ON THE CALCULATION OF PELAGIC FISH SHOAL TONNAGE BY NIGHTTIME AERIAL OBSERVATION

BY

DAVID LINDSAY CRAM B.Sc. (Hons) M.Sc.

Sea Fisheries Branch and Zoology Department

University of Cape Town

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Frontispiece: A low-light level television image of the 22,6m fishing vessel "Runtu" setting its purse-seine net near the end of a long pilchard shoal. The image is a montage of five separate picture frames in succession.

Dedicated to Anke and Juliana.

CONTENTS

INTRODUCTION

The South West African part of the Southeast Atlantic Sardinops ocellata pilchard fishery based principally at Walvis Bay and to a lesser extent Lüderitz, has been through the cycle of expansion, collapse and renewal which is such an unfortunate feature in the history of the world's pelagic fisheries. The collapse occurred in 1968 - 70 after an expansion phase lasting nearly 20 years: the renewal phase appeared to take 3 to 5 years. One of the many reasons for the rapid renewal of the stock was the enforcement of a strict and very reduced quota since 1971, that this quota was accepted for so long was due to the re-inforcement of traditional scientific methods through the development of a quantitative approach to fish biological research in which both Government and Industry had some faith. This approach involved a method of stock assessment by aerial observation which was new to fisheries science and designed to estimate the apparent abundance of the pilchard stock directly and rapidly throughout its geographical range in a manner independent of catch statistics, and variation in temporal or spatial distribution caused by environmental, or other, perturbations.

As the South West African pilchard fishery expanded between 1949 and 1956, the development of quantitative fisheries biology was slow. The early efforts were concentrated upon the need of establishing the biological parameters upon which population studies are based.

In 1952 an investigation was commenced into the size composition of the commercial catch which was continued through to 1957 (Matthews 1960). Simultaneously, age studies were commenced which led to a knowledge of the age composition of the commercial catch (Nawratil 1961) and its growth (Nawratil 1962). Environmental studies were commenced on phytoplankton (Kollmer 1962, 1963) hydrography (Stander 1962, 1964, 1967) seasonal occurrence of thermoclines (Du Plessis 1967) oceanographical conditions associated with red tides and fish mortality (Pieterse & van der Post 1967) and chaetognaths (Venter 1969). In addition, this work published in the Research Reports of the Marine Laboratory, South West Africa Administration was supported by a large body of biological research associated with the Cape pilchard fishery and published in the Investigation Report Series of the Sea Fisheries Branch.

Despite the rapid growth of the South West African pilchard fishery up to the 250 000 ton level with no apparent reduction in "availability", the South West Africa Administration adopted a cautious management policy and fixed a quota of 250 000 tons for the 1954 season (Matthews 1960). However, it was not until the 1955 season that this quota became effective. Prior to this time it had been realised that the yield of the now very valuable fishery should be scientifically evaluated, so in 1956 the South West Africa Administration Marine Research Laboratory in Walvis Bay started a tagging programme to provide material for stock assessment and migration studies. The tagging programme extended from 1956-1967, but no effective results were available until 1970.

Thus during the period 1961-1968 when quotas were progressively raised and the South African floating factories commenced operations outside South West African territorial waters, there was no scientific basis for management action. Perhaps more unfortunate was the lack of such a basis for management during the decline in landings experienced from the 1969 season onwards. However, Stander and De Decker (1969), in their examination of the anomalous conditions experienced off South West Africa in 1963, sounded a note of caution when they concluded that the anomalous conditions described had an undoubted impact upon the environment, the plankton, the oil yield (and thus the condition) of the fish and that the survival of fish larvae in 1963 had been impaired.

A short while later, the first quantitative study of *S. ocellata* was produced by Newman (1970) who analysed the tag-recovery data produced by the South West Africa Administration Marine Laboratories' tagging work between 1956 and 1967. The paper gave two estimates of stock size, 6,25 million tons for 1957-60 and 7,5 million tons for 1963-66.

Unfortunately, the pilchard catch peaked in 1968 and dropped very considerably in 1969 and 1970 (Table 1). During the commercial fishing season of 1970, the South West African pelagic fishery factory management, the Boat Owners Association and the fishermen became extremely concerned about an apparent lack of pilchards over a wide area off the South West African coast (Fig. 1). Despite substantial searches by parts of the large fleet (more than 100 vessels) sufficient pilchard shoals had not been located.

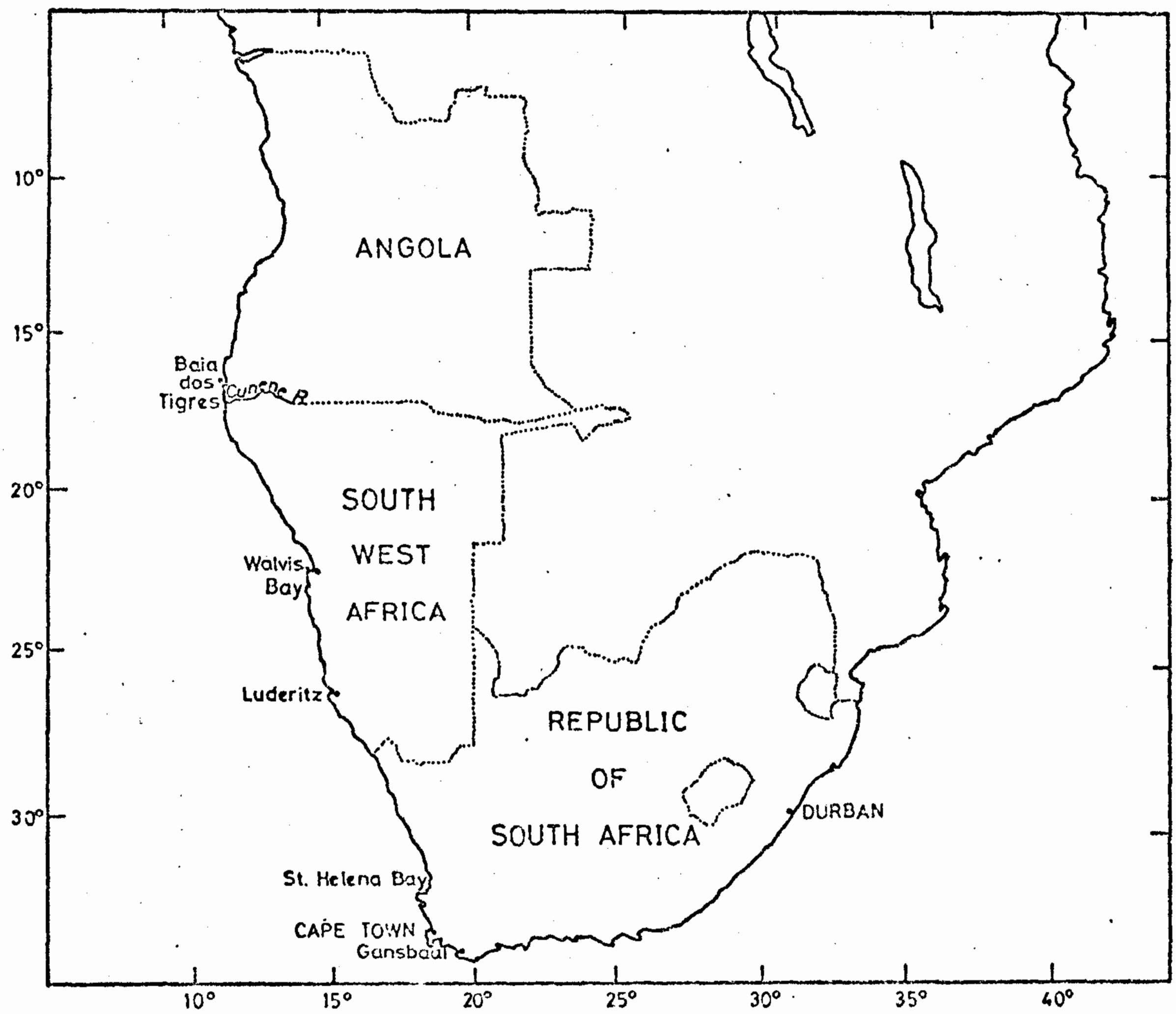

FIGURE 1 : Distribution of pelagic fisheries in South and South West Africa

The reduction in landings between 1968 and 1970 was dramatic, from 1,53 million to 0,57 million tons, while the catch-area had expanded from 80 nautical miles South and 100 nautical miles North of Walvis Bay to cover virtually the whole Northern half of the South West African coast.

TABLE 1. TOTAL PILCHARD LANDINGS WALVIS BAY, LUDERITZ AND S.A. PELAGIC FACTORIES 1949-74 EXCLUDING ANGOLAN LAND-BASED AND FOREIGN PELAGIC FACTORY CATCH (SEA FISHERIES BRANCH).

YEAR	TOTAL CATCH X 1000 TONS	YEAR	TOTAL CATCH X 1000 TONS
1949	8.8	1962	436.1
1950	51.5	1963	602.6
1951	140.2	1964	722.3
1952	248.9	1965	734.3
1953	289.1	1966	784.2
1954	276.3	1967	1020.9
1955	250.4	1968	1528.8
1956	251.3	1969	1224.8
1957	250.8	1970	566.4
1958	251.7	1971	375.5
1959	299.2	1972	368.2
1960	312.6	1973	406.0
1961	378.0	1974	557.0

These observations made by the industry, coupled with their belief that two pilchard populations existed off South West Africa (one in the far North and one between Palgrave Point and Walvis Bay) led to the conclusion that the "southern population" had "disappeared" leaving a northern population which could and should be exploited. The suggested existence of a northern population was of cold comfort to the fishmeal and oil factories of Walvis Bay and particularly, at Lüderitz in the south, but the "disappearance" of the "southern" population represented a disaster to the extremely valuable canning industry of Walvis Bay, since fish caught more than a short distance from the factory are unsuitable for canning. If this suggested "disappearance", the decline in landings (Table 1) and the increased search-area were, in fact, a symptom of a reduction in stock size, the prospects for the forthcoming 1971 season looked ominous both for the industry and the stock. No details of egg production were available from 1963 onwards and no quantitative fish biological data could be processed from the period 1967-70. Therefore, during the period of maximum landings and the subsequent decline when management advice was urgently required, there were few data upon which a quantitative study could be based. Consequently, in mid-1970 a research programme was created within the then Division of Sea Fisheries, among whose primary objectives were the determination of the rate of decline in pilchard stock size and the probable short-term yield of the pilchard population, together with an examination of the structure of the pilchard population in South West Africa.

Having decided upon these objectives, the interactions within the South West African pilchard fishery were carefully examined in an attempt to discover the existence of areas where data pertaining to the most urgent problem, that of stock size, could be most readily and speedily obtained. Treated simplistically, the basic components of the fishery are illustrated in Fig. 2, where the populations biomass represents the object which could and should be exploited. The suggested existence of a northern population was of cold comfort to the fishmeal and oil factories of Walvis Bay and particularly, at Lüderitz in the south, but the "disappearance" of the "southern" population represented a disaster to the extremely valuable canning industry of Walvis Bay, since fish caught more than a short distance from the factory are unsuitable for canning. If this suggested "disappearance", the decline in landings (Table 1) and the increased search-area were, in fact, a symptom of a reduction in stock size, the prospects for the forthcoming 1971 season looked ominous both for the industry and the stock. No details of egg production were available from 1963 onwards and no quantitative fish biological data could be processed from the period 1967-70. Therefore, during the period of maximum landings and the subsequent decline when management advice was urgently required, there were few data upon which a quantitative study could be based. Consequently, in mid-1970 a research programme was created within the then Division of Sea Fisheries, among whose primary objectives were the determination of the rate of decline in pilchard stock size and the probable short-term yield of the pilchard population, together with an examination of the structure of the pilchard population in South West Africa.

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The term yield should be more closely defined, or at least restated, as the yield on various time scales. This can be considered in two categories, the long-term and short-term prediction of yield. The population dynamics approach to determining yield in a fishery is usually through well understood methods of establishing the maximum sustainable yield from analysis of catch per unit effort and effort data obtained from the fishing fleet through catch statistics. There are other methods of establishing yield through general production models where natural mortality, fishing mortality, age, growth and recruitment are involved. In most cases the stock size is not determined (catch per unit effort is an index of stock size) but should a knowledge of stock size be required it could be obtained through tagging experiments, cohort analysis or analysis of catch and mortality.

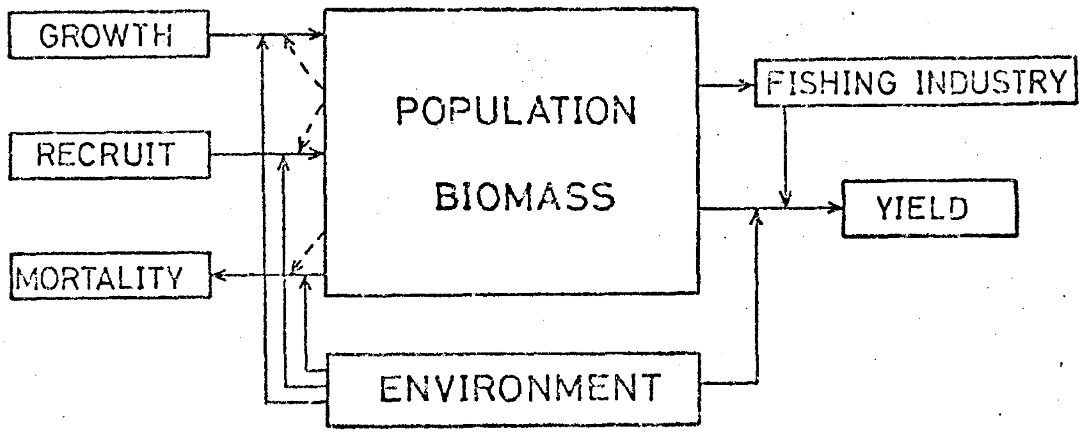

FIGURE 2. Schematic Diagram of a Fishery.

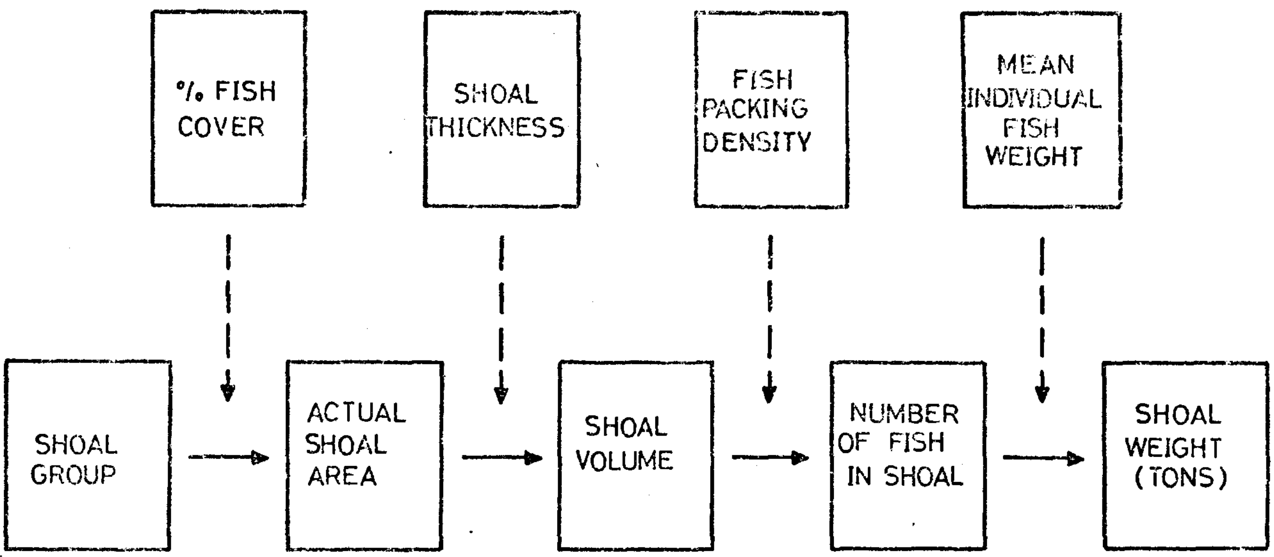

FIGURE 3. Flow-chart of the initial concept of shoal tonnage estimation.

Most methods and models require good quality data spread over a number of years (five or more for pilchards) and ignore the effects of the environment upon the rates of growth, recruitment and mortality as it is assumed that these effects are random and thus cancel each other out with time. Thus, in general, the maximum sustainable yield and other models are set for equilibrium conditions defined by the environmental conditions prevailing during the period data were collected. The predictive value of the maximum sustainable yield is great, but restricted to equilibrium conditions. Thus the impact of anomalous conditions within the environment (cf. Stander and De Decker 1969) will affect the rates of growth, recruitment and mortality thus affecting the population size and also the yield. Few of the methods or models allow for variations in the space/time distribution of the population. The environment could, through only slight pertubations, considerably alter the availability of the population to the fishery, as happened in 1963, to the detriment of the Walvis Bay industry.

The maximum sustainable yield is a long-term prediction, but the response of the population to changes in the environment occur in the short term, especially if the fishery is dependent upon recruitment for its yield; so ideally, the system of yield prediction should be similarily responsive. Methods of yield prediction must be used which involve or eliminate the effect of the environment upon availability and the rates of growth, recruitment and mortality. A solution to this problem would be to embark upon large-scale simulation modelling, including the environment, but this leads back to the need for long time-series and the need for ecological studies of considerable exactitude. It seemed more attractive to embark upon a multidisciplinary project which combined environmental research and population dynamics techniques with relatively instantaneous annual direct measurements of stock size. Such censuses will be free of bias introduced by distributional variation, environmental effects or dependence upon catch data.

When the South West African pilchard population entered its final decline in 1970 there were no contemporary estimates of yield or stock size, and none likely to be produced in the immediate future, it became of great importance to determine the stock size in a relatively instantaneous and readily repeatable manner in order to determine probable short-term yield and thus be able to set realistic conservation-orientated quotas. This was essential as there was no time available for long-term research, considering that the fishing power of the South West African fleet was such that it could inflict severe damage to the stock if catches continued in an unrestricted manner.

Accordingly, the multidisciplinary research programme set up in 1970 to examine the pilchard problem focussed its attention on rapid stock size estimation and the ecology of the pilchard (Cram and Visser 1972, 1973; Cram 1974). In reviewing methods of rapid stock assessment the only options appeared to be egg and larvae surveys, remote sensing and acoustics, and all were eventually used, but as aircraft seemed to offer the quickest means of data collection, the aircraft technique was the first one to be introduced.

In the late sixties, U.S. fisheries scientists had been experimenting with light-amplification devices as an aid to locating fish, especially with the U.S. Army "starlight scope". In 1970 a summary of this work was published in Commercial Fisheries Review, (Roithmayr 1970) together with a photograph taken with a starlight scope coupled to a TV camera, showing Spanish mackerel individually outlined by bioluminescence. The above information, that luminescence was electronically detectable and recordable, coupled with the knowledge that pilchard shoals off South West Africa were visible to the naked eye at night both from the deck of a ship and from aircraft led inevitably to the conclusion that if most shoals are visible and represented the bulk of the polulation, then quantified observations on shoal luminescence from the air could represent a rapid way of estimating the stock size.

After a preliminary night-time aerial survey in November and December 1970 during which pilchard shoals were seen on numerous occasions, it was decided to respond to the urgent problems by commencing an aerial research programme without delay. A method of semi-quantifying observations of luminescence was developed and used on three surveys in 1970/71, 1972/73 and 1974 (Fig. 3.).

At the end of 1973, the stock was obviously recovering rapidly due to good recruitment and effective conservation, so the initial desperate acquisition of data ceased. An unfortunate feature of the "desperation phase" was that due to the enormous pressure for results, it was not possible to accomplish time-consuming experimental work to validate the method in detail.

However, it had become clearly apparent that this new method had a number of very valuable contributions to make to pelagic fish research and an analysis of the method comprises the subject of this thesis, even though the survey data were all collected prior to registration for the degree.

When planning the evaluation, it became obvious that any justification for the method would have to cover a number of major fields, each of which could absorb a thesis in themselves. So it transpired that this thesis, being the first evaluation of, and justification for a new method, would be rather unusual: instead of being extremely detailed in one avenue of research it became very wide-ranging covering, in some depth, all the desciplines which contribute to the method. Initially, it seemed that the data were more than adequate, but as work proceeded, the value of certain sections became reduced. Particularily disappointing was the failure of a complex aircraft-fishing vessel co-operative experiment which was to have provided vital calibration data relating shoal dimensions to shoal weight. The meticulous planning and training of those involved was negated by a trivial fault in the TV camera which could not be repaired in time. This particular lack in the data considerably weakened the arguments, but fortunately did not destroy the overall significance, so it seemed justifiable to proceed with the thesis.

Some data (for example, dinoflagellate distribution off South West Africa) had been collected by other scientists and was not available to this study, so such gaps were filled by extensive review. In addition, the value of the use of aircraft in fishery research is certainly not highly regarded, so a substantial review is used to establish the <u>bona fides</u> of aircraft involvement. Had these reviews been omitted, the development of ideas would have suffered and required assumptions to have been made in important areas.

The outcome is that about half the content of the thesis contains original work and the remainder the supporting review sections.

This thesis therefore examines the problems associated with making aerial observations on pelagic fish. They can be put under four general headings: variability in bioluminescence parameters, fish behaviour patterns, choice of bioluminescence sensor and observational methodology. The sources of bioluminescence in the sea are reviewed and the distribution of such species off South West Africa is described, to demonstrate that the potential for shoal luminescence exists on a virtually continuous basis. The cause of shoal luminescence variability is sought in the literature and it is postulated that exhaustion of the luminescent system is the prime cause of observed effects. It is interesting to note that biological rhythms in luminescence emission favour observations all night with an abrupt "cut-off" just before dawn and an abrupt "switch-on" just after dusk.

A comparison is made between quantitative measurements on bioluminescence in the literature and those made <u>in situ</u> off South West Africa, which shows that, for the reported concentrations of dinoflagellates, fish shoals will be visible, as calculated values for shoal irradiance compare favourably with that which was measured.

Fish behaviour largely governs whether or not a shoal will be visible and indentifiable. Diurnal vertical migration is important, as, if the shoals do not migrate into the surface zone of visibility, they will not be observed. As part of the research programme a study of diurnal vertical migration was made and this indicated that virtually all shoals are visible at night.

Equipment for observing and recording images of fish shoals is of a specialised nature and the evolution of requirements is described as they proceeded from the eye to low-light-level television.

The method of shoal tonnage estimation is then described with examples and with details of experimental work accomplished to assist in the calculations. The three annual surveys were all slightly different in methodology, and although sufficiently similar to allow comparison of results from each year, illustrate the development occurring in the approach arial observations. The three surveys are described in detail.

In conclusion, the approaches to stock assessment of the South West African pilchard are considered from certain points of view and the relative merits of each mehtod discussed. The advantages of being able to quantitatively evaluate the sources of error and bias in the aerial/acoustic method are noted and its value to management discussed. Particularly stressed is that the distribution of virtually the entire stock can be continuously monitored and its size estimated with a relative precision of, at the worst ± 50% once or twice a year. Finally, attention is drawn to the fact that many of the worlds large pelagic fisheries occur in areas which, in terms of bioluminescence and fish behaviour potential, seem suitable for aerial/acoustic research.

Areas for further research have been clearly delineated, and research has already commenced in many cases. This has limited the opportunity to conduct extra work on this thesis.

Appendices contain a description of an attempt at empirical calibration of the aerial/acoustic method, and a number of publications referring directly or indirectly to the aerial/ acoustic method and its employment in management decisions. The summary reports on the Cape Cross programme, written in conjunction with -G.A. Visser, summarise the results provided by a large team: the role of aircraft and acoustics can be seen in perspective. The paper on surface-shoaling Cape hake was an interesting by-product of a pilchard survey, and demonstrated other advantages of aerial observations. F.H. Schulein collected the shipboard information. The papers on the role of remote sensing in fisheries research in South Africa and the rapid stock assessment of pilchard populations are self-explanatory. The proposed strategy for pelagic fish stock assessment is the latest development of the aerial/acoustic method. The acoustics research was conducted by I. Hampton. This paper grew out of the paper "Notes on experience with combined echo-integrator/research aircraft surveys leading to estimates of pelagic fish stock size" which was presented to a symposium in Norway by I. Hampton. The short note on low-light-level television as an aid to pilchard research shows some typical shoal shapes. J.J. Agenbag shared in the collection of the bulk of the aerial information and has, through practical advice and lengthy discussion, beenof great assistance in the development of fishspotting research.

1.0 BIOLUMINESCENCE

Measurements of stimulated bioluminescence are the basis of the new method, but little is known about the spatial and temporal variation in bioluminescence off South West Africa from a scientific standpoint. From the fishing industry's point-of-view, bioluminescence is a virtually continuous phenomenon, for it has been used in fish location since the fisheries inception, and for this reason it was not considered to be sufficiently variable to warrant study at a time when all efforts were focussed on the fish stock. As bioluminescence is fundamental to the method, publications will be reviewed to determine to what extent the potential for bioluminescence exists off South West Africa on an annual basis. Quantitative measures of bioluminescence from other areas are reviewed and compared with in situ measurements of bioluminescence off South West Africa and with calculations based upon the data in the literature describing the South West African luminescent plankton population. Observations from the research aircraft made over a period of three years have clearly shown that fish shoals are invariably brighter along the leading edge than the trailing edge. As the bioluminescent outline is used for measurement purposes the accurate delineation of the shoal outline is important. Factors affecting this variability in emission are reviewed and a hypothesis put forward that of the relevant factors, exhaustion of the bioluminescent system is the most likely cause. In addition a separate cause of variation in apparent intensity is due to variation in the depth of shoals. Studies on diurnal vertical migration show that a significant proportion of pilchard shoals are always within the visible zone.

1.1 SOURCES OF BIOLUMINESCENCE

Bioluminescence is a ubiquitous phenomenon in the surface waters of the oceans, and has been observed and recorded since the early history of ocean travel. Staples (1966) refers to reports from the Fifteenth to Eighteenth Century giving descriptions of the "phosphorescence" of the sea from the East Indies to the Atlantic Ocean. Holder (1887) is quoted by Staples (op. cit.) as reporting a vivid display of luminescence off Simonstown (False Bay), noting that wherever the luminescence was brightest the water was coloured red and ".....contained such an immense quantity of little globules (Noctiluca) that it had the consistency of syrup, the globules consisting of more than half the volume of the seawater". Staples also quotes unidentified sources who report that observers on the Meteor in 1926 noted diffuse luminescence all along the coast of Equatorial Africa down to Angola. The light was reported as continuous and rather intense in the vicinity of Mocamedes. Further south, along the coast of South West Africa the incidence of bioluminescence was observed to increase markedly.

Other unidentified observers reported that False Bay in November had an "unclean and greasy appearance" by day but resembled a "lake of molten gold" at night. Strong bioluminescence was reported in Table Bay during January and February when "dark water" develops. Staples (1966) reports extensively on 3 000 authenticated ships' reports and scientific studies clearly illustrating that luminescence is widespread in all oceans including (or especially) the Polar oceans in all seasons.

It is noted that a bias exists in the reports due to the geographical limitations of the major shipping lanes, and wherever possible scientific, ecological or biological data was used in his report to reduce this bias.

The sources of bioluminescence in the ocean are diverse, there being luminescent members of the Bacteria and Phyla Protozoa, Coelenterata, Aschelminthes, Annelida, Arthropoda, Mollusca and Chordata. No luminescent members of the Phyla Platyhelminthes, Nemertea, Ectoprocta, Brachiopoda, Chaetognatha and Echinodermata have been reported.

The evidence for the low concentration of free-living bacteria in the plankton suggests that the effectiveness of the group in mid-water light production is minimal (Boden and Kampa 1964). Except for a report by Haneda (1955) of luminescent "plankton snow" - the cast-off exoskeletons or dead remains of larger planktonic organisms to which luminous bacteria were presumably adherent - there is no indication that this group is ever sufficiently abundant to be considered a significant source of bioluminescence. However, bacteria are involved in the luminescence of certain cephalopods and Teleosts.

The dinoflagellates (Protozoa) probably make the greatest contribution to bioluminescence in the surface waters of the sea. Table 3 lists the known luminescent species. One of the earliest to be recognised was Noctiluca, possibly due to its large size and brilliant luminescence, (Baker 1753; de Quatrefages 1850; quoted by Sweeney 1963). Later workers identified other sources of luminescence as techniques and instrumentation improved, for example, Gonyaulax polydra, (Kofoid 1911).

Sweeney (1963) examined dinoflagellates in the California Current to determine which of those collected were luminescent and which were not. Previous work indicated that one or more species of eight genera were luminescent.

More than half the dinoflagellates tested by Sweeney proved to be non-luminescent, including two species previously recorded as being luminescent, namely, *Prorocentrum micans* and *Ceratium furca*. All species of Gonyaulax tested were luminescent and other genera included both luminescent and non-luminescent forms. It was observed that while one culture of *Noctiluca* isolated from the Gulf of California was brightly luminescent, two other cultures from La Jolla plankton were not luminescent. The probability exists that the non-luminescent form was another species.

TABLE 3. LIST OF LUMINESCENT DINOFLAGELLATES. DERIVED FROM SWEENEY (1963) KELLY (1968) AND TETT (1971).

LUMINESCENT SPECIES	LUMINESCENT SPECIES
Ceratium fusus	Peridinium brochii
Ceratium dens	P. candelbrum
C. furca (Pacific)	P. claudicans (Atl.)
C. tripos	P. conicum
Gonyaulax digitale	P. curtipes
G. spinifera	P. depressum
G. catenella	P. devergens
G. hyalina	P. engrammum
G. Monilata	P. globulus
G. polygramma	P. granii
G. polyedra	P. leonis
G. sphaeroidea	P. ocatum
G. spinifera	P. oceanicum
Gymnodinium flavum	P. pallidum
	P. pentagonum
G. sangiunium	P. punctulatum
	P. subinerme
	P. steinii
	P. seta
	Pyrocystis lunula
	Pyrocystis noctiluca
	Polykrikos schwartzii
	Pyrodinium bahamense
Noctiluca miliaris	Scrippsiella sweenyi
N. scintillans	

The relationship between dinoflagellates and luminescence has been fairly extensively studied. Using the essentially unialgal culture of Pyrodinium bahamense in Oyster Bay, Jamaica, the total intensity of bioluminescence has been related to dinoflagellate numbers (Soli 1966) and the total number of photons emitted by individuals has been shown to remain constant at night (Seliger and McElroy 1968). In the North Atlantic a significant correlation was found between stimulated bioluminescence and luminescent dinoflagellate concentrations, where the most common species were Ceratium fusus, Gonyaulax spp. and Peridinium claudicans. Dinoflagellate luminescence in the North East Atlantic has been studied by Tett (1971) who determined that the relationship between spontaneous luminescent flash rate and cell number per litre was linear.

Other records of dinoflagellate luminescence include the work of Nordli (1957) on Ceratium in the Norwegian Sea. It was found that C. fusus was luminescent, but C. tripos, C. furca and C. lineatum did not luminesce in culture. Nordli states that C. tripos is luminescent in the sea (no source). Hastings and Sweeney (1958) worked on the diurnal rhythm of luminescence in Gonyaulax polyedra; Plain and Plain (1963) on the decay and recovery of luminescence in G. monilata, Swift and Taylor (1967) on chloroplast movement and bioluminescence in Pyrocystis lunula; Hardy and Kay (1964) on experiments with light on Peridinium depressum, Ceratium horridum and C. tripos var. balticum. Dinoflagellates are abundant in the South West African plankton (section 1.2.).

Luminescence has been observed in seven genera of Radiolaria:

Thalasocola, Myxosphaera, Collosphaera.
Sphaerozoum, Collozoum (Harvey 1952) Cytocladus and Aulosphaera (Nicol 1958). Radiolaria are widely distributed and may significantly contribute to sea surface luminescence. They are abundant off South West Africa (Kollmer 1963).

TABLE 4. LUMINESCENT COELENTERATA

Group	Genera (or species)	Author
Coelenterata Hydromedusa	Lizzia, Rathkea, Stomatoca Laodicea, Melicertissa, Mitrocoma, Obelia, Phialidium, Aequoria, Halopsis, Liriope, Geryonia, Solmissus	Harvey (1952)
	Mitrocomella, Eutonina, Tima, Leuckartia	
	Grossota, Ageinura, Colobonema	Nicol (1958)
Coelenterata Siphonophora	Voigtia glabra, V.spiriosa	
	Rosacea plicata, Hippopodius hippopus	Nicol (1958)
	Diphyes, Ablya, Praya, Agalma	Harvey (1952)
Coelenterata		Harvey (1952)
Scyphozoa	Pelagia	
	Atolla wyvillei, Periphylla periphylla	Clarke & Conover David & Nicol (1962)

The luminescent coelenterata, tabulated in Table 4, are relatively unimportant as contributors to fish shoal luminescence, but are interesting in that off South West Africa, large congregations of Aequoria sp. and Pelagia noctiluca have been observed at night and their luminescence mistaken for fish shoals. Having had some mis-identification confirmed by vessels, aircraft observers became proficient at distinguishing jellies from fish, usually by flashing a powerful light: jellies do not respond, but fish become alarmed and swim vigorously, causing bright flashes of luminescence, a clearly distinguishing feature.

The Ctenophora are probably all luminescent (Boden & Kampa 1964) and are occasionally visible to aircraft as streaks on the water (cf. Fig. 4(b)).

On the Annelida, only two families can be considered part of the plankton, the Tomopteridae and Syllidae, and of these only the Tomopteridae are wholly pelagic. Little is known about tomopterid luminescence except, in contrast to the vast bulk of the planktonic luminescent organisms, its light is yellow (Boden & Kampa 1964). The group is unimportant to this study.

Of the phylum Arthropoda, it is only within the Crustacea that luminescent planktonic organisms occur, being reported from Ostracoda, Copepoda, Mysidacea, Euphausiacea and Decapoda (Table 5).

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TABLE 5. BIOLUMINESCENT CRUSTACEA

Group	Genus (or species)	Author
Crustacea Ostracoda	Cypridina hilgendorfii, Cypridina Pyrocypris, Conchoecia	Harvey (1952)
	eleven Conchoecia species	Angel 1968
Amphipoda		Fage (1934) and Woltereck (1905)
(Hyperiidae)	Steetsia, Scypholanceola	Quoted from Boden and Kampa (1964)
Copepoda		Clarke,
Calanoidea Aetidei-dae	Chiridius obtusifrons	Conover, David & Nicol (1962)
Lucicutiidae	Lucicutia flavicornis	
	L, grandis	Nicol (1962)
Metridiidae	Metridia Lucens, M. longa, M. princeps, Pleuromamma sp., P. robusta, P. xiphias, P. abdominales, P. gracilis, Gaussia princeps	
Heterorhabidae	Heterorhabdus robustus, H. papilliger, H. norvegicus, Heterostylites longicornis, Hemirhabdus grimaldii, Disetta palumboi	
Augaptilidae	Euangaptilus magnus Centraugaptilus horridus	
Copepoda Cyclopoida Oncaeidae	Oncaea conifera	Boden and Kampa (1964)
Mysidacea	Gnathophausia, Siriella Gastrococcus, Mysis	Boden and Kampa (1964)
Euphausidacea	Euphausia, Nyctiphanes, Meganyctiphanes, Thysa-noessa, Nematoscelis, Stylocheiron, Nemato-brachion, Thysanopoda	Boden and Kampa (1964)

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FIGURE 4 (a) Luminescent patches, probably the euphausiid Nyctiphanes capensis (Cram and Malan, in press)

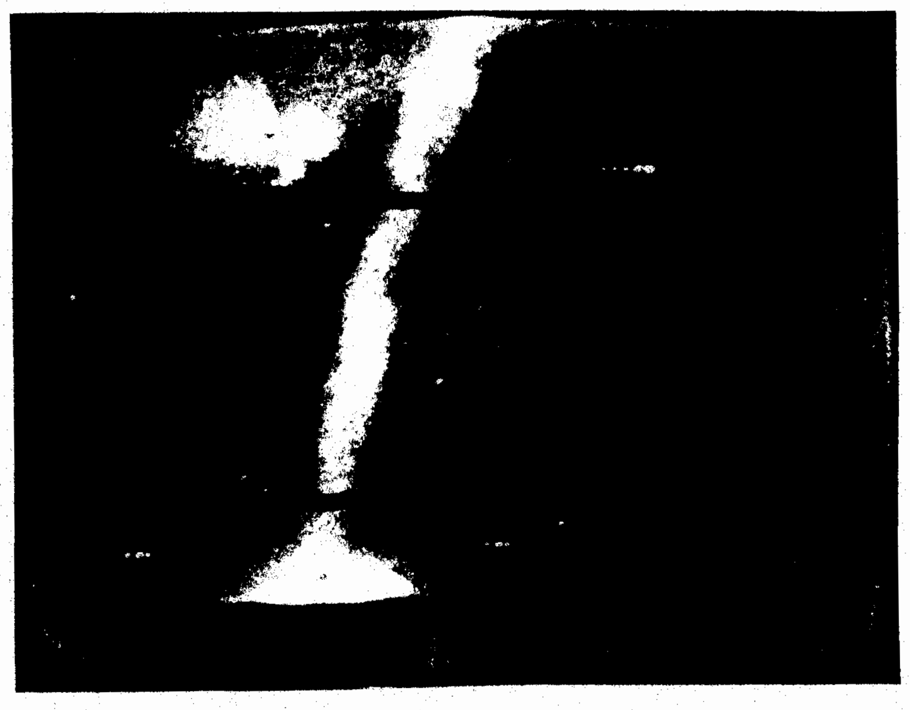

FIGURE 4 (b) : Plankton streak, extremely long.

The West coast plankton contains representatives of all groups of luminescent crustacea. Of particular interest is the euphausiid Nyctiphanes capensis which is particularily abundant in South West Africa and has frequently been observed in characteristic "striped" swarms (Fig. 4(a)) which also were confused with fish shoals until feedback from ground-truth data enabled observers to confidently identify them. It is interesting to note that C. Wyville Thomson observed Nyctiphanes norvegica luminescence as "...large spots and long bands of milk-white water" (Thompson 1885). This description tallies with the shape of N. capensis swarms seen off South West Africa.

Two classes of Mollusca, the Gastropoda and Cephalopoda are luminescent. Only a few records of gastropod luminescence occur: unauthenticated pteropod and authenticated nudibranch observations. It is in the Cephalopoda that luminescence is well developed, particularly in the Decapoda. Although Decapods may be numerous they have not been identified and do not contribute to shoal luminescence.

The chordate subphylum Tunicate contain luminescent forms such as Pyrosoma, Oikopleura and a number of salps and doliolids. Offshore, they give considerable displays of luminescence, but are not usually present in the pilchard habitat.

A very large number of the Pisces (sub-Phylum Vertebrata) are luminescent. Eight families and one sub-order possess luminescence generated by symbiotic bacteria. (Macrouridae, Gadidae, Monocentridae, Anomalopidae, Acropomatidae, Leiognathidae, Saccopharyngidae and Ceratoidea).

There are two families of Teleosts with self-luminous photophores, and Stomiatoidea and Myctophoidea (Harvey 1957). The myctophids are of particular interest as they are occasionally found in great abundance on the West Coast and contribute significantly to the pelagic fishery of the Western Cape (Centurier Harris 1974). Thus, they are capable of contributing substantially to the background of illumination in the sea.

That much of the plankton and nekton is known to emit bioluminescence has been determined through a large body of research conducted on a widely-spread basis around the world. That these data are relevant to the Benguela Current System off South West Africa is confirmed by Hart and Currie (1960) and Boden (1954) whose work demonstrates that most of the known luminescent species are present in our waters. The potential for fish-shoals to excite luminescence thus exists, but the identity of those organisms which produce the light which outline the shoals is not known. Probably it is caused by all those members of the plankton and nekton unable to swim away from the path of the shoals and it is more than likely that the dinoflagellates play a leading role. It has been frequently suggested in the literature that dinoflagellates are important in natural bioluminescence in the ocean, as it has been found experimentally that a high proportion of stimulated bioluminescence was produced by organisms which passed through a 0,24mm filter (Clarke and Kelly 1965). In addition, Tett (1971) showed statistically that a numerical relationship existed between natural, non-stimulated bioluminescence and dinoflagellate numbers, and concluded that they were the major contributors to bioluminescence in the area of study.

Thus emphasis has been given to the dinoflagellates in succeeding pages. The contribution from the crustacea and teleosts is not ignored; but in any case, the literature is more scanty for each group than that for the easily cultured dinoflagellates, and is incorporated where relevant.

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1.2. THE DISTRIBUTION OF LUMINESCENT ORGANISMS OFF SOUTH WEST AFRICA

Despite the fact that off South West Africa there have been very few occasions when bioluminescence has not been observed from the research aircraft, it is not known whether the potential for luminescence is widespread or restricted to certain times and places. There are two sources of data on the distribution of plankton off South West Africa: the scanty literature, and a vast amount of partly-processed qualitative and quantitative data derived from 1970 onwards by the Sea Fisheries Branch. Unfortunately, the Sea Fisheries Branch's data was being processed for another process and thus was not available to this study, so the literature is reviewed to derive whatever information exists on the distribution of luminescent organisms in space and time which will, in turn, provide information upon whether or not the potential for bioluminescence is continuous or sporadic.

Pronounced dinoflagellate blooms have been observed at or near Walvis Bay by a number of authors. Early observations were made on Noctiluca (Marchand 1928) and Gymnodinium galatheanum blooming within the Bay (Copenhagen 1953, Braarud 1957). Hart and Currie (1960) produced the first and so far only large scale attempt at describing the physical/chemical processes and plankton distribution in the Benguela Current. Although concentrating heavily upon the diatoms, considerable information on the dinoflagellates can be gleaned from the distributional data presented.

Of the dominant species, Prorocentrum micans is non-luminescent, and Peridinium triquentum of unknown capability. The widespread distribution of the microplankton and its dinoflagellate fraction of approximately one order of magnitude less, coupled with the Gonyaulax spinifera bloom between Walvis Bay and Möwe Point and the blooms reported above from South of Walvis Bay indicate how widely spread the luminescent dinoflagellates were in 1950.

Kollmer (1962) reported upon the occurrence of dinoflagellates in the ocean adjacent to Walvis Bay in 1958, where dinoflagellates were abundant all year. Unfortunatley except for Ceratium tripos, no dinoflagellates were identified to species, but as the genus Peridinium was identified and many of the species are luminescent, it is probable that the samples contained luminescent forms. The observation was made that dinoflagellate abundance increased markedly during periods of warm water occurrence along the coast in Summer. Additional data was presented on the depth distribution and cell count of total phytoplankton at selected stations. This quantitative distribution showed monthly changes in phytoplankton cell-count over a six month period. Hart and Currie (1960) found that in any net haul, the dinoflagellate content would be one order of magnitude less than total phytoplankton. In order to get an approximation of dinoflagellate numbers along Kollmer's station-line, his cell counts are reduced by an order of magnitude and summarised in Table 6.

TABLE 6. DEPTH DISTRIBUTION OF DINOFLAGELLATE NUMBERS PER VOLUME. RECALCULATED FROM KOLLMER (1962)

December	(1958)	0-5m	1,25 million cells/litre
		5-20m	0,13-1,25 million cells/litre
February	(1959)	0-15m	0,13-0,25 million cells/litre(approx.)
March	(1959)		
	Offshore	0-20m	0,25-1,25 million cells/litre
	Inshore	0-20m	0,03-0,13 million cells/litre
April	(1959)	0-35m	0,03-0,13 million cells/litre
May	(1959)	0-50m	0,03-0,25 million cells/litre

The depth range encompasses the normal range of pilchard shoals. Whether or not the numbers are accurate is not strictly important as they merely place some dimension upon distributional data. It is inferred from the data that both luminescent and non-luminescent dinoflagellates were present off Walvis Bay in appreciable concentration in the waters occupied by pilchards.

This was followed by a more general work on phytoplankton and zooplankton which was divided into three parts (Kollmer 1963). Based on collections made in 1958-59 Kollmer sub-divided the plankton into three fractions: as *Aulosphaera* (radiolaria) dominated fraction; a *Calanoides carinatus* dominated fraction and a tunicate-coelenerate-Ctenophore dominated fraction. These major ecological groups existed in discrete areas along the coast, extending in "strips offshore" , as Kollmer termed them, between Conception Bay and Ambrose Bay.

In the near-coast strip (15-50n.miles offshore) typical neritic plankton occurred: larvae, as well as Copepods, Ostracods and gammarid Amphipods, together with large numbers of Noctiluca and Alausphaera, both luminescent. The second "strip", extending from the outer boundary of the Aulausphaera "strip" extended to about 120n. miles and was dominated by Calanus carinatus, but contained abundant luminescent Metridia lucens. Further offshore the Salps, Doliolids, Siphonophores and Ctenophores predominated. Although only the smaller forms may be responsible for the luminescent emission of fish shoals, the widespread occurrence of the smaller luminescent forms within the study area, further indicates the potential for luminescence.

The third part of the same paper refers to the monthly cell counts of selected families, genera and species from 1959-60. The presence of dinoflagellates can be detected throughout the year, over the study area extending from 25^{o}S to 21^{o}45 and approximately sixty miles seaward. The cell-counts determined by Kollmer (1963) are in agreement with those derived from Kollmer (1962) and modified by the ratio of dinoflagellates to phytoplankton derived from Hart and Currie (1960). Kollmer shows that dinoflagellate species were present throughout the year, blooming in summer 1960 to give cell concentrations three times those in Winter.

The principal interest in dinoflagellates has been in their property of blooming in "red-tides" with occasional detrimental effect upon fish and shellfish.

In order to extend the evidence of widespread dinoflagellate occurrence to the North and South of the South West African fishery area, it is worth referring to the literature on red tide organisms. Red tide due to Nesodinium sp. has been observed in the vicinity of Cape Town (Hart 1934 quoted by Pieterse and van der Post 1967). De Jager (1957) reported a bloom dominated by (non-luminescent) Prorocentrum micans in the St. Helena Bay area. Grindley and Taylor (1962) carried out extensive work on a dense bloom extending at least between Walker Bay and False Bay which was dominated by Gonyaulax polygramma in association with Prorocentrum micans. A later incident in 1966 at Elands Bay was caused principally by Gonyaulax grindleyi in concentrations of 0.5-6.7 million cells/litre (Grindley and Nel 1970). In the latter two red tide occurrences, large-scale fish and crustacean mortality occurred.

To the North of South West Africa, dinoflagellate blooms have been recorded as red tides by Silva (1953 quoted by Pieterse and van der Post 1967) and Paredes (1962). Exuviella baltica was responsible both times, although in the latter case in association with a number of other dinoflagellates.

At Walvis Bay, collections made within the Bay by Pieterse and van der Post (1967) provided the list of dinoflagellate species laid out in Table 7.

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In general, the number of dinoflagellates in Walvis Bay normally fluctuated between 0,1 and 3,0 million cells/litre and could increase up to 30 million cells/litre under bloom conditions. Further, Pieterse and van der Post (1967) found that the blooms had a higher concentration at 0m than at 5m but that greater differences in cell count occurred if the counts from the ocean side of the Bay were contrasted with those from the landward side. However, both parts of the dinoflagellate populations followed the same patterns of dense blooms in Summer, lesser blooms in Autumn and minor blooms in Winter. The differences in cell-counts approximated to 17 million/litre on the landward side to 2 million/litre on the ocean side. Without presenting any source of data, Pieterse and van der Post (1967) report that during the period of their study March 1964 - February 1965, dinoflagellate blooms occurred widely along the South West African coast.

In a somewhat more detailed study, but similar, to that of Kollmer (1962), Reyssac (1973) described the occurrance of 32 species of dinoflagellates (Table 8) occurring at four stations off Walvis Bay between June 1965 and April 1966.

TABLE 8. DINOFLAGELLATES OBSERVED OFF WALVIS BAY (REYSSAC 1973) WITH ADDED NOTATION TO BIOLUMINESCENT ABILITY.

Group, genera, species	Luminescent	Group, genera, species	Luminescent
Dinophysiaceae.		Ceratiaceae.	
Dinophysis fortii	No	Ceratium azoricum	?
D. sacculus	No	C. candelabrum var. candelabrum	?
Glenodiniaceae.		C. declinatum var. normale	?
Glenodinium sp.	?	C. extensum	?
Gymnodinium sp.	?	C. falcatum	?
Peridiniacea.		C. furca	Yes
Peridinium brochii	Yes	C. fusus var. seta	?
P. conicum	Yes	C. gibberum	?
P. crassipes	?	C. horridum	?
P. depressum	Yes	C. lineatum	?
P. biabolus	Yes	C. massiliense	?
P. divergens	Yes	C. massiliense var. protuberans	?
P. granii	Yes	C. pentagonum	?
P. oceanicum	Yes	C. trichoceros	?
P. pallidum	Yes	C. tripos var. arlanticum	?
P. pentagonum	Yes		
P. pentagonum var. depressum	?	Prorocentraceae.	
		Prorocentrum micans	No
P. steinii	Yes	Noctilucaceae	
Gonyaulax polygramma	Yes	Noctiluca miliaris	Yes

The comment is made that dinoflagellates were always scarce during the period of study, which is not in entire agreement with the results reported by other workers. In general, therefore, published work shows that dinoflagellates and other luminescent organisms are widely distributed from Mowe Point to the Orange River and to one hundred and eighty miles offshore. They have occurred in the ocean off Walvis Bay in concentrations of 0,03-5,5 million cells/litre at the surface and 0,03-1,25 million cells/litre down to fifty metres. Other luminescent plankton, for example Alausphaera and Metridia lucens were also abundant in the research area from Conception Bay to Ambrose Bay.

The seasonal variation in hydrological and biological properties indicate that two situations occur in general : a summer period when upwelling is reduced and influxes of warm water occur from offshore and a winter period when upwellling is persistent. This seasonal cycle appears to have been consistent since 1950 except during the anomalous el Nino-type situation in 1963. The William Scoresby surveys of March and September 1950 occurred at the beginning and end of winter, and the distribution of conservative properties and plankton strongly resembles later data. Kollmer's work covered a monthly sampling programme from summer to winter 1958/59, and that of Pieterse and van der Post a cycle from summer 1964 to summer 1965. Similarily Reyssac worked between winter 1965 and winter 1966. Hart and Currie (op. cit) qualitatively recorded a similar pattern on the two surveys in 1950 over a wide area. Kollmer (1962) showed a decline in dinoflagellate numbers with season changing from summer to winter.

1.3 QUANTITATIVE MEASURES OF BIOLUMINESCENCE

Aerial observations of fish shoals, together with the literature and data reviewed in the previous section, indicate that the potential for detecting fish shoals exists off South West Africa. However, for this potential to be realised in the form of fishery-orientated data, it is necessary to record the images of fish shoals for processing purposes. In the design of systems for the collection of such images, the spectral distribution and intensity of the luminescence emanating from a fish shoal are the most important considerations. Within the literature on luminescence, there are abundant references to the fact that pelagic shoals can be luminescent but none which specifically refers to any measurement of luminescence spectrum or strength. There are two ways of approaching such lack of knowledge; either to deduce the probable values of the parameters in question or to measure them. Both avenues have been explored, the literature review serving as background against which the results of experimental work can be seen in perspective. This section will review the literature of relevant measures of bioluminescence parameters to produce approximations of intensity and spectral distribution, and describes the results of direct measure made on fish shoal luminescence.

Although Staples (1966) reported numerous qualitative observations of luminescence on an oceanwide scale, there are very few similar quantitative studies. Bityukov (1971) reported on work with a towed photometer designed to determine intensity, the number of flashes and their amplitude spectrum during a cruise from the Aegean Sea to the Atlantic Ocean.

Latitudinal profiles showed significant variability : the intensity was least in the Sargasso Sea area, the Canary Current close the coast and in the Aegean Sea. The most intense luminescence was 14×10^{-2} uW/cm^2 observed in the Straits of Gibralter and East of the Azores (30°S, 20°W) at $11,7 \times 10^{-2}$ uW/cm^2. These levels were approximately 600 times greater than the Sargasso area and 5 times greater than the Aegean.

A similar transect was conducted in the Western Indian Ocean by Clarke and Kelly (1964) who measured vertical distributions of light penetration and luminescence at twenty four stations on a North-South transect from Equatorial to Sub-antartic water on 51°-60°E. Luminescent flashing was found at every station and at every depth investigated below that at which light from the surface interfered. The total number of flashes was highest near the surface everywhere, with a latitudinal increase from north to south, where larger catches of invertebrate plankton were made. No attempt was made to determine the strength or spectral distribution of the bioluminescent flashes.

The measurement of the spectral distribution and intensity of bioluminescence has been attempted with in situ and laboratory experiments by various authors. The in situ observations have all been characterised by the strenuous efforts made either to exclude or include the "observer effect", depending upon the approach concerned. In essence, removal of the observer effect is accomplished by arranging equipment to remotely view a body of water in a stereoscopic manner thus excluding any induced liminescence near the gear caused through stimulation by the gear itself (Boden, Kampa and Snodgrass 1965).

Inclusion of the observer effect is usually accomplished by continuous pumping of water through a light-proof observation chamber where maximal turbulence (and luminescence) occurs (e.g. Seliger, Fastie and McElroy 1961). Although long the subject of controversy, both approaches are valid as Tett (1971) demonstrated statistically that the relationship between luminescence and dinoflagellate numbers is valid whether the luminescence in the sample is spontaneous or mechanically stimulated.

Many workers have accomplished research in the naturally occurring dinoflagellate-rich "phosphorescent" bays occuring in the West Indies. Clarke and Breslau (1960) worked on a comparison between Phosphorescent Bay, Puerto Rico, and the Gulf of Naples using the bathyphotometer designed originally by Wertheim (1954), modified and redesigned by Clarke and Wertheim (1956), and Clarke and Hubbard (1959). The instrument was sensitive to 10^{-7} $\mu W/cm^2$. It was mounted 50cm from the bow-wave of a motor boat, and on a transit through the entrance to the Bay from seaward, the luminescence increased by a factor of 100 to 3×10^{-2} $\mu W/cm^2$. The sky light "background" was between 10^{-3} and 10^{-2}, of which less than 4% is reflected from the sea surface (Drennan 1971). In Phosphorescent Bay the spontaneous luminescence was weak and only agitation brought the emission up to nearly 10^{-2} $\mu W/cm^2$. In contrast, similar agitation in the Gulf of Naples produced 10^{-4} to 10^{-3} $\mu W/cm^2$.

A number of workers have produced measurements of spectral energy and radiance from laboratory experiments. Their results are summarised in Table 9.

Group and species	Irradiance at 1m in air, $\mu W/cm^2$	Spectral peak (nm)	Temperature (°C)	Source
DINOFLAGELLATA				
"dinoflagellates"	-	482	-	Soli (1966)
Pyrodinium bahamense	-	478	-	Soli (1966)
Pyrocystis lunula	-	477	-	Nicol (1958)
Noctiluca miliaris	$0,1 \times 10^{-6}$ J	470	23	Nicol (1958)
"all species tested"	$10,0 \times 10^{-9}$	480	-	Kelly (1968)
RADIOLARIA				
Cytocladus major	$5,3 \times 10^{-9}$	-	22	Nicol (1958)
Aulosphaera triodon	" "	-	"	" "
HYDROMEDUSAE				
Colobonema sericeum	$9,3 \times 10^{-9}$	460	8	" "
	$9,5 \times 10^{-9}$	-	8	" "
	$0,4 \times 10^{-9}$	-	13	" "
Crossota alba	$9,3 \times 10^{-9}$	-	11	" "
SIPHONOPHORA				
Vogtia spinosa	$13,7 \times 10^{-9}$	-	8	" "
	$320,9 \times 10^{-9}$	-	21,8	" "
	$120,0 \times 10^{-9}$	-	8	" "
V. glabra	$2,4 \times 10^{-9}$	470	20	" "
Rosacea plicata	$13,7 \times 10^{-9}$	-	20	" "
	$2,6 \times 10^{-9}$	-	22	" "
Hippopodius hippopus	$4,2 \times 10^{-9}$	-	22	" "
SCYPHOMEDUSAE				
Atolla wyvillei	$0,3 \times 10^{-9}$	470	24	" "
	$199,9 \times 10^{-9}$		13	" "
CTENOPHORA				
Beroe sp.	$16,9 \times 10^{-9}$	510	24	" "
CRUSTACEA				
Acanthephyra purpurea	$1,9 \times 10^{-9}$		9	" "
	$8,2 \times 10^{-9}$	476	9	" "
Euphausia pacifica	$160,0 \times 10^{-9}$ – $200,0 \times 10^{-9}$	476	-	Kampa and Boden(1957)
Meganyctiphanes norvegica	$1,2 \times 10^{-9}$	-	16	Clarke, Conover, David & Nicol (1962)
Thysanoessa raschii	-	476	-	Boden (1959)
Metridia lucens	$0,6 \times 10^{-9}$	482	14	"" "" "
TELEOSTI				
Sarsia koefoedi	$2117,0 \times 10^{-9}$	-	12-15	Nicol (1958)
Myctophum punctatum	$0,9 \times 10^{-9}$	470	16	" "

TABLE 9 : Intensity and spectral peak of luminescence of some pelagic animals

For ease of comparison, the units and the exponents have been made identical (where possible), and the values recalculated as for 1m in air using the inverse square law. Fig. 5 is an example of the spectral energy curves obtained for dinoflagellates (Soli 1966).

