RESEARCH AND MANAGEMENT IN SOUTHEAST ATLANTIC PELAGIC FISHERIES

DAVID L. CRAM
Sea Fisheries Branch
Cape Town, South Africa

ABSTRACT

The South and South West African pelagic fisheries have been subject to serious declines in their most valuable fish population, *Sardinops ocellata.* In both fisheries the anchovy, *Engraulis capensis,* has become important. The history of the fisheries is described and subsequent progress discussed. Adequate legislation has been available as a basis for resource management, but until 1970 was not employed at critical periods in the fisheries history, since scientific input was lacking. Methods of past and present management are discussed and advantages of the present system noted. Recent research has shown that problems in these pelagic fisheries are multidisciplinary and that the most rewarding approach to solution is through integrated multidisciplinary research. A period of large scale survey work has highlighted many of the disadvantages of population biology and focussed on the need for rapid ways of detecting adverse change within the fisheries. Future work is described which concentrates on survey work giving rapid stock size estimates whilst producing valuable input in conventional monitoring of fishery statistics.

INTRODUCTION

Those of us involved in pelagic fish research in other parts of the world owe a considerable debt of gratitude to those workers in the United States who previously established the guidelines and have subsequently maintained the lead in so many aspects of this work. It may be possible to discharge our debt today in some small way by informing you on the history and problems of two related pilchard fisheries in the Southern Hemisphere (Figure 1), by describing a different management approach towards exploitation control and by mentioning a few new twists in established research method.

The fisheries are both located in the upwelled component of the Benguela Current System on the west coast of southern Africa and in the main located at about 35°S and 22°S respectively (Figure 2). The southern fishery, on a quota of 360,000 metric tons, is based upon six fishing harbors in the vicinity of Cape Town, whilst the northern fishery on 820,000 tons quota is based at Walvis Bay and to a limited extent at Lüderitz. In addition, an Angolan pilchard fishery makes a variable catch on the same *Sardinops ocellata* complex as the Walvis Bay fishery. Foreign and South African floating factories have made considerable catches on the South West African stock during a few years in the mid-sixties (Figure 3). A small catch is made off Durban during the annual pilchard migration (Baird, 1971).

Both the Cape and South West African pilchard populations have suffered declines, but the South West African group have apparently recovered. The Cape pilchard cannery industry has been replaced by a multispecies fishery where canning has declined, whilst in South West Africa, canning of pilchard is of paramount importance in the now multispecies fishery. In both fisheries the pilchard catch has declined and effort been diverted into anchovy and maasbanker in the north, and anchovy, maasbanker, mackerel, redeye, and lanternfish in the south.

Management strategy has changed. At the time of the Cape pilchard decline there was ample legislation but only a limited scientific basis for management action, whereas more recently the scientific input has allowed a firmer approach to exploitation control in both fisheries.

In the past, management action tended to be optimistic and expansionist; whereas recently, management has tended to be conservationist and both fisheries are at the moment tightly controlled.

Management of the pilchard stock in the multispecies South West African fishery has been successful and single stock management strategies will probably be applied to the Cape fishery in future.

The approach of the Sea Fisheries Branch to research has been through well known population dynamics and biological techniques as well as egg and larval and aerial/acoustic methods in more recent years. In the future, an increased committment to survey work is anticipated, with remote sensing techniques providing a substantial input to more conventional techniques. The aerial/acoustic techniques used at the Branch show increasing promise and are likely to be further developed.

HISTORY AND MANAGEMENT OF SOUTH AFRICAN ADMINISTERED PELAGIC FISHERIES

It is the present intention of management authorities to control pelagic resources in a conservative manner commensurate with the concept of maximum sustainable yield. However, the rate of exploitation will be controlled within the latter limit by economic realities which will also give expression to the view of the state regarding equitable and just distribution of the yield of the resource among various parties sharing in its exploitation. In practice, the Sea Fisheries Branch acts in terms of simplier guidelines of establishment of potential yield whilst more complex problems are referred to a higher authority on an *ad hoc* basis (Report 1971). The Sea Fisheries Branch is responsible to the Department of Industries whose duty it is to coordinate information into policy form for submission as policy proposals to the Minister of Economic Affairs (Figure 1). Subsidiary information is derived from the Fisheries Development Corporation of South Africa Ltd. (finance to fishing industry, construction and maintenance of fishing harbors, and technique development), the Fishing Industries Research Institute (processing practice, product development, and fault detection and advice), and the Fisheries Development Advisory Councils (statutory bodies carrying representation from all interested parties within the industry and responsible directly to the minister) together with a measure of scientific input from universities and museums.

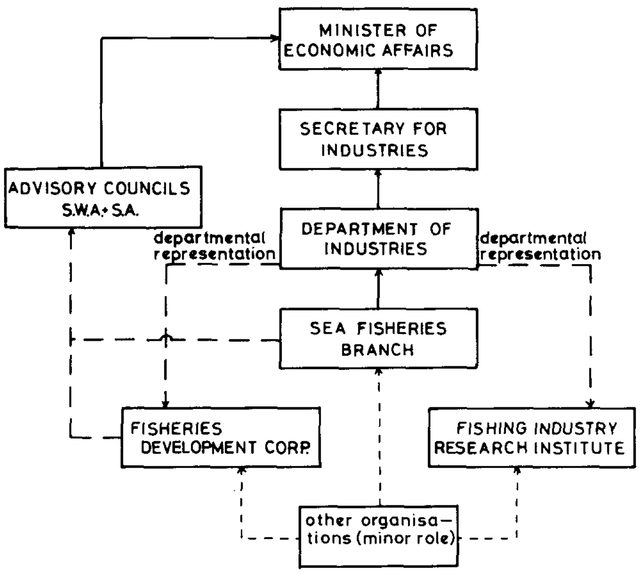

FIGURE 1. Management structure for South African fisheries.

Although not well integrated, the system works well and relatively recently the Advisory Councils have been good forums for discussion leading to development of rational resource exploitation.

South African multispecies pelagic fishery

From the beginning of the 19th century onwards, there was a considerable cottage industry for the export of dried and smoked fish (principally snoek, *Thyrsites atun*). Towards the end of that century considerable interest was focussed upon fisheries after an American schooner, ALICE, arrived off the Cape in 1890 and made large catches of mackerel and maasbanker with a purse net. This caused a local furore which resulted in an act (20 of 1890) which prohibited the use of purse nets along the Cape coast. A Commission of Enquiry was set up in 1892 to enquire into sea fishing and its formal report was the foundation for future legislation. The immediate result was the Fish Protection Act of 1893 which provided for closed seasons and size limits and repealed the 1890 act against purse nets.

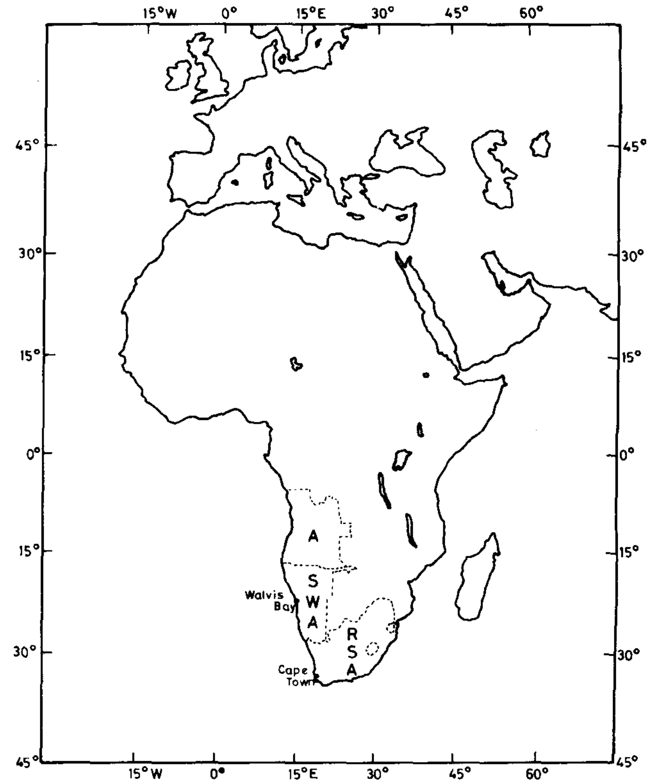

FIGURE 2. Location of pelagic fisheries off southern Africa.

Research commenced in earnest in 1896 when J.D.F. Gilchrist was appointed as marine biologist to the Cape Government, and in 1897 the first steam trawler research vessel, PIETER FAURE, was delivered. The Cape Government repealed most existing legislation with ordinance 12 of 1911 which provided for licensing of craft and gear, and empowered the Cape Administration to prescribe seasons and methods of fishing for various species. A fisheries advisory board was set up with Gilchrist as chairman.

There was a gap in research between 1905 and 1920 when the survey restarted with another steam trawler, PICKLE. At this time Gilchrist recorded that anchovies and pilchards occurred in abundance and were the principal food of the snoek. In 1924 the central government of the Union of South Africa took over financial responsibility for fisheries from the Cape Government, making this the concern of the Department of Mines and Industries. This was followed in 1929 by the formation of the Departments' Division of Fisheries and Marine Biological Survey, with a new research trawler, AFRICANA.

Perhaps the pelagic fishery dates from 1935 when the example of California was followed and some local entrepreneurs experimentally canned pilchards; but at any rate, in 1939 the demand for canned fish began to rise both locally and abroad. Italian fisherman made lampara type nets and caught shoal fish in Saldanha Bay. In 1940, 2,000 cases were packed on government contract at Lambert's Bay, and in 1941 the fishery began to expand despite problems with gear, poor cannery equipment, and a lack of tinplate. As the pelagic catch increased, 1943 was considered a record year with a pilchard landing of approximately 5,500 tons. The Fishing Industry Development Act of 1944 created the Fisheries Development Corporation and made the Department of Commerce and Industry responsible, through the Division of Fisheries, for the administration of the Sea Fisheries Act of 1940 relating to standards for export, control, and administration.

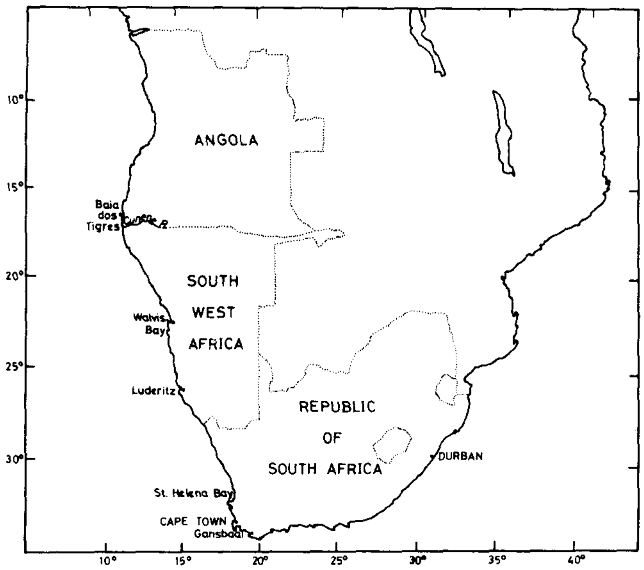

FIGURE 3. Detailed location of pelagic fisheries.

In 1944 the first plant for making fishmeal from pelagic fish began operating. By then pilchards were 55% of the total fish pack, and the cannery industry was getting organized. Experiments with gear in 1947 showed that a purse seine net was too heavy, so light pursed lampara nets were used, and successfully, for a number of years. Approximately 55,000 tons of pilchard was caught in 1948. The industry grew rapidly and by 1950 there were 13 factories catching over 80,000 tons of pilchards.

In 1950 the fishery was controlled by a comprehensive act and brought under investigation by the Division of Fisheries in a "Pilchard Research Programme." The 1950 legislation and its effects have been summarized by Du Plessis (1959) who noted that the control measures were not unilaterally enforced by the state but adopted after consultation with the processors and fishermen. The following measures were adopted:

- A minimum mesh size of 38mm between knot (mesh changed in 1956 to 32mm on introduction of synthetic materials).
- Limitation of processing plants; by 1953 the overall capacity limit of 221 metric tons/hour was reached.
- Provisions were made for closed seasons.
- Boat limitation was introduced, and no increase in numerical strength or total boat hold capacity was permitted.
- Limitation of installation of canneries (effective after 1953).
- Quotas were adopted and became effective in 1953 with a 250,000 ton (226,900 metric) combined pilchard and maasbanker quota, until 1958.

Unfortunately no distinction was made between pilchard and maasbanker catches, but it is possible to separate the catch records. The period 1950–58 saw considerable technological change as echosounders and winches were introduced and net size increased.

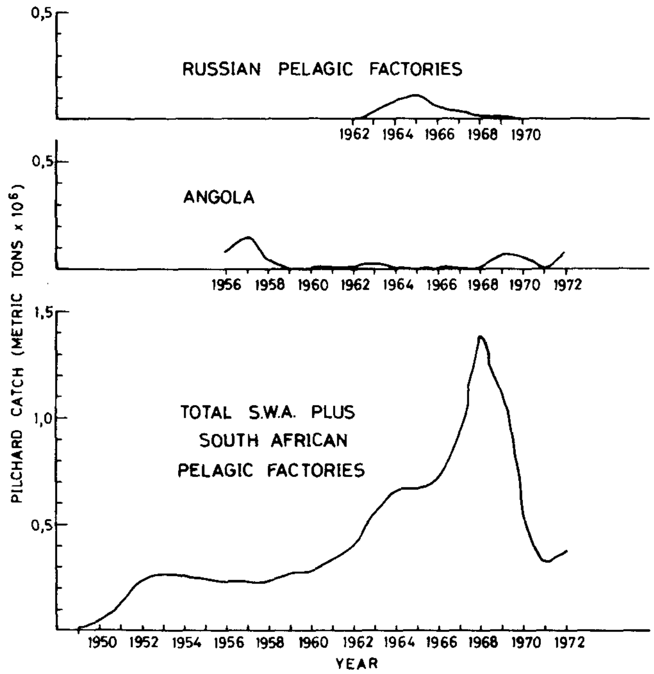

FIGURE 4. Southwestern Africa pilchard catch 1950–1972 from all data sources available.

