributions of scales to the sediment from death and deciduousness have been calculated. These can be used to extrapolate back from a count of scales in the sediment to estimate the size of the fish population producing them.

In a given core of area 'a' representing a fishery over an area 'A' containing fish with a scale flux 'ϕ', the number of fish 'F' is given by:

$$F = \frac{S \times \frac{A}{a}}{\phi t}$$

Where 'S' is the number of scales found in a slab of the core 'l' deep.

The sedimentation rate 'σ' over the area is given by

$$\sigma = \frac{l}{t}$$

Substituting for $t = \frac{l}{\sigma}$

$$F = \frac{SA\sigma}{\phi a l}$$

Fluxes due to death or deciduousness or both can be substituted in this formula to give estimates of numbers of fish (or biomass if multiplied by the average weight of each fish). With the pilchard there is little difference between deciduousness flux and death flux, but, in the case of the anchovy, population estimates will vary by a factor of 5 depending upon which flux is used in the calculation. However, the actual relative importance of each process in the natural environment still needs to be assessed before any meaningful combinations of death and deciduousness flux can be substituted in this equation.

Fish	Scale Type	Flux (scales/fish/day)
Pilchard	T	0,54
	C	0,30
	S	0,32
	Other	0,40
	Total	1,56
Anchovy	X	0,92
	Y	0,52
	S	0,36
	Other	0,55
	Total	2,42

Table III.1. Scale fluxes due to death for pilchard and anchovy

	No of days	Total scales	Scales/day
	7	159	23
	8 (Period A)	175	29
	12	221	18
Tank 54	7	486	69
7 anchovy	9 (Period B)	227	25
45 pilchard	7	335	62
	7	191	27
	8	476	59
	7	302	43
	8	300	37
Tank 58	5 (Period C)	248	50
28 anchovy	5	712	142
36 pilchard	13 (Period D)	1 472	113

Table III.2. Count of scales accumulating in laboratory tanks

Period	Tank 54		Tank 58	
	A	B	C	D
TOTAL	175	227	248	1 472
PILCHARD	163	217	168	1 172
T	97	117	137	724
C	44	75	27	416
S	14	20	2	24
Others	8	5	3	8
ANCHOVY	12	8	77	300
X	10	3	63	232
Y	0	0	4	20
S	1	5	9	40
Others	1	-	1	8

Table III.3. Detailed scale counts in the tanks for periods A, B, C and D

Scale type	Flux			
	54A	54B	58C	58D
Total pilchard	0,45	0,53	0,94	2,50
Total anchovy	0,21	0,13	0,55	0,82
T	0,30	0,29	0,76	1,55
C	0,12	0,18	0,15	0,89
Pilchard S	0,04	0,05	0,01	0,05
X	0,21	0,05	0,45	0,64
Y	-	-	0,03	0,05
Anchovy S	0,01	0,08	0,06	0,11

Table III.4. Scale fluxes due to deciduousness for pilchard and anchovy

Tank	Period	Total Pilchard Flux	Total Anchovy Flux	$\frac{\text{Anchovy Flux}}{\text{Pilchard flux}}$	$\frac{\text{T scale loss}}{\text{total scale loss}}$
54	A	0,45	0,21	0,47	0,55
54	B	0,53	0,13	0,25	0,52
58	C	0,94	0,55	0,58	0,55
58	D	2,50	0,82	0,33	0,49

Table III.5. Flux ratios

Scale Type	Flux due to deciduousness in tanks (scales/fish/day)		Flux due to death (scales/fish/day)
	Range	Mean	
Total pilchard	0,45-2,50	1,50	1,56
Total anchovy	0,13-0,82	0,48	2,42
T	0,29-1,55	0,92	0,54
C	0,12-0,89	0,51	0,30
Pilchard S	0,01-0,05	0,03	0,32
X	0,05-0,64	0,35	0,92
Y	- -0,05	0,05	0,59
Anchovy S	0,01-0,11	0,06	0,36

Table III.6. Comparison of death and deciduousness scale fluxes

		Scale loss from death	Scale loss from deciduousness
Pilchard	T	374 (34%)	869 (52%)
	C	220 (20%)	484 (29%)
	S	209 (19%)	138 (8%)
	Total	1 100 (100%)	1 661 (100%)
Anchovy	X	266 (38%)	371 (44%)
	Y	168 (24%)	109 (13%)
	S	105 (15%)	126 (15%)
	Total	700 (100%)	840 (100%)

Table III.7. Total scale loss due to death and deciduousness for a pilchard and an anchovy

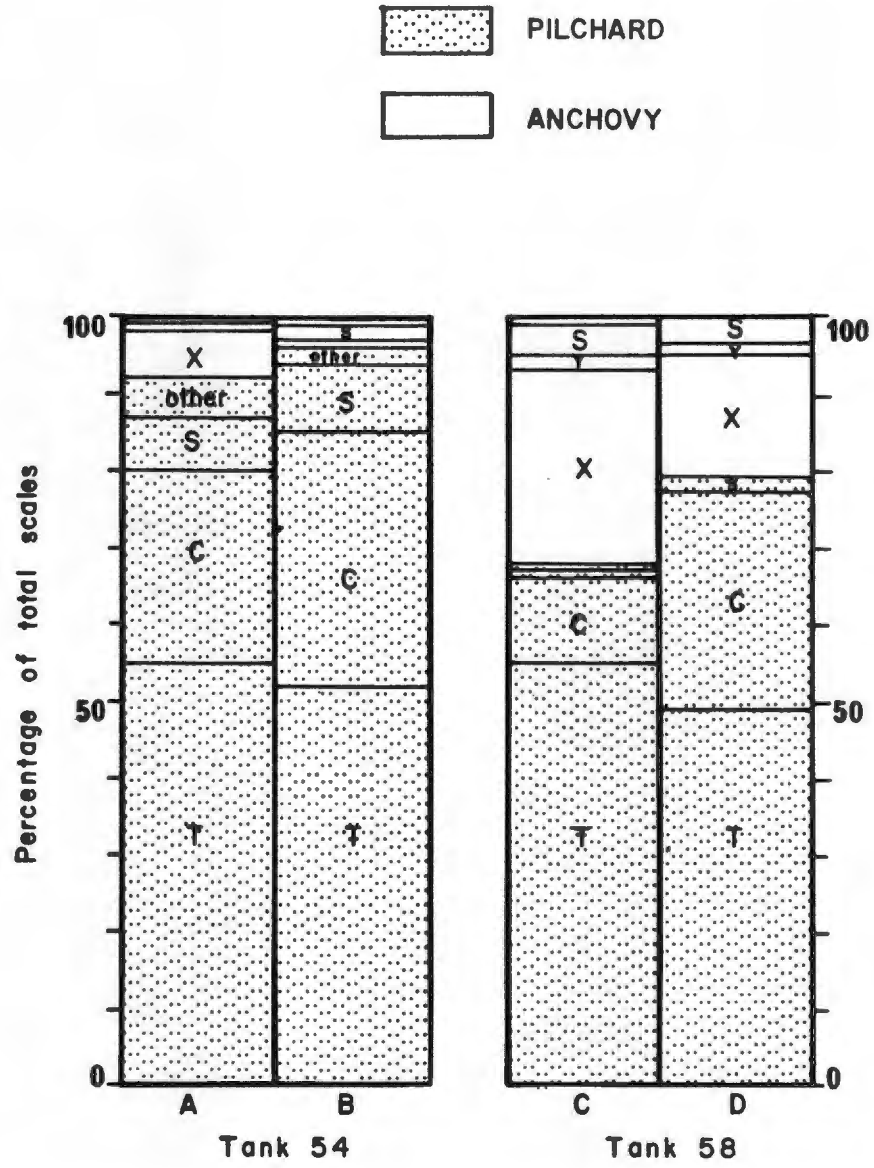


Figure III.1 Percentages of the different types of scales counted in tanks 54 (for periods A and B) and 58 (for periods C and D)

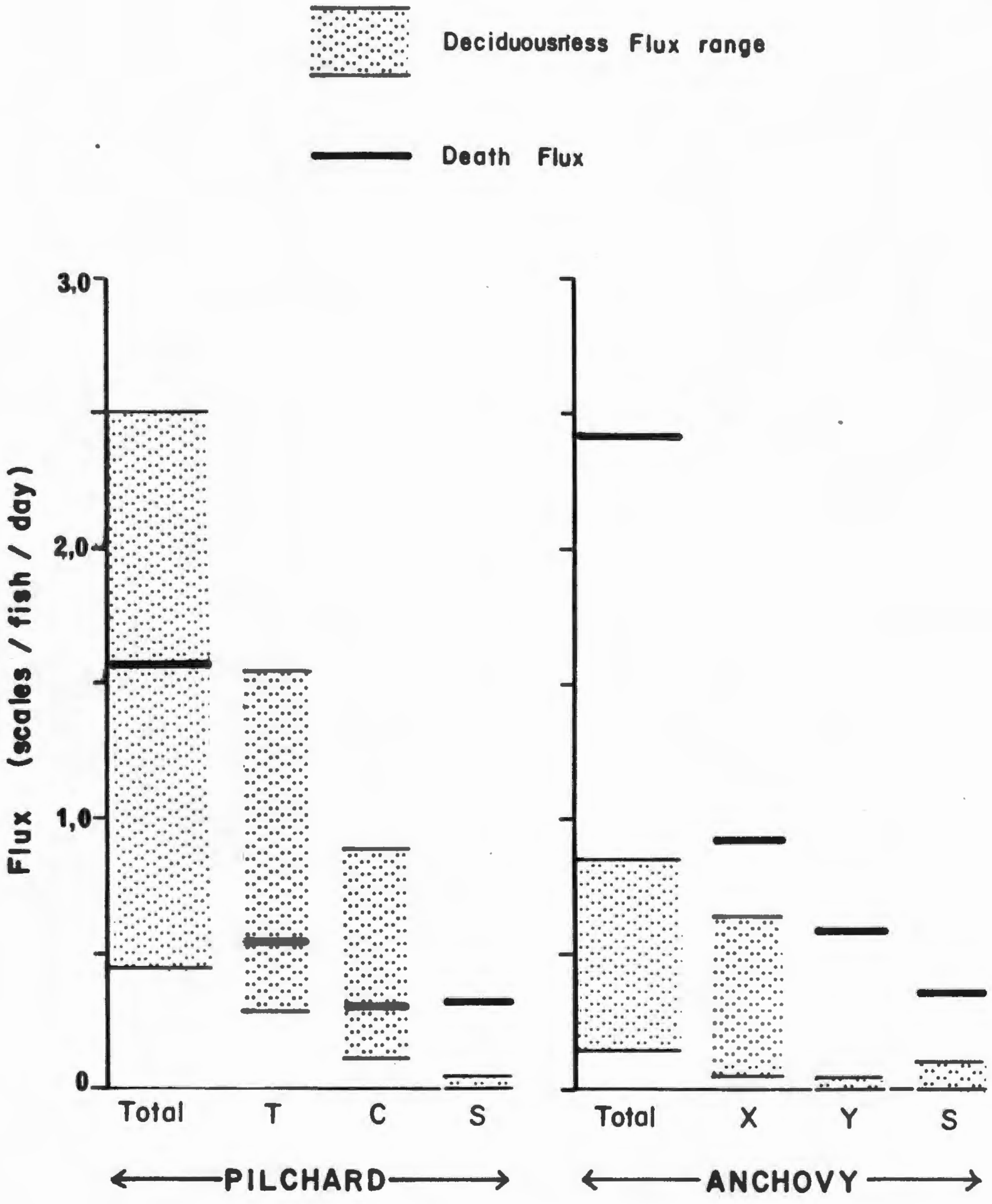


Figure III.2 Comparison of death and deciduousness fluxes of pilchard and anchovy

CHAPTER IV

SCALES IN THE SEDIMENT 1. GRAB SAMPLES

IV.1. INTRODUCTION

In the previous two chapters I have looked in detail at scales on both pilchard and anchovy. By performing laboratory experiments I have reduced possible errors in scale identification and calculated expected scale fluxes from both species. I will now consider the environment in which the scales are accumulating. In most areas of the sea settling organic matter which reaches the bottom is rapidly scavenged by benthic organisms (Smith 1985) or decomposed by bacteria (Ohwada et al, 1983) and does not remain long in the sediment. The environments which do favour preservation of organic debris are consequently of great interest. In Chapter I I described some of these environments and considered the interlinked topographic, oceanographic and biological factors which are responsible for them. The diatomaceous mud belt off Namibia is one such environment. In this Chapter I shall describe these muds in more detail and describe a pilot study to ascertain whether scales are accumulating in them to any significant extent.

IV.2 THE DIATOMACEOUS MUD BELT OFF NAMIBIA

Marchand (1928), in describing the sediments found off South West Africa in the Walvis Bay region, refers to them as being greenish, of a clayey consistency and giving off a 'stench' that is 'almost unbearable'(p 1). He describes the consistency of this 'evil smelling mud' as being such that there was a danger of losing the trawling gear as it sank through the mud. Although he dismissed trawling in this azoic zone as being 'merely a waste of time' he did note 'fishbones by the bucketful'(p 1) and concluded that the area seemed to be some kind of burial ground for fish.

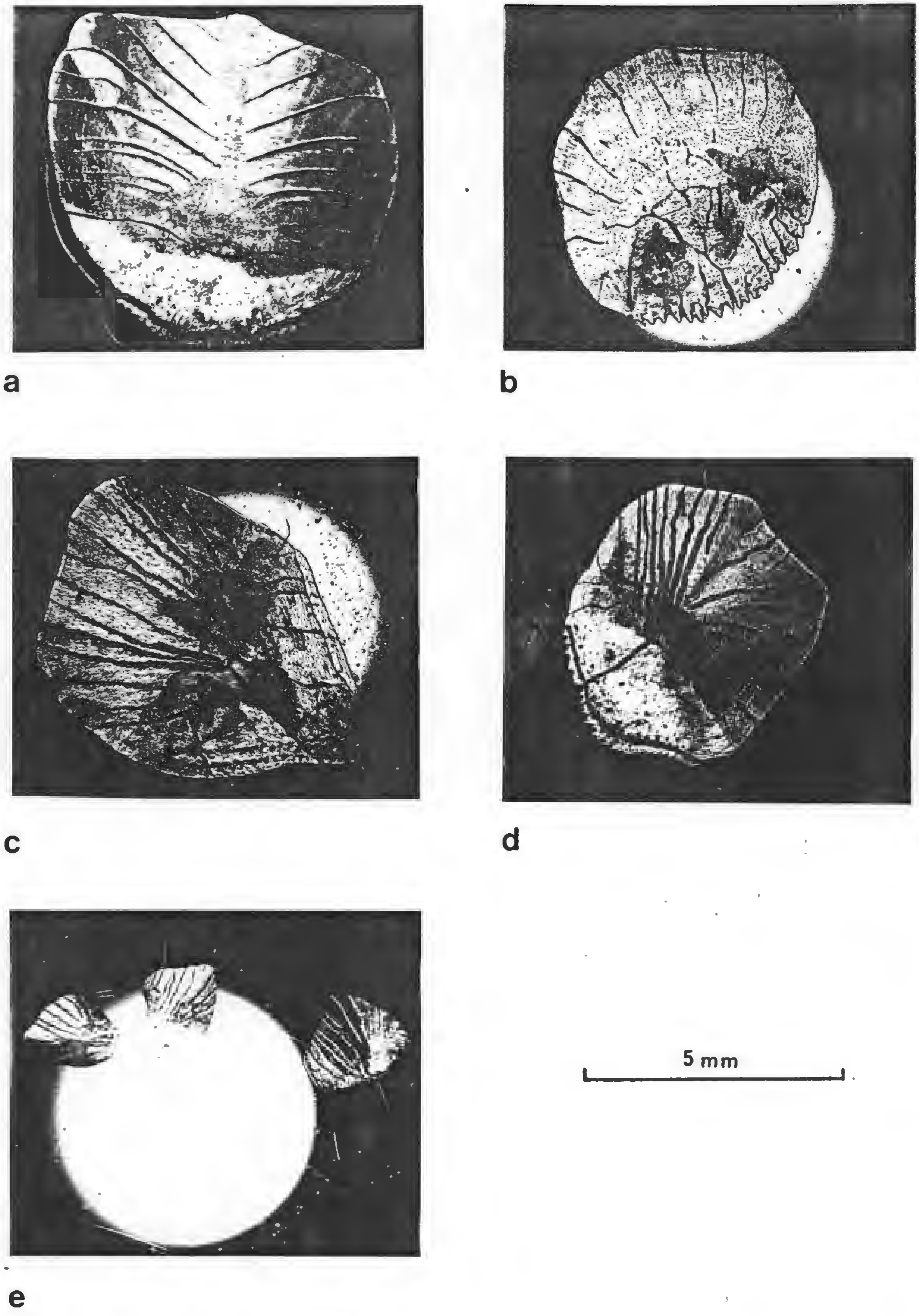


Figure II.6 Pilchard scales. a) T-scale, b) C-scale, c) S-scale, d) T/S or C/S-scale, e) t-scale

A detailed study of the sediments on the continental margin off South West Africa between 17°S and 25°S has been made by Bremner (1978, 1983). He identified a 740 km long belt of diatomaceous muds stretching from 19°S to 25°S, parallel to and within 45 nautical miles of the coast. (Figure VI.1). Summerhayes (1983) gives depths of the mud belt as between 30 m and 130 m, but points out that the diatomaceous muds extend into Walvis Bay and can be as shallow as 1 m or as deep as 220 m. Based on past sea level fluctuations, Bremner (1983) estimates that the age of the diatomaceous mud belt is about 5000 years. The maximum thickness attained is 15 m, giving a sedimentation rate of 3 mm/year.

These muds are extremely rich in opal (up to 90% by weight) and organic matter (up to 23,9% by weight). Both of these extraordinary enrichments are due to the high productivity in the area (see Chapter 1) and peak off the coast between Ambrose Bay (21°S) and Sandwich Harbour (23°30'S) (See Figure IV.1). The sediments are derived almost entirely from planktonic sources. Bremner (1983) lists the most abundant species to be Chaetoceros sp., Actinocyclus ehrenbergii, Coscinodiscus sp., Fragilaria karstenii, Thalassionira nitzchioidea and Raphoneis surirelloides. Because of dissolution of the less robust diatom frustules settling through a longer water column, the opal is diluted somewhat by organic matter in the deeper water (Bremner 1978).

In view of its planktonic source silt- and clay-sized material makes up about 75% of the sediments and up to 100% in the areas of peak productivity. Sand-sized faecal pellets are found along the seaward edge of the mud belt and terrigenous material ranging in size from silt to gravel occurs on the landward edge of the muds. Bremner (1980) found fish debris to constitute over half the coarse fraction of the diatomaceous muds, with fish scales making up about 4,5% of this fraction. He noted that although many of the scales were fresh in appearance some were altered to light to dark brown by phosphatization, a process whereby apatite precipitates from phosphorous-saturated interstitial fluids in the muds onto phosphatic solids such as fish scales.