In summary, the average wavelength value for peak emission of bioluminescence in laboratory experiments on organisms from all groups tested except Ctenophores is 475nm, SD/6,0nm. This narrow band co-incides with the wavelength for maximum transmission in seawater (Jerlov 1951).

The emmission of luminescence by single individuals varied between $0{,}04 \times 10^{-9}$ and 200×10^{-9} $\mu W/cm^2$ (excluding vertebrates, colonial organisms such as *Pyrosoma* and the Siphonophores).

These values provide an idea of the range of quantities involved with single animals. However, the plankton population is heterogeneous and present in very large numbers per unit volume, and it would be of value to determine whether experimentally measured values of bioluminescent irradiance would be visible from the altitude used by a research aircraft. A number of *in situ* observations have been reported in the literature and four are summarised in Table 10, with a calculated sensor irradiance for 300m.

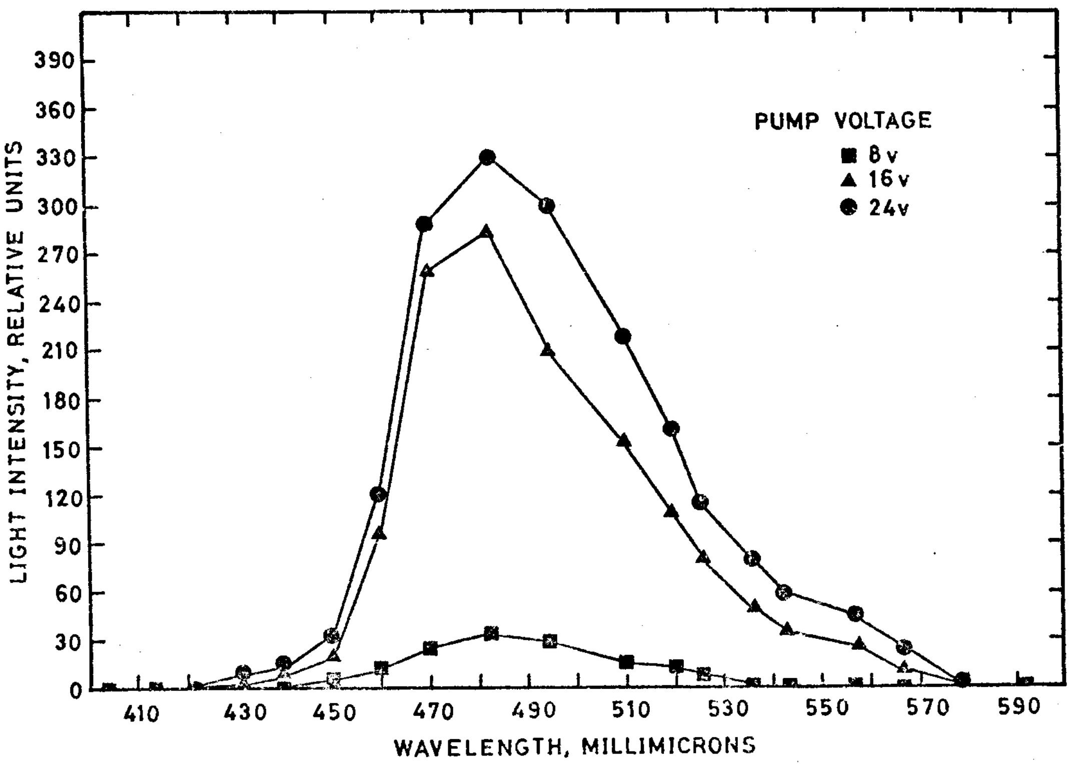


FIGURE 5. Spectral curve of light emitted by dinoflagellates at Oyster Bay, Jamaica, West Indies, under stimuli of different intensities (different pump voltages). (Soli 1966).

TABLE 10. In situ measurements of bioluminescence recalculated for irradiance at a sensor at 300m altitude (inverse square law).

in situ observation				calculated irradiance at 300m
quantity $\mu W/cm^2$	place	distance	Source	($\mu W/cm^2$)
14×10^{-2}	Gibralter	towed (50cm?)	Bityukov (1971)	$0{,}4 \times 10^{-6}$
$11{,}7 \times 10^{-2}$	Azores	towed (50cm?)	Bityukov (1971)	$0{,}3 \times 10^{-6}$
3×10^{-2}	Puerto Rico	50cm	Clarke & Breslau (1960)	$0{,}83 \times 10^{-7}$
5×10^{-3}	Naples	50cm	ditto	$0{,}1 \times 10^{-7}$

One preliminary experiment has been conducted off South West Africa on the measurement of irradiance from the ocean surface which included bioluminescence from fish shoals and other phenomena. During the one successful flight on 16 April 1975 conditions were not ideal due to the presence of low stratus cloud, although the atmosphere above the luminescent patches was clear. For the purpose of the experiment, an International Light Co. radiometer (IL 700/760) was fitted with a telephoto lens and bore-sighted to the Bosch-Fernseh TV camera. This meant that the radiometer was viewing a portion of the field of view of the TV camera; conversely, anything recorded by the radiometer would be imaged by the LLLTV.

The instrument was calibrated at the National Physical Research Laboratory of the CSIR and was set to register the irradiance in lux over a 2π solid angle. A 230mm telephoto lens was fitted which means that at 1000m altitude the irradiance in a field-of-view of approximately 100m is measured (and in proportion at other altitudes). The multiplication factor to convert measurements thus obtained to a 2π solid angle was established experimentally. The conversion of lux to $\mu W/cm^2$ was accomplished by calculation.

In operating this sensitive equipment great care was taken to eliminate stray light and to regularly zero the photomultiplier output to ensure freedom from drift. The equipment was used over shoals of fish of unknown species and a number of euphausiid swarms of unknown species. The photometer output was recorded on a strip chart graph recorder and photographs were taken from the LLLTV signal displayed on a monitor (Fig. 6). At an altitude of 600m the background irradiance from the sea at the sensor was between $1{,}0 \times 10^{-6}$ $\mu W/cm^2$ and $1{,}6 \times 10^{-6}$ $\mu W/cm^2$. Where luminescent areas associated with fish or euphausiids were present, the maximum irradiance measured at the radiometer was $3{,}4 \times 10^{-6}$ $\mu W/cm^2$ (Cram and Malan inpress).

Recalculation of the irradiance at the sensor at 600m to 300m altitude gives values of $4{,}0 - 6{,}4 \times 10^{-6}$ $\mu W/cm^2$ for background and $13{,}6 \times 10^{-6}$ $\mu W/cm^2$ for luminescent shoal areas.

These values are slightly higher than these recalculated from <u>in situ</u> measurements (cf Table 10) but considering that assumptions were made about the towing distance in Bityukov's method, the direct measurements made in South West Africa are in reasonable agreement, despite the fact that the depth of the luminescence source was unknown.

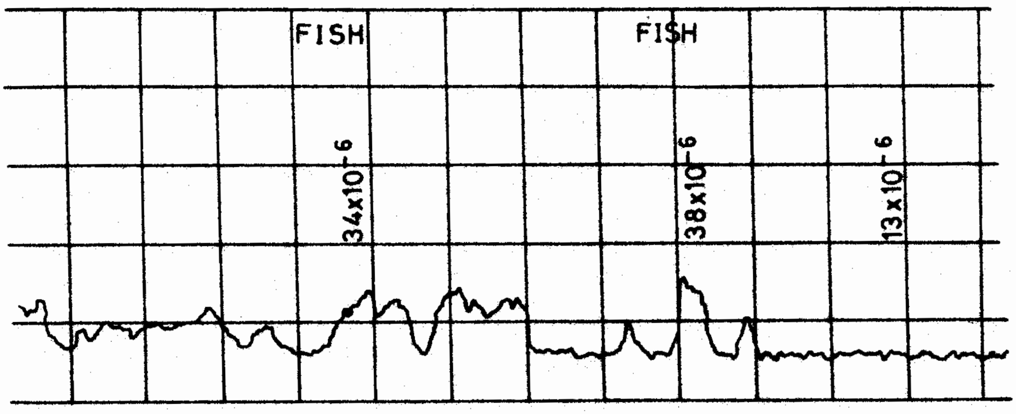


FIGURE 6. Irradiance at the photometer from fish shoals and background.

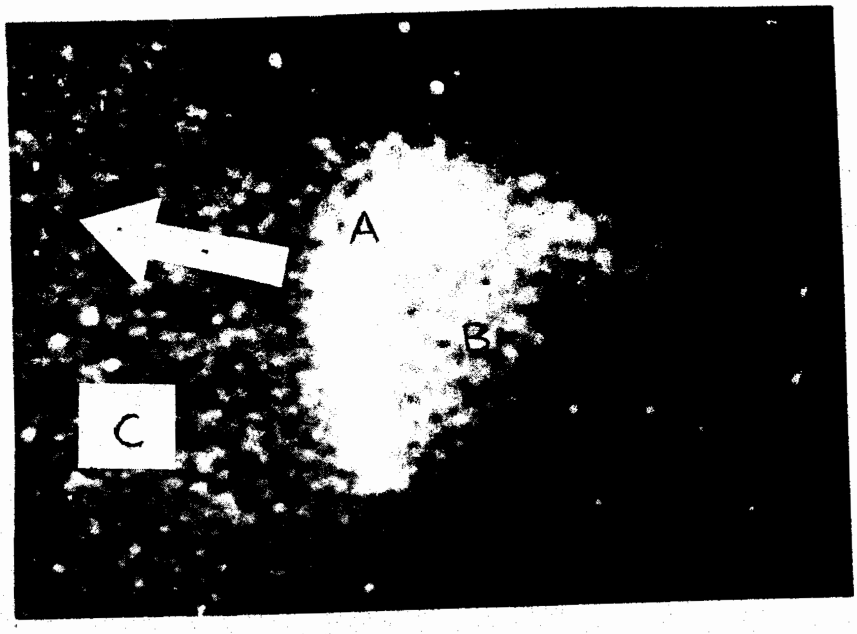


FIGURE 7. Small pilchard shoal (- 90m along edge) Arrow shows direction of movement A, leading edge; B, trailing edge; C, light produced in TV image by electronic "noise".

The luminescent areas providing the radiometer values of $3,4 \times 10^{-6}$ $\mu W/cm^2$ at the sensor were, in practice, reasonably clearly visible to the naked eye. The unaided dark-adapted eye with a pupil of 0,5cm can detect an irradiance of 1×10^{-8} $\mu W/cm^2$ of retina when looking at a uniform circular field subtending 47^o to the eye and having a spectral peak at 510nm. As $1,5cm^2$ of retina will be covered, the irradiance at the retina will be 3×10^{-8} $\mu W/cm^2$. Thus, the lowest calculated irradiance value in Table 10 would probably be invisible, whilst the remainder of the stimulated emissions would be just visible at 300m.

It is known that shoals in South West Africa are visible to the eye and have had irradiance measurements falling well within the sensitivity of the eye, and, accepting the assumptions made, it would seem that in widely differing localities the potential is present for outlining shoals with bioluminescence in visible quantities.

1.4.1. Exhaustion.

Although it is possible to intuitively explain the bright leading edge in terms of mechanical stimulation by the fish, the diminution of light intensity towards the rear could be due to exhaustion of luminescent capability, or a variety of other factors. The bioluminescent response of Noctiluca miliaris to mechanical and electrical stimulation has been studied in detail by Nicol (1958). In general, when a single cell is mechanically stimulated by agitating its container, the intensity of the flash depends on the vigour of the excitation, above a threshold beneath which no response occurs.

The flashing mechanism is subject to fatigue : when mechanically stimulated the cells flash several times and then weaken and finally the light disappears. Following a rest period of several minutes the cells recover and flash brightly once more.

A single electric shock above a threshold value elicits a flash of light, and with bursts of shocks, a cell flashes repetitively, one flash per stimulus. With fast stimulus ($>$ 3/sec) some fusion of consecutive responses occurs, the effect being more pronounced with increasing frequency.

With gradually increasing stimulation, the response increased accordingly : by doubling the stimulating voltage a fivefold increase in flash intensity resulted. A plateau is eventually reached above which no increase occurred and ultimately exhaustion of the system occurs and the intensity of the response diminishes.

If the initial stimulus is of sufficient strength, fatigue sets in immediately with a resultant progressive decline in response intensity. After electrical stimulation it was found that the recovery of full flash intensity required an interval of about 2 to 5 min. at 19°C. Noctiluca cells often, but not always, show facilitation under electrical stimulation. Nicol (op.cit.) demonstrated facilitation in Noctiluca by subjecting a cell to repetitive stimuli at a rate of 9 stimuli/sec. Facilitation occured until a plateau was reached at just less than one second, after which exhaustion progressively reduced the intensity of response. As previously mentioned, the luminescent response to very vigorous stimuli fatigued immediately, therefore facilitation can be inhibited by exhaustion.

The decay and recovery of luminescent ability in Gonyaulax monilata have been studies by Plain and Plain (1963) who found that when stimuli of constant intensity are applied at regular time intervals, progressively lower light intensities result, caused by a temporary exhaustion of flashing system. Recovery was found to be complete provided that the organisms were allowed to rest for a suitable period of time. A mathematical model was proposed which described the response of G. monilata to regularily spaced mechanical stimuli, and laboratory measurements were compared with the model. It was assumed that the intensity of luminescence produced on stimulation was proportional to the number of dinoflagellates able to respond at the beginning of the time interval and that during and after stimulation the ability to respond will be recovered at a constant rate. An expression for the net rate of recovery was derived from an assumed recovery constant and an assumed decay constant.

Plain and Plain do not quote their origin of data for the recovery constant and decay constant. They do not include any phenomena such as facilitation or summation, as their experiment was constructed around a constant stimulus lasting 0,5 sec, with a delay of 30 sec to the next stimulus. However, their experiment indicates that when large numbers of dinoflagelliates are subjected to regular stimulation, progressively lower light intensities result due to exhaustion of the luminescent system.

The rhythmic production of luciferin, with a peak in darkness hours, observed directly by Bode, Desa and Hastings (1963) was also observed indirectly by Soli (1964), when G. polyedra is stimulated to exhaustion of light emission. It was observed that the organisms could regain the ability to emit light if allowed to rest for a "suitable" period, but the time required for recovery to the initial state of luminescence depended upon the intensity of previously emitted luminescence. The stronger the stimulus, the greater the amount of reduced luciferin consumed and the longer the time required by the cell to resynthesise the compound back to the previous level, from basic materials produced during photosynthesis. That is, as noted by Seliger, Fastie, Taylor and McElroy (1962) light is required for the recovery of bioluminescence capability in certain bio-chemical systems, such as in the photosynthetic dinoflagellates, which prevents as fast a recovery as observed in heterotrophic forms such as Noctiluca.

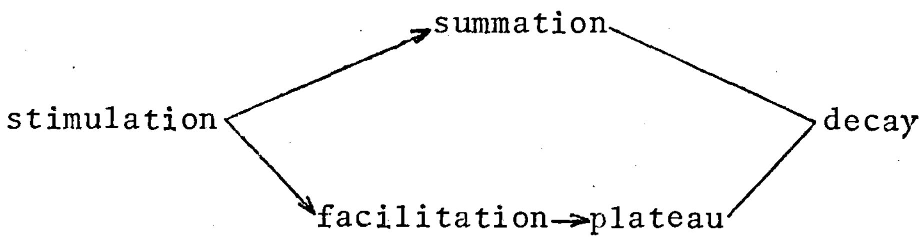
Brief consideration could be given to the luminescent zooplankton. David and Conover (1961) examined Metridia lucens, which produces external luminescence through the extrusion of a substrate and enzyme from glands. The duration of individual responses varies from 3-50 sec. for all luminescent responses with intensities between 10^{-3} and 10^{-4} $\mu W/cm^2$. There was no apparent relationship between the intensity of a luminescent emission and its duration. The animal recovers quickly, within 20 sec. of initial stimulation, but fatigues with repetitive stimulation : after four stimuli in 50 secs. the animal is no longer able to flash.

Further experimentation was conducted by Clarke et al (1962) who electrically stimulated the copepods M. lucens, M. longa and Pleuromamma robusta until luminescence ceased. They were allowed to rest and were then tested over the next 24 hours to determine when the ability to luminesce was recovered. From one to two hours there was no light; luminescence was largely restored eight to twenty four hours after exhaustion.

A pilchard shoal can be of varying size and shape, but in very general terms (see Section 4.2) a shoal may be between 10 and 60 m in diameter. The fish concentration is variable and may be 20 fish/m^3 on average, with certain parts of the shoal being more dense than others. The normal maximum swimming speed suggested for herring-like fish is 2 fish lengths / sec., which for S. ocellata is 0,5 m/sec. At this speed, the number of tail beats will be between 10 and 100/sec. The stimulus from the shoal to luminescent plankton comes not only from the turbulence associated with the tail beat but also from the turbulent flow along the fish and within its wake.

The stimulus from a shoal is thus virtually continous and random.

Assuming that a natural population of dinoflagellates behaved in a similar manner to *Noctiluca miliaris*, *G. monilata* or *G. polyedra*, and the copepods like *M. lucens*, *M. longa* and *P. robustus*, then, on the arrival of a shoal at a specific time and place, the plankton luminescent system would react as follows:



Due to the suggested continuous and random nature of the stimulation, summation and immediate decay is the more likely response, as observed by Plain and Plain (1963). To the aerial observer, therefore, any fish shoal should be bright along the leading edge where stimulation and summation of response is occurring, and then less bright to dark towards the trailing edge as decay in response occurs. The continuous stimulation will prevent any recovery during the period of the shoals passage (20-120) secs at the previously mentioned rates). Heterotrophic dinoflagellates such as *Noctiluca miliaris* can recover the ability to luminesce within a few minutes, but it has been suggested that if photosynthetic flagellates are stimulated to the point where the luminescent substrate is totally exhausted, it may require photosynthesis to restore luminescent capability (Seliger, Fastie, Taylor and McElroy 1962). The copepods will be exhausted and will require about eight hours to recover.

That the trailing edge is indistinct is an important factor in measurement, for if the rear portion of the shoal were only dimly (or non-) luminescent it is possible that it would be neither observed nor included in measurements. Roithmayr (1970) reported that thread herrings have a clear luminescent outline, in contrast with pilchards, and attempts have been made off South West Africa to determine whether or not there is a dark area in the trailing edge of a shoal where fish are present but invisible, or whether the luminescent area, however variable in brightness, contains all the fish.

One such experiment conducted in conjunction with RV Kuiseb on a relatively dense group of shoals indicated that the time at which fish shoals commenced to record on the vessels fish finding echo-sounder was also the time at which the aerial observer noted the ships entry into a luminescent shoal area. The aerial observations were communicated by radio and noted on the echo-sounder paper. Conversely, on one occasion when working with a group of fishing vessels on an extraordinarily large shoal, one vessel, F.V. Consortium Delta, which was being guided towards the shoal trailing edge reported fish on the echosounder before it was clearly visible to the aerial observer.

The results of the two observations are inconclusive : the results of the observations made on one occasion upon a number of shoals with R.V. Kuiseb may not represent the norm and the one observation made with F.V.Consortium Delta was made upon an atypically large shoal.

Various other attempts have been made to clear up this point. All failed, mostly due to a combination of factors involving the extreme difficulty of ensuring that the vessel and aircraft are in the right place at the right time for synchronous observation as the vessel enters a shoal.

Whilst it can be predicted that the trailing edge of a shoal will be less brightly luminescent through exhaustion of the luminescent systems in the plankton, it has yet to be proved that there is a dark area behind the shoal containing fish but being invisible to the eye.

1.4.2. Temporal and spatial variations in luminescent organism concentration.

The bioluminescence associated with fish shoals is observable all year round off the South West African coast. It has been demonstrated that an adequate concentration of luminescent organisms is present all year in certain areas. Staples (1966) has records of luminescence from all seasons off South West Africa, although his data are very sparse.

The literature contains numerous estimates of dinoflagellate concentrations in various parts of the world from unity to 30 million cells/litre. In general these are "spot" samples taken during a small scale investigation. Off South West Africa the estimates of dinoflagellate count are extremely variable. In order to reliably predict whether or not an adequate supply of bioluminescence exists for a given fish shoal in a given area requires observations of high resolution and precision and these do not exist in the literature.

The variations of luminescent emission caused by blooms has been demonstrated by Seliger, Fastie and McElroy (1961) in their study of Chesapeake Bay. Stimulated bioluminescence was measured with an in situ photometer on a transect from an inlet into Chesapeake Bay. The record is short, about 1 km in length and the bioluminescent emission was very variable. This non-random emission of light was attributed to the interception of blooms of luminescing organisms.

The dynamics of the plankton off South West Africa is not understood. Sampling intervals have been too long and, as phytoplankton cells respond to their environment very rapidly, conventional methods fail to study their dynamic ecology, particularly if the sampling interval is in terms of weeks or months. The most meaningful study should be throughout the 24 hour period. Thus, in the absence of specific data, it is conjectured that in the relatively homogeneous ocean off South West Africa the daily, weekly or seasonal succession of luminescent organism is such that patchiness will occur, allowing brighter response to shoals in certain areas. In an area where different water masses are present at frontal boundaries, quite dramatic differences in luminescent emission can be observed on either side of the front. Observations made off Cape Point have shown repeatedly that recently upwelled water is poorly luminescent, but other water inside the front is uniformly brilliant. Outside the front, depending upon circumstances, luminescence may be variable to nil. Thus patchiness can have an impact upon the observation of shoals in certain areas but there is insufficient data to predict its effect.

Data presented in previous sections indicates that luminescent forms are abundant in South West African waters and some of the variation in shoal illumination may be attributed to variation in luminescent organism biomass. However, other factors weigh more heavily, such as the position of the shoal in the water column, turbidity of the ocean and surface roughness. The effect of variation in plankton biomass on luminescence emission cannot be deduced.

1.4.3. Rhythms in luminescent activity

If the emission of bioluminescence is subject to variations in activity or strength on a rhythmic basis, then there is a possibility that during the period dusk to dawn there will be periods when the bioluminescence exhibited by a fish shoal is enhanced or inhibited, and its visibility to the aerial observer affected.

Rhythmic behaviour in luminescent organisms, particularly dinoflagellates, has been extensively studied *in situ* and in the laboratory. Hastings and Sweeney (1958) studied cultures of *Gonyaulax polyedra* exposed to varying light/dark regimes and concluded that the observed diurnal rhythmicity is the result of an endogenous oscillatory mechanism. *In situ* measurements by Backus, Yentsch and Wing (1961) of bioluminescence in the surface waters of the sea, displayed a pronounced diurnal rhythm particularily notable for the very rapid rate of increase of flashing 30 minutes after sunset.

These results were similar to those of Hastings and Sweeney (1958) and Sweeney, Haxo and Hastings (1959) in that a circadian rhythm of luminescence was evident. Backus *et al* postulated that inactivation of the bioluminescent system was caused by photo-inhibition, rather than an endogenous rhythm. Later, Yentsch, Backus and Wing (1964), again working *in situ* determined that the principal external factors influencing the light emission of dinoflagellates are photo-inhibition and photo-enhancement and that consideration of these two factors accurately predicts the vertical distribution of bioluminescence during daylight and darkness.

Backus, Clarke and Wing (1965) studies the effect of the solar eclipse of July 20 1963 on scattering layer and luminescent organisms, which responded to the eclipsing sun much as they do towards the setting sun. They suggested that considering this and their previous work, the exogenous factor of changing light level largely controls, the behaviour, over-riding the existing endogenous rhythms. However, Kelly (1968) pointed out that the organisms were brought in from daylight to darkness and were only able to recover from photo-inhibition by an amount determined by the endogenous rhythm reported by Hastings and Sweeney (1958). Had the eclipse been prolonged, recovery from photo-inhibition may have been complete and it may have become apparent that photo-inhibition of flash rate is not the only cause of daylight decrease in flashing rate.

Taylor, Seliger, Fastie and McElroy (1966) made observations on dinoflagellate populations with *Pyrodinium behamense* in a phosphorescent bay in Jamaica, where simultaneous *in situ* measurements of bioluminescence and cell count indicated that this dinoflagellate exhibits both a diurnal physiological rhythm in luminescence capacity and a diurnal vertical migration.

Kelly and Katona (1966) noted an endogenous rhythm of bioluminescence in a natural population of dinoflagellates near Woods Hole. The work was intended to bridge the gap between culture and *in situ* experiments by bringing a natural population into the laboratory for study. It was found that the flashing rates of populations maintained in darkness decreased during daylight hours, and that the effect of photo-inhibition on flashing was greater during daytime. Both dark-adapted flashing rates and the sensitivity to photo-inhibition are controlled by an endogenous diurnal rhythm. Thus Kelly and Katona suggest that the biochemical emission of light by dinoflagellates is accompanied by three controlling factors : first, the sensitivity to stimulus and an associated effector system; second, a mechanism whereby sensitivity to stimulus is controlled by light inhibition ; thirdly, an endogenous rhythm in luciferin production. Although these three factors control the emission of luminescence in the laboratory, luminescence *in vivo* may be subjected to variations other than those limited by exogenous effects or endogenous rhythms, because successions of species often occurs in the natural environment and these species may exhibit different characteristics. For example, in a hypothetical succession of *G. monilata* followed by *Noctiluca miliaris* it would be observed that the initially prevailing endogenous rhythm disappeard with time as *N. miliaris* displays no evidence of an endogenous rhythm controlling luminescence.

Seliger and McElroy (1968) continued their work on Oyster Bay, studying patterns of stimulable bioluminescence in *Pyrodinium bahamense*. A seasonal variation in the onset of the evening increase of stimulable luminescence activity was correlated with sunset time, and thus it is stated that in nature the nocturnal rhythm is entrained by the photoperiod.

Among the crustacea, Mauchline (1960) reported a diurnal rhythm for the Euphausiid *Meganyctiphanes norvegica*, which increased its flashing rate at night. Apart from the dinoflagellates, this is the only organism which is known to show an endogenous rhythm of luminescence.

The rhythmic oscillations in luminescence production can be summarised under four headings:

1. an endogenous rhythm of luciferin production,

2. a mechanism of sensitivity control by exogenous photo-inhibition,

3. an endogenous rhythm of sensitivity to stimulus,

4. the sensitivity-stimulus-endogenous rhythm is entrained by the photoperiod to allow for changing day length.

It is also possible that vertical migration of organisms may alter observed intensities.

However, these factors are unlikely to affect the detection of fish shoals in the ocean because the endogenous rhythms of luciferin production and sensitivity come into effect near dusk and dawn, as does the exogenous factor of photo-inhibition. Thus the bioluminescent system comes into action at dusk and ceases at dawn : apart from that reported by Soli (1966) there is no rhythmic diminution in intensity during the dark period. The effect of vertical migration observed by Soli (op.cit.) was possibly a function of the very shallow lagoon in which he worked. A migration of a few centimeters in the ocean would not be observed under any but the most turbid conditions.

The potential for locating fish shoals exists all night. At dusk, during the short period before the activation of the bioluminescent system, it would be impossible, in any case, to detect shoals as the level of background illumination is too high to detect the dim shoals. Backus, Yentsch and Wing (1961) demonstrate this very clearly in a figure describing the changes in light level at dusk.

Rhythms of bioluminescence have no effect on the ability to detect fish. In addition, the diurnal vertical migration of the fish shoals will not have brought them near the surface by dusk, so, even if the light level allowed, there is less likelihood of the fish being observed.

Suggestions have been made that by employing sophisticated filtering techniques it may be possible to detect bioluminescence during the day. In this case the rhythmic nature of bioluminescence, emission and the diurnal vertical migration of fish would effectively prevent such a technique from being successful.

1.4.4. Temperature effects

The physiological effect of temperature upon bioluminescent capability has been observed on both culture material and during *in situ* observations. *Per se*, temperature has no effect on luminescent ability as bioluminescence has been recorded in all waters from the coldest to the warmest. Bioluminescence has been observed within sea-ice, as the luminescent organisms within are stimulated by the impact of an ice-breaker (Staples 1966)

Sweeney and Hastings (1957) in their observations of diurnal rhythmicity in *Gonyaulax polyedra* noted that the natural period is a function of light and temperature. As the temperature is raised the natural period of luminescence becomes longer, but the difference was so small that, essentially, the rhythm was temperature-independent.

Seliger, Fastie, Taylor and McElroy (1962) observed that *P. bahamense* is very temperature sensitive. The normal temperature of Oyster Bay during summer is 27-28^{o}C and it was observed that no bioluminescence occurred if the temperature fell below 24^{o}C. A similar observation was made by Yentsch and Laird (1968) during their studies off Woods Hole between 1961-63. The endogenous rhythms that were apparent in summer disappeared when water temperatures fell below 14^{o}C.

The water temperatures off South West Africa do not display great seasonal variation except in enclosed areas in summer. Then, however, a succession of massive dinoflagellate blooms has been observed which would significantly contribute to the luminescence potential. The differing ocean regimes off South West Africa possess their own luminescent fauna and flora and as changes in temperature are usually caused by water-mass movement, it is likely that there will be a continuity of potential for luminescence at all times, although not necessarily at the same level.

1.5. DIURNAL VERTICAL MIGRATION OF PILCHARDS

The limiting depth at which a fish shoal can be detected from the air is determined by its contrast with background. If it is assumed that a fish shoal with an irradiance equal to that of background can be detected (i.e. the irradiances are additive and produce a signal-to-noise ratio of 2) then the depth beyond which the shoal would become invisible due to the attenuation of luminescence can be given by the expression: (Drennan 1971)

$$H\ R_s = We^{-KD}$$

where H = scene incident irradiance (sky light)

R_s = reflectance of the sea surface

W = bioluminescent irradiance

e^{-KD} = transmittance of water (D = depth in meter)

An estimate of this depth can be made from data collected experimentally off South West Africa, combined with calculations based upon experimental data.

The expression HR_s (scene incident irradiance multiplied by a factor for surface reflectance) is actually background as observed by the radiometer used in the measurements of shoal irradiance, the mean value being $1,3\text{x}10^{-6}$ $\mu W/cm^2$. W, the bioluminescent irradiance of fish shoals, was calculated from the mean value of dinoflagellate luminescence irradiance values from Table 9 (Section 1.3) namely $5,3\text{x}10^{-9}$ $\mu W/cm^2$ at 1 meter, and a range of values of dinoflagellate concentrations from (section 1.3). The extinction coefficient (K) is derived from research cruises off South West Africa. It should be pointed out that a trade-off exists between numbers of dinoflagellates and the transmission of light through the water in which they occur : the more turbid the water the greater the attenuation. The bloom recorded as 30 x 10^6 cells/m^3 had an extinction coefficient of K=0,98. Therefore, the larger values of cell count have been omitted from the values substituted in the above equation, whose results are displayed in Table 11.

Agenbag (1973) continuing work commenced by the author, reported on the diurnal vertical migration of pilchard shoals. The work commenced in 1970 as a study of the depth and thickness of shoals recorded on the echosounders of vessels involved in aerial/acoustic fish shoal research. A total of 3 931 shoals were observed at the following times : September 1970 (277), October 1970 (362), November 1970 (238), December 1970 (399), October 1971 (259), November 1971 (264), December 1971 (322), January 1972 (1 237), February 1972 (573). The distribution of data is biased towards the summer months, when aerial/acoustic surveys occur, but within those periods the data is well spread over time. Depth measurements were tabulated under hourly headings, where each heading covered the interval minus thirty to plus twenty-nine minutes about each hour (Table 12).

The average depth for each interval was then plotted against time (Fig. 8).

TABLE 11. Depth at which shoals are visible : Background constant 1,3x10^{-6} $\mu W/cm^2$, emission of individual bioluminescence constant 5,3x10^{-9} $\mu W/cm^2$, extinction co-efficient most likely to be observed.

Plankton Population x 10^9 cells/metre cubed	Extinction co-efficient	Depth at which shoal would be visible (m)
0,03	0,3	8,3
0,10		12,3
0,22	0,4	11,2
0,50		13,3
1,25	0,5	12,5
1,26		13,0

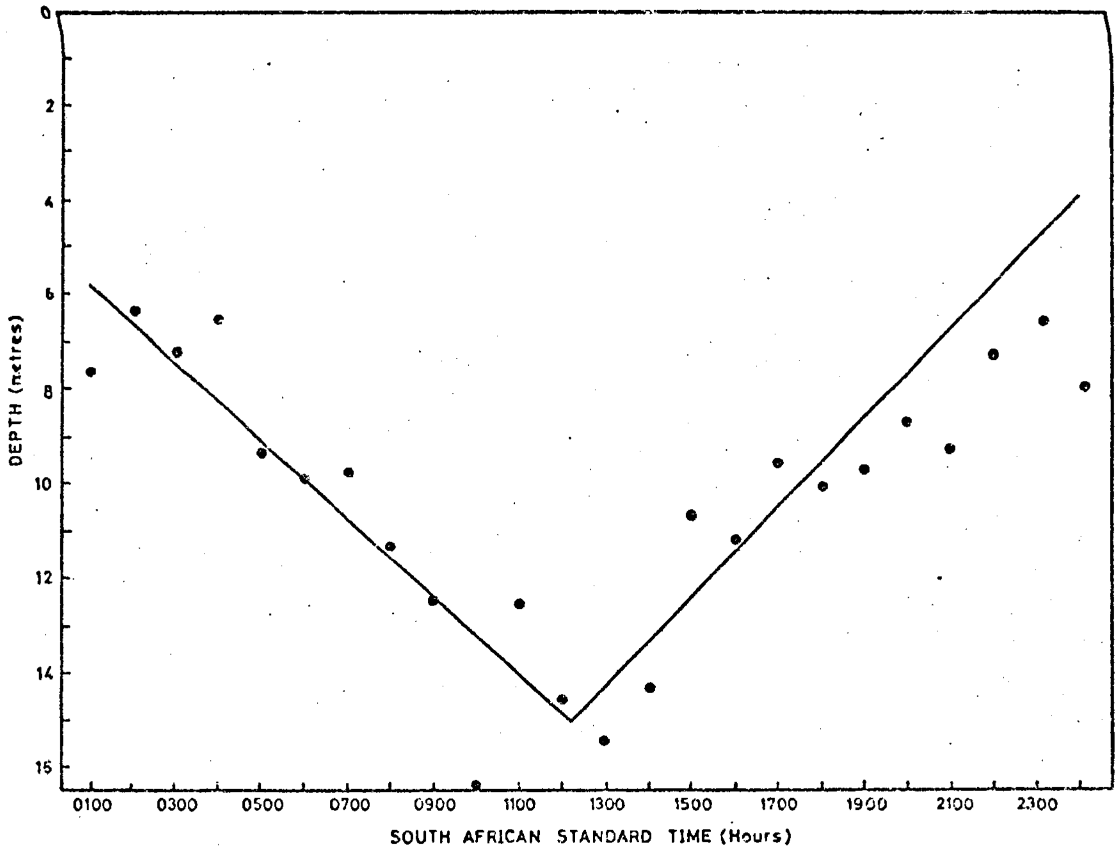


FIGURE 8. Vertical migration of pelagic fish shoals during 24 hour period. (Agenbag 1973)

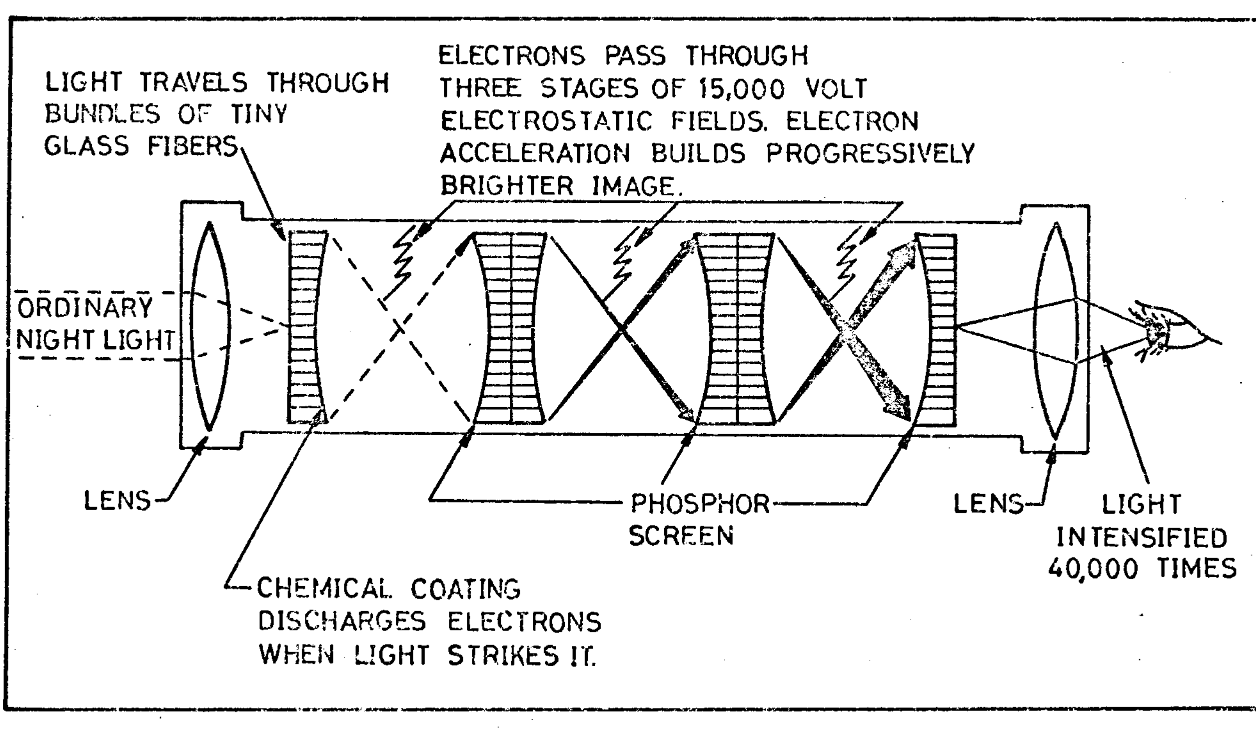


FIGURE 9. Three-stage cascaded image intensifier (RCA 1972).

TABLE 12.

Extract from Agenbag (1973) (Table 1) to show depth of tops of shoals at night.

TIME	NO. OF OBS.	AVERAGE DEPTH TO TOP OF SHOAL (m)	SD (m)
2000	175	8.8	6.5
2100	144	9.4	6.9
2200	242	7.4	6.2
2300	190	6.7	4.6
2400	169	8.0	6.9
0100	123	7.6	6.8
0200	198	6.3	3.9
0300	162	7.2	4.5
0400	188	6.5	3.4
0500	165	9.8	7.8

Although the curve is sinusiodal, Agenbag did not attempt to fit the curves to a trigonometric function, as all that was being demonstrated was that the depth to the top of shoals varies during the night. Separate regression curves were fitted to the data points in the intervals 0100 to 1200 hrs and 1300 to 2400 hrs. Linear correlation co-efficients for these curves were 0,92 and 0,91 respectively. The graph in Fig. 8 illustrates the tendency of shoals to migrate to greater depths during the day, reaching a maximum around midday. The depths were measured from the transducer level : consequently, the distance from the surface to the transducer has to be added in order to obtain the true depth below the surface. The draught of the vessels ranged from 2,6 to 3,0m, so adding 3,0m to the values in Table 12 and Fig. 8, gives a maximum average depth of 18-19m. and a minimum depth of 3 + 6,3m, S.D.3,9 at 0200 hrs. The night-time value is biased against shallow shoals which were near or above the transducer and would thus not be recorded. Visual observations have confirmed that shoals are present at the surface on many occasions.

Apart from Drennan's calculation, modified for the Benguela Current System (average conditions D=10,8m, turbid conditions D=8,6m), the maximum depth to which fish shoals can be seen from the air is unknown, since no event has been scientifically reported of a shoal being present on an echo-sounder but invisible to the eye or observing equipment, except for one instance when an abnormally large shoal was partly invisible from the air. Other factors such as exhaustion of the bioluminescent system may have operated in this instance.

Available survey information indicates that shoals are generally visible to 12m which is supported by the calculated values in Table 11 : for the period normally used for fish-spotting (2000 - 0500 hrs). 74% of the shoals will be visible. This is an underestimate due to bias as, apart from shoals being shallower than the transducer, the actual depth to which shoals can be seen on any one survey is unknown. Fish shoals have been reliably recorded as visible to 16m.

The pattern of diurnal migration demonstrated is often distorted through change imposed by short-term environmental conditions, but was nevertheless observable in all nine seperate months data.

2.0 THE DEVELOPMENT OF A QUANTITATIVE APPROACH TO AERIAL OBSERVATIONS OF FISH SHOALS.

Within the worlds pelagic fisheries, visual sighting has always played a vital role in the searching and catching process, both during the day and at night. The use of the bioluminescence caused by fish shoals as an aid to tactics is well known and reported for most pelagic fisheries, for example the California sardine fishery (Higgins and Holmes 1921, Scofield 1929) and other pelagic fish (Squire 1972), for the U.S. tuna fleet (Green, Perrin and Petrich 1971) and in South Africa since the inception of the pelagic industry in 1944 (Table 13). The costs in time spent in searching for pelagic fish is considerable: Norton (1969) reported that the U.S. tuna fleet spent 75% of its time in searching. At this level of cost it must have seemed obvious to increase the searching power of vessels and the next stop from masthead is to aircraft.

Aerial assistance in fishing activity can be considered either as "aerial scouting" or as "fishspotting". Aerial scouting is defined as the location of fish shoals over a wide area, after which the information is fed back to a fishing fleet control centre as a basis for strategic deployment of the entire fleet. Fishspotting is defined as the location of shoals in the vicinity of fishing vessels, followed by tactical assistance in directing the vessels to the shoals, possibly with the provision of advisory information on when to commence the fishing operation.

TABLE 13. SUMMARY OF COMMERCIAL FISHES DETECTED BY LUMINESCENCE (ROITHMAYR 1970)

	East Pacific	West Africa	Gulf of Mexico	Gulf of Maine
Coastal:	Sardine (Sardinops caerulea)	sardine (Sardinella aurita)	thread herring (Opisthonema oglinum)	herring (Clupea harengus)
	anchovy (Engraulis mordax)	herring (Sardinella eba)	Spanish mackerel (Scomberomorus maculatus	mackerel (Scomber scombrus)
	mackerel (Scomber japonicus)	mackerel (Scomberomorus) maculatus	bluefish (Pomatomus saltatrix)	butterfish (Poronotus triacanthus)
	smelt (Atherinopsis californiensis		menhaden (Prevoortia patronus)	menhaden (Brevoortia tyrannus)
	saury (Cololabis saira)		ladyfish (Elops saurus)	
	jack mackerel (Trachurus symmetricus)		bluerunner (Caranx crysos)	
			tarpon (Megalops atlantica)	
Oceanic:	bluefin (Thunnus thynnus)	yellowfin (Thunnus albacares)		
	yellowfin (Thunnus albacares)	skipjack (Katsuwonus pelamis)		
	skipjack (Katsuwonus pelamis)			

	Mediterranean Sea	Caribbean Sea	Australia	North Sea	Indian Ocean	South Africa	Philippine Islands
Coastal:	sardine (Sardinella aurita)	sardine (Sardinella either anchovia or brasiliensis)	pilchard (Sardinops pilchardus)	herring (Clupea harengus)	mackerel (Rastrelliger kanagurta)	pilchard (Sardinops ocellata)	sardine (Sardinella fimbriata)
	mackerel (Scomber scombrus					maashanker (Trachurus trachurus	

The earliest record which refers to aerial assistance was a successful operation in the California sardine industry in December 1919 (Anon.1919). This was followed by fishspotting exercise for the entire 1920 menhaden season in Chesapeake Bay (Harrison 1931) which was so successful that the Navy aircraft was withdrawn as it was felt that the point was proven, and that the industry should take over the operation. From then until after 1944 "the use of airplanes to locate schools of fish on the West Coast has been tried intermittently with partial success only." (Scofield 1951).

World War II brought about tremendous development in aircraft technology which changed the pattern of private ownership of aircraft. A period of rapid growth in aerial work then increased. Squire (1961) refers to the activity of 70 commercial spotters in North America, covering the tuna, California pelagic industry, herring, menhaden and salmon fisheries.

In other parts of the world aircraft were successfully used, for example in USSR (Marty 1965,Maslov 1968), Australia (Anon 1963), New Zealand (Anon 1965) and South America (Sams 1971). In South Africa, aerial scouting is a relatively new phenomenon (Anon 1968) despite some early flights in the St. Helena Bay area in 1955 (Marchand, Sea Fisheries Branch Correspondence files). Development was rapid from 1967 and the aerial scouting service is regarded as highly beneficial to the Industry.

The literature does not contain many references to the cost-benefit of aircraft operations, Norton (op. cit) being one of the best. Jones and Sund (1967) examined the efficiency of aircraft search power in comparison with a ship by conducting searches and experiments with tuna shoals and "working" birds under various weather conditions. They concluded that an aircraft would locate about nine times the number of tuna schools located from a ship.

Thus, the use of aircraft for qualitative observations of fish shoals has been well established and widespread for the last fifty years. Undoubtedly, there will have been much thought as to how to involve aircraft in quantitative observations, but the literature is scanty and began to appear mostly from 1968 onwards. Sette (1949) reports that he personally investigated the possibility of estimating abundance by searching for shoals of pilchard from aircraft off Southern California. These investigations were unsuccessful, as the attempts at quantification were less reliable than actual fishing, although Sette was aware of some of the advantages of aerial estimates of abundance for he states"it is desirable to have some way of estimating abundance that would be free of the availability influence".

Cushing, Devold, Marr and Kristjonsson (1952) in their extensive review of (then) modern methods of fish location refer also to the qualitative and apparent financial advantages of aerial scouting and fishspotting. Indeed, they felt that the use of aerial scouting as a research tool had been little investigated and that the potential in this field might be great.

Aerial surveys have been conducted in Canada on the herring spawning grounds of the Queen Charlotte Islands (Outram 1962). The method used was highly original: assuming that estimates of the amount of spawn deposited gives an indication of spawning stock size, the area of sea occupied by milt-laden water was estimated from the air. Herring spawn is attached by benthic flora but the whitish coloured milt is clearly seen in the water, persisting over a few days. The extent of spawn was measured in miles of coastline. Although moving in the direction of quantifying aerial observations of stock size this work did not result in any estimate of stock size being produced.

In 1962 a pelagic fish monitoring programme was initiated in southern and central California utilising six fishspotter pilots to provide information which could be processed to give an index of apparent abundance of all species of shoal-fish seen (Squire 1965).

In 1966, the first of a series of aerial investigations of surface shoaling fish was commenced from the Bureau of Commercial Fisheries (BCF) Exploratory Fishing and Gear research base at Pascagoula, Miss. USA (Bullis 1968, Bullis and Pease 1968). Continuing these studies, Pease and Drennan (1969) observed that to assess widespread pelagic resources it was necessary to survey wide areas in relatively short periods of time, collecting information on location, identity and size of pelagic shoals. To this end, multispectral photographs and spectroradiometric measurements were made on numerous fish shoals in the East and Northern Gulf of Mexico to determine the spectral characteristics of different species. This work was anticipated to lead to identification of shoals by aerial photography or other remote-sensing techniques and to determine their distribution. In order to collect sufficient ground truth information with which to interpret the fish shoal photography, the BCF Base established a Fishery Resources Assessment Programme based on aerial photography, SONAR equipped research vessels and commercial fishing vessels, with the objective of studying a method of fish stock assessment which would permit a regular and timely dissemination of information on the "availability" of a particular fish to commercial fishermen. The programme involved the location and photography of a fish shoal followed by SONAR (echosounder) examination to determine the vertical profile followed by catching of the entire shoal. The objects of the experiment were only generally stated but presumably were to establish a relationship between shoal surface area and weight. No results were available, but the direction of future research was clearly indicated.

Drennan (1969) having reported the first known efforts to use low-light-level sensors to detect the luminescence caused by plankton when disturbed by fish, followed-up with a review of potential applications of remote sensing including an extensive section on bioluminescence and its detection (Drennan 1971). In detecting bioluminescence, the type of sensors described by Roithmayr (1970) and others commercially available with a brightness gain of about 75 000, provide numerous advantages:

1. they permit the use of optical objectives that are much larger than the dark adapted eye pupil without reduction in the angular field of view, thus allowing more light to be collected.

2. the best photocathode materials have a quantum efficiency (capability of converting photons into visible information) of 0,20 for white light, thus improving on the eye whichhas a quantum efficiency of 0,05;

3. with suitable modification, the output of an image intensifier can be sensed by an image tube of a TV camera producing good quality video images.

Contrast, or brightness relative to ambient light conditions, is important and sufficient contrast must exist between the shoal and water for it to be detectable. If it is assumed that a target with an intensity equal to that of background can be detected, then the depth beyond which the luminescent signal would be attenuated to an undetectable level can be calculated at 16,07 metres. Drennan decided therefore that the use of low-light-level sensors to detect bioluminescence stimulated by fish shoals has potential application in quantitative aspects of fisheries research.

Drennan was one of the NMFS scientists working at the Exploratory Fishing and Gear Research Base at Pascagoula Mississippi(in conjunction with the National Environment Statellite Service Spacecraft Oceanography Project) who initiated the testing of low-light-level sensors in late 1968. The first test used the "Starlight Scope", developed by the U.S. Army Night Vision Laboratory. The scope is a three stage, cascaded, electrostatically focussed intensifier with objective and eyepiece lenses (Fig. 9). For the tests reported by Roithmayr (1970) conducted in October 1968 off Port St. Joe, Florida, the Starlight Scope was coupled to a closed circuit

TV camera (CCTV). For the test, conducted aboard a commercial seiner. Spanish mackerel were first trapped by the net then examined by the CCTV/Scope. The fish were visible from about 15 meters and were between 1,5 and 3,0 meters below the sea surface: the fish were individually visible through their luminescent outline (Fig. 10).

At the end of 1968 and early 1969, tests were conducted off Florida using a different scope called the stabilised airbone night observation system (SANOS) mounted in a Grumman Albatross and a helicopter. A commercial day fishspotter was chartered to locate schools of fish to reduce flying time of the expensive survey aircraft. Thread herring shoals were located on videotape from an altitude of 1 070 meters. The school was approximately 152 meters in diameter (Fig. 11). Other schools of 150 to 300 meters wide were located on succeeding nights.

This feasibility study demonstrated several facts:

1. that bioluminescence associates with fish schools makes them conspicuous at night;

2. that the perimeter of a school is well defined;

3. that schools can be detected with sensor/camera from 1 500 meter, and recorded on videotape.

As a result, the principle of image collection was proven and the project was taken over by the NMFS Fishery Engineering Laboratory at the National Space Technology Laboratory (NSTL). During the Fishery Engineering Laboratory initial study, a comprehensive project plan was drawn up for the development of an operational system.

FIGURE 10. Spanish mackerel (Starlight Scope & video monitor. Fish 1,5 23,0 below surface. (Roithmayr and Wittmann 1972)

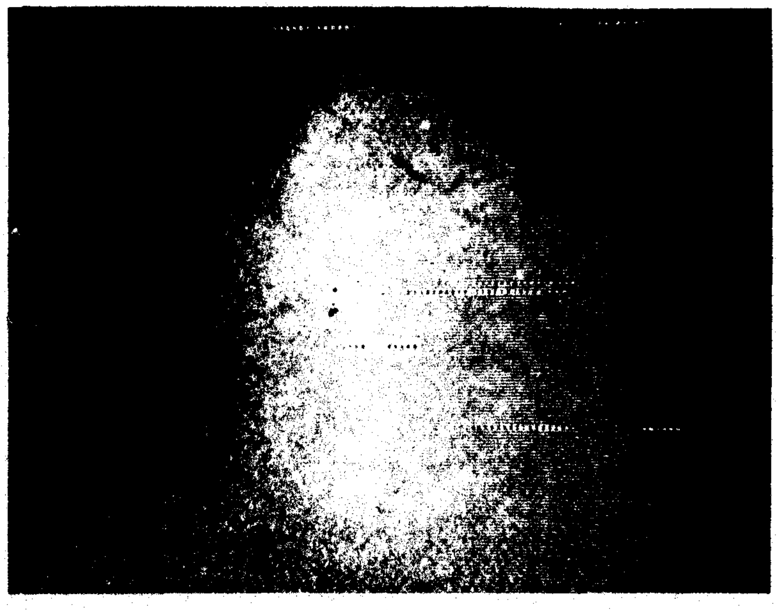


FIGURE 11. Thread herring shoal 182 m in diameter (Night Ovservation Device). Altitude 1070 m. (Roithmayr 1970).

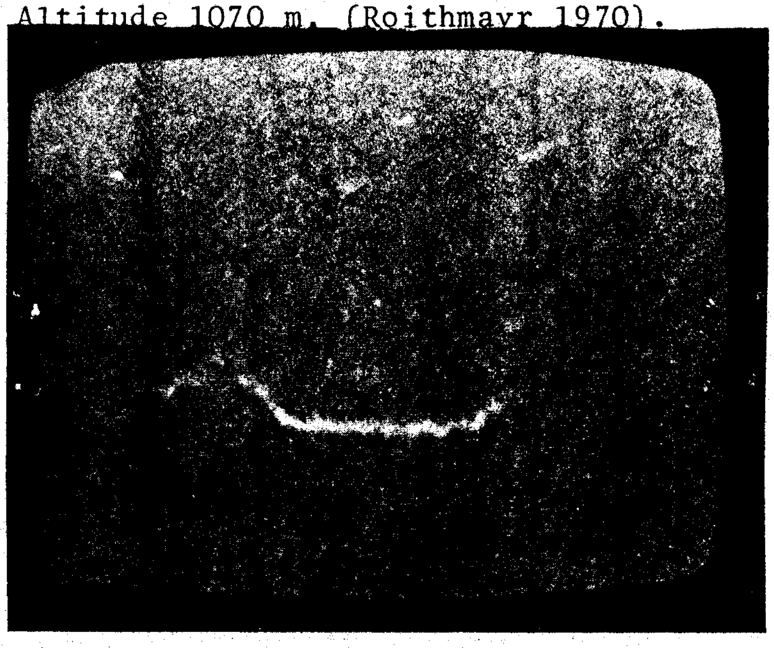


FIGURE 12. Gulf menhaden (Low light level TV) Altitude 1 000 m. (Roithmayr & Wittmann 1973).

Consistent with this project plan, FEL staff leased a night observation device (NOD) for testing purposes and used it with the CCTV used in the Pascagoula tests. The results of the first tests were considered marginal as instrument limitations severely affected the operation: the system field-of-view was too limited, the system was too bulky and it had a poor dynamic range.

During July 1971 field tests commenced on a prototype operational system which included a leased RCA low-light-level TV camera, an RCA five-inch TV monitor, half-inch Sony Videotape recorder and a 250 watt 24 vDC : 115 vAC inverter. The system was mounted on seat rails and the camera viewed the sea surfact through a hole in the floor via a front-surface mirror mounted on the camera rack. An f1,2 55 mm lens was selected for the system as it gave maximum contrast and resolution whilst permitting objects of interest to remain in the field of view sufficiently long.

The first operational test was conducted near Seattle, Wash. in conjunction with the Seattle NMFS and its research vessel John N. Cobb. The object of the flights was to detect saury shoals along the Vancouver, British Columbia and Californian-Oregon border coast. The operation consisted of two phases due to conditions of moon. The first phase was unsuccessful in that no saury shoals were observed by either the aircraft or ship. However the TV system functioned perfectly, although certain changes were required. These minor modifications were accomplished and with favourable biological conditions the second phase was successful as saury, anchovy and euphausiid swarms were observed and their images recorded on videotape.

The identity of the schools or swarms was confirmed by a research vessel.

Later in 1971, the NMFS system was used in the Mississippi Sound to attempt the detection of menhaden (Roithmayr and Wittman 1973). These, together with another later series of flights in the Gulf of Mexico were designed for co-operative work with a commercial fishing vessel. Three large concentrations of menhaden shoals were located and on one night over one thousand shoals were observed. These results indicated that the TV sensor detected shoals invisible to the naked eye and could record them for later analysis (Fig. 12).

Following another test flight in 1972, the NMFS participated in the ERTS-A satellite programme from July- October 1972. The overall objective of the NMFS ERTS-A experiment was to demonstrate the feasibility of utilising satellite imagery for determining the availability and distribution of living marine resources. The experimental approach used was to convert satelline and aircraft remotely sensed data into oceanographic parameters, relate these parameters to the fishery resource and then determine if the relationships have meaning in terms of the commercial fisheries and their management. From the low-light-level TV side the results were most encouraging with 4 274 individual sightings of shoals observed, measured, recorded and entered into a data bank.