The Pilchard Research Program which commenced in 1950 utilized all the resources of the Division and, from 1957, those of the South West African Administration Laboratory in Walvis Bay. Most of the work conducted has been published by David Davies in the Investigational Report Series of the Division and summarized in Davies (1957). The work covered distribution, associated species, reproduction, size, growth and age, feeding, migration, disease, and predators. Buys (1959) studied the hydrographic environment and commercial catches in St. Helena Bay and discovered a relationship between the annual average temperature from 0–50m and the pilchard catch the following year, and a relationship between the average value at 20m with maasbanker catches the following year. However, despite the strong correlation, Buys regarded the evidence as of little predictive value.

In 1953 a Boat Limitation Committee was set up to advise on numbers of vessels to be allowed into the fishery. Nevertheless the committee's advice was not accepted by the government on several occasions (Report 1971, para. 493).

The pilchard/maasbanker quota remained at 226,900 between 1953 and 1958 whereafter it was raised. In practice the quota was not applied rigorously as factories were permitted to fish all season whether or not quotas were filled. Other conservation measures introduced in 1950 were also of varying value. The imposition of a closed season occurred over the period when minimal catches were made in any case. The limitation on processing plants was seldom effective as the plants rarely received raw material in excess of their capacity, but the government unilaterally awarded extra licenses in 1965 increasing total processing capacity by 20% (Report 1971, para. 496). The restrictions on nets had only a limited effect, for all cotton nets were replaced by synthetics between 1950 and 1956 and the lighter weight and better handling qualities of synthetics increased the efficiency of the gear. Nets also became larger as vessels of progressively greater size were built (Stander and Le Roux, 1968).

In 1965 the government granted concessions for two fishmeal factory ships to operate outside the 12 mile limit of South Africa and South West Africa, placing no limit on the processing capacity or the fleets serving them. The vessels commenced operation in 1966 and 1967 and considerably increased the effort available in the South African and South West African fishery. It is recorded that the Commission of Enquiry Into the Fishing Industry regarded the increases in capacity allowed in 1965 as inordinately generous and that this increase set in motion an unhealthy trend in the fishery (Report 1971, paras 496-8).

As the pilchard catch began to decline after 1963, the fishery began to diversify with increasing catches of anchovy, *Engraulis capensis,* from 1964; redeye herring, *Etrumeus teres,* also from 1964; and principally one species of lanternfish, *Lampanyctodes hectoris,* from 1970 (Centurier, Harris, 1974). In 1971 the total catch was fixed by quota at 362,000 metric tons, and raised in 1972 and 1973 to 380,000 metric tons. In 1974 the quota was initially reduced to 365,000 metric tons but, during the season, was raised to 400,000 metric tons, with the provision that all mackerel catches made further than 25 n. miles offshore would be excluded from the quota. During the period 1964–75, the overall catch has remained approximately constant (Figure 5).

Aerial spotting commenced in 1967 but has only functioned as an aid to the deployment of fleets, rather than for the tactical deployment of fishing vessels, and as such is probably underutilized.

South West African Pilchard Fishery

There had been an inshore fishery for snoek for a number of years at Walvis Bay when, in 1922, a factory ship operated at Walvis Bay. The 1,481 ton SHERARD OSBORN acted as a processing plant for pilchards caught by catching vessels. Pilchards were canned, oil and meal were produced, but the venture was a failure. The first legislation affecting the South West African industry was promulgated immediately: Proclamation 18 of 1922 referred to the protection of seals and fish in territorial waters, closed seasons and size limits, and as such was the basis for future legislation.

In 1947 a snoek cannery in Walvis Bay began experiments with canning pilchards and producing meal and oil from whole fish and offal. By 1948 the catch exceeded capacity and a modern plant was ordered from the U.S.A. Three canneries incorporating fish-meal and oil plants were operating by 1949 when the South West Africa

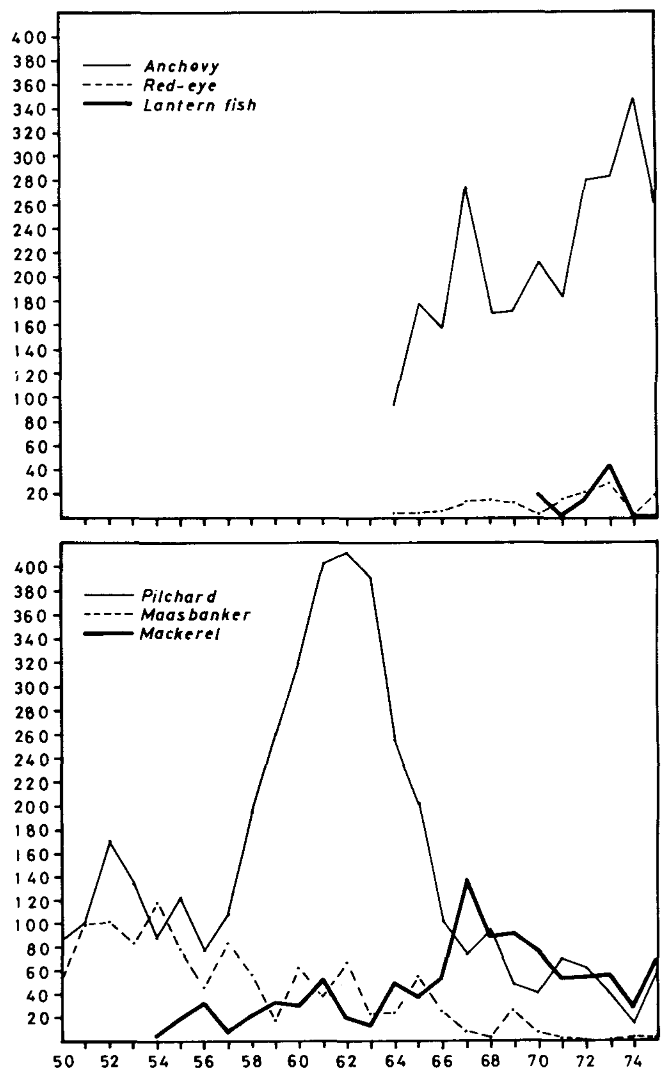

FIGURE 5. South African pelagic catch 1950–1975.

Administration decided that controls were required. In 1949 the Union of South Africa Parliament passed the South West Africa Amendment Act giving the territory the same powers as the four provinces of the Union. The South West Africa Administration, however, retained the right to legislate in certain domestic matters. In mid-1949 the Sealing and Fishing Ordinance was passed which gave the South West Africa Administration considerable powers over the fishing industry. Every vessel and factory had to be licensed; the maximum catch of any species could be fixed by notice in the *Government Gazette;* the number and capacities of fishmeal and oil plants in any defined area could be limited; the use of floating factories would be prohibited; taxes would be applied; there would be closed seasons and sanctuaries; and statistics would be collected from fishermen and factory owners.

The Marine Research Laboratory recruited a scientist in 1950 and research work commenced in 1952 following the launch of a small research vessel. By 1952 the fishing fleet consisted of about 100 boats and the administration imposed boat limitation restrictions to the effect that each factory could have 24 boats unless it already had more, in which case the number should be reduced in the course of time. At this time processing had expended to six large plants and in 1953 the reduction plants were limited to six with no single plant exceeding 30 tons/hour. In addition, catch quotas were applied, and a closed season introduced from 15 November to 28 February.

Incidentally, this total catch quota of 226,800 tons was not based upon scientific evidence derived from the fishery but from assumptions derived from the history of the California pilchard fishery. To enable the factories to adjust to the lowered catch, a temporary additional quota of 22,700 tons was granted for 1954, so the 226,800 ton quota became operative in 1955. The gross aggregate tonnage of the factories' vessels was restricted in 1954 to 495 tons for larger and 328 tons for smaller factories and during 1955 the number of vessels in the fishery declined.

The closed season covered the period when pilchards had spawned and were close to the harbor but in poor condition for canning, and with a low oil yield of about 2 gal/ton. Although this restriction was later removed, the bulk of the catch was still made in the mid-year period when fish condition was good and oil yield up to 18 gal/ton could be expected.

These conservation measures operated for 5 years, and had some impact: catches were tailored to production programs, production was streamlined, and waste began to be eliminated. The industry became stable and predictable. During this period of stability the administration realized that the yield of this now very valuable fishery should be scientifically evalulated, so in 1956 the Marine Research Laboratory at Walvis Bay started a tagging program to provide material for stock assessment and migration studies. The tagging program extended from 1956 to 1967 but no effective results were available until 1970.

The stable period ended in 1959 as a feeling grew that a larger catch could be taken from the pilchard stock. The South West African Administration associated itself gradually with this line of thought and at the insistence of the industry began to increase quotas progressively (Report 1971, para. 524).

In 1961 another cannery opened with a new quota, and further increases gave a quota of 626,000 tons by 1963. At this time it was felt necessary to safeguard the resource from international pressure, so the Territorial Waters Act (87 of 1963) extended the South and South West African territorial waters to 6 miles plus a 6 mile contiguous fishing zone.

In 1964 the quota was increased to 653,000 tons as two new factories opened, one in Walvis Bay and the other at Lüderitz. A concession on gear also was made with one vessel from each factory being allowed to use small mesh anchovy nets (11mm stretched mesh) in an attempt to commence an anchovy fishery. Quotas did not change in 1965 and 1966, but this period was the turning point in the history of the stock.

In 1966 a South African floating factory began operation off South West Africa and two further licenses were granted, against the wishes of the South West African Administration. A second floating factory with 18 catchers began operating in 1967 whilst the first floating factory increased its catchers from six to nine.

The South West Africa Administration was alarmed by this development and granted a special quota of 8,700 tons per factory partly to satisfy insistent demand and partly to raise money for research through a special research levy of R5,00 per ton on the special quota. In addition a new 90,355 ton quota was granted. This was followed by a further 90,355 ton quota in 1968, but the disagreement between the two authorities was settled by stabilization of South West African quotas at ten quotas of 81,650 tons plus 5,400 ton research levy quota and by limiting the South African floating factories to two, which had to operate outside the 12 mile contiguous fishing zone.

The factory ships were placed on a 499,000 ton quota for 1969 and 454,000 for 1970. This decision, however, was reviewed in 1969 and the factories were requested to withdraw in 1970.

In 1967 and 1968 the pilchard catch rose to 1 million and 1.5 million tons respectively. With all out efforts by the floating factories and land based factories, the catches in 1969 fell to around 1 million tons, and then in 1970 when no floating factories operated, to approximately 450,000 tons.

By this time most organizations connected with the fishery feared that a major decline had occurred, so a special research program was created and given access to the substantial funds accumulated by the Research Levy Fund since 1967.

The new program was referred to as the Cape Cross Program and represented a departure from traditional research methods. The sectional approach to research was replaced by an integrated multi-disciplinary approach involving accelerated sampling of the catch, a large scale egg and larvae program (South West African Pelagic Egg and Larvae Survey—SWAPELS), aerial research with night-viewing devices and airborne radiation thermometry, an acoustics program using a high frequency echosounder and integrator, genetics and fecundity studies, hydrobiological surveys, and so on (Cram and Visser, 1972, 1973; Cram, 1974). Having gained the confidence of the head office of the Department of Industries initially, heavy funding from the Research Levy Fund allowed a considerable investment in capital and running expenses which gave a good yield in terms of the conservation of the pilchard.

As a first result of accelerated research, in 1971 the ten established factory quotas of 81,650 tons were split on a 33%:66% basis giving a 27,215 ton pilchard quota and 54,435 ton "other species" quota, with the provision that the factory closed on filling its pilchard quota. The object was to reduce effort on pilchard whilst increasing effort on other species in order to retain the economic viability of the fishery whilst conserving the pilchard stock. In the same legislation, a 6 month closed season was proclaimed from 1 September to 31 March, and the area in the north where the juveniles predominated in experimental catches was closed to fishing. These restrictions were internationally broadcast through the International Commission for South East Atlantic Fisheries (ICSEAF), and member states were requested to act in accordance. Although cumbersome and open to abuse, this regulatory mechanism works well through an intensive inspection system which ensures that most catches delivered to the jetties are examined and sampled by government inspectors. These samples are the basic scientific data extracted from the catch. The split quota caused an increase in cannery efficiency as a "tally" system was developed to spread the pilchard quota over the entire season, boats only being allowed to present a fixed amount of fish (tally) to the factory for each trip. This eliminated gluts and scarcities and allowed the development of an optimal cannery program. Between 1971 and 1975 the split quota has been progressively readjusted from a 33:66 basis to 50:50.

There is a strong contrast between management styles in the 1960s and 1970s characterized by the attitude to quota increases. In the 1960s optimism was the keynote in expanding fisheries, and management was virtually by consent in a situation where scientific advice was absent or equivocal. In particular, economic argument had force and tended to prevail; it has been reported that, despite the existence of ample legislation, the effect of conservation orientated regulations was minimal. Concessions and quotas were relatively freely awarded until the industry itself became aware of disconcerting signs and began to insist upon scientific work being undertaken. This system of management did not work.