IV.3. METHODS

Between 1972 and 1974 Dr Bremner collected over 550 grab samples of the sediments on the Namibian continental shelf. He kindly made small subsamples of material from six of these available for a pilot study on fish scale distribution. I selected these subsamples to give a wide coverage of the diatomaceous mud belt. Four samples were selected from the main concentration of muds between Walvis Bay and Cape Cross, 3773, 3775, 4031G (henceforth known as 4031) and 3753G, one from the thin northern strip of mud off Ambrose Bay (21°S) , 3990G (henceforth 3990) and one from the deeper water to the seaward side of the main mud belt 4033G (henceforth 4033) (Figure VI.1)

As Bremner (1978) pointed out, there is no clear sediment/water interface above the diatomaceous muds and the gentle gradation from watery mud to muddy water makes it difficult to estimate the age of the sediments sampled by the grabs. They do, however, include the most recent accumulations of planktonic material, fish debris and terrigenous matter.

Subsamples of approximately 200 gms were removed from Dr Bremner's grab samples which had been stored in airtight plastic tubs for the past 9 to 10 years. Each sample was weighed and its approximate volume estimated before it was separated into three size categories by wet sieving through 70μ and 300μ meshes. The less than 70μ fraction was discarded and the 70μ - 300μ fraction set aside for a separate fine fraction study (by Johnson and Herbert). The greater than 300μ fraction was dominated by large diatom frustules (the four samples collected from the main mud belt) or sand-sized faecal pellets (the northernmost and westernmost samples). Fish scales and bones were evident in all the samples.

To separate the fish debris from the faecal pellets I tried two methods, one based on the difference in densities between the fish debris and the faecal pellets, and the other on chemical disaggregation of the pellets.

Settling

The greater than 300μ fraction was allowed to settle through a high density fluid (1,41 gm/cc) made up of potassium carbonate diluted with distilled water. The fish scales and diatoms settled rapidly and the floating faecal pellets could be poured off.

Disaggregation

Faecal pellets in the sample disaggregated when boiled in a solution of three parts water and one part 50% hydrogen peroxide for about 10 minutes. Further sieving through a 30μ sieve served to separate off the fish debris and large diatoms.

Faecal pellets were only found in two of the samples to any great extent, and the majority of the greater than 300μ fraction of the samples taken from the main mud belt was composed of large diatom frustules. Based on my experience of the sizes of the fish scales of interest to me in this study I decided to resieve the samples through a 710μ mesh. In this way the majority of diatoms and faecal pellets were separated from the fish scales of interest. The 300μ-710μ fraction was kept as it was found to contain some very tiny fish scales and small fish bones and vertebrae, but the greater than 710μ fraction formed the basic sample for this study.

Using a reference collection of fish scales supplied to me by Dr R Thomas of SFRI and the reference photographs I had compiled (see Chapter II) I was then able to identify the scales in this greater than 710μ fraction under a low power microscope. The larger scales were manually picked from the wet sample and put into separate vials (one each for pilchard, anchovy, maasbanker and one for the other scales). I found the tiny hake scales too time consuming to manipulate with tweezers so they were counted in the wet sample using a graticulated dish.

IV.4 RESULTS

The mud samples were all dark olive green in colour and flecked through with tiny angular specks of white. These specks were more prominent in the samples taken from the extremes of the mud belt. The mud was surprisingly non-odorous, possibly due to the length of time the samples had been stored. Shell debris was evident in the two outlying samples (3990G and 4033G). Tables IV.1 and IV.2 summarize the results.

IV.5. DISCUSSION

IV.5.a All Fish

The mud collected by the grab represents a mixture of the most recent sediments deposited on the continental shelf off Namibia. The subsamples analyzed had an average of 41 fish scales per 100 ml of mud. The relative proportions of the scales counted can be seen in Figure IV.2.

Looking at Table IV.1 and IV.2 no real trends are evident. Shell fragments and faecal pellets are found in the samples collected from deeper water. Sample 4033, which had the lowest weight percentage of opal, contained many large (up to 2,7 cm), fragile mollusc shells. Anchovy, pilchard and maasbanker scales were present in all the samples, but no pattern of species distribution emerged. In all cases, pilchard scales predominated over anchovy and maasbanker scales. The percentage of hake scales was most variable, ranging from zero to 49%. Snoek scales were present in four of the six samples. Some sole scales were found.

Fishing statistics over the last 30 years (Crawford and Shelton 1978, Nawratil 1961) indicate that the major species present are pilchard (Sardinops ocellata), anchovy (Engraulis japonicus), maasbanker (Trachurus trachurus), mackerel (Scomber japonicus), hake (Merluccius capensis) and snoek (Thyrsites atun). The area of study, the inner shelf in the Walvis Bay region, is known to be a nursery ground for large numbers of juvenile pilchard, anchovy and maasbanker (Thomas 1985, 1983, Kompowski and Slosarczyk 1976). At about 10 months old the pilchard and anchovy migrate northwards, the pilchard returning as adults (three year olds) to spawn (Thomas 1985). The maasbanker also move offshore out of the Walvis Bay region as they get bigger (MacPherson E, Mombeck F and Schulein F H 1982). Pilchard, anchovy and maasbanker juveniles are attracted to the region because of the availability of planktonic food. They in turn are preyed upon by larger pisciverous fish such as snoek, hake and mackerel (Bergh 1983). The scales found in the grab samples seem to reflect the major components of the moving fish populations in the waters above.

The number of predator and prey species scales found in the samples is shown in Figure IV.3. The number of scales has been normalized to 100 ml of sample for comparative purposes. Scales of predator species only exceed those of prey species in one sample which contained an anomalously high percentage (49%) of hake scales. No clear relationship is apparent between predator and prey scales in the grab samples.

IV.5.b. Pilchard and anchovy

Pilchard and anchovy are central to this study and so I shall look at the occurrence of their scales in the grab samples in more detail. (See Table IV.3).

The pilchard scale to anchovy scale ratio is, with the exception of sample 3753, within the range of 1,4-3,4. Sample 3753 had the least scales (only 34) and ratios are therefore very sensitive to single scale counts. Random error is accordingly high so I feel justified in excluding the ratios obtained from this sample from the discussion and calculations.

The grab samples, comprising recent sediments, can be thought of as integrating the scales accumulating from fish populations of both the prefishery period (before 1950) and the period after the onset of major commercial exploitation. In its early stages the pilchard dominated the fishery, but since the early 1970's the anchovy catch has increased to partially fill the gap left by the collapse of the pilchard fishery (Thomas 1985). Pilchard and anchovy scales accumulating in the sediment over this period are in the ratio of 2,5 pilchard scales to every anchovy scale.

IV.5.c Implications for deciduousness

In Chapter III I have shown that deciduousness is a factor which should be taken into account when basing estimates of fish populations on scale counts. The effect of deciduousness is evident in the scales accumulating in the sediments. The expected T-scale to total pilchard scale ratio based on the number of T-scales on a pilchard is ,34 (Chapter II). The T-scale to total pilchard scale ratio in the four tank experiments and in five of the grab samples is listed below.

Tank	,6	,5	,8	,6		average	,65
Sediment	,6	,6	,8	,7	,7	average	,68

The T-scales in both environments formed a remarkably constant 65% of the pilchard scales accumulating. In the tanks scales were lost solely due to deciduousness. The implication is that the scales accumulating in the sediment do so primarily as a result of deciduousness also. Considering the natural life cycle of these pelagic fish this can be seen to be entirely possible. In Chapter III.2. natural mortality was seen to be due primarily to predation. Upon being pursued by a predator a highly deciduous fish would no doubt lose many scales. The tank experiments showed that total daily fluxes varied, but the proportion of T-scales lost did not, thus indicating that although trauma can influence the numbers of scales lost, they are lost in a fixed ratio. Thus during the capture phase of predation, scale loss would be according to deciduousness proportions. No reference has been found to fish scales passing through the guts of predators and papers such as Wilson et al (1985), Walter (1984), Duffy and Laurenson (1983) and personal communications (Payne, Lipinski) indicate that scales are decomposed in the gut. Thus, accepting that predation is the major cause of natural mortality, the only scales accumulating in the sediment from this type of death can all be attributed to deciduousness. Deciduousness becomes the only significant process contributing to scales in the sediment.

The formula derived in Chapter III for considering relative population calculations is accordingly based on deciduousness flux alone and

$$\frac{\text{Pilchard population}}{\text{Anchovy population}} = 0{,}32 \; \frac{\text{No. of pilchard scales}}{\text{No. of anchovy scales}}$$

The ratio of pilchard to anchovy scales over all the grab samples was found to be 2,5 (section IV.5.b). Substituting in the formula above gives the ratio of the numbers of the pilchard to numbers of anchovy as 0,8. In the relatively recent period sampled by the grabs, the number of anchovy has been greater than the number of pilchard.

IV.5.d Preservation

The similarity between the proportions of T-scales found in the laboratory and in the sediments also has implications with respect to the preservation of scales in this periodically anoxic environment. A total of 546 scales were found in just over 1 200 cc of sediment. The majority of these scales were intact and well preserved, showing little evidence of either mechanical abrasion, chemical dissolution or bacterial decomposition. About a quarter of the scales were phosphatized rendering them brown and brittle, but on the other hand some of the pilchard scales were perfectly preserved with the easily-lost wing still attached.

Preservation of a fish scale at the bottom of the sea would appear to be dependent on the degree of mechanical abrasion it is subject to, on its chemical composition and that of its surroundings, and on any bacteriological action. At the depths being considered in this study, depths of greater than 50 m, the effect of wave action on the bottom sediments is restricted to weak currents generated by distant storm waves (Bremner 1978) and mechanical abrasion is essentially non-existent.

Little is known about the chemical composition of fish scales. Van Oosten (1957) stated that the scales of teleost fish contained 41-84% organic protein and up to 59% mineral residue in dry matter. When present icthylepidin formed about 76% of the organic protein and the remaining 24% was collagen. The inorganic salts are principally calcium phosphate and calcium carbonate. The predominantly anaerobic conditions in the sediments of the study area contribute towards the preservation of fish scales. Soutar (1966) gives the pH of anaerobic sediments as about 8,0. This high pH does not favour the dissolution of the inorganic carbonates and apatites found in fish scales (Berger 1976). The phosphatization encountered is indicative of the sediment pore waters being saturated with phosphorus (Bremner 1980), depositing phosphorus on scales rather than leaching it from them.

Soutar (1967) also states that bacteriological action is decreased in an anaerobic environment as anaerobic bacteria are unable to break down organic matter as efficiently as aerobic bacteria. In his paper on the micropaleontology of anaerobic sediments (Soutar 1969) he compares the number of scales found in a core taken in a slightly anaerobic environment, with those taken in highly anaerobic conditions and finds three times as many scales preserved in the latter. Ohwada et al (1983) describe the appearance of fish scales being attacked by micro-organisms in a highly eutrophic environment. None of the scales found in the sediments off Namibia had the perforations he describes.

Scale fragments are, however, found in the samples extracted from the sediment, so some degradation is taking place, either in the sediment, the sample treatment or a combination of both. Van Oosten (1957) and Ohwada (1983) accept that the chemical composition of the hard tissue and organic constituents of fish scales varies from species to species, as does the thickness and physical structure of the scales. Intuitively I feel that this would lead to differential preservation of the scales of different species. Hake scales, for example, seem to fray away at the edges where their deeply etched circuli reach the edge of the scale. Pilchard scales are twice as thick as anchovy scales (Chapter II) and therefore would seem to be more robust. This becomes significant especially when the scales have undergone phosphatization which tends to make the scales brittle and puts the thinner anchovy scales at risk.

Comparison of the T-scales to total pilchard scale ratios found in the tank and in the grab samples shows that there is no differential preservation between pilchard T-scales and other pilchard scales. Differential preservation between pilchard and anchovy scales, however, still remains a possibility. De Vries and Pearcy (1982) looking downcore found the average anchovetta scale: vertebrae ratio in older sediments to be lower than in younger sediments. They also found a marked decrease in the average proportion of smaller scales in the older samples. Both these factors point to some destruction with time of anchovetta scales. This will be considered further in the next chapter.

Sample No	Approx depth*	Approx Wt % Organic Matter	Wt %* Opal	Faecal pellets	Large diatoms	Shell fragments	Phosphatization notable	Pilch	Anchov	Maasb	Hake	Snoek	Sole	Wt gms	Approx vol ccs	Total No Scales	Scales 100 mm Sample
3990	90–100	12–19	88	X		X		X	X	X	X	X		244	230	102	44
4033	120–130	19–24	±50	X		X	X	X	X	X	X	X	X	225	200	55	27
3773	90–100	7–12	88		X			X	X	X	X		X	193	180	110	61
3775	40– 50	4– 7	88		X			X	X	X	X		X	372	250	137	55
4031	100–110	12–19	88	X				X	X	X	X	X	X	215	220	108	49
3753	60–70	4	88		X		X	X	X	X		X		184	170	34	20

*Data taken from Bremner 1978

Table IV.1. Analysis of grab samples

Sample No.	Total No. Scales	Anchovy		Pilchard		Maasbanker		Hake		Snoek		Sole		Other	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
3990	102	12	12	41	40	18	18	12	12	7	7			12	12
4033	55	6	11	14	25	12	22	12	22	7	13	4	7		
3773	110	20	18	50	45	9	8	22	20			2	2	7	6
3775	137	18	13	26	19	6	4	67	49			14	10	6	4
4031	108	13	12	40	37	11	10	14	13	10	9	18	17	2	2
3753	34	3	9	16	47	8	24			5	15			2	6
TOTAL	546	72	13%	187	34%	64	12%	127	23%	29	5%	38	7%	30	5%

Table IV.2. Analysis of scales found in grab samples

Sample	Pilchard Scales		Anchovy scales scales		Total	P/A	T/Pilchard	X/Anchovy
	Total	T	Total	X				
3990	41	26	12	8	53	3,4	,6	,66
4033	14	8	6	3	20	2,3	,6	,5
3773	50	39	20	12	70	2,5	,8	,6
3775	26	18	18	8	44	1,4	,7	,4
4031	40	30	13	8	53	3,1	,7	,6
3753	16	14	3	-	19	5,3	,9	
TOTAL	187	135	72	-	259	2,5*	,7*	,56

*Excluding sample 3753G

Table IV.3. Pilchard and Anchovy scales in grab samples

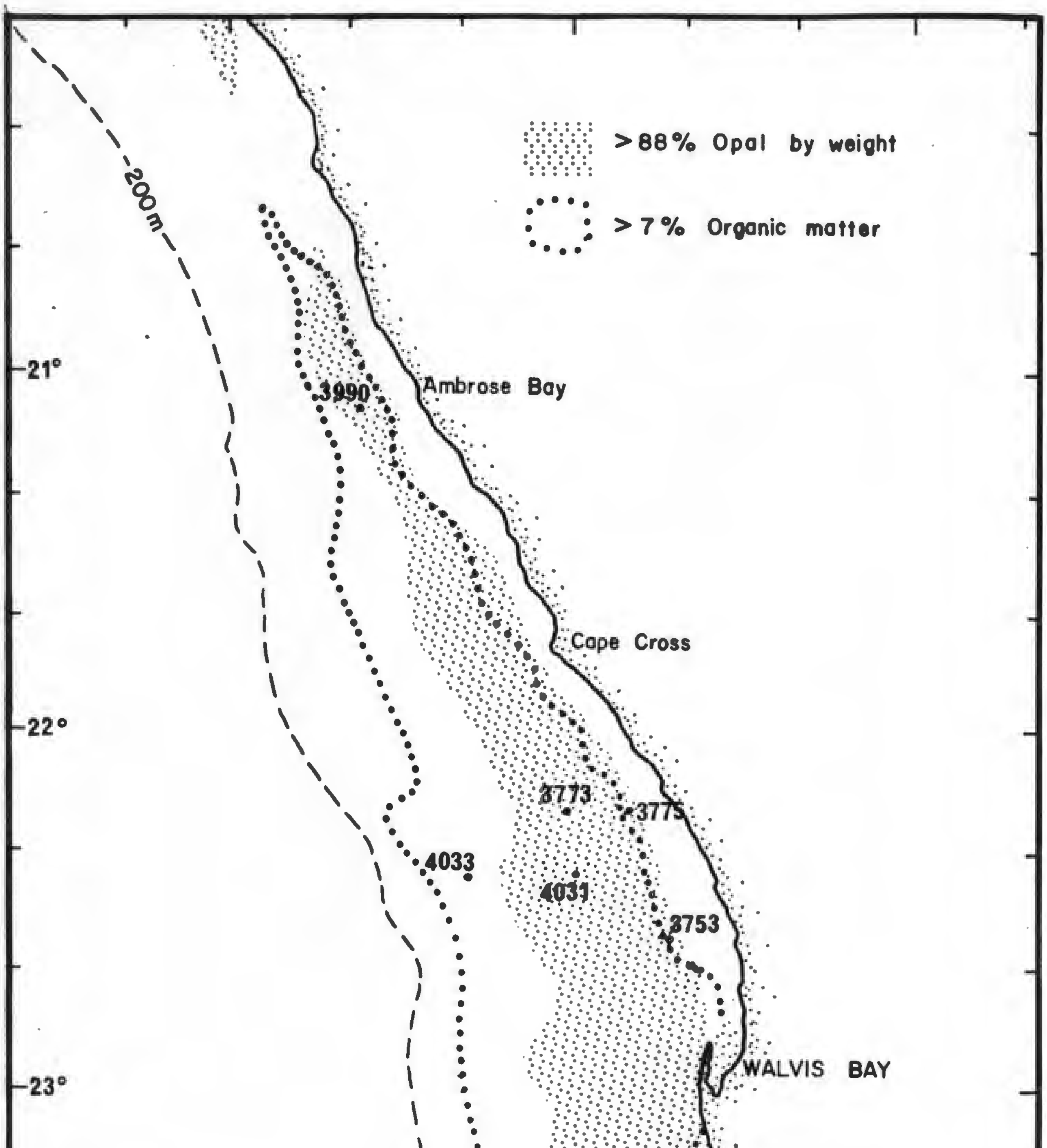


Figure IV.1 **The northern Namibian coastline showing the position of the diatomaceous mud belt (hatched) in relation to the sediments rich in organic matter.** The positions of the grab samples are indicated (After Bremner 1978)