The RCA system ultimately purchased by the NMFS was used on a pilot project in the detection of herring shoals off Scotland in 1973. Twelve flights were made giving forty hours of search time, and bioluminescence was detected on seven flights with a total of 1 000 shoals sighted, of which perhaps half were seen twice due to poor navigation. Herring were positively identified on two occasions in the presence of fishing vessels - one of which proved that luminescence was visible to sixteen meters. The shape of a pair-trawl was seen twice. The exercise was determined to be successful as TV proved to be an aid in the location of herring shoals.

Thus two potential avenues are open for quantified observations of fish shoals, firstly the use of data collected by commercial fishspotters whilst carrying out a commercial operation analogous to the log-sheets completed by fishing skippers and second, the use of remote sensing devices, particularly electronoptical. Both types of system have been used : the former in California and the latter in South Africa and, to a limited extent, in the USA.

2.1. MEASURES OF PELAGIC FISH APPARENT ABUNDANCE BY AERIAL FISHSPOTTER OBSERVATION.

The first recorded estimate of fish abundance from aerial observations was published by Squire (1972) using commercial fishspotting data collected on a cooperative programme by certain spotters contracted to the Tiburon Marine Laboratory. There are a number of variables that affect the statistical accuracy of fishspotter data which are difficult to evaluate, such as individual differences in their ability to locate fish, determine species and estimate shoal size and estimate total tonnage available in a single area. However Squire was satisfied that since at least five experienced observers were used in the programme each year he was able to assume that reasonable annual averages were obtained. Squire analysed spotter data acquired from September 1962 to December 1969 to determine if it could be used:

1. to compute an accurate undex of apparent abundance;
2. to obtain a trend in apparent abundance of pelagic fishes, and in particular those of the under-utilised species.

The method used has the great advantage of simplicity. The coast of California was divided into zones consisting of "block areas" of 10 min. Lat. x 10 min. long. During the survey years 17 593 hours of flying were logged, covering 37 186 block areas in day and 20 442 at night.

To determine criteria concerning the frequency of observation during the day and night for each of the species more commonly observed, the ratios in numbers of sightings and tonnages observed were calculated for the period September 1962 to December 1966. Information on the diurnal and nocturnal frequencies and magnitude of occurrence of each species is of importance in evaluating which observation, day or night, might be more important in discerning the trend of apparent abundance. The amount of fish spotted during 1962-1966 was considerable: 5 289 521 tons of anchovy, jack mackerel, bonito, mackerel and yellowtail. The trend in sightings of each species per year was obtained by expressing the number of sightings as a percentage of all block area flights. In calculating the index of abundance, four arbitary tonnage ranges were selected for each species, to cover the entire range of observed tonnages. The mid-point tonnage was divided by 100 for anchovy and 10 for Pacific bonito, jack mackerel, Pacific mackerel and Pacific sardine to provide a tonnage range value (X) of convenient size for the formula

$$\text{Index}_{\substack{\text{species}\\ \text{zone}}} = \frac{N_1X_1 + N_2X_2 + N_3X_3 + N_4X_4}{N_t}$$

Where $N_{1,2,3,4}$ = number of block area flights in which species occurred at values $X_{1,2,3,4}$

$X_{1,2,3,4}$ = tonnage ranges

N_t = total number of block area flights in zone per year.

The data demonstrates that for 1962-66 the northern anchovy, jack mackerel, Pacific mackerel, Pacific sardine were observed more frequently and in greater abundance at night. Pacific bonito and yellowtail were observed more frequently and in greater abundance during the day.

The data on index of abundance and certain of the commercial catch data display a similarity of trends. The relationship between the index and the trend of abundance estimates followed the declining trend of spawning biomass of Pacific mackerel (84%) from 1963-68 with index decline of 89% from 1963-66. The jack mackerel abundance has been estimated from egg and larval surveys from 1951-54 as 1,4 - 2,4 million tons. In 1968 the population was estimated as being the same. However the commercial fishery experienced a decline, which was only much later detected in more conventional data. The history of the Californian sardine is well known for its cycle of exploitation and over-exploitation. The end of the over-exploitation cycle is clearly shown by the night and day indices in Fig. 13.

Squire believed that, like all other methods then available, the true relation of the index of apparent abundance to the abundance cannot be determined. However the value of the index in descerning trends is undisputable. The index shows little effect of fluctuation in economic demand : trends in the apparent abundance within the survey area are apparent before they are reflected in the catch. The pacific mackerel has a number of reliable population size estimates and the trend in the index closely agrees with the declining trend in population size. It therefore appears that this simple semi-quantitative index is useful in the evaluation of catch variation and long-term trends in total abundance in exploited and extent pelagic resources.

The value of semi-quantitative spotter data to fisheries research has been proved in California. This original

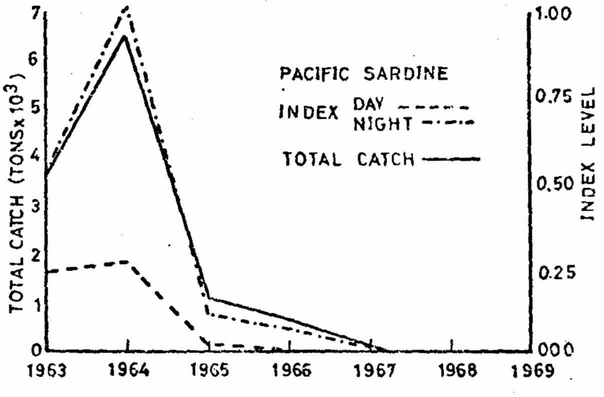


FIGURE 13. Total catch and average index value for the Pacific sardine. (Squire 1972)

application of fishery data is regarded by many scientists in CALCOFI as the best index of abundance of pelagic fish in existance. In consequence, methods of reducing bias through subjectivity by spotters are being worked-out, together with methods of using the data or the overall method to produce quantities instead of indices.

Having not had a spotter programme of the California variety with which to work, the attitude here was to use aircraft and to make quantified observations right from the start. Unlike the spotter programme, which involves both day and night observations, the method described here only utilises night-time observations of bioluminescence excited by pilchard shoals.

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It was found almost immediately that this was of no practical value due to the large range of sizes and large number of shoals involved, for it was not possible to group the shoals in categories without measurement and one was never certain which shoals had been counted and which had not, as the area containing the shoals was repeatedly traversed.

Although such observations were useful, they did not assist in achieving the primary objective and steps were taken to acquire an image intensifier with which to attempt low-light television observations.

2.2.2 OBSERVATIONS WITH IMAGE INTENSIFIERS

An image intensifier is an electro-optic device which "magnifies" or intensifies light (Figures 9 & 14). The brightness gain is defined as the ratio of apparent brightness when looking through the system to the natural brightness of the scene, and is often between 30 - 50 000.

First generation intensifiers such as "Lolite" consists basically of three components (Figure 9): an objective lens, the three-stage, cascaded image tubes and an eyepiece lens. When very faint light is collected by the objective, it is focussed onto the fibre-optic plate of the first stage of the image tube. These closely packed fibre optic rods conduct the light to the curved photocathode from which electrons are emitted in proportion to arriving photons. The electrons leaving the photocathode are accelerated by an electrostatic field, usually of around 15kV and focussed upon a phosphor screen where the kinetic energy of the electrons is transformed into visible light. This light is passed through

FIGURE 14. Image intensifier, P.P.E. "Lolite". Photo Philip Micheu.

another fibre-optic plate onto the photocathode of the next stage where the process is repeated through to the third stage. At the third stage, the image formed on the phosphor screen is viewed through an eyepiece lens. The amount of light amplification factor is not the criterion of efficiency, for greater gain does not necessarily mean that the low-light-level scene becomes more visible. The collecting power and transmission quality of the objective lens are of primary importance, for the image tube can only amplify what light is collected. A fast lens and high transmissivity are required. In the image tube, the efficiency of the transfer of energy, the distortion and contrast losses from stage to stage, and the degree of random photon "noise" of the photocathodes and phosphors place a lower limit on the ability to perceive a low light level scene. The image intensifier shown in Fig. 14, has an 0,74 lens of focal length 64mm and 86mm diameter. This extremely fast lens has 4 x the light-gathering capacity of an f1,0 lens.

The first intensifier used for observation of fish shoals was of low quality: the image tube was low grade and the lens was a multi-element zoom lens. It was purchased in order to link it with a TV camera for recording shoal images. It failed to work in an operational mode due to contrast loss, excessive noise and very poor performance on a moving scene. Although tested, the TV camera system was never used: the image intensifier was used alone.

The Lolite (Fig. 14) produces images of shoals which are very clear to the eye, having good resolution (0,4 milliradians) and light collecting capacity. The sub-structure of shoals, where any, is clearly visible and in most cases the entire periphery of a shoal is visible. No photographs have been produced from the tube and no permanent images are obtainable.

2.2.3 OBSERVATIONS WITH LOW LIGHT LEVEL TELEVISION

Interest thus turned towards low-light-level television cameras. In 1971, contact was made with the manufacturers of low-light-level TV systems and numerous demonstrations were requested. Probably due to the military nature of the equipment under discussion, of the five manufacturers contacted, only one was prepared to demonstrate, Bosch Fernseh of Darmstadt, Germany.

The first camera used operationally was a secondary electron conduction (SEC) vidicon system. The SEC vidicon TV camera was one of the early hopes for military applications of detecting objects at night. The system used to detect fish shoals consisted of an intensified SEC image tube which is a SEC tube with one stage of an image intensifier in front. This combination gives very high sensitivity, low lag and is very robust. Fig. 15 shows a diagram of the tube and intensifier, and a short description of its operation will be given as this is relevant to the choice of TV system for shoal detection. After the collected light has been intensified (80x) it passes through the fibre-optic plates of the intensifier/image tube junction and strikes the photocathode of the image tube. Here, as before, photo-electrons are emitted which are electrostatically focussed onto the target of the SEC camera. These electrons dissipate their energy within the fibrous KCI target by the generation of secondary electrons which, under the influence of an electrostatic field, migrate towards the

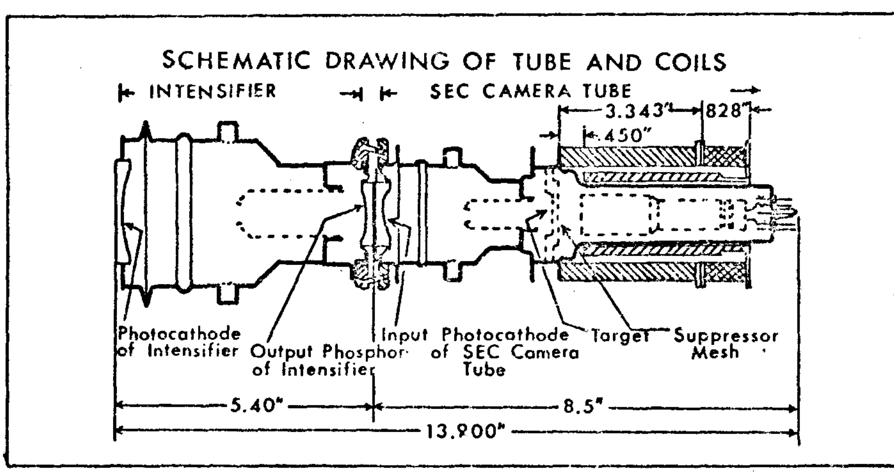


FIGURE 15. Intensified SEC tube (from Westinghouse TD 86 - 827)

inner edge of the target and there create a positively charged pattern corresponding in spatial distribution and intensity to the optical image focussed onto the faceplate of the first intensifier. The important feature of the SEC tube is that the secondary electrons are accelerated within the target by the electrostatic field, so additional light gain is obtained. The positive charge image on the target is "read" by an electron beam at regular intervals: electrons are deposited on the positively charged target in a regular scanning procedure, where the deposition of electrons creates a current pulse, which after amplification, produces the video-signal which can be used to produce a video picture on a TV monitor. These camera tubes have high sensitivity and can resolve moving scenes well. Due to the electrostatic properties of the KCI target, more than 90% of the positive charge image is "read" on the first scan of the electron gun which means that there is almost no residual image left for subsequent scans to read out. Thus there is little blurring of a moving low-light-level scene. A further important property of the SEC target is that its low-contrast sensitivity is very good. Fish shoals are low-light-level targets with low contrast at times and ability to resolve low contrast scenes becomes important. The internal electronic noise is low, giving a very good signal-to-noise ratio in the videosignal. The disadvantage of these tubes is that when subjected to bright scenes such as illuminated fishing vessels on a dark ocean the bright image is permanently burnt onto the target, reducing the performance of the tube considerably.

The second type of tube tested was the electron bombardment silicon (EBS) target vidicon, and this was the type eventually purchased. The general arrangement of the intensified EBS tube is very similar to that of the intensifier SEC except for the structure of the target. The target consists of a two-dimensional array of diodes formed on a silicon wafer about 15 μ thick. The target consists of different silicon structures laid down in a sandwich form which is then etched in a grid to form "islands" of differing structures of silicon, the diodes. The target is situated with the diodes facing the electron gun. The incoming photooelectrons discharge the diodes, and the videosignal is formed by recharging them with the reading beam. The EBS target is extremely sensitive and is capable of detecting extremely low light level scenes. However, its dynamic resolution is poor: the electron gun cannot "read" all the charge pattern on the target at one scan, a significant proportion remaining to be read out with succeeding scans. Thus moving images appear blurred or leave a smear behind them if they are bright. In addition, the signal-to-noise ratio in the videosignal is lower than the SEC tube. However, the EBS tube is virtually incapable of damage through burning and can thus be more confidently used in areas where high illumination levels can be anticipated from ships.

These characteristics of the two types of tube have been observed in practice and it has been found that the advantage of being able to obtain images for light levels below the detection limit of the SEC tube is at least partly offset by the lag and noise distortion in the EBS signal (Table 14). However, as the EBS system is more sensitive and robust it was decided to purchase a camera with this type of tube.

TABLE 14. COMPARISON OF FERNSEH CAMERAS USED UNDER TEST. NOTE THAT THE EBS SYSTEM HAS 30x GREATER SENSITIVITY THAN SEC.

Camera body	Image Intensifier	Camera tube	Lens			Tube sensitivity
			f no.	focal l.	f.o.v.	
Fernseh TV720	West'hse WL-30677	West'hse SEC WL-30691	1.0	70 mm	$16^o x 22^o$	15 000 μA/1m
TV720	WL-30677	EBS WX-31792	1.0	70 mm	$16^o x 22^o$	420 000 μA/1m

The camera has been extensively used in field tests and functions satisfactorily. However, when the low-light-level TV is used over fish shoals it will not only receive radiation emitted by the plankton but also ambient radiation reflected from the surface of the sea. So as to isolate the radiation of the plankton and improve the signal-to-noise ratio of the shoal image, it was decided to manufacture discriminating filters that will transmit bioluminescence whilst supressing light in other wavelengths (Boettcher et.al. 1974). The spectrum of bioluminescence was taken as that for *Noctiluca miliaris* measured by Nicol (1958) which shows peak emission at about 470 nm with a rapid drop to zero at 430 nm and 580 nm. The principal problem is that the low-light-level TV tube was developed for military purposes, which demand the ability to observe scenes by reflected starlight, which contains a high proportion of infra-red light. The TV tubes are thus very sensitive in the infra-red range, and when looking at the sea, will observe reflected starlight from the surface which acts as interference (or "noise") in the images of fish shoals.

Optical filters were thus built with a cut-off at approximately 400 and 600nm, and placed in a filter holder before the lens. The consequent exclusion of the longer wavelength light within the sensitivity range of the photocathodes means that the signal-to-noise ratio in the part of the spectrum of interest has been greatly increased. At the time the present filters were constructed, little information was available upon the spectrum and intensity of the plankton luminescence off South West Africa. As this information becomes available now, filters with narrower "windows" will be constructed which will further increase the signal to noise ratio.

The Bosch-Fernseh TV camera is a non-military version of a military camera. This "demelitarised" version is considerably cheaper than the military version, having a much reduced specification for rough handling and extreme operating conditions. Despite the reduced specification it has operated reasonably well in the research aircraft. The camera is a single unit, cylindrical in shape, 12 cm in diameter and 72 cm in length and is fitted with an Astro Tachonar f1,0 75 mm lens (Fig. 16). The camera is mounted upon a rack above a hole in the aircraft floor, and can be raised and lowered from and to the operating position. It has been found in practice that vertical mounting is not ideal as any dust or insulation particles within the image tube can ultimately fall onto the target and cause spots on the

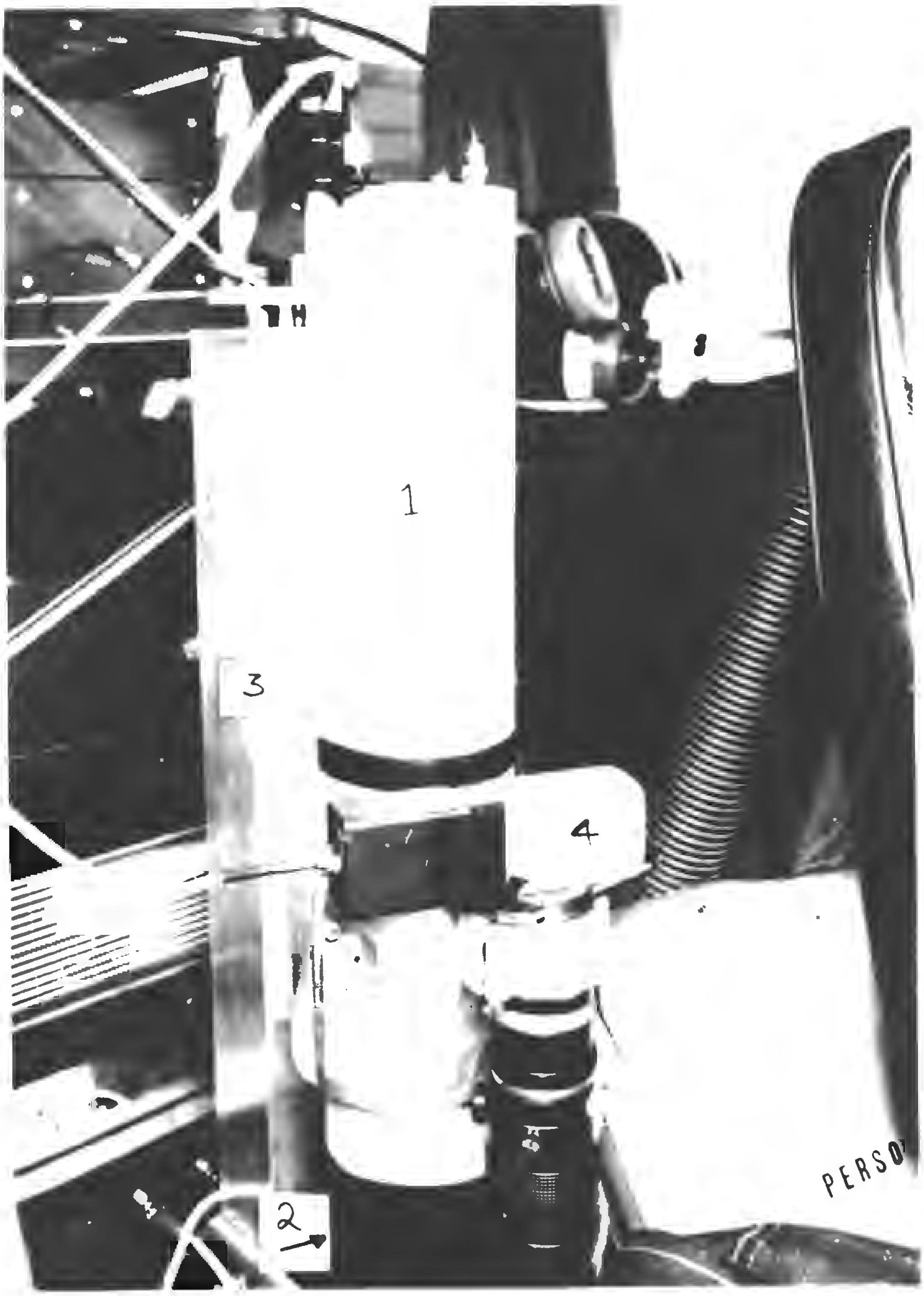


FIGURE 16. Bosch-Fernseh TV camera, mounted vertically in research aircraft. 1, camera body; 2, lens (cover); 3, mounting rack; 4, photometer boresighted to TV camera for measuring strength of fish shoal illumination.

FIGURE 17. Rack-mounted TV equipment in the research aircraft. 1. TV monitor. 2. videotape-recorder. 3. inverter. At the time, two complete low-light-level systems were installed in the aircraft.

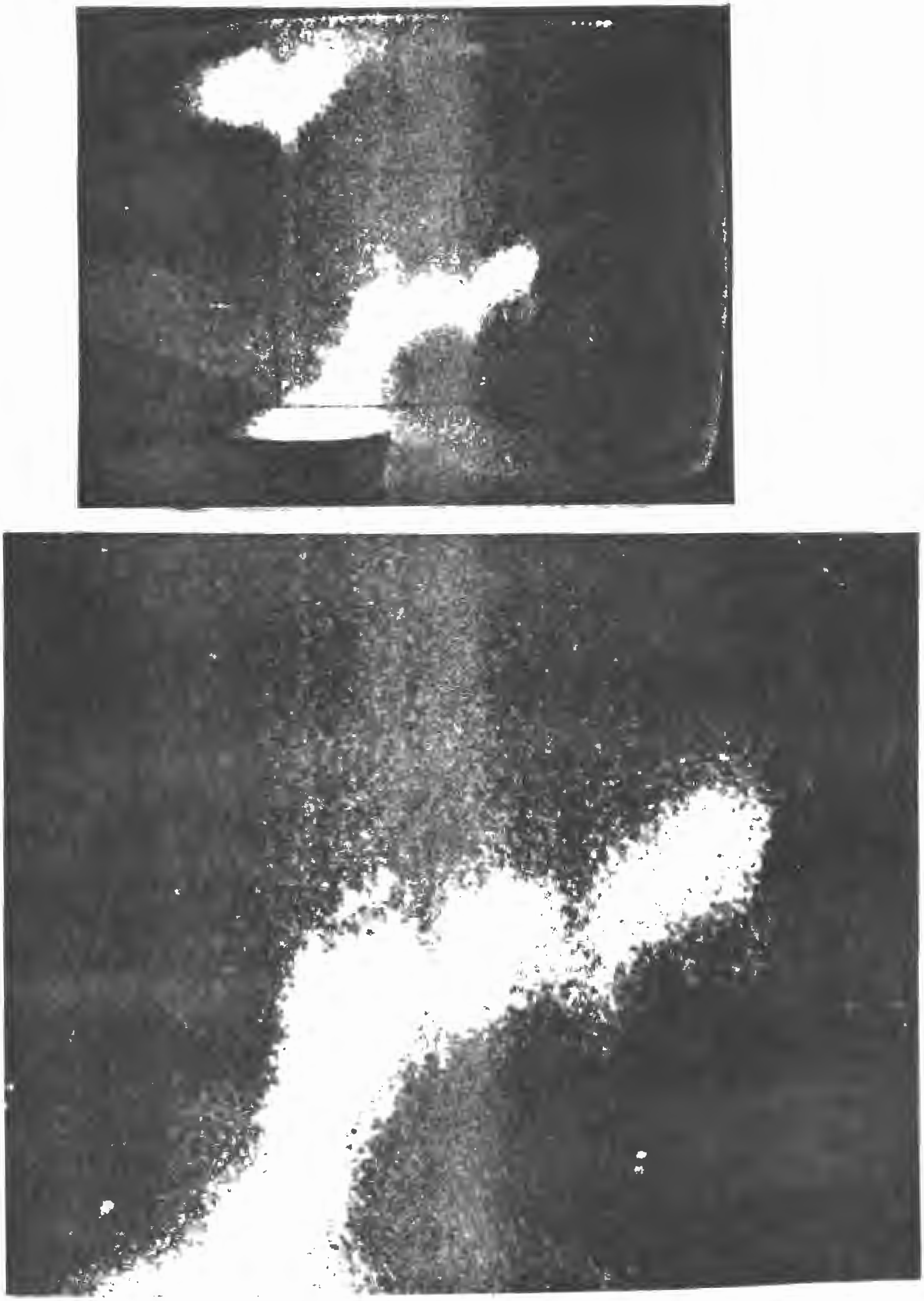


FIGURE 18. Pilchard shoals, video image from SEC system.
Top: Whole screen (note burns on target)
Bottom: Enlargement of same shoals.

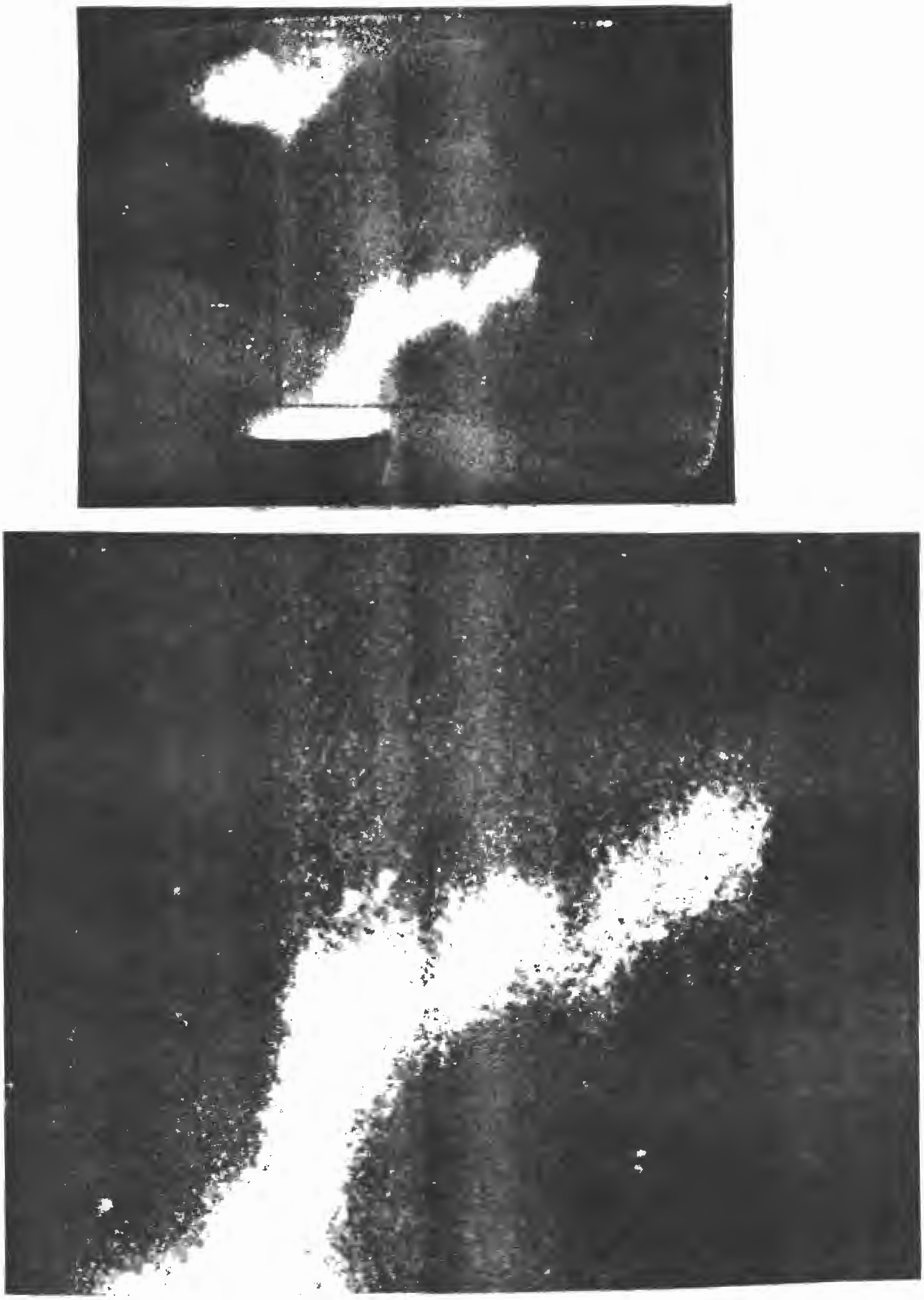


FIGURE 18. Pilchard shoals, video image from SEC system.
Top: Whole screen (note burns on target)
Bottom: Enlargement of same shoals.

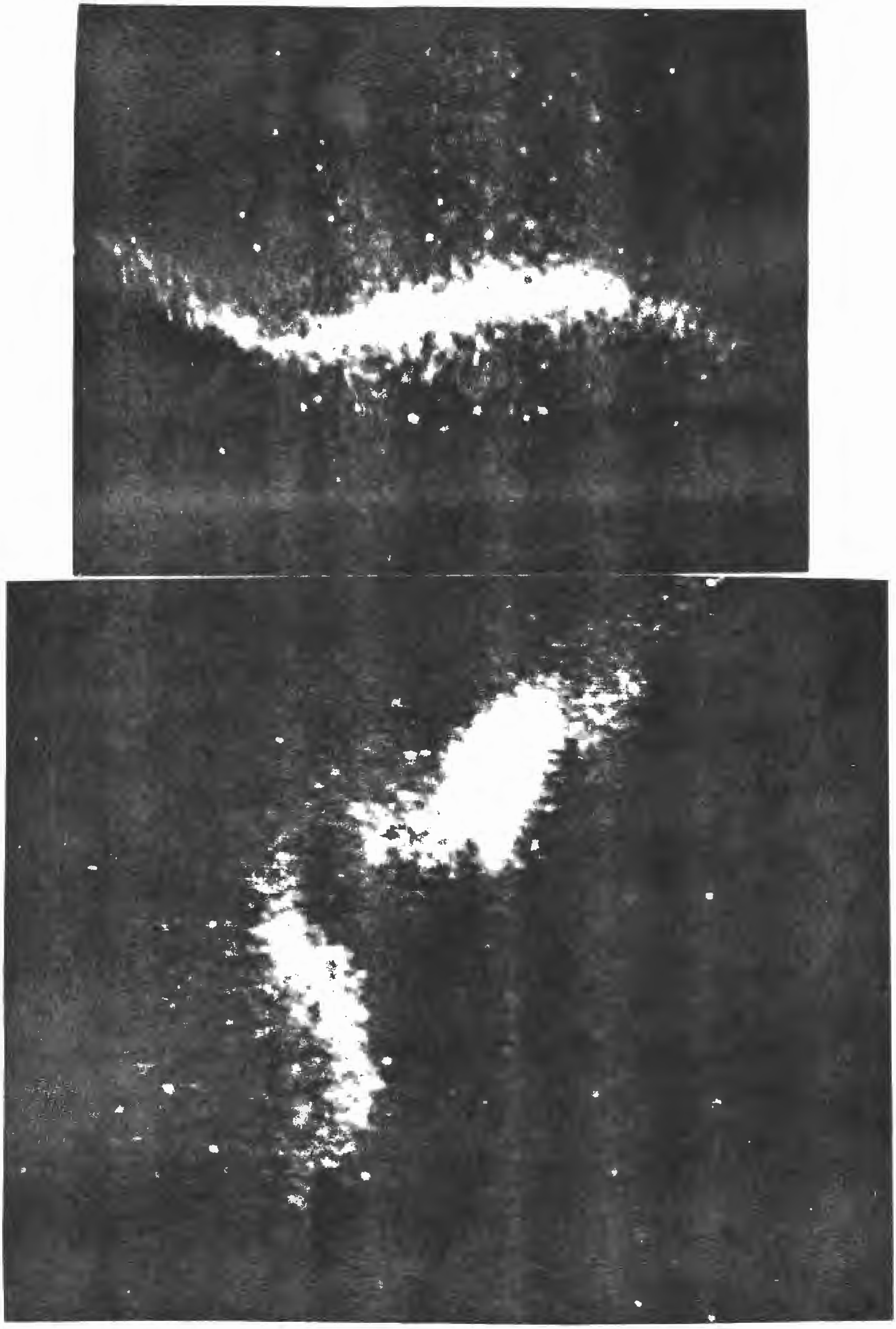


FIGURE 19. Pilchard shoals, video image from EBS system
Note bright area of noise caused by self-emission of
electrons from the photocathode of intensifier.

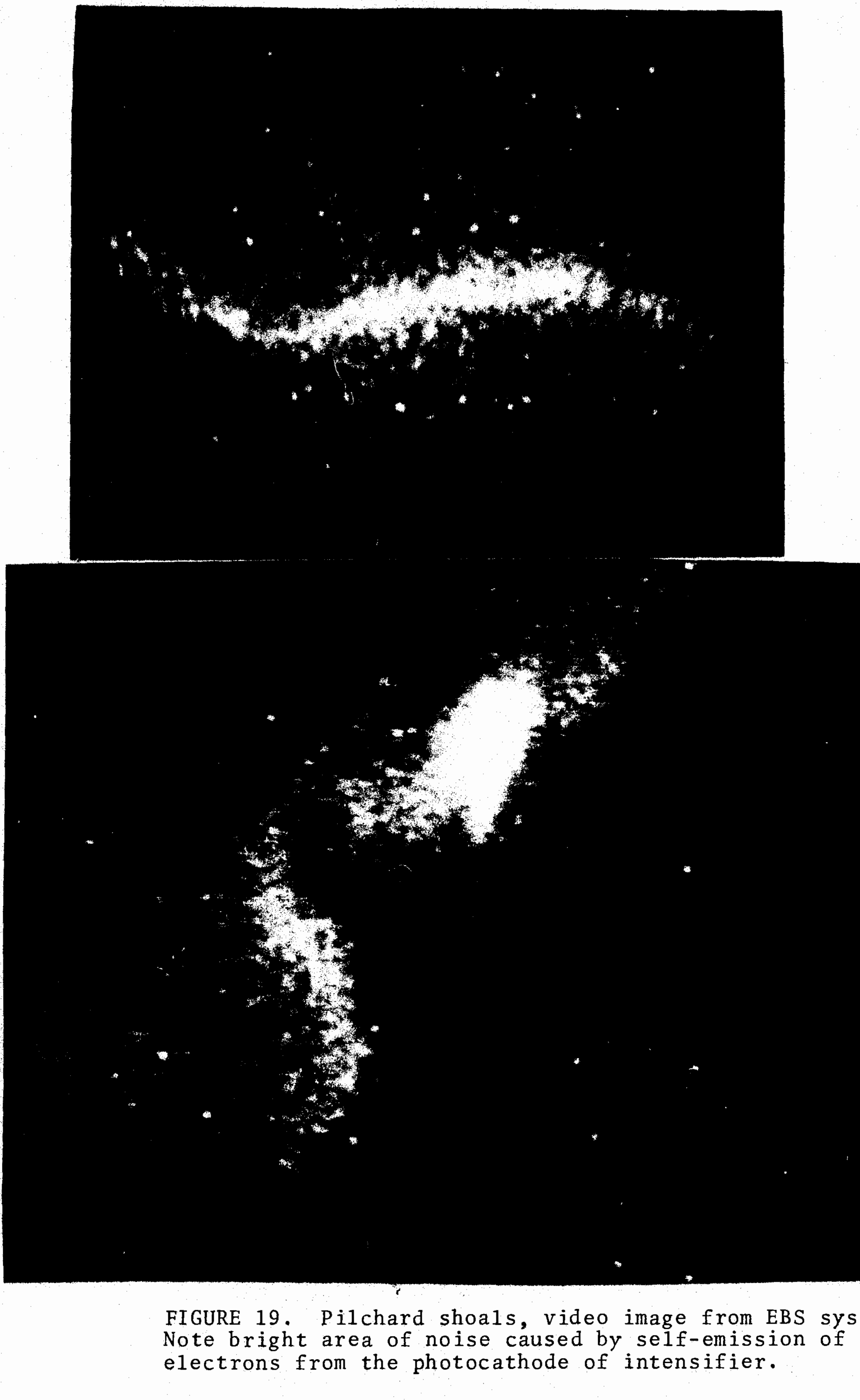


FIGURE 19. Pilchard shoals, video image from EBS system Note bright area of noise caused by self-emission of electrons from the photocathode of intensifier.

video image. The camera has developed a slight shading in one area of the target probably due to this factor. Low-light-level TV cameras should ideally be mounted horizontally with light from the sea surface being reflected off a 45^{o} mirror and if possible never tilted lens-down.

The videosignal from the TV camera is displayed on a television monitor and stored on a videotape-recorder conveniently mounted in racks (Figure 17). Power is supplied directly from the aircrafts 24 v.DC for the camera and through a 24v. DC : 220 v AC inverter for the television monitor and videotape recorder.

As previously mentioned, the EBS systems have poor dynamic resolution, some lag distortion and considerable noise on the videosignal, in comparison with the SEC system tested. However, good quality imagery is usually obtained from the SEC system, and would probably suffice for a survey system (Fig 18).

The EBS system can provide excellent imagery when conditions are optimal (Fig. 19) but as conditions rarely are optimal it would be advantageous to possess a more flexible TV system. Having had considerable operating experience, it has been possible to specify a very advanced system which would eliminate the problems of poor dynamic resolution and lag which cause blurring of the picture, as well as increase the signal to noise ratio to acceptable levels. This system will be capable of automatic data processing in that the measurements of shoal area could be accomplished by a computer via an interface. Acquisition of such a camera would be the first step in the direction of modern fisheries surveillance.

3.0. THE METHOD OF SHOAL TONNAGE ESTIMATION FROM AERIAL OBSERVATION.

Initially the idea behind aerial shoal tonnage estimation was simply to measure the surface area of all pilchard shoals seen: this sum of areas would be the basic parameter of apparent abundance of the stock. However, as previously reported, the early attempts at obtaining video imagery were a failure so alternative methods had to be developed which did not involve the acquisition of imagery.

During 1970 and 1971, the fish-shoal distributional data showed clearly that pilchard shoals are grouped in discrete areas, and that the pilchard population, gathered in several of these groups, is distributed widely along the coast of South West Africa north of 25^{o}S. (Figure 20). This grouping was a considerable help, for had the shoals been ungrouped, the task of quantitatively sampling their number would have been more difficult. However, this convenient grouping existed and it was decided to use it in an area-sampling technique using a direct viewer or image intensifier. Figure 21 is a block diagram of the steps used to estimate the tonnage of a shoal group.

The sampling technique is relatively simple. Having located a shoal group, the airborne observer draws up a survey grid of maximum intensity depending on the time remaining for survey work. The survey lines are flown and from the data acquired, the area enclosing the whole shoal group can be estimated, together with the percentage of that area which is covered by fish shoals. Thus an estimate of the area of all shoals in the group (actual shoal area) can be obtained. Synchronously with the aerial survey, a research vessel samples the same

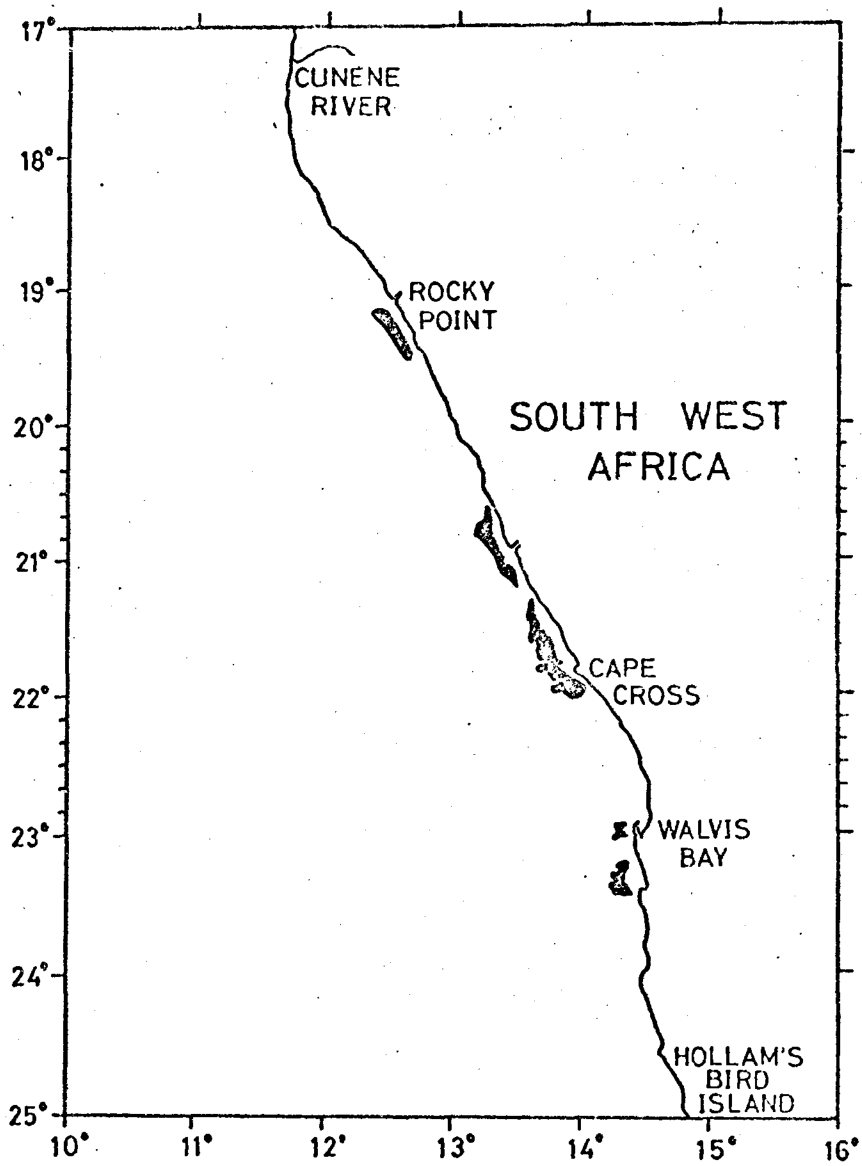


FIGURE 20. Distribution of pilchard shoal groups, January 1973.

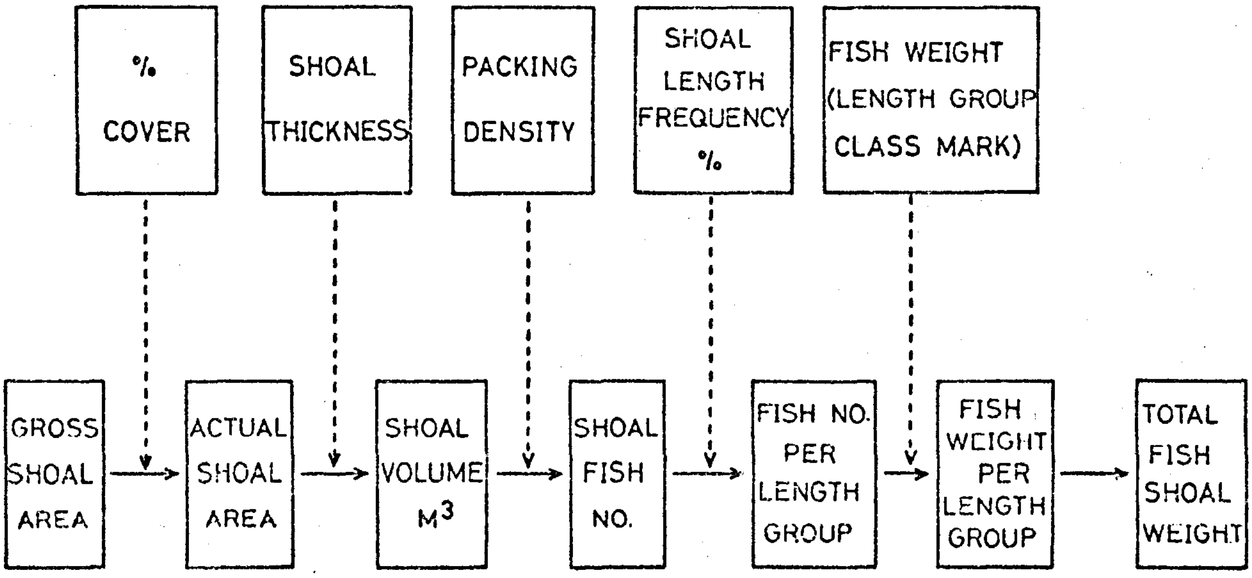


FIGURE 21. Block diagram of the steps in calculating shoal group tonnage.

shoal group acoustically to determine the mean shoal thickness. Having obtained the shoal volume, the number of fish in the shoal can be calculated using the packing density value obtained empirically (Section 3.5). The simplified version of the stepwise calculation then required the mean fish weight from samples captured from the shoal group, to provide the weight of the shoal group. A complexity which was used from 1972/73 was to determine the length frequency distribution of the samples from the shoal group, then calculate the number of fish of each length group present in the shoal. Using the length/weight relationship previously derived for pilchard, the weight contribution from each length group can be summed to provide the weight of the shoal group.

3.1. THE SHOAL GROUP.

Figure 22 is a reconstruction of the distribution of shoals within a shoal group. The five categories of association describe the horizontal relationship of each individual shoal. The areas within the contours refer to a decreasing degree of horizontal association from 16% through 12%, 8%, 4% to 2%. The area within, for example, the 12% contour has 12% covered by fish shoals. This implies a random distribution which in fact does not exist, there is a degree of contagion in the association of shoals which is only visible in the original data. Figure 22 is not intended as a quantitative distribution but rather to show that there is some structure to a shoal group varying from a "super-shoal" to outlying, widely scattered shoals. The shape is extremely variable as are the patters of association.

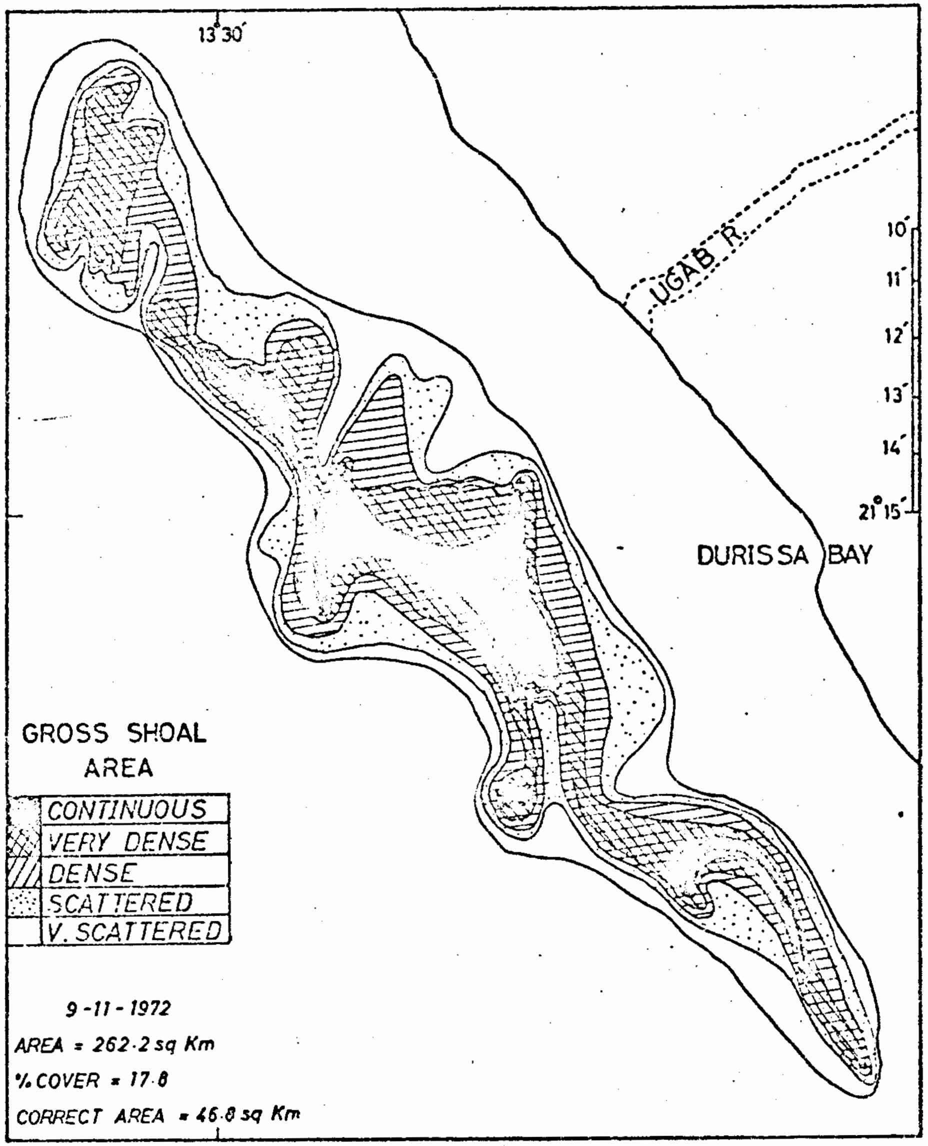


FIGURE 22. Horizontal distribution of shoals within a shoal group.

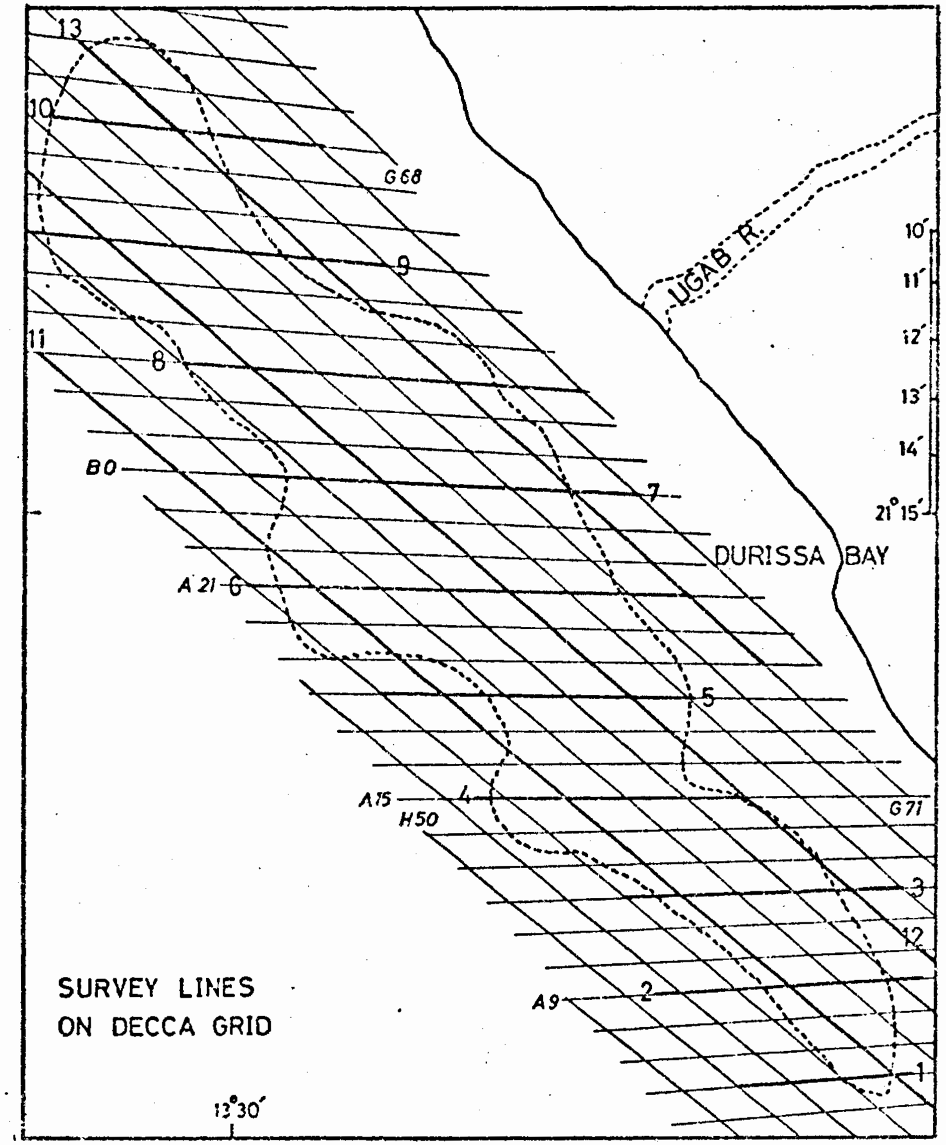


FIGURE 23. Survey grid for shoal group shown in Figure 22.
Thin lines numbered A15, G71 are Decca lattice, thick lines superimposed, numbered 1 to 13 are survey lines.

3.2. THE MEASUREMENT OF GROSS SHOAL AREA AND PERCENTAGE COVER.

An estimate of the percentage of the shoal-group area actually covered by shoals is made by a sampling technique with a direct viewer or image-intensifier. When shoals were bright, the direct viewer was used, on some occasions when dim, the image intensifier. But in any case, the viewer or the intensifier served only to provide a consistent and fixed field-of-view with which to examine the sea surface and make observations. In this way observations made by eye can be semi-quantified.

Having located a shoal group the scientist-in-charge of the aircraft establishes the approximate size of group and draws up a survey grid designed to utilise to its maximum the time available for survey. Figure 23 shows the survey grid for the shoal group shown in Figure 22. The heavy lines are the 13 survey lines which for convenience of navigation are always superimposed upon the DECCA navigational lattice for the area (the thin lines numbered A15, H50 etc.). The outline of the shoal group is shown in a dashed line. Each survey line commences and ends at specific points on the DECCA latice, and, as the viewer and intensifier have fixed fields-of-view, the line is actually a two-dimensional swathe across the shoal group, varying in width according to altitude. Each survey swathe is timed in seconds from its starting to its ending-point and observations on shoals are referenced against time. As each individual shoal passes through the field of view, its duration-in-view is noted by reference to the running stop-watch and the relative size in the field of view is estimated.

The relative size of shoals had eight categories $^{1}/8$ to $^{8}/8$ of the field-of-view, (f.o.v.) but in practice only five were used $^{1}/8$ $^{1}/4$ $^{1}/2$ $^{3}/4$ and 1. Samples of these data are given in Table 15.

When all lines have been completed, and the data returned to the laboratory, the area of the shoal group (gross shoal area) and the percentage cover can be determined.

The shoal group outline is drawn by connecting all the first and last geographical points at which fish shoals occurred on each survey swathe. Any lack of observations within the swathe are not taken into account when drawing the outline as this is corrected for in the way in which the swathe data are processed. To make the shoal group area conform with reality as much as possible, subsidiary information is included on shoal location obtained while the aircraft was manoeuvering at the beginning or end of a survey swathe.

The calculation of the percentage of the swathe area covered by shoals is simple. The width of the swathe is 8 units ($^8/8$ of field-of-view) and the percentage of the swathe covered by fish shoals can be calculated as follows, using the data in table 15.

Swathe width x swathe length = swathe area

Total of relative sizes of shoals per swath = 96 arbitrary units.

Total possible records for 110 sec. swathe = 110 x 8

$$\therefore \text{ area occupied by shoals} = \text{swathe area} \times \frac{96}{110 \times 8}$$

% of shoal area occupied by shoals =

$$\text{swathe area} \times \frac{96}{110 \times 8} \times \frac{1}{\text{swathe area}} \times 100\ \%$$

As the swathe areas cancel out, the % cover per swathe can be calculated from the formula:

$$\text{percentage cover} = \frac{\text{sum of relative sizes} \times 100}{\text{swathe duration (secs)} \times 8}$$

So for the sample data above

$$P.C = \frac{96 \times 100}{110 \times 8} = \underline{10,9\%}$$

In order to derive the "actual shoal area" the mean percentage cover for all swathes is multiplied by the gross shoal areas The usual values lie between 2-17%.

Considering the shoal group depicted in Figures 25 and 26, the following characteristics were determined:

Field of view	48^{o}
Altitude of aircraft	475 m
Swathe width	406 m
Total swathe area	122 sq. km.
Shoal group area	2 124 sq. km.
Percentage cover	5 %
Actual shoal area	106,2 sq. km.
Number of shoals observed on swathes	814
Total shoal no. in shoal group $\frac{814 \times 2124}{122}$ =	14 170
Percentage of shoal group area covered by aerial survey swathes=	5,7 %

3.3. SHOAL THICKNESS

Pilchard shoals vary considerably in vertical extent (Figure 24). The reasons for the variation are not precisely known but are presumed to relate to environmental conditions such as the depth of the thermocline. Such explanations will not fit the circumstance of wide variation in shoal thickness in one area, as in Figure 24. There are insufficient data to attempt prediction of the thickness of fish shoals in the population, so the survey technique demands synchronous surveys by aircraft and boat in order that short-term variations in shoal thickness are taken into account.