During the 1970s with declining or uncertain fisheries and better scientific advice, the government felt able to take an aggressively conservation-minded attitude, especially in South West Africa where sudden and strong action apparently became necessary. Both the South African and South West African pelagic fisheries are virtually national fisheries, not tightly controlled by the Department of Industries with regard to the fixed wetfish price (irrespective of species), the fixed selling price of all products, and the extensive legislation covering all aspects of catching and processing. At the moment, stability appears to exist.

CURRENT RESEARCH

Research on South African pelagic stocks has always proceeded along conventional lines, building up biological information with which catch data can be quantitatively analysed. Hydrobiological and egg data have been acquired, but their employment as management tools has been minimal. The yield of the Cape multispecies fishery has been recently established through an analysis of catch-per-unit effort and effort, and the sizes of component stocks

TABLE 1

Cape Pelagic Fish Catch 1949–75 *

Year	Species						Total
	Pil-chard	Maas-banker	Mack-erel	Anchovy	Redeye	Lantern fish	
1949......	17,279	3,367	–	–	–	–	20,647
1950......	86,075	49,154	–	–	–	–	135,229
1951......	101,064	99,357	–	–	–	–	200,421
1952......	171,066	101,572	–	–	–	–	272,638
1953......	133,147	84,552	–	–	–	–	217,699
1954......	88,304	118,137	4,044	–	–	–	210,481
1955......	121,994	78,822	20,228	–	–	–	221,044
1956......	76,512	45,752	32,670	–	–	–	154,934
1957......	108,568	84,615	7,364	–	–	–	200,547
1958......	194,857	56,415	21,580	–	–	–	272,852
1959......	260,181	17,676	33,088	–	–	–	310,945
1960......	318,032	62,926	30,985	–	–	–	411,943
1961......	402,318	38,935	52,398	–	–	–	493,651
1962......	410,249	66,649	20,355	–	–	–	497,253
1963......	390,660	23,168	13,201	–	–	–	427,029
1964......	255,022	24,241	50,244	92,395	2,474	–	424,376
1965......	202,669	55,294	39,470	117,685	2,052	–	477,170
1966......	113,565	26,288	54,899	157,234	4,501	–	356,487
1967......	73,448	8,552	138,864	275,839	12,676	–	509,379
1968......	94,100	1,318	90,106	169,793	13,504	–	368,821
1969......	48,582	25,772	92,845	171,241	12,804	–	351,244
1970......	41,059	7,522	77,740	214,713	2,931	18,203	362,168
1971......	65,168	1,603	54,279	184,839	14,267	2,575	322,731
1972......	62,108	960	55,594	280,229	20,000	15,238	434,129
1973......	41,861	257	56,728	283,489	26,520	42,560	451,415
1974......	16,649	1,616	30,898	348,898	792	334	398,782
1975......	57,787	804	67,951	261,500	17,781	58	405,881

* Thousands of metric tons.

are approximately determined from virtual population analysis. The bulk of this work is published in the Investigational Report Series of the Sea Fisheries Branch. In South West Africa, research proceeded along similar lines with the emphasis on acquisition of catch and basic fish biological and hydrological data. A tagging experiment from 1957 to 1968 yielded stock sizes and migration patterns. This work is published in the Research Reports of the Marine Laboratory of the South West Africa Administration as well as the Investigational Reports mentioned above. In 1970 research rapidly expanded in an integrated multidisciplinary program (Cape Cross Program) of which little has been formally published; however, the four informal reports generated by this program will be published fairly soon.

a decline began. The decline in mature fish anticipated that of the total owing to good recruitment and heavy mortality on mature fish over a period of a few years. The total abundance index declined severely after 1963. After 1965 anchovy nets with 11mm mesh size were widespread, so the size compositions before and after this date are not comparable.

The abundant year class or classes arose from years when the spawning biomass was low or declining, thus larval survival must have been good. The high levels of abundance in 1960–63 are sensitive to the estimate of fishing effort. If hold capacity as an index of effort underestimated the rate of increase in effort, the real level of abundance may have been much lower than suggested. Since good effort data are only available from 1964, the existing effort data from 1957–61 can only be qualitatively examined.

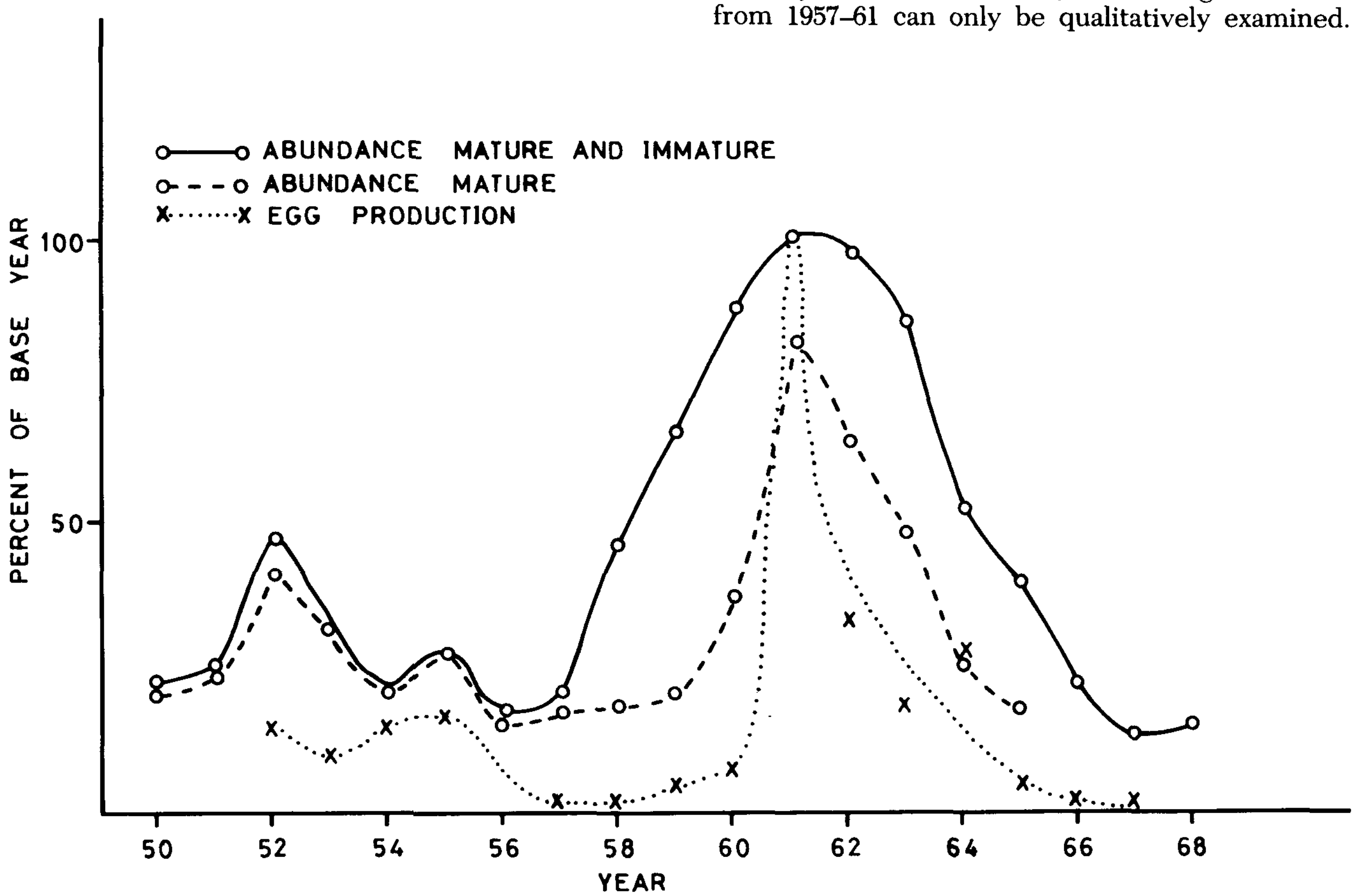

FIGURE 6. Pilchard and Pilchard egg abundance during the period 1950–1968.

South African Multispecies Pelagic Fishery Population Biology

Newman (1974) reviewed trends in the fishery and landings by species were derived from this work (Table I and Figure 5).

From 1950 to 1957 most of the catch was sexually mature and the stocks remained fairly constant. In 1958–59 the total pilchard abundance index increased due to good recruitment (Figure 6). The index increased to a peak in 1960–61 and thereafter

There is information to confirm that an increase in pilchard abundance took place in 1958–61. Du Plessis (1959) and Stander and Le Roux (1968) commented on the large proportion of young fish in the size composition data for 1958. In 1957 the fish had a modal length of 16cm which moved to 19cm in 1958, consistent with the growth data presented by Davies (1958) and Baird (1970).

Innovations such as echosounders were introduced before the decline commenced, but others such as

TABLE 2

Changes in Characteristics of the Fishing Fleet*

Year	Hold capacity **	No. boats	Mean hold capacity	Notations
1950	4.8	150	32	–
1951	6.4	183	35	–
1952	7.3	197	39	–
1953	8.3	229	36	–
1954	8.5	225	38	–
1955	8.3	228	36	Echo Sounder introduced
1956	8.2	222	37	–
1957	8.2	210	39	–
1958	8.5	201	142	–
1959	8.7	105	52	–
1960	8.3	143	58	Echo Sounder 100%
1961	9.3	131	71	
1962	9.8	122	81	
1963	10.9	127	86	Power blocks
1964	11.4	126	90	
1965	11.7	125	94	Fish pumps
1966	11.9	125	95	Sonar Introduced
1967	14.3	135	106	
1968	14.5	130	112	
1969	14.5	129	113	
1970	14.5	113	129	

* From Newman (1974)
** X 10^3 short tons

power-blocks, sonar, and fishpumps were introduced after 1961 (Table 2). There was a trend towards fewer, larger vessels, a trend which continued until 1966. In the late 1960s aerial fish spotting commenced. All the above would tend to increase efficiency of effort in terms of hold capacity. From 1962 the catch per ton capacity declined rapidly confirming a decrease in abundance.

From 1964 onwards effort was diverted into anchovy, and the pilchard decline was compensated for by the increase in anchovy (Table 1). The evidence led to the empirically derived assumption that a multispecies yield of between 400,000–500,000 could be expected and that it was not likely to be increased by expending further fishing effort.

An assessment of fishing effort, stock abundance, and yield for the South African multispecies pelagic fishery has been published in abstract form (Newman, Crawford, and Centurier-Harris, 1974). The multispecies catch per boat lunar month was used to calculate the fishing power of individual vessels for each year from 1964 to 1972 using Robson (1966) methodology. Fishing power for each year was regressed against vessel storage capacity, horsepower, age, and net dimensions to evaluate the effects of these parameters on fishing power. Storage capacity was shown to have a significant effect on fishing power in most years. Vessel horsepower and age were important in the earlier and later years respectively. A dummy variable in the regression equation showed that the change from 32mm to 11mm mesh size improved boat efficiency by 64% while fish pumps increased fishing power by 36% and sonar, 18%.

A two dimensional array of catch per boat fishing season (7,16 lunar months) arranged by boat and year was used to calculate catch per standard boat fishing season for the period 1964–72. This catch per unit effort (CPUE) estimate and annual total catches were used to determine the total effort in each year, which was then adjusted for the introduction of fishing aids to produce an improved CPUE time series.

Effort increased from 800 to 1,500 standard boat lunar months between 1965 and 1972 while the CPUE of all species declined from 600 to 290 metric tons per standard boat lunar month in the same period. Plots of CPUE on effort of the previous year showed empirically that a yield of about 360,000 metric tons can be expected from the stocks, and that an increase in effort would not be advantageous and may have a detrimental effect.

The abundance of pilchard from 1953 to 1972 was estimated by virtual population analysis. Strong recruitment in 1955 and 1956 led to a rapid increase in population resulting in a stock size of 2.4 million metric tons in 1959. Thereafter the stock declined because of heavy fishing and more normal recruitment. In 1972 the population was at 11% of its peak value in 1959. These large fluctuations confirm CPUE information of Stander and Le Roux (1969).

Virtual population analysis shows that anchovy stocks have remained fairly stable between 1964 and 1972 at about 600,000 metric tons. There is no evidence that anchovy stocks have increased as the pilchard declined. Blanket net catches show some increase after 1959, but this is when the pilchard were most abundant (Newman, Crawford, and Centurier-Harris, 1974).

Aerial/Acoustic Surveys in South West Africa

Since 1971 the Branch has been attempting to develop aerial/acoustic methods of stock size measurement (Cram 1972, 1974). Work has centered upon development of survey strategy and measurement methods. Initially it was thought that aerial and acoustic methods could be used separately, but observations on *Sardinops ocellata* shoal groups showed that extreme patchiness of shoals, their mobility, and the tendency of fish to avoid survey vessels may invalidate results of quantitative acoustic surveys on the stock. These errors can be reduced considerably by employing a survey strategy in which aircraft delimit areas of high fish occurrence into which aerial and acoustic observations are concentrated at the expense of areas of low fish occurrence. The technique calls for aircraft sensors to obtain horizontal dimension data whilst the vessel's acoustic gear makes synchronous measurements of shoal thickness and fish packing density on as many shoals as possible within the shoal group (Cram and Hampton, 1976).

The sources of error in the aerial/acoustic method have been critically examined and distinctions have been drawn between biased and unbiased sampling errors and errors of physical measurement. Sources of sampling bias have been examined on the basis of experience in the fishery from 1970 to 1975 and, where possible, quantitative arguments were used. Statistical sampling errors have been estimated from the variance in aerial and acoustic samples taken from integral subpopulations of the total stock.

A tentative error limit of ± 50% is fixed on estimates of relative apparent abundance, but no estimate has been made of error limits in absolute determinations of apparent abundance as the necessary experimental work on the acoustic target strength of *Sardinops ocellata* is not yet complete.