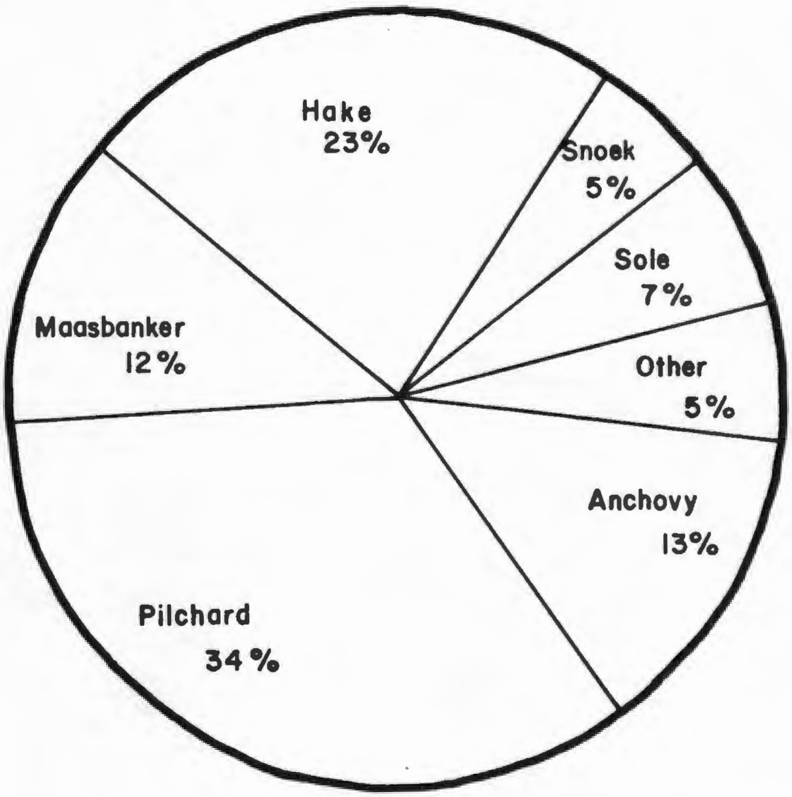


Figure IV.2 Diagram summarizing the percentages of the scales of different species found in the grab samples

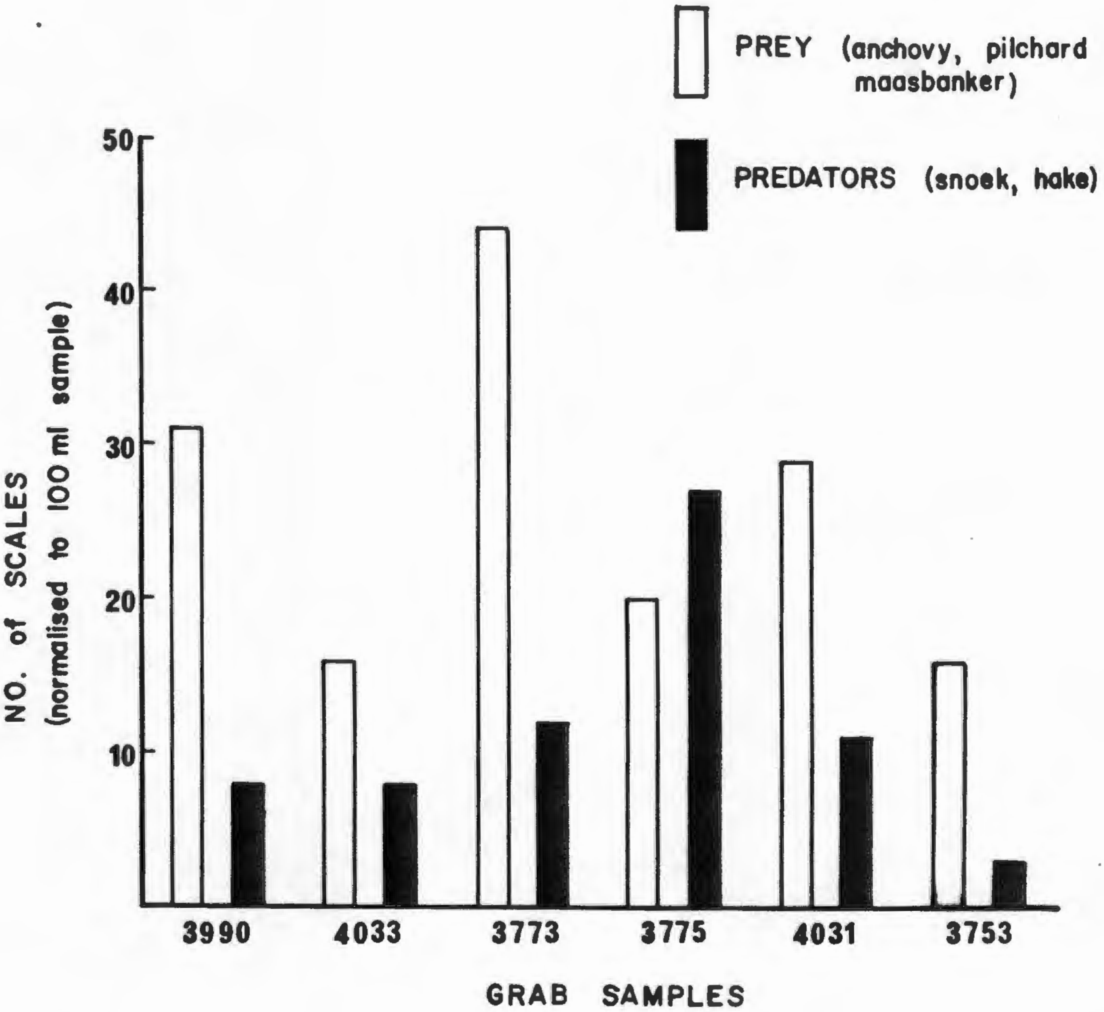


Figure IV.3 Numbers of predator and prey scales found in each grab sample

CHAPTER V

MARINE LAMINATED SEQUENCES

V.1. INTRODUCTION

Although fish scales had been reported from surface marine sediments as long ago as 1947 by David (Soutar 1967), it was Soutar and Isaacs of Scripps Institution of Oceanography who first explored their potential as historical indicators. In earlier Chapters I have considered some of the prerequisites that must be met before meaningful historical conclusions can be drawn from the sedimentary record. The scales must be correctly identified (Chapter II) and their relationship to the living fish populations understood (Chapters III and IV). An understanding of the degree of preservation is needed, both at the sediment water interface (Chapter IV) and downcore, and of paramount importance is the presence of an undisturbed sedimentary record so as to allow the examination of scales in discrete time intervals. In this chapter I shall look downcore at the diatomaceous muds collected off Walvis Bay in order to establish whether this last prerequisite is met.

V.2. EARLIER STUDIES OF MARINE LAMINATED SEQUENCES

Rhythmically laminated marine sediments are rare (Schrader et al 1980) but because of their potential for studying paleoenvironmental changes they have attracted much attention (Soutar 1971, Calvert 1966, Schrader et al 1980, Schrader and Baumgartner 1981, Soutar and Crill 1977). The main focus of attention has been the Santa Barbara Basin off the coast of California and the Guaymas Basin in the Gulf of California where laminated sediments were first collected in 1939 and 1940 (Calvert 1966). The first environmental prerequisite for the occurrence of laminated sediments is the existence of a stable oxygen minimum layer at the bottom of the water column (Calvert 1966). Low oxygen, less than 0,5 ml O_2/l, has the effect of excluding burrowing benthic organisms and is often the result of high productivity (Chapter 1). The second prerequisite is a rhythmically varying sediment supply.

Calvert (1966) discussed the laminated diatomaceous sediments in the Gulf of California in great detail. He found regularly alternating light coloured and dark coloured laminae approximately 2 mm thick. The light laminae contained more diatoms than the darker-coloured laminae. He suggested two possible origins for the laminations:

(1) A steady supply of fine-grained inorganic material (river runoff) interrupted seasonally by a mass of organic material produced by increased plankton production.

(2) A uniform supply of organic material from settling plankton with annual pulses of terrigenous material river runoff.

Based on his findings that the plankton supply was relatively steady compared to the very seasonal river input, and on the similarity between the diatom assemblages in the dark and light laminae, the predominance of opal in the light laminae, and the variable thickness and sometimes size-grading found in the darker laminae, he concluded that the seasonal influx of terrigenous material was responsible for the layering, and, furthermore, that the dark-light couplets were varves.

Soutar (1971) and Soutar and Crill (1977) have described layered sediments from the Santa Barbara Basin. Soutar (1967) ascribes the darker, denser layers to winter accumulation due to inorganic runoff from the winter rains and the lighter, less-dense layers to a higher percentage of diatom frustrules reflecting an increased organic production in the surface waters. The two layers are taken to represent a varve. In 1977 Soutar and Crill added another element to the theory of laminae formation. They reported a dense "mat" on the surface of the Santa Barbara Basin sediments. They tentatively identified its interweaving filaments as a sulphur-reducing bacteria, Beggiatoa. They relate the low-density characteristics of the lighter laminae to the formation of this mat. The open matrix of the mat would trap sediment particles and so form a less dense layer when sedimentation rates were sufficiently low as not to smother the bacteria, ie in early autumn.

Working off Peru De Vries and Percy (1982) found coarsely laminated and banded sediments incalcated with discontinuously laminated and bioturbated sediments. They made no attempt to call them varves or explain their formation, using them merely as an indication that no major reworking of the sediment has taken place.

In the same area Gallardo (1977) reported on the large coherent microbial communities living at the sediment-water interface below the low oxygen waters of the Peru-Chile Subsurface Countercurrent. He identifies the bacteria as Thioploca spp (related to Beggiatoa). He describes Thioploca as having "many individual filaments within a common sheath forming large, whitish-yellow, twine-like structures that attain 100-500μ in diameter and several centimeters in length, therefore perfectly visible to the naked eye"(p 331). Henrichs and Farrington (1984) also describe Thioploca-like fibrous bacteria in the surface sediments of the Peru upwelling region. They occur in diatomaceous ooze overlain by low-oxygen water. Copenhagen (1953) shows an illustration of similar-looking sulphate-reducing bacteria found in the bottom muds in the Walvis Bay region. Gallardo (1977) suggested that they might have an important role to play in the ecology of this and other similar upwelling regions. Their possible contribution towards the formation of laminations should not be overlooked.

V.3 LAMINATED SEQUENCES ON THE WALVIS SHELF

V.3.a Background

Based on the similarity of the Walvis shelf oceanographic regime to that of the areas discussed above, laminations could be expected to form in the diatomaceous muds underlying the low oxygen water described by Copenhagen (1953) and Hart and Currie (1960). In 1972 Gencor collected 51 cores from the diatomaceous mud-belt off Namibia. The Gencor core logs (seen by Rogers 1983) report laminated sequences in 21 of these cores. Rogers (1983) noted that the laminations tended to begin more than a metre below the present sea floor. Diester-Haas (1978) also found laminations in a single core recovered from off Swakopmund. Thomas (1980, 1982) collected 30 short box cores from the same muds but was unable to detect any laminations (possibly because of the limited penetration of his cores, the longest of which was about 50 cm long). In 1983 the Marine Geoscience Unit of UCT in collaboration with the Geological Survey (GSO) collected a further two cores using the GSO vibrocorer aboard the Sea Fisheries Research Institute vessel, R S Benguela. Laminated sequences were again found.

Bremner et al (1983) give a detailed description of the recovery of these cores. One of the problems in working with laminated sequences is how to keep them from being disturbed during collection and sampling. This was not possible with the top of the cores which were slushy and had to be stored separately in ready-made plastic containers. Below about 50 cm from the top, the sediment was sufficiently consolidated to hold its shape. Extrusion from the cores was accomplished in the following manner. One side of the core barrel was removed whilst it was resting in a specially constructed cradle. The core was loosened from the barrel using a knife, and a partially constructed perspex core box was inserted into the corer which was then inverted over the box. In this way the sediment was transferred, undisturbed, from the core barrel to the perspex storage box which was then sealed and stored at 2°C. These two cores form the basis of a series of investigations by the Marine Geoscience Unit. The coarse fraction of both cores SF7 and SF14 was looked at in this study, but the more detailed analysis concentrated on SF14.

V.3.b Core SF14

Core SF14 was taken at 22° 40,1'S, 14° 00,1'E in water 125 m deep. Its position relative to the mud belt is shown in Figure V.1.

The onboard core description from Bremner et al (1983) is given below.

No.	Nearest place name	Downcore length (m)	Description
SF14	Walvis Bay	0-0,25	Sloppy diatom mud with unbroken, disarticulated bivalves
		0,25-0,50	As above, but only shell fragments
		0,50-1,60	Soft diatom mud with minor shell fragments

A more detailed description is presented in diagram Figure V.2.

Most of the core consisted of three shades of olive green diatomaceous ooze. A light yellowish green mud accounted for less than 10% and the blackish olive green mud for 15-20% of the core. The remaining 70% of the mud was a medium olive green colour. Shell fragments formed sharp white blobs in the mud and were more prevalent in the upper part of the core. Contacts between the different coloured muds were of three kinds: i) slow gradational from dark at the top to light at the bottom; ii) sharp at the upper limit of such gradational sequences; iii) indistinct and swirling sometimes over a vertical distance of as much as 4 mm but mostly over 1-2 mm.

The finely-laminated sequences are to be found at the bottom of the core starting at a depth of about 130 cm from the surface. The clearest laminations are between 142 and 153 cms depth downcore, but even these are difficult to trace and count. Estimates of the number of laminae per centimetre vary from 6 to 11 but average out at 7,7. Laminae of all three shades of green are present but it is very difficult to detect a cyclic correlation between the colours. The medium green is dominant alternating with the pale yellow green. Concentrations of darker laminae occur at approximately 2 cm intervals, and in two cases (at 144 and 146 cm) the darker laminae overlie the lighter laminae unconformably, cutting across 2 or 3 of them. The darker laminae appear to be less continuous than the other laminae on the whole, but some dark bands do run right across the core. Contacts between laminae are fairly even but some microstructure (of the order of 0,3 mm) is present.

A thin section of the core, cut perpendicular to the laminae shows the colour changes to be due to the presence or absence of an amorphous yellowish-greenish-brown material. Diatom frustules form the bulk of the core and minute salt grains are scattered through this background. A few grains of quartz and mica are also present. Large faecal pellets up to 3 mm long are evident in varying stages of integrity. These are also composed almost entirely of diatom frustules and are detectable because of a difference in colour of the organic matrix around the diatoms. Streaks and blobs of a dark, reddish-brown amorphous material are found in the darker laminae and often seem to accrete around a faecal pellet.

The coarse fraction of the core (less than 1% by volume) consisted mainly of fish scales and bones, some mollusc shell fragments, large diatoms and pteropods and long fibrous threads. These could be bacteria such as the sulphate reducing Beggiatoa described by Soutar and Crill (1977) or Thioploca (Gallardo, 1977). Very little is known about the necessary conditions for the growth of Thioploca (Henrichs and Farrington 1984) except that they occur on the sediment-water interface in anoxic areas and it is suspected that they are important in the cycling of carbon, nitrogen and sulphur in the sediments.

V.3.c The formation of laminations in SF14

There are a number of factors to be considered when suggesting a causal mechanism for the laminations in the muds off Walvis Bay:

i) variations in productivity;
ii) the role of Thioploca
iii) possible cyclical terrigenous input
iv) variations in the plankton species making up the sediment.

Variations in productivity are associated with seasonal upwelling cycles. The upwelling maximum in this area occurs in late winter and spring (Shannon 1985). The upwelled nutrient-rich water would result in massive plankton blooms in the euphotic zone and an abundant rain of sediments to the ocean floor. The cycling of carbon and nitrogen by sulphate-reducing bacteria would not be as efficient under these circumstances as when the fluxes were lower. This could result in layers formed by alternating bands in which organic material has been more or less well cycled. This could explain the presence or absence of the greenish amorphous material seen in thin section to be the cause of the colour layering. Thioploca would contribute to the formation of laminations both by forming a mat which stabilizes the accumulating particles, and by reducing this accumulating organic material when not smothered by the great flux.

The possible effect of seasonal terrigenous imput to the sediments should also be considered. The diatomaceous muds contain a very low percentage by weight of terrigenous material, less than 10% (Bremner 1978), the majority of it being in the very fine sand-size fraction. This is as would be expected from a consideration of the terrigenous input to the sediments from the arid Namibian coast. Unlike the Gulf of California region there is no regular annual river runoff here. River runoff is episodic, with at most an annual flushing. Exceptional flooding occurs on a time scale of decades. Wind-blown sand and dust could form a seasonal input into the marine sediments. Shannon (1985) describes the occurrence of "berg" winds during autumn and winter which have been shown on satellite photographs to transport sand and dust out to sea to a distance of over 150 km. Any seasonal effect resulting from these winds in the sediment is likely to be filtered out in the settling of such fine material through the water column. The very arrival of fine particles at the bottom of the sea is dependent on their being incorporated into larger particles such as faecal pellets (Dunbar and Berger 1981, Fowler and Small, 1972).

Pokras and Winter (1985) have recently completed a study of the diatom assemblages in the laminae of core SF14. They find neritic species, mainly Delphineis karstenii, dominant in the lighter laminae and the cosmopolitan species, Thalassiosira excentrica s.l., more abundant in the darker laminae. They suggest that the neritic species in the lighter laminae are indicative of the presence of upwelled waters, whereas the more oceanic species occur in times of less intense upwelling. Darker and lighter laminae would reflect seasonal changes in upwelling and could be considered as varves.

Until the top and bottom of a laminated sequence have been dated, we cannot be sure that the laminations are varves. At the estimated sedimentation rate of 2-3 mm per year (Bremner 1983, Johnson, pers. comm.) 3-5 varves per centimeter would be expected. This is in accordance with the 7,7 laminations per centimetre counted in SF14. In this region so dominated by seasonal upwelling a seasonal cause for the laminations is very likely. The annual alternation between the highly productive, cold, upwelled waters present in late winter and spring and the intrusion of warmer Angolan and Oceanic waters in summer is bound to be reflected in the sediments.

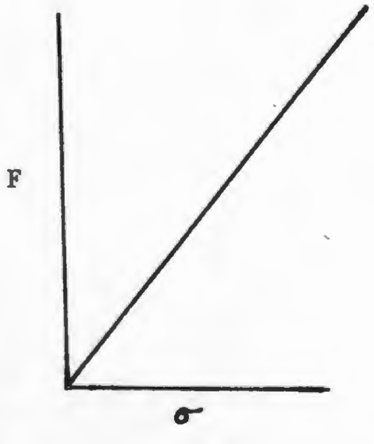
It seems reasonable to conclude that the laminations in SF14 do represent varves and that the sequence from 133 cm to 160 cm has accumulated steadily over a period of about 108 years. Only minor local unconformities have been detected effecting two to three laminations, one to two years, a time interval unfortunately too fine for detection in the fish scale study.