For the measurement of shoal thickness two vessels have usually been available. Both are small fishing vessels equipped with standard echosounders. These vessels were strategically positioned in advance of an aerial survey so that at least one would be relatively near any shoal group that should be located by the aircraft. As the aircraft starts its survey, if the vessels are not on the shoal group already they are called to the general area and given a string of DECCA co-ordinates to delineate the study area. Then the skipper or scientist-in-charge draws up some sort of grid to take into account the time required for sampling with the purse-seine net and carrying out an echo-survey synchronously with the aircraft.

Figure 25 shows the outline of a shoal group and the track of two vessels carrying out sampling and echo surveys. The ships track is irregular in comparison with aircraft track (Figure 26). This irregularity was due to the need of covering as much of the shoal as possible during the aircraft survey:

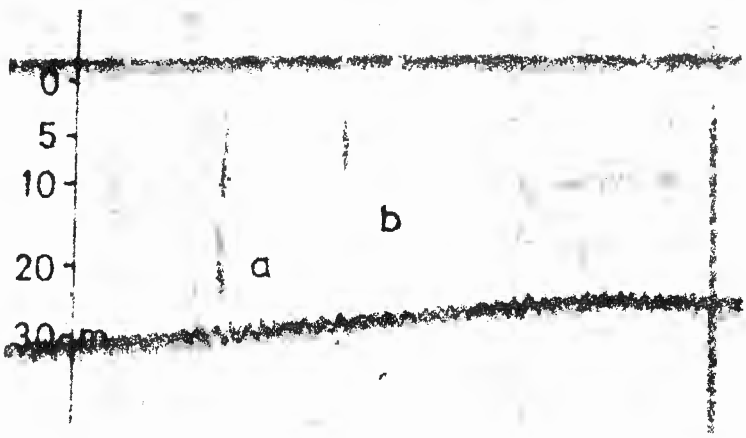


FIGURE 24 : Echogram of pilchard shoals.

a. 20 m shoal thickness
b. 5 m shoal thickness

(Cram 1974)

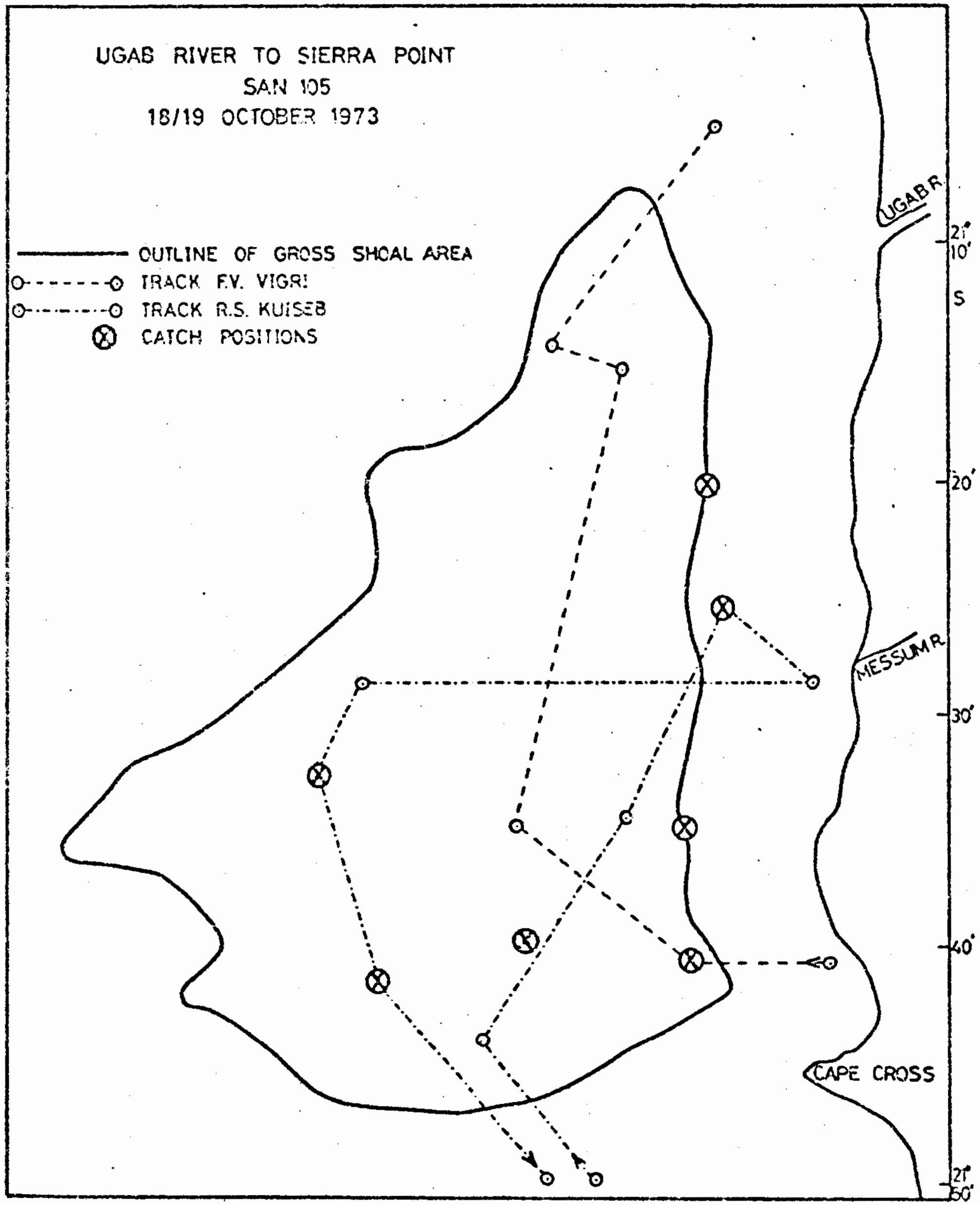


FIGURE 25. Echo-survey grid conducted by two vessels. Catch positions marked by a cross.

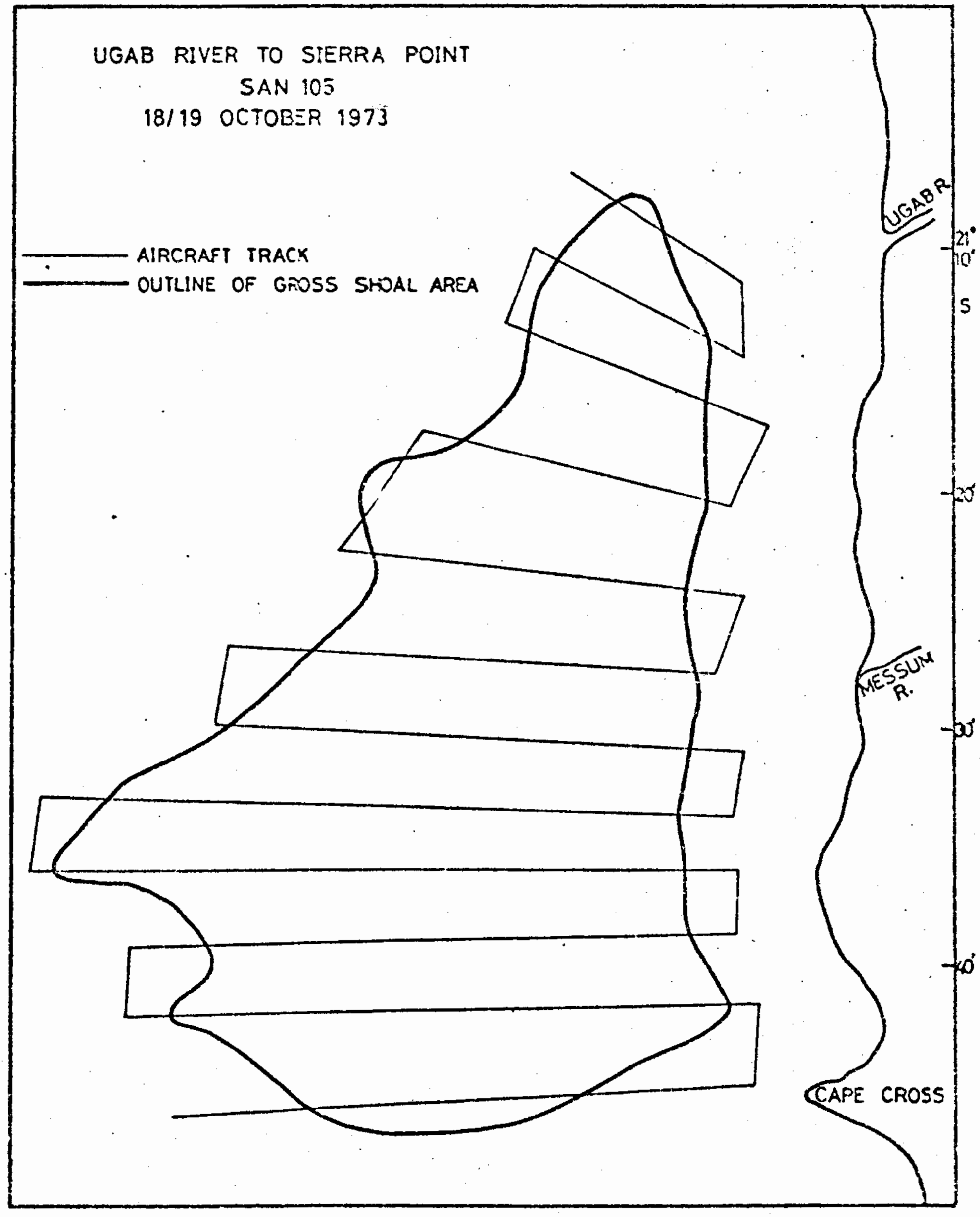


FIGURE 26. Aircraft survey grid superimposed upon shoal group outline.

there was no time to carry out a systematic grid. Survey considerations demand that as much work be completed synchronously: if, for example, the experimental catches were left until later so that more echo survey could be accomplished there was no guarantee that weather would be suitable for making catches, or that the shoal group had retained its identity or had not moved off somewhere. In principle, a delay in sampling the fish is acceptable as they do not grow much in a few days or weeks, but in practice there is no guarantee of successful completion of an integrated survey unless every advantage is taken of good weather to accomplish the maximum work. Thus poor acoustic sampling of a shoal group is accepted, bearing in mind that the shoal group under consideration had 129 shoals sampled acoustically (0,09% of the calculated total) which is just more than 10% of the 814 shoals sampled from the air.

The mean shoal thickness is calculated according to the formula.

$$\text{mean shoal thickness} = \frac{\sum_{i=1}^{N} T_i \quad L_i}{\sum_{i=1}^{N} Li}$$

where T_i is the thickness of a shoal

L_i its horizontal dimension

N the number of observations

In this calculation, all the thickness measurements are weighted by the apparent horizontal dimension to compensate for the fact that thicker shoals are often horizontally large and thus the use of unweighted shoal thickness values may bias the mean thickness value towards that the more abundant shoals of small horizontal dimension and shallow thickness.

For the shoal group in Figures 25 and 26, the mean shoal thickness was 5,2 m, S.D. 3,2 m.

3.4. THE SHOAL VOLUME

Using information from previous sections, the actual shoal area is 106,2 x 10^6 m^2 and the mean shoal thickness is 5,2 m. The shoal volume is 552,2 x 10^6 m^3.

3.5. SHOAL FISH NUMBER

Conversion from shoal volume to fish number relies on the knowledge of the fish packing density, the number of fish per m^3. This factor is very important in the calculation but regrettably is not known precisely yet.

It had been hoped initially that this measurement would be accomplished by acoustic means, but to date this has not proved possible. Consequently, in 1972 it was decided to conduct a catching experiment in an attempt to empirically determine the density of pilchard shoals. The principle of the experiment was to use a commercial purse-seiner to catch a measured volume of a shoal and to weigh it on the factory scales, thus determining a mass/volume ratio which can be transformed into fish number/unit volume with the mean fish weight of the catch.

In practice the measurement of the horizontal dimensions of a shoal, or part thereof, is extremely difficult so the area was estimated by an observer in the research aircraft, as the fishing vessel set its net. The shoal and the net are usually clearly visible (see frontispiece and Fig. 27) and the proportion of the net which retained fish can usually be estimated.

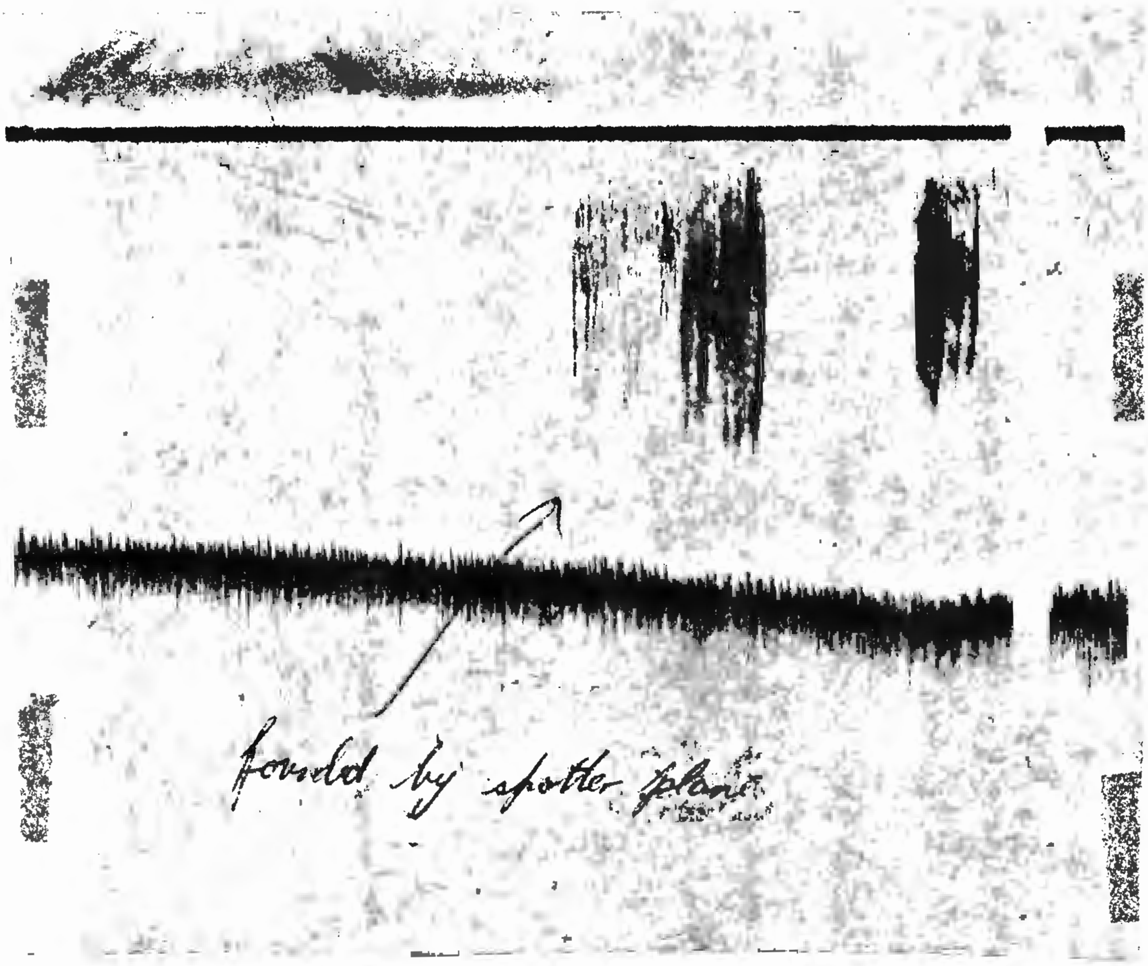
TABLE 16. DIMENSIONS AND SURFACE AREA OF PURSE-SEINE NETS USED BY VESSELS PARTICIPATING IN THE CATCHING EXPERIMENT.

Vessel	Net Dimension		Net Area
	Depth(m)	Length(m)	M^2
Ogri	64	329	8620
Roggeveld	59	348	9604
Consortium Delta	77	457	16628
Boetie Akie	73	423	14197
Astrid	64	320	8148
Julie Lynn	64	366	10642

Before the catching procedure commenced a record of the vertical dimension of the shoal was made on the vessels echo-sounder (Fig. 28). The dimensions of the vessels nets and net areas are laid out in Table 16. The calculation of area assumes the nets to be round.

The assumption is made that the net represents a cylinder of circumference net-length, of which a proportion is filled in horizontal extent (as estimated from the aircraft) and in vertical extent (as measured from echograph). The volume occupied by the fish shoal retained by the net can thus be

FIGURE 27 : A purse-seine net surrounding a pilchard shoal. Boat in lower left corner; net curving away from top and back to bottom of boat. Scale 1cm.20m



FIGUR : Echogram of a pilchard shoal

deduced. During weighing at the factory, a sample of fish gives the mean weight of individual fish. The total number of fish in the catch can thus be estimated and, knowing the total volume, the fish number per unit volume (packing density) can be determined.

During the experiment, a number of problems were encountered. Under normal circumstances, the amount of fish retained by the setting of a purse-seine net is reduced prior to the final pursing of the net by escapement between the open wings and bottom. Despite efforts to reduce escapement, this occurred to an unmeasurable extent. The skippers were encouraged initially to attempt to fill their nets although they do not do this in normal fishing practice. The result was that the extremely large nets retained huge quantities of fish, (more than 1 000 tons was estimated) causing the nets to capsize and damage the gear. Consequently, the skippers were asked to adopt a normal fishing practice and the area of the fish in the net was estimated by the observer on the basis of the proportion of the net filled by fish (Fig. 27).

On examining the length frequency distribution of the experimental catches, it was observed that the shoals sometimes contained a broad range of fish lengths. The frequency distributions were either unimodal or multimodal, implying that fish of different ages as well as different lengths were present in some shoals (Fig. 29). The multimodal length frequency distributions introduced a potential biological problem in that it is possible that fish of different size adopt a different station with respect to adjacent fish in the shoal.

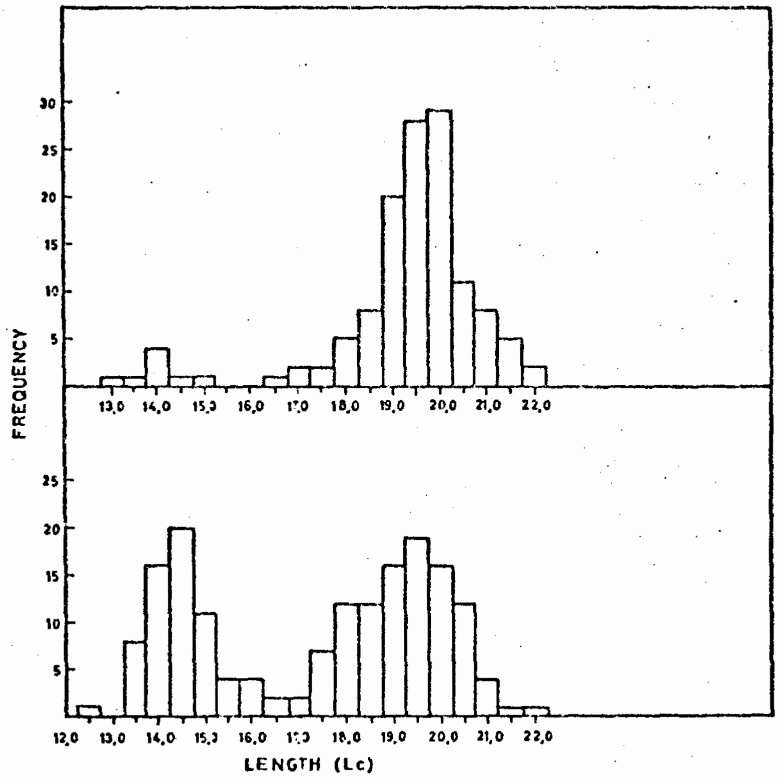


FIGURE 29. Histogram of pilchard Length Distribution.

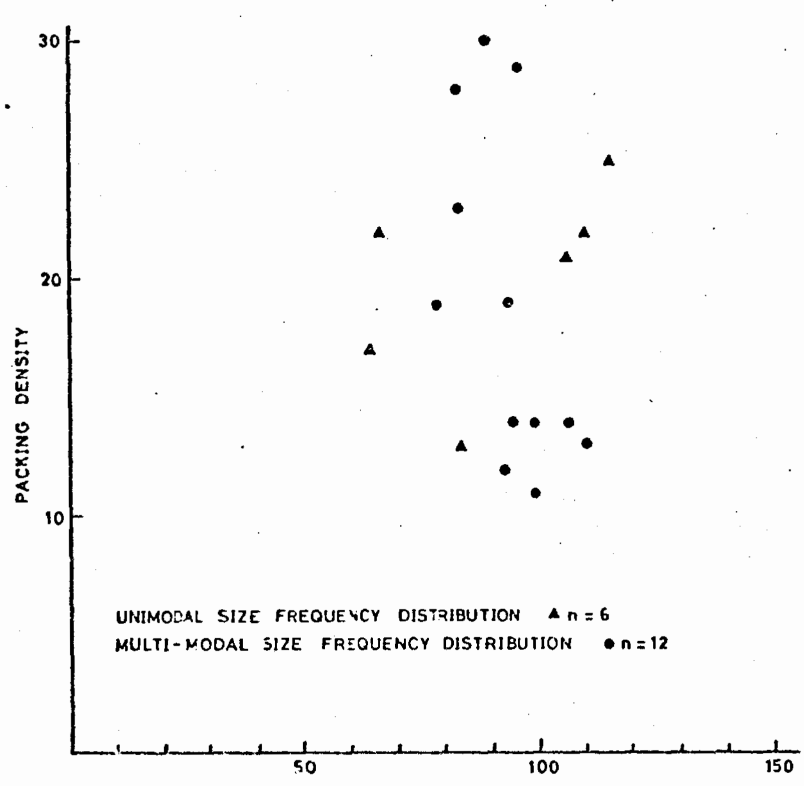


FIGURE 30. Relationship between packing density as calculated, and mean fish in experimental catches.

That is to say, smaller fish may have a higher packing density than larger fish, rendering the establishment of an average packing density value very difficult in biologically sound terms.

The packing density was calculated for each of the six "unimodal" catches by obtaining the catch weight from the factory scales, or by using the skippers estimate of the fish caught when there was a considerable discrepancy between these two caused by escapement problems during pursing. Using the length frequency distribution obtained from a sample of the catch (for example Fig. 29) and the length/weight curve for the species, the mean individual fish weight in the catch was obtained. From the catch weight and the mean individual fish weight, the number of fish in the catch is estimated. The volume of the shoal was calculated from the aerial and acoustic observations and, divided by the fish number, provides the density of fish per unit volume: the packing density. The same method was used with the "multimodal" catches.

For the six "unimodal" catches, the packing density was calculated as 20,0 fish/m^3, SD 3,9 fish/m^3 and for the 12 "multimodal" catches a packing density of 18,8 fish/m^3 S.D. 6,7 fish/m^3. The relationship between packing density and mean fish weight is displayed graphically in Fig. 30. It can be seen that there is no clear trend in packing density as a function of mean individual fish weight. The results are difficult to interpret as the range of fish length over which samples were collected is restricted to 65-115 gm, and factors such as escapement and inadequate measurements cause substantial error. In an attempt to improve the estimate it was decided at the time to ignore the multimodal catches due to the potential difficulties caused by behavioural differences in different age groups, particularly that evidence from other sources (Graves 1975 e.g.) that smaller fish may pack more densely than larger fish, although the weight distribution may be similar. The value of 20,0 fish/m^3 would be used, assuming an average packing density for shoals, irrespective of the size range contained therein.

Later analysis of the variances for the unimodal and multimodal catch packing density values showed that there was no significant difference. Therefore the decision to omit the multimodal catches was not sound statistically, but possibly sound biologically.

For fish with a mean weight of 100 gm. the value of 20 fish/m^3 represents a weight of 2,0 kg/m^3 which is in agreement with an estimate by Tibbo and Brawn (1960) of 2,0 kg/m^3 for the Eastern USA herring stock. Photographic studies of Californian anchovy shoals give very high packing density values, up to 350 fish/m^3 (Paul Smith pers. comm. 1976). However, Graves (1975) reported on ten observations of anchovy schools with a mean density of 115 fish/m^3 (S.D. 99). Assuming a fish weight of 18 gm, the mean value gives a weight of 2,07 kg/m^3.

The determination of packing density of shoals for the purposes of routine stock size estimation cannot be accomplished in the manner described above, as the variability of packing density with size may be great and the use of a constant value undoubtedly introduces bias.

In situ acoustic studies by Hampton (1973) produced a value of 23 fish/m^3 from preliminary studies on captive live fish. Later studies have confirmed a linear relationship between fish number and echo return voltage which implies that the acoustic techniques will be satisfactory for the measurement of packing density (Hampton pers. comm. 1976). However, despite the limitations in the method described above, it was the only way of obtaining a packing density value: once obtained, it was used in the calculation. Later, the value reported by Hampton (op.cit.) was used as it was felt to be a more reliable estimate.

Thus, the shoal fish number can be calculated from shoal volume, and using the example in 4.4 of 552,2 x 10^6 m^3, and the figure of 23 fish/m^3, the shoal fish number is 12 700,6 x 10^6.

3.6. SHOAL GROUP FISH WEIGHT

During the echo-survey of the shoal group, experimental catches are made with a purse-seiner to produce fish samples. These samples are all analysed for length frequency distribution and other information. The number of experimental catches per shoal group is usually less than ten and, in the case of the shoal group being used as an example of the method (Fig. 22) the total was six.

Table 17 is a summary of the data for estimating the weight of fish in the shoal group. The size frequency distributions from the samples are weighted and listed in column 8. The frequency distributions are weighted by a constant factor to eliminate errors introduced by the very variable number of fish in each sample. The frequency per length group is expressed as a percentage of the total weighted frequency in column 9. The total number of fish in the shoal group has already been estimated (section 3.5) as 12 700,6 x 10^6 fish and the number of fish in each length group is then calculated by multiplying the shoal group fish number by the frequency percentage of each length group to give the fish number per length group (column 10). From the length/weight curve for pilchard, (Newman 1970) the mean weight at each length group class mark can be determined (column 11), and multiplying this weight by the length group fish number gives the weight of fish within each length group, given in column 12 in metric tons. The sum of these weights is the weight of fish in a shoal group, that in the example given being 930 438 metric tons.

Length Group (cm)	Sample No X 021	X022	X023	X024	X025	X026	Weighted frequency per length group	%	Shoal Fish No.	Average weight of fish per length group (g)	Weight of fish per length group (metric ton)
8,5			6,0				6,0	0,20	25401200	9,04	229,6
9,0			14,0				14,0	0,46	58422760	10,60	619,3
9,5			9,0				9,0	0,30	38101800	12,33	469,8
10,0			6,0				6,0	0,20	25401200	14,22	361,2
10,5			20,0				20,0	0,66	83823960	16,32	1368,0
11,0			85,0				85,0	2,80	355616800	18,57	6603,8
11,5			147,0				147,0	4,84	614709040	21,05	12939,6
12,0			99,0				99,0	3,26	414039560	23,70	9812,7
12,5			85,0				85,0	2,80	355616800	26,59	9455,9
13,0			23,0	2,0			25,0	0,82	104144920	29,68	3091,0
13,5			6,0				6,0	0,20	25401200	33,01	838,5
14,0			3,0		4,4		7,4	0,24	30481440	36,56	1114,4
14,5				2,0			2,0	0,07	8890420	40,36	358,8
15,0	4,4						4,4	0,15	19050900	44,39	845,7
15,5	2,2	2,2			4,4	2,6	11,4	0,38	48262280	48,72	2351,3
16,0	2,2	2,2		8,1	6,5	7,7	26,7	0,88	111765280	53,25	5951,5
16,5	6,6	28,7	3,0	2,0	15,3	28,1	83,7	2,75	349266500	58,11	20295,9
17,0	24,3	33,1		20,2	41,4	43,4	162,4	5,34	678212040	63,19	42856,2
17,5	24,3	99,4		70,8	89,4	112,4	396,3	13,04	1656158240	68,61	113629,0
18,0	24,3	121,5		99,2	85,1	84,3	414,0	13,63	1731091780	74,30	128620,1
18,5	8,8	79,5		107,3	69,8	69,0	334,4	11,00	1397066000	80,28	112156,5
19,0	37,6	33,1		50,6	34,9	33,2	189,4	6,23	791247380	86,54	68694,4
19,5	103,9	19,9		44,5	17,4	28,1	213,8	7,03	892852180	93,17	83187,0
20,0	123,7	30,9		42,5	32,7	25,6	255,4	8,40	1066850400	99,59	106247,6
20,5	77,3	28,7		36,4	43,6	28,1	214,1	7,04	894122240	107,4	96028,7
21,0	48,6	15,5		10,1	41,4	28,1	143,7	4,73	600738380	114,8	63715,9
21,5	13,3	11,1		6,1	17,4	12,8	60,7	2,00	254012000	122,8	31192,7
22,0	2,2			4,1	2,2	2,6	11,1	0,37	46992220	131,1	6160,7
22,6	2,2						2,2	0,07	8890420	139,7	1242,0
										TOTAL	930437,8

TABLE 17. DATA FROM WHICH SHOAL GROUP WEIGHT IS CALCULATED

3.7 DEVELOPMENTS IN SURVEY STRATEGY AND DATA COLLECTION.

All upwelling systems adjacent to hot land masses are characterised by persistent low stratus cloud forming at the interface (the inversion) between the cold marine layer and the hot upper air. Subject to prevailing meteorological conditions the altitude of the inversion will vary; if low, no aerial surveying will be possible, which has been the case on 17% of previous surveys. If high, that is, above 300 m, then aerial survey will be possible.

Although the aircraft is more vulnerable to atmospheric weather effects than the vessels, sea conditions frequently interrupt experimental fishing work as purse-seining is not possible in rough weather.

The DECCA navigational aid off South West Africa begins to lose effectiveness to the north at Palgrave Point (about 20° 30'S) and by Rocky Point (19° 00') is virtually ineffective. This produces two problems; firstly because the survey technique relies heavily on the DECCA system and secondly that there are dangers associated with inadequate navigation at night far from the nearest lighted airstrip. The net result is that the Northern sector (north of Rocky Point, fig. 1) has had inadequate cover and this may have resulted in a consistent underestimate of stock size. However, this negative bias is not evaluable until survey work is restarted with an alternative navigation system.

The initial survey strategy was to attempt to survey the entire coastal water with the aircraft and ships once each month.

This strategy did not work for navigational and weather reasons: surveys were conducted piecemeal wherever weather permitted and inevitably certain areas remained unsurveyed. Repeating such surveys on a monthly basis did not materially improve the quality of the data, as similar geographical discontinuity occurred. In 1973, when the last direct viewer survey was accomplished, an alternative strategy was used, whereby the coast from Hollams Bird Island to the Kunene River was subdivided into three areas which were surveyed consecutively during three adjacent dark moon periods. Each area was repeatedly surveyed until all shoal groups were located and studied. Adequate overlap with the adjacent area ensured that emigration effects during the interval before the next survey were minimised. The intensity of surveys coverage varied according to whether shoal groups were located or not. Fig. 31 shows the aircraft search pattern when no shoal groups were located. The intensity of coverage ensured that no shoal groups, or even substantial shoals, would have been missed.

From the aerial point-of-view, this strategy represents a considerable improvement, and a similar improvement in acoustic techniques has also been made to produce the present aerial/acoustic survey strategy. Biological factors have a profound effect upon the validity of un-assisted acoustic surveys, when such surveys are carried out on the typical grid system usually employed. The patchiness of the shoal groups (Fig. 20) has considerable effect: Cram and Hampton (1976) simulated a number of typical survey grids upon a known distribution of pilchard shoals. The accuracy of the simulated acoustic survey increased with length, but 47% of the typical grids gave results differing from the known distribution by more than

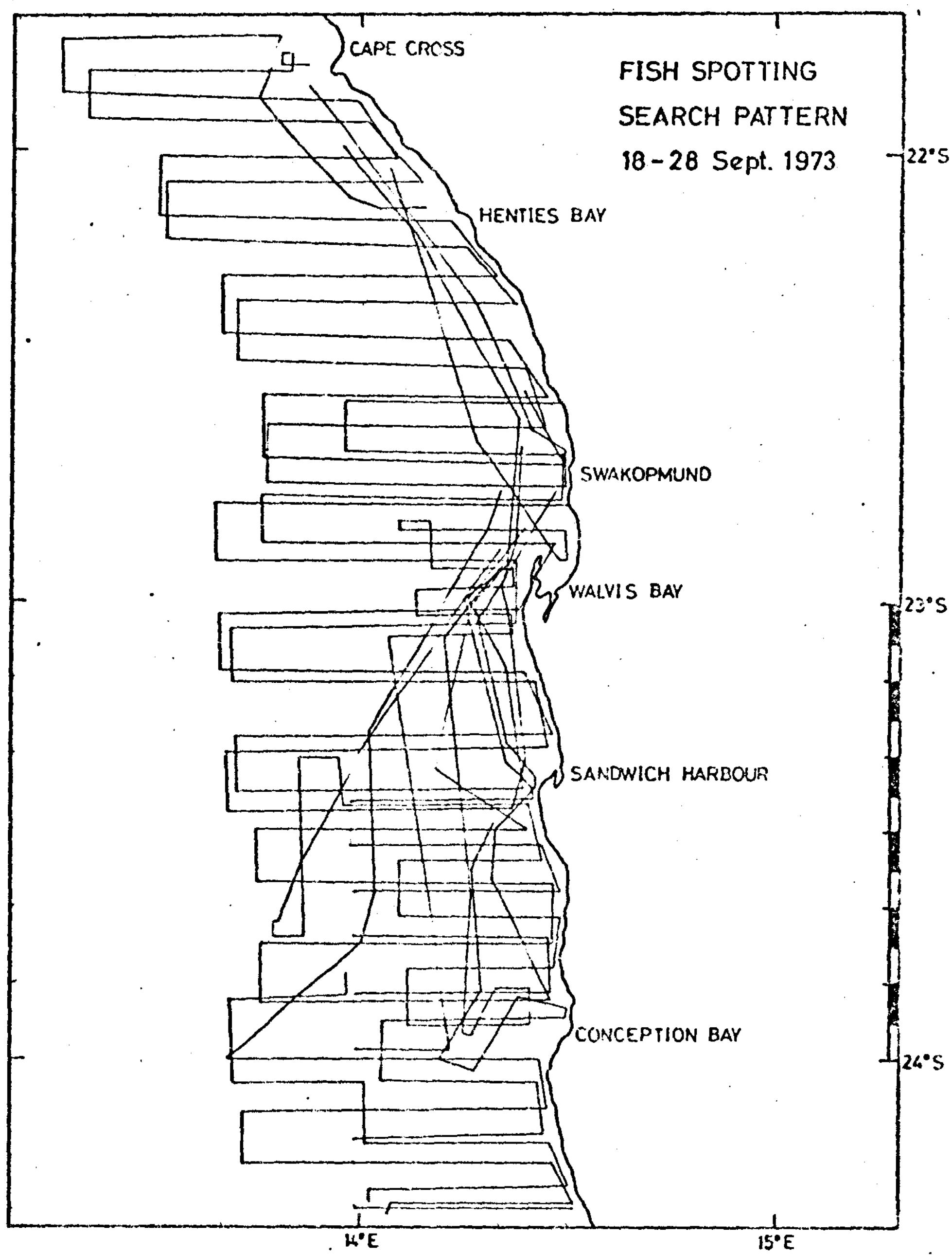


FIGURE 31. AIRCRAFT SEARCH PATTERN, SOUTHERN SECTOR OF SOUTH WEST AFRICAN COAST, 1973.

25%, the arbitrary level of precision required. Aerial observations of shoal mobility have demonstrated that large shoal groups can move up to 27 n miles in 24 hours, a speed of about 1 kt. A vessel carrying out a typical grid of lines 45 n miles long and 10 n miles apart would also progress at 1 kt in a direction normal to the survey lines. In this event, an acoustic measurement of shoal group horizontal dimension would be meaningless. Even on a coarse grid the extent of the shoal group would be under- or over-estimated by 40%. Thus, increasing the duration of a survey in an attempt to increase the precision of an estimate made on a patchy distribution could be counter-productive due to shoal mobility. The effect of shoals avoiding a research vessel is a factor which is common to any survey strategy and cannot yet be assessed.

The ideal strategy is to use an aircraft to locate and roughly map the shoal groups within the species range, whereafter the ship and aircraft would synchronously survey each group in turn. All areas between the shoal groups would be ignored, thus concentrating all effort into areas of known fish occurrence. This technique would be effective in reducing the major sources of survey error. A reprint of this paper is included in Appendix 2.

There have been major developments in the equipment used for both the aerial and acoustic measurements. The LLLTV has been modified in such a way as to allow it to scan both fore-and-aft and from side to side of the aircraft. This will allow, firstly, an enhanced searching ability as the search-swathe would be up to 75^{o} on either side of the aircraft; and secondly the ability to "track" a fishing vessel whilst flying a circular course above it by using the scanning ability of the LLLTV. This will render catching experiments very much easier as it removes the principal problem caused by the fixed field-of-view camera: that of positioning the aircraft exactly over the shoal. In addition, the LLLTV will be equiped with a device which compensates for the forward motion of the aircraft with a rocking mirror. This stabilises the image in the TV camera and considerably increases the quality of the image.

The principal development in the acoustics field is the incorporation of a digital data logger into the echo sounder system. By logging each echo on magnetic tape a very thorough statistical analysis of error becomes possible. Further developments based around the data logger are systems which continually monitor the performance of the echo sounder whilst on survey, enabling corrections to be made for any deviations from specified performance.

With the LLLTV and 120 kHz echo sounder in an automatic data processing mode, only two types of measurements will be required from each shoal group: the horizontal dimensions of shoals and the mean surface density of fish in the shoal. These two measurements would be supplemented by purse seine catches for fish samples.

The advantage of this sophisticated system is that accurate observations can be easily made and then easily subjected to error analysis.

4.0 THREE ATTEMPTS AT ESTIMATING THE APPARENT ABUNDANCE OF THE SOUTH WEST AFRICAN PILCHARD STOCK.

The method described above, or slight variations of it, has been used on three occasions to estimate the apparent abundance of pilchard off South West Africa. The aircraft programme commenced in October 1970, but the first useful observations were only made in December of that year. A break in flying followed until July of 1971 after flying began in earnest during August. The September flight was severely hampered by weather, so the first survey flight was not until October 1971. The aircraft observation method was developed then and continued, essentially unchanged, through to the last survey at the end of 1973. The quality of research vessel support progressively increased, as initially only a fishing vessel was available but later, in addition to the fishing vessel, at least one research vessel was also available. Equipment has progressively increased in sophistication in both the aerial and acoustic aspects. From the aerial side, after the initial vidicon-TV coupled intensifier failed to work, the direct-viewer was extensively used. Later, a better image-intensifier was purchased and, later still, a low-light-level television upon which work is still being undertaken to develop the ideal survey instrument. The acoustics equipment has varied from fishing echosounders through to an echo-integrator, which was replaced by a digital data-logger in 1975.

In 1971, the method used was the simple, initial concept of the method (Fig. 3). The length frequency of the experimental catches was not determined, only the average weight of the fish in the sample.

In addition, due to the lack of suitable vessels, it was not always possible to make measurements of shoal thickness synchronously with the aircraft observations. In these cases, a thickness value was derived from acoustic data acquired during the same part of the night on the same shoal group, but on other nights. The shoal thickness was not weighted by apparent horizontal dimension. The packing density value used was 19 fish/m^3 and was derived from a single experimental catch. The packing density value was obtained in the manner described in section 3.5.

The approach to survey strategy developed haphazardly, and in response to the rapidly changing ideas on the method and the results achieved. At that time it was believed that it would be possible to cover the entire South West African coast within one dark-moon survey period, usually 16-18 days. It became apparent that this was not possible due to the prevalence of low cloud and fog, so much so that at the end of the 1971/72 survey period, at no time had there been a clean sweep of survey during which all shoal groups had been unambiguously detected and measured. This created problems in interpretation of the data which were not easily solved, until eventually it was decided to divide the area into five regions and to use only the shoal groups within these five regions in December 1971. The weights of all the shoal groups were added to give the estimate of apparent abundance: where more than one set of observations were made in any one of the five regions, the average of the estimated shoal group tonnages were taken. The results are listed in Table 18, and the estimate of apparent abundance was 2,04 million tonnes.

AREA	DATE	Gross shoal area(km²)	% cover	Actual shoal area (Km²)	Thickness (m)	Shoal volume (m³)	Packing density	Shoal fish number (million)	Exp. catches	% pilchard in shoal	Number of pilchard in shoal	Mean fish weight (g)	Shoal weight (metric ton)
Sand Table Hill to Palgrave Pt	7/8-12-71	330,24	2	6,604	23,8	157,175200	19,15	3009,905	CC 52	91,2	2745,033	126,432	347060,0
"	8/9-12-71	331,76	1	3,318	14,63	48,548880	19,15	929,713	CC 54	100	929,713	129,744	120624,7
Palgrave Point to Ugab River	6/7-12-71	1173,16	2	23,7316	11,947	283,521430	19,15	5429,4348	CC 55	100	5429,4348	106,25	576877,4
"	14/15-12-71	396,53	0,785	3,1128	12,389	38,5645	19,15	738,51	CC 55 CC 56	100	738,51	106,25	78466,71
Ugab River to Sierra Point	9/10-12-71	196,44	2	3,93	12,389	48,6888	19,15	932,39	CC 57 CC 58	100	932,39	34,672	32327,84
"	12/13-12-71	437,59	1,3	5,6887	12,389	70,4773	19,15	1349,64	CC 57 CC 58	100	1349,64	34,672	46794,73
"	14/15-12-71	246,62	2	4932	12,389	61,1025	19,15	1170,1129	CC 57 CC 58	100	1170,1129	34,672	40570,15
"	15/16-12-71	283,72	14,75	41,849	12,389	518,467	19,15	9928,65	CC 57 CC 58	100	9928,65	34,672	344246,1
Sierra Point to Swakopmund	13/14-12-71	368,56	3	11,057	12,504	138,2567	19,15	2647,62	CC 62 CC 63	100	2647,62	125,785	333030,3
Swakopmund to Sandwich Harbour	10/11-12-71	118,9	5	5,945	9,145	54,367	19,15	1041,128	CC 60 CC 61	99,7	1038,0047	113,285	117590,3

Estimate of apparent abundance : 2 037 589 tonns

TABLE 18 : SUMMARY OF DATA ON SHOAL GROUP OBSERVATIONS FOR 1971/72 ESTIMATE OF PILCHARD APPARENT ABUNDANCE

By 1972/73, the original concept had been expanded to include the length frequency distribution analysis (Fig. 21). Also, the catching experiment described in section 3.5 had produced a packing density value of 20 fish/m^3. The estimate of stock size was derived from seven shoal groups located between the Cunene River and Conception Bay. All except the one sampled in January 1973 were sampled in December 1972. The surveys were sequential and thus the amount of confusion on the identity of shoal groups was reduced. Even so, the incidence of poor weather was high enough to demonstrate once again the inadequacy of a method which relied on locating and measuring each shoal group in one survey period.

The results are in Tables 19-25. The survey information is listed at the top of the tables. The lower sections describe the length frequency distribution, weighted by a factor to eliminate any bias caused through the different size of samples. The weighted number of fish in each length group is expressed as a % of the total catch and transformed to number of fish with the fixed value of packing density. Using the length/weight relationship for pilchard the weight of the fish in each length group is determined. The sum of these weights is the shoal group weight. The estimate of apparent abundance for 1972/73 was 3,04 million tonnes. The method used for the 1973/74 estimate involved a considerable change in survey strategy. The overall survey area was divided into three sections which were covered during three consecutive dark-moon periods. The strategy was very successful, particularily as two (or three on occations) research vessels were employed, which virtually ensured that synchronous surveys were made. The packing density value of 23 fish/m^3 obtained through the use of the Simrad high frequency

Location area	Date	Gross shoal area (km^2)	% Cover	Actual shoal area (Km^2)	Thickness (m)	Shoal volume (m^3) ($X10^6$)	Packing density (fish/m^3)	shoal fish number ($X 10^6$)
Ugab River to Sierra Pt	5/6-12-72	676,93	25	169,2	4,35	736,02	20	14720,4

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length Group	X004	X028	X045	X048	Number of fish in sample	Percentage of catch	Number of fish in shoal (10^6)	Weight of fish in shoal (tonnes)
85	0,00	0,00	0,00	14,93	14,9	.37	54,93	496,68
90	0,00	0,00	0,00	44,78	44,8	1,12	164,78	1 747,19
95	0,00	0,00	0,00	79,60	79,6	1,99	292,94	3 611,76
100	0,00	0,00	0,00	124,38	124,33	3,11	457,72	6 512,78
105	0,00	0,00	0,00	77,11	77,1	1,93	283,79	4 628,27
110	0,00	0,00	0,00	42,29	42,3	1,06	155,63	2 891,16
115	1,64	0,00	0,00	19,90	21.5	,54	79,29	1 668,42
120	4,93	0,00	15,87	2,49	23,3	,58	85,73	2 032,67
125	4,93	0,00	7,94	2,49	15,4	,38	56,52	1 502,89
130	4,93	0,00	0,00	0,00	4,9	,12	18,16	539,09
135	14,80	5,68	7,94	2,49	30,9	,77	113,75	3 755,03
140	29,61	1,89	39,68	2,49	73,7	1,84	271,11	9 914,32
145	64,14	0,00	7,94	4,98	77,1	1,93	283,58	11 447,10
150	93,75	5,68	0,00	9,95	109,4	2,73	402,54	17 877,70
155	65,79	18,94	15,87	12,44	113,0	2,83	416,00	20 264,58
160	65,79	70,08	31,75	37,31	204,9	5,12	754,14	40 177,80
165	69,08	79,55	111,11	54,73	314,5	7,86	1 157,25	67 246,28
170	106,91	79,55	396,83	124,38	707,7	17,69	2 604,25	164 634,69
175	103,62	90,91	198,41	104,48	497,4	12,44	1 830,55	125 595,13
180	77,30	96,59	119,05	92,04	385,0	9,62	1 416,77	105 257,84
185	47,70	83,33	39,68	52,24	223,0	5,57	820,49	65 865,16
190	54,28	51,14	7,94	32,34	145,7	3,64	536,14	46 410,19
195	82,24	70,08	0,00	19,90	172,2	4,31	633,76	59 042,33
200	54,28	119,32	0,00	17,41	191,0	4,78	702,93	70 349,59
205	44,41	96,59	0,00	4,98	146,0	3,65	537,20	57 654,06
210	9,87	75,76	0,00	12,44	98,1	2,45	360,88	41 465,77
215	0,00	39,77	0,00	4,98	44,7	1,12	164,68	20 225,12
220	0,00	11,36	0,00	2,49	13,9	,35	50,97	6 681,66
225	0,00	3,79	0,00	0,00	3,8	,09	13,94	1 947,35

TOTAL WEIGHT OF FISH IN SHOAL 961441,50 METRIC TONS

TABLE 19 : ESTIMATE OF APPARENT ABUNDANCE 1972/73
DATA FOR SHOAL GROUP 5-6/12/72 UGAB RIVER, SIERRA POINT

Location area	Date	Gross shoal area (Km^2)	% Cover	Actual shoal area (Km^2)	Thickness (m)	Shoal volume (m^3) (X10^6)	Packing density (fish/M^3)	Shoal fish no (X10^6)
Palgrave Point to Ugab River	6/7-12-72	365,72	27,6	100,9	4,3	433,87	20	8 677,4

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X008	X027	X038	X051	Number of fish in sample	Percentage of catch	Number of fish in shoal (x10^6)	Weight of fish in shoal (tonnes)
80	0,00	0,00	0,00	4,12	4,1	,10	8,94	68,30
85	0,00	0,00	0,00	16,48	16,5	,41	35,76	323,35
90	0,00	0,00	0,00	59,07	59,1	1,48	128,13	1358,62
95	0,00	0,00	0,00	82,42	82,4	2,06	178,79	2204,37
100	0,00	4,61	0,00	142,86	147,5	3,69	319,90	4551,79
105	0,00	11,52	0,00	125,00	136,5	3,41	296,16	4830,05
110	0,00	13,82	0,00	65,93	79,8	1,99	173,03	3214,39
115	0,00	8,06	0,00	49,45	57,5	1,44	124,77	2625,47
120	0,00	5,76	0,00	26,10	31,9	,80	69,11	1632,76
125	0,00	5,76	0,00	2,75	8,5	,21	18,46	490,75
130	4,71	8,86	0,00	0,00	12,8	,32	27,70	822,47
135	7,06	10,37	0,00	0,00	17,4	,44	37,81	248,07
140	14,12	5,76	0,00	1,37	21,3	.53	46,10	1685,93
145	42,35	10,37	0,00	1,37	54,1	1,35	117,35	4737,13
150	87,06	21,89	0,00	0,00	108,9	2,72	236,35	10496,77
155	110,59	41,47	0,00	0,00	152,1	3,80	329,88	16069,40
160	162,35	82,95	4,69	0,00	250,0	6,25	542,33	28893,28
165	131,76	77,19	0,00	0,00	209,0	5,22	453,29	26340,27
170	181,18	81,80	0,00	0,00	263,0	6,57	570,48	36064,58
175	150,59	130,18	23,47	2,75	307,0	7,67	665,98	45693,14
180	65,88	180,88	234,74	8,24	489,7	12,24	1062,42	78931,81
185	7,06	116,36	183,10	20,60	327,1	8,18	709,64	56966,94
190	7,06	42,63	187,79	43,96	281,4	7,04	610,53	52849,30
195	9,41	26,50	66,03	46,70	143,6	3,59	311,62	29030,84
200	16,47	21,89	89,20	93,41	221,0	5,52	479,36	47973,95
205	0,00	28,80	89,20	54,95	172,9	4,32	375,19	40266,33
210	2,35	36,87	75,12	59,07	173,4	4,34	376,17	43222,17
215	0,00	21,89	37,56	57,69	117,1	2,93	254,12	3120 ,13
220	0,00	3,46	9,39	23,35	36,2	.90	78,53	18293,10
225	0,00	0,00	4,69	6,87	11,6	,29	25,08	3504,18
230	0,00	1,15	0,00	4,12	5,3	.13	11,44	1700,68
235	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
240	0,00	0,00	0,00	1,37	1,4	.03	2,98	499,84

TOTAL WEIGHT OF FISH IN SHOAL 589806,50 METRIC TONS

TABLE 20 : ESTIMATE OF APPARENT ABUNDANCE 1972/73

DATA FROM SHOAL GROUP 6-7.12.72 PALGRAVE POINT TO UGAB RIVER

Location area	Date	Gross shoal area (km^2)	% cover	Actual shoal area (km^2)	Thickness (m)	Shoal volume (m^3) ($X10^6$)	Packing density (fish/m^3)	Shoal fish no. ($X10^6$)
Cunene River to Cape Frio	7/8-12-72	841,36	16,5	138,82	4,4	610,81	20	12216,2

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X 031	X 040	Number of fish in sample	Percentage of catch	Number of fish in shoal ($x10^6$)	Weight of fish in shoal (tonnes)
6,0	000	18,43	18,4	0,92	112,59	388,88
6,5	000	18,43	18,4	0,92	112,59	484,06
7,0	3,61	23,04	26,7	1,33	162,79	858,89
7,5	000	9,22	9,2	0,46	56,30	359,55
8,0	000	9,22	9,2	0,46	56,30	430,09
8,5	3,61	4,61	8,2	0,41	50,20	453,93
9,0	14,44	4,61	19,0	0,95	116,35	1233,69
9,5	3,61	000	3,6	0,18	22,05	271,87
10,0	7,22	000	7,2	0,36	44,10	627,51
10,5	10,83	000	10,8	0,54	66,15	1078,88
11,0	25,27	000	25,3	1,26	154,36	2067,57
11,5	32,49	000	32,5	1,62	198,46	4176,04
12,0	36,10	000	36,1	1,81	220,51	5228,48
12,5	18,05	000	18,1	0,90	110,25	2931,72
13,0	14,44	000	14,4	0,72	88,20	2618,62
13,5	000	000	000	000	000	000
14,0	10,83	000	10,8	0,54	66,15	2419,16
14,5	10,83	4,61	15,4	0,77	94,30	3806,64
15,0	21,66	000	21,7	1,08	132,31	5816,03
15,5	25,27	4,61	29,9	1,49	182,50	8890,38
16,0	32,49	9,22	41,7	2,09	254,75	13572,29
16,5	18,05	18,43	36,5	1,82	222,85	12949,80
17,0	10,83	69,12	80,0	4,00	488,37	30873,73
17,5	72,20	101,38	173,6	8,68	1060,27	72746,03
18,0	173,29	230,41	403,7	20,18	2465,84	183197,94
18,5	238,27	138,25	376,5	18,83	2299,80	184618,06
19,0	133,57	133,64	267,2	13,36	1632,17	141095,63
19,5	68,59	36,87	105,5	5,37	644,15	60010,19
20,0	7,22	46,08	53,3	2,67	325,58	32584,02
20,5	000	23,04	23,0	1,15	140,74	15104,67
21,0	000	46,08	46,1	2,30	481,48	32342,07
21,5	3,61	23,04	26,7	1,33	162,79	19993,48
22,0	3,61	18,43	22,0	1,10	134,64	17648,99
22,5	000	4,61	4,6	0,23	28,15	3932,19
23,0	000	4,61	4,6	0,23	28,15	4184,90

TABLE 21

ESTIMATE OF APPARENT ABUNDANCE 1972/73

TOTAL WEIGHT OF FISH IN SHOAL

870045,25 tonnes

Location area	Date	Gross shoal area (km²)	Percentage cover	Actual shoal area (km²)	Thickness (m)	Shoal volume (m³) (X10⁶)	Packing density (fish/m³)	Shoal fish no. (X10⁶)
Hoarusib River to Sand Table Hill	8/9-12-72	625,864	7,8	48,82	6,26	305,6	20	6112,0

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X 024	X043	X056	Number of fish in sample	Percentage of catch	Number of fish in shoal (X10⁶)	Weight of fish in shoal (tonnes)
3,0	9,55	000	000	9,5	0,32	19,45	10,30
3,5	23,87	000	000	23,9	0,80	48,62	38,80
4,0	69,21	000	000	69,2	2,31	141,01	161,07
4,5	124,11	000	000	124,1	4,14	252,84	397,21
5,0	66,83	000	000	66,8	2,23	136,15	284,91
5,5	14,32	000	000	14,3	0,48	29,17	79,23
6,0	2,39	000	000	2,4	0,08	4,86	16,77
6,5	2,39	000	000	2,4	0,08	4,86	20,90
7,0	2,39	000	000	2,4	0,08	4,86	25,65
7,5	000	000	000	000	000	000	000
8,0	000	000	000	000	000	000	000
8,5	2,39	000	000	2,4	0,08	4,86	43,97
9,0	9,55	000	15,27	24,8	0,83	50,55	536,03
9,5	2,39	000	38,17	40,6	1,35	82,62	1018,68
10,0	4,77	000	251,91	256,7	8,56	522,95	7440,80
10,5	33,41	000	419,85	453,3	15,11	923,44	15060,29
11,0	121,72	000	175,57	297,3	9,91	605,68	11252,11
11,5	212,41	000	91,60	304,0	10,13	619,38	13033,19
12,0	193,32	000	7,63	201,0	6,70	409,40	9707,36
12,5	54,98	000	000	54,9	1,83	111,83	2973,73
13,0	21,48	3,72	000	25,2	0,84	51,34	1524,05
13,5	9,55	3,72	000	13,3	0,44	27,02	892,10
14,0	9,55	3,72	000	13,3	0,44	27,02	988,22
14,5	7,16	000	000	7,2	0,24	14,59	588,84
15,0	000	000	000	000	000	000	000
15,5	000	22,30	000	22,3	0,74	45,44	2213,65
16,0	2,39	141,26	000	143,7	4,79	292,66	15591,99
16,5	000	234,20	000	234,2	7,81	477,14	27726,26
17,0	000	371,75	000	371,7	12,39	757,37	47879,39
17,5	000	133,83	000	133,8	4,46	272,65	18707,00
18,0	000	55,76	000	55,8	1,86	113,61	8440,28
18,5	000	11,15	000	11,2	0,37	22,72	1823,96
19,0	000	11,15	000	11,2	0,37	22,72	1966,81
19,5	000	3,72	000	3,7	0,12	7,57	705,58
20,0	000	3,72	000	3,7	0,12	7,57	757,98

TOTAL WEIGHT OF FISH IN SHOAL 191907,06 tonnes

TABLE 22

ESTIMATE OF APPARENT ABUNDANCE 1972/73

Location area	Date	Gross shoal area (km²)	Percentage cover	Actual shoal area (km²)	Thickness (m)	Shoal volume (m³) (X10⁶)	Packing density (fish/m³)	Shoal Fish number (X10⁶)
Sandwich Hbr. to Meob Bay	10/11-12-72	281,67	15,3	43,1	1,83	78,87	20	1577,4

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X002	X013	Number of fish in sample	Percentage of catch	Number of fish in shoal (x10⁶)	Weight of fish in shoal (tonnes)
11,5	000	1,45	1,5	0,07	1,14	24,05
12,0	000	000	000	000	000	000
12,5	000	000	000	000	000	000
13,0	000	4,35	4,4	0,22	3,43	101,81
13,5	000	8,70	8,7	0,43	6,86	226,41
14,0	15,08	24,09	41,2	2,06	32,46	1187,21
14,5	35,18	65,22	100,4	5,02	79,18	3196,27
15,0	50,25	178,26	228,5	11,43	180,23	8004,37
15,5	65,33	246,38	311,7	15,59	245,84	11975,69
16,0	85,43	297,10	382,5	19,13	301,70	16073,40
16,5	105,53	118,84	224,4	11,22	176,96	10282,86
17,0	160,80	40,58	201,4	10,07	158,83	10040,96
17,5	185,93	2,90	188,8	9,44	148,93	10218,11
18,0	150,75	1,45	152,2	7,61	120,04	8918,48
18,5	95,48	000	95,5	4,77	75,30	6405,01
19,0	35,18	4,35	39,5	1,98	31,17	2698,37
19,5	10,05	1,45	11,5	0,57	9,07	844,95
20,0	5,03	1,45	6,5	0,32	5,11	511,04
20,5	000	1,45	1,4	0,07	1,14	122,68

TOTAL WEIGHT OF FISH IN SHOAL 90471,66 tonnes

TABLE 23 : ESTIMATE OF APPARENT ABUNDANCE 1972/73

Location area	Date	Gross shoal area (km^2)	Percentage cover	Actual shoal arae (km^2)	Thickness (m)	Shoal volume (m^3) (X10^6)	Packing density	Shoalfish number (X10^6)
Swakopmund to Sandwich Hbr.	11/ 12-12-72	293,58	8,7	25,54	4,4	112,38	20	2247,66

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X034	Number of fish in sample	Percentage of catch	Number of fish in shoal (X10^6)	Weight of fish in shoal (tonnes)
16,0	5,18	5,2	0,52	11,65	620,45
16,5	5,18	5,2	0,52	11,65	676,73
17,0	20,73	20,7	2,07	46,58	2944,91
17,5	15,54	15,5	1,55	34,94	2397,10
18,0	46,63	46,6	4,66	104,81	7787,03
18,5	72,54	72,5	7,25	163,04	13088,38
19,0	124,35	124,4	12,44	279,50	24194,47
19,5	165,80	165,8	16,58	372,67	34718,50
20,0	259,07	259,1	25,91	582,30	58275,92
20,5	124,35	124,4	12,44	279,50	29997,13
21,0	82,90	82,9	8,29	186,33	21409,91
21,5	41,45	41,5	4,15	93,17	11442,54
22,0	25,91	25,9	2,59	58,23	7632,75
22,5	10,36	10,4	1,04	23,29	3253,80

TOTAL WEIGHT OF FISH IN SHOAL 218439,69 tonnes

TABLE : 24. ESTIMATE OF APPARENT ABUNDANCE 1972/73

Location area	Date	Gross shoal area (km²)	Percentage cover	Actual shoal area (km²)	Thickness (m)	Shoal volume (m³) (X10⁶)	Packing density (fish/m³)	Shoal fish number (X10⁶)
Sierra Point to Swakopmund	8/9-1-73	102,36	17,8	18,22	4,36	79,50	20	1590,00

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X030	X047	X060	Number of fish in sample	Percentage of catch	Number of fish in shoal ($X10^6$)	Weight of fish in shoal (t.)
7,0	000	000	11,72	11,7	0,39	6,21	32,77
7,5	000	000	15,63	15,6	0,52	8,28	52,89
8,0	000	000	23,44	23,4	0,78	12,42	94,90
8,5	000	000	50,78	50,8	1,69	26,91	243,37
9,0	000	000	89,84	89,8	2,99	47,62	504,89
9,5	000	000	160,16	160,2	5,34	84,88	1046,54
10,0	000	000	222,66	222,7	7,42	118,01	1679,09
10,5	000	000	136,72	136,7	4,56	72,46	1181,76
11,0	000	000	50,78	50,8	1,69	26,91	500,00
11,5	000	000	27,34	27,3	0,91	14,49	304,95
12,0	000	000	23,44	23,4	0,78	12,42	294,53
12,5	000	000	7,81	7,8	0,26	4,14	110,10
13,0	000	000	3,91	3,9	0,13	2,07	61,46
13,5	000	000	7,81	7,8	0,26	4,14	136,69
14,0	000	000	3,91	3,9	0,13	2,07	75,71
14,5	000	000	3,91	3,9	0,13	2,07	83,57
15,0	000	000	7,81	7,8	0,26	4,14	183,90
15,5	5,67	000	7,81	13,5	0,45	7,14	347,90
16,0	14,16	17,17	3,91	35,2	1,17	18,68	994,99
16,5	19,83	21,46	7,81	49,1	1,64	26,02	1512,22
17,0	31,16	7,25	7,81	116,2	3,87	61,60	3894,24
17,5	11,33	25,75	23,44	60,5	2,02	32,08	2200,73
18,0	33,99	51,50	19,53	105,0	3,50	55,66	4135,57
18,5	84,99	90,13	7,81	182,9	6,10	96,95	7732,85
19,0	101,98	163,09	35,16	300,2	10,01	159,12	13774,01
19,5	113,31	115,88	19,53	248,7	8,29	131,82	12281,00
20,0	229,46	167,38	11,72	408,6	13,62	216,54	21671,05
20,5	155,81	128,76	3,91	288,5	9,62	152,89	16408,84
21,0	133,14	90,13	3,91	227,2	7,57	120,41	13834,59
21,5	48,16	25,78	000	73,9	2,46	39,17	4811,01
22,0	14,16	21,46	000	35,6	1,19	18,88	2474,86
22,5	000	4,29	000	4,3	0,14	2,27	317,77
23,0	2,83	000	000	2,8	0,09	1,50	228,22

TOTAL WEIGHT OF FISH IN SHOAL 113251,75 tonnes

TABLE 25 : ESTIMATE OF APPARENT ABUNDANCE 1972/73

echosounder was used instead of that from the catching experiment. The survey data are listed in Tables 26-30.