Aerial observation of pilchard shoals has had an impact upon attitudes towards other aspects of research, particularly ecology. When the location of the bulk of the stock is known, it is possible to relate occurrence of shoal groups to environmental conditions, spawning groups to shoal groups, and to relate fish distribution to distribution of effort in the fishery. Pilchard shoals are very variable in size, from super shoals of many kilometers length to small shoals of a few meters length. Shoals may be ribbon like, crescentic, or round; the ribbon shaped ones usually being the largest (Cram & Agenbag, 1974). Anchovy shoals size appears to differ with age groups: younger fish tending to form large shoals, and adult fish smaller shoals (Schülein, Sea Fisheries Branch, personal communication). The few observations available suggest that sizes of shoals may be very variable.

In the multispecies fishery, identification of shoals is always a problem, particularly so when the relatively small anchovy shoals are entrained by a large pilchard shoal group. Experienced observers are at an advantage, but are not infallible. With improved TV equipment and a National Marine Fisheries Service (NMFS) type drop camera it may be possible to determine more reliably the difference between anchovy and pilchard shoals when they are closely adjacent.

Ichthyoplankton Surveys in South West Africa

Since 1971 egg and larvae research has been an important part of the research program in South West Africa. A large scale survey program ran for 2 years between August 1972 and April 1974 during which monthly cruises were conducted between August and April to coincide with the spawning patterns of the major pelagic species. The horizontal distribution of pilchard eggs was adequately delineated throughout the survey area.

Two separate seasonal and geographical spawnings were found: one in a southern inshore area peaking during August to September at 13,0°C to 16,6°C, the other in a northern offshore area peaking during February and March at 16,5°C to 22,0°C (Figure 7).

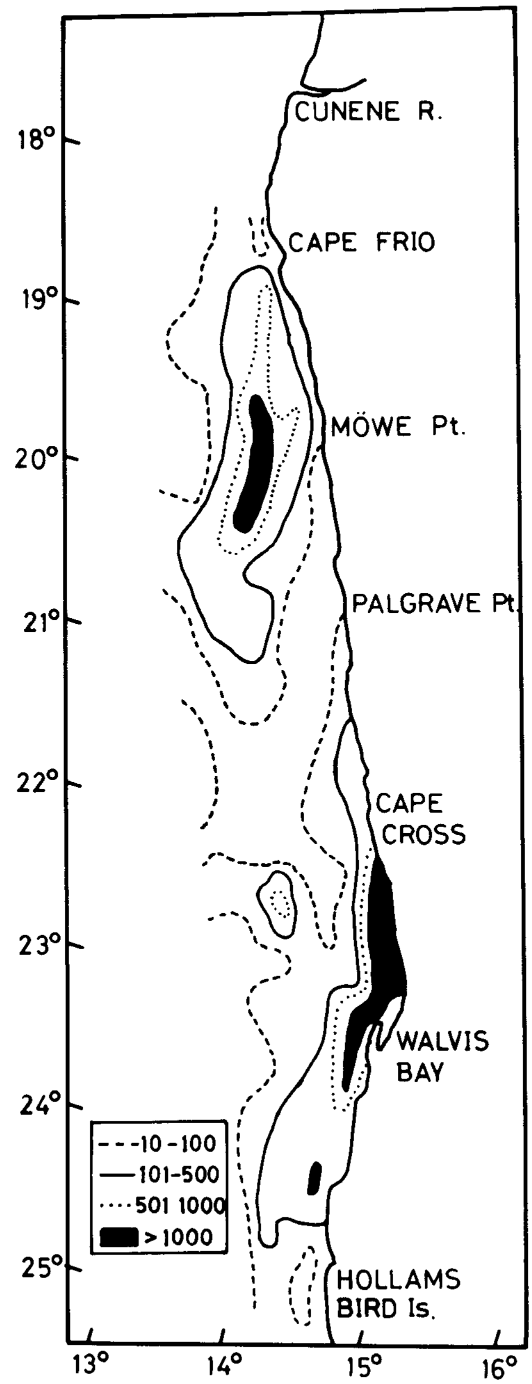

FIGURE 7. Spawning group distribution.

Pilchard eggs collected in bongo net samples were sorted into development stages, and the abundance of each stage was divided by stage duration to give numbers produced per day. Using these values the instantaneous coefficient of loss per day Z was calculated from

$$\frac{N_2}{N_0} = c^{-Zt}$$

where:

N_0 = initial number of eggs
N_2 = number surviving to the next stage in t days
t = mean stage duration.

Egg mortalities of 87% and 89% were derived for the two survey periods.

The stock size of the adult pilchard was determined from egg production and calculated at 1.7 million metric tons for 1972/73 and 2.3 million metric tons for 1973/74. The sources of error associated with this type of estimate are well known. The main contribution to the variance in the stock estimate is variability of egg distribution in space and time.

This problem was examined by taking 20 replicate bongo net tows in a 5 x 5 nautical mile area of high egg occurrence. The distribution of pilchard egg count showed a large number of tows with zero counts on one bongo unit in conjunction with high counts on the second bongo unit.

A probable explanation for the great differences in some catches is that the samples bordered on the peripheries of egg patches which, it would seem, are sharply delineated. As the mean of counts for the area will be influenced by the number of zero counts, within-tow observations were pooled. An analysis of the mean number of eggs per haul gave confidence limits of 0.68–1.36 at 95% level, which are in accord with the "half or double rule" reported by Silliman (1946).

Anchovy eggs were found in the summer months, December to April, in the northern area. Spawning appeared to be continuous, but eggs were most abundant in January and February in water of surface temperatures 17°C to 22°C. In contrast with other areas containing pilchard and anchovy stocks, *Engraulis capensis* is frequently found in warmer areas than *Sardinops ocellata.*

Embryos of the South West African pilchard, *Sardinops ocellata,* obtained at sea have been incubated from blastodisc stage to hatching at 27 different combinations of salinity, temperature, and dissolved oxygen (salinity range: 33–36°/₀₀ Temperature range 13–22°C, Oxygen range 1.5–1.7ml/1). Observations on rate of development, survival of eggs until hatching, viable hatch, percentage of malformations, and dimensions of newly hatched larvae were made. The combined effect of salinity, temperature, and dissolved oxygen on rate of development and larval survival was examined using multiple regression techniques. Pilchard eggs were defined as euryphaline, euryoxic, and stenothermal. Survival was maximum or near maximum within the range 16–21°C and 33–35°/₀₀ salinity where the dissolved oxygen exceeded 1.5ml/1. Decrease in dissolved oxygen content associated with increase in temperature caused retardation of development.

Mean larval length at hatch was 3.59mm. The growth of the larvae during the yolk sac stage and the efficiency of yolk utilization were also determined. Larvae increased in length for 3–5 days after hatching, after which time there was a progressive decrease in size, probably owing to starvation. In trial 24 (35°/₀₀, 18°C,5.2ml/*l* O_2) individual larvae reached their maximum length. Growth rate, taken as the increase in length in millimeter per day, showed a linear correlation with temperature. In an additional experiment, the mean ages at which embryos and larve attained five definite morphological and physiological stages were observed at 10 different constant temperatures (11–22°C).

The average time for morphological development of the eggs decreased exponentially with increasing temperature. Incubation time (fertilization-hatching) ranged between 118 hours at 11°C to 30 hours at 22°C. Below 13°C a functional jaw and retinal pigmentation failed to develop.

The rate of development of the round herring egg, *Etrumeus teres,* also was determined and incubation time was found to vary from 135 hours at 11°C to 30 hours at 20.5°C (O'Toole and King, 1974).

TABLE 3
Species and Percentage Composition of Larvae taken in South West Africa Ichthyoplankton Surveys

Species	Percentage	
	Survey 1*	Survey 2**
Pelagic larvae		
Goby, *Sufflogobius bibarbatus*	66.6	60.0
Anchovy, *Engraulis capensis*	16.6	1.9
Pilchard, *Sardinops ocellata*	3.7	17.5
Mesopelagic larvae		
Myctophid and Gonostomatids	4.5	12.4
Maasbanker, *Trachurus trachurus*	3.12	4.9
Hake, *Merluccius capensis*	1.3	0.9
Soles, *Austroglossus microlepis* *Dicologlossa cuneata*	3.0	1.5
Others	1.1	0.8

* 1971-72.
** 1972-73.

All fish larvae were extracted from the SWAPELS samples and identified as far as possible to species level (Table 3). Those belonging to commercially important groups were measured to the nearest millimeter. Larvae of the following families were represented in the catches: Clupeidae, Engraulidae, Gonostomatidae, Myctophidae, Gadidae, Merluccidae, Carangidae, Trichiuridae, Scorpaenidae, Triglidae, Gobiidae, Blenniidae and Soleidae.

Pilchard larvae were widely distributed over the research area and correspond well with the egg distribution already outlined. They were most abundant at surface temperatures of 14.0°C–16°C in spring and at 18–21°C in summer. Larvae were particularly numerous during January, February, and March in waters of 18–21°C. The geographic limits of anchovy larval distribution were not delimited to the north or to the seaward of the research area. It is assumed that considerable spawning must have occurred further north and west of latitude 18°S. Larvae were more common in night hauls with peak abundance occurring from midnight to 0200 hours (O'Toole, Sea Fisheries Branch, person. comm.).

Environment off South West Africa

The distribution of conservative and non-conservative properties of sea water off South West Africa showed great similarity to that reported by Hart and Currie (1960) and Stander (1964). It was therefore apparent that since 1970 no large scale departures from normal oceanographic conditions had occurred.

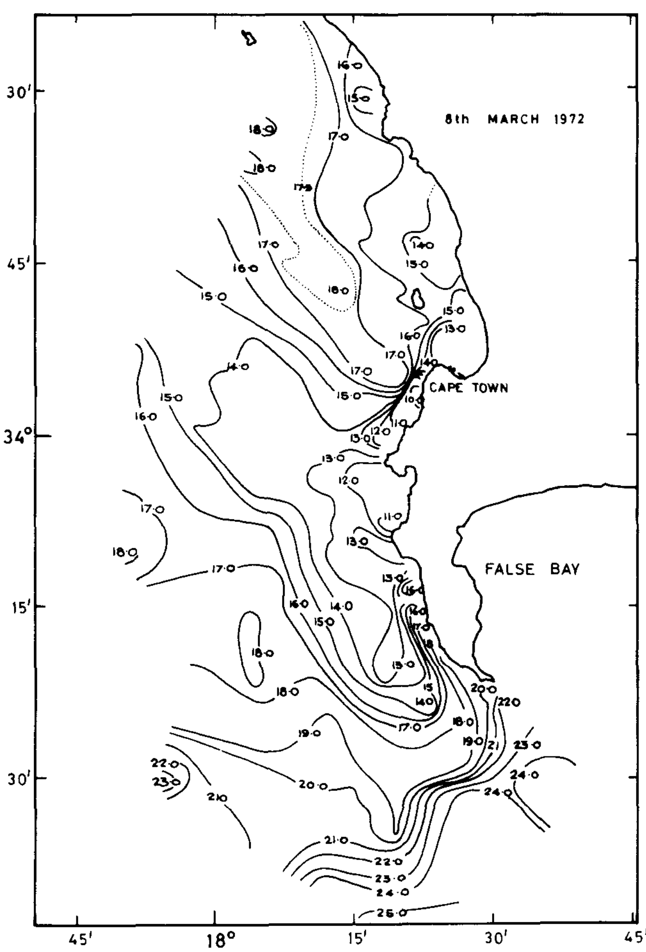

FIGURE 8. Southern end of the Benguela Current upwelling component.

Airborne radiation thermometry (A.R.T.) provided more detailed information on surface temperature distribution throughout the Benguela Current system, particularly on the coastal upwelling zone. The southern end of the upwelling component of the system exists in the region of Cape Town and is noticeable for the intense thermal gradient formed during periods of active upwelling (Figure 8).

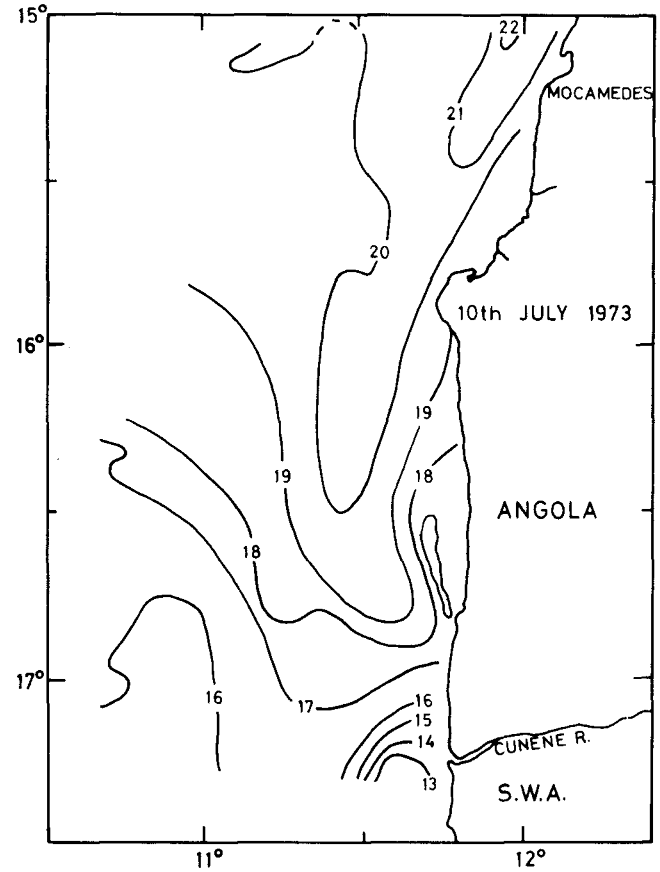

FIGURE 9. Northern end of the Benguela Current upwelling component.