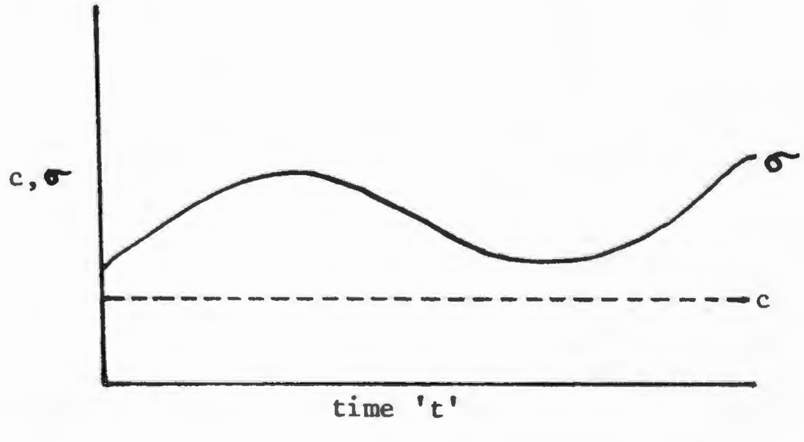
V.3.d Sedimentation and the accumulation of fish debris

Consideration of the sediments off Walvis Bay has shown them to be almost exclusively of planktonic origin. Unlike those in the Californian Basins, even the laminations may result from variation in the phytoplankton.

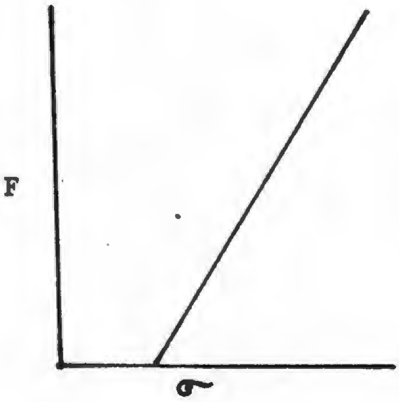
Several models of the relationship between sedimentation rate and the accumulation of fish debris can be constructed based on the tightness of their response to varying primary productivity. Let 'F' be the number of fish producing a concentration of scales 'c' in sediments accumulating at a sedimentation rate 'σ'. F is preseumably proportional to the scale flux (scales/cm /yr); so c is proportional to f/σ .

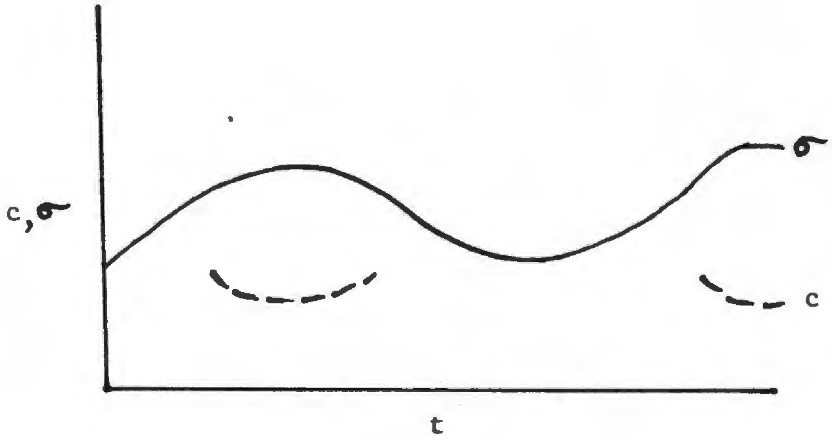
Model 1. The number of fish is linearly related to primary production and, hence, to sedimentation rate.



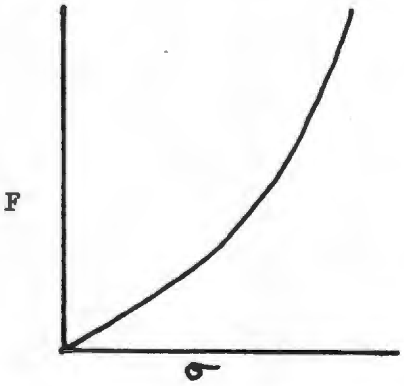


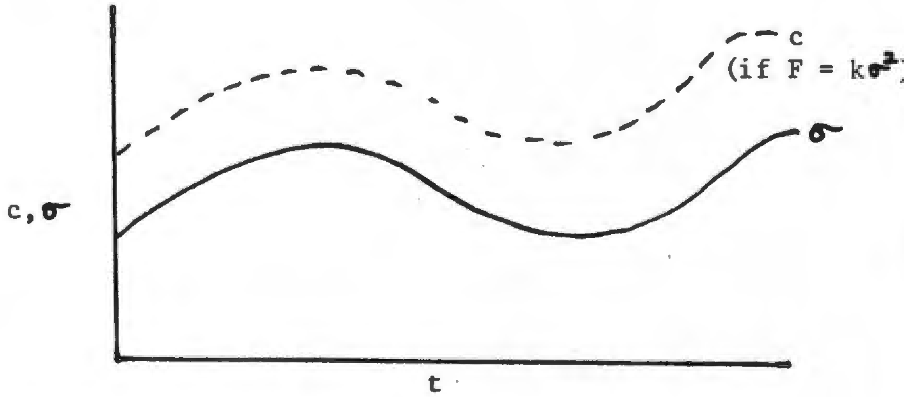
Model 2. The number of fish is linearly related to sedimentation rate, but with a threshold.





Model 3. The number of fish is non-linearly related to the sedimentation rate.





Fluctuations in the sedimentation rate are amplified in the scale concentration fluctuations.

Clearly, variations in sedimentation rate must be taken into account when looking at fluctuations in fish scale concentrations.

The sediments form the historical framework within which population variations are sketched. Understanding of the processes of sedimentation is intimately related to any understanding of population fluctuations recorded in the sediments.

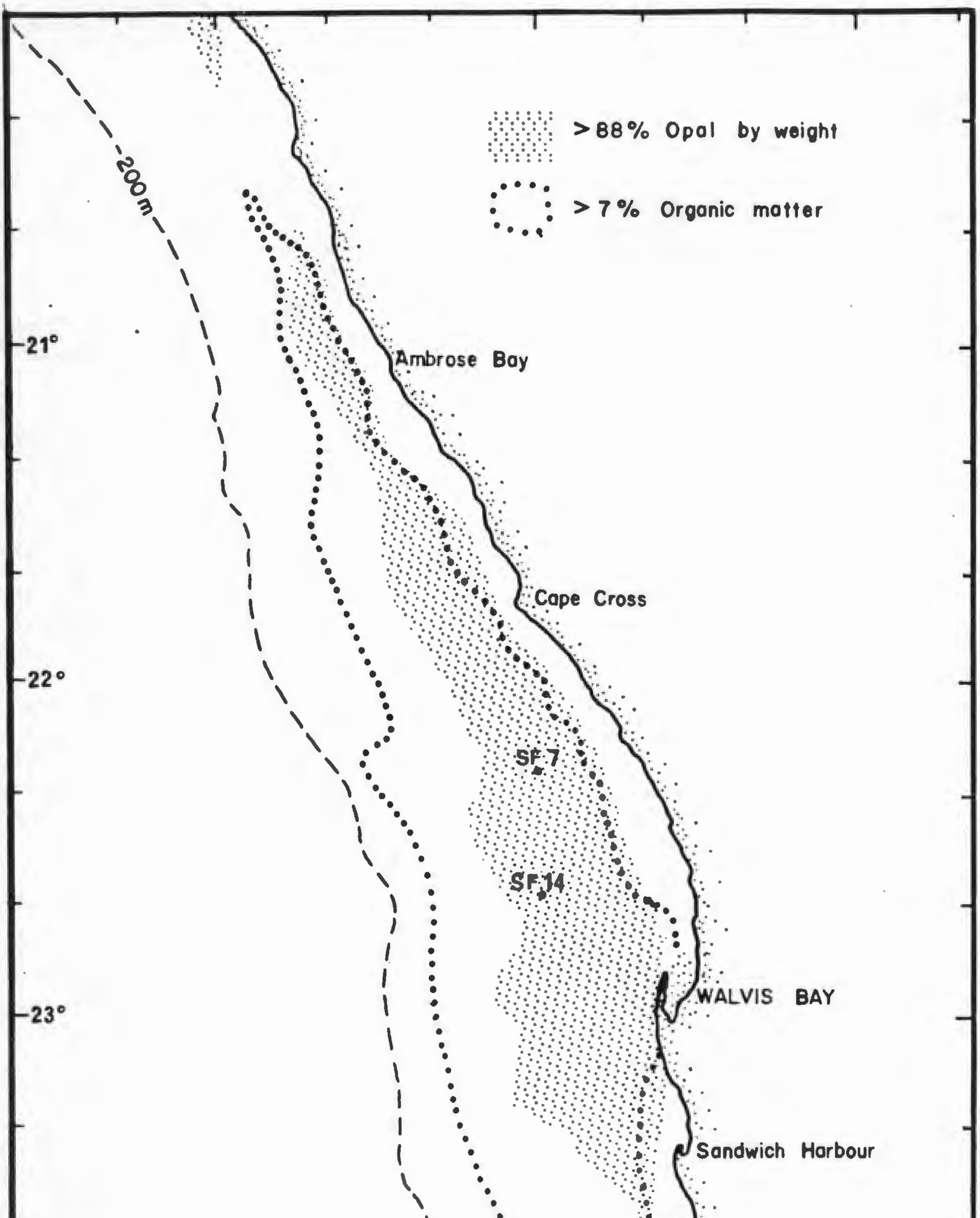


Figure V.1 Location of cores SF7 and SF14

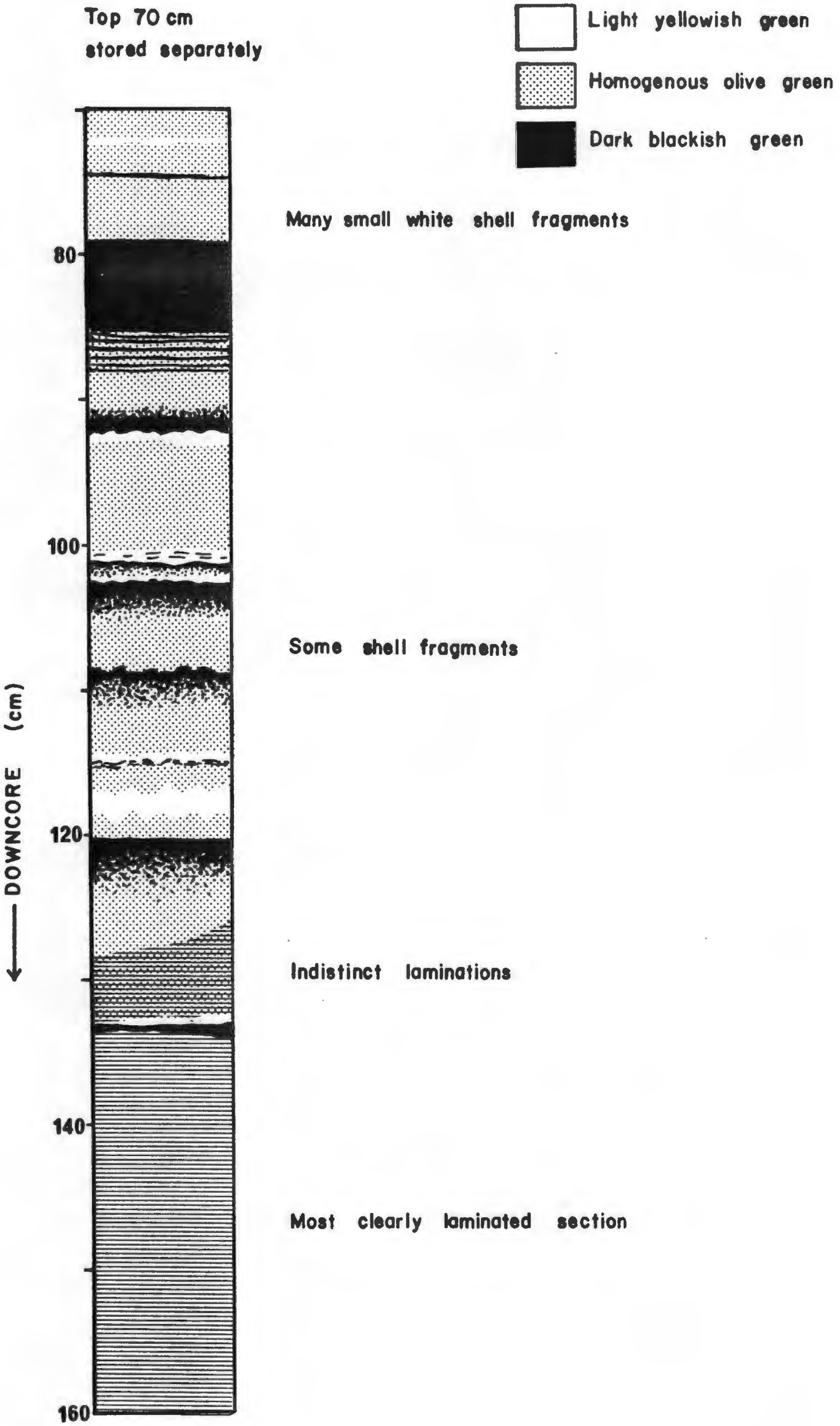


Figure V.2 Core SF14

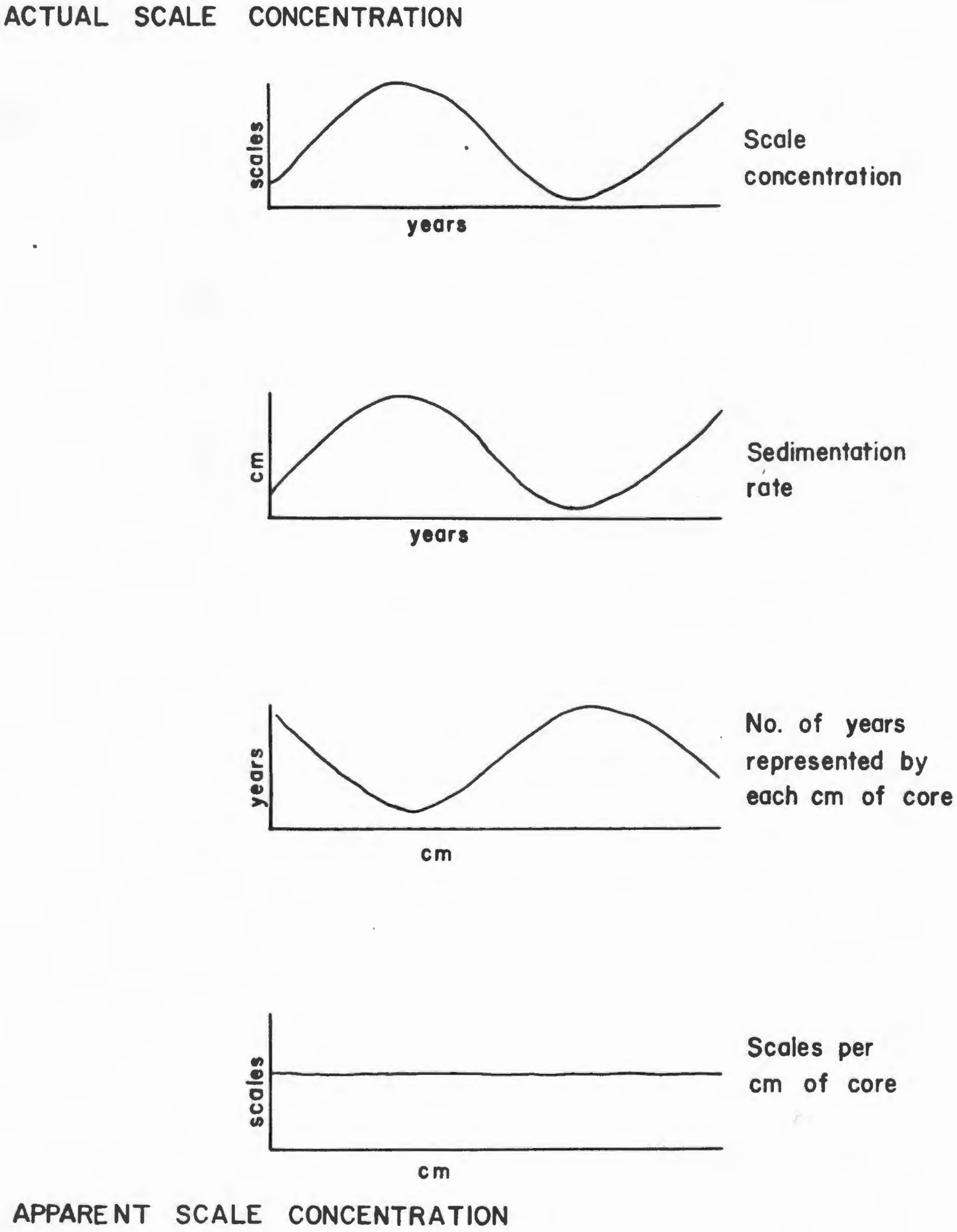


Figure V.3 Hypothetical plot showing how scale number fluctuations can be masked

CHAPTER VI

SCALES IN THE SEDIMENTS 2. CORES

VI.1. INTRODUCTION

The stage is now set for looking at the cores taken in the diatomaceous muds off Namibia to see whether they hold any potential for ellucidating past fish populations. In order to establish the presence of scales at depth in the muds, scale counts were initially carried out in two of the cores, SF7 and SF14. I followed this up by a detailed analysis of the scales in the laminated section of SF14. Although the quantity of sediment looked at in each case is small, the data obtained are able to contribute significantly to the discussion on scale preservation in the sediments. An enticing glimpse of past fish populations is also given, showing the potential of even a cautious analysis of scale data.

VI.2 SAMPLE TREATMENT

The method of subsampling the cores was carefully devised so as to reduce the possibility of sampling across time boundaries. (Figure VI.1 summarizes the treatment of samples). Each 10 cm x 10 cm x 90 cm core was sliced into 1 cm x 10 cm x 90 cm slabs. This not only gave greater control when sampling time intervals but the slabs were also easier to handle, photograph and X-ray. The slabs were stored at 2°C in perspex slab boxes sealed with waterproof packaging tape for later sub-sampling. Seven slabs were cut off core SF14. One was incomplete, one was stored for archive purposes, one reserved for a separate fine fraction study and four slabs were made available for this study.

Before subsampling the slabs further I photographed each slab in black and white. Attempts to use filters to enhance the colour contrast of the laminations were unsuccessful. A test X-ray of the core did not increase the visual contrast of the laminations either.