Five shoal groups were located and measured between Cape Frio and Swakopmund. The estimate of apparent abundance for 1973/74 was 3,61 million tonnes.

Location area	Date	Gross shoal area (km²)	Percentage cover	Actual shoal area (km²)	Thickness (m)	Shoal volume (m³) (X10⁶)	Packing density (fish/m³)	Shoal fish number (X10⁶)
Hoarusib River to Sand Table Hill	20/ 21-11-73	991,45	2,36	23,40	4,15	97,10	23	2233,36

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X0035	X0036	X0037	number of fish in sample	Percentage of catch	Number of fish in shoal (X10⁶)	Weight of fish in shoal (tonnes)
16,0	5,71	000	6,91	12,6	0,42	9,40	500,80
16,5	11,43	6,29	36,87	54,6	1,82	40,64	2361,27
17,0	80,00	12,58	152,07	244,7	8,16	182,13	11513,99
17,5	125,71	88,05	258,06	471,8	15,73	351,25	24099,85
18,0	308,57	125,79	359,45	793,8	26,46	590,95	43904,30
18,5	251,43	289,31	115,21	655,9	21,86	488,32	39200,27
19,0	74,29	188,68	57,60	320,6	10,69	238,65	20658,08
19,5	51,43	150,94	6,91	209,3	6,98	155,80	14514,84
20,0	57,14	75,47	000	132,6	4,42	98,73	9880,40
20,5	22,86	37,74	000	60,6	2,02	45,11	4841,22
21,0	000	12,58	6,91	19,5	0,65	14,51	1667,23
21,5	5,71	6,29	000	12,0	0,40	8,94	1097,51
22,0	5,71	6,29	000	12,0	0,40	8,94	1171,35

TOTAL WEIGHT OF FISH IN SHOAL 175411,13 tonnes

TABLE 26 : ESTIMATE OF APPARENT ABUNDANCE 1973/74

Location area	Date	Gross shoal area (km^2)	Percentage cover	Actual shoal area (km^2)	Thickness (m)	Shoal Volume (m^3) (X10^6)	Packing density (fish/m^3)	Shoal fish number (X10^6)
Palgrave Pt. to Sierra Pt.	21/ 22-10-73	629,39	2,72	17,12	4,61	78,92	23	1815,18

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X0021	X0022	x0023	x0024	x0025	x0026	Number of fish in sample	Percentage of catch	Number of fish in shoal(X10^6)	Weight of fish in shoal (t.)
8,5	000	11,86	000	000	000	000	11,9	0,20	71,50	646,58
9,0	000	27,67	000	000	000	000	27,7	0,46	166,84	1769,06
9,5	000	17,79	000	000	000	000	17,8	0,30	107,26	1322,39
10,0	000	11,86	000	ooo	000	000	11,9	0,20	71,50	1017,41
10,5	000	39,53	000	000	000	000	39,5	0,66	238,35	3887,18
11,0	000	167,98	000	000	000	000	168,0	2,80	1012,98	18818,71
11,5	000	290,51	000	000	000	000	290,5	4,84	1751,85	36863,25
12,0	000	195,65	000	000	000	000	195,7	3,26	1179,82	27974,65
12,5	000	167,98	000	000	000	000	168,0	2,80	1012,98	26935,54
13,0	000	45,45	3,91	000	000	000	49,4	0,82	297,66	8836,89
13,5	000	11,86	000	000	000	000	11,9	0,20	71,50	2360,52
14,0	000	5,93	000	000	000	000	5,9	0,24	87,29	3192,22
14,5	000	000	3,91	000	000	000	3,9	0,07	23,56	950,86
15,0	000	000	000	000	8,73	000	8,7	0,15	52,67	2339,01
15,5	4,73	000	000	8,55	4,37	5,00	22,3	0,37	134,36	6544,95
16,0	4,37	000	15,63	12,82	4,37	15,00	52,2	0,87	314,65	16763,33
16,5	56,77	5,93	3,91	29,91	13,10	55,00	164,6	2,74	992,68	57683,44
17,0	65,50	000	39,06	81,20	48,03	85,00	318,8	5,31	1922,40	121529,94
17,5	196,51	000	136,72	175,21	48,03	220,00	776,5	12,94	4682,29	321255,13
18,0	240,17	000	191,41	166,67	48,03	165,00	811,3	13,52	4892,19	363462,00
18,5	157,21	000	207,03	136,75	17,47	135,00	653,5	10,89	3940,46	316324,13
19,0	65,50	000	109,38	68,38	74,24	65,00	382,5	6,37	2406,48	199655,63
19,5	39,30	000	85,94	34,19	205,24	55,00	419,7	6,99	2530,67	235762,00
20,0	61,14	000	82,03	64,10	244,54	50,00	501,8	8,36	3026,01	302842,50
20,5	56,77	000	70,31	85,47	152,84	55,00	420,4	7,01	2535,03	272068,50
21,0	30,57	000	19,53	81,20	96,07	55,00	282,4	4,71	1702,72	195642,94
21,5	21,83	000	11,72	34,19	26,20	25,00	118,9	1,98	717,24	88089,59
22,0	000	000	7,81	4,27	4,37	5,00	21,5	0,36	129,36	16957,16
22,5	000	000	11,72	8,55	4,37	10,00	34,6	0,58	208,84	29174,55

TOTAL WEIGHT OF FISH IN SHOAL 2 680 671,00 tonnes

TABLE 27 : ESTIMATE OF APPARENT ABUNDANCE 1973/74

Location area	Date	Gross shoal area (km²)	Percentage cover	Actual shoal area (km²)	Thickness (m)	Shoal volume (m³) (X10⁶)	Packing density (fish/m³)	Shoal fish no. (X10⁶)
Sand Table Hill to Palgrave Pt.	23/ 24-10-73	629,39	2,72	17,12	4,61	78,92	23	1815,18

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X030	Number of fish in sample	Percentage of catch	Number of fish in shoal (X10⁶)	Weight of fish in shoal (tonnes)
16,5	15,38	15,4	1,54	27,93	1622,73
17,0	15,38	15,4	1,54	27,93	1765,41
17,5	20,51	20,5	2,05	37,23	2554,68
18,0	20,51	20,5	2,05	37,23	2766,31
18,5	56,41	56,4	5,64	102,39	8219,83
19,0	107,69	107,7	10,79	195,48	16921,38
19,5	256,41	256,4	25,64	465,43	43360,36
20,0	251,28	251,3	25,13	456,12	45648,53
20,5	169,23	169,2	16,92	307,18	32968,13
21,0	76,92	76,9	7,69	139,63	16043,45
21,5	10,26	10,3	1,03	18,62	2286,52

TOTAL WEIGHT OF FISH IN SHOAL 174157,31 tonnes

TABLE 28 : ESTIMATE OF APPARENT ABUNDANCE 1973/74

Location area	Date	Gross shoal area (km²)	Percentage cover	Actual shoal area (km²)	Thickness (m)	Shoal volume (m³) (X10⁶)	Packing density (fish/m³)	Shoal fish number (10⁶)
Sierra Point to Swakopmund	31-10/ 1/11-73	516,68	5,18	26,76	4,0	107,04	23	2461,83

No samples taken.

Assumed mean weight of fish = 100 g

Shoal tonnage = 2461,83 X 100 = 246183 tonnes

TABLE 29 : ESTIMATE OF APPARENT ABUNDANCE 1973/74

Location area	Date	Gross shoal area (km^2)	Percentage cover	Actual shoal area (km^2)	Thickness (m)	Shoal volume (m^3) ($X10^6$)	Packing density ($fish/m^3$)	Shoal fish number ($X10^6$)
Cape Frio to Huarusib R.	26/ 27-11-73	2779,4	1,23	34,19	5,87	200,68	23	4615,59

WEIGHTED LENGTH FREQUENCY DISTRIBUTION OF EXPERIMENTAL CATCHES

Length group	X0036	X0042	X0043	Number of fish in sample	Percentage of catch	Number of fish in shoal($X10^6$)	Weight of fish (t.)
16,0	6,91	21,28	ooo	28,2	0,94	43,37	2310,57
16,5	36,87	47,87	28,57	113,3	3,78	174,33	10130,15
17,0	152,07	202,13	79,37	433,6	14,45	667,07	42169,75
17,5	258,06	377,66	212,70	848,4	28,28	1305,32	89559,22
18,0	359,45	244,68	365,08	969,2	32,31	1491,15	110784,41
18,5	115,21	101,06	161,90	378,2	12,61	581,84	46707,33
19,0	57,60	5,32	117,46	180,4	6,01	277,53	24023,36
19,5	6,91	ooo	34,92	41,8	1,39	64,36	5996,03
20,0	000	000	000	000	000	000	000
20,5	000	000	000	000	000	000	000
21,0	6,91	000	000	6,9	0,23	10,64	1221,97

TOTAL WEIGHT OF FISH IN SHOAL 332902,88 tonnes

TABLE .30 : ESTIMATE OF APPARENT ABUNDANCE 1973/74

4.1 THE VALIDITY OF THE DIRECT VIEWER METHOD

The simplest approach to evaluating the estimates of shoal group area is through an examination of the repeatability of aerial measurements upon a constant population. Since most of the biases are of biological origin and therefore liable to fluctuate widely, an acceptable agreement between replicate estimates would indicate not only that the precision is tolerable but also that the biases are not so large as to invalidate the method. Although no surveys have been accomplished specifically to test precision, five replicate measurements of single shoal group areas occur within the survey data (Table 31).

TABLE 31. REPLICATE SURVEYS: SHOAL GROUP AREA

Date	Area of shoal group Km^2
7/12/71	330
8/12/71	332
15/12/72	535
16/12/72	494
17/12/72	473
13/05/72	767
14/05/72	481

The groups were surveyed on successive nights and, in one case twice in the same night (Fig. 32). The areas measured on the same night varied by 17%. Unfortunately, no shoal thickness or percentage cover measurements were made on these groups, but if it is assumed that the vertical and horizontal distribution of the fish did not change significantly between

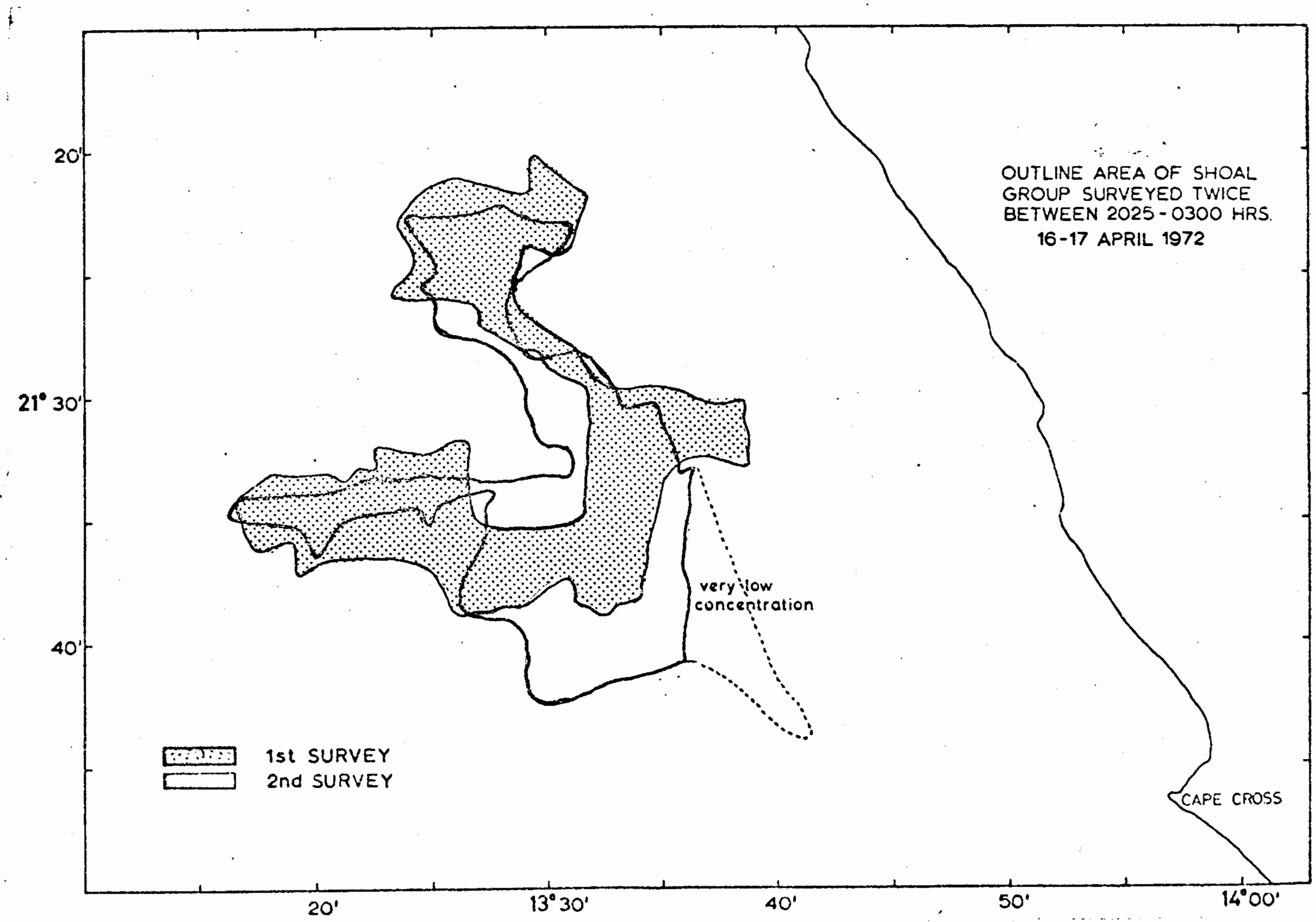


FIGURE 32 : Outlines of a shoal group surveyed twice between 2025-0300 16-17 April 1972

replicate surveys, the measured areas should be comparable. On this assumption, the comparatively good agreement between the replicate estimates points towards the validity of using the bioluminescent area as a measure of fish abundance.

One shoal group was covered by the full range of aerial and acoustic observations on two occasions four days apart in December 1971 (Table 32).

TABLE 32. OBSERVATIONS CARRIED OUT ON THE SAME SHOAL GROUP.

Date	area of shoal group (km^2)	mean fractional cover of shoals	mean shoal thickness (m)	Total volume of fish in shoal group (km^3)
12/12/71	474	1,3	12,4	0,076
16/12/71	284	4,5	6,1	0,078

There are wide variations in the area and fractional (%) cover measurements, yet the values of shoal volume are extremely close. The closeness may be fortuitous, as the possible ranges of errors in the component measurements are large, but the agreement does provide further evidence that the aerial method of measuring relative abundance may be valid.

4.1.1. ESTIMATION OF ERRORS

A. AERIAL MEASUREMENTS OF SHOAL AREA

As it is not possible to measure all shoals in any one aerial survey, the population is sampled on a number of regularily spaced survey lines, introducing a random sampling error which increases with the degree of patchiness of the shoals. In addition to this are random errors in the physical measurement of the luminescent areas due to an element of subjectivity which leads to a poor estimate of percentage cover. The random error in the estimate of total visible shoal luminescence can be assessed statistically as follows. If a shoal group extending a distance D in the north / south direction is surveyed on N east / west lines, the total area, A, of luminescence in the shoal group can be estimated from

$$A = \frac{D}{N} \sum_{i=1}^{N} li \quad pi$$

where A is total area

N is the number of E/W lines

D is the N/S distance

li is the length of line i

pi is the percentage cover on line i

A_t the total area of luminescence is obtained by summing A over all the groups comprising the stock.

Assuming negligible random errors in D for each of the groups, the standard error in A_t is given by the standard error in the mean of li pi. As an example, the standard error in A_t for the 5 shoal groups in Figure 20 has been calculated. The five groups were surveyed on 53 East/West lines averaging

2,4 n. miles apart. The mean of li pi was 0,26 n. miles and the SD 0,16. A Chi-square test for goodness of fit showed that the distribution of li pi was not significantly different from a normal distribution ($0,10 < p < 0,20$) so statistics appropriate to the normal distribution were assumed.

The values of li pi were not statistically independent because of the patchy distribution of the shoals within the shoal groups. For Example, considering the two largest shoal groups in Figure 20, the northern one being group 1 and the southern, group 2, the auto correlation co-efficients between li pi values for adjacent lines with a line spacing of approximately 2 n. miles was 0,413 for group 1 and 0,223 for group 2. These weakly positive auto-correlation co-efficients indicate that a relationship exists between the data collected on adjacent lines. That is to say, not all of the information collected is new, as the li pi values were only effectively independent at line spacings of 3,5 to 4,0 miles, that is, when alternate lines were compared. This is expressed in Fig. 32 which shows the auto-correlation between li pi values for different line spacings, from 2 n. miles apart (adjacent line) to 13 - 15 n. miles apart (7 or 8 line separation) for each shoal group. A weak positive correlation exists on adjacent lines at 1,8 n. miles apart, zero correlation at 3,6 n. miles apart (that is, 100% new information on each line) and a weak negative correlation at about 7 miles which demonstrates that a high abundance of bioluminescent shoals in one area is associated with a low abundance in another. That is, the shoals have a patchy distribution within the shoal group.

Taking the mean auto-correlation co-efficient for adjacent swathes 2,4 n. miles apart as 0,2 for the 5 shoal groups (Fig. 20), the standard error in A_t was calculated to be 0,0223 using an expression derived by MacCall (1975):

$$S\bar{x} = \frac{S}{N(1-r^2)}$$

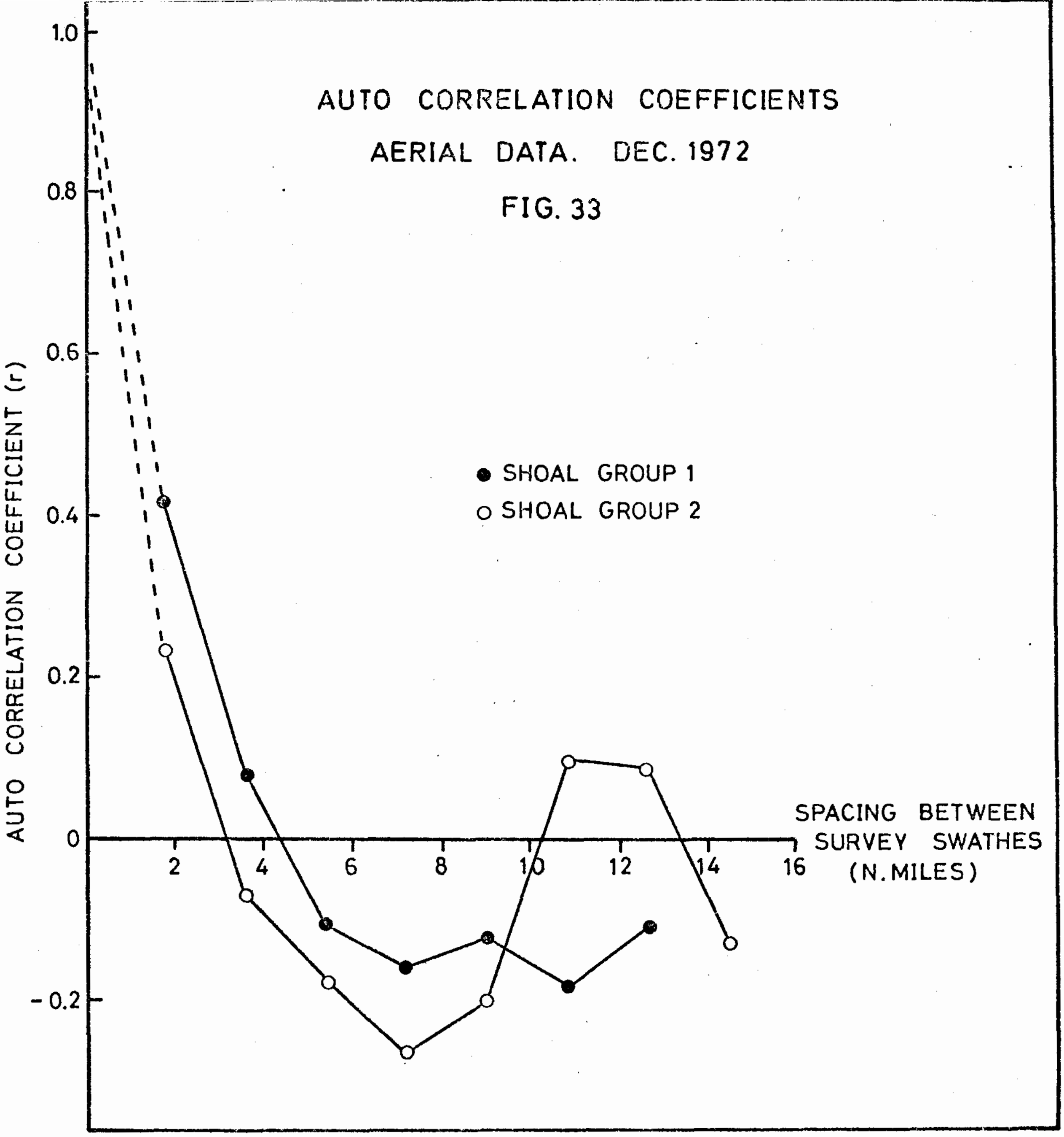
where Sx is the standard error in the mean

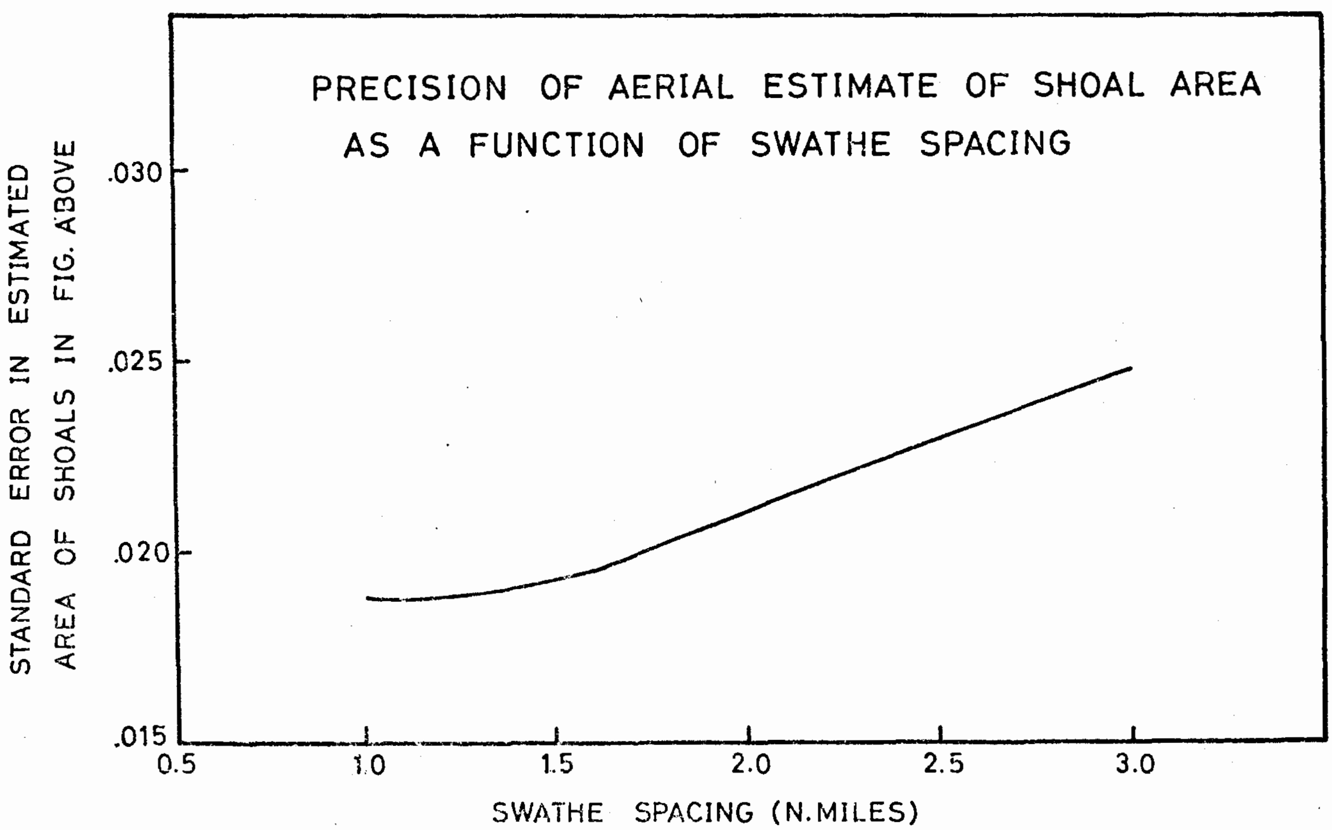
S is the standard deviation in a single sample

r is the autocorrelation co-efficient.

The standard error in A_t (the estimate of total shoal group area) is less than 20% at the 95% confidence level. The effect on the standard error of decreasing or increasing the intensity of the survey can be roughly estimated from Fig. 33, which shows the precision of A_t as a function of line spacing. The precision decreases slightly with increasing line spacing. The standard error in each case was calculated from MacCall's expression taking for r the appropriate mean value from the two graphs in Figure 33.

The method requires that effectively all the fish shoals be visible from the air, and assumes that the bioluminescence areas observed accurately represent the horizontal areas of the shoals. There are a number of possibilities for bias. Shoals may be partly or totally invisible if the concentration of luminescent organisms is too low. This is not a serious source of bias as it appears from sections 1.1 and 1.2 that there are sufficient luminescent forms present on the fishing grounds to illuminate the fish shoals. It is noted in section 1.4 that at no time in the year do aerial observers or fishermen


AUTO CORRELATION COEFFICIENTS
AERIAL DATA. DEC. 1972
FIG. 33
SHOAL GROUP 1
SHOAL GROUP 2
AUTO CORRELATION COEFFICIENT (r)
1.0
0.8
0.6
0.4
0.2
0
- 0.2
2
4
6
8
10
12
14
16
SPACING BETWEEN SURVEY SWATHES (N.MILES)


PRECISION OF AERIAL ESTIMATE OF SHOAL AREA AS A FUNCTION OF SWATHE SPACING
STANDARD ERROR IN ESTIMATED AREA OF SHOALS IN FIG. ABOVE
.030
.025
.020
.015
0.5
1.0
1.5
2.0
2.5
3.0
SWATHE SPACING (N.MILES)

experience difficulty in locating bioluminescence shoal for any length of time. The exhaustion of the bioluminescence system may render parts of the shoal invisible, but this has yet to be convincingly demonstrated. Any bias would be negative.

The shoals may be too deep to be seen from the air. As reported in section 1.5, a diurnal vertical migration brings 74% of the shoals into the visible zone. This is an underestimate due to the failure to detect shoals shallower than the transducer, so it is tentatively estimated that 80% or more of the shoals will be in the visible area. This is not a quantitative argument, but does indicate that the problem of the shoals lying too deep to be detected is not severe. The bias would be negative.

When shoals of different species aggregate into a common shoal group it is not always possible to discriminate between species from the air. A crude correction is made according to the percentage by weight of pilchards in sample catches made under aerial guidance in the shoal group area. The average percentage in 84 research catches was 82,7% pilchard. It appears reasonable to assume that applying a correction of this nature should at least halve any error, in which case the residual species mixing error in the corrected estimate would be less than ± 10%. Using these plausibility arguments, together with the indirect quantitative evidence suggests that the extent of total bias in the aerial method may not exceed ± 25%.

B. SHOAL THICKNESS MEASUREMENT

The echosounders used in the past for measurement of shoal thickness were uncalibrated and subject to many errors and biases. Corrections have not been possible in all cases and the overall bias is not known. Echosounders over-estimate shoal thickness, but this was not known at the time, and results in a positive bias. The use of the horizontal dimension weighting factor introduces a negative bias. Shoals partly or completely above the transducer will not be detected, giving negative bias.

C. PACKING DENSITY

As detailed in section 3.5, no estimate of the error could be made, but attention was drawn to the sources of bias. Chief among these are the effect of escapement of fish from the net which gives a negative bias to the estimate, and the utilisation of a single value for all length groups which will induce bias of either positive or negative polarity.
In summary, the precision of the aerial measurement of shoal area appears to be of the order of 20% at the 95% confidence level. The bias in the aerial measurements has been estimated as less than ± 25%. The random errors and bias in shoal thickness and packing density were not evaluated, hence there is no estimate of the overall accuracy of the method. No further attempts will be made to establish the accuracy of the measurements of packing density of shoal thickness as in future these parameters will be determined by calibrated echosounder, which supersedes the catching experiment/fishing echosounder approach (see section 4.2 and 4.3).

4.1.2. COMPARISON OF RESULTS WITH THOSE FROM OTHER METHODS.

Since 1970 estimates of stock size have been made from independent sources at irregular intervals. These values are not directly comparable with that obtained from the direct-viewer method as all three are sampling different elements of the stock, namely: the direct viewer only censuses shoaling fish approximately 10 cm (0-1 year) and greater; the virtual population analysis (V.P.A.) only applies to recruited year classes 4 years old and greater; quantitative egg sampling leads to an estimate of the spawning stock size. Nonetheless, the different estimates should show similar trends. Fig. 34 displays the estimates in graphical form. The aerial/acoustic estimates of stock size fall between the estimates from the other two methods. The accuracy of estimates of spawning stock size are half to double the calculated value at the 95% confidence level. There are no estimates of accuracy or precision for the results from virtual population analysis.

The trends are similar but the biases in the egg data and VPA are not known. Although reservations are expressed in Section 5 concerning the validity of VPA data for years earlier than 1970, it must be pointed out that the post-1970 data may be more reliable. Even so, the extent of any bias in the estimates of stock size are not known. Hence no reliable estimate of the absolute accuracy of the aerial/acoustic method can be made by comparison with these other data, as no fixed point of reference is available. The similarity in trend is encouraging, however.

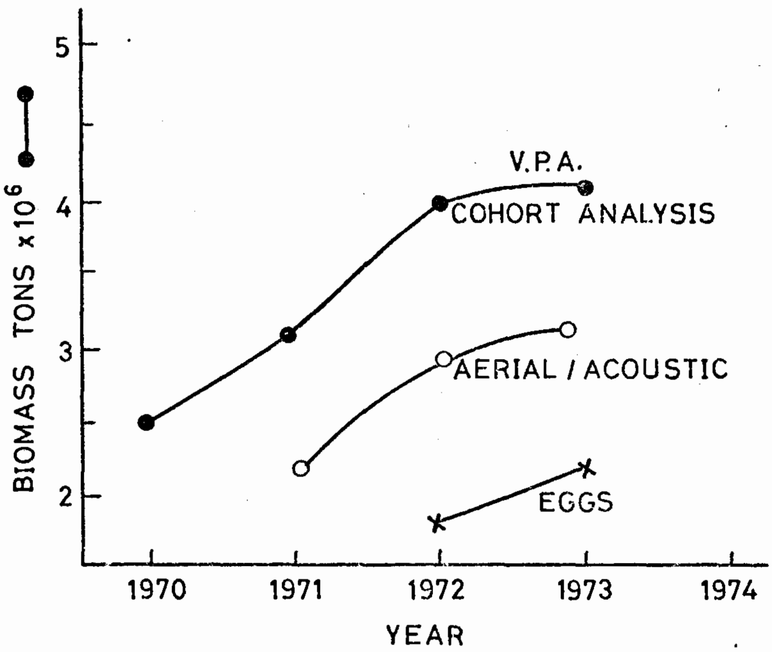


FIGURE 34. Stock size estimates for pilchard. VPA (Newman et al 1974) Quantitative egg collection King (1974).

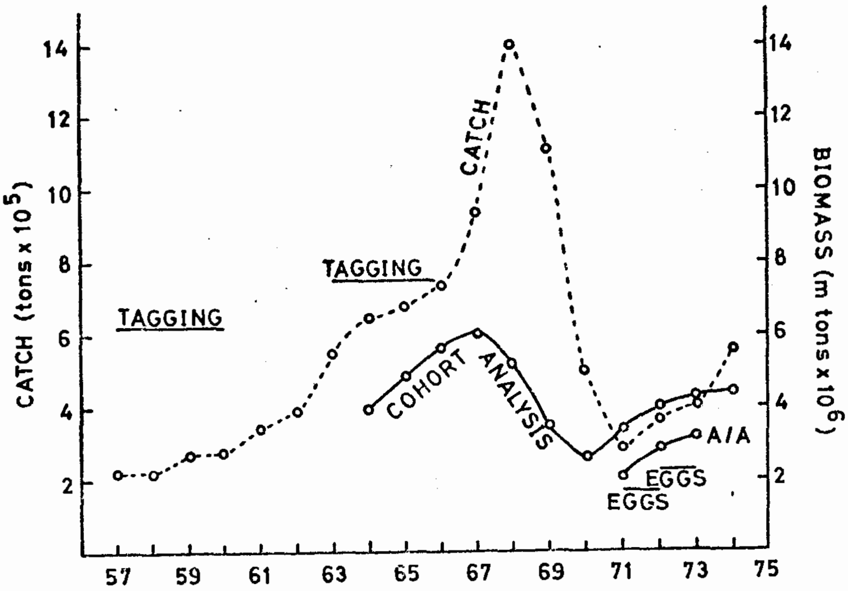


FIGURE 35. Estimates of stock size (pilchard) and catch SWA 1957 - 74.

4.2 RECENT DEVELOPMENTS

In the modern aerial/acoustic survey, the precision will be improved through the use of sophisticated LLLTV and acoustic equipment whilst the worst sources of bias will be constantly evaluated.

The LLLTV, because it provides recorded imagery of the fish shoals, allows objective measurement of the area of bioluminescence. The element of subjectivity involved in the direct viewer method is eliminated and thus any analysis of the aerial data becomes more meaningful. A design feature of the LLLTV system will be to make an unbiased measurement of individual shoal area with a precision of 10%. Use of the LLLTV will allow a more intensive survey programme, on a reduced time-scale. The saving in time will allow repetitive surveying of shoal groups giving data suitable for statistical analysis. Since the images will be recorded, reprocessing will become possible with more sophisticated analysis.

The use of LLLTV and, possibly, an automatic data processing system will provide data suitable for two dimensionsl modelling of shoal group space and time distribution, from which statistical survey errors can be estimated by simulation of different survey strategies. In this way, an optimum survey strategy can be developed to suit prevailing shoal group distributions.

The calibrated echosounder and automated digital data logger (Hampton and Glaum 1975) allows echoes from shoals to be recorded on magnetic tape for later statistical analysis. The mean shoal surface density (weight of fish per square meter of shoal surface area) is calculated from known calibration constants of the electro-acoustic system and a knowledge of the sound reflecting properties of the species in question. The sound reflecting properties of fish are extremely difficult to measure accurately so large errors are likely to occur in absolute measures of fish density. However, assuming that these properties remain constant, reasonable measurements can be made of the relative fish density in different areas and at different times.

A start on the statistical analysis of the acoustics data has already been made by Hampton (in press) who has produced a sample analysis of acoustic measurements made on a single shoal group during a 24 hour survey in February 1975. He showed that the precision in the estimated mean surface density of 92 shoals encountered at night was approximately 5% at the 95% confidence level.

The variance was 7 times greater than predicted theoretically (Moose 1971) for uniformly dense shoals, which indicated that the largest source of variance was probably the non-uniform distribution of fish within the shoals. The good precision of the estimate, however, indicates that variation in shoal surface density at night is not so great that a reasonable relative estimate of the mean cannot be made by sampling a small fraction of the shoals within the group. The statistical analysis gave some indirect information on the possible magnitude of biases arising from shoal reaction to the vessel and the exclusion of shoals shallower than the transducer (believed to be the most serious sources of bias in the relative estimates).

It was estimated that the total bias in the relative estimate could be kept to about 10%.

The overall precision of this new aerial/acoustic method can be estimated by projecting the above information to the five shoal groups shown in Fig. 20. It is assumed that the distribution of shoal density in February 1972 was typical and can be applied to a survey conducted at a different time. Assuming that approximately the same number of acoustics samples would be taken from each of the five shoal groups and that the distributions of density within the shoal groups would be similar, the precision in the estimate of mean surface density for the five groups can be derived from the precision obtained in surveying the single group in February, that is, the precision is 5% divided by $\sqrt{5}$, or 2,24% at 95% confidence interval.

Combined with the previous estimate of 20% for the precision in the aerial method of shoal area this gives a projected overall precision of 22% at the 95% confidence level.

If it is assumed from the argument in section 4.1 that the bias in the aerial measurements does not exceed 20%, then the total bias in the combined method will be approximately 30%. It is tentatively concluded that estimates of relative stock size accurate to ± 50% should be possible with the new method.

5.0 DISCUSSION

The rational management of pelagic fisheries is a most difficult task, and one which few nations have achieved, despite a considerable investment in research. The performance of the Peruvian anchoveta is a case in point where, despite a long time series of qualitative acoustic observations derived from the Eureka programme and considerable work on catch statistics by Peruvian and FAO experts, the quality of the results was such that at a critical period the management authorities were unable to resist economic argument for exploitation with a satisfactory scientific argument for conservation (Clarke 1975). South African administered pilchard fisheries have suffered two such declines for the same basic reason : a lack of hard data to convince an optimistic management system that conservation is necessary.

Many of the population dynamics methods have their origin in the 1940's (e.g. Ricker 1941) and have been steadily developed thereafter, until today there are a number of techniques available to the pelagic fisheries biologist. There were those who believed that there were better methods than monitoring the commercial catch and, following Hensen's (1895) proposals, large-scale egg and larvae surveys were mounted in the 1940's in an attempt to determine trends in fish populations (Sette and Ahlstrom 1948). In addition, during this period the use of acoustic equipment for scientific use was suggested, and in the late 1950's the early attempts at stock size estimation were made. Although the proponents of aircraft surveys had been active since the 1920's it was not until 1963 that even a qualitative aerial fishspotter programme was initiated.

The development of a method of making quantified observations of pelagic fish shoals with either low-light-level television, image-intensifiers or direct viewers appears to be the only new direct approach to stock size estimation since the 1950's, although the method traces its history to 1919. It would have been possible to carry out the direct viewer method from 1919 onward, but the actual measurement of shoal size had to await the development and declassification of military night-viewing devices. It is certainly interesting that despite an obvious need for information, such a simple technique as described here has not been previously employed elsewhere. Perhaps the need was more clearly perceived in South West Africa where such a large proportion of the population depended completely upon the well-being of the fishing industry, thus motivating the management authorities more than in other fisheries in the past.

What has the aerial method provided for management? Principally, at a time of crises when information was urgently needed, a stock estimate of unknown accuracy was produced, which indicated that the stock may have been substantially reduced, and as a result of this work quotas were substantially reduced. The lack of error estimates was certainly an awkard factor, but the practicality of the method was established with a previously sceptical management authority. In a situation where catch statistics lacked conviction, the existence of maps detailing the distribution of shoals, together with estimates of their tonnage, was convincing. With succeeding annual surveys, it became quite apparent that the stock was recovering, and the performance of the fishery corroborated this. However quotas rose slowly as a cautious management philosophy had developed.

The industry is currently on a more sound footing.

In that one crises situation the method demonstrated its value, but in a more stable period, could improvements be made in the method to create a less crude input to management? In section 4.1 the random errors and bias are listed : an important fact is that all known sources of error and bias can be experimentally evaluated, which is extremely important considering that observations are made upon congregations of the entire shoaled stock. Thus a carefully controlled survey can result in a 15% area sample and a 0,09% acoustic sample producing an estimate of apparent abundance with a precision of ± 50% at the worst. The newest development in methodology requires only two measurements to be made, the actual shoal area from the LLLTV and the mean fish density from the acoustics equipment. Purse-seine samples complete the survey. The accuracy of the LLLTV measurements are currently unknown but likely to be high; the random sampling errors in both LLLTV and acoustics are likely to be low. The biases can be evaluated on synchronous survey, particularly easy being the largest source of bias in the estimate: the percentage of shoals in the visible zone. Either by examining acoustic data constantly and making cross-checks with aircraft observations or by measuring the turbidity of the water, a constant check on the depth of the visible zone will be possible. Increased sensitivity of the LLLTV will allow areas of low luminescence within the shoal to be seen and thus included in the measurements. The bias due to misidentification of shoals can be reduced by better training of aerial observers; however this source of bias is probably slight as the aerial/acoustic estimate is corrected by the weight percentage of pilchards in the experimental catches. The average percentage species composition in 86 research catches made during aerial/acoustic surveys was 83% pilchards, so although this correction is crude it serves to reduce the error considerably.

The acoustic measurements of shoal thickness and density, being physical measurements, are more easily quantified. Glaum and Hampton (1975) and Hampton (in press) have described equipment and methods which serve to reduce errors and bias in acoustic measurements made on fish shoals through the use of a sophisticated digital data logging system for the returned echo, and subsequent computer processing of that data. As previously stated the random sampling error is small and the bias negligable. The direct viewer method did not have the benefit of advanced acoustic techniques and the shoal thickness measurements were corrected in favour of the more numerous small shoals with a weighting factor incorporating horizontal dimension which itself introduced bias which could only be evaluated empirically. The new technique does not require a shoal thickness measurement as such, only a mean fish density measurement, (number of fish/m^2 of the shoal thickness) so this source of bias is eliminated.

The extent and effect of shoal avoidance of a research vessel can also be experimentally evaluated by using a small vessel equipped with an echosounder to monitor the behaviour of shoals in an undisturbed state before the approach of a research vessel. The activity of the fish would be recorded by both sets of acoustic gear and enable the extent of avoidance of the vessel to be determined. Cram and Hampton (1976) have demonstrated that avoidance of towed acoustic vehicles is severe most probably due to the towing cable disturbing the fish. The acoustics system will be limited by the depth of the transducers, as at the normal depth of about 3m a portion of the shoals may be missed. The true depth of shoals would be determined in the two-ship survey described previously, but in a survey mode it is quite practical to have the transducer much nearer the surface. Alternative systems such as upwards sounding transducers or upwards-oblique sounders have their limitations due to the physical problems involved when fish are not insonified from above, as fish sound reflectivity is a function of the fish's attitude to the sound beam.

In general, too few purse-seine samples were taken during the aerial work, particularily in the north of the area. This logistics problem need not arise in future.

The case for the application of a new method to a fish population depends upon the way in which existing methods have been applied to the stocks and upon the quality of the results derived. When seen within the context of existing methods the advantages of the aerial/acoustic method becomes apparent. Especially obvious is the ease with which the sources of major bias in the aerial/acoustic method can be evaluated, when compared with the great problems existing in this area in other methods.

All the available estimates of stock size and the uncorrected pilchard catch since 1957 are depicted in figure 35. The vertical axes refer separately to the catch (left side) and biomass (right side). Three notable points emerge which have had considerable impact upon management and upon research attitudes and progress:

particularily if the tags were placed in representatives of the northern population. Although the increase in fishing area after 1964 would have reduced tag loss somewhat, emigration is a source of bias which would reduce the tag returns for the same landings and thus tend to inflate the estimates 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 ocellata* 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 and 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 x 10^6 tons for 1959-60 and 8,8 - 3,3 x 10^6 tons for 1963-66 (Table 33). The figures for 40% mortality are very similar to that reported by Newman (1970), namely 6,25 - 7,50 million tons.

TABLE 33. PILCHARD BIOMASS ESTIMATES FROM PETERSEN METHOD.

Year	Range of Biomass x 10^6 tons with initial tagging mortality		
	20%	40%	70%
1959-60	8,1	6,1	3,1
1963-66	8,9	6,4	3,3

The estimates of initial mortality do not include an estimate of sustained mortality due to tagging, which would serve to reduce estimates of stock size.

Baird, Newman, Ratte and Schülein (1972) point out that the estimates of total mortality for the period 1967-71 are higher than that of 0,7 calculated for the period 1963-66 by means of tagging and reported by Newman (1970) (Table 34).

TABLE 34. INSTANTANEOUS MORTALITY RATES (PILCHARD) 1967-71 (BAIRD ET AL 1972)

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 general decline in both 6/5 and 7/6 year-classes is consistent with a progressive decline in stock size over the period.

The discrepancy in calculated mortality rates for the consecutive periods by a factor of between 1,5 and 3,5 could also 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 pronounced effect of the large catches from 1966-68 suggest a high rate of exploitation on a smaller stock than the 6,25-7,50 million tons calculated, and that the high estimate resulted from a lack of evaluation of the principal errors and biases (Table 35).

TABLE 35. SOURCES OF BIAS IN TAG-RETURN STOCK SIZE ESTIMATE.

Source of bias	Result on Calculation of stock size estimate
Effect of emigration of tagged fish from recovery area	Inflates estimate size
Estimate of initial tagging mortality too low	Inflates estimate size
Lumping 1st and 2nd year recovery rates masking rapidly increasing 2nd year rate	Inflates estimate size
Didn't account for sustained tagging mortality	Reduced estimate

If the effect of these biases were taken into account, the initial tagging mortality would be an important factor and although the value may be extremely variable in practice, a value of 70% may be more applicable than one of 40%, and would have given a stock size nearer 3,0 million tons (Table 33).

Considering the trend in stock size between 1964-74 derived from virtual population analysis (Fig. 35). Schülein, Newman and Centurier Harris (1975) report a rapid increase in stock size between 1964-67 whilst the catch increased slowly at first then rapidly to 1968. 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 not impossible provided that an outstandingly large year class passed through the fishery. However, Schülein (1974) reported that recruitment was poor from 1965-67 and Newman (1970) reported that the stock was declining from 1963-66 but not severely, so in fact, the stock may not have been increasing as the virtual population analysis indicated.

If the levels of stock size reported for 1964-67 are too high the source of bias should be sought in the manner in which the basic data was acquired, namely, the manner in which the catch was made. As virtual population analysis is independent of fishing effort data and only requires the total number of fish of each age caught per year and a value for the co-efficient of natural mortality, bias can only exist in the catch data and the assumed value for mortality. In any case an error in the co-efficient of mortality becomes reduced in the earlier years in question 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. Fig. 20 shows a typical distribution of pilchards off South West Africa with shoal groups spread along the entire coast. Schulein (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 of class four, only this and older groups were used in the VPA. Between 1959 and 1964 the fishing area was small, being an area of about 900n. miles^2 around Walvis Bay, so that many shoal groups were unlikely to be represented in the fishery, and the juveniles would have been poorly represented. After the search area had expanded after 1964, the other shoal groups would have become incorporated into the catch, as would be more juveniles.

This substantial alteration in fishing pattern, from a search area of 900 to 2 800n. miles^2, affected the basic data: the estimates of stock size made each year in the expanding fishery may not be comparable, as each may refer to a different management area covering part of the range of the stock.

TABLE 36. SEARCH AREA/YEAR (FROM NEWMAN 1970)

Year	1959	1960	1964	1965	1966
Search area (sq. naut. miles)	899	549	548	2110	2771

Therefore each increase in area could have introduced a bias towards a larger population size. The increase in population shown for the period of increasing catches probably refers more

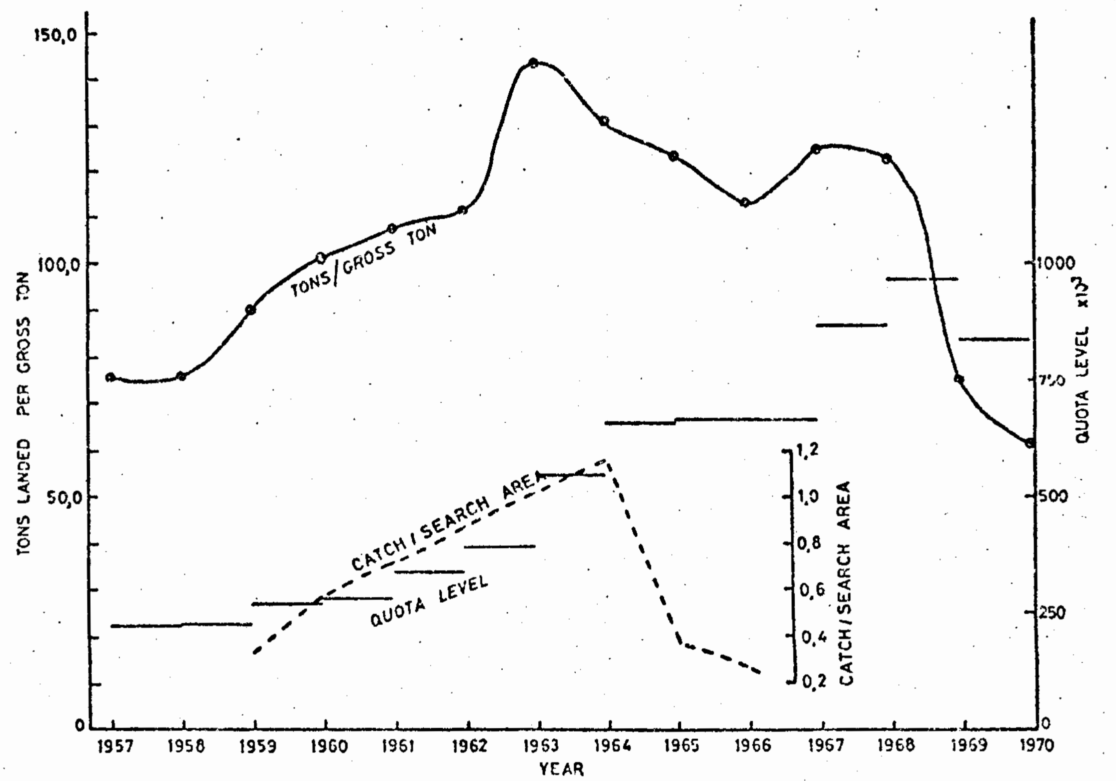


FIGURE 36. Indices of cpue and quota levels 1957-70.