A quantitative relationship between surface temperature and local wind direction and velocity has been derived for the area near Cape Town, and W. R. H. Andrews has shown that a relationship exists between surface wind stress and the distribution of numerous properties in deeper water. Based on these relationships A.R.T. data up the coast have been interpreted as showing that the coastal upwelled component of the system is very responsive to variations in local wind stress. Coastal upwelling occurs in about seven semipermanent sites between the northern limit near the Angolan border (Figure 9) and the southern end near Cape Town. Seasonal migrations of the South Atlantic atmospheric high pressure system cause changes in the coastal winds which provide year long refreshment to the surface waters by upwelling. Although upwelling winds blow intermittently over the whole year in the entire area, their effect is focused on certain areas in a seasonal manner. In summer, when the high migrates south, coastal pressure gradients are enhanced in the south and weakened in the north, so upwelling is at a maximum in the south and reduced in the north. In winter, the high migrates north and upwelling is at a maximum in the north and a minimum in the south. In the center of the system near Lüderitz there appears to be more constancy. Although refreshment by upwelling is constant, it is seasonably and geographically separated and, at present, the biological implications of this situation are unknown.

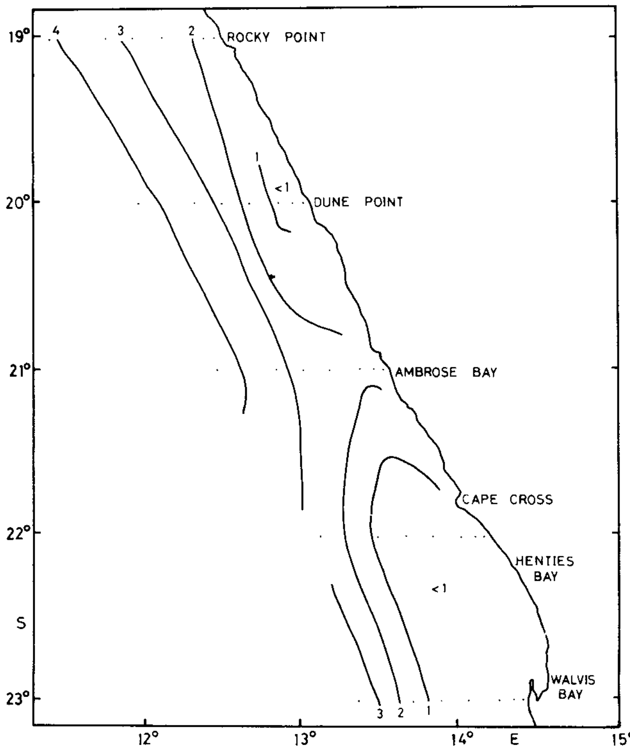

FIGURE 10. Dissolved oxygen (ml/1) at 50 m for June 1973.

Planktology and other hydrological investigations have been accomplished to examine distributions and as part of an ecological study on pelagic fish. The ecological work implies that salinity and temperature of the coastal zone are rarely unsuitable for pelagic fish, but that their distribution can definitely be limited by the dissolved oxygen content and dense phytoplankton (principally *Fragilaria karstenii*). Oxygen content values of less than 1 ml/1 are common in deeper water throughout the fishing ground and can occur up to the 5m depth (Figure 10). Areas of low oxygen content tend to be devoid of catch and, dependent upon their position and persistance, can have a considerable influence on fish availability (Visser *et al.*, 1973; Wessels *et al.*, 1974).

Phytoplankton and zooplankton occur in zones approximately parallel to the coast: the densest phytoplankton being close inshore and densest zooplankton being offshore. Pilchard shoals avoid the dense *Fragilaria karstenii* tending to be found in less dense phytoplankton and zooplankton mixed areas (Figure 11). Anchovy do occur in the *Fragilaria karstenii* areas although both anchovy and pilchard are rarely caught in he high zooplankton (low phytoplankton) areas. *Fragilaria karstenii* is usually very abundant around Walvis Bay, particularly in the upwelling center south of Walvis Bay, and seems to be the preferred habitat of the goby, *Sufflogobius bibarbatus.* Extensive goby catches have been made with purse seine nets in this area, but the quantities were not recorded separately from other species.

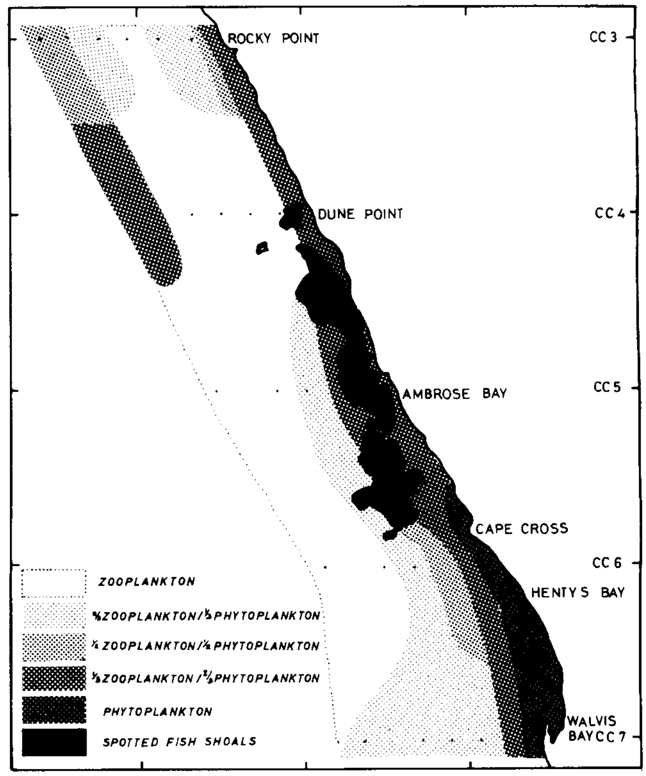

FIGURE 11. Plankton and fish shoals (April 1972).

The concept of the intermediate zone of phytoplankton/zooplankton and oxygen content is doubtless an oversimplification. However, it served as a useful first concept with which to interpret data, and combined with the fishspotter data led to ideas of fish shoal ecology, using the shoal group as a biological entity, which is useful input to availability studies.

Feeding Studies on South West African Pelagic Fish

A start was made on a study of feeding selectivity in pilchard and anchovy in South West Africa and it was found that the gill raker mechanism of the post-larval fish is such that filter feeding is impossible. Particulate feeding occurs until a length of 100mm is achieved in pilchard and 80mm in anchovy after which diatoms dominate the diet. Below these sizes competition for food could occur with the extremely abundant goby larvae constituting an important source of competitive pressure on food organisms (King and McLeod, 1977).

Population Genetics of the South West African Pilchard

Nongenetic characters, such as time (season), water temperature, and locality separate spawning groups of pilchard along the south and west coasts. Tagging work indicates that there is little migration between the major stocks of pilchard in South and South West Africa (Newman, 1971). In South West Africa, ecological and seasonal differences separate two spawning groups. A preliminary genetics project showed that genetic imbalance occurred in all three regions sampled (two in South West Africa, one in the Cape). The regional samples showed different proportions of alleles. The simplest model suggests that the species contains several stock units breeding in isolation which is continuous over generations in spite of much physical mixing on the sampled fishing grounds.

South West African Pilchard Population Biology

Research on the South West African pilchard stock has centered upon the need to quantify and explain the decline which happened in recent years. (Table 4).

TABLE 4

South West African Pilchard and Anchovy Catch 1947–1975 *

Year	Pilchard	Anchovy
1947	0.9	
1948	2.7	
1949	8.0	
1950	46.7	
1951	127.2	
1952	225.8	
1953	262.2	
1954	250.6	
1955	227.1	
1956	227.9	
1957	227.5	
1958	229.1	
1959	273.5	
1960	283.3	
1961	343.5	
1962	397.4	
1963	555.2	
1964	635.9	
1965	661.0	0.6
1966	712.0	2.6
1967	932.2	24.8
1968	1,363.9	161.2
1969	1,010.7	226.1
1970	513.7	188.9
1971	324.0	187.8
1972	373.5	136.6
1973	408.1	295.5
1974	561.6	252.8
1975	561.4	200.5

* Thousands of metric tons.

When available estimates of stock size are considered with the pilchard catch over the same period, three notable points emerge, which have had important impact on management (Figure 12):

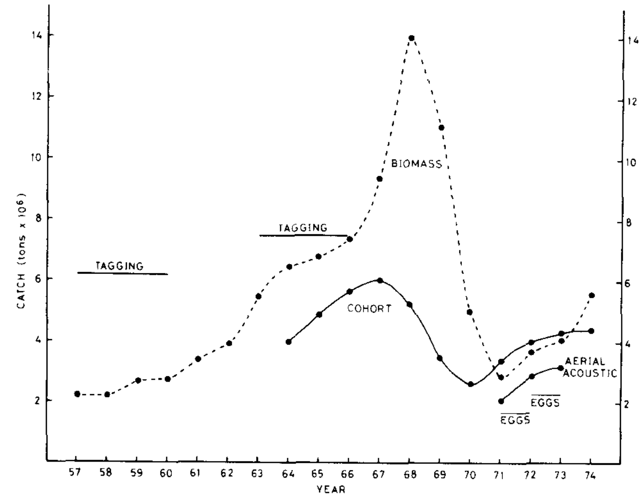

FIGURE 12. Stock size estimates and catch (Pilchard).

1. The 1957–60 and 1963–66 estimates of stock size are high in comparison with all other (later) estimates.
2. The stock size trend from 1961 to 1974 shows a relationship with the trend in catch.
3. All estimates from 1970 onwards display the same trend with approximately similar values.

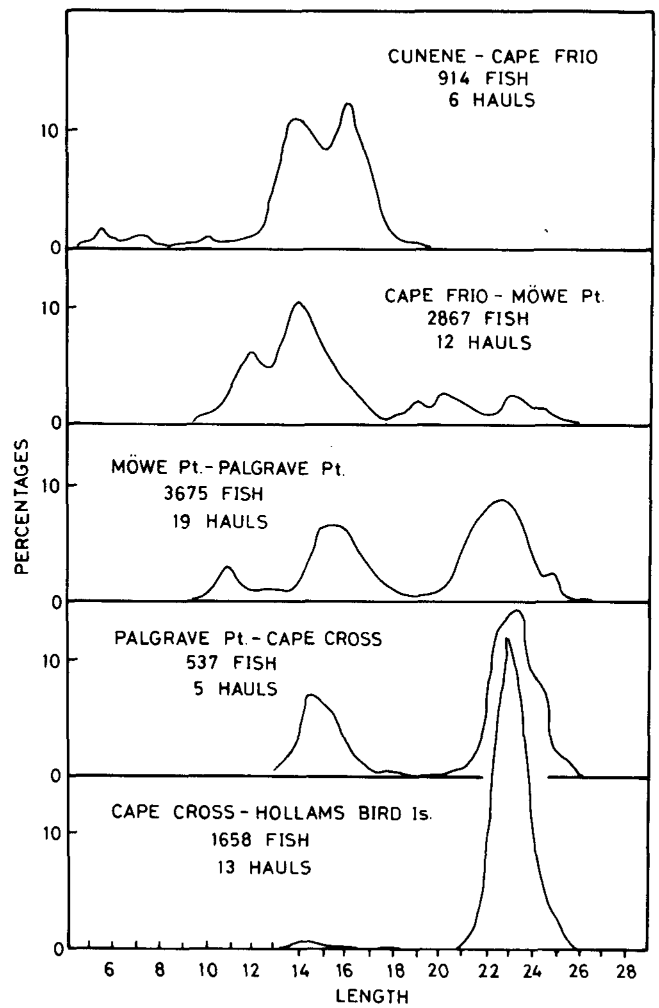

FIGURE 13. Percentage frequency distribution per area. Experimental catches September–December 1970 (Schülein).

Tagging Experiments

Stock size estimates of 6.25 million tons (1957–60) and 7.50 million tons (1963–66) were derived from an analysis of returns from a tagging experiment conducted by the South West Africa Administration Marine Laboratory (Newman, 1970). The analysis showed that emigration of tags from the catch area of the fishery was negligible.

Recent work on the distribution of *Sardinops ocellata* has demonstrated that the stock is widespread latitudinally (Figure 13). The assumption can be made that this is the usual distribution due to the Angolan fishery performance and aerial work accomplished between 1970 and 1974, which showed no change in distribution. Furthermore, this widely distributed population is subdivided into two spawning populations (Figure 7) with different ecological preferences (King, 1974). Fecundity studies show that samples taken during the spawning periods are significantly different in successive months, but cannot be separated consistently into northern and southern groups either temporally or spatically. Representatives of all groups can be captured at Walvis Bay (Le Clus, 1974). A preliminary muscle esterase genotyping experiment indicated that subpopulations could occur within the South West African population (Thompson and Mostert, 1974).