In order to correlate from slab to slab as accurately as possible while subsampling, I lined up each slab using a distinctive dark layer at 130 cm depth as a marker. 1 cm slices were cut off each slab parallel to the laminations. Each subsample was stored in a self-sealing plastic sachet, labelled and weighed. Analysis of each of the four subsamples was done separately. If no major differences between subsamples at a particular level were apparent, I felt confident to add the separate counts to constitute a single data set for that level. This method provided a control against possible inclination of the laminations with respect to the core.

The coarse fraction was separated in the same way as described for the grab samples (Chapter IV) and the scales were mounted and identified using the methods described in Chapter II.

VI.3 RESULTS

The scales found in portions of the two cores collected by Bremner et al (1983) were counted. A simple count of scale distribution with depth was made on a 1 cm x 1 cm x 10 cm slab taken from core SF7 (22° 25,0 S and 14°03,0 E depth 103 m). (The coarse fraction from these samples was supplied by R Herbert who is working on the distribution of foraminifera down core). A more detailed analysis of 1 cm x 4 cm x 10 cm slabs of sediment from the laminated section of core SF14 forms the major part of this study.

The results are presented in Tables VI.1, VI.2 and VI.3.

VI.4 DISCUSSION

VI.4.a General

Well preserved, often intact scales are found distributed downcore in both SF7 and the laminated interval of SF14. Table VI.4 shows a comparison of the number of scales per 100 ml of sample at three depths in each core (top, middle and bottom) with the number of scales found in the grab samples. Scales per 100 ml in the top, middle and lower thirds of Soutar's cores from the Santa Barbara Basin (Soutar 1967) are also presented for comparison.

The number of scales per 100 ml in the grabs ranges from 20 to 61 and those in the Namibian cores from 5 to 29. Although these ranges overlap there do seem to be fewer scales downcore than in the surface sediments. Averaging out over all the grab samples and over each core gives:

	Scales/100 ml sample	Pilch & Anch/100 ml sample
Grabs	44	21
SF14	14	7
SF7	10	8
Soutar	63	10

VI.4.b Preservation

There are several possible explanations for the reduced number of scales in the cores. Discounting possible winnowing during the recovery of the grab samples, the simplest is that there were fewer fish thus contributing fewer scales in the historic time periods looked at in the cores. A second explanation assumes approximately similar fish stocks contributing scales to the sediment, but a scale loss during burial time or sample treatment. The first explanation can only be true if we can satisfactorily disprove the second, that is, prove that there is no scale loss between deposition and counting.

In Chapter IV I used a comparison of the ratios of pilchard T-scales to total pilchard scales in both the tank experiments and the grab samples to show that pilchard scales do not seem to be destroyed in the sediment. The same can be done downcore. The average ratio of ,7 is again found.

	PT/Total pilchard
Tanks (ave)	,7
Grabs (ave)	,7
SF14 upp	,7
SF14 mid	,8
SF14 bot	,6
SF 7 upp	,7
SF14 mid	,6
SF14 bot	,6

That pilchard scales are preserved downcore can be seen from their appearance. Of the total of 107 scales found in the Namibian cores 70 are in near-perfect condition even after going through the rigors of sample treatment.

The same cannot be said for anchovy scales. Of the 21 anchovy scales found only one was undamaged. Nine scales were partially incomplete being either large fragments or having lost parts of the scale between the cracks. The remaining 11 anchovy 'scales' identified were nothing more than identifiable fragments.

In Chapter IV I suggested that the small, ragged-edged hake scales might also be easily broken up in the sediments or during sample treatment. Phosphatization (which was noticeable in some of these) would increase their brittleness. De Vries and Pearcy

(1982) comment on the decrease in the average proportion of smaller scales in older samples. This supports the idea that the small hake scales do not survive as well as larger scales. Contrary to this however, Soutar and Isaacs (1969) found an increase in hake scales with depth, It is also possible that the paucity of hake scales counted in the Namibian cores is an artifact of the sample preparation. Most hake scales are much smaller than the average pilchard or anchovy scale and could therefore be more easily lost in a sieving and selecting process.

Scale counts downcore indicate that the more robust pilchard scales are well preserved over the passage of time. Anchovy scales are likely to be fragmented so some loss can be expected. Unidentifiable fragments are found in some slices in both cores. These fragments usually appear to be of clupeoid scales but could not be identified as either pilchard or anchovy. In the light of the discussion on scale preservation I feel that it is reasonable to assume that these scale fragments probably represent the remains of at least one anchovy scale. I have therefore amended the scale counts by adding an anchovy scale at each level where fragments are found, provided no larger fragment of anchovy had already been identified at that level (thus obviating identifying two fragments from the same scale as two scales). Table VI.4 can be amended to Table VI.4.a, and the averages over all the cores and grab samples becomes:

	Scales/100 ml sample	P + A scales/100 ml sample
Grabs	44	21
SF14	15	8
SF 7	12	10
Soutar	63	10

A comparison can now be made of the proportions of the scale types integrated through all the grab samples and over the laminated range of SF14. (SF7 underwent different sample treatment which seems to have resulted in a loss of smaller scales. It will accordingly be excluded from the more detailed discussion.)

	Grab samples	SF14
	%	%
Pilchard	34	39
Anchovy	13	16
Hake	23	14
Maasbanker	12	16
Snoek	6	8
Sole	7	2
Other	5	5

Integrated proportions of scale types in the core and grabs are seen to be very similar with the exception of the percentage of hake scales. Because of their small size and potentially weaker structure, hake scales may have been preferentially lost between deposition and counting. If clupeoid fragments are accepted as being derived from anchovy scales, there seems to be little evidence for any other differential loss of scales with time.

Preservation can also be considered by looking at the variation of the scales/bones ratio downcore. In Table VI.5 intervals of 4 cm are grouped together and ratios calculated.

The ratio of the total scales to total pteropod shells counted is also presented. Pteropods tend to be abundant in upwelling regions. They feed on phytoplankton and detritus and Bé and Gilmer (1977) report the close association between pteropod abundance, seasonal plankton blooms and nutrient levels. Thus conditions favourable for supporting fish populations are also favourable for pteropods, and possible differential preservation or sorting would be detectable by variations in this ratio. Both ratios are remarkably constant down the core showing no trends to indicate any significant degradation of scales over the interval considered (100-120 years).

In conclusion, based on the small volume of core material analyzed it is difficult to quantify whether there has been an overall loss of scales between deposition and counting. Pilchard scales appear to survive with no significant loss, and, if fragments are included in anchovy scale counts, so do the thinner anchovy scales. Hake scales are preferentially lost, probably because of their small size. The other scales comprise similar proportions of both the grabs and the core. Implications of this study on preservation are that caution should be exercised in extrapolating from scale numbers to absolute populations, but that comparisons between populations (excluding hake) based on scale counts would appear to be valid.

VI.4.c Downcore analysis of SF14

Graphs of the concentrations of scales, bones and pteropods downcore are presented in Figure VI.2a, b and c. As I discussed in chapter V, concentration is equal to flux divided by sedimentation rate. If sedimentation rate varies down core, the variations shown in Figure VI.2 may not result from changes in flux.

In principle, sedimentation rate in a laminated interval is obvious - it is equal to the thickness of the lamina. However, as I mentioned in chapter V, lamina are difficult to follow in SF14. As a test, I repeatedly counted two intervals of the core which appeared to have different sedimentation rates:

Periods of	Slices	Laminae/cm	Confidence 2
High sed. rate	149-152	8,2	2,2
Low sed. rate	141-143	6,7	3,0

At a 95% confidence level the variation in laminae per centimetre between the two contrasting periods is not significant. Accordingly I feel that it is reasonable to plot concentrations downcore with confidence that variations in the sedimentation rate will not mask variations in scale fluxes.

Some form of simple statistical treatment is needed to enhance the trends and eliminate random fluctuation. A simple test of whether normal statistics can be applied to the scale counts is shown in Figure VI.3. Scale frequencies are clearly not normally distributed. A more useful way of looking at the data is to do a running sums (Table VI.6).

Figure VI.2d shows a trend analysis of running sums of seven for scales, pteropods and bones. Fluctuations are smoothed out and general trends become obvious. Numbers of bones, scales and pteropods all increase with depth, bones having the most steady increase. Pteropods increase gently but this increase levels off in the middle of the laminated section and a slight decrease in numbers is apparent before the final steep increase. Fish scale numbers are the most variable, increasing in two steps to a local maximum in the middle of the section considered. They remain level before dipping steeply to a sharp minimum in the lower third of the interval. The numbers then increase sharply at the bottom of the core. The running sums also reveal clearly that the pteropods and fish scales show similar distribution patterns downcore. Bones and scales also show the same broad trends except for one period just beyond half-way down when bones continued to increase as scales decrease with depth.

Figure VI.4 shows the downcore counts of scales, bones and pteropods smoothed by running sums of four. Superimposed on the general decrease in scales upcore, four peaks in fish scales are still apparent after smoothing. It would seem that the fish populations are varying cyclically with a period of 6 cm between minima (equivalent to about 24 years at a steady sedimentation rate of 2,5 mm/year). The same periodicity is not evident in the distribution of the bones or pteropods.

Running sums of three were selected to present the variation in the pilchard and anchovy scales downcore (Figure VI.5). Scale numbers, particularly for the anchovy, are very low and thus only broad generalizations can be made. Over the laminated period considered both pilchard and anchovy appear to have declined. The trend is more evident in the pilchard which shows variations in decreasing amplitude against a steadier smaller number of anchovy scales.

Over the period spanned in the laminated section of SF14 the number of pilchard scales decreases sharply over the first 4 cms deposited. The slower concurrent decrease in the anchovy scales continued for another 2 cms, then, with this lag, the anchovy increased reaching a peak some 3 cms after the pilchard peaked. This anchovy peak coincides with a pilchard minimum. The next pilchard maximum is at the same time as the following anchovy minimum. Pilchard then decrease steadily for another 4 cms. Anchovy again show a concurrent but slower decrease. The last 7 cm deposited show similar steady pilchard and anchovy populations co-existing at a much reduced level than at the start of the period. The trend in the anchovy population appears to lag behind the pilchard trend. The population dynamics evident in the graph show two distinct phases which are repeated. A population decline phase - sharper for pilchard than for anchovy, but continuing longer for anchovy, and a possible flip-flop phase after these periods of sharp decline, when pilchard and anchovy populations replace each other.

Table VI.7 shows the P/A scale and P/A population ratios based on summed intervals of 3 cm downcore. (3 cm intervals were chosen to improve statistics and in an attempt to avoid masking the 6 cm cycle detected in the fish scale counts). Figure VI.7 shows a plot of the $\log_e$ P/A biomasses over the laminated interval based on Table VI.7. (The correction to biomass was made by taking the relative numbers of scales and relative average weights of pilchard and anchovy into account).

The cursory look at this one window of time downcore has shown that although the pilchard appear to predominate off Namibia, there has been at least one prehistoric period when anchovy were more plentiful than pilchard.

Table VI.1. Distribution of scales downcore in SF7

Depth downcore cm	Pilchard T	Pilchard Other	Anchovy	Other species	Fragments
133	1			hake	
134	2	1			X
135	2				
136					X
137	1				
138					
139	3				
140	2				
141		3		hake	
142					
143	1			maasb	
144	1	2			X
145	1			unident,maasb	
146	1				
147					
148	1				
149					
150	1		1		X
151		1		hake	
152	1				
153		1			X
154	1		1		
155		1			
156	1	1			
157					
158					X
159					
160					
161					

continued/

Depth downcore cm	Pilchard		Anchovy	Other species	Fragments
	T	Other			
162					
163					
164		1			
165	1				
166	2				
167					
168					
169					
170					X
171					
172					
173					X
174					
175					
176	1	1			
177		1			X
178					
179					
180	1				
181		2			
182	2	1			
183					
184					
185					
186	1				
187					
188	1			sole	
189	1				X
190					X
TOTAL	30	16	2	7	

Table VI.2. Distribution of scales downcore in SF14

Depth downcore cm	Pilchard		Anchovy	Other species	Fragments
	T	Other			
133					
134	1				
135	1				X
136					
137	1	1		2	
138			2	2	X
139		1		2	
140					
141		1			
142				3	X
143	1		2	7	
144	2	1		3	X
145	2		1	2	X
146	2				X
147			2	5	
148	2	1		2	
149	4			6	X
150	3		1	6	X
151	2			3	
152	1	1		2	
153	1	1		1	X
154	1			2	X
155	1			5	X
156	2	3	1	1	X
157	1	2	1	7	
158	6	1	2	3	
159	7	5	5	4	
160 (incomplete)	1	1			
TOTAL	42	19	17	68	

Table VI.3. SF14 Distribution of total coarse fraction downcore

Depth	Pilch.	Anch.	Hake	Maas.	Snoek	Other	Pterop.	Other Mollus.	Radiol.	Fish Bones	Bacteria
133							14			3	X
134	1						11	2		2	X
135	1	F					17		2	3	X
136							17				X
137	2		1	1			22				X
138		2	1	1			18			3	X
139	1			1	1		8	1		2	X
140							23		1	2	X
141	1						20				X
142		F	1	2			24		1	2	X
143	1	2	1	4	1	1	21	2		1	X
144	3		2			1	31	1		3	X
145	2	1		1	1		33	2	1	3	X
146	2	F					47	1	3	3	X
147		2	2	2		1	46	6		3	X
148	3			2			30	5	1	2	X
149	4	F	3	2	1		36	7		2	X
150	3	1	2	1	2	1	34	8	1	8	X
151	2			1		2	28	5		3	X
152	2				1	1	34	8		1	X
153	2	F				1	42	1		7	X
154	1	F		2			17	6	1	6	X
155	1	F	2		2	1	30	3		6	X
156	5	1	1				23	3	2	3	X
157	3	1	2	1	4		69	9	2	10	X
158	7	2	1	1		1	172	22	2	8	X
159	12	5	2	2			71	20	1	5	X
(160)	2						22	2		6	X
TOTAL	61	17	21	24	13	10	10 959	114	18	97	

	Total scales	P&A scales	P&A scales/ Total scales	P scales	A scales
3990	44	23	0,52	17	5
4033	27	10	0,37	7	3
3773	61	39	0,64	28	11
3775	55	18	0,34	10	8
4031	49	24	0,49	18	6
3753	20	11	0,55	9	2
SF14 top	5	3	0,60	2	1
SF14 mid	15	7	0,47	5	2
SF14 bot	29	19	0,66	14	5
SF7 top	16	13	0,81	13	-
SF7 mid	6	6	1,00	6	-
SF7 bot	6	6	1,00	6	-
Soutar top	18	7	0,39	1	5
Soutar mid	31	9	0,29	2	7
Soutar bot	42	14	0,33	2	12

Table VI.4. Comparison of number of scales per 100 ml sample

	Total scales	P&A scales	P&A scales/ Total scales	P scales	A scales
3990	44	23	0,52	17	5
4033	27	10	0,37	7	3
3773	61	39	0,64	28	11
3775	55	18	0,34	10	8
4031	49	24	0,49	18	6
3753	20	11	0,55	9	2
SF14 top	6	4	0,67	2	2
SF14 mid	16	8	0,50	5	3
SF14 bot	29	19	0,66	14	5
SF7 top	18	15	0,83	13	2
SF7 mid	7	7	1,00	6	1
SF 7 bot	9	9	1,00	6	3
Soutar top	18	7	0,39	1	5
Soutar mid	31	9	0,29	2	7
Soutar bot	42	14	0,33	2	12

Table VI.4a. Comparison of number of scales per 100 ml sample - corrected by adding in anchovy scale fragments

Slices	Total scales Total Bones	Total scales Total pteropods
136 - 139	$\frac{11}{5}$ = 2,2	$\frac{11}{65}$ = 0,17
141 - 143	$\frac{15}{5}$ = 3,0	$\frac{15}{88}$ = 0,17
144 - 147	$\frac{21}{12}$ = 1,8	$\frac{21}{157}$ = 0,13
148 - 151	$\frac{31}{15}$ = 2,1	$\frac{31}{128}$ = 0,24
152 - 155	$\frac{19}{20}$ = 1,0	$\frac{19}{123}$ = 0,15
156 - 159	$\frac{51}{26}$ = 2,0	$\frac{51}{335}$ = 0,15

Table VI.5. Ratios of scales/bones and scales/pteropods downcore in SF14

Slice	Original No of scales	Running groups of					
		twos	threes	fours	fives	sixes	sevens
133	0						
134	1*	1	2				
135	1*	2*	2	2	6		
136	0	1	5	6	11	11	14
137	4	4	9	10	13*	14*	14
138	5*	9*	12*	12*	12	13	14
139	3	8	8	12*	13*	13	16
140	0	3	4	9	12	16	26
141	1	1	4	7	17	22	28
142	3	4	14	14	20	23	28
143	10*	13	19	20	25	25	28
144	6	16*	21*	24*	27	28	35
145	5	11	14	24*	31*	34	39
146	3	8	15	21	26	36	47*
147	7*	10	15	20	31	37	47*
148	5	12	23	26	36	41	46
149	11*	16	26*	33*	38*	41	45
150	10	21*	26*	31	35	42*	46
151	5	15	19	30	34	39	43
152	4	9	13	23	27	38	38
153	4	8	12	17	24	34	41
154	4	8	15	19	26	31	42
155	7	11	18	22	33	37	49
156	7	14	25	29	41	45	66*
157	11	18	30	37	58*	62*	
158	12	23	44*	51*			
159	21*	43*					

* local maxima

Table VI.6. Trend analysis of scale counts downcore

Slices	P Scales	A Scales	P/A Scales	P/A No. of fish	Corrected P/A biomass	Log_e P/A biomass
134 - 136	2	1	2,0	0,60	1,6	0,47
137 - 139	3	2	1,5	0,48	1,2	0,18
140 - 142	1	1	1,0	0,32	0,8	-0,22
143 - 145	6	3	2,0	0,64	1,6	0,47
146 - 148	5	3	1,7	0,54	1,35	0,30
149 - 151	9	2	4,5	1,44	3,6	1,28
152 - 154	5	2	2,5	0,80	2,0	0,69
155 - 157	9	3	3,0	0,96	2,4	0,88
158 - 160	19	7	2,7	0,86	2,2	0,79