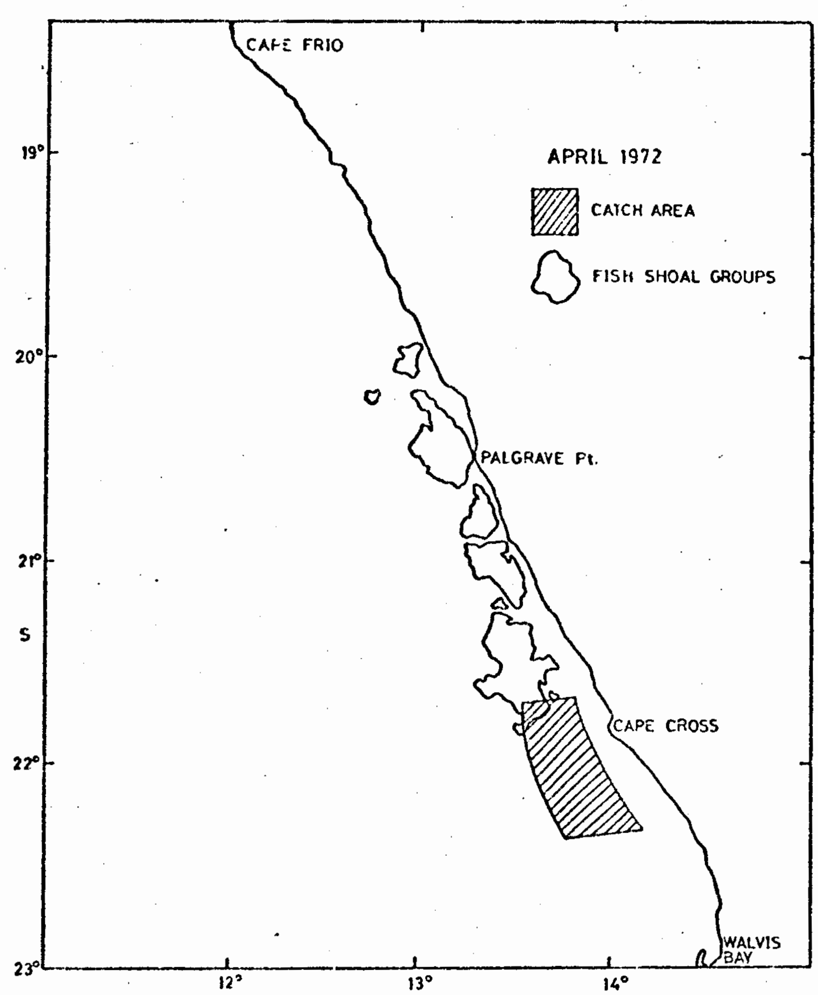


FIGURE 37. Distribution of shoal group and and catch position frequency April 1972.

shoal group due to information exchange by radio. Fig. 37 illustrates a situation in April 1972 where the catch area was distributed at the southern end of one shoal group whereas other shoal groups were present to the north. No randomising of search occurred : the vessels travelled to a known fish occurrence, made a catch and returned. This localisation of effort causes bias and error in the analysis of cpue, for the movements of shoal groups north or south may have a considerable impact upon effort, greater than any short-term change in abundance. The analysis of cpue data to detect non-randomisation of fishing effort is almost impossible without prior knowledge of where the shoal groups are, thus all effort and cpue analysis on pilchard in South West Africa are biased through the effect of variable availability caused by shoal movements and restraints placed upon the fisherman by the requirements of the canneries.

More sophisticated analyses of catch per unit effort and effort run into more sophisticated problems of bias. Considering any multispecies fishery, effort will be distributed not at random but partially dependent upon the cannery requirements and the state of the fishing vessels' personal quotas. In addition if the multispecies catch per boat lunar month is used to calculate the fishing power of individual vessels then the effect of vessel storage capacity, engine horse power, vessel age, net dimensions, presence or absence of sonar must all be evaluated, (Newman, Crawford and Centurier Harris, 1974). In addition the skipper effect is important, reflected particularily in skill with the use of sonar. The effect of these parameters upon fishing power can be established by regression techniques but they have not been evaluated as such. Numerical evaluation of the errors and biases in such calculations is extremely difficult.

A further complication in catch statistics analysis is that long time-series of data are required, usually in excess of 5-7 years for effective analysis. In addition, the time series should be acquired during a stable period in the fishery. It is unfortunate that modern pelagic fisheries have shown themselves to be highly unstable : the Sardinops ocellata populations off Southern Africa are a good example in this respect. The source of error and bias in the aerial/acoustic method are identified (section 4.1) and some of the more obvious biases and errors in previous work on the South West African pilchard have been discovered. Comparison of the two analyses demonstrates that direct measurement techniques have many advantages over conventional techniques.

Firstly, the random and non-random errors in the aerial/acoustic method are amenable to evaluation, whereas those of conventional techniques are, in most cases, extremely difficult to evaluate. This is principally because the direct measure is made upon a large sample of the fish stock itself; the method is free of problems induced by space/time variation in stock distribution caused by factors such as environmental variation and free of problems induced by relying for data upon a sub-sample of the catch.

Secondly, the accuracy of any absolute estimate of stock size can be determined as well as the precision in any relative estimate. This is not the case for most conventional techniques where bias and error are unevaluated.

Thirdly, almost no previous knowledge of the fishery is required to make a direct estimate of stock size, but other techniques require substantial information drawn from the fishery for many years. In the case of the Southern African pilchard five to seven years was required, in a "stable" period, for effort analysis, and the South West African pilchard two three-year periods were deemed useable from a tagging programme lasting 11 years.

Fourthly, an aerial/acoustic survey can be accomplished in one to three months, so, logistics permitting, surveys could be conducted more than once per year. This gives scope for adjustments and improvements in methodology to occur as each survey is an independent unit with an unique result drawn from unique data. The biggest disadvantage of conventional techniques is that they usually have only one data set acquired over a large number of years. Thus no opportunity exists to acquire a new set of data incorporating improved methodology in data collection. Inadequate data cannot be improved upon very readily.

Fifthly, the short period of data acquisition required for the direct estimate ensures stability during data collection. The extended period required for conventional data collection makes it difficult to acquire a stable time-series in the data, considering the instability which most pelagic populations exhibit.

These factors, in themselves, are an excellent motivation for the use of this new technique on the South West African pilchard. On the other hand there are advantages in catch statistics analysis in that, apart from estimates of stock size, other important information on age distribution, mortalities, yield and effort distribution become available (always remembering that the basic quantity stock size is represented in most calculations as a number or an index). These data can be of great value to management, particularly in regulating fisheries subject to excess effort by boat limitation or other strategies.

The data incorporated into direct measurements of stock size also has valuable input to other research fields. The observations on shoal group location have been incorporated into ecological research which is made considerably easier by the knowledge of the exact location of shoals. The comparison of hydrological and biological data with shoal group distribution led to the development of a concept that the shoal groups occupied an intermediate zone between dense phytoplankton inshore and dense zooplankton offshore in an area where oxygen content was neither supersaturated nor depleted (Visser et al 1973). This over-simplified concept was useful in framing ideas for sophisticated ecological work where the shoal group itself would be monitored from the air whilst the full range of hydrobiological stations were occupied both around the shoal group and within it. Thus the ecological preferences of the pilchard would be more clearly understood as would the impact of a shoal group within the environment. This challenging project is only possible with aerial surveillance of the shoal group which would, in addition to providing geographical location, provide an estimate of tonnage.

A hypothesis has been developed suggesting that recruitment may be monitored with the aerial/acoustic method, providing that the 1 year old fish are shoaled. Although few surveys have been accomplished in the North, where the juveniles apparently predominate, shoals containing 0 and 1 year old fish have been sampled

In general, it has been shown that if shoals are visible to the eye, they will be recorded by the LLLTV as long as the systems limitation with respect to dynamic sensitivity are not exceeded.

Luminescence is already used for the detection of fish in the East Pacific, West Africa, Gulf of Mexico, Gulf of Maine, Mediterranean and Caribbean Seas, Australia, North Sea, Indian Ocean, Philippine Islands, the Antarctic and South Africa (fig. 8) all of which luminescence would be capable of detection by the present system. Thus increasing the sensitivity of the LLLTV system by one or two orders of magnitude would allow the detection of fish on a world-wide basis with the probable exception of those most sterile areas, which would undoubtedly lack pelagic fish in commercial quantities. It would also assist in eliminating certain sources of bias which relate to low levels of luminescence, such as dark areas in the shoal and shoals being at or below the level of visibility. In establishing a general case for luminescence detection it is worth pointing out that pelagic shoal fish tend to exist in relatively fertile areas where productivity is high thus increasing the potential for luminescence. The properties of luminescent systems within planktonic organisms are such that there are no physiological limitations to the ability to emit light in the numerous areas of the world where studies have been made. If a sufficient concentration of luminescent organisms exists, a fish shoal will be visible, as long as it is in the visible depth zone.

It is a feature of most pelagic fisheries that gross fish behaviour is similar. The fish collect in shoals of irregular shape and variable dimensions. A diurnal vertical migration

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It is a feature of most pelagic fisheries that gross fish behaviour is similar. The fish collect in shoals of irregular shape and variable dimensions. A diurnal vertical migration usually occurs, which brings the fish into the visible zone at night, where they are usually active enough to outline the shoal with bioluminescence. Most species are coastal and are amenable to echo-sounding surveys, except those inhabiting exceptionally shallow water, such as menhaden in the Mississippi Sound.

The ability to detect shoals through bioluminescence in so many areas of the worlds ocean and to detect and measure the dimensions of these shoals with currently available equipment establishes the aerial/acoustic method as potentially applicable to most pelagic fisheries. Many fisheries are suffering, and will continue to suffer from a lack of conventional data of adequate quality, and could be substantially assisted by a direct measurement technique. Particularily vulnerable are large fisheries such as the Peruvian anchoveta where the economic implications of inadequate methodology can be critical.

The utility of the method has been proven in the South West African pilchard fishery, for it is very doubtful whether the industry would have accepted such drastic quota restrictions unless they felt that the evidence was convincing. In this regard it is interesting that the Californian authorities are considering supplementing their co-operative fishspotter programme with a means for quantifying observations similar to that described in this work.

After living with this method for so long, it is difficult to remember that is is a new technique to fishery science and it is gratifying that other groups around the world have seen the potential, considered it cost-effective, and have started developing methods to suit their fisheries.

APPENDIX 1

AN ATTEMPT AT EMPIRICAL CALIBRATION OF THE METHOD.

As an analysis of the direct-viewer method seemed difficult, and further data were required, it was decided in August 1974 to attempt empirical calibration of the method. Although three estimates of stock size had been made, neither the accuracy nor the precision of these estimates were known. In theory this could be determined by capturing an entire shoal group after making the aerial and acoustic observations; in practice this is impossible due to the very large number of shoals and considerable tonnage involved. On the other hand, a shoal group is nothing but a concentration of a large number of small shoals, most of which can be caught by a commercial fishing vessel. Since the ratio of individual shoal dimension to shoal group dimension can be deduced, the accuracy of the measure of shoal group weight can be estimated. The precision of the method can be obtained through comparing the actual weights of a number of shoals with the weights calculated from aerial observations.

Through comparison of shoal tonnages calculated from survey observations (area, thickness, fish weight etc.) and the actual weights of the shoals obtained by catching and weighing, it was hoped to obtain a calibration factor with which to improve the estimate of stock size. The choice of shoal size for the catching experiment was critical. Figure 38 is a histogram describing the distribution of shoal size from 2 275 acoustic observations. The horizontal dimensions of the shoals are unlikely to be correct, but the correction factor proposed by the FAO (FAO 1970) is unlikely to be correct either, so rather

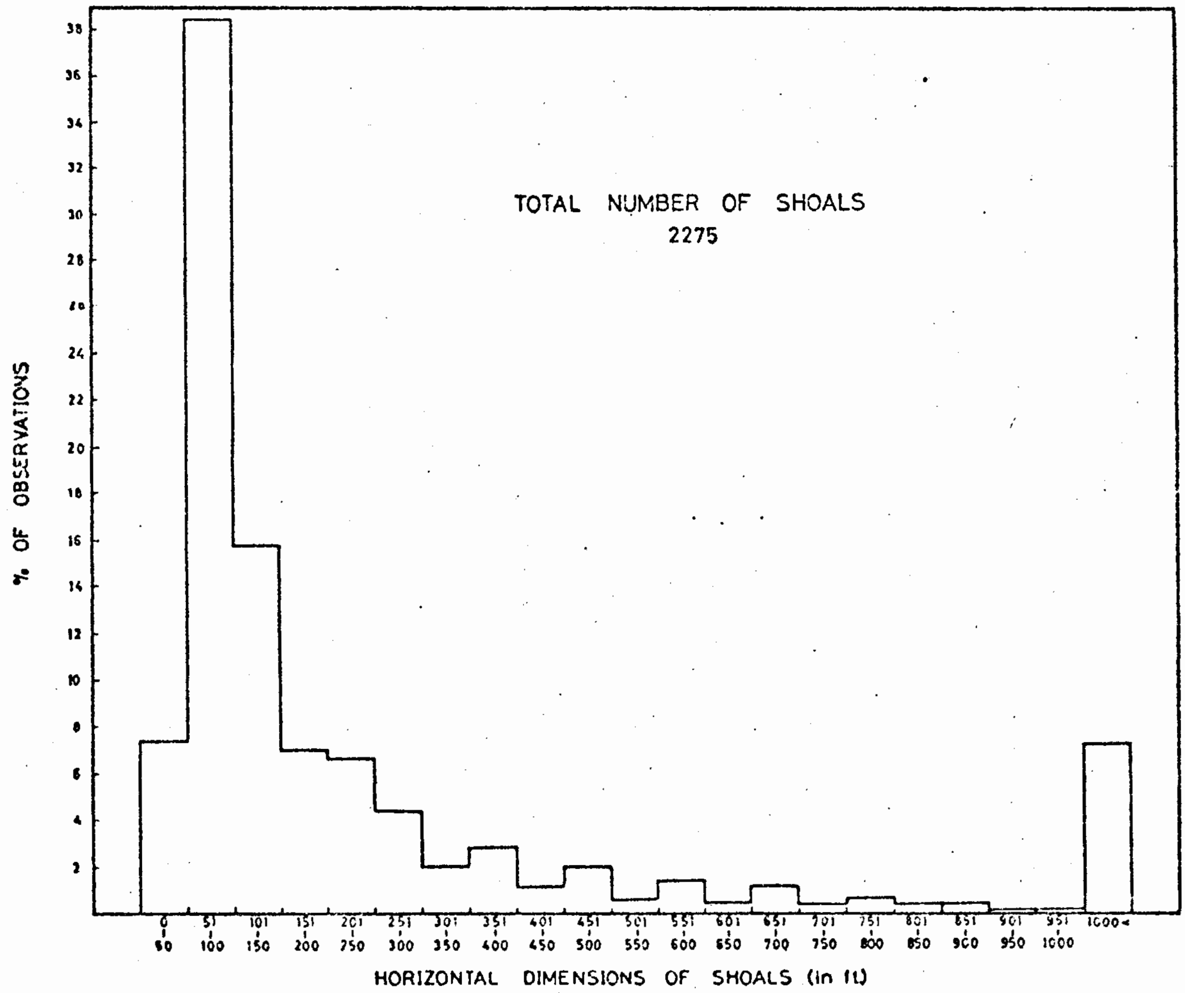

FIG. 38 APPARENT HORIZONTAL DIMENSIONS OF SHOALS
(in metres converted from ft.)

than alter all shoal sizes by a constant factor, the dimensions are left as measured. The shoal size distribution is interesting, particularly in the 7% of shoals of horizontal dimension > 328 m. These will probably represent parts of the super-shoals which are frequently observed. The frontispiece is part of an extremely large super-shoal. The most abundant shoals are those with an apparent horizontal dimension of 17 - 33 m.

In setting criteria on size-range for sampling, practical problems were encountered. While it is desirable that a calibration factor be derived from catches of shoals made over the normal horizontal dimension range for pilchard, this is quite out of the question. Table 37 is a table of calculated shoal weights for pilchard assuming the shoals are circular, have a thickness of 10 m, a packing density of 23 fish/m^3 and a mean fish weight of 100 g.

TABLE 37. CALCULATED SHOAL WEIGHTS

Shoal dia. (m)	Shoal area (m^2)	Calculated Shoal wt. (tons)
8	50	1
23	415	9
38	1 017	26
53	2 205	51
69	3 737	85
84	5 539	127
99	7 694	177
106	8 820	235

As it is essential that escapement of fish from the net be reduced to a minimum, an upper limit of around 100 tons was imposed, for above this weight (with the type and sizes of net involved) gear damage was possible and escapement through the unpursed net most likely. This placed an effective limit upon the size-range of shoals which could be sampled to the lower quarter of the distribution. However, such an experiment was still worthwhile as approximately 75% of the observed shoals in Figure 5, fall within the size range deemed catchable.

The suggested method for the calibration experiment was as follows:

(i) The aircraft will find a suitable shoal on the edge of a shoal group where the shoal concentration is low. This requirement is essential since it is very difficult to relocate a specific shoal in a densely populated area.

(ii) The aircraft will guide one of the boats toward the selected shoal and ensure contact.

(iii) Before the boat reaches the shoal a number of TV pictures of the shoal will be obtained.

(iv) On arrival at the shoal, a vertical echo-profile must be obtained, with a low gain setting on the echo-sounder.

(v) The boat should then catch the entire shoal, preventing escapement and seal activity through the use of explosive thunderflashes. Echo- and Sonar paper will be marked to correctly identify the shoal.

(vi) On arrival at the factory, the catch will be pumped out and weighed. A bulk sample will be collected as well as the log sheets and echopaper.

(vii) The bulk sample will be analysed for length and weight distribution.

Although based on experience and well-designed, the experiment failed due to a fault at the most important point: the TV camera. Having spent three nights in preliminary work with the fishing boats gaining understanding of any small problems and finding solutions, the TV camera failed when the experiment commenced in earnest. The fault was of a trivial nature, but it could not be fixed in time to revive the experiment. No calibration was accomplished.

It was found however that the experiment would work in practice, with one important change. The difficulty of guiding a vessel to one shoal and retaining contact with that one shoal and the vessel was nearly insurmountable. A much more simple method was to circle the aircraft in such a way as to regularly pass over the area of interest. obtaining an image of a number of shoals every two minutes. The fishing vessel would operate within this limited area, select a shoal of suitable dimension by sonar and catch it. Once the catching procedure has started and been video-taped, reference to preceding passes over the area will identify the as yet undisturbed shoal and its horizontal dimensions could be measured. This type of experiment is practical, given good weather and will undoubtedly be attempted again, with more reliable gear, off Cape Town.

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A proposed aerial/acoustic strategy for pelagic fish stock assessment

D. L. Cram and I. Hampton

Sea Fisheries Branch
Cape Town, South Africa

Aerial and acoustic observations on *Sardinops ocellata* shoals in the Southeast Atlantic show that the extreme patchiness of the shoals, the mobility of the fish and their tendency to avoid vessels, may invalidate the results of quantitative acoustic surveys on the stock. It is suggested that these survey errors can be reduced considerably by employing an aerial/acoustic strategy where the aircraft locates and measures the shoal area, and the vessel makes synchronous measurements of shoal thickness and packing density from as many shoals as possible. The combined data provide a direct estimate of stock size.

Introduction

In mid-1970 it became apparent that serious depletion had occurred in the commercially important stock of the Southeast Atlantic pilchard, *Sardinops ocellata* Pappé. Accordingly, the Sea Fisheries Branch of the Department of Industries launched a large multi-disciplinary research programme to determine the extent of the decline and to suggest appropriate management action (Cram and Visser, 1972). Since it was believed that population dynamics and catch statistics alone would not give sufficient up-to-date information to regulate a stock susceptible to rapid fluctuations, aerial and acoustic methods of measuring the stock size directly were introduced. The aerial method involves locating and measuring, at night, bioluminescent areas known to be caused by fish shoals near the surface (Cram, 1972; 1974). These observations are supplemented by synchronous measurements of shoal thickness made with standard fishing echo-sounders. A 120 kHz scientific echo-sounder and integrator with towed transducers has been used to determine the fish density within the shoals. Recently the integrator has been replaced by a digital data-logging system (Hampton and Glaum, 1975).

Initially it was intended to determine the horizontal distribution and area of the fish by independent aerial and acoustic techniques, so that the two methods would provide a check on one another. However, experience of pilchard distributions and shoal behaviour, gained mainly from aerial observations, have shown that independent acoustic determinations of shoal horizontal dimensions are susceptible to three survey errors which may be sufficiently severe to invalidate the results. These are:

1. the extreme patchiness of the shoals over the population's range;
2. the mobility of the fish;
3. the tendency of the shoals to avoid survey vessels.

These factors could invalidate results obtained from independent acoustic surveys upon any fish with shoaling behaviour similar to *S. ocellata*.

Due to the above survey problems and the fact that biological conditions in the survey area favour aerial observations, independent acoustic surveys have been abandoned in favour of a combined technique where the horizontal dimensions are determined from the air, and shoal thickness and fish density are measured synchronously by the scientific sounder and data-logging system.

Acoustic determination of shoal horizontal dimensions

Patchiness

In the coastal upwelling zone of the Southeast Atlantic, pilchard shoals are normally found grouped in a number of relatively large discrete areas varying considerably in size and distributed over the area in a generally unpredictable manner (Fig. 1). The shoal groups consist of aggregations of individual shoals (Fig. 2) in varying degrees of association with one another (Fig. 3). In making acoustic

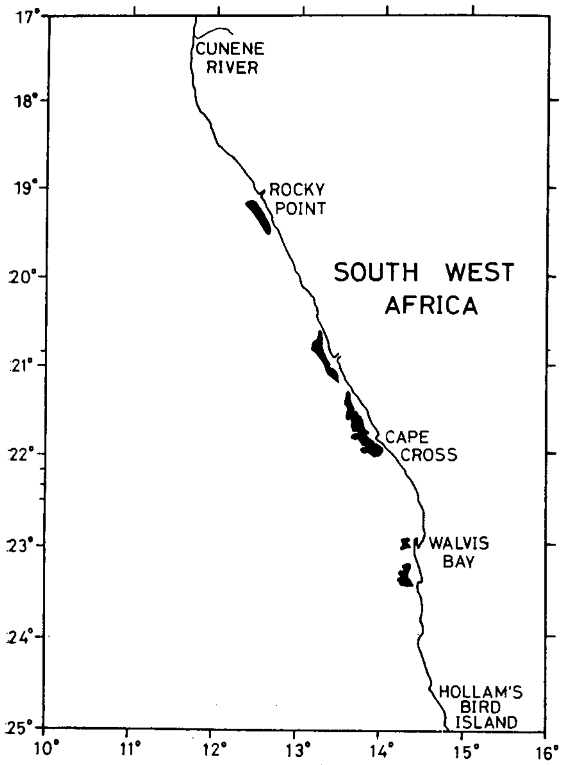

Figure 1. Pilchard shoal groups mapped by aerial survey, 3 to 12 December 1972.

stock estimates on patchy distributions of this kind, the approach commonly used for demersal fish, where the stock size is estimated from interpolations of abundance measurements along regular survey lines covering a widespread area (for example Cushing, 1968), will not necessarily be valid, as this method applies best to fish sparsely and continuously distributed over the survey area.

To examine this point quantitatively, we have simulated a number of such acoustic surveys on the pilchard distribution shown in Figure 1 and obtained the variance in the abundance estimates expected from each of the simulated surveys. A series of imaginary, but typical grids was superimposed on Figure 1 and fish abundance for each grid calculated from the intersection of the grid lines with detailed maps of the individual shoal groups contoured in categories of horizontal density (e.g. Fig. 3). It was assumed that on a transect across a contoured area a survey vessel would encounter fish over a fraction of the transect equal to the fractional cover of fish within the area. It is appreciated that this assumption may not be valid, particularly in areas of lower fractional cover, and that it would be more correct to use smaller scale maps showing the individual shoals. However, the shoals were too numerous to measure individually with the aerial technique employed at the time, so the above assumption was adopted, accepting that the variances would be underestimates reflecting only part of the sampling error.

The simulated surveys consisted of 4 series of rectangular grids chosen to cover the area from 17°00′S to 25°00′S on E/W lines 45 n m long and spaced 40, 30, 20 and 10 n m apart respectively. This covers the area of known pilchard occurrence. The ship's survey speed was taken as 5 knots which is our usual speed when towing transducers. (Although vessels employing hull-mounted transducers will travel faster than this, we have chosen to limit the simulation to our own conditions). At 5 knots the surveys would take approximately 8·5, 10, 13, and 22 days respectively to complete which covers a range of typical acoustic survey durations. Each series consisted of 10 grids, each displaced 0·1 of a line spacing to the south of the previous grid in the series. The displacements between successive grids in the 4 series were therefore 4·0, 3·0, 2·0 and 1·0 n m respectively.

The results of the simulation are shown in Table I. $\bar{A}$ is the mean area of the fish calculated from the 10 grids in the series and σ the corresponding standard deviation. ΔA is the difference between $\bar{A}$ and the area estimated from the actual aerial survey by measuring the contoured areas in Figure 3 and similar contour maps of the other shoal groups. This area was found to be 109 n m^2.

It will be noted that the means lie close to the aerial value and that as expected, ΔA decreases with survey length. The values of σ do not show as clear a trend, probably because 10 grids are insufficient to give a quantitative relationship between standard deviation and survey duration.

Table 1. Summary of simulated acoustic survey results. For further explanation see text.

Series No.	Line spacing (nm)	Grid duration (days)	$\bar{A}$	σ (n.miles^2)	ΔA
1	40	8·5	95	26	−14
2	30	10	117	43	8
3	20	13	105	39	−4
4	10	22	109	24	0

In order to determine whether the errors possible from a single acoustic survey would be acceptable for a stock estimate to regulate the fishery, we have taken as an example the decline of the Cape pilchard

Figure 2. Two individual pilchard shoals detected by low-light-level television camera. Photographed off videotape. Shoals approximately 500 m and 900 m long respectively.

(*S. ocellata*) stock between 1963 and 1966. Between these years the catch declined at an average rate of 35% per annum after being stable for three years (Stander and Le Roux, 1968; Baird, in press), and assuming that this was the rate of decline of the stock, a stock assessment technique sensitive to annual changes of say 25%, would have been necessary to decide that remedial action was necessary. Of the 40 simulated grids, 19 (47%) gave areas differing by more than 25% from the aerial value. These discrepancies represent errors in determining the area of the fish in Figure 1 from a discrete number of transects, and provided that the distribution is typical, the discrepancies are valid measures of the survey errors to be expected regardless of errors in the aerial estimate of shoal area used in the simulation.

The sampling errors demonstrated by this simple simulation are significant even though they represent only part of the overall sampling error. Although the simulation is of an acoustic survey on one known distribution only, it serves to demonstrate semi-quantitatively the sampling errors likely to arise from the patchy distribution of the fish.

Shoal mobility

A number of observations extracted from previously collected aerial data have shown that pilchard shoal groups may move considerable distances in the time required to complete an acoustic survey with towed transducers. One such case is illustrated in Figure 4 where a shoal group was observed to move 27 n m southward in 24 h, averaging approximately 1 knot. A vessel surveying this area on 45 mile long lines, 10 miles apart as in series 4 of the simulation, would also progress southwards at approximately 1 knot, and measurements of shoal horizontal extent would be meaningless. Even on the coarsest grid the speed southward would only be 2·3 knots and the north/south extent of the shoal would be overestimated by more than 40%. Errors of the same order would be introduced on northwards surveys. Although ship-board sightings, sonar, and a knowledge of general migratory patterns can give some indication of the general direction of shoal movement, this information is inadequate for any form of quantitative correction and only indicates

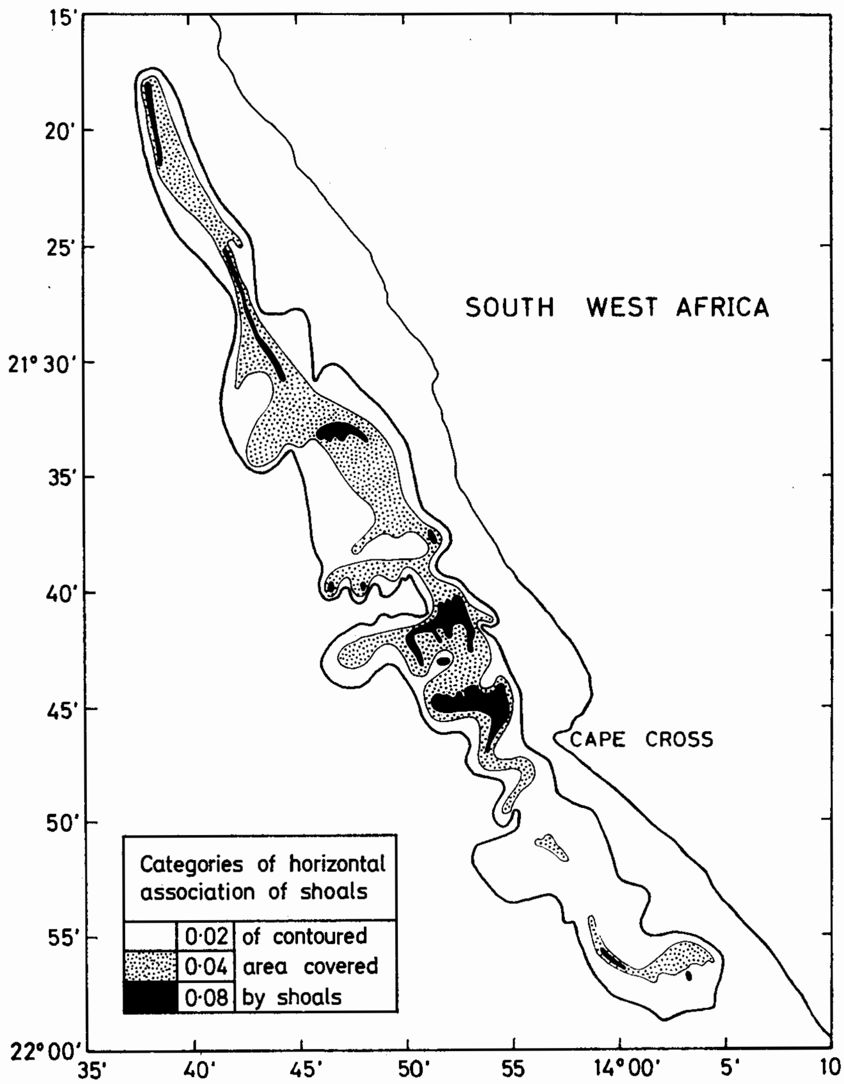

Figure 3. Distribution of individual shoals within largest shoal group in Figure 1. Map made from aerial survey, 5 December 1972.

whether measurements would be positively or negatively biased.

Shoal movement therefore constitutes a source of serious error which increases with duration of survey, so that the advantages of mounting longer surveys to reduce the statistical sampling errors described in the previous section are largely offset.

Shoal avoidance

From the air we have frequently observed pilchard shoals avoiding an approaching vessel by splitting in its path or turning to one side. Although we have no photographic evidence to prove that shoals have avoided survey vessels entirely, comparisons between echo-sounder recordings from a hull-mounted transducer and a transducer towed 130 m astern at the same time, have demonstrated that the towed transducer missed many shoals lying in the ship's track. During a survey from 16 to 18 May 1973, it was found that while 68 shoals were detected by the hull-mounted transducer, only 13 shoals and a few fragments were detected by the towed transducer.

Even more severe difficulty has been experienced in detecting pilchard shoals near the surface with an upward-sounding 120 kHz transducer towed at 15 m

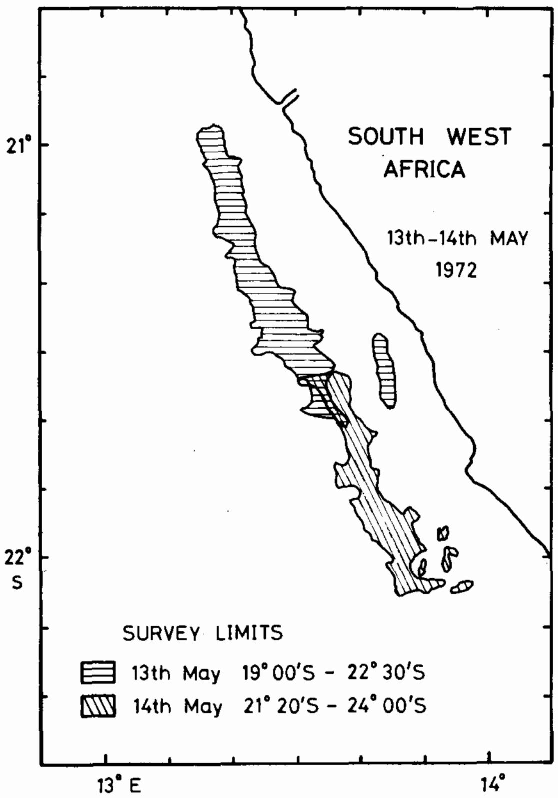

Figure 4. Southward movement of a shoal group in 24 h between 13 and 14 May 1972. Shoals mapped from aerial survey.

depth. Shoals have often not been detected even when known to be present from aerial and shipboard sightings, and it is concluded that shallow shoals in the path of the transducer are usually disturbed by the towing cable which must pass through the fish before the shoal is insonified.

These observations indicate that under our conditions, measurements of shoal horizontal cover obtained from towed transducers are not quantitative. Although shoal avoidance could probably be reduced by towing more slowly, both the statistical sampling errors and the problems due to shoal movement would be aggravated, and the overall accuracy would not necessarily be improved. Avoidance errors appear smaller if the hull transducer is used, but it is still not known whether the errors fall within acceptable limits.

Aerial shoal mapping

The above arguments show that it is preferable to remove from the vessel the responsibility for measuring the horizontal dimensions and distribution of the fish shoals. Fortunately this information can readily be obtained from aerial surveys. The technique has been briefly described (Cram, 1972; 1974), but for convenience the relevant parts are summarised here.

Initially, the entire survey area is surveyed sufficiently intensely to locate and delineate all shoal groups. Close surveys are then mounted on each shoal group in turn as follows. The bioluminescent outline of the shoal is roughly determined again, and a survey grid which will provide maximum coverage of the shoal group in the remaining dark moon period of the night, is drawn up in the aircraft. For convenience each swathe follows a Decca lane along which the aircraft's track is plotted on small scale Decca lattice charts (Fig. 5). On each swathe the bioluminescence is observed with a direct viewer, image-intensifier, or recently, a low-light-level television camera, and the fraction of the field-of-view covered by fish estimated each second. These observations are averaged to give the fraction of the swathe covered by fish, which together with a knowledge of the swathe width and length gives the area of fish shoals within the swathe. The area of fish within the whole shoal group is obtained by proportion from the sum over all swathes and the total area of fish by summing over all shoal groups.

The shoal groups shown in Figure 1 were surveyed in 10 nights of which 2 were lost due to poor weather. The close surveys on the shoal groups were considerably more intensive than possible with a survey vessel. For example, the large shoal group shown in Figure 6 was surveyed on 25 east/west lines on average 4·1 miles long and 1·8 miles apart. Total survey time was less than 3 h. At the survey altitude of 500 m the swathe was approximately 550 m wide so that 17% of the area of the shoal group was actually observed. In contrast, a survey vessel equipped with an echo sounder of 20° beamwidth steaming the same grid at 5 knots would complete the grid in 35 h while insonifying only 0·8% of the area at a depth of 10 m. 0,08

Statistical sampling errors are therefore greatly reduced by using an aircraft. In addition, errors due to shoal movement are almost negligible due to the relatively fast survey speed, and shoal avoidance problems are eliminated entirely.

All shoals must however be visible from the air if the aerial observations are to provide valid abundance estimates. We believe that this is not a serious objection in our circumstances, as echo recordings of 3931 pilchard shoals off the west coast of Southern Africa showed that at night fewer than 7% of the shoals were deeper than 8 m, which has been found to be the approximate limit of visibility under normal conditions. Shoals at depths of between 15 and 20 m

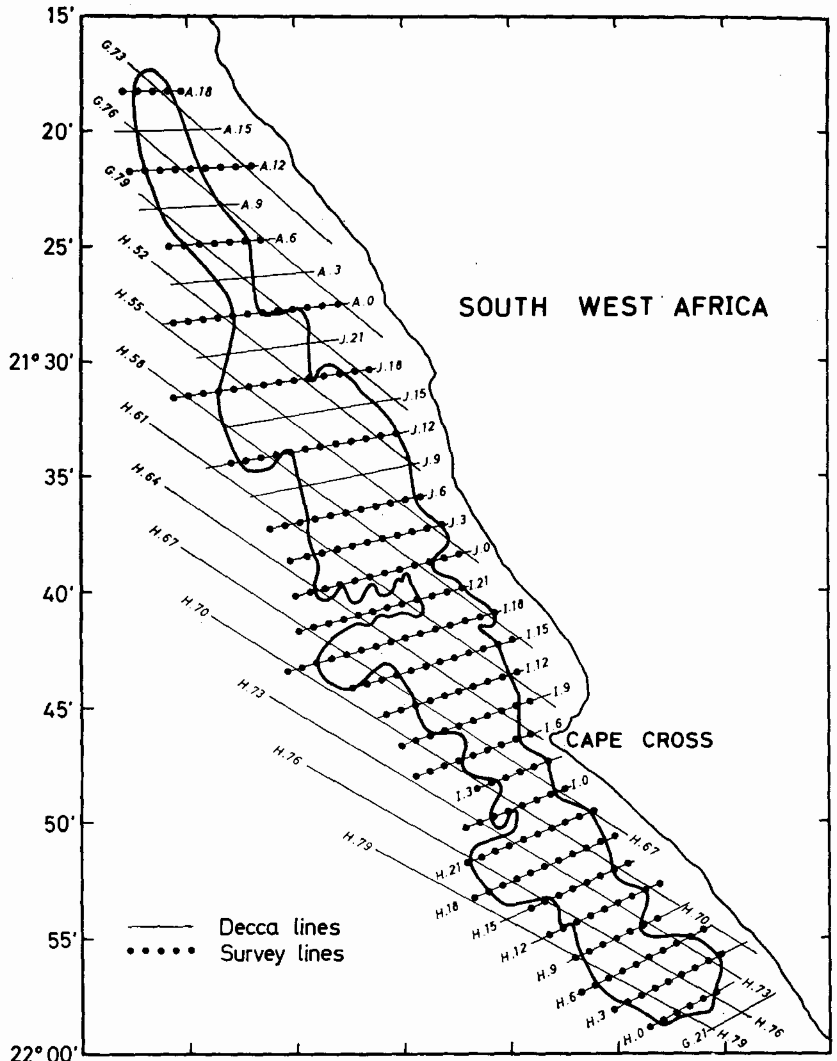

Figure 5. Grid employed in aerial survey of shoal group in Figure 3.

have been observed from the air on occasion. Furthermore, low-light-level television techniques now being introduced will allow the fish to be detected at greater depths than possible with the direct viewer.

Proposed combined aerial/acoustic survey strategy

The basis of the combined method is to use an aircraft to locate and roughly map the shoal groups within the population's range, whereafter the vessel would operate synchronously with the aircraft to study each shoal group in turn. All areas between shoal groups would be ignored, thus concentrating effort into areas of known fish occurrence.

Using a low-light-level television camera with wide angle lens and videotape storage system now being introduced, the aircraft could cover a shoal group completely, allowing every component shoal to be located and measured in area. While these measurements were being made, the vessel would work a loose grid structured to sample shoal thickness and target strength as widely as possible throughout the shoal group in the time available for synchronous study. As it would be most important to sample the maximum number of shoals to obtain the best possible statistical sample, the vessel would use sonar to locate the shoals and deviate from its grid whenever necessary to encounter them: the rigid adherence to a grid would not be necessary.

A purse seine vessel would work in close conjunction with the survey vessel to sample length distribution within the shoal group. This would enable the mean density (number of fish-per-unit-volume) of the shoals to be calculated from calibration data on the relationship between the length and target strength of individual specimens.

The aerial measurements of the total area of the shoals within the group, and acoustic samples of mean shoal thickness and density, will allow the total number of fish within the shoal group to be calculated, from which the total weight of the shoal group would be calculated from the size distribution of the fish. The size of the stock would then be estimated by summing the tonnages of the shoal groups.

Conclusion

It is concluded that the proposed aerial/acoustic technique would be effective in reducing all three major sources of survey error associated with independent acoustic estimations of *S. ocellata* stock size from a single vessel. The method should be considered for making direct assessments on other pelagic species whose behaviour and distribution patterns present survey problems similar to those encountered with *S. ocellata*. The aerial technique should be feasible in other pelagic fisheries (Cram, 1974), and as there are no major technical difficulties in synchronising aerial and ship-borne surveys in areas served by normal navigation systems, the combined method could also probably be widely applied, particularly in areas where acoustic stock estimation programmes have already been established. The cost of hiring an aircraft for regular surveys should be measured against the quality of the results obtainable and the more effective use of ship's time.

Acknowledgements

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NOTES ON EXPERIENCE WITH COMBINED ECHO-INTEGRATOR/RESEARCH AIRCRAFT SURVEYS LEADING TO ASSESSMENTS OF PELAGIC FISH STOCK SIZE

by

I. HAMPTON and D. L. CRAM

(Sea Fisheries Branch, Cape Town)

PUBLISHED BY THE DIRECTOR OF SEA FISHERIES, BEACH ROAD, SEA POINT, CAPE TOWN

SUMMARY

Patchiness of pelagic fish has been observed in the S.E. Atlantic. It is suggested that acoustic surveys should be mounted within the "gross shoal area" rather than on fixed grids. Gross shoal areas must therefore be exactly located. Avoidance reactions of fish to vessels have been observed in *Sardinops ocellata* and *Trachurus trachurus*. Acoustic research vessels have a limited ability to assess the horizontal dimensions of fish shoals. A viable direct measurement of stock size exists in combining acoustic surveys with airborne shoal tonnage estimation surveys. A survey of this nature was conducted during April, 1973, confirming the advantages provided by combined operations.

1. INTRODUCTION

In mid-1970 it became apparent that serious depletion had occurred in the South East Atlantic *Sardinops ocellata* stock, accordingly a large multi-disciplinary research programme was launched to determine the extent of the decline and to suggest appropriate management action.

Two of the techniques employed were airborne night-time shoal tonnage estimation (Cram 1972) and the use of a 120 KHz echo sounder and integrator. Initially, the techniques were applied separately, with airborne fishspotting research commencing in 1970 and the echo-integrator in 1972, but the obvious advantages of combining these two techniques led to the first combined exercise in April, 1973.

2. ACOUSTIC SURVEYS

Due to the patchiness of pelagic fish shoals in the S.E. Atlantic the only direct way to assess the size of the stock in an area is to locate and measure every shoal in the area. The approach used for demersal fish where the stock is estimated from interpolations of fish density along pre-selected survey lines over a widespread area relies on the fact that the fish are distributed sparsely and continuously over the area, and is clearly not valid for highly-localised pelagic fish shoals. Since it is not possible to sample every shoal in an area acoustically, the best that can presently be obtained from our vessel is an average value for shoal thickness and packing density in the area.

Although shoal thickness may be measured from recordings on a conventional echo sounder, a high-frequency echo-integrator operating at a short pulse length is needed to measure shoal density. The technique employed is to set the integrator to sample a depth range which encompasses the whole shoal and then to measure the average number of fish per sound transmission recorded from this depth range, as the ship passes over the shoal. From a knowledge of the beam geometry a figure can be calculated for the average packing density over the selected depth range. This depth range is then taken as the thickness of the shoal to be used with the packing density figure in any abundance studies.

It is unfortunate that in spite of the high resolution obtainable with a high-frequency echo sounder, packing densities of pelagic shoals may be too high to enable one to resolve echoes from single fish. The method of calibrating the equipment on single fish (Midttun and Nakken, 1971) cannot then be used and absolute measurements of the number of fish per sounding cannot be made. However it is always possible to make relative measurements from shoal to shoal and if necessary empirical calibrations can be carried out to arrive at an absolute figure.

Work is in progress on an acoustic method of measuring shoal thickness and density from the *R.V. Benguela* (a research vessel of the Sea Fisheries Branch, Cape Town) equipped with a Simrad 38 KHz echo sounder with a transducer mounted in the hull 15 m from the bow at a draught of 3 m and a Simrad EKR/QM 120 KHz scientific sounder and echo-integrator with two transducers mounted in V-fins towed obliquely 130 m behind the ship. One of the transducers sounds upwards from a depth of 15 m and the other downwards from 6 m. The appropriate transducer is selected according to the depth of the fish shoals.

Practical, non-technical, problems have been encountered in examining fish shoals at sea:

i. Location of shoals

Since the essence of any pelagic fish counting method must be to sample as many shoals as possible during a survey period, and since pelagic fish shoals exhibit extreme patchiness, the location of each gross shoal area within the target species range is extremely important. It has been observed that research vessels executing search patterns have failed to locate large *Sardinops ocellata* shoal areas, which were marginally or completely out of sonar range (Fig. 1). If the premise of necessity of sampling all shoals is accepted, the location factor represents a drawback to any fish-counting research vessel.

ii. Shoal avoidance of research vessel

Airborne observation of fishing (non-acoustic) research vessels repeatedly showed that *S. ocellata* shoals were very responsive to the vessel's presence and took evasive action either by "splitting" or by "turning". Shoals which "split" in the vessel's

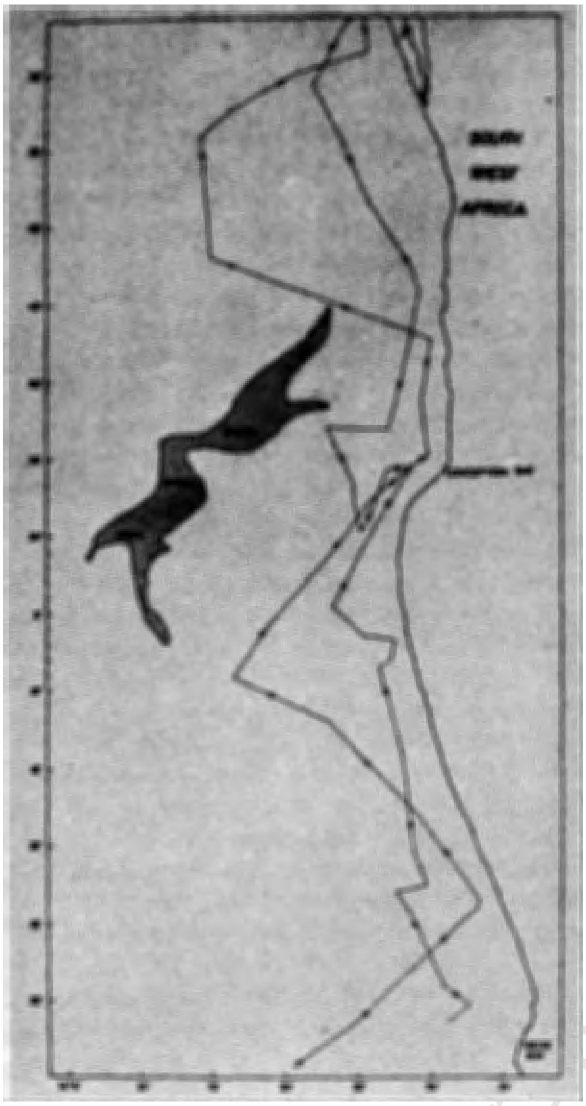

FIG. 1: Research fishing vessel track, November 1972, with *S. ocellata* gross shoal area observed by the research aircraft.

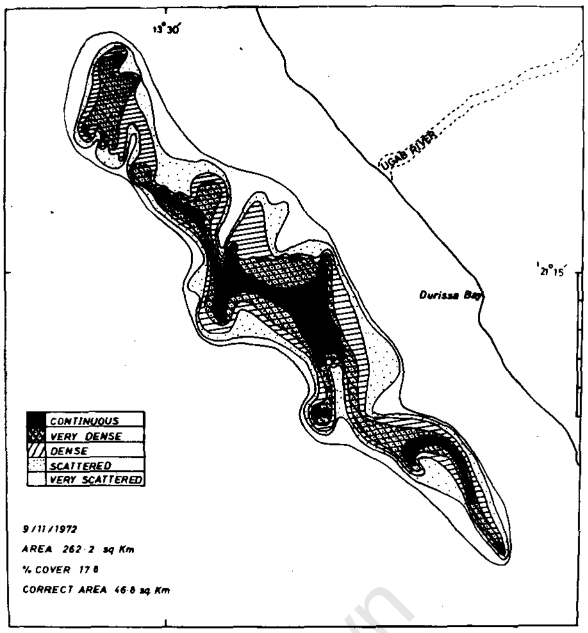

FIG. 2: *S. ocellata* gross shoal area reconstructed from direct viewer observations. Latitude scale in 1 nm units.

path either reformed behind the vessel or continued swimming away separately on either side. In either case, the possibility exists that such shoals may not have passed through the beam of a hull mounted transducer and without doubt have been missed by towed transducer. Such shoal behaviour could affect the accuracy of total fish counts. Historical observations are not available for maasbanker (*Trachurus trachurus*) or anchovy (*Engraulis capensis*).

4. AIRBORNE PELAGIC FISH RESEARCH

Pilchard shoals are rarely encountered in isolation but are usually located in close association over relatively large areas (Fig. 2). Within this area, which is defined as the gross shoal area, individual shoals (Plate 1) may be found in varying sizes and degrees of association with each other, while the size of the gross shoal area may vary very considerably. A measurement of the surface area of such a shoal would be a parameter of fish abundance. At present, there is little possibility of directly measuring the areas of individual shoals other than by video-taping a TV image, and, even then, when working on *S. ocellata*, the extremely large numbers of shoals within the gross shoal area prohibit the

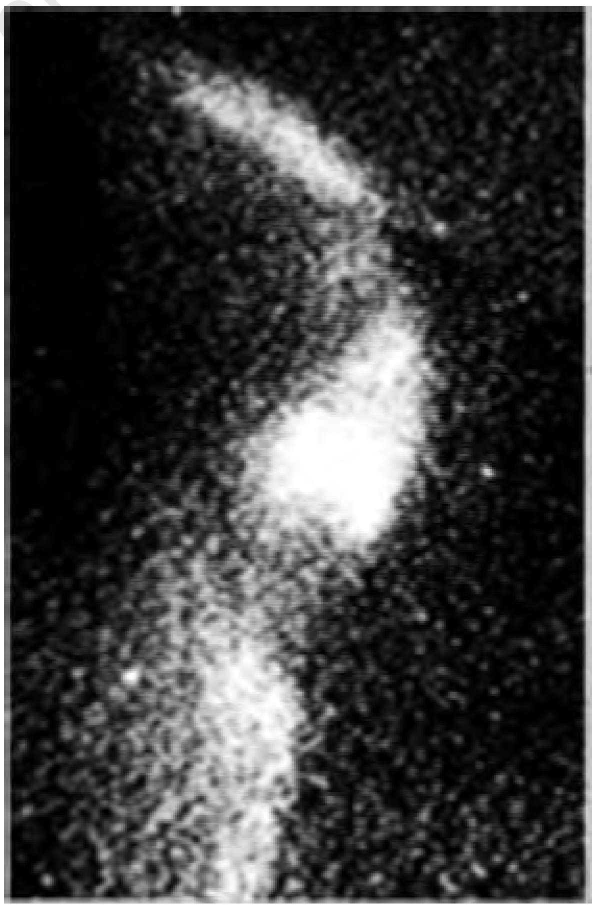

PLATE 1: *S ocellata* individual shoal. Photograph from videotape. Scale 1cm : 10m (approx.)

manual reduction of such data. When a proposed interface between the videotape and a computer is completed, it will be possible to cover the gross shoal area with a minimum number of survey swathes with marginal overlap; thus each individual shoal will be measured directly. Until that time, quantitative measurements will be made by a simple visual method the accuracy of which is not clearly known, although a statistical analysis of the method is in progress.

The aircraft flies closely spaced search patterns in specified areas until fish are located. After a brief initial examination to ascertain the approximate length and breadth dimensions a survey grid is drawn up in the aircraft and immediately commenced. The number of survey swathes is determined by the approximate gross shoal area dimensions and the number of darkness hours remaining (Fig. 3). Each survey swathe brackets the known

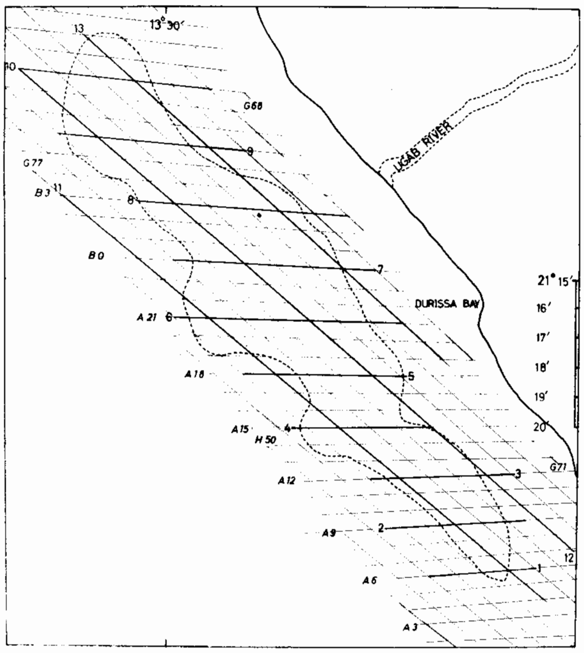

FIG. 3: "Operational plan" for the study of the gross shoal area in Fig. 2. Dotted line — margin of gross shoal area; heavy lines numbered 1–13, survey swathes; faint lines numbered H50 etc., Decca lanes.

approximate gross shoal area dimensions, and is carefully plotted on small scale DECCA lattice charts from the aircraft's DECCA NAVIGATOR. During each swathe of the grid, observations are made on the occurrence of fish shoals with an image intensifier or direct viewer, while the time of occurrence is noted from a stopwatch. The observation on the shoal is stratified according to the apparent shoal size down the viewer or intensifier tube. From these data, it is possible to recover the gross shoal area and to denote the occurrence of fish shoals along each swathe as the total number of seconds of observation expressed as a percentage of the duration of the swathe, within the gross shoal area. The mean figure of "percentage cover" from all swathes is used to correct the gross shoal area into "actual shoal area", which is a direct measure of the sum of the areas of all shoals within the gross shoal area.

An acoustics-independent method of determining packing density of fish has been used, which involves weighing at a factory the weight of fish caught within a known volume of water. Briefly, the aircraft selected a suitable shoal and guided a purse-seiner into position, where the net was set. The surface area of the net is calculated and the volume of water occupied by fish is determined by using the measured thickness of the fish shoal on the relevant echotrace. During weighing at the factory scales, samples are taken and the mean weight of individual fish is calculated. Packing density can be obtained from the ratio of fish number to volume of water occupied. In the absence of other information, it is assumed that packing density does not vary with size and therefore the estimation of fish number within a shoal rests on the airborne and echo sounder observations. The transformation from fish number to fish weight is accomplished by using the length/weight key to establish the weight contribution from each size group within the length frequency distribution of a number of samples from the particular gross shoal area.

The methods employed have been varied frequently in accordance with new ideas, but comparable calculations have been made for the periods November to January, 1971/72 and 1972/73 of 2,1 m. metric tons and 2,9 m. metric tons respectively. There is good agreement between the 1971/72 figure of 2,1 m. metric tons and that produced by other means, which gives a measure of confidence in the 1972/73 figure of 2,9 m. metric tons.

The problems associated with this type of method are numerous:

i. Weather

The incidence of low stratus cloud and sea level fog frequently disrupts the continuity of observations.

ii. Dependence on echosounder data

The shipborne shoal thickness observations must be made synchronously with the aircraft work to ensure that the effect of alteration in shoal thickness during vertical migration is nullified.

iii. Variation in packing density

Packing density data are sparse and possibly incorrect, despite the 44 experimental sets and agreement with other published figures for clupeiods.

iv. Shoal visibility to aircraft observers

The depth at which fish shoals occur is critical—below an approximate depth of 8 m the luminescence is not clearly visible to the aircraft. However, data shows that of the 3 931 shoals tested only 7 per cent were below the "visible" range (J. J. Agenbag—pers. comm.).

v. Luminescence emittance variability

Changing environmental parameters may effect the light-producing powers of the plankton, although there is little evidence that this factor is important.

vi. Precision of methodology unknown

The accuracy of actual shoal area measurement is not known precisely and can only be verified when a new TV and videotape system comes into operation in June, 1973. The strength of the luminescence emission is such that no problems are anticipated with the TV technology presently available.

5. ADVANTAGES OF COMBINING ECHO-INTEGRATOR AND AIRBORNE SURVEYS

It is essential to the airborne shoal tonnage estimation method that a ship conducts a synchronous echosurvey; there are great advantages for an acoustic research vessel in co-operating with a research aircraft, both for shoal location and for the acquisition of the hitherto unavailable horizontal shoal dimension measurements. The combination of these two complementary methods will provide data far superior to that which can be obtained individually.

i. Search time and strategic deployment

As previously mentioned, because of the patchiness of *S. ocellata* shoals, it is considered advisable to carry out measurements on each gross shoal within this species' range. Thus, the location of each gross shoal area becomes extremely important. The aircraft can, subject to weather limitations, search large areas closely and rapidly and, having located a gross shoal area, relay its position and dimensions to the research vessels which can immediately set up their survey grids and move into the area. Efficient use of an aircraft (and good weather) can dramatically reduce a vessel's search time. Exact positioning of a vessel relative to fish shoals is extremely easy.

ii. Shoal behaviour

Erroneous conclusions can be drawn from echo-sounder data unless the effects of shoal avoidance of the vessel are closely monitored. Information on this aspect of shoal behaviour can be continuously observed by a research aircraft.

iii. Dimensional measurement

The aircraft can only measure the horizontal dimensions of shoals while the ship can only effectively measure vertical dimension. The aircraft can produce a shoal distribution map (such as Fig. 2) onto which can be superimposed the vertical measurements made by the vessel along a number of survey lines. Thus the shipborne measurements of biomass distribution may be extrapolated to cover the known horizontal dimensions of the gross shoal area to produce a measure of total shoal biomass. Alternatively, from the same aircraft raw data, a measurement of actual shoal area can be obtained which, when combined with the shipborne measurements of shoal thickness and density, will yield an estimate of total shoal tonnage. Although somewhat similarly derived, the two estimates are sufficiently different to provide an interesting comparison. By working all the gross shoal areas within a species geographical range with combined shipborne and airborne methods, an estimate of stock size could be made within three months.