Considering that the recovery area for tags (Figures 14, 15) was only a small proportion of the

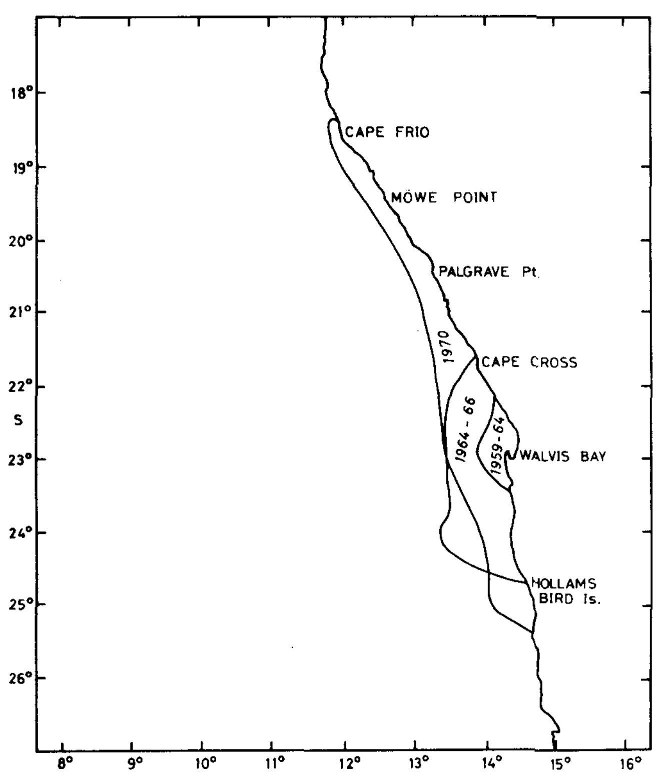

FIGURE 14. Increasing fishing area (from Baird, Newman, Ratte, Schülein, 1973).

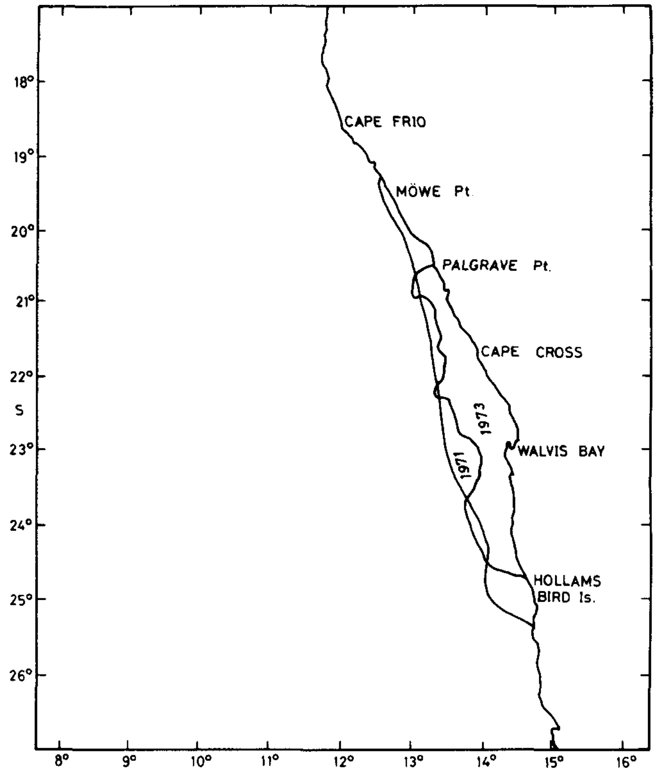

FIGURE 15. Decreasing fishing area.

area within which the shoal groups nomadically move, it is likely that emigration is a very significant factor, particularly so if tags were placed in representatives of a northern spawning group. Although the increase in the fishing area after 1964 has increased the likelihood of more effective tag recapture, emigration is probably a significant source of bias reducing the tag returns of the same landings and thus tending to inflate the estimate of stock size.

A second important source of error concerns estimates of initial tagging mortality. Unfortunately, no experimental work was done on *Sardinops ocellata* and a value of 40% was used, derived from work done on *Sardinops caerulea,* being the mean value for fish greater than 18.5 cm. However, the range of values reported by Clark and Janssen (1945) was 20% to 70% with very great variation between groups of tagged fish. From the description of the methods used by Clark and Janssen and some knowledge of the method used on *Sardinops ocellate* it is highly likely that at least similar variation occurred.

Using a Petersen population estimate,

$$\frac{C}{B} = \frac{R}{M}$$

where:

C = the catch
B = biomass
R = tag returns
M = number of fish tagged,

the catch, tag-returns, and a range of initial tagging mortalities from 20% to 70% give ranges of biomass from 8.1 – 3.1 million tons for 1957–60 and 8.8 – 3.3 million tons for 1963–66 (Table 5). The figures for 40% are very similar to that reported by Newman (1970). The estimates of initial tagging mortality do not include an estimate of sustained mortality due to tagging, which is likely, and would serve to reduce estimates of stock size.

TABLE 5
Range of Pilchard Biomass Estimates, with Various Initial Tagging Mortalities, in Millions of Tons

Years	Percent initial tagging mortality		
	20%	40%	70%
1959–60	8.1	6.1	3.1
1963–66	8.9	6.4	3.3

Baird, Newman, Ratte, and Schülein (1972) point out that the estimates of total mortality for the period 1967–71 (Table 6) are higher than that of 0.7 calculated for the period 1963–66 by means of tagging (Newman 1970). The general decline in both 6/5 and 7/6 year-classes is consistent with a progressive decline in stock size over the period.

TABLE 6
Instantaneous Pilchard Mortality Rates, 1967–71

Year	Total mortality at age		
	5/4	6/5	7/6
1967	-	1.99	2.44
1968	0.30	1.85	2.26
1969	0.74	1.60	1.25
1970	0.26	1.34	2.22
1971	0.67	1.08	1.86

The discrepancy in calculated mortality rates for the consecutive periods by a factor of between 1.5 and 3.5 could be the result of an underestimate of mortality from tag returns. Tag return data were lumped to give a mortality rate reflecting average conditions. This procedure masked the rapidly increasing second year recovery rates and possibly resulted in an underestimate of mortality giving an inflated estimate of stock size.

The apparent effect of the high 1966–68 catches on the population suggests a fairly high rate of exploitation, indicating that the effect of a probable high tagging mortality outweighs the effect of bias through emigration. Taking into account sustained tagging mortality and a low estimate of total mortality, the population during the period 1957–66 may have been lower than that reported, somewhere nearer the level of 3 million tons indicated by the 70% initial tagging mortality level. No deductions can be drawn as to the contribution to the estimated stock size from the putative northern population.

Stock Size Trend 1961–74

The trend in population size from 1961 to 1974, as derived from virtual population analysis (Schülein, Newman, and Centurier-Harris (1975), is that the biomass apparently increased in the period 1964–1967 quite rapidly whilst the catch increased slowly at first, then rapidly to 1968, whereafter both fell abruptly until they picked up in 1970 and 1971 respectively (Figure 16). The large increase in catch was led by quota relaxations, yet, despite a doubling of the catch between 1966 and 1968 from 0.75 to 1.5 million tons, the population is reported to have been increasing. This is possible, provided that a large year-class passed through the fishery. The values of stock size from 1964 to 1967, 4.5–6.0 million tons, are lower than those quoted for the period 1963–66 from the tag return data, 6.25 to 7.50 million tons, which have been previously questioned, and could be interpreted with the aid of reported recruitment patterns. In 1963 an el Nino type situation resulted in anomalous hydrographic and biological conditions in the fishing area. Stander and De Decker (1969) reported on these conditions, observing that oil yield was depressed and that larval survival would be impaired. Despite the anomalous conditions, the fishery maintained its catch and a strong recruitment occurred.

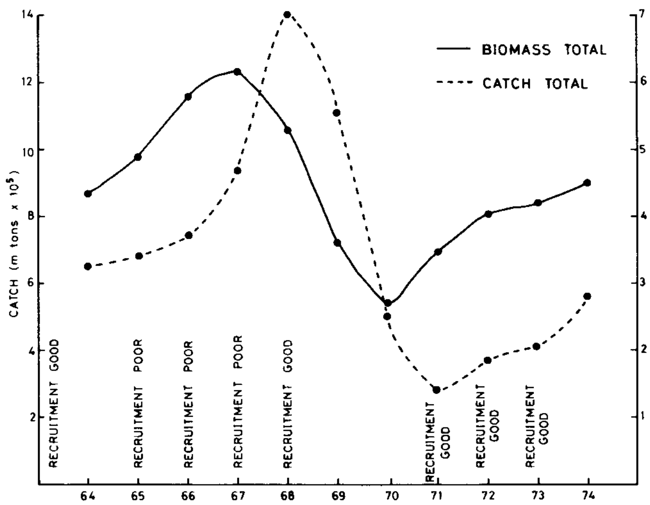

FIGURE 16. Trends in Pilchard catch and biomass (Schülein, Newman, and Centurier-Harris, 1975) with added annotation for recruitment.

A study of data on environmental conditions and oil yield, and possible larval survival and recruitment has led to the development of an empirical model stating that oil yield is an indicator of environmental suitability, and the state of the environment dictates larval survival and hence later recruitment (Schülein, 1974). Using the 1963 anomaly which was associated with low oil yield, Schülein suggests that as recruitment occurs at ages from 2 to 4, the poor recruitment experienced from 1965 to 1967 was the result of high larval mortality in 1963. Thus the extremely rapid increase in catch from 1966 to 1968 took place at a time when the stock could have been reduced by poor recruitment in 1965–1967 (Newman, 1970) which exaggerated the effects of heavy fishing and lead to the decline of 1969–70.

Recruitment was strong in 1963 (Newman 1970), weak between 1965–67, and strong again in 1968–69 and 1971–73 (Schülein 1974). The effects of strong recruitment in 1963 were visible in 1965–66, but by 1967 the fish responsible were about 6 to 8 years old, and not well represented in the catch, less than 20% by weight in recent years (Schülein, Newman, and Centurier-Harris 1975). On the other hand the poor recruitment of 1965 and 1966 may have resulted in a net loss to the population, which could have resulted in a declining population after 1963. Newman (1970) reported from the analysis of tag return data that the population size was declining from 1963 to 1966, but not severely.

If the stock size levels reported for 1964–67 are too high, the source of bias should be sought in the manner in which the basic data are acquired, namely the manner in which the catch is made. As virtual population analysis (VPA) requires the total number of fish of each age caught per year, a value for the coefficient of natural mortality, and one year for which the fishing mortality rate has been independently estimated, bias can only exist in the catch data and the assumed value for the coefficient of natural mortality. In any case, an error in the mortality coefficient becomes reduced in the earlier years under consideration, so the bias, if any, should be sought in the catch.

For VPA to succeed, the catch must be made upon a discrete population or within a previously defined management area. The distribution of pilchards off South West Africa indicates shoal groups are spread along the entire coast (Figure 13). Schülein (1972) has shown that a latitudinal distribution of age exists throughout the entire coastal zone, with younger fish in the north and older fish in the south. As recruitment has previously been regarded as incomplete until age four, only this and older age classes were used in the VPA.

TABLE 7

Search Area by Year *

Year	1959	1960	1964	1965	1966
Search area (nautical miles)	899	549	548	2,110	2,771

* Newman 1970

Between 1959 and 1964, the fishing area was small, being less than 900 square nautical miles around Walvis Bay, so that many shoal groups were unlikely to be represented in the fishery. From 1964 the search area rapidly increased, until by 1970 the entire coastal zone was searched, thus incorporating more of the shoal groups into the fishery. This increase, from 900 (in 1959) to 2,800 (in 1966) and then to about 9,000 square nautical miles (in 1970) affected the basic data (Table 7). The estimates of stock size made each year in the changeable fishery may not be comparable, as each may refer to a different management area covering part of the range of the stock. The increase in population size shown for the period of increasing catches may refer more to increasing search area than to increasing abundance.

In 1968–70 the catch declined considerably and the search area expanded, nearly covering the approximate reported distribution of the stock. The catch was further reduced in 1971 when a restrictive quota was applied. At this time the stock probably commenced to increase in response to the good recruitment reported by Schülein (1974), indicating that the reduction in effort on pilchard came at an opportune moment.

A further indication that bias may exist in VPA estimates can be obtained from catch-per-unit-effort (CPUE) assessments which have been attempted from three sources: landings per gross ton of the fleet, the area which had to be searched to obtain the catch, and fuel utilization. The last two are interdependent.

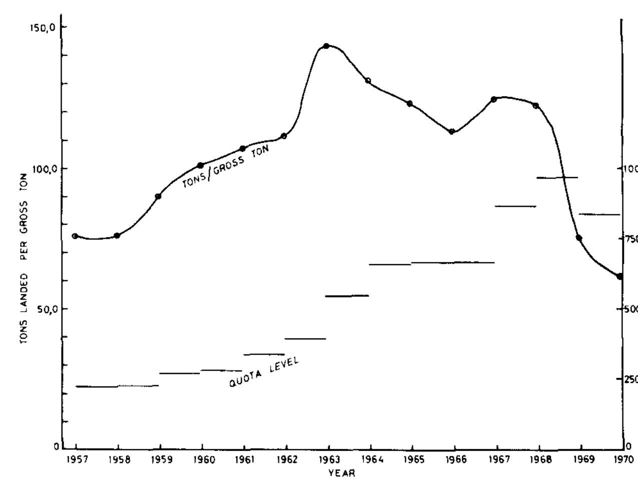

FIGURE 17. Pilchard catch-per-unit-effort (CPUE) index (Baird, Newman, Ratte, and Schülein, 1972) with added quota levels.

While trends in landings of pilchard per gross ton have been determined (Figure 17), gross fleet tonnage does not take into account increases in vessel efficiency, changes in vessel size, or alterations in the number of trips, but can give some indication of effort. From 1957 to 1963 the quota increases allowed the catch to rise and so did the landings per gross ton, indicating that the quotas prevented full utilization of effort. Between 1964 and 1966 the index declined despite freezing of quotas for that period, but in 1968 and 1969 the quotas were substantially raised giving an upsurge in the index before the decline in 1969 and 1970 associated with a slight quota restriction in 1969 and the failure to meet the quota in 1970. Baird, Newman, Schülein, and Ratte (1972) regard the 1970 index as unbiased as the quota was not filled, suggesting that this indicated a reduction in abundance of about 50% the level of 1964–68.