Table VI.7. P/A scale and P/A population ratios downcore in SF14

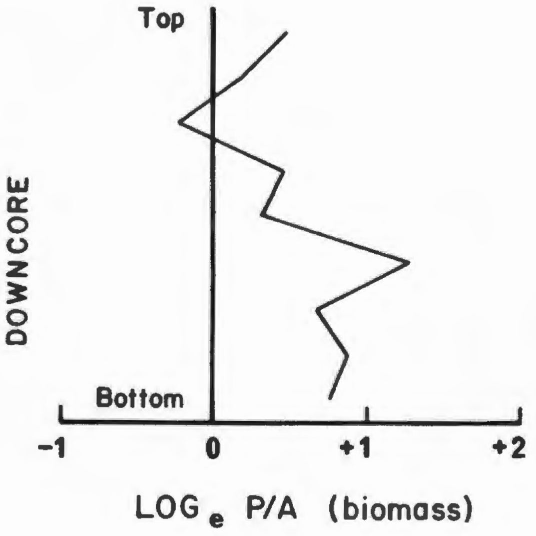


Figure VI.7 Downcore variation in Log_e P/A (biomass)

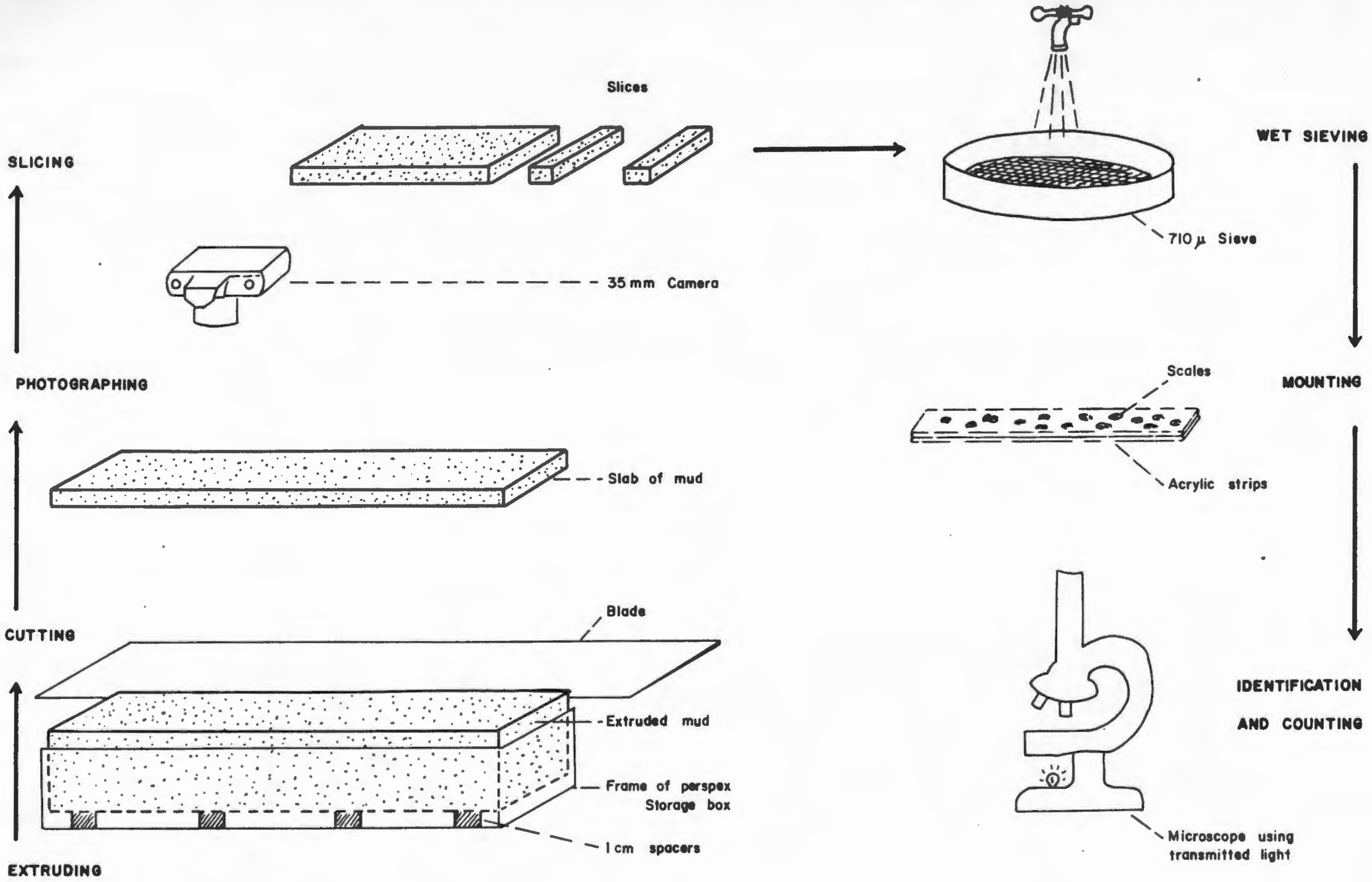
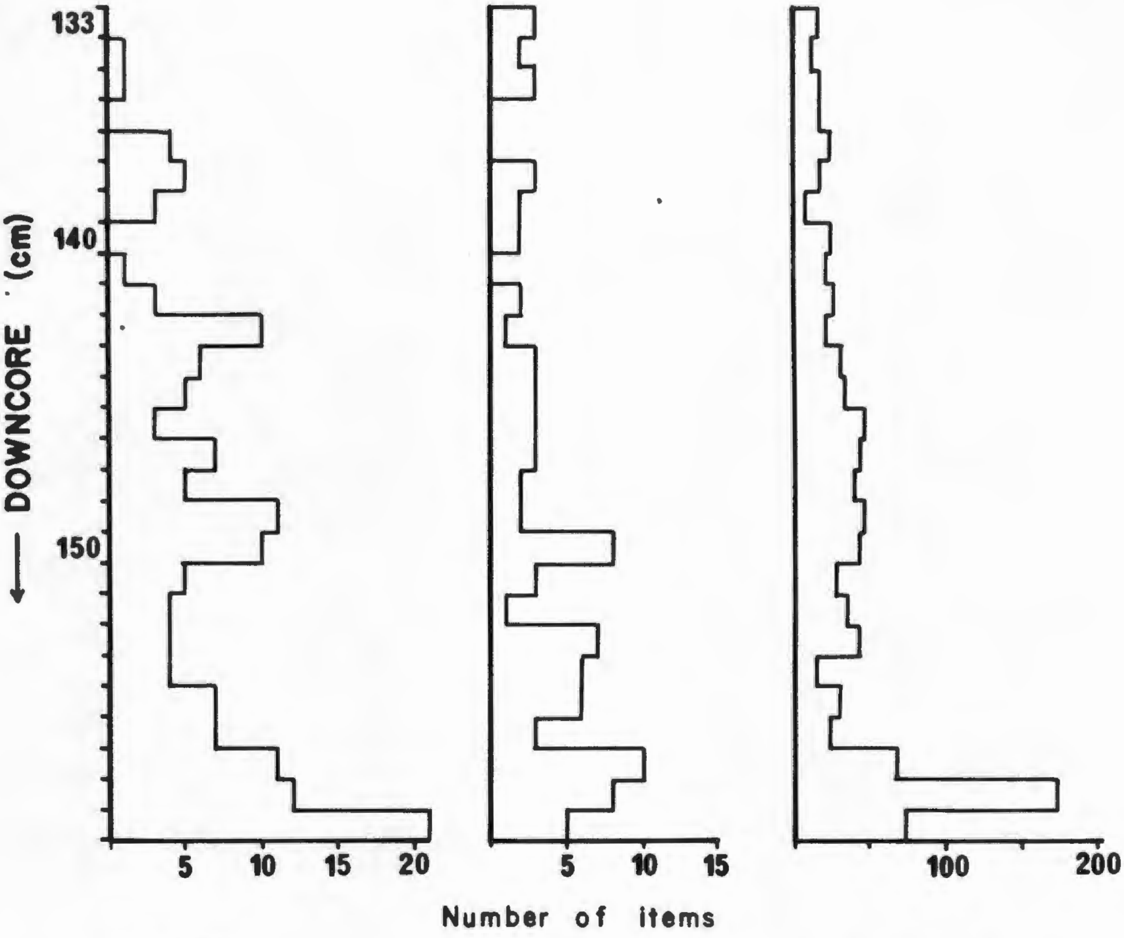
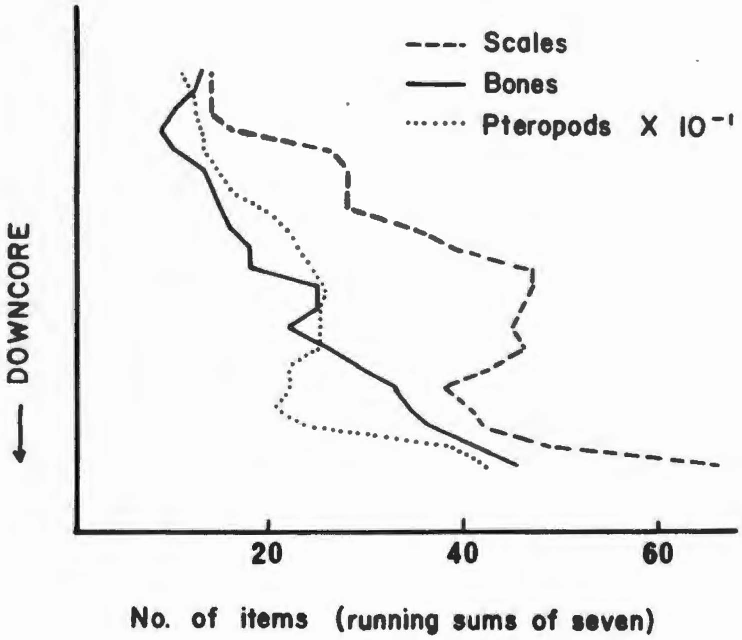


Figure VI.1 Treatment of samples from core SF14



a. Scales **b. Bones** **c. Pteropods**



d. Trend analysis

Figure VI.2 Downcore distribution of a) Scales b) Bones c) Pteropods and d) Downcore trend analysis

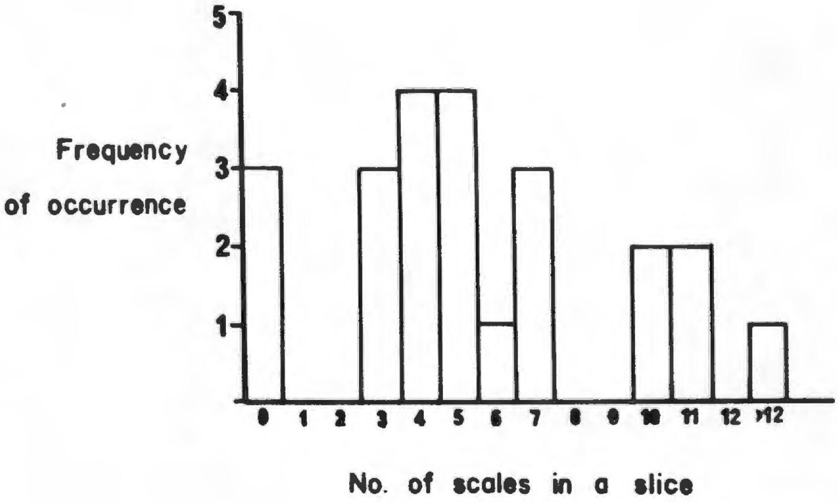


Figure VI.3 Test of applicability of normal statistics to downcore scale counts

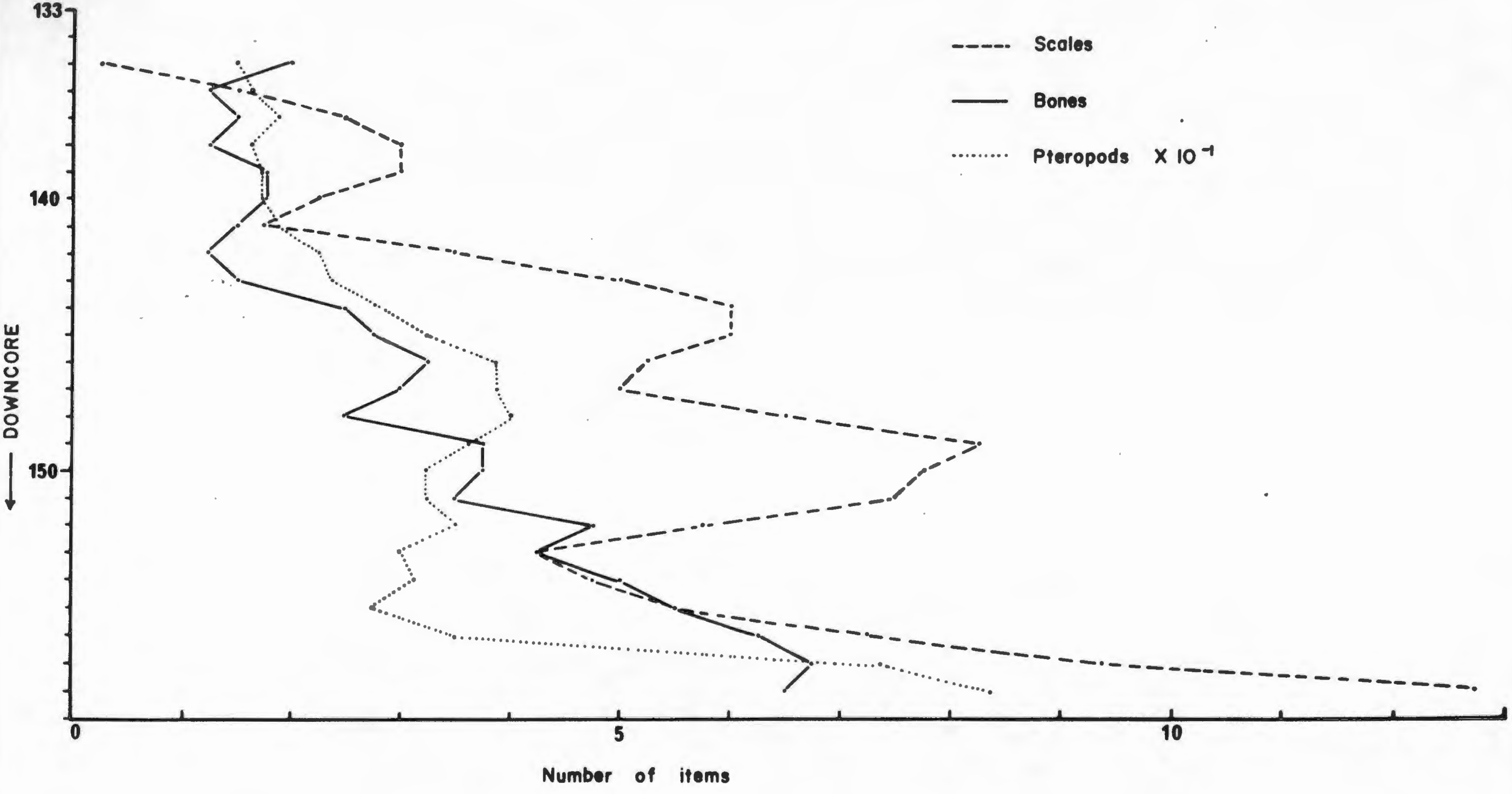


Figure VI.4 Plot of scales, bones and pteropods downcore in SF14
(Numbers of items are the average of four adjacent slices)

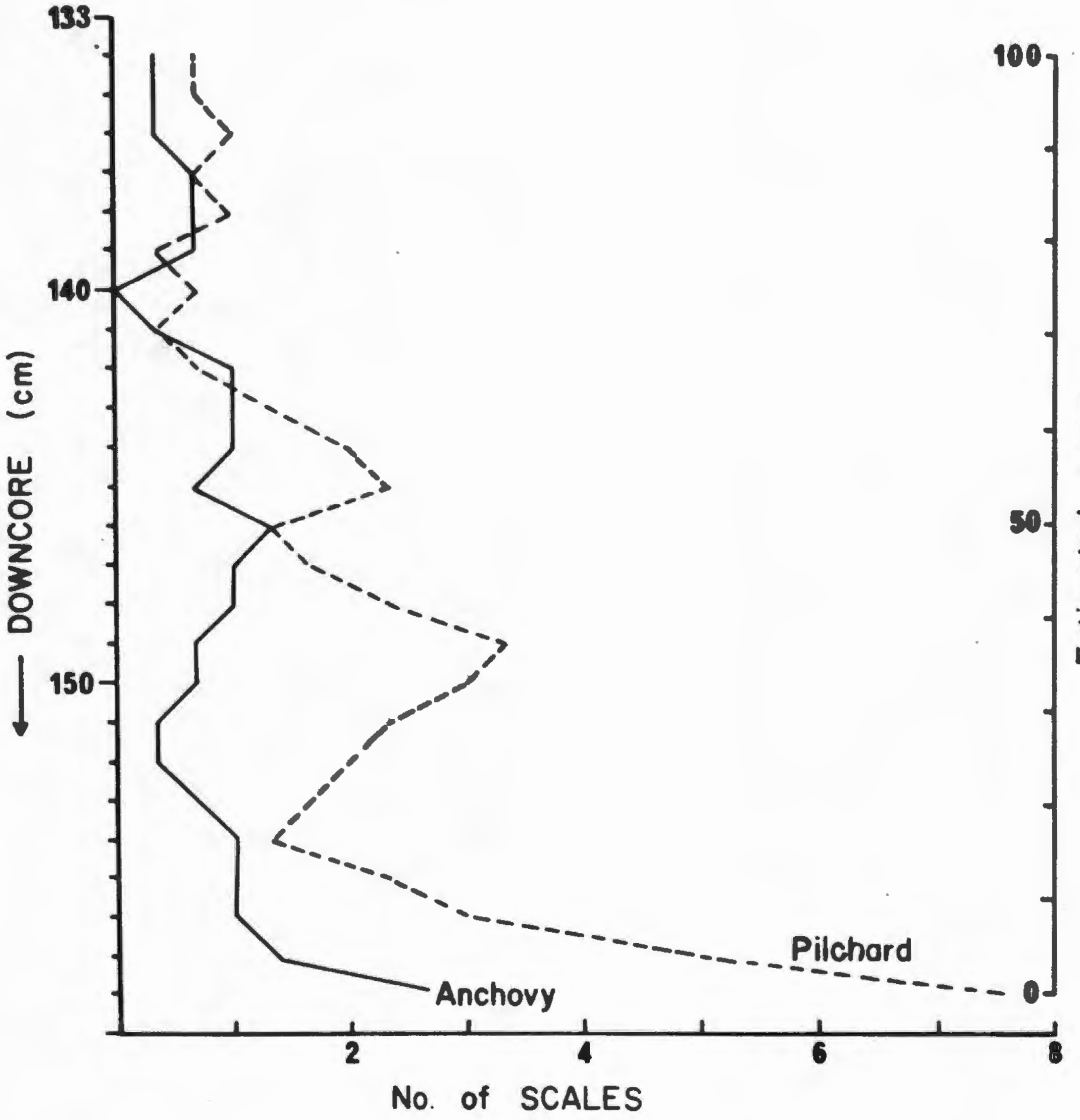


Figure VI.5 **Variation of pilchard and anchovy scaled downcore in SF14**
(Numbers of scales are the average of three adjacent slices)

CHAPTER VII

CONCLUSIONS

VII.1. INTRODUCTION

In 1967 Soutar published a paper, the main purpose of which was "to point out the existence of material which could allow the introduction of a relatively longtime-perspective into the character of the fisheries and oceanographic conditions off California" (p 136). In subsequent papers (Soutar and Isaacs, 1969; 1974) he develops these ideas, refining them to such an extent that in the 1974 paper he gives a detailed estimate of sardine, anchovy and hake biomasses in the Santa Barbara Basin over the past 150 years. De Vries and Pearcy (1982) applied these ideas of Soutar and Isaacs in order to reconstruct a history of Holocene fishes, particularly the commercially important anchovetta off Peru. These studies were especially relevant against the background of the recent collapse of both the Californian sardine fishery and the Peruvian anchovetta fishery.