6. THE APRIL 1973 EXPERIMENT

Preliminary work has been chiefly aimed at discovering to what extent fish shoaling near the surface are disturbed by a vessel passing through them and consequently escape detection by the ship-borne measuring equipment. For this purpose during a survey off the South West African coast in April, 1973, the fish spotting aircraft was engaged to keep visual contact with the ship whenever possible during dark moon periods and to report on the behaviour of shoals as the ship passed through them. Comparison of echo-chart recordings from the 38 KHz transducer near the bow with those from the 120 KHz transducers towed 130 m astern of the ship provided additional information on shoal avoidance behaviour.

A research purse-seiner was in close attendance and made experimental catches for identification purposes. Full two-way radio contact was maintained between the two vessels and the aircraft and all verbal information correlated with recordings on the *R.V. Benguela's* two echo sounders by recording the radio conversations on magnetic tapes synchronised with the echo sounders.

In order to reduce time spent in finding fish the aircraft conducted a preliminary survey of the fishing ground on the first night and selected an area of high fish concentration to work in on subsequent nights. The vessels were then called into the area and worked with the aircraft during dark moon periods whenever visibility allowed. Before the arrival of the plane every night the *R.V. Benguela* conducted an acoustic search of the area in an attempt to relocate the main body of the fish and be in a position to start work as soon as the aircraft arrived.

7. SOME RESULTS OF THE APRIL 1973 SURVEY

Poor visibility and short dark moon periods at the time of the survey restricted co-ordinated work to an average of about 2 hours per night for 7 days. Good luminescent conditions prevailed and agreement between acoustic recordings of fish and sightings from the aircraft and the ship was generally good. The upward-sounding transducer was not extensively used due to problems of acoustic interference with echoes from the surface water.

In the area selected for the exercise considerable concentrations of mixed pilchard (*S. ocellata*) and maasbanker (*Trachurus trachurus*) shoals were found. The difference in luminescent shoaling patterns of the two species was sufficiently clear at sea level for the catching vessel to make selective catches and identify both species. Only the pilchard shoals could be identified with confidence from the air, although the shoal mixing was clearly evident. Echo-recordings of the two species could be clearly distinguished (see Plate 2).

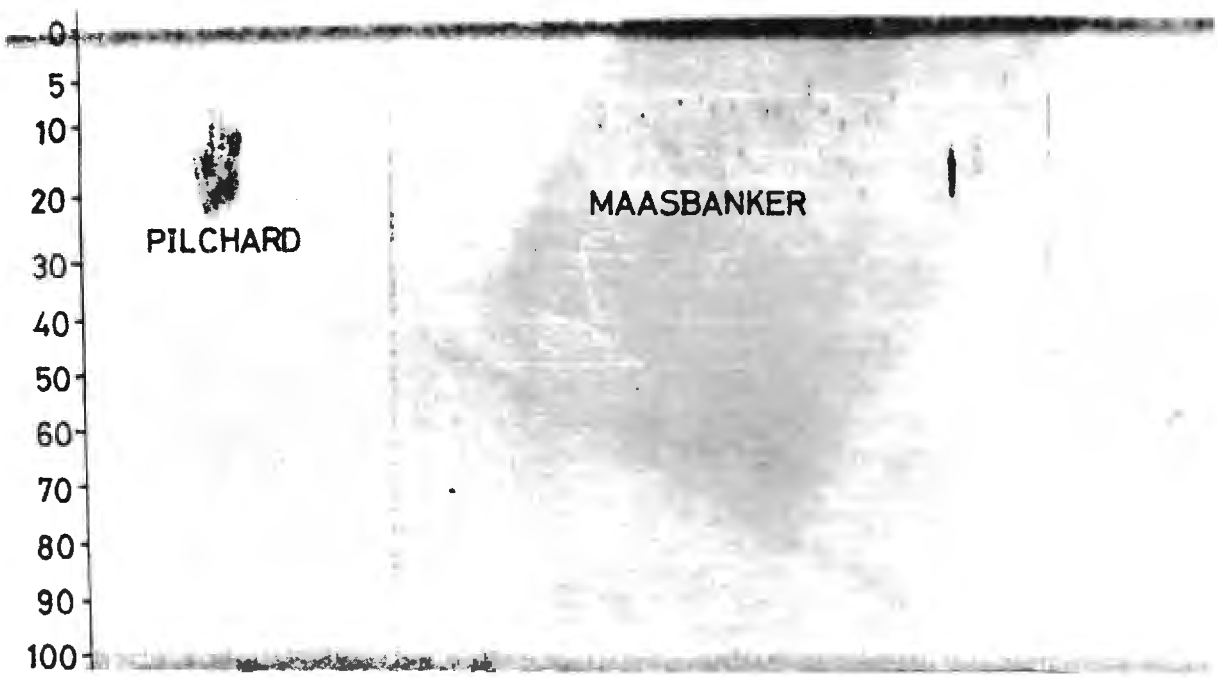

PLATE 2: Pilchard and maasbanker shoals detected by 38KHz transducer. (Faded echo-roll carefully touched-up).

From the air it was observed that on this occasion the pilchard shoals did not avoid the ship on approach of the vessel and remained in unbroken shoals until the vessel began to pass over the fish, whereafter the fish passed from view under the ship and generally reappeared astern in two distinct shoals separated by the ship's track.

On a number of occasions the fish reformed into single shoals shortly after the ship had passed. From the bridge, the pilchard shoals could usually be seen passing under the bow, and on every such occasion, were recorded shortly thereafter on the forward echo sounder. This indicated either that the fish did not immediately move out of the path of the vessel or that the apparent "splitting" of the shoal was due to the fish in the path of the vessel sounding and becoming invisible to the aircraft.

Pilchard shoals recorded on the forward echo sounder were frequently detected at approximately the same depth by the downward-sounding transducer towing about 20 m to starboard and 130 m astern. This correspondence is clearly demonstrated in Plate 3.

On one evening it was found that shoals clearly recorded by the forward echo sounder were hardly detected by the downward-sounding towed transducer (see Plate 4) in spite of the fact that the aircraft observed considerable luminescence about the transducer at the time. The reason for this was not discovered, but the transducer could have been at the same depth as the fish thus failing to receive echoes, while the movement of the transducer caused accelerated fish movement and correspondingly bright luminescence.

In contrast to the pilchards, maasbankers attempted to swim away rapidly as the vessel approached and it was largely due to this difference in behaviour that these shoals could be distinguished from pilchards. Comparison of echo-recordings showed that fewer maasbanker shoals were detected by the towed transducer than the forward

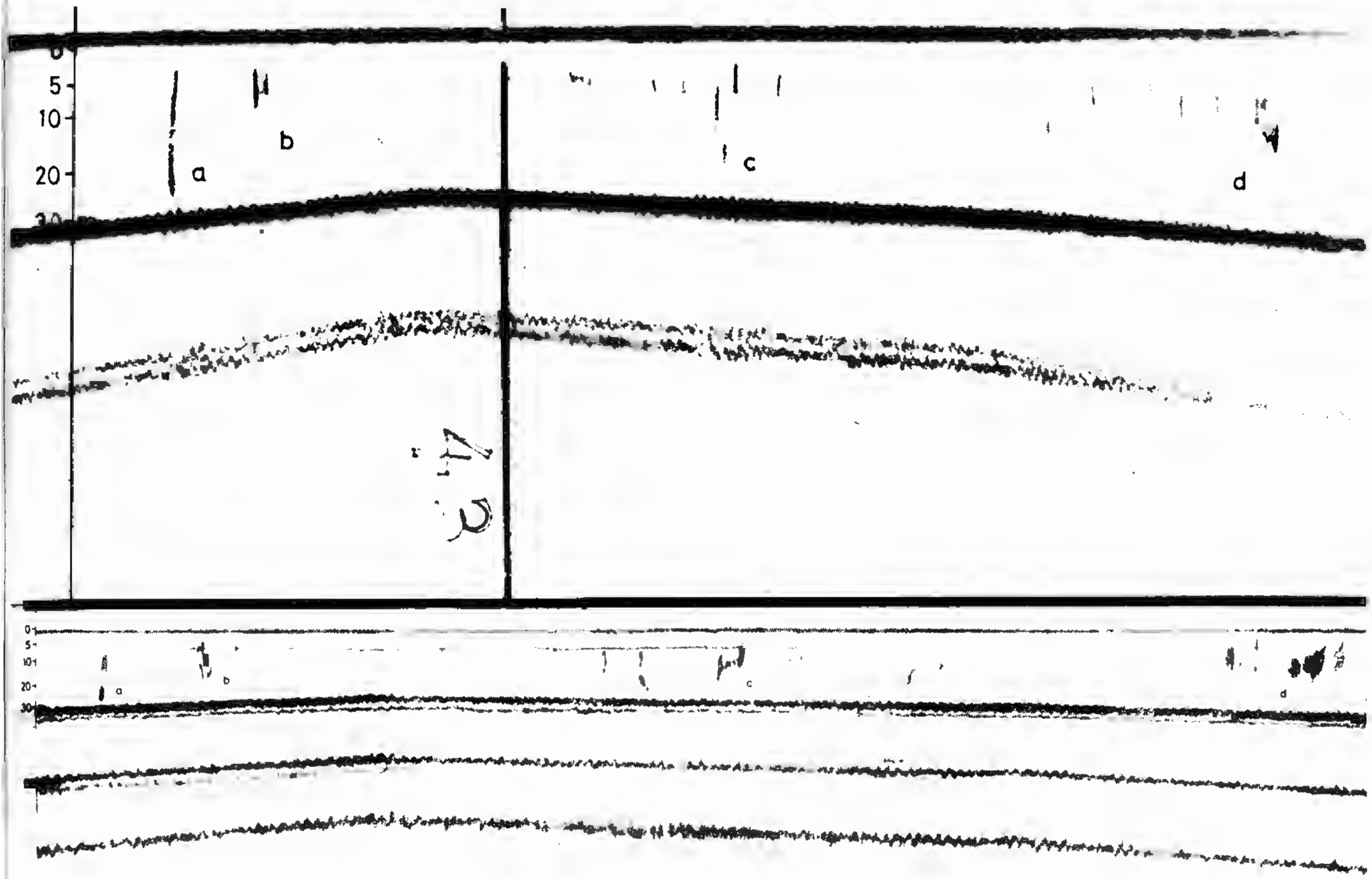

PLATE 3: Pilchard shoals detected by (*top*) the hull-mounted 38KHz transducer (*bottom*) the towed 120KHz transducer. The ratio of paper speed is 2 : 5. (Faded echo-roll carefully touched-up).

mounted transducer, which is further evidence for the shoal's avoidance of the ship. The maasbanker appeared on the echo-recordings at depths ranging from 5 to 15 m below the transducers but since the fish were often observed visually on the surface it is likely that a considerable proportion of the fish was shallower than the transducers. This is supported by the evidence that, on a number of occasions, when from both aerial and ship-board observation the ship was known to be passing through a shoal, no fish was detected by either transducer.

8. CONCLUSIONS

The observations discussed were made only on the pilchard (*S. ocellata*) and maasbanker (*T. trachurus*), but are possibly indicative of problems likely to be encountered in acoustic research on any densely shoaling sardine-, anchovy- or mackerel-type fish. Herring shoals, being more widely scattered and individually "house-sized" represent another type of problem, and are, therefore, not under discussion.

The effective management of populations of short-lived pelagic fish may require stock assessments which are catch-per-unit-effort and fish-sampling independent, for the latter methods are relatively slow in providing answers. Direct measurement of stock size would then be essential to more effective management as such assessments can be accomplished in a very short time. This is of particular value to a newly exploited, expanding fishery, a well established fishery in trouble without a good biological research background or a fishery which is experiencing sudden, unpredicted, unexplained major fluctuations.

In these situations, whatever direct measurement method is employed, rapidity and a reasonable degree of accuracy is required. All aspects of fish-counting technique are improving at a formidable rate, but this alone will not necessarily ensure accuracy of results. The localised distribution of the pelagic fish shoals under discussion requires that each gross shoal area be located and worked. Failure to locate certain gross shoal areas of *S. ocellata* would cause considerable underestimation of stock size. Most observations made since 1970 by the research aircraft have demonstrated

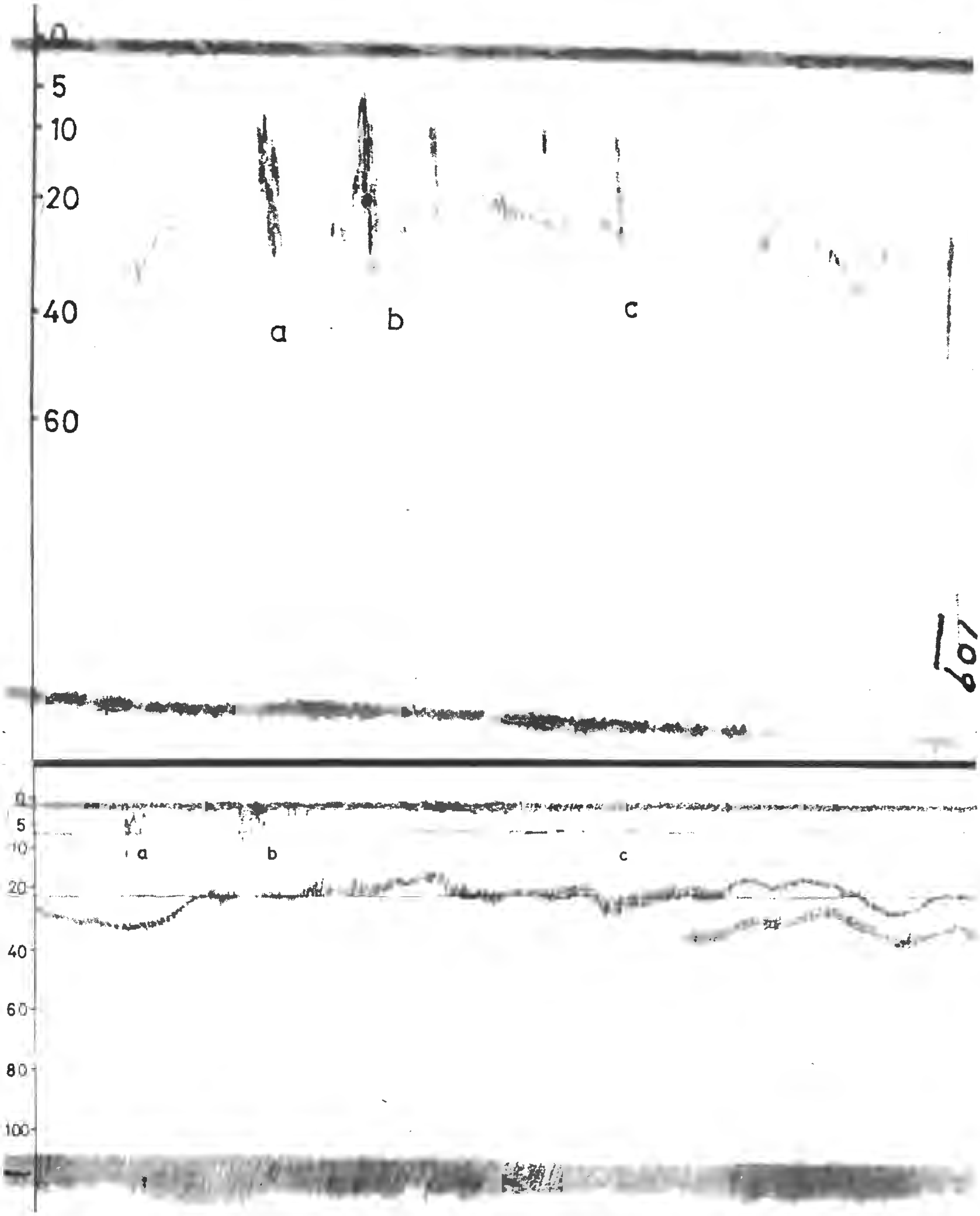

PLATE 4: Pilchard shoals (*top*) large pilchard shoals detected by 38KHz hull-mounted transducer, (*bottom*) corresponding small traces on 120KHz towed transducer. (Faded echo-roll carefully touched-up.)

that ships are relatively inefficient at locating fish shoals. It follows, therefore, that such ships would be totally in ignorance of the horizontal dimensions of any gross shoal area under attention and would consequently be unable to plan a search pattern to encompass the gross shoal area without wastefully searching areas devoid of fish. In addition, the mobility of pelagic fish shoals causes a constant changing of dimensions: the horizontal measurements made by an acoustic research vessel may be very different from that obtained with a synoptic overview. The smallest scale interaction between the vessel and the shoal, that of avoidance, may also achieve significance. The response to a vessel's presence seems to be variable but, in general, the more active the fish, the greater the avoidance reaction.

The observations and limited experimentation recorded here suggest that a viable method of direct measurement of pelagic fish stock size exists in the combination of echo-integrator and airborne shoal tonnage estimation methods. Such a combined survey could be considered either an acoustic survey with airborne support or a remote sensing exercise with acoustic ground truth.

Reference has been made to the use of low light level TV, which utilisation has many advantages, but is not necessarily essential. Ultra long range sonar is becoming available, but, in the forseeable future is likely to have neither the horizontal operational range of an aircraft nor the resolution of airborne measurements. It is believed that the proposed satellite observations of pelagic shoal luminescence may, at this time, be discounted due to the logarithmic diminution of light intensity with distance in the atmosphere and the persistent low stratus cloud in most upwelling areas. Doubtless future electron-optics development will defeat the low light level problem, but the weather is likely to remain undefeated.

The problem of measuring absolute fish densities with the echo-integrator is still unsolved due to difficulties in calibrating the equipment on single fish (Midttun and Nakken 1971) within a densely-packed pelagic shoal. The instrument has a nominal resolution of 10 cm on a 0,1 ms pulse, which we have found insufficient to resolve echoes from single pilchards within a shoal. Although it will probably be necessary to use an empirical calibration at this stage of the project, it is hoped that new developments in echo sounder technology will make direct calibration possible in the near future. It is believed that an echo-integrator offers the best prospect of making direct measurements of packing density and the project will be continued in the short term to this end.

9. ACKNOWLEDGEMENTS

The Director of Sea Fisheries is thanked for permission to submit this Information Note. The efforts of numerous colleagues in the collection of field data are acknowledged with thanks.

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The Role of Aircraft-borne Remote Sensors in South African Fisheries Research

D.L. CRAM

Division of Sea Fisheries, Sea Point, Cape Town.

SYNOPSIS

Aircraft-borne remote sensors are used by the Division of Sea Fisheries in their present intensive investigation into the pilchard resources of South West Africa. An image intensifier is used during night-time observations of shoals to calculate tonnages of fish from the bioluminescence of the plankton on which they feed. A radiation thermometer provides quasi-synoptic surface temperature maps of the fishing grounds.

The combined use of these two techniques provides data which cannot be procured rapidly by conventional methods and which are essential from a stock management point of view. The data will provide a comprehensive picture of trends in the fishery and enable fisheries administrators to adopt remedial measures in advance of any serious stock depletion.

SINOPSIS

Die Afdeling Seevisserye maak in die huidige intensiewe ondersoek na die sardynstapel van Suidwes-Afrika gebruik van afstandsensors aan boord van vliegtuie. 'n Beeldversterker word gebruik om die tonnemaat van sardynskole te bereken deur die luminessensie van die plankton waarvan die vis leef, in die nag te bestudeer. 'n Stralingstermometer word gebruik om kwasie-oorsigtelike oppervlaktemperatuurkaarte van die visgrond te berei.

Die gesamentlike gebruik van hierdie twee tegnieke voorsien gegewens wat nie maklik deur konvensionele metodes verkry kan word nie en wat uit die oogpunt van visstapelbeheer noodsaaklik is. Die data sal 'n omvattende beeld van tendense in die visbedryf voorsien wat die owerhede in staat sal stel om betyds gepaste stappe te doen ten einde ernstige stapelvermindering te voorkom.

ACKNOWLEDGEMENTS

The author acknowledges the encouragement of the Director of Sea Fisheries, Dr B. van D. de Jager, in all aspects of this research programme. Thanks are due to Mr G.H. Stander for his helpful criticisms of this hastily produced manuscript.

INTRODUCTION

The catching ability of modern fishing fleets can allow fish resources to be exploited beyond their maximum sustainable yield. These can become seriously depleted before the existence of the situation can be recognized from data collected by classical means (Gulland[3]). For effective control, early warning of ominous signs in a fishery must be provided by management advisers, either by the employment of 'scientific intuition' and qualitative data or by the use of rapid methods of fish-stock assessment when conventional quantitative data are lacking. The rapid assessment of stock size may necessitate the use of new equipment and new ideas which usually require time to stabilize into full usefulness.

When the Division of Sea Fisheries commenced their intensive investigaton into the pilchard fishery of South West Africa in 1970, the organizers of the Cape Cross Programme were faced with an unfortunate situation. The valuable pilchard fishery, which had been enjoying stable growth from its inception in 1949, followed by a short period of rapid expansion when catches were doubled, suddenly in 1969 and 1970 entered a period of decline.

Although excellent qualitative data were available, the basic observations on which studies of stock size are based were scanty. Together with other factors, this prevented the accurate establishment of the stock size during the critical period of sudden exploitation and decline. To provide suitable data upon which to base proposals for the management of the South West African pilchard resource, the most rapid means of obtaining quantitive data of fish abundance and a relevant physical oceanographic parameter were employed. Accordingly, in 1970, the Division entered the field of remote sensing with the development of airborne methods of assessing the abundance of pilchard shoals and the use of airborne radiation thermometry for studying the distribution of sea-surface temperatures.

FISH SHOAL TONNAGE ESTIMATION BY IMAGE INTENSIFICATION

The emission of light by plankton when disturbed by a pilchard shoal clearly outlines the shape of the shoal (Figure 1). The surface area of the shoal, which hitherto was an unobtainable parameter of pilchard availability, can be measured from the air and forms the basis of shoal tonnage estimation.

Although the method outlined in Figure 2 is crude in the extreme it is capable of considerable sophistication. Briefly, the method relies on DECCA navigation to plot the overall area within which a concentration of pilchard shoals occurs.

the South West Africa pelagic fish population transiently or drastically. A drastic anomaly, such as occurred in 1963 (op. cit.) resembles the 'el Nino' conditions experienced off Peru when the upwelling area is drastically reduced by incursions of warm water. As this anomaly is long-lasting it is easily detected because of the enormous displacement of the normally stable frontal system between upwelled and oceanic waters. A large-scale change in the character of the environment of this nature would be certain to cause dramatic effects such as the ultimate displacement of the pelagic population to a distance of some hundreds of miles or, more important, a failure of spawning which would considerably affect the fishery at the time of recruitment in later years.

Figure 3 shows a normal summer situation where warm oceanic water has been temporarily driven over the colder 'fish-bearing' water under the influence of the occasional summer northerly winds. The pattern of surface temperature distribution resembles that of a massive collapse of the South West African part of the Benguela Current system, except that during anomalous conditions the whole vertical structure of the environment is altered and not, as in this case, just the surface.

Short-term anomalies may restict the spawning migrations of pelagic fish to an area in which the survival of eggs and larvae may be reduced.

Small, transient anomalies have a very interesting effect on the spawning migration of the pilchard off South West Africa. Tongues of warm oceanic water have been observed temporarily to block the normal southward migration, and this produces a corresponding drop in egg production on the spawning grounds. Later, on with the withdrawal of these intrusions, migration is resumed and egg production rises (Fig. 4).

Thus the observation of short term intrusions has promoted the understanding of delayed and sporadic spawning of the pilchard stock of South West Africa. Basic research into upwelling processes and productivity have shown the value of radiation thermometry in Southern African upwelling areas, where strong horizontal gradients exist (Andrews & Cram[1]). Here the airborne surveys have provided a quantity, the 'area of upwelling' which has previously not been clearly defined. This has enabled the construction of a simple first approximation, from direct measurements, of the potential production of the Benguela Current System in units of metric tons of carbon fixed per day, (Andrews, Cram & Visser[2]). Although the research can be considered basic, it is hoped that ultimately such studies will be of value in long-term fisheries prediction.

THE ROLE OF REMOTE SENSORS

Both an image intensifier and a radiation thermometer have been used together off South West Africa to gain an understanding of the relationship between fish and their environment. Hoeever, remote sensors cannot alone provide a complete picture of such interactions and must always be used in conjunction with routine biological, chemical and physical sampling.

The present role of remote sensors in fisheries research is the acquisition of certain data in new and rapid ways to compensate for a lack of specific data on crucial aspects of pilchard stock strength. In future, remote sensors will be used for the rapid perception of phenomena associated with the decline of the fishery, thus enabling effective countermeasures to be made timeously by management authorities. Whether the present effective management of the pilchard stock will halt the decline begun in 1968 is still in doubt, but the use of remote sensors will provide indications of the stock's recovery, or further decline, in advance of conventional methods.

Remote sensing techniques are at the heart of the Division's new philosophy of rapid management action, and will continue to be so until their usefulness declines.

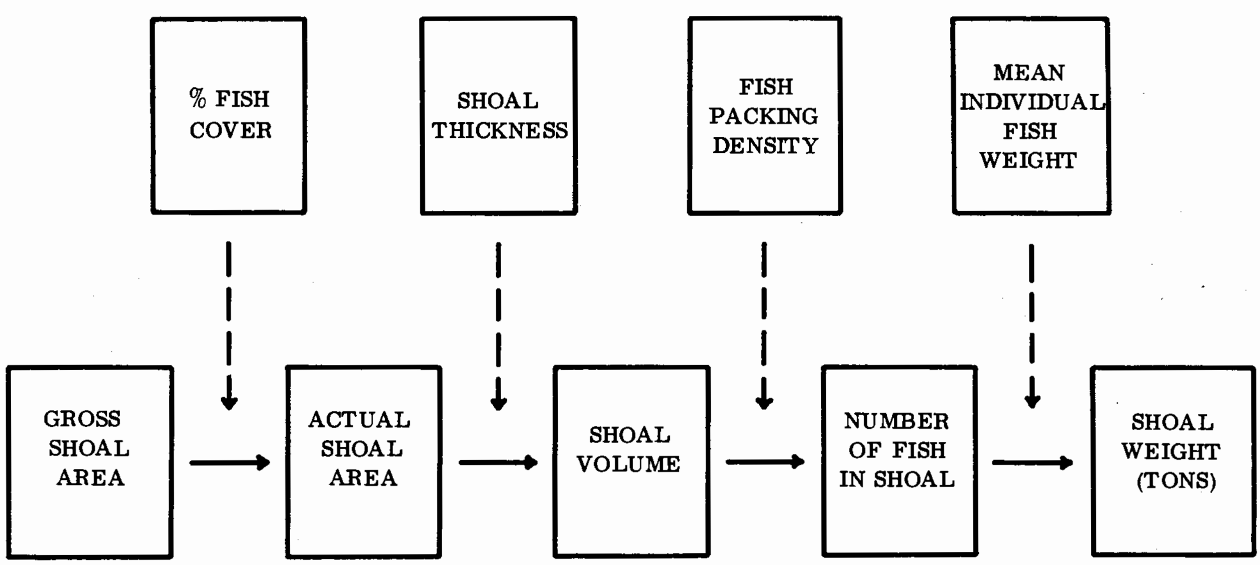

Fig. 2 · Flow chart of steps in the calculation of shoal tonnage

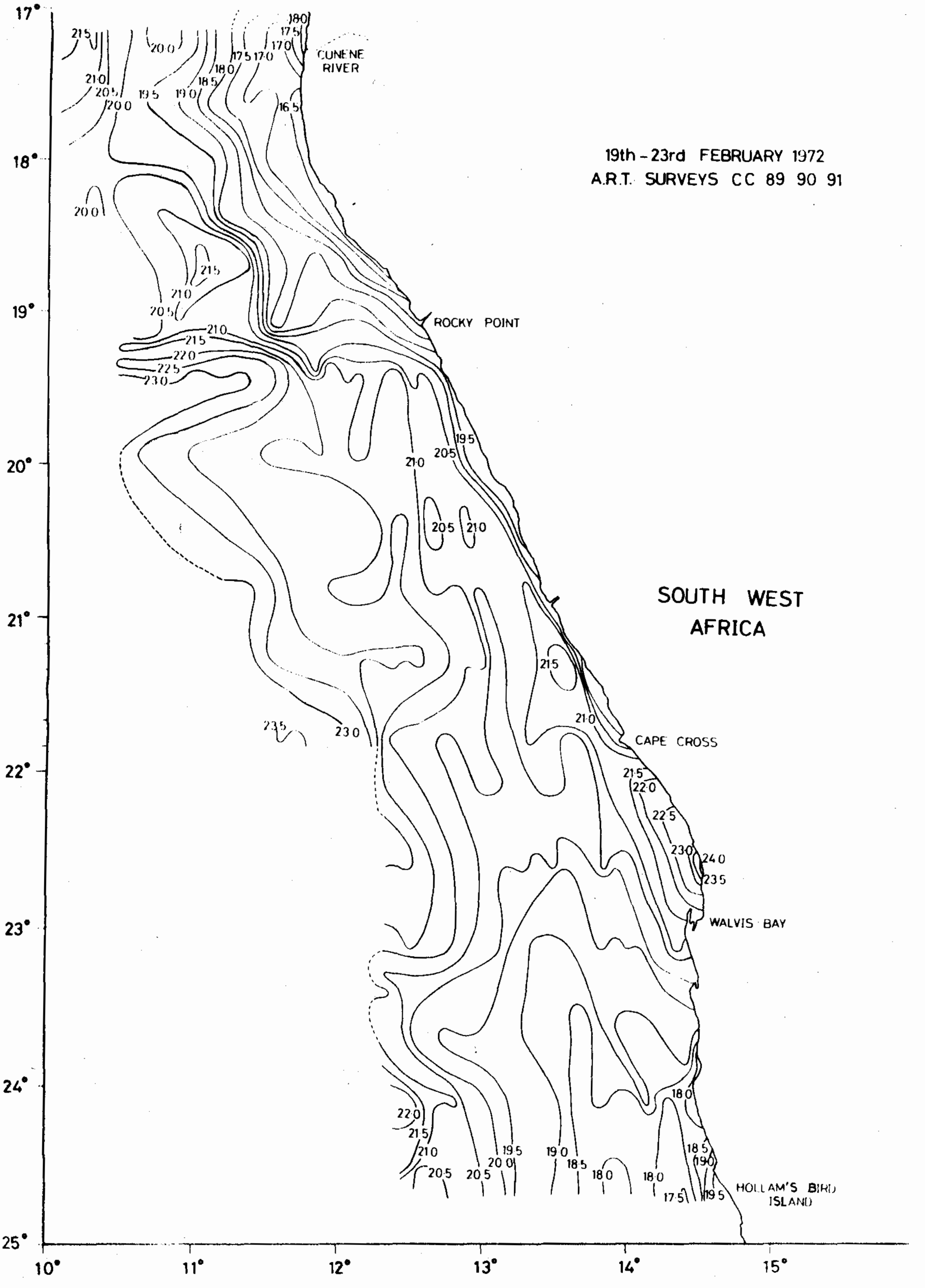

FIG. 3 A. R. T. surface temperature map, showing distribution of warm surface water during summer northerly-wind conditions

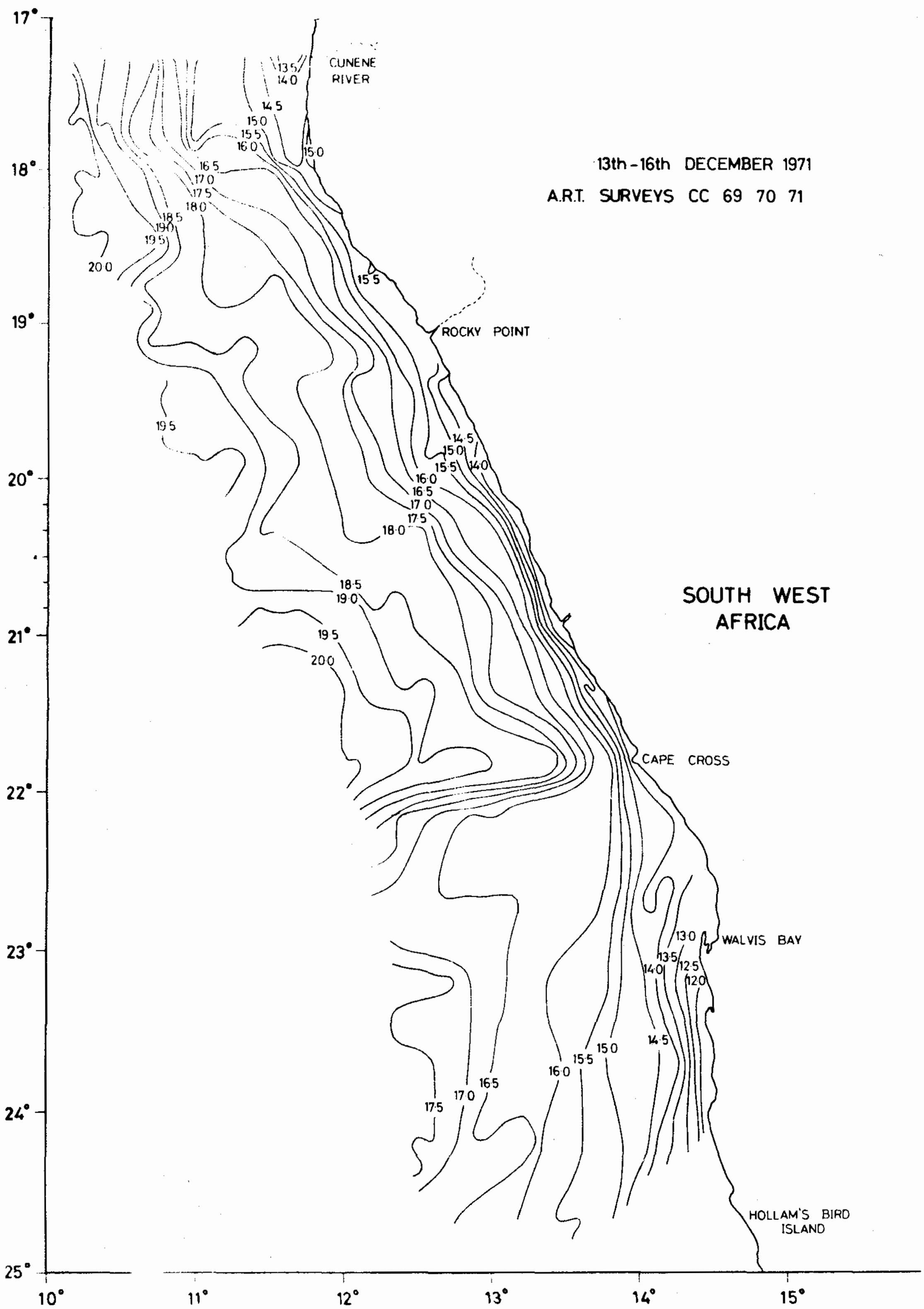

FIG. 4 A. R. T. surface temperature map showing a transient intrusion of warm oceanic water at Cape Cross

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DISCUSSION

D.E. Pedgley

Are you able to make any estimates of the total pilchard population at any one time and, if so, what area do you need to cover and how long does it take to cover it?

D.L. Cram

Yes, we have made estimates of the population strength of the order of 1,4 million tons, which agrees reasonably well with the other stock estimates.

To reach these conclusions an area 450 nautical miles by 25 nautical miles is investigated each month and for this a period of ten to twelve days is the normal length of time taken to observe the complete area.

Dr K.A. Viewing

I would be grateful if Mr Cram could tell us the depths to which this form of remote sensing is able to penetrate in searching for shoals of fish?

D.L. Cram

Observations confirmed by research vessels show that shoals of fish can be detected from the air during moonless nights to a depth of approximately 14 meters. Fish have a pronounced diurnal vertical migration and are usually quite close to or even at the surface during the night.

D.L. Kyle

Could Mr Cram tell us what instrumentation is used for image intensification and whether the information is recorded off film or on a viewer and if the film has a printout from the DECCA navigation system to give the exact position?

D.L. Cram

A three-stage cascaded, electrostatically-focussed intensifier is used on a direct viewer, however in the near future we hope to use a videotape for image storage.

The navigation fixes from DECCA are manually recorded and it is unlikely that we will link the DECCA output to the video tape as we frequently operate at the limit of the South West African chain which sometimes makes positioning problematical.

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RAPID STOCK ASSESSMENT OF PILCHARD POPULATIONS BY AIRCRAFT-BORNE REMOTE SENSORS

by

D.L. Cram

Sea Fisheries Branch
Cape Town, South Africa

ABSTRACT

Airborne night-time observations with image intensifiers on the luminescent outlines of pilchard shoals can be used as primary data for the direct measurement of stock size. Such a method has been used on *Sardinops ocellata* in the S.E. Atlantic, and is described. The results have proved useful in stock management strategy. LLLTV has been employed for image collection, storage and experimental processing. Both silicon-diode array and secondary electron-conduction systems give good results under ideal conditions, with signal to noise ratios conducive to automated video-signal processing. Under the normal non-ideal survey conditions lag and sensitivity characteristics produce video-signals unacceptable for automated processing. Direct-viewing image-intensifiers provide better images than LLLTV. In order to assess the size of a pelagic stock through remote sensing methods it is more important to know the thickness and the density of shoals than to measure the actual shoal area precisely.

1. INTRODUCTION

During the pilchard fishing season of 1970, the declining trend in landings observed since 1968 was confirmed, indicating that the South West African portion of the South East Atlantic pilchard population (*Sardinops ocellata* Pappé) was subject to overfishing. The pattern of increasing pilchard catches leading to a sudden, steep and, so far, permanent decline is regrettably familiar from the performance of many fisheries, such as those of the Californian sardine (Murphy, 1966) and the Cape pilchard (Stander and le Roux 1968; Baird, in press) (Fig. 1). Management authorities in South Africa became determined that this pattern would not be repeated on such a valuable fishery and, consequently, an intensive research programme was mounted to determine the extent of the decline and to suggest remedial action. Of the four independent methods of stock assessment employed, one, a method of airborne shoal tonnage estimation (Cram, 1972) involves an application of remote sensing. The object of this method is to attempt a direct, rapid measure of stock size which can be updated annually, so that short-term fluctuations in abundance can be observed and short-term predictions of yield obtained. Research work has been concentrated on the rapid development and use of a simple direct-observation method while experimenting with low-light-level TV systems in order ultimately to provide a video-signal suitable for automated signal processing.

2. BIOLUMINESCENCE

The South East Atlantic pilchard is a pelagic shoal fish inhabiting the near-shore waters of the cold upwelled component of the Benguela Current System. This upwelled water provides the nutrient input which supports an extremely high rate of phytoplankton production and standing crop upon which the pilchards graze. Many species of phytoplankton are luminescent, and off the Southern African Coast they are sufficiently numerous to clearly outline the shape of the pilchard shoals moving through them at night. (Pl. 1). The most numerous luminescent organisms are the Dinoflagellates, with *Noctiluca miliaris* a particularly powerful light emitter. The copepod *Metridia lucens* also undoubtedly contributes to the luminescence associated with fish shoals. The spectral emissions of *N. miliaris* and *M. lucens* are known from laboratory work to lie between 420 and 580 nm with a peak emissions between 470 and 480 nm (Nicol 1962). Nicol (op. cit.) has found that at 1 m from the source the illumination produced in a flash from a single *N. miliaris* is 0.01×10^{-9} uW/cm^2. From the work of David (1962) it is estimated that the equivalent illumination from a single *M. lucens* is 4×10^{-5} uW/cm^2.

3. DIRECT OBSERVATION SURVEY METHOD

Bioluminescent outlines of pilchard shoals are visible to the naked eye from the air and it is suggested that since approximately 90% of pilchard shoals are within the visible zone between 2000 hrs. and 0400 hrs. (Agenbag, pers. comm.), the sum of the luminescent shoal areas is a parameter of pilchard abundance (Pl. 2). Since it is known that the thickness of shoals is variable (Pl. 3) it has been decided to use shoal volume (rather than shoal area) as the parameter of abundance, but only when the thickness and area measurements are obtained from synchronous airborne and acoustic surveys.

Pilchard shoals are found concentrated into areas termed gross shoal areas, and the aerial method involves the location of all such areas, and their subsequent measurement. Following the visual location of a gross shoal area (Fig. 2) the approximate dimensions are measured from the aircraft's Decca Navigator, after which a survey grid is immediately constructed on the relevant Decca chart, (Fig. 3) to give maximum intensity of coverage within the remaining darkness hours. Observations are then made along each swathe with either a direct viewer or a Pilkington Perkin Elmer "Lolite" night-sight, consisting of an objective lens, image-intensifier tube and eyepiece. The lens is f0.74, 86 mm diameter with a 64 mm focal length and 20° field of view. Transmission is optimised in the 500-800 nm range. The three-stage cascaded intensifiers are 25 mm Mullard XX1060 with S20ER photocathodes, and an automatic brightness control. The monocular eyepiece has an 8X magnification.

Each survey swathe across the gross shoal area is timed to and from fixed geographical points. As each individual shoal passes through the field of view its duration-in-view is timed and the sum of such times is expressed as a fraction of the swathe duration. The observations made on each swathe allow the reconstruction of the horizontal dimensions of the gross shoal area, together with the distribution of the individual shoals (Fig. 2). The actual shoal area (Fig. 4) (the sum of shoal areas within the gross shoal area) is obtained by multiplying the measured gross shoal area by the average fractional cover for all swathes. The actual shoal area, (usually 5 - 15% of the gross shoal area) when combined with synchronous echosounder readings of shoal thickness, provides the shoal volume.

The conversion of shoal volume to fish number requires a knowledge of the mean fish density within each shoal. In practice, this quantity is very difficult to measure precisely, but an empirical catching experiment conducted in 1972 provided a value of 20 fish per cubic metre which was used in subsequent calculations. The final calculation, that of shoal tonnage is made by using the mean fish weight obtained from synchronous research catches made in the gross shoal area. Three stock estimates have been attempted: from November to January 1971/72, 2.1 million tonnes; from November to January 1972/73 2.9 million tonnes and from September to December 1973, 3.2 million tonnes. The only check at present available on these estimates is that they agree reasonably well with those from other sources, while the trend of increasing abundance is similarly confirmed. The method is crude but development is in progress as attempts are made to determine the precision of the measurements and the accuracy of the stock estimates. In order to make these error estimates a low-light-level TV system must be employed for image collection, storage and experimental processing.

4. LOW LIGHT LEVEL TELEVISION

Since 1972, two types of television camera manufactured or assembled by Fernseh GMBH, Darmstadt, Germany, have been on operational test in the survey area. The cameras both employed the Westinghouse WL-30677 image-intensifier which increases the sensitivity of both systems by a factor of 100. Some details of the two systems are shoan in Table I.

Camera body	Image intensif	Camera tube	Lens f no.	Lens focal l.	Lens f.o.v.	Tube sensitivity
Fernseh TV720	West'hse WL-30677	West'hse SEC WL-30691	1.0	70 mm	$16^{o}x22^{o}$	15,000 uA/lm
TV720	WL-30677	EBS WX-31792	1.0	70 mm	$16^{o}x22^{o}$	420,000 uA/lm

TABLE I. CAMERA SPECIFICATIONS

Clarity and fidelity in the reproduction of a moving low-light-level scene depends chiefly on the sensitivity and dynamic resolution of the tube and the signal-to-noise ratio in the TV image produced. From Table I it can be seen that the EBS tube is nearly thirty times more sensitive than the SEC tube. The greater sensitivity has been confirmed in practice, brighter images of fish shoals have been obtained from higher altitudes with the EBS tube, than with the SEC tube.

The effect of image motion on the dynamic resolution of the SEC tube is shown in Fig. 4, where the dynamic resolution as a function of face-plate illumination is shown for a static image and images moving at 20 sec/picture width and 10 sec/picture width. No specification on the dynamic resolution of the EBS tube was available, but from the published lag characteristics, it is evident that the dynamic resolution of this tube over its useful range is generally inferior to that of the SEC tube over its useful range. This is also confirmed in practice and it has been found that the advantage of being able to obtain images for light levels below the detection limit of the SEC tube is at least partly offset by the increased lag distortion in the EBS tube at these light levels.

The proposed technique with the existing EBS camera is to reduce image motion to acceptable limits by flying at the maximum altitude which the sensitivity of the tube will allow. In practice this will not always be possible due to cloud cover or fog and it is felt that a tube which combines the sensitivity of the present EBS tube with the good lag characteristics of the SEC tube would be of most general use.

5. SURVEY CONSIDERATIONS

Both weather and biological factors can limit the effectiveness of airborne surveys of fish shoals in upwelling areas. Ground, or low-level fog frequently prevents survey flights over the sea. Stratus cloud forms at the inversion between cool surface air and warm upper air and frequently forces the research aircraft to fly beneath at about 300 m. At this altitude, using our widest angle lens, a Zeiss Planar f1.4 with 47^{o} field of view, the field is approximately 250 m in diameter and at 90 kts the image will cross the picture width in about 6 seconds. Neither system can cope with such a degree of image motion. In contrast, at 1500 m altitude, the field is approximately 1270 m and the image crosses the picture width in about 25 secs. Both systems perform adequately with this degree of image motion.

The variability of luminescence emission is considerable, but the instances of fish presence being confirmed by a research vessel and being invisible to the aircraft are very few. Observed variation in luminescence emission will probably be due to the variable concentration of light-emitting plankton as well as the depth of the shoal causing the stimulus. The vertical migration of shoals is known (Fig. 5) and brings the fish shoals into the visible zone during darkness hours. With changing moon phases, the useable dark moon period can restrict the duration operations.

When shoals of the major species are closely adjacent, identification is usually possible. However if shoals should mingle, identification is unreliable. A research purse-seiner is essential for providing ground truth to avoid misidentification of fish shoals and to assist in distinguishing jellyfish swarms (Aequoria aequoria and Pelagia noctiluca) from the fish shoals they closely resemble. Euphausiid swarms are common and brilliantly luminescent, but are usually easily distinguishable from fish shoals.

6. FUTURE DEVELOPMENTS

Under the guidance of the National Physical Research Laboratory, the Sea Fisheries Branch is attempting to specify a TV system which is optimised for the detection of bioluminescence and subsequent signal processing. The spectral emittance and intensity of bioluminescence will be studied in the laboratory, from ships and from the research aircraft, which data will allow sensor matching and the construction of interference filters to produce a video-signal suitable for automated processing.

At low altitudes, the poor dynamic resolution caused by rapid image motion is unacceptable. There is a possibility that some type of forward-motion compensation may overcome the dynamic resolution problem, and an evaluation is in progress. It has been suggested that the best method of eliminating the effects of rapid forward motion is to use instrumentation which relies on forward motion for picture height, consequently the value of line scanners in application to this work is being considered.

7. CONCLUSION

Although the concept of "maximum sustainable yield" of a fish stock is not easily approached through a knowledge of stock size, there are advantages to stock management accruing from a knowledge of stock size and its annual fluctuations. The use of a simple direct-measurement technique is valuable in that it is uncomplicated in comparison with statistical methods involving population dynamics, and thus more believable to non-scientific management authorities. Therefore, the use of such techniques may have more impact in management than will better established conventional methods of assessing population size.

The use of LLLTV for fish shoal research has many advantages, particularly regarding the measurement of shoal areas and percentage (fractional) cover, where the measurements may be more accurate than those made with a direct viewer. However, potential users should be aware that the factor weighing heaviest in the step-wise calculation of shoal tonnage (Fig. 3) is the fish (packing) density within the shoal. Without a reasonable knowledge of this quantity, and, to a lesser extent, of the percentage of shoals likely to be visible at any one time within the "visible zone", an investment in TV equipment at relatively high cost may not repay the user with better quality results than those obtainable at low cost through a direct viewer.

In the research programme currently being undertaken off South West Africa, the airborne shoal tonnage estimation method is but one of four methods of assessing stock size. The value of retaining independence as a check on the reliability of stock estimates from different sources is undeniable, but in practice it seems confirmed that the integration of complementary methods from different disciplines provides better results in the long run. Thus, in future, the method involving aircraft-borne sensors will be carried out co-operatively with shipborne acoustic fish-counting methods as the aircraft provides hitherto unobtainable horizontal shoal dimension parameters while the acoustic research vessel provides shoal thickness and continuous measurements of fish density in numbers of fish per cubic metre (Cram and Hampton, in press).

The method of pilchard stock size estimation described seems suitable for most pelagic shoal fish, while of particular value to latent stocks with no biological research background. Survey problems are anticipated in high latitude summers and areas of low bioluminescence, but there seems to be few reasons why the technique should not be applicable in most other areas, to the advantage of rational management of valuable, not easily renewable, fish resources.

8. ACKNOWLEDGEMENTS

The Secretary for Industries and Director of Sea Fisheries are thanked for their permission to attend this Symposium. Messrs Agenbag and Hampton are thanked for their assistance with the manuscript and Mrs R. Wiederhold for the illustrations. J.J. Agenbag is further thanked for providing details of shoal diurnal migration from his forthcoming publication.

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Plate 1

Composite photograph from TV monitor showing a large pilchard shoal. A portion has been caught by a commercial fishing vessel (a) within its purse seine net (b). Scale approximately 1 cm : 25 m.

Plate 2a

Plate 2b

Pilchard shoals photographed from TV monitor: a. "arrowhead" configuration, b. "line" configuration. Scale approximately 1 cm: 10 m.

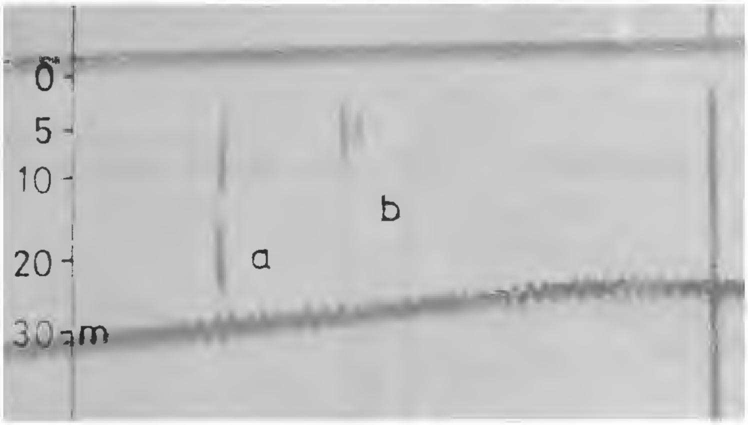

Plate 3

Section of echosounder paper output showing two pilchard shoals of varying thickness.

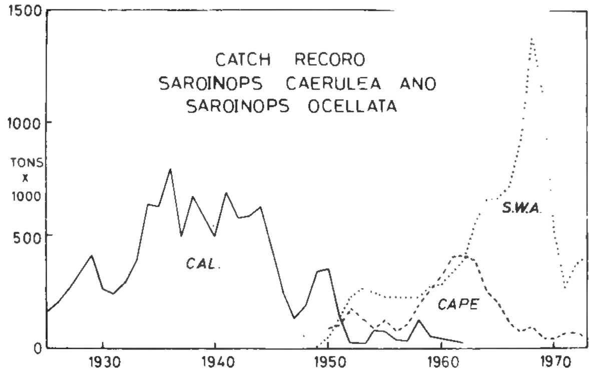

Fig.1

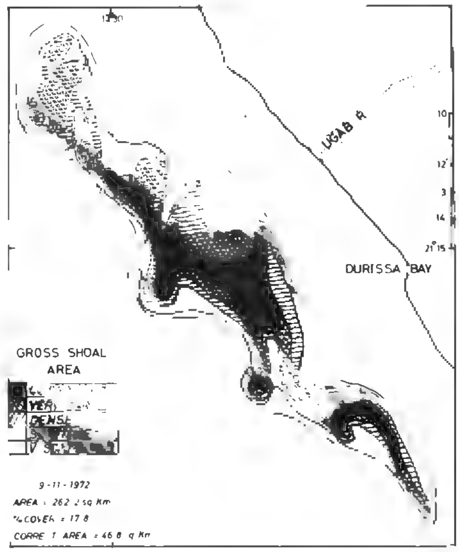

Fig.2

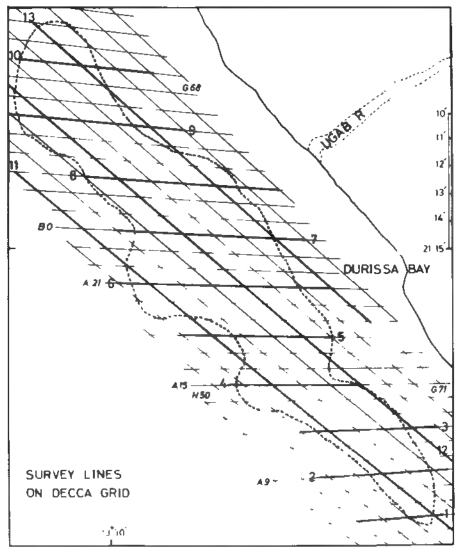

Fig.3

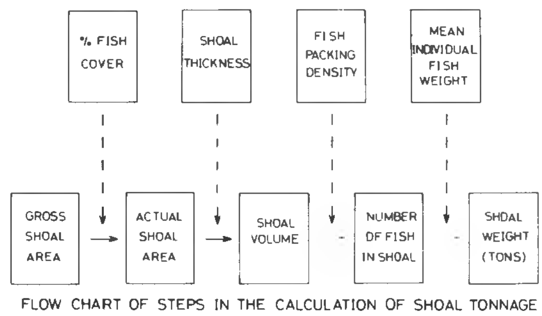

Fig.4

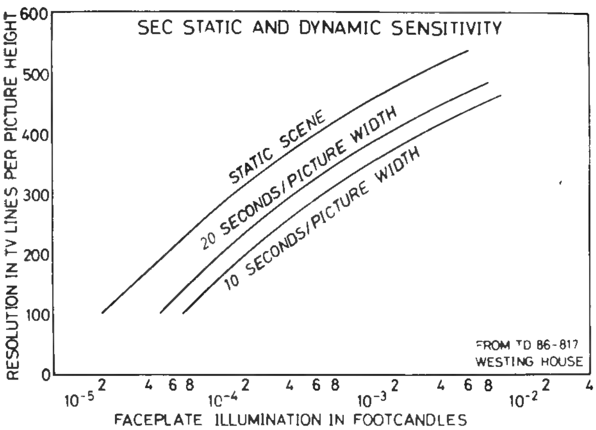

Fig.5

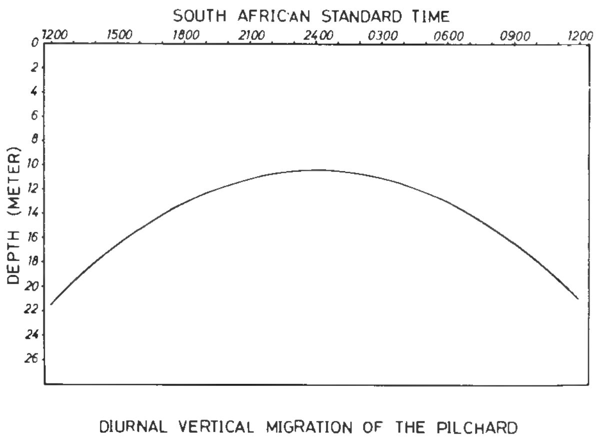

Fig.6

J. Cons. int. Explor. Mer, 35(3): 272–275. Juin 1974.

Observations on surface-shoaling Cape hake off South West Africa

D. L. Cram

Sea Fisheries Branch
Cape Town, South Africa

F. H. Schülein

Sea Fisheries Branch
Walvis Bay, South West Africa

An unusual occurrence of surface-shoaling Cape hake, in association with extensive swarms of *Nyctiphanes capensis*, was located off South West Africa in November 1971 by a night-flying research aircraft, and sampled by a research purse-seiner. Synchronous airborne radiation thermometry and a hydrobiological cruise enabled the occurrence to be explained in terms of the vertical and horizontal distribution of dissolved oxygen content during upwelling conditions inducing a temporary midwater swimming habit in the fish, coupled with a fortuitous location of the euphausiid swarms. It is suggested that the fish followed the diurnal vertical migration of the euphausiids to the surface for feeding purposes.