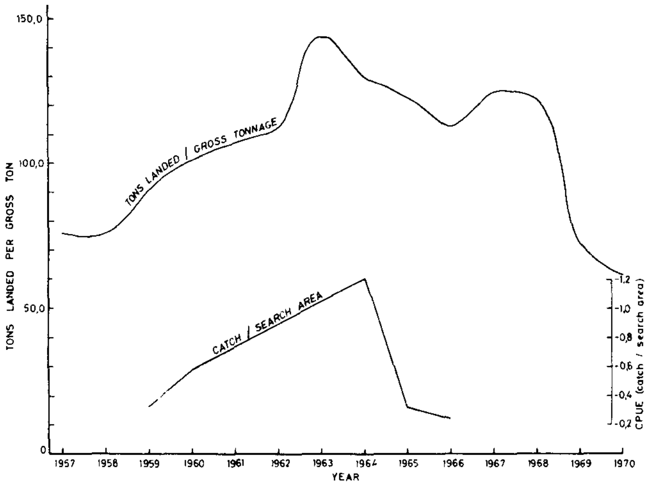

FIGURE 18. Indices of pilchard catch-per-unit-effort (CPUE).

In attempting to determine trends in stock size from either index, the effect of quota changes should be taken into account. A close relationship was demonstrated for landing/gross ton compared with quota levels, except for the period 1964–66 and after 1969 (Figure 18). During the period 1964–66 the landings/gross ton declined despite a period of quota stability. The landings/gross ton were compared with catch/search area (calculated from Newman, 1970, Tables I and V), although the catch/search area declined severely after 1964 (Figure 18). Additional CPUE information comes from landings/fuel issues and catch/search area (Figure 19). The landings/fuel issue data indicate that CPUE was high in 1964 but thereafter a consistent decline took place, recovering in 1970–72. The numerical level of the decline from 0.14 metric ton/liter in 1965 to 0.04 metric ton/liter in 1971 is similar to the levels calculated from tagging, 1963–66, and mortality estimates, 1970–72 (Newman and Schülein, 1973). Correspondence between catch per fuel issues and catch/search area would seem likely as they are interrelated: the greater the area searched, the more fuel used. These data could as easily be measures of availability as abundance, but probably combine indices of both. The problem is that it is impossible to extract the effect of availability, so the best interpretation of these CPUE data would be that availability and apparent abundance were changing during the period in question. The terms availability

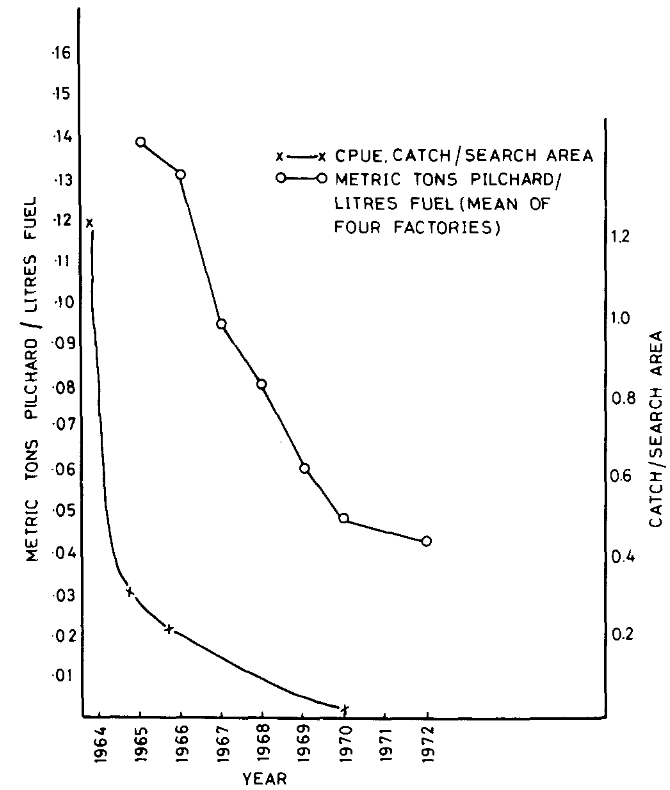

FIGURE 19. Catch-per-unit-effort (CPUE) landings/fuel issues (Newmand and Schülein, 1973) with added notation of CPUE catch/search area.

and apparent abundance are used according to Marr (1951).

As the canneries require fish in prime condition, cannery fish have to be caught as near to the factories as possible, and as the shoal groups are distributed near the coast over a considerable latitude this usually means traveling north to the nearest shoal group. It is usually unnecessary for any vessel to proceed further than the nearest catchable shoal group owing to information exchange by radio. During April 1972 the catch area was distributed at the southern end of one shoal group, while other shoal groups were present to the north (Figure 20). This localization of fishing effort renders CPUE analysis difficult, for the movement of shoal groups north and south will have a considerable impact on effort, probably greater than any short term change in abundance.

All CPUE indices show a decline from about 1964 to 1970 as may reevaluated virtual population analysis estimates. The important question becomes, "How severe was the decline?"

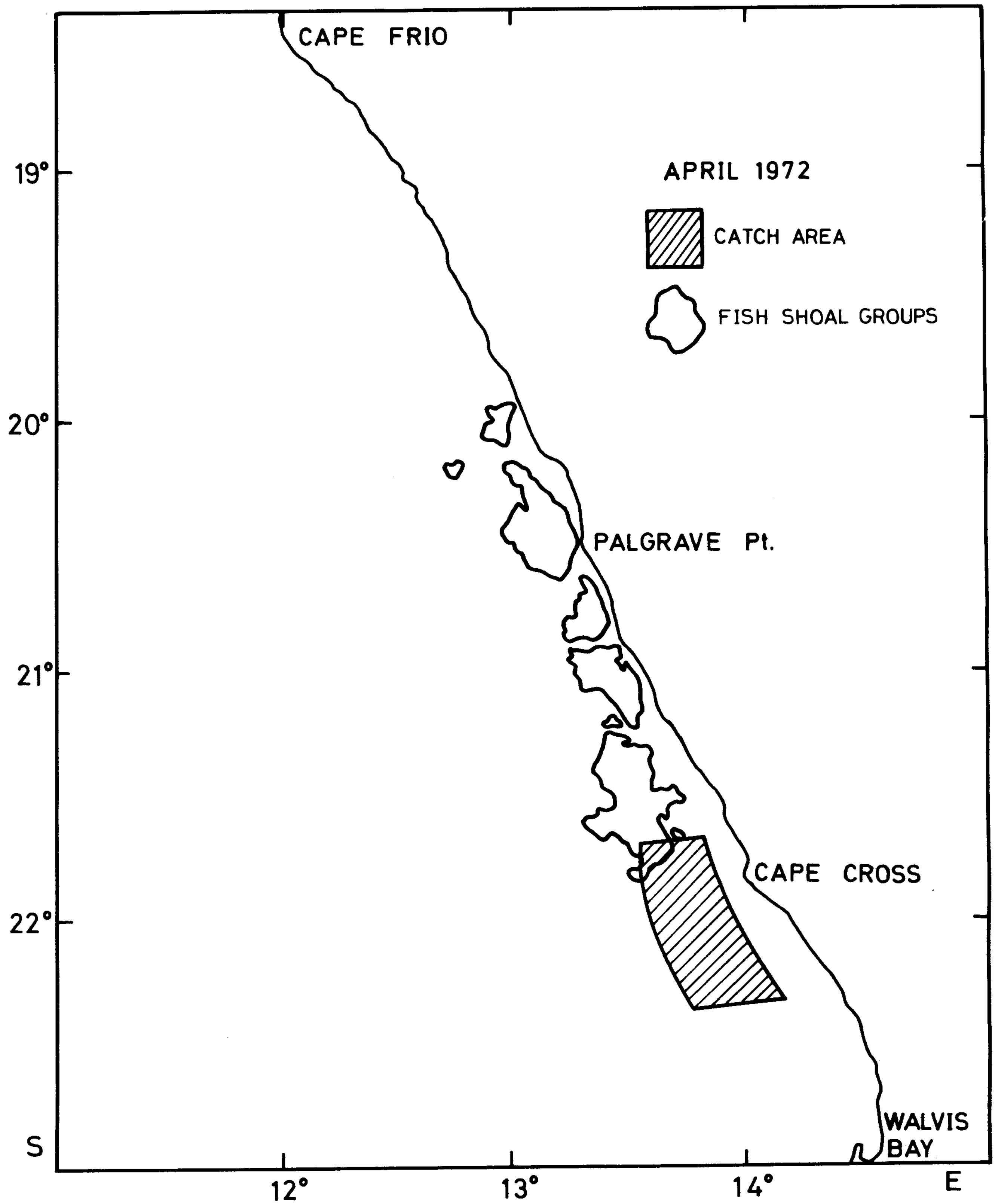

FIGURE 20. Pilchard school groups and catch area.

Current Trends In Stock Size

Estimates of population size have been made from aerial/acoustic data at 2.1, 2.9, 3.2 million metric tons for 1971/72, 1972/73 and 1973 respectively (Cram, 1972, 1974). No estimate of the variance in the estimates is available. Quantitative egg capture data gave two estimates of 1.7 and 2.3 million metric tons for 1972–73 and 1973–74 respectively. The estimates are subject to error giving a range of possible spawning population size from half to double the estimate (King, 1974).

Baird, Newman, Ratte, and Schülein (1972) suggested that increased fishing mortality in 1967–71 had a significant impact on the age structure of the population. In 1967, 55% of the landings consisted of fish 5 years and older, whereas in 1971 these age groups contributed 25%. The trend conforms except for 1970 when the value was 40%. The high proportion of older fish in the catch in 1970 and the trend of increased mortality (Table 4) suggest the depletion of the stock was neither sudden nor severe. Considering the suggested revision of stock estimates from tag return data and VPA for 1965–68 with the data for 1970 onwards, it would seem the decline in pilchard population size was real but not as serious as suspected and of the order of 30%, approximately from 3 million to 2 million metric tons and extending from about 1965 to 1970.

Subsequent to the restrictive quota on pilchard, the stock size is increasing because of good recruitment and is probably at a level of 3 million metric tons. The decline experienced between 1964 and 1970 is explicable in terms of recruitment variation exaggerated by a short period of high fishing mortality, and the stock can now be considered as recovered.

South West African Anchovy Population Biology

Engraulis capensis occurs from the Kunene River on the northern border of South West Africa to Cape St. Sebastian on the south coast of South Africa. Anchovy fishing started off Walvis Bay in 1963 when two vessels were equipped with 11 mm mesh nets to determine the anchovy fishery potential. Commercial fishing started the following year (1964) when two vessels from each of the eight Walvis Bay factories (and the Lüderitz factory) were equipped with 11 mm nets. Good catches by these boats suggested the possibility of full scale exploitation, and by 1968 all vessels were equipped with anchovy nets.

Prior to 1971 no accurate differentiation was made between pilchard and other species landed, but factory estimates indicate that the catch of anchovy (and other species) increased from about 575 metric tons in 1965 to 295,483 tons in 1973 (Table 3). Following the commencement of the new research program in 1970, accurate records of the anchovy landings were kept from 1971 onwards.

Age determination proved difficult initially as the otoliths were found to be blank in younger fish and finely cracked in older fish making the identification of growth zones very difficult. Scales therefore were used, which were hard to obtain through the commercial fishery as the action of catching and pumping stripped many scales off the fish. However, experimental fishing yielded suitable age material. The formation of new rings starts in May, thus fish spawned at the beginning of the spawning season (October) and at the end (April) will be 6 and 12 months old respectively before the first annual ring appears. The protracted spawning season is assumed to be responsible for the pronounced variation in lengths at age, particularly of 1 year fish. The mean length of 1 year old fish is 9.3 cm with a range 5.5-11.4 cm.

Fifty percent maturity occurs at 9.5 cm (0 to 1 year) and 100% maturity at 11.0 cm (2 years and older). The development of gonads starts in September and is continuous through to April. Eggs occur continuously within the plankton during this period.

The age composition of the catch has shown a similar trend to that in the Cape anchovy fishery. In 1971 the modal age group was 2 years, in 1972 the modal age was 0, and in 1973 the contribution of the 0 year class to the fishery rose considerably (Table 8).

TABLE 8

Age Composition in Numbers of Fish for the Commercial Anchovy Catch, Walvis Bay 1971–73 * and Cape 1965–67

South West Africa

Year	0	1	2	3	4
1971	17.3	11.4	41.9	26.3	3.1
1972	41.3	28.2	16.2	13.0	0.9
1973	56.9	27.2	11.9	6.1	2.5

South Africa

Year	0	1	2	3	4
1965	28.7	41.0	20.5	8.4	1.4
1966	68.6	20.6	9.4	1.4	
1967	73.5	22.5	2.6	1.4	

* Ratte, 1973

Schülein (1974) suggested that the good recruitment of 0 year anchovy in 1972–73 was partially due to favourable conditions for larval survival in 1972–73, based upon good oil yield values in those years.

TABLE 9

Total Instantaneous Anchovy Mortality*

Year	Age			
	1/0	2/1	3/2	4/3
1971			0.47	2.14
1972	0.38	0.56	0.22	2.67
1973	0.92	0.65	0.66	0.91

* Ratte, 1974

In 1971 when fishing mortality was low in the younger age classes, estimates of total mortality from catch curves were also low (Table 9). Later, between 1972 and 1973, the total instantaneous mortality rates of the younger age classes rose considerably. Using these mortality estimates, the catch averaged between 1971 and 1973, fishing mortality, and estimates of natural mortality between 0.8 and 0.4, the anchovy population size is estimated at between 0.5 and 1.0 million metric tons. The shift of modal age between 1971 and 1973 suggests heavy exploitation.