Soutar's initial study simply presented the downcore distributions of the scales. From aggregations of sardine scales at certain depths he concluded that over the last 1000 years the Pacific sardine abundance has varied against a more constant anchovy and hake abundance. By the 1974 paper he and Isaacs integrated other available data with the scale counts, data on the varves in the sediment, the age of the sediment and the historical fish population estimates, and the paeleo-oceanography of the area to give actual pre-fishery biomass estimates. From this they were able to state that the recent decline in sardine abundance is indistinguishable from natural pre-fishery fluctuations.

Common to these studies is the low number of scales from which conclusions about fish biomass fluctuations are made. Variability is greatly magnified in the extrapolation from the scales in the sediment to the populations in the water above. Random error can only be reduced by increasing sample sizes, by no means an easy proposition. The possibility of systematic errors needs to be recognized and these errors eliminated or at least evaluated to enhance the potential value of this kind of study to fisheries scientists.

To this end my thesis has three main objectives:

1. the quantification of possible errors due to scale mis-identification and a lack of understanding of the processes whereby scales enter and accumulate in the sediment;

2. an assessmenmt of the suitability of the area off Walvis Bay for carrying out a study such as those done by Soutar and Isaacs and De Vries and Pearcy. This involves consideration of the sediments accumulating and the causes of any laminated sequences that may be found;

3. an interpretation of the scale information available from the study of a small sample giving a window onto a period of about 100 years long in the middle of the last millenium.

VII.2 BASIC SCALE STUDIES

VII.2.a Identification

Relatively little work appears to have been done on fish scales other than attempting to use them for ageing purposes. Soutar (1967) identified his scales by comparison with a reference collection. De Vries and Pearcy (1982) refer to the same reference collection. Photographs of clupeoid scales in the literature (Soutar 1967, 1971, Miller 1955, Nawratil 1961 and Davies 1958) belie the difficulty in actually distinguishing between any but the most characteristic scales of each species (see Figure VII.1). To overcome this problem I undertook a detailed study of the scales on pilchard and anchovy which had died non-traumatically in rearing tanks at the Sea Fisheries Research Institute.

Two reliable distinguishing features emerged: i) the presence of crenulations around the edge of a pilchard scale-wing which were absent from the anchovy scale-wing and ii) different scale thicknesses in each species. Anchovy scales measured were all thinner than 0,4 mm, having an average thickness of 0,21 mm whereas 78% of the pilchard scales measured were thicker than 0,4 mm (mean 0,53 mm). There are problems in using both these distinguishing features - the scale-wing is often separated from the scale, and measurement of scale thickness is time-consuming whether done directly or indirectly by using differential settling velocities. Ideally an accurate spot visual identification system was needed. To this end all the scales from both a pilchard and an anchovy were systematically removed, mounted on acrylic slides and photographed to obtain a set of reference photographs of the scales on each fish. Not only did this exercise result in more accurate scale identification, but it also gave an interesting insight into the types and distribution of scales on each species.

Six distinctive types of pilchard scales were identified, each being found on a different part of the fish, (Figure VII.2a).

Most interesting are the distinctive T-scales, the typical pilchard/sardine scales of the literature. On the fish they make up 34% of the total scales. Pilchard scales as a whole show a wide variety of shapes and sizes and arrangement of radii. Only by recognizing this unsuspected variety can identification error be reduced.

Anchovy scales exhibit less overall variation in size and appearance, but nevertheless seven categories were identified from different parts of the fish. The typical anchovy scales, the X- and Y-scales, are found on a similar part of the fish to where the T-scales are on the pilchard, along the central portion of each side, from head to tail (Figure VII.2b).

The confusion between the scales of the two species arises from the misidentification of all non-typical pilchard scales as anchovy scales. This would result in a bias towards anchovy whereby pilchard scales are underestimated by up to 45% and anchovy scales overestimated by up to 70%. However, by using the reference photographs, I estimate that scale identification error can be reduced to ±2,5% (this excludes using the very small scales for identification purposes).

VII.2.b Scale abundance ratios

The identification of pilchard T-scales and measurement of the T-scale to total pilchard scale ratio has provided an insight into the role of deciduousness in clupeoid scale loss. Pilchard and anchovy are known to be highly deciduous fish (Nawratil 1961, Miller 1955) but no attempt has previously been made to quantify the contribution of deciduousness to the scales accumulating in the sediment. As part of this study I counted the types of pilchard and anchovy scales accumulating at the bottom of two fish-rearing tanks at the Sea Fisheries Research Institute. The numbers of fish in the tanks were known, as was the accumulation period, and a scale flux of numbers of scales per fish per day was calculated. This flux was compared to that which would be expected as a result of death for both pilchard and anchovy. The deciduousness flux for pilchard was 1,50 scales/fish/day, very similar to the death flux of 1,56 scales/fish/day. For anchovy the deciduousness flux was 0,48 scales/fish/day, less than that of pilchard and 1/5 the calculated death flux of anchovy - 3,42 scales/fish/day. Although actual deciduous fluxes for the two species varied from period to period, their ratio at any given time was remarkably constant.

One of the most interesting ideas to emerge from this scale study was the potential for using the pilchard T-scale to total pilchard scale ratio as an indicator of cause of death. In the deciduousness study the T-scales formed a remarkably constant proportion, 0,65, of the pilchard scales accumulating in the tanks. Comparing this proportion with the proportion found on the body of the fish indicates their preferential loss from the fish. Consideration of the T-scale to total pilchard scale ratio of the scales accumulating in the surface sediments (grab samples) gave the surprisingly similar ratio of 0,68. Downcore the ratio was again the same, 0,67. If scale loss to the sediments were due to death this ratio would be expected to be 0,40 (considering only scales larger than 3 mm). If due to deciduousness combined with death over the lifetime of a pilchard the ratio would be 0,53. The ratios found in the sediments as a whole indicate that deciduousness is the predominant source of scales to the sediment.

Consideration of the life history of these pelagic fish shows this to be entirely possible. The major cause of death is predation (Brongersma-Sanders 1957). Deciduous scale loss would take place during the capture phase of predation. Scales remaining on the fish appear to be digested in the gut of the predator (Wilson et al 1985, Walter 1984, Duffy and Laurenson 1983; Lipinski, Payne pers comm) and do not find their way to the sediment. Back extrapolations from scales accumulating in the sediments to fish populations must take into account the role of deciduousness and the bias introduced by differential deciduousness between species.

VII.2.c Implications for population comparisons

Anchovy have been shown to be less deciduous than pilchard thus proportionately more anchovy scales are lost in the digestive processes of predators and do not find their way to the sediment. Comparative population calculations based on scale counts can be corrected for this bias. The number of pilchard scales in the sediment should be divided by 1,5, the deciduousness flux of pilchards, and those of anchovy divided by 0,48, the anchovy deciduousness flux, to give an accurate estimate of relative populations. The following formula applies:

For deciduous scale flux only:

$$\frac{\text{No of pilchard}}{\text{No of anchovy}} = 0{,}32\ \frac{\text{Pilchard scales}}{\text{Anchovy scales}}$$

This can be compared to the formula for death flux:

For death scale flux only:

$$\frac{\text{No of pilchard}}{\text{No of anchovy}} = 1{,}55\ \frac{\text{Pilchard scales}}{\text{Anchovy scales}}$$

As it happens, the two biases discovered in this study of fish scales operate in opposite directions. Misidentification of pilchard scales as anchovy scales overestimates the number of anchovy present. Ignorance of the role of differential deciduousness underestimates them. The combined effect of these errors is still significant, however, and is seen in Table VII.1 which gives figures for equal numbers of pilchard and anchovy. One cannot but hypothesize that these errors contributed to the vast numbers of anchovy and anchovetta scales found in relation to sardine scales by Soutar and Isaacs and De Vries and Pearcy.

VII.2.d Preservation

Another potential source of error in using fish scale counts in the sediments as indicators of past fish populations, is imperfect or differential scale preservation. It is recognized that the processes of bacterial decomposition and chemical dissolution of organic and many mineral salts is inhibited in intensely anaerobic environments (Soutar 1966). The depositional environment off

Walvis Bay is highly anaerobic with values as low as 0,5 ml O_2 per litre being reported at the sediment-water interface (Chapman and Shannon 1985).

The arguments for scale preservation in anaerobic sediments in previous studies have been based on comparisons of numbers of scales found downcore from cores taken both in and out of anaerobic environments (Soutar 1971), on the concurrent preservation of delicate microfossils (Soutar 1971), and on the constancy or otherwise of the scale to vertebrae ratio (De Vries and Pearcy 1982). In general, the results obtained in the present study area support the hypothesis that scales found in the surface sediments reflect the fish populations in the water above them. Downcore, the scales to fish-bones ratios and the scales to pteropod ratios are remarkably constant. In addition the pilchard T-scale to total pilchard scale ratio remains the same from the time of actual scale loss right through burial in the sediment for hundreds of years. It is true that there seem to be fewer scales in the laminated sediment as a whole than would be expected from the study of the surface sediment. On the other hand, the number of scales found in the lower part of the core where the highest downcore scale abundances are, are comparable with those in the surface sediments. (Figure VII.3 shows a comparison between the numbers of pilchard plus anchovy scales found in the grab samples, the Walvis shelf cores and Soutar's core).

Although actual population estimates based on scale counts are dependent on there being no significant overall scale loss with time, population comparisons at any given time are not. Differential preservation between the species compared becomes important. There seems little doubt that the thicker pilchard scales are well preserved. The constancy of the T-scale to total scale ratio and their very appearance support this. The thinner highly-cracked anchovy scales appear to be broken up into fragments rather than decomposed. (This could be as a result of sample preparation). If fragments are included in anchovy scale counts there seems to be little scale loss with time. The proportions of anchovy, maasbanker, snoek and other species scales are similar in the surface sediments to those in the laminated section of SF14. The only significant differential scale bias in the core appears to be in the numbers of the tiny brittle hake scales.

Comparisons of pilchard and anchovy populations based on scale counts in the sediments would seem to be entirely valid. However, any link to predator populations, including hake, is not recommended. Absolute population size calculations should be made with caution, always remembering that the possibility of an overall scale loss with time in the Walvis Bay area has not been excluded. Consideration of a larger sedimentary sequence would help to show whether the fact that fewer scales were found in SF14 represent a period of lower fish populations or result from scale decomposition.

VII.3 SUITABILITY OF THE AREA OFF WALVIS BAY

The collapse of the pilchard fishery off Namibia in the mid 1970's is one of the last of several such documented sudden declines in fish stocks - California and Japan in the early 1940's, Peru and South Africa in the early 1970's and the massive decline in the catch of the North Sea herring from 1965-1975 (Lasker and MacCall 1983). A study of the fluctuations of past fish populations in these areas would help to elucidate the causes of these recent collapses. John D Isaacs of the Scripps Institution of Oceanography suggested that the sediments might contain the key to the past fish populations (Soutar 1971).

Before any such study can be made, certain conditions must be fulfilled. The area to be studied should be relevant to the fishery, the scales that accumulate should be undisturbed and intact in the sediments, the flux of sediments to the sea floor should be steady and, ideally, the sediments should be varved to reflect annual deposition.

The Walvis Bay area is the centre of the Namibian fishery. The historical spawning grounds of the pilchard are there (Matthews 1964), and juvenile pilchard and anchovy shoal together in the nutrient rich upwelled waters on the Walvis Shelf (Thomas 1983, 1984). A flux of scales to the sediments is assured. As well as attracting the fish, the high productivity of the area may result in anoxic bottom waters. Burrowing benthic organisms which could disturb the sediments are excluded. This anaerobic environment also preserves the accumulating fish debris.

The sediments accumulating in this area are also the result of the high productivity, and consist almost entirely of diatom frustules and organic matter (Bremner 1978). The laminations that have been found in these sediments (Rogers 1983, Diester-Haas 1978, Bremner et al 1983) are evidence of periods of undisturbed regular accumulation. After a detailed look at one such laminated sequence in core SF14 it is reasonable to accept that the laminations are a result of seasonal variations in the sedimentation. The interaction between the sulphate reducing bacteria, Thioploca, found in anoxic areas and the alternating high sedimentation rate during the peak upwelling season of late winter and spring and lower rate during summer would result in varves. A count of the number of varves per centimetre is in agreement with the estimated sedimentation rate of 2-3 mm/year (Bremner 1983).

In summary it would seem that the diatomaceous muds off Walvis Bay do hold potential for past fish population studies. Well-preserved fish scales are found downcore in undisturbed laminated sequences which provide a time framework within which to analyse scale distributions.

VII.4 PILCHARD AND ANCHOVY POPULATIONS OFF WALVIS BAY

The scales found in the grab samples collected in the diatomaceous mud-belt off Walvis Way reflect the fish populations living in the waters above. Scales of pilchard, anchovy, maasbanker, hake and snoek are found. Of greatest interest in terms of population studies are the pilchard and anchovy whose scales account for 45% of those recovered. The pilchard found in the area are mainly juveniles and two-to three-year-olds (Thomas 1985). They average about 1 100 scales/fish and have an expected lifetime of two years based on a natural mortality of 0,5. The anchovy are mainly juveniles which shoal with the young pilchard (Alant 1983). Each fish has about 700 scales. Their estimated natural mortality is 1,1, giving them an expected lifetime of 0,8 years. Juvenile pilchard weigh between 2 and 3 times as much as the same age juvenile anchovy. This study has shown that pilchard are three times as deciduous as anchovy.

Soutar and Isaacs (1974) related scale counts to fish biomass by comparing the scales found in the sediments deposited since 1930 with fisheries population estimates for the same period. The same procedure cannot be carried out in the Walvis Bay region. No very recent laminated sequences have been found and biomass estimates only date back to the 1950's. An alternative method for estimating biomasses can be based on the study of scale flux. De Vries and Pearcy (1982) suggested estimating relative stock densities by taking into account the average number of scales and weight of each species. Their calculations were based on a scale flux due to the death of the fish, assuming that all the scales on the fish would find their way to the sediment.

However, the scales accumulating in the sediment have been shown to result from deciduousness which has been quantified in this study. Numbers of scales can thus be related to numbers of fish losing them. The formula derived in Chapter III can be used to make an estimate of fish densities off Walvis Bay.

$$F = \frac{SA\sigma}{\phi al}$$

or for fish density, $\frac{F}{A} = \frac{S\sigma}{\phi al}$

where F = number of fish
σ = sedimentation rate
ϕ = deciduousness flux
S = number of scales
al = volume of sediment containing S scales
A = area considered

Using average figures derived from Table VI.4a for numbers of pilchard and anchovy scales per 100 ml sediment and the experimentally derived deciduousness fluxes (anchovy o = 0,48 scales/fish/day, pilchard o = 1,50 scales/fish/day) and a sedimentation rate equal to 0,25 cm/year, the fish densities can be calculated. These are shown in Table VII.2 which also contains an estimate of the densities off California based on Soutar's data and off the South coast of South Africa based on the combined acoustic and egg survey cruise in 1984 (Hampton, pers. comm.). (Average weight of a pilchard was taken to be 40 gm and of an anchovy 15 gm, Armstrong, pers. comm.) The estimates obtained from the scale data compare well with those obtained by the combined acoustic and egg survey methods and point to the potential for using scale counts to estimate past fish densities.

With the present data, however, relative population calculations are more reliable.

For juvenile pilchard and anchovy the following relationship applies:

$$\frac{\text{Pilchard biomass}}{\text{Anchovy biomass}} = 0{,}32 \times 2{,}50 \times \frac{\text{Pilchard scales}}{\text{Anchovy scales}}$$

where 0,32 is the relative deciduousness correction
2,50 is the relative weight correction for juvenile fish (determined in the course of this study)

When adult fish are considered the weight correction is 5,0 (from De Vries and Pearcy).

The pilchard/anchovy biomass ratio determined from the integrated scale counts of all the grab samples is 2,0 (based on juvenile weights) or 4,0 (based on adult weights). Earliest biomass estimates from VPA of pre-collapse stocks give a pilchard/anchovy biomass ratio of 3,0 (averaged over 1972-1975 from le Clus and Melo 1983 and Thomas 1983). The closeness of the scale-derived value to the VPA-based ratio indicated the robustness of these relative population calculations based on fossil scale counts.

Pilchard/anchovy biomass ratios found in the laminated section of SF14 range from 5,6 to 0,4 (based on juvenile weights). Using the same conversion, the ratios found by Soutar and Isaacs (1974) in the Santa Barbara Basin range from 1,28 to almost 0. In the Soledad Basin only one short period had a P/A biomass ratio greater than 1. The value of 2 was the highest found by them. De Vries and Pearcy (1982) did not calculate P/A ratios, but anchovetta scales greatly outnumbered sardine scales at all but one level in the core presented.

The composition of the fish stocks in the Benguela upwelling region off Namibia seems to be distinctly different from that off California and Peru. Both during the earlier part of this century and during a hundred year period about 500 years ago there were more pilchard than anchovy. The reverse is true in the Pacific regions where the data presented shows the anchovy/anchovetta to have been dominant for hundreds of years. Against this large stable population of anchovy/anchovetta the sardine population seems to vary cyclically. Soutar and Isaacs (1974) attribute this to interspecific and auto-ecologic factors" (p 272) but Lasker and McCall (1983) point out that it could be an artifact of the sardines moving in and out of a preferred anchovy habitat.

Figure VII.4 summarizes the pilchard and anchovy biomass fluctuations (calculated from the formula in section VII.4 for 3 cm intervals) found in the laminated section of core SF14. Here, off Walvis Bay, over the short period covered by the laminations, the total fish population is in a period of decline. The biomasses drop by a factor of 10. This decrease occurs as a series of cycles with a period of about 25 years. (It is interesting to note that Crawford and Shelton (1978) detect 30 year cycles in Guano production on islands off South West Africa since the turn of the century). Within this general pattern the pilchard and anchovy interact in two ways. Periods of rapid pilchard decline are accompanied by anchovy declines. The pilchard seem to recover some years ahead of the anchovy and then the two stocks go into a period of pilchard maxima coinciding with anchovy minima. During these flip-flops the combined stock size remains more or less level.