Introduction

The Cape hake (*Merluccius capensis*) is known as a demersal fish which may, to a limited extent, occur in the water column above the area swept by a bottom trawl. Juvenile hake are reported to possess a midwater feeding habit, but the occurrence of either adults or juveniles at the surface is uncommon. Although catches of hake are occasionally made at the surface by purse-seiners of the Western Cape pelagic fishing industry, their occurrence in the South West African fishery is virtually unknown and the only records available refer to isolated hake in hauls of pelagic fish. Therefore, the discovery of a shoal of hake at the surface during a pelagic fish research programme in November 1971 was treated with interest. The method of location of the hake was possibly unique, and this, together with synchronous data from an airborne radiation thermometer and a hydrobiological survey has enabled some suggestions to be made for the presence of supposedly demersal fish at the surface.

The work in November 1971 was part of a continuing programme of research into the pilchard resource of South West Africa, the Cape Cross Programme, and involves the use of a night-flying aircraft for shoal examination with a research purse-seiner for biological sampling. During a routine survey flight on 11 November 1971 at 2330 h (local time), an unusual type of bioluminescent sea surface area was observed by eye from the aircraft. The bioluminescent area was diffuse with numerous small brighter areas and considerably different in shape from that of shoals of pilchard (*Sardinops ocellata*), anchovy (*Engraulis capensis*) or maasbanker (*Trachurus trachurus*). Consequently, the purse-seiner was directed to the luminescent area for sampling and an echo-survey. On reaching the edge of the luminescent area, observers aboard the vessel noted a continuous diffuse luminescence ("milkiness") whose source was unobservable from the deck, with occasional brighter spots of luminescence caused by the activities of groups of about 50 fish. After a short echo-survey, the net was set enclosing two small fish patches, which proved to be Cape hake, *Merluccius capensis* (van Eck, 1961). The catch included a large number of *Nyctiphanes capensis*, a luminescent euphausiid which undoubtedly caused the luminescence classed by the airborne observers as "unusual" to distinguish it from the luminescence caused by phytoplankton when disturbed by pelagic fish shoals. In addition to emitting their own light, the *Nyctiphanes capensis* were probably stimulating the ubiquitous luminescent phytoplankton by their swimming activity. Following the recovery of the net, the echo-survey was continued throughout the whole luminescent area until 0400 h 12 November, when the vessel was required elsewhere.

Results

The fish caught in the net were 67 Cape hake, and 3 red-eye (*Etrumeus teres*). In addition, approximately 8 kg of euphausiids (*Nyctiphanes capensis*) were collected from the substantial amount caught. The standard length of the hake ranged from 17·0 cm to 25·0 cm with a modal length of 19·5 cm. The mean standard length was 19·9 cm and the mean weight was 69·2 kg. Sex was not determined since the gonads were undeveloped. The fish stomachs were all full, with a meanweight of 3·9 g of undigested *Nyctiphanes capensis*.

The bioluminescent area containing the surface-shoaling hake and euphausiids was measured with the Decca navigator of the research aircraft at 86·1 km² (Cram, 1972). The ship's echosounder displayed a diffuse layer of, presumably, euphausiids in the upper 36 m. No fish shoals were recorded as they were visibly at the surface and therefore above the echosounder transducer which was 2 m below the waterline. The net of the research purse-seiner is 333 × 40 m in dimension with a mesh size of 7 mm. Hence the 67 hake caught represent an extremely small catch for this type of net. However, considering the area of the luminescent patch (86·1 km²), the area enclosed by the purse-seine net (8820 m²) and assuming from visual observations made aboard the aircraft that the fish patches were uniformly distributed within the luminescent area, a total of approximately 653 000 fish, or 45·2 metric tons, were at the surface. At the time of observation the sea was calm, the wind a southerly breeze, force 3, and the sky overcast with the cloud base at 460 m.

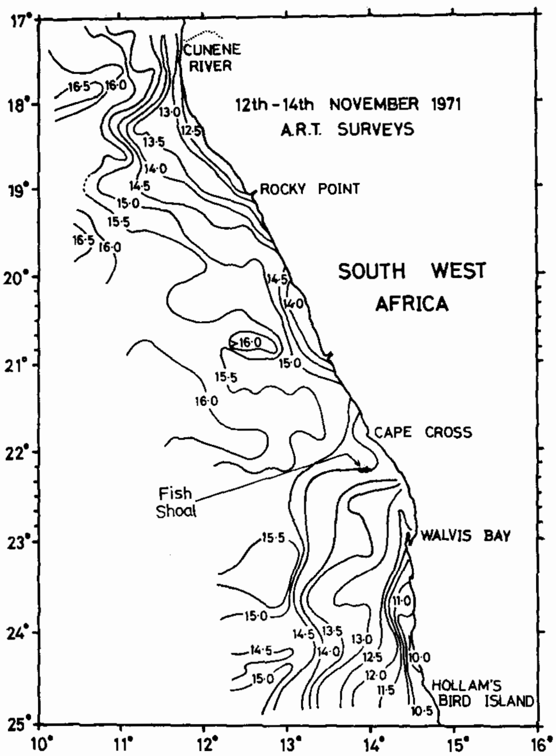

Figure. 1. Airborne radiation thermometer isotherm map, November 1971.

Radiation thermometry flights were made synchronously with the fish research, providing a quasi-synoptic surface temperature map of the entire fishing ground (Fig. 1). In addition, line CC6 of the hydrobiological survey was conducted on 22°S, 12 nm north of the shoal, on 17 November 1971, providing a vertical section of oxygen content (Fig. 2) and temperature (Fig. 3). For comparative purposes, the vertical section of oxygen content along line CC6 for October 1971 is also included (Fig. 4).

Discussion

As the occurrence of surface-shoaling hake off South West Africa is very uncommon, a reason for the appearance of this shoal may be sought in the prevailing environmental conditions. During October and November, conditions varied rapidly. In October, upwelling had just ceased at the time of observation and the inshore oxygen content had been slightly increased by mixing, except between 3–5 nm offshore where the influence of the anoxic conditions on the bottom can be observed (Fig. 4). Between the times of observation in October and November, upwelling had recommenced: the quasi-synoptic surface-temperature chart (Fig. 1) shows the existence of the typical coastal upwelling zones, the low-temperature zone near 24°S and a higher temperature zone near 21°S. There is no explanation for the presence of the low-temperature zone near 19°S which is regarded, at the moment, as unusual. The vertical distribution of dissolved oxygen in November 1971 shows that a shoreward movement of oxygen-deficient water had occurred along the bottom and into the upper water near the coast. In addition, an area of high oxygen content was present at the surface, centred at about 12 nm from the coast. It is likely that this represents a section through the offshore band of high production and standing crop which is frequently accompanied by an abundance of herbivorous zooplankton grazing on the seaward edge. The surface-temperature chart (Fig. 1) indicates that a shoreward intrusion of warmer surface water had occurred between 21° and 22°S which brought the high-production zone shorewards to its observed position.

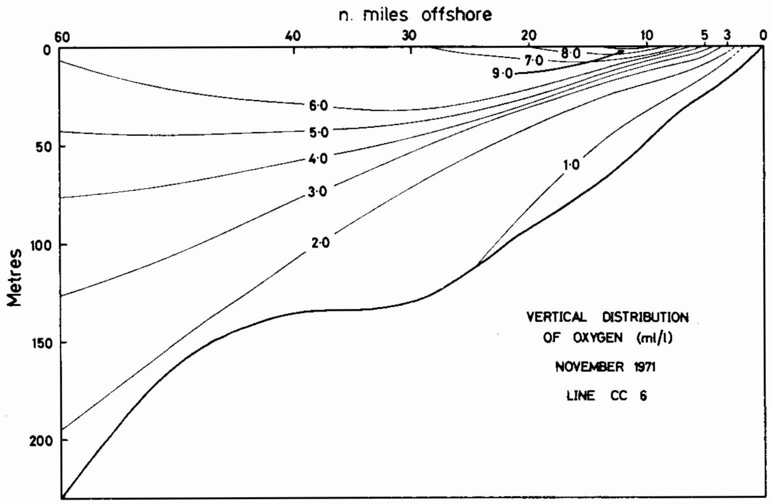

Figure 2. Vertical distribution of dissolved oxygen content 3–60 nm offshore on 22°S, November 1971.

Thus, it is suggested that, early in November, the onset of upwelling and consequent shoreward movement of bottom water with a low dissolved oxygen content forced the juvenile hake to adopt a temporary mid-water swimming habit.

Sundnes (1957) reported a "critical level" of oxygen content for cod at 2·7 ml/l and an asphyxiation level at 0·80 ml/l. In the vicinity of the surface shoaling hake, the oxygen content from 45 m to the bottom was less than 1·0 ml/l and the "critical level" of 2·7 ml/l occurred at a depth of about 25 m. Assuming the oxygen requirements of cod are similar to that of Cape hake, the latter are unlikely to descend below 45 m and are more likely to be above "the critical level" at 25 m; thus, it is not impossible that the fishes' presence at the surface was solely due to the influence of oxygen-deficient bottom water. However, as the fish were in an area of abundant herbivorous zooplankton situated about 12 nm offshore, they would undoubtedly encounter swarms of *Nyctiphanes capensis*, a well known vertically migrating euphausiid (Boden, 1955).

It is rare for Cape hake to occur at the surface but very common for *N. capensis*. The hake could have encountered the euphausiids at some point in the water column and may have followed the swarm to the surface to continue feeding on them during the night. Since November 1971, euphausiid swarms have been frequently observed at night by the research aircraft and vessels, but never with Cape hake in attendance. It is therefore concluded that the presence of Cape hake at the surface was a result of

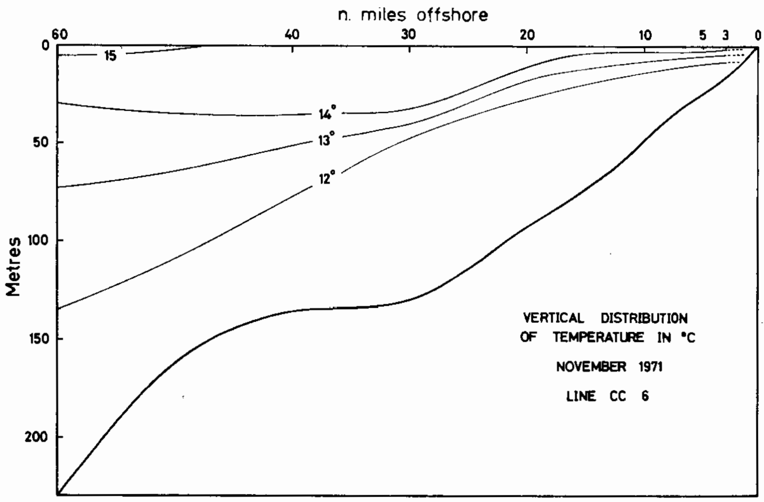

Figure 3. Vertical distribution of temperature 3–60 nm offshore on 22°S, November 1971.

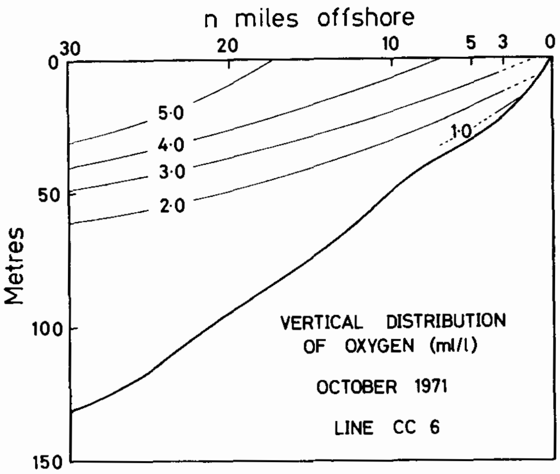

Figure 4. Vertical distribution of dissolved oxygen content 3–30 nm offshore on 22°S, October 1971.

the coincidence of the different environmental phenomena under discussion.

Acknowledgements

Mr. D. P. F. King (Sea Fisheries Branch, Walvis Bay) is thanked for his information on the habits of herbivorous zooplankton. Mr. L. Botha (Sea Fisheries Branch, Cape Town) is thanked for his discussions on surface-shoaling hake in the Western Cape. The Director of Sea Fisheries is thanked for permission to publish this paper.

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South West African pilchard stock continues to recover

Summary of results of Phase IV of the Cape Cross Programme

By D. L. Cram, Sea Fisheries Branch, Cape Town

Introduction

DURING 1973 and the early part of 1974, the Cape Cross programme satisfactorily achieved its objective of providing a scientific basis for the management of the South West African *Sardinops ocellata* fishery. Consistent with the guidelines laid down in 1970, the scientific effort is still concentrated upon the pilchard in order to ensure the viability of the very valuable canning industry for social and economic reasons. However, other species are not ignored, and the Phase IV report contains an interesting section on anchovy biology.

Although the split quota is a somewhat cumbersome regulatory mechanism, it has demonstrated that it is possible to manage single stocks within a multispecies fishery, and gives confidence to further attempts to find a more flexible approach to single-stock management within multispecies fisheries.

In summary, the report contains three estimates of pilchard stock size obtained from different methods: namely, the direct measure through airborne shoal tonnage estimation; the indirect, catch-independent method through quantitative egg sampling; and the catch-dependent method through mortality analysis. Ecological aspects are covered through an analysis of pilchard availability and through a suggested method of recruitment prediction through indirect evaluation of environment quality.

Stock assessment

The method of shoal tonnage estimation has slightly increased in precision and produced an estimate of pilchard stock size of 3,2 million tons, an increase of 12 per cent over that determined for the previous year. Now that the long-overdue TV camera has arrived, calibration of the method becomes possible through error estimates of measurement procedures and by comparisons of estimated and actual shoal weights. The automated videosignal processor being designed and built by the electronics section will be of very great assistance in this part of the work.

The contract with the CSIR, to conduct joint research on certain aspects of bioluminescence and TV research, has now been agreed upon and the equipment ordered for the first stage. This will consist of an investigation of the spectral emission and strength of bioluminescence in order that specifications may be drawn up for optimisation of TV component design. In order to increase the efficiency of this aspect of research, the Branch will carry out independently certain development programmes while the long-term work continues with the co-operation of the CSIR.

The South West African Pelagic Egg and Larvae Survey (SWAPELS) has produced an estimate of pilchard spawning stock size of 1,7 million tons, a figure which, as explained in the report, is an underestimate of the actual commercially available stock size. Considering that the spawning stock is probably the III+ to VIII+ age classes, a considerable proportion of the stock is excluded from the estimate.

The processing of SWAPELS data is heavily dependent upon computor work, and serious delays were encountered in writing and de-bugging the very large programmes now in use.

The basic sampling gear development has stabilised around the B50 Bongo samplers equipped with nets of 550 and 900 micron mesh size. Plans exist to automate the recording of flowmeter and other haul data, these being refinements required to increase the precision of measurements.

Pilchard stock size has been estimated through mortality analysis at 0,8 to 1,8 million tons. Unfortunately, this method is not sensitive to short-term fluctuations in abundance and the estimate seems low when compared with the 1973 catch and the rate of population growth observed from the airborne method.

Regarding other species, the report contains an estimate of anchovy stock size, produced from mortality data, of 0,5 to 1,0 million tons, together with the information that the changes in age composition of the catch has been from II+ to 0+ (modal age group) between 1972 and 1973, indicating that changes have occurred in the structure of the anchovy fishery. This may indicate that the anchovy resource is under increased pressure, to the advantage of the pilchard.

Ecology

Ecological research has taken two main lines: an investigation of pelagic fish availability through "shoal ecology" and an interesting method of prediction of pilchard recruitment.

With hydrological data for the months of June and July available for comparison with catch position frequency data it is apparent that low oxygen content surface water in the area between Ambrose Bay and Walvis Bay acted as a form of "barrier" to fish movement, as very few catches were made in the area, compared with north of Ambrose Bay.

There is a correlation between oxygen content, phytoplankton concentration and upwelling, and the relationship between fish shoal occurrence and phytoplankton concentration in June and July 1973 confirms previous findings that pilchard catches are unlikely to be made in the "belt" of high phytoplankton concentration often found along the coast.

The ecology and availability studies in general proved rewarding in 1973, with new information on currents and fuller information on the oxygen minimum layer, zooplankton and phytoplankton, leading to a better understanding of pelagic fish availability. This aspect of the programme has made a very worthwhile contribution in enabling the distinction to be made between the availability and abundance of the pilchard. The concept of an "intermediate" zone in which fish shoals are likely to be found has been changed to incorporate new findings and an availability study of a more advanced nature is being planned.

Research conducted since 1965 has indicated that a relationship exists between fish oil yield and a poor quality environment, defined by anomalous conditions. Further, that a relationship exists between a poor quality environmental period and subsequent recruitment three years later. Thus the deduction is made that a low oil yield in one year implies that recruitment may be poor in three years' time.

Should this hypothesis be proved correct, a simple method of qualitatively forecasting recruitment becomes available. A very interesting observation made in the same contribution to the report is that despite very heavy fishing during an environmentally "good" year (i.e. high oil yield) there was no effect on subsequent recruitment.

Development

Considering the development of scientific methods during Phase IV certain aspects require mention. The acoustic and airborne shoal tonnage estimation methods have been united in a combined aerial/acoustic direct stock size measurement method. The two methods are complementary and their integration is a logical step. The loss of two "independent" methods of stock estimation (which could have acted as a reciprocal check on results, as well as on those from other methods) and their replacement by one, better, is well worthwhile.

The method continues to show promise and with the delivery of the television camera, the development of calibration techniques for the airborne method will be possible in 1974.

Similarly, the calibration of the acoustic equipment will receive increased attention during 1974, as the equipment will be removed from the *RV Benguela* and installed in a mobile test-rig at Walvis Bay, where uninterrupted work can be accomplished over a period of months. Ship's time permitting, a major integrated survey will be mounted in the closed season of 1974/75.

At present, the combined aerial/acoustic method can only be applied to pilchard, while the two other methods of stock assessment, that of population dynamics based on sampling the commercial catch, and the SWAPEL surveys can produce stock estimates of more than one species. This situation is accepted for the aerial/acoustic method at present, but long-term planning involves other species.

A valuable feature of the SWAPEL surveys is that catch- and availability-independent estimates of stock size can be obtained. In addition to the pilchard, anchovy data collected in 1973/74 will be fully processed in 1974/75 although it is not certain at this time whether the limitations in the sampling of anchovy eggs will allow an estimate to be produced. Maasbanker egg data collected during 1974/75 will also be worked up. Larvae collection data will be quantitatively analysed to complement the successful taxonomic and ecological studies completed so far.

The work on anchovy and maasbanker egg data will partly depend for success on fecundity research. Pilchard fecundity research methods have proved successful and must be extended to other species. Numerous problems can be anticipated with anchovy, which is believed to be a serial spawner. Fecundity studies are the "achilles heel" of egg programmes and all efforts will be made to strengthen this weakness.

Research aimed at obtaining a maximum sustainable yield for the pilchard fishery will be increased as far as possible, but results are not anticipated until the end of 1975. Meanwhile, the interesting hypothesis that pilchard recruitment can be predicted from oil-yields three years previously, can be worked up without delay. The ability to qualitatively predict recruitment would be a very valuable management tool in future.

Conclusion

From the results summarised above, it seems likely that the recovery of the resource is well advanced, although management authorities should beware of overconfidence. In the absence of a maximum sustainable yield figure for the fishery the quotas will be allowed to rise by small increments as long as annual surveys show the stock to be increasing substantially in size.

It is anticipated that by the end of 1975 a maximum sustainable yield figure will have been produced from catch and effort data, and that data in hand will have been more fully analysed. In the interim period, the catch will not be allowed to approach what is subjectively assumed to be a reasonable upper catch limit.

The effectiveness of the split quota has been reduced over the years by certain illegal practices. However, the principal objective of the split quota, that of the conservation of the pilchard, seems to be achieved in part. Although apparently still reduced from the level of 6,25–7,50 million tons calculated for the period 1957-66, the stock is increasing in abundance and may no longer be threatened to the same extent as previously.

Consequently, ways of reducing the wastage of the resource (by illegal practices) must now be sought, most likely through the replacement of the split quota by a system of regulation which will permit the still necessary conservation of the pilchard while focussing the attentions of the industry heavily onto anchovy and other species.

Subject to successful negotiation in 1974, it should be possible to create a resource management system for the 1975 season, all being well, which would combine increased pilchard quotas with new and more effective controls. Further, factory management should be requested to observe quota maxima carefully and to avoid catches in excess of the quota.

In conclusion, it is felt that the industry is now feeling the benefit of the conservation measures in force since the 1971 fishing season, especially when the recent quota re-adjustment is taken into consideration. In view of the stated objective of managing the pilchard resource on a maximum sustainable yield basis, the industry can be assured that whenever scientific evidence justifies it, the quota will be raised (or lowered) to that of the maximum sustainable yield.

Acknowledgements

Members of the team are congratulated and thanked for their valuable contributions during the year, the Director of Sea Fisheries is thanked for his considerable encouragement, and the Dept. of Industries for the heavy funding which enabled the results to be achieved.

SWA pilchard stocks show first signs of recovery

Summary of results of Phase III of the Cape Cross pelagic research programme

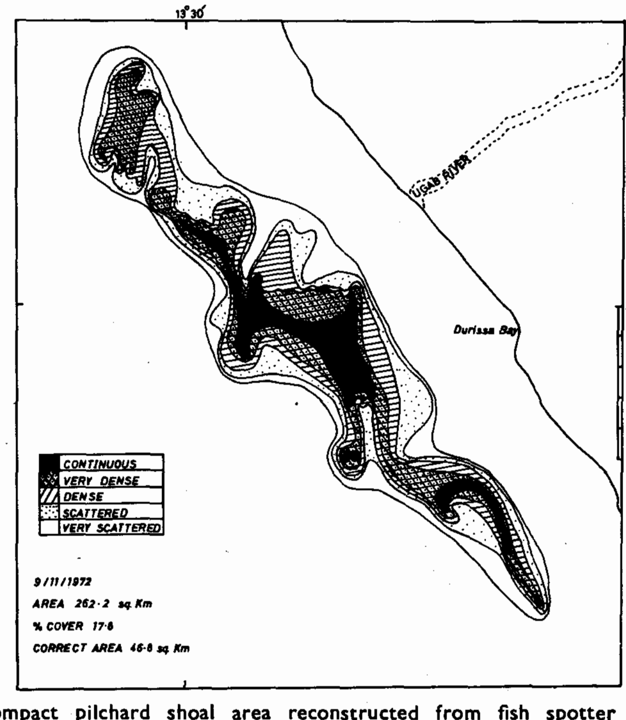
by D. L. Cram and G. A. Visser, Sea Fisheries

Introduction

THE PURPOSE of Phase III of the Cape Cross Programme was identical with that of Phases I and II namely, to provide the Dept. of Industries with a sound scientific basis for the effective management of the South West African pilchard, *Sardinops ocellata*. Unlike the previous phases, comparative data collected by the present research team is now available, while all research projects are operational and producing results.

The report, which was recently submitted to the Secretary for Industries, is the most detailed and comprehensive report so far produced and reflects great credit on the scientific team responsible. Research during Phase III was made possible by the generous funding provided by the Dept. of Industries and the continued support and encouragement of the Director of Sea Fisheries.

The method of research was to direct the attention of widely differing disciplines to a problem of stock reduction. Each discipline has produced a meaningful, though partial comment, and, when considered together, a good view of the whole problem is obtained. In brief, the stock is still reduced but the decline has halted and a recovery commenced. The environment affected fish distribution so as to bring the shoals nearer to Walvis Bay, resulting in the delivery of high quality fish to canneries. A brief summary of the results follows.



Compact pilchard shoal area reconstructed from fish spotter observations.

Stock assessment

Experiments with airborne shoal tonnage estimation continue and represent the first serious attempts to calculate the stock size of a pelagic fish population by direct measurement. The methodology is similar to that used for the Phase II calculations and still lacks precision, particularly in the calculation of actual fish shoal area from the observed gross shoal area (fig. 1). For the remainder of the calculation, better use has been made of the data. Results produced in 1971/72 have been recalculated to conform with the method used for 1972/73 data processing.

The results of airborne shoal tonnage estimation are:

November – January 1971/72: 2,12 million metric tons.

November – January 1972/73: 2,94 million metric tons.

The method has not so far been subjected to a rigorous statistical analysis and it is just not possible to carry out empirical calibration by catching an entire measured shoal. However, there is excellent agreement between the 1971/72 figure of 2,14 million metric tons and that of Baird, Newman, Ratte and Schülein (Phase II Report 1972) of approximately 2 million metric tons and that for 1970-1972 of Newman and Schülein (Phase III Report 1973) of approximately 1½ million metric tons, which gives a measure of confidence in the figure of 2,94 million metric tons calculated for 1972/73.

The shoal tonnage estimates indicate that the decline in pilchard abundance ceased at least by the end of 1972 and that a recovery has taken place since that time. The recovery is very small indeed when it is compared with the depletion which has occurred since 1957-1966 when the stock strength was calcu-

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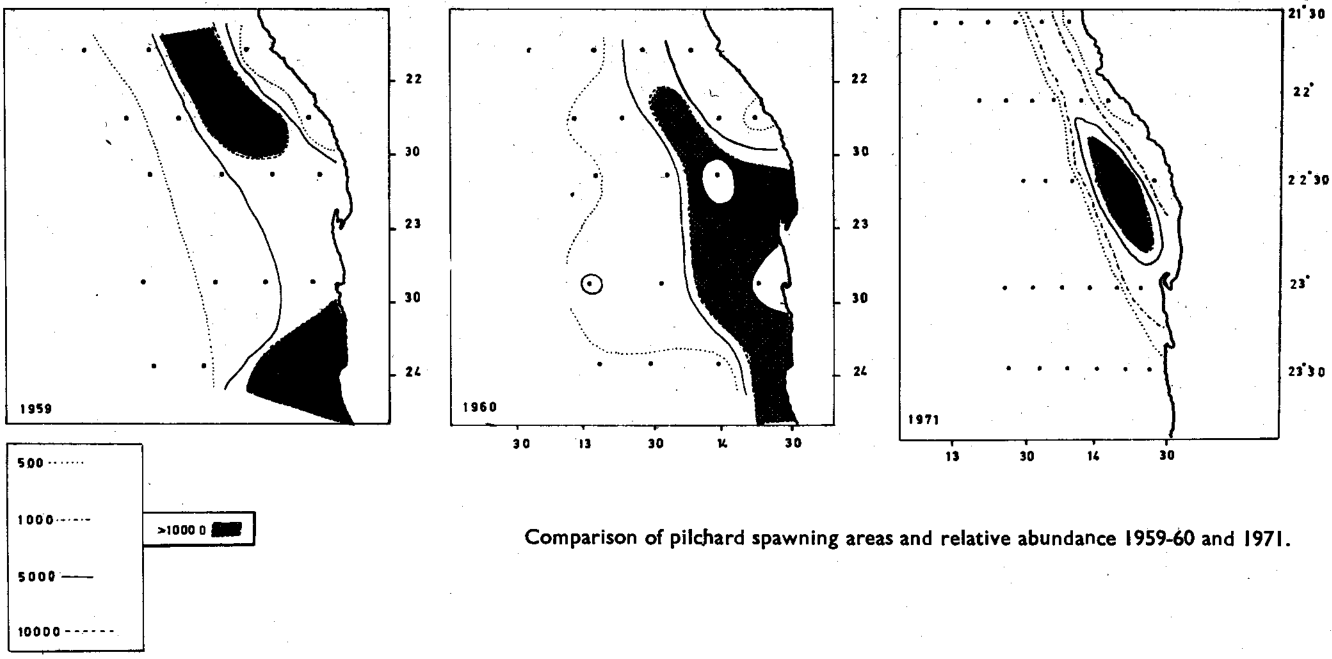


Comparison of pilchard spawning areas and relative abundance 1959-60 and 1971.

lated at 6,25 to 7,50 million tons (Newman 1970) and re-inforces the opinion that the stock is still under severe pressure.

The conventional population dynamics methods also confirm that a decline in the pilchard stock took place after the high catches of 1966-68. Valuable new catch per unit effort data has been made available on the catch of pilchard per unit of fuel issued at four Walvis Bay factories. An important feature of the data is that the decline in catch per unit effort from about 0,13 metric tons per litre in 1965/66 to 0,05 metric tons per litre in 1970, is of the same order as the difference in population size calculated during the same two periods, that is, 6 million and 2 million tons respectively.

Unfortunately, quota restrictions and other complications make it impossible to comment on the trend in population size in 1972. However, the trend can be seen to validate previous observations on the decline made through other methods.

Mortality estimates made from age and catch data show that a decrease in mortality rates has occurred. The mortality rates associated with high catches of 1967 to 1968 are themselves high but were low in 1971 and 1972 when the catch was reduced by the quota restriction. This indicates that the data is meaningful.

Estimates of population size have been made from mortality and catch size data. During 1967-1969 the population was of the order of 2 million metric tons or lower. For 1970-1972 the population was 1½ million metric tons or lower. Both these estimates are roughly similar and both are substantially less than in the pre-1966 period. Unfortunately the values considered are averages for three year periods and they are not sensitive to short term trends, that is, changes from year to year.

Both airborne and conventional methods are in good agreement as both indicate a similar large decline in stock size. The airborne method, with its new experimental approach has been sensitive to small changes on a year to year basis. Quota restrictions and other complications prevent the conventional methods from indicating trends in 1972 or from being sensitive to year to year changes. However, it is abundantly clear from the results of both independent methods that the massive decline has halted but the drastic depletion of the resource still exists.

Biology of anchovy and maasbanker

It was found from vertebral counts, growth curves, periods of gonad development and spawning that the same anchovy species (*E. capensis*) occur in both South West African and South African waters. Anchovy mortality data imply that no increase in the stock has occurred.

Maasbanker work has been limited, but extensive age studies have been conducted.

No estimates of stock size are available, nor is the appearance of these species predictable in the 1973 season.

Pelagic egg survey 1971/72

Two major spawning centres corresponding to the spawning peaks of spring/summer and summer/autumn occurred during the pilchard spawning cycle. The start of the pilchard spring/summer spawning was later than normal, probably due to the influx of warm oceanic water into the survey area.

There is a distinct temperature difference between the sites of spring/summer and summer/autumn pilchard spawners. The northern summer/autumn spawning could be a result of a northward offshore "summer" spawning migration, a separate spawning group in the north or the product of another clupeoid, namely *Sardinella* species. The "summer" spawning peak is not a secondary one resulting from the pilchard being a serial spawner.

The indications are that pilchard spawning was not as intense as in the 1960's which undoubtedly reflects the lower number of adult fish in our waters during 1971 (fig. 2).

Anchovy and pilchard display slight differences in spawning behaviour. The bulk of anchovy spawning occurred between December and March. Anchovy show a "preference" for colder inshore waters although they did spawn over a wide range

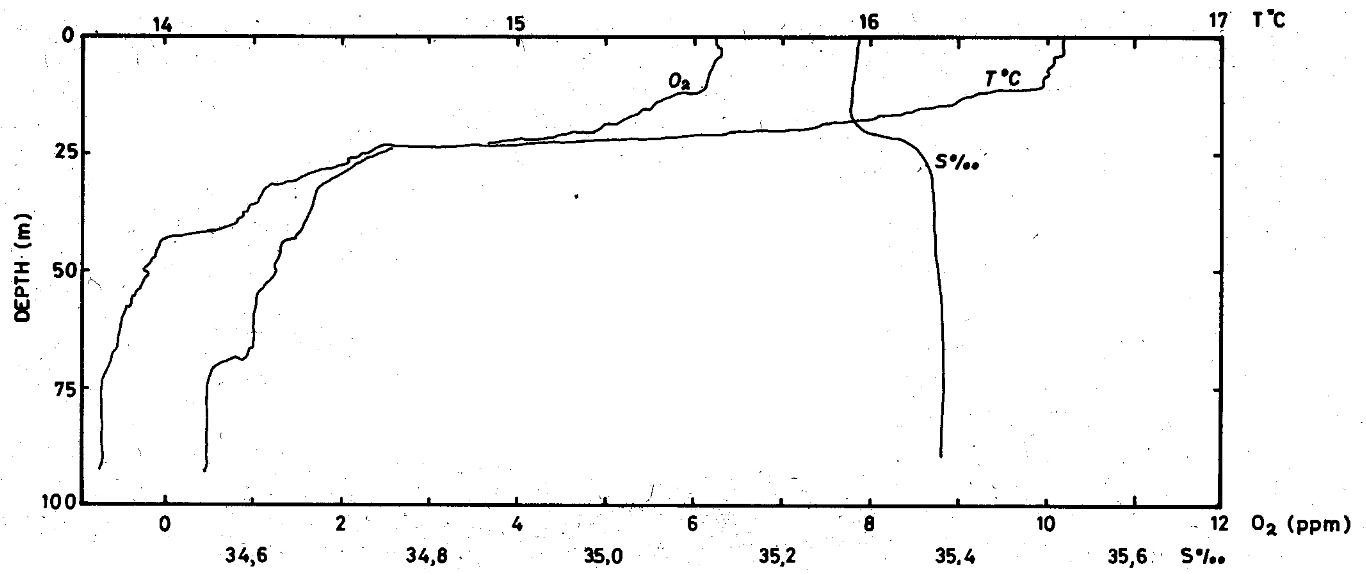


Fig. 3: STDO$_2$ continuous trace showing shallow surface warm water above pronounced thermocline.

of temperatures. Both anchovy and pilchard were widely distributed in 1971/72. Anchovy occurred at 19 per cent of the station occupied while pilchard occurred at 16 per cent. Anchovy outnumbered pilchard eggs in the area with a ratio of 1,46:1. The larval studies had little success due to inefficiency of the sampling gear.

This egg programme was restricted in its aims, due to the unsuitability of thre equipment and the limited abilities of the available research vessel. However, despite the quantitative inadequacy of this survey, the results of the programme were of considerable value in planning more intensive coverage of the pilchard spawning centres for the SWAPELS programme of 1972/73.

Pelagic egg surveys 1972/73

In August 1972, a new programme was initiated (SWAPELS) which, it is hoped will assist in the fulfilment of the chief aim of the research, namely an estimate of pilchard stock size. Available information is limited as the survey period extends from August to April, and data processed to date only includes September to December.

Pilchard eggs were obtained during the four months of survey with peak spawning occurring in October and November. The distribution and abundance of pilchard eggs for 1972 was more widespread than in 1971, with the more intensive spawning occurring in the Conception Bay area. The temperature in which pilchard eggs were obtained off South West Africa in 1972 was slightly lower than 1971, indicating more favourable conditions for spawning in 1972. A comparison between egg occurrences of previous years and the results of 1972 indicates a recovery in the present parent population.

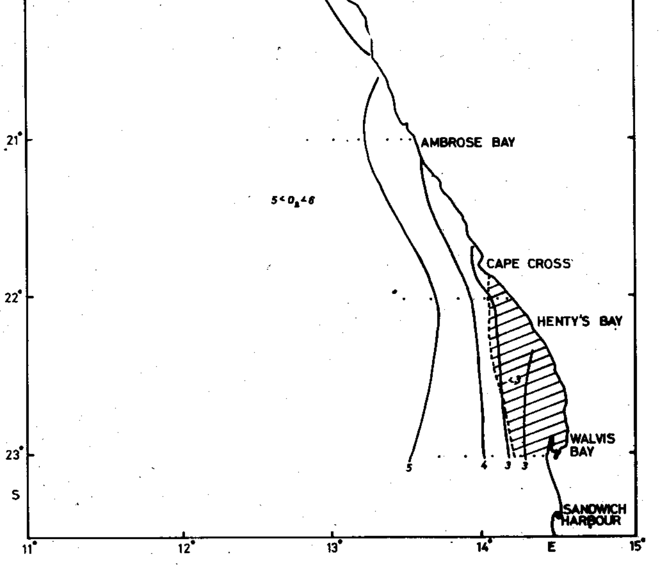
Anchovy sampling was inadequate to give any indication of the abundance and distribution of anchovy eggs for 1972. Two major changes in sampling techniques are being implemented.

Larval studies show a northward drift of pilchard larvae, with larger forms occurring in the north. Anchovy larvae distribution implies that anchovy spawning may have occurred to the south of the research area. A total of twelve larval species from ten families were recorded and their relative abundance charted. The Goby larvae *G. bibarbatus* was the most abundant fish larvae obtained during the four months of survey.

The environment

Ecological studies undertaken during Phase III of the Cape Cross Programme covered hydrographic conditions and the phyto- and zooplankton distributions in relation to the pelagic fish shoals in South West African waters.

Two important features of the hydrographic environment dominated the water characteristics during the 1972 fishing season. Firstly, there were larger expanses of warm water over the fishing grounds creating somewhat anomalous conditions,



especially during the early months of the fishing season. Fortunately this warm layer was only observed at or near the surface, thereby enabling the pelagic fish, which prefers the cooler water, to survive by diving underneath this unfavourable surface water (fig. 3).

The vertical distribution of fish shoals in relation to the temperature stratification was discovered by comparing synchronous echo sounder and hydrological data, which, in addition, gave valuable information on the occurrence of the "plankton layer." During this anomalous period the phytoplankton, which is an important fish food, was displaced southward (fig. 4) thereby creating a more favourable environment close to Walvis Bay.

The second important feature of the hydrographic condition was the persistence of a narrow, shallow counter current close to the coast flowing from north to south past Walvis Bay. This counter current recognisable as a "tongue" of high salinity was found only in the closed season during the preceding two years.

That almost every major concentration of fish observed by the fish spotting aircraft was found straddling the counter current could only mean that the fish utilised this southward current for their migration (fig. 5). This could also be construed as a reason for the pilchards to be more readily available to Walvis Bay than in the previous years.

The influence of the current can be seen clearly in the accompanying figure which shows that during April 1972 the counter current branched off Cape Cross. It seems that the fish shoals followed this current, moving further offshore. At the same time, almost 70 per cent of the number of commercial catches were made in this branch of the current with the fleet apparently exploiting part of the southernmost fish shoal found by the fish spotter.

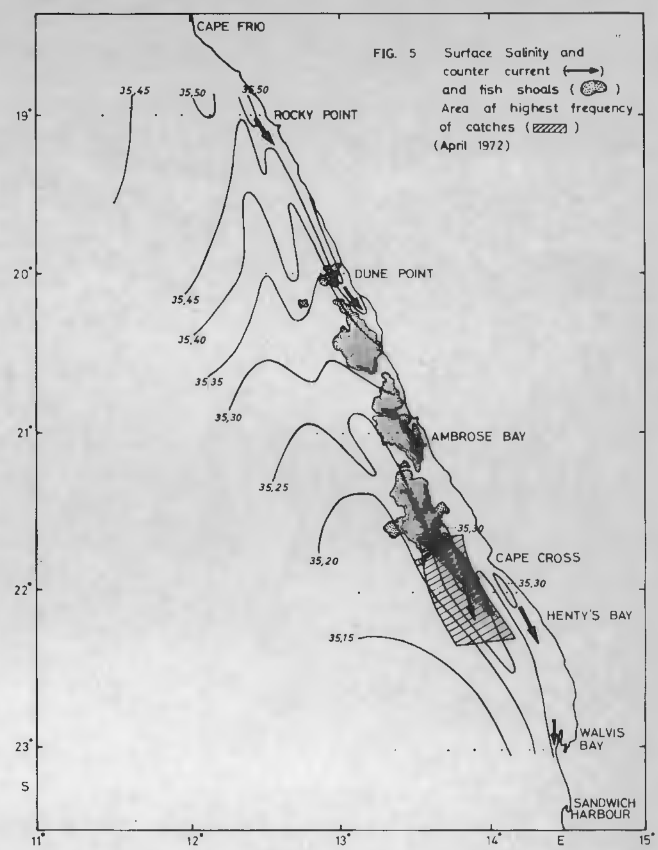
In other words, the environmental conditions were responsible for an increase in availability of pilchards close to Walvis Bay. It must be remembered that this phenomenon may be responsible for a misconception, namely that increased availability may be looked upon as a major increase in the stock size.

During 1972 it was also proved that pelagic fish prefer the "intermediate" zone between the maximum concentrations of zooplankton offshore and phytoplankton inshore (fig. 6). This phenomenon was also found during the preceding two years. Wherever fish shoals and dense concentrations of phytoplankton did occur simultaneously it was proved beyond doubt that the fish were found atop the plankton and not in it.

High frequency echo sounder and echo integrator

In 1971 a Simrad 120-kHz echo sounder and echo integrator was purchased as an aid in assessing the South West African pelagic fish stocks. The echo integrator is essentially a calibrated echo sounder which accumulates information received from sound scatterers in the ocean over long periods.

By applying the target strength-per-fish method the average packing density of a pilchard shoal at night was found to be 23 fish per cu metre of water.



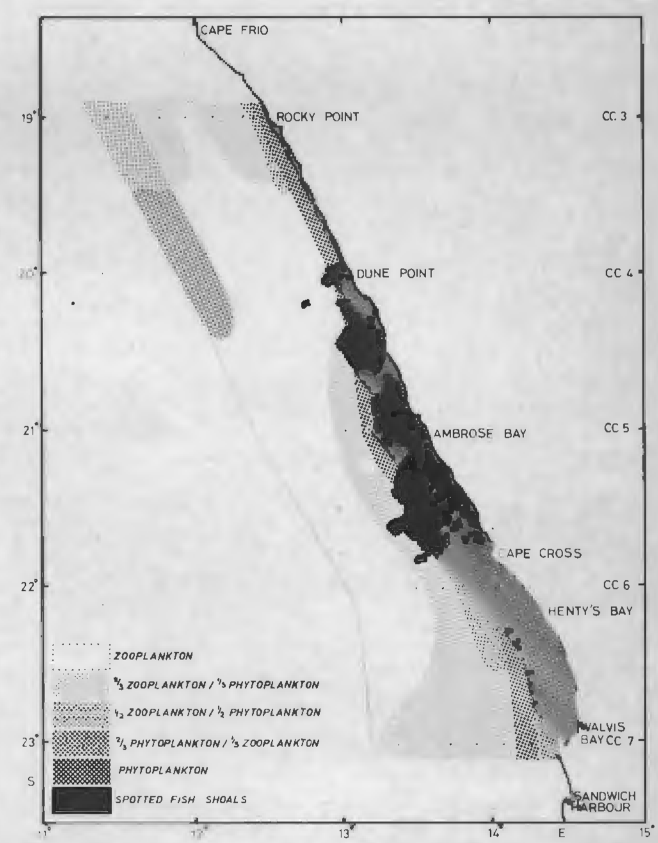


Fig. 6: Fish shoals concentrated in the "intermediate" zone between dense inshore phytoplankton and dense offshore zooplankton.

This figure agrees very well with the packing density of 20 fish per cu metre by a completely independent method using purse seine nets on commercial vessels and the fish spotting aircraft.

There is still much experimental work to be done with the equipment during the coming year and it is hoped that more accurate data can be obtained. The instrument shows much promise towards giving accurate estimates of the packing density from shoal to shoal which is vital for calculating the available tonnage of pelagic fish.

Food and feeding selectivity of the pilchard, anchovy and maasbanker

The gill raker mechanism of post-larval pilchard and anchovy is such that the fish are incapable of filter feeding. Particulate feeding on zooplankton occurs until a length of 100 mm is achieved in pilchards and 80 mm in anchovy, when diatoms begin to dominate the diet.

Below these sizes competition for food could occur, with the abundant goby and other larvae contributing to the pressure on food organisms. A study of this aspect is now being commenced. Above these sizes competition could occur, but, between the very high organic production and the severely reduced stock size it is unlikely that feeding competition is a limiting factor in population growth.

The fecundity of the SWA pilchard

In order to calculate spawning stock size from pelagic egg collections it is essential to know the egg production of the female fish. A study was therefore recently commenced which showed that the mean number of eggs produced by 49 fish was $23{,}2 \pm 1{,}3$ thousand, and ranged from 8,1 thousand for a fish of 18,9 cm standard length and 105,8 g body weight to 52,1 thousand for a fish of 21,9 cm standard length and 179,4 g body weight.

Pilchard genotyping

The techniques of zone electrophoresis of tissue proteins and specific staining of enzymes have recently added another method of identifying fish stocks to marine research. The work started in December 1972 and the results are so far encouraging, and a satisfactory rate of experimental and development progress is being made.

Other projects

As a pre-requisite to the fish spotting programme it was necessary to study the diurnal vertical migration of fish shoals. This research, carried out on data incidentally acquired by other projects, shows statistically that a diurnal vertical migration occurs on a well defined pattern. The change in vertical distribution is accompanied by a change in the thickness of the fish layer. The data will be of great benefit to the fishspotting, echo integrator and midwater trawling programmes.

Shoal identification by chemical methods research continues. An analysis of pilchard body oil has been pursued to the point where satisfactory separation of components was obtained. The investigation will be completed by September 1973.

Conclusion and recommendations

The dramatic decline in pilchard stock size, the effects of which in 1970 caused the commencement of the Cape Cross Programme, has been halted. All evidence suggests a stabilisation at the 1 million to 2 million ton level, with certain evidence of an increase between 1972 and 1973 provided by the airborne shoal tonnage estimation and egg programme.

While stock is still badly reduced, the success in halting this decline is due to the quota system, closed season extension and sanctuary proposed following the Phase I "crash programme" in 1970.

The anchovy and maasbanker catch in 1972 did not come up to expectation, but the data imply that no great change in the fishery has occurred. The abundance of these two fish in the 1973 fishery is impossible to predict.

Interpretation of environmental conditions suggest that the increased availability of pilchards at Walvis Bay in 1972 was a temporary feature induced by a higher than normal incidence of northerly winds. No assurance can be given that similar environmental conditions will prevail in 1973, leading to high availability, which is not synonymous with high or increased abundance.

A study of shoal ecology has proved very rewarding, for the distribution of fish in relation to biotic and abiotic factors is now quite well understood. These data have no predictive value but will enable a much more effective analysis of availability trends to be produced.

As a result of this work, the following recommendations are made. First, that a limited increase in pilchard quota be considered, provided that the increase does not cause the pilchard quota to exceed 50 per cent of the overall 90 000 short ton factory quota.

Secondly, it is recommended that the quota restrictions, sanctuary regulations and catch species composition, as detailed in the relevant fisheries regulations, be strictly adhered to and backed by the force of law. This will ensure that illegal practices such as "incorrect identification on landing" will be stamped out once and for all, as they provide Sea Fisheries with slightly erroneous data on which stock size calculations are partly based. The illegal practices work against the industry's best interests, as they affect the quality of Sea Fisheries' management advice.

Thirdly, it is recommended that the industry does not seek to have the quota reviewed within the next fishing season, based upon their own interpretation of availability and selective fishing of the pilchard. The quota increase recommended is based upon a *minimum* of one year's data and much intensive scientific work over the last *three* years. To request a review three months or so after an already generous recommendation, will not result in any new information being presented or in any change in attitude of Sea Fisheries.

With regard to the future management of the South West African stock, it must be clearly and unequivocally stated that the decline of the stock from six to less than two million tons between 1966 and 1970 was due to the over-exploitation of a national fishery. The present stability of the reduced stock must be seen as the basis of future growth, and growth cannot be achieved without conservation.

The industry must decide what it wants: restoration of the stock to its former level or the stagnation of a fragile, reduced stock. It cannot have both increased quotas and guaranteed growth.

Reprinted from The South African Shipping News and Fishing Industry Review: March, 1973

The intensive research programme into the South West African pelagic resources, conducted by the Division of Sea Fisheries last year, has yielded a wealth of positive results, sufficient for a realistic management of the fishery during 1972. The report on the programme gives no indication of the long term prospects for the fishery, and 1972 must again be regarded as a "test" year during which the pilchard stock is provided with what is hoped to be an adequate chance of recovery. Its present strength is estimated at less than 2 million tons compared with 6 to 7 million tons up to 1966 when a massive onslaught was launched upon it by the land based industry and the factory ships.

The overall emphasis on conservation of the pilchard has shifted from concern that the ferocious appetite of the anchovy has forced the pilchard out of its traditional grounds to a straightforward limitation of the catch. This attitude is justified by the findings that the environment has changed little in the past decade, that there is still an abundance of food material available, and that, except in the early stages of development, the anchovy and pilchard do not compete for food. Investigations into the degree of possible competition in the early stages are continuing.

While pilchard landings are to be restricted on the same basis as last year, catches of other species should be higher during 1972, according to the findings of the research programme. If one of the main recommendations of the report on the programme can be implemented — that the industry makes a greater effort by means of aerial fish spotting to identify the species composition of the shoals before catches are made — then the pilchard stock will stand a greater chance of rapid recovery since the tendency to dump "unwanted" pilchards would be reduced. If, as the research findings suggest, more anchovy than last year can be landed, and if the maasbanker catch can be maintained, then the immediate future for the industry, although stringent, is by no means bleak.

CAPE CROSS RESEARCH PROGRAMME — PHASE II

Summary of results by D. L. Cram and G. A. Visser

Introduction

THE primary purpose of phase II of the Division of Sea Fisheries' Cape Cross programme was to provide sufficient data for the proper management of the pilchard stock off SWA. The programme has largely lived up to its expectations with a vast amount of data being accumulated since the end of the 1970 "crash programme".

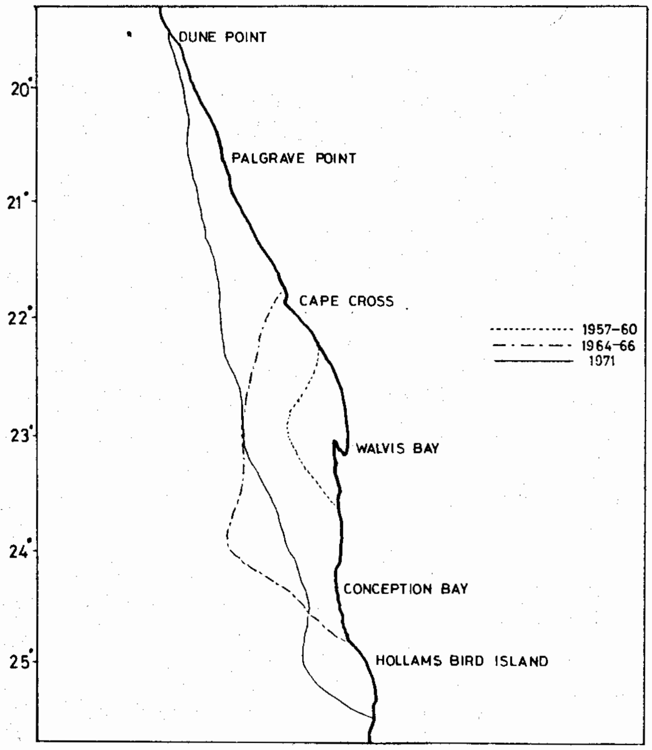


Fig. 1: Chart showing the enlarged area covered by the Walvis Bay fishing fleet in search of pilchards since 1957.

The stock size has been estimated and the environmental conditions evaluated in an attempt to set a realistic exploitation rate.

This success is due to the encouragement received from the Director of Sea Fisheries, Dr. B. van D. de Jager, the generous funding provided by the Department of Industries and the dedication of the research team, Messrs. Agenbag, Baird, Blamire, Cram, Miss de Vos, Messrs. King, Kruger, MacLeod, Newman, Ratte, Robertson, Schülein, Visser and Wright.

Environment

Hydrological conditions greatly influence fish availability and the normal migration patterns. Extremely low oxygen content of the inshore waters during the period June to July last year pushed fish offshore, so that fish availability in the inshore waters in the north was negligible, preventing easy capture by the industry's vessels. Even predators (seals and birds) were observed moving offshore following the fish.

In addition, intrusions of warm oceanic water into the fishing grounds, together with low oxygen water inshore, prevented the fish from migrating north or south as can normally be expected.

These intrusions could easily be detected with the aid of the airborne radiation thermometer. For example, last year the bulk of the fishery was around Ambrose Bay and the expected southward spawning migration did not occur until late December.

The ART shows that the high temperature intrusion in August was long-lasting. In September the effect of the intrusion was still being felt. In October the normal inshore cold belt of water was re-established and a minor pilchard migration to the south took place with some spawning occurring off Swakopmund.

With the reappearance of the intrusion in November and early December (see Figure 2) the southward migration was inhibited as illustrated by the low egg production.

In late December mature fish appeared off Walvis Bay and egg production vastly increased, indicating a return to the temperature regime favourable to pilchard migration.

Food

Biological studies indicate that food is present in abundance. Dietary investigation show that large maasbankers eat juvenile fish, while maasbankers under 20 cm usually feed on zooplankton. Pilchards and anchovies have a mixed diet of phytoplankton and zooplankton with the former dominating.

The dominant phytoplankton species, *Fragilaria karstenii*, occurs in a belt of low oxygen water along the coast. Beside the offshore margin of this belt extends a large zooplankton population feeding on the rich phytoplankton. Between the two regions, in an area of oxygen content of greater than 3,5 ml/l the majority of fish shoals occur.

Studies on competition for food between anchovy and pilchard indicate that there is a significant similarity between the food-gathering structure of 0+ year pilchards and 1+ year anchovies.

This similarity disappears with increasing age. Thus, competition can potentially occur only during the early stages when the porosity of the feeding structures are similar. With increasing age, the anchovy feeding structure has a larger porosity only capable of catching the larger plankton species.

However, the limited studies undertaken so far indicate that feeding selectivity is minimal and in the presence of abundant food, competition is likewise minimal.

Assessment of the pelagic stock

The history of the SWA pilchard stock is well known: a stable period of exploitation up to 1967, rapid catch size increase in 1968 (to 1,5 million tons of pilchards), then a steady decline in landings, accompanied by increased catches of other species.

Trends in the availability of pilchards are difficult to evaluate because the catch is limited by quotas. In addition, detailed catch statistics are not available, so gross fleet tonnage had to be used as an indication of effort.

As this parameter does not take into account new innovations, increased time spent fishing and so forth, it is not only crude but probably underestimates real effort quite seriously.

Between 1964 and 1968 the catch per unit effort of vessels at Walvis Bay remained more or less constant, but in 1969 and 1970, fell considerably. The open quota in 1970 was not filled by pilchards despite an all out effort, so the low catch per unit effort during this season, by comparison to earlier

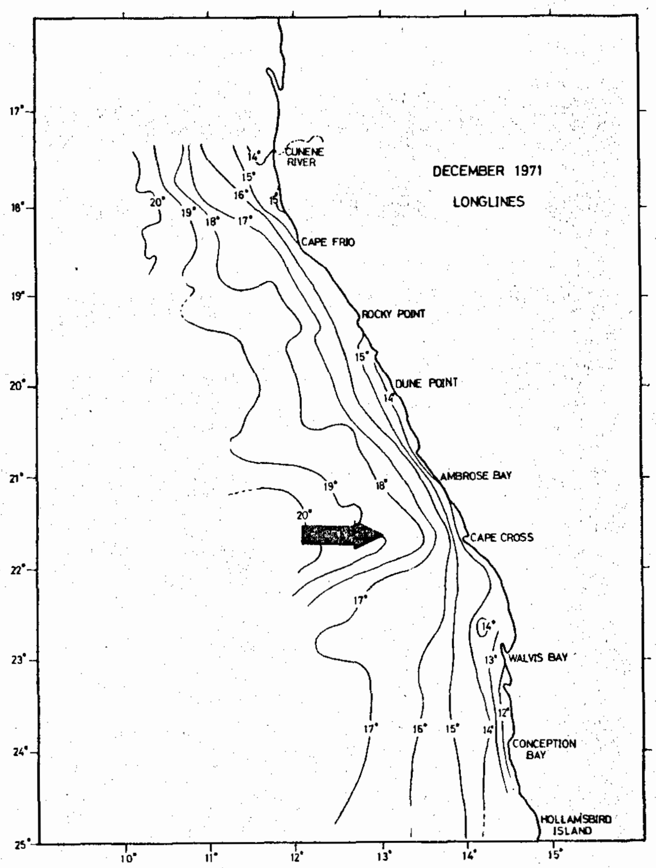


Fig. 2: An intrusion of warm oceanic water in November and early December inhibited the southward migration of the pilchard.

years, is probably a valid indication of decreased pilchard abundance and suggests a decline of about fifty per cent in stock size.

Two other observations confirm the above trend. Over the same period the area exploited increased considerably as shown in Figure 1. In addition, a factory vessel which never landed less than 180 thousand tons per annum from 1967 to 1969 only managed to catch 62 thousand tons of pilchards in 1971.

Age composition of commercial catches for the years 1967 to 1971 shows that increased fishing has made an impact on the age structure of the population, and the mortality rates have been calculated.

From catch and mortality figures it is estimated that the commercially available stock was of the order of 2 million tons during 1967 to 1969. This is considerably less than the 6 to 7 million tons estimated by means of tagging for an earlier period (1963 to 1966).

It must be emphasized that because of the nature of the data the above stock sizes are indications only and their limits of accuracy are wide. Nevertheless, a decline is shown which confirms the trends discussed above.

No estimates are available of the present size of the anchovy population, but comparing the age composition with that of the Cape population suggests that the present catch level does not fully

ACKNOWLEDGEMENTS

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