TABLE 10

Average Anchovy Length per Age Group

South African Stock

Age years	LC	Range LC
1	7.9	6.5–10.0
2	10.4	
3	11.9	
4	13.0	

South West Africa Stock

Age years	LC	Range LC
1	9.3	5.5–11.4
2	10.9	9.3–12.4
3	11.9	10.6–13.0
4	12.7	12.0–13.2

There is some evidence that the South West African and South African anchovy populations are separate. Meristic characteristics are identical, although the mean length and range for 1 year group is more than in the South African stock (Table 10). This could be attributed to the wider size range available in South West Africa and the arbitrary formation of growth rings on the scales particularly between May and October, rather than to faster growth. It is possible that a similar length and range exists in the South African stock.

The development of resting and immature gonads in the two areas occurs in September and continues until April, with peak activity in December, January, and February in South West Africa (Table 11). Spawning occurs in widely separate locations, within a range of surface temperatures from 13.3 to 22.0°C.

The change in age structure accompanying the South African anchovy fishery occurred without influencing the South West African stock, although the pace at which the 0 year group grew to prominance was less in South West Africa than in the Cape. The population in South West Africa was not fully exploited until 1972 whereas in the Cape the 0 year group predominated from 1966.

The presumably separate South West African anchovy population has been present in catchable concentrations since 1964, when the pilchard population was at its recent probable maximum. The catch increased rapidly as effort increased until effort stabilized in 1968. After a slight increase in 1969 the catch dropped slightly, until the good recruitment of 1973 when the catch doubled. The anchovy stock thus exists in parallel with the pilchard stock, is relatively small, heavily exploited, and the fishery is recruitment dependent.

TABLE 11

Comparisons of Gonad Development, Spawning, and Formation of New Annual Rings in *Engraulis capensis* in South East Atlantic

SOUTH AFRICAN STOCK

Month	Gonad development	Spawning occurrence	New rings forming
FIRST YEAR			
May			
June			X
July			X
Aug.			(max.)
			X
Sept.	X	X	X
Oct.	X	X	X
Nov.	X	X	X
Dec.	X	X	
SECOND YEAR			
Jan.	X	X	
Feb.	X	X	
March	X	X	
April	X	X	

SOUTH WEST AFRICAN STOCK

Month	Gonad development	Spawning occurrence	New rings forming
FIRST YEAR			
May			X
June			X
July			X
Aug.			X
Sept.	X		X
Oct.	X	X	(max.)
			X
Nov.	X	X	
Dec.	X	X	
SECOND YEAR			
Jan.	X	X	
Feb.	X	X	
March	X	X	
April	X	X	

Problem Areas

Current research has been directed towards solving specific problems associated with management of the stocks. Many avenues of research have been explored and an almost unlimited amount suggested, but it seems that we still require very basic information on the fishery, as it is not yet possible to manage effectively all the valuable stocks presently exploited. Principal problem areas are the establishment of stock size and yield, single stock management in the multispecies fishery, and stock identity.

Pilchard conservation was promoted by the split quota system, but this produced its own problems through daily pilchard tallies, as each factory strove to spread its pilchard catch throughout the season in order to maximize its effort on anchovy. Inevitably this led to dumping of pilchards caught inadvertently or dumping following the location of an anchovy shoal. Dumping appears to have been a fairly common practice in the past, for the Commission of Enquiry into the Fishing Industry (Report, 1971) notes evidence that 10–50% of the catch was dumped. Furthermore, the commission noted that statistics of the factories in respect of fish delivered to them always were less than the amount supplied. The introduction of automatic scales and the inspectorate in 1971 should have solved the shore based problems, but nevertheless cast doubt on the value of commercial catch data. It also has been alleged that pilchard has been identified as anchovy on occasion to defeat the split quota regulations, increasing the element of doubt about the accuracy of catch figures. Assessment of effort is not easy owing to the spatial and temporal variation in distribution of effort in the multispecies fishery, and effects of availability, in particular, contaminate effort data. The fishing pattern on pilchard stocks is variable, the wider the search area the more younger fish are caught, thus recruitment varies. The recruitment pattern may vary asynchronously within components of the multispecies fishery, causing effort to be diverted to whichever species has strongly recruiting year classes. Most methods in population dynamics require a stable time series of data but these are not available at least for South West Africa.

The existence of these problems strikes at many assumptions made in calculating stock size and yield, preventing accurate estimates being made, and rendering difficult the management of single stocks in the multispecies fishery. The problem was solved initially almost arbitrarily when the 1970 quota was split 33/66% by weight. Since then, however, the pressure of small upward adjustment of the reduced pilchard portion was irresistible despite some objection from scientists. It has been difficult to produce a valid argument against the creeping upward adjustment of the pilchard quota as, for example, a 10% readjustment is extremely meaningful economically but scientifically undetectable, and may represent 50,000 tons of fish. This continual readjustment of the split quota has an adverse impact upon population dynamics as effort varies from year to year, and sometimes within a season.

Single stock management is an essential element of present and future management strategy, but hampered in South West Africa by a lack in ability to accurately assess stock size annually with known confidence limits, or to establish an accurate annual value for yield. In the Cape, the only current source of data is catch statistics, which are subject to previously mentioned sources of error and bias, compounded by the fact that up to five species are represented in the catch. Here the problems of single stock management are acute as the canning industry is very reduced and the most favoured species are either severely depressed (pilchard) or subject to excessive variations in availability (mackerel). Moreover, with the 0 year group anchovy predominating in the catch, it is likely that any pertubation in recruitment (*vide* the opposite of the 1973 occurrence in South West Africa) would have an unfortunate effect on the fishery. The main problem in the Cape would thus seem to be similar to that of South West Africa: management of single stocks to resuscitate a cannery industry, while maintaining the reduction industry at an optimum level.

The principal biological problem is fundamental to management strategy and research: the determination of population homogeneity. The work of the egg program, fecundity, population biology, genetics research, and tagging point to two separate geographical anchovy and pilchard populations, with subgroupings present in the latter species both in South West and South Africa. The existence of subpopulations in South West Africa severely complicates matters for, at the present, it is not known what proportion of each putative stock is represented in the fishery, and thus in the estimates of stock size. For the South West African pilchard, a knowledge of what proportion of which stock occurs where, will have a substantial effect on future exploitation of the resource when development occurs in the country. Similarly, in the Cape a resuscitation of the depressed pilchard stock will probably be facilitated by a thorough biological inventory to determine areas and situations within which conservation is required.

An important, though non-scientific, problem is the credibility and communication of research results to the industrial and management authorities. Experience has shown that scientific management advice to the authorities will be opposed by a powerful lobby using economic arguments augmented by their own interpretation of trends in the fishery. Scientific information is passed to the Department of Industries, which also receives industrial information from other sources, and is then formulated in a policy proposal for submission to the Minister of Economic Affairs. Since the varied information has to be collated by officials with economics and administrative qualifications, it has been essential that complex scientific appraisals be reduced to the minimum and preferably augmented by results of direct measurement techniques. It is a regrettable experience that the fishing industry tends to be aware of the shortcomings of its catch statistics and tends to be wary of esoteric statistical analysis of these data.

Lastly, the problem of uncontrolled foreign participation in the pelagic industry exists today.

Although the International Commission for Southeast Atlantic Fisheries (ICSEAF) has been in action since 1971, it has not focused much attention on the pelagic stocks. Foreign catch has been occasionally significant (Figure 3) and there is no legal apparatus to prevent a foreign fleet from catching outside the territorial or contiguous fishing zones.

FUTURE RESEARCH

Although there is a considerable armory of techniques and methods available within the many aspects of fisheries science, the Branch's pelagic research is, in general, only at first base. Such estimates of stock size and yield available are insensitive and inflexible, and therefore not well suited to managing fisheries subject to sudden change. The overriding problem is a lack of good basic data on the stocks and this should be reflected in our future work.

When faced with a choice of major strategies, that which provides the quickest, most precise management advice should be chosen. This would tend to eliminate strategies such as an ecosystem approach through ecological energetics which, while undoubtedly useful, is unlikely to influence the management of presently exploited pelagic fish stocks.

Population Studies

Whilst the collection and analysis of catch and effort data from logbooks will continue, survey capability must be developed to aid in single stock management within the multispecies fishery. Maximum sustainable yield, particularly when applied to a multi-species fishery, is an inflexible tool in a fishery subject to variable recruitment or alterations in fishing pattern. Estimates of stock size must become more accurate, and dependence on the catch reduced.

Survey input to population dynamics would possibly assist management through the differentiation of trends in availability and abundance. Routine aerial observations on shoal group location may allow the development of an availability index which, together with data on catch position from logbooks, may help to refine effort data.

The present aerial/acoustic methods will be enhanced through experimental work at sea which will lead to better estimates of the variance in stock size than presently available. Statistical sampling errors in aerial measurement of shoal surface area and acoustic measurement of mean surface fish density will be evaluated. Sources of bias need further study, particularly the variation in visibility of shoals from the air and the degree of avoidance of research vessels by shoals. A further source of bias in absolute measurements of stock size is target strength variation. A comprehensive experiment on live pilchard has been accomplished but the results are not yet available. This work will be continued with other species.

An important use of the aerial/acoustic strategy is prediction of pilchard recruitment. As recruitment to the present fishery is from 2 to 4 years, and complete at 4, 2 to 4 years are available for annual assessment of year class or size class abundance, and for observing their progress. The present aerial/acoustic strategy, when applied within the complete geographical range of shoal groups, will allow the estimation of biomass contribution from all fish which form shoals, and indications exist that this behaviour commences during the first year. Insufficient samples were taken during previous surveys (particularly in the north where young fish tend to be more common), but increased experimental purse seine catches supplemented by camera drops should give adequate size distribution data from enough shoals.

Although the "turnover" of anchovy is much faster, they may be amenable to a recruitment orientated aerial/acoustic survey as some evidence exists that 0 year shoals tend to be substantially larger than shoals of older fish. This possibility will be examined although, at this stage, the logistic problems in such a quick-fire survey are daunting.

Aerial/acoustic technology development will proceed. A possibility exists that a state-of-art system will be developed in conjunction with the National Fisheries Engineering Laboratory of the National Marine Fisheries Service (USA). The object will be to use the most advanced technology practicable for determining shoal dimension, mean surface density (number of fish/m^2 of shoal thickness), packing density (number of fish/m^3 of shoal), shoal thickness, and to detect fish shoals deeper than the visible range of the eye or bioluminescence sensors.

The future of the South West Africa pelagic egg and larva program (SWAPELS) is uncertain. Although estimates of pilchard stock size have been made, their accuracy is insufficient for any input to management other than support. Furthermore, these surveys are labor intensive and utilize considerable ship time. Gear problems, especially clogging, have characterized attempts to quantify anchovy egg collection.

No serious attempts have been made at predictions based upon larvae collections, although this is an area in which we will be largely guided by CALCOFI experience.

There are three approaches to using South West African Pelagic Egg & Larvae Survey: 1. for pilchard, anchovy, and maasbanker annual estimates of spawning stock size; 2. for all commercially valuable species once every 3 years; and 3. of the entire exclusive economic zone once every 5 years.

The only large scale alternative is to leave eggs completely and develop an 0 group prediction system using the resources that went into SWAPELS.

Biological Research

The genetic structure of the pelagic populations is not known. It is intended to use techniques of genetics on larvae and spawning adults from more areas in the geographic range of the pilchard and to test for more polymorphic isozyme systems in the species. This work should be extended to anchovy and other commercially exploited stocks.

It is by no means sure that all elements of the inshore pelagic stocks have been located. Surveys will be conducted in the semi-permanent upwelling areas to determine the existence of any other stock units.

Ecological Research

It is intended to use aerial observation in conjunction with shipborn research on shoal ecology to determine what factors principally control availability. The object will be to make availability trends more readily understandable to management rather than to derive a predictive model.

Competition of food is important to the qualitative recruitment model, based on oil yield being equivalent to environmental "quality." If good oil yield means good recruitment of both anchovy and pilchard, this will create additional competition unless it can be absorbed by the "suitable" environment. A feeding competition study will be evaluated. In this regard the high oil yield and its presumably associated anchovy 0 group recruitment in 1973 will be interesting to compare with pilchard recruitment between 1975 and 1977.

The bulk of the South West African anchovy stock appears to exist in warmer water than pilchard in contrast with the norm expressed by Longhurst (1971). Physiological studies may indicate whether the anchovies have an ecological advantage there, or in the Cape, if a general cooling of the environment occurs.

Research conducted since 1970 has indicated the presence of a large goby population (*S. bibarbatus*). The fish have featured in the purse seine fishery but the quantity is not known (Schülein, Sea Fisheries Branch, person. comm.). SWAPELS has generated much distributional data and a very tentative estimate of stock size in the 10^5 metric tons range (O'Toole, Sea Fisheries Branch, person. comm.) Acoustics cruise data show the goby population is widespread and extremely numerous. During a scattering layer study, target back scattering strength was determined which enables differentiation of gobies from the euphausiids with which they are frequently associated. Target strength is approximately known. Vertical migration and distribution of adults and larvae are known (d'Arcangues and Hampton, Sea Fisheries Branch, pers. comm.)

It is hoped to commence a quantitative study on the goby population in order to provide good base line data prior to the inevitable exploitation.

CONCLUSION

The Sea Fisheries Branch's strength in pelagic fish research is in the comprehensive logbook and inspection systems, the development of an aerial/acoustic method of assessing stock sizes, and the egg and larva program. Judicious interweaving of the best aspects of each technique with hydrobiological and other data will bring rational management of pelagic resources much nearer.

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