Understanding the effect of environmental change on populations is complex. It requires not only recognition of specific environmental changes but an understanding of all the stages in the life cycles of the species affected. In other words, the environmental effects differ depending upon the characteristics of the fish species (Nakai et al 1967). Lasker and MacCall (1983) review the theories of fluctuating clupeoid stocks off California at length. Off Namibia certain hypotheses can be presented. The overall fluctuations in fish (and pteropod) populations occur over a 20 to 30 year cycle, the same periodicity noted by Shannon (1985) for El Nino type events. Changes in water temperature are known to affect recruitment (Boyd et al 1985, Nakai 1967, Lasker and MacCall 1983). Superimposed on these overall effects are interspecific effects depending on the reactions of each species to the environmental changes. Pilchard, for example, have been noted by Boyd et al (1985) to be less disadvantaged by the anomalous conditions off Namibia than the anchovy, and Thomas (pers. comm.) has suggested that under favourable conditions the pilchard are more inclined to spike than the anchovy, who tend to maintain a steadier stock size.

Although to quote Lasker and MacCall (1983, p 118), "unfortunately the paleosedimentary record provides little evidence on causal mechanisms driving the patterns of apparent fish abundance" it certainly provides a wider environmental perspective than is otherwise available. Even as a result of this pilot study, based as it is on a small sediment sample, three important factors emerge:

(1) the Namibian system is distinctly different from the Pacific systems now and in the past. It is a pilchard dominated system;

(2) major fluctuations in fish stocks have taken place off Namibia before fishing commenced;

(3) for short periods in the past the anchovy biomass has exceeded the pilchard biomass. The change-over could only be due to natural causes.

VII.5 FUTURE STUDIES

This pilot study on pilchard and anchovy scales as past population indicators off Namibia has served a dual purpose. The assumptions on which a study like this are based have been critically assessed. Future studies will now be more firmly based as a result of data that have been collected and interpreted here. Secondly, the potential for using fish scales off Namibia has been clearly demonstrated. Well-preserved scales exist in laminated sequences in sufficient numbers to enable meaningful deductions about past populations to be made.

A coring programme is under way to sample the diatomaceous muds underlying the fish populations off Walvis Bay. A new, giant box-corer has been designed and shown to be capable of collecting samples 20 times the size of those on which this pilot study is based. The potential information to be gained from this study is enormous - the increased scale counts will reduce random fluctuations and past population trends can be analyzed in more detail. Actual biomasses can be calculated and maps of fish densities constructed for different periods in the past. Microfossil studies downcore can relate environmental changes to fish population levels. Carbon-14 dating can place these fluctuations in historical perspective. The marine geologists will be able to provide the fisheries scientists with the long data sets they require to understand the clupeoid fish population fluctuations of the present and future.

	CORRECT (based on deciduousness flux and correct identification	INCORRECT (based on death flux and a misidentification of 45% pilchard scales as anchovy scales)
Pilchard scale loss (scales/fish/day)	1,50	$1,56 - \frac{45 \mathrm{x} 1,56}{100} = 0,86$
Anchovy scale loss (scales/fish/day)	0,48	$2,42 + \frac{45 \mathrm{x} 1,56}{100} = 3,11$
$\frac{\text{Pilchard number of fish}}{\text{Anchovy number of fish}}$	1	0,43

Table VII.1. Quantification of error due to misidentification of pilchard and anchovy scales and ignorance of the role of deciduousness

Source	No of pilchard scales/100ml	Pilchard density fish/m^2	Pilchard density gm/m^2
Grabs	15,0	0,7	28,0
SF14	7,0	0,4	16,0
SF7	8,0	0,4	16,0
Soutar	1,6	0,1	4,0
Hampton	-	-	-

Source	No of anchovy scales/100ml	Anchovy density fish/m^2	Anchovy density gm/m^2
Grabs	6,0	0,9	12,9
SF14	2,7	0,4	6,0
SF7	-	-	-
Soutar	8,0	1,1	16,5
Hampton	-	0,7	10,0

Table VII.2. Comparison of fish densities

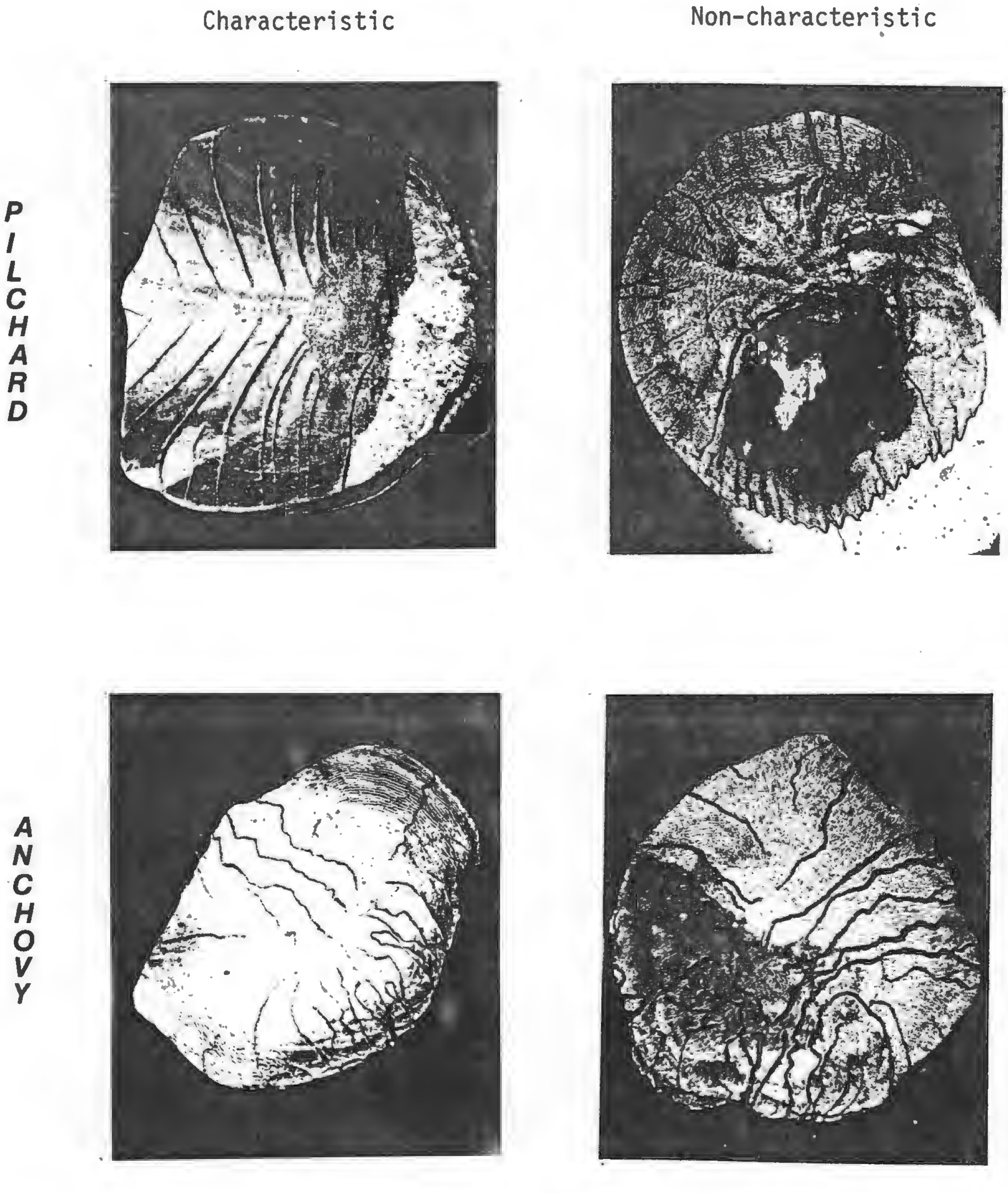
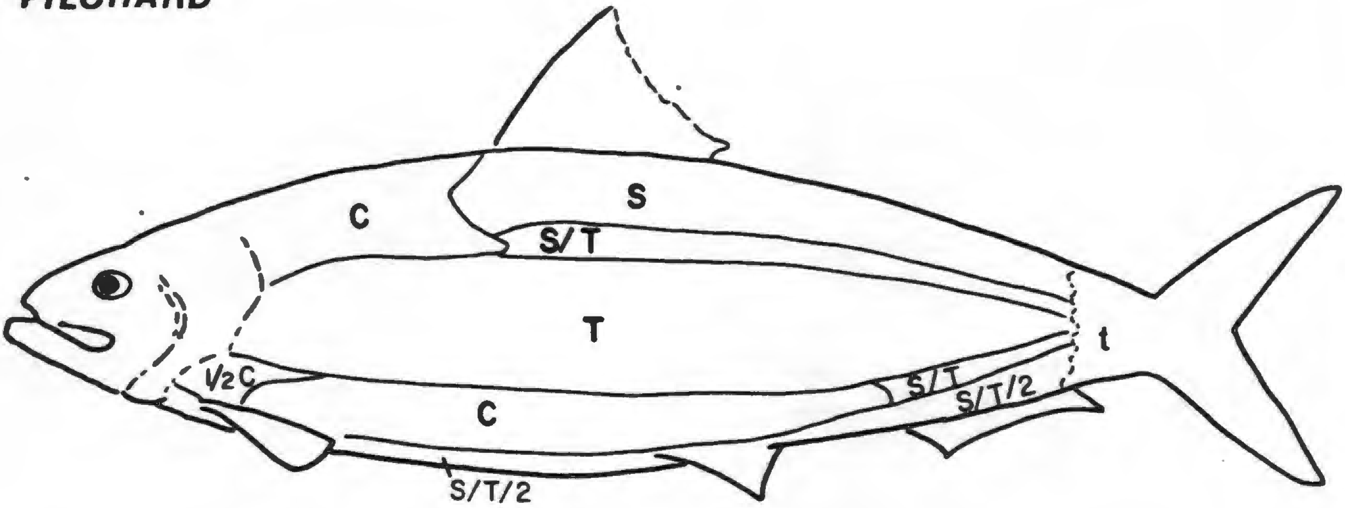


Figure VII.1 Characeristic and non-characteristic pilchard and anchovy scales *a) PILCHARD*



b) ANCHOVY

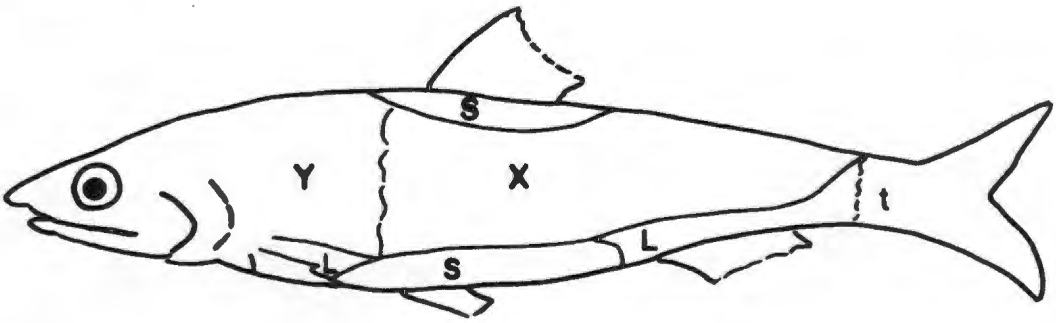


Figure VII.2 Distribution of scale types on a) Pilchard b) Anchovy

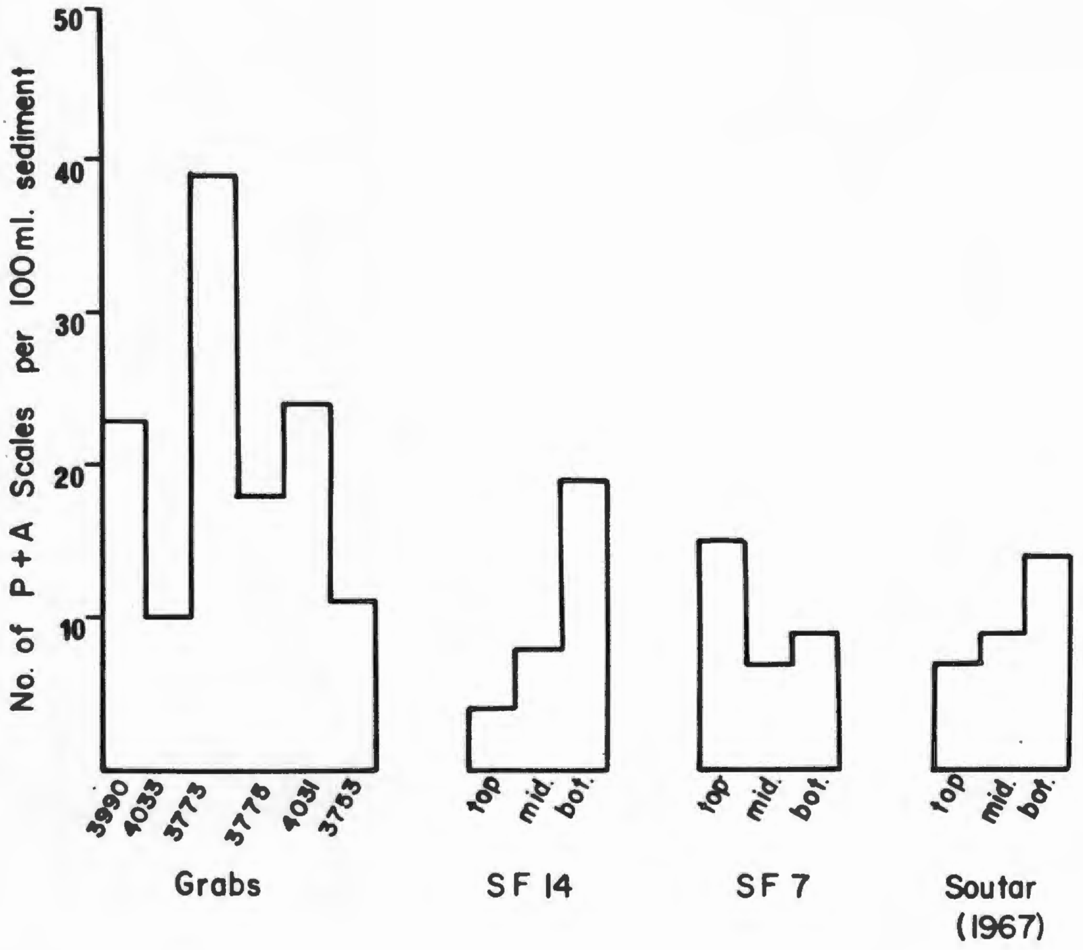


Figure VII.3 Comparison of the number of pilchard plus anchovy scales found in the grab samples, the Walvis shelf cores and Soutar's cores

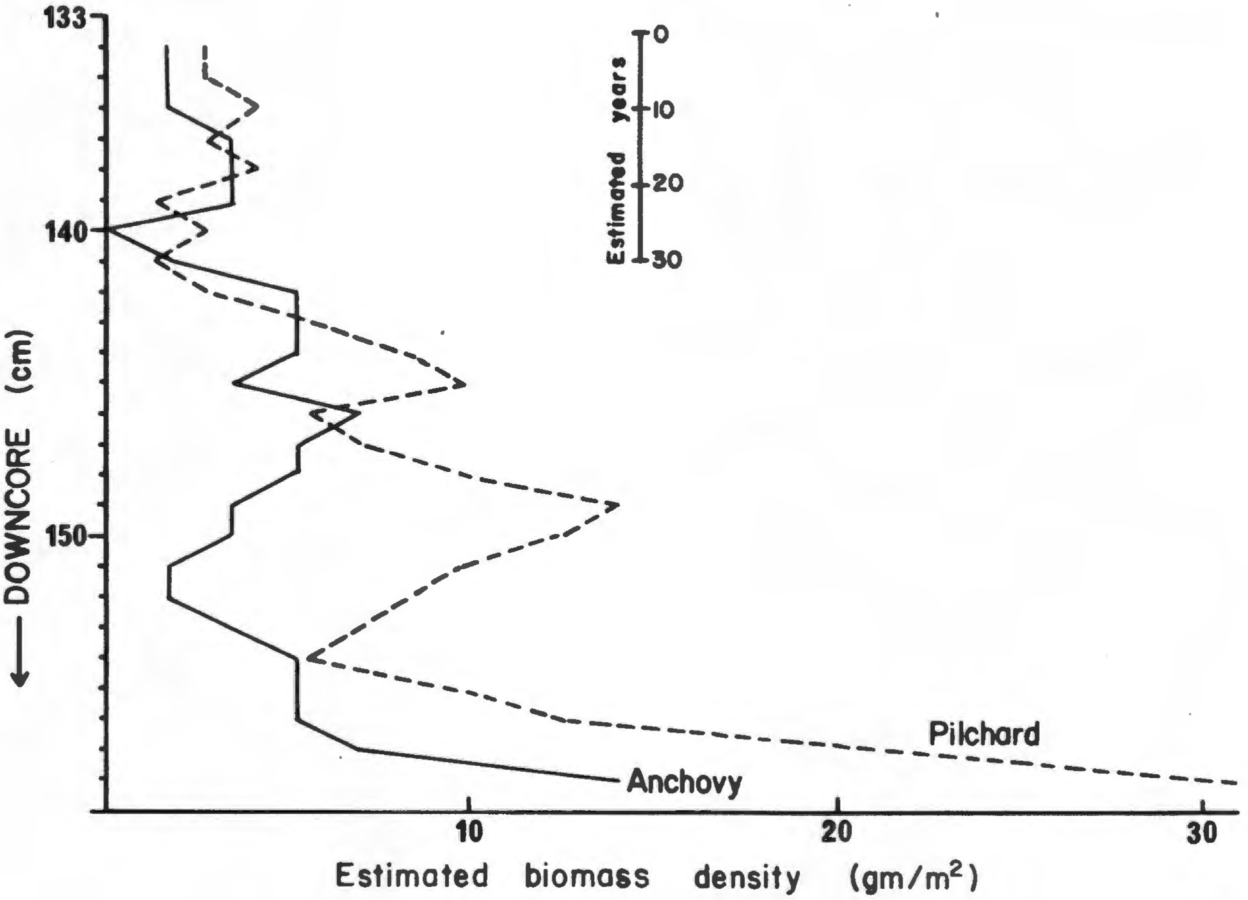


Figure VII.4 **Pilchard and anchovy biomass fluctuations over the laminated interval of SF14**

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