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A REVIEW OF SOME PELAGIC FISH STOCKS IN OTHER AREAS

J.-P. Troadec, W. G. Clark[1], and J. A. Gulland
Fishery Resources and Environment Division, FAO, Rome, Italy

INTRODUCTION

In addition to their immediate interest for a better utilization of fish resources, investigations into the factors that determine the collapses frequently observed in pelagic fisheries have a direct bearing on the understanding of some of the key problems which fishery science is facing today, namely, the determination of the shape and variability of the stock-recruitment relationship and its effects on the long-term, natural variability of fish stocks.

So far stock assessment methodology has in practice been based on two assumptions of stability in time: (i) of the carrying capacity of the ecosystem, and (ii) of recruitment. As historical series of observations become longer for more and more fisheries, it is obvious that such simple assumptions do not properly describe the long-term behaviour of exploited fish populations. The lack of stability which seems to be a regular feature of coastal pelagic stocks has been noted for some time and has in fact led to the present symposium. The comparison of events which characterize the sudden decline of coastal pelagic fisheries can also provide an effective method for identifying some of the main causes of these collapses and some of the basic dynamic features of coastal pelagic populations.

Among the various phenomena which may play a major role in the collapse of pelagic fisheries, the following seem especially important:

The effects of the shape of the stock-recruitment relationship on stock stability.
The variability in recruitment and the number of age classes within the population.
The competition among stocks and their alternation within the ecological niche they are sharing.
The effects of changes in stock availability on its vulnerability to fishing operations.
The difficulty of accurate monitoring (especially through catch and effort data of commercial vessels) of the actual decline in size of pelagic stocks, particularly when they tend to react by reducing their area of distribution rather than their density, and when the increase in fishing efficiency is grossly underestimated.

Such an analogical approach is facilitated as documentation on pelagic stocks and their reactions to external stresses, natural or man-made, is rapidly growing: first, because stock assessment investigations have in the last decade or two spread all over the world; second, because longer series of observations are available as fisheries become older; finally, because new indicators of historical trends in stock size (e.g., observations of scale deposits in bottom sediments, records of annual guano yields, records on early fishery performances extracted from the non-specialized literature) are being identified. Such indicators have a fundamental interest for they enable comparisons to be made of stock variability before and after exploitation has been initiated.

However, there are still few reviews integrating the most recent observations made on the major pelagic stocks of the world. Because of the considerable documentary research and compilation required to identify and integrate the key events which have occurred throughout the historical development of each fishery, the present paper had to be limited to a review of a few case studies. Moreover, an exhaustive review was not justified since studies on several stocks outside the North Atlantic were being prepared specially for this symposium. The five multispecies pelagic resources examined here (California, Peru, southwest coast of India, Namibia, and Ghana/Ivory Coast) have been selected on the following criteria:

To avoid as much as possible duplication with other contributions to the symposium.
To restrict the review to fisheries for which sufficient information was available to permit the drawing of useful conclusions for the work of the symposium.

[1] Present address: University of Washington, Center for Quantitative Science in Forestry, Fisheries and Wildlife, 3737 15th Avenue NE, Seattle, WA 98195, USA.

JP TROADEC

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PELAGIC STOCKS OFF CALIFORNIA AND BAJA CALIFORNIA

The California Current upwelling zone extends along the west coast of North America from Vancouver Island to the southern tip of Baja California (Mexico). Primary production is high throughout this zone, but pelagic fish are apparently more abundant off the southern half of the state of California (USA) and the northern half of the peninsula of Baja California than in waters to the north and south.

Regular, large-scale surveys off the state of California and Baja California were begun in 1949 with the original purpose of discovering the reasons for the decline and eventual collapse of the California sardine fishery after the Second World War. This programme (California Cooperative Oceanic Fisheries Investigations, CalCOFI) has continued for almost thirty years as an integrated study of the oceanography, plankton, fish, and fisheries of the region, making it perhaps the most studied marine region in the world. It is nevertheless still one of the most puzzling, and the large changes that have been observed recently in the abundance of the major pelagic fish stocks have yet to be explained.

Moreover, these changes appear to have been taking place for at least the last few thousand years, long before the development of intensive fishing. These historical changes are shown by changes in the abundance of fish scales in the strata of anaerobic sediments in deep basins off the coast. Cores of these sediments provide a very long data series unique to this region.

The commercially important planktivorous species are the sardine (*Sardinops caerulea*), anchovy (*Engraulis mordax*), chub mackerel (*Scomber japonicus*), and jack mackerel (*Trachurus symmetricus*). All have changed considerably in abundance over the last thirty years, and there have also been changes in the abundance or distribution of important predator or competitor species, such as hake (*Merluccius productus*), bonito (*Sarda chiliensis*), and saury (*Cololabis saira*).

SARDINE (*Sardinops caerulea*)

There are three stocks of sardine in the area: a Gulf stock confined to the Gulf of California, a southern stock on the Pacific coast from southern Baja California to Los Angeles, and a northern stock from Punta Baja (about 330 km south of the USA-Mexico border) northward. It is the northern stock that collapsed and that has been the most intensively studied; the other two are still being fished in Mexico, where in recent years annual catches have increased from about 30 000 to nearly 150 000 tonnes.

In the northern stock, the rate of natural mortality is about 0·4 (Murphy, 1966). Most fish mature sexually when two years old, and all are mature at age three (Ahlstrom, 1960). Partial recruitment to the purse-seine fishery also occurred at age two, and full recruitment by age four (MacCall, 1979). Individuals older than thirteen years have been found, and fish eight years old and older made up a few per cent of the catch in number in some years, so the natural lifespan is probably around ten years.

The fishery

The history of the northern stock and its fishery is related in the definitive review by Murphy (1966), recently revised and updated by MacCall (1979). Catches were small until a canning industry developed in California during the First World War. Thereafter catches in California increased more or less steadily and the fishery was extended as far north as British Columbia. The largest catch, over 700000 t, was taken in the 1936/1937 season, and for about ten years fishing effort was roughly constant and annual catches stable in the range 500000–700000 t.

Just after the Second World War (1946–1948), catches fell sharply (to 118000 t in 1947/1948) all along the coast, and for all practical purposes the sardine disappeared from waters north of California. There was a partial recovery, mostly in the southern half of California, during the years 1949–1951, when catches increased again to 320000 t, but there was another severe drop in 1952/1953, to only 12000 t for the season. Except for a brief increase in 1958/1959, when the catch rose to 110000 t, stock abundance and catches off California remained low until 1962/1963 and then declined to practically nothing. Since 1966 sardine fishing has been prohibited in California. A small fishery began in northern Baja California in 1951 and took catches of 10000–15000 t per year until 1961, but over the following few years this fishery failed as well.

The stock

The size and structure of the stock during the years 1932–1965 have been reconstructed by cohort analysis; summary figures are given in Table 1. These results are in general agreement with other measures of stock size (commercial catch per effort, systematic night fishing surveys, CalCOFI plankton surveys). Since 1965, the stock has remained at a very low level – no more than a few thousand tonnes (Klingbeil, 1977).

MacCall (1979) has examined the stock-recruitment relationship and found no evidence of density dependence. Instead, recruitment was on the average

Table 1. California: Stock size, recruitment and catch of the northern stock of the California sardine, 1932–1965. 1932–1944 from Murphy (1966); later years from MacCall (1979)

	Adult stock (age 2+) ('000 t)	Recruitment (age 2) (millions)	Catch[a] ('000 t)
1932	3 531	3 981	268
1933	3 422	8 680	352
1934	3 633	14 202	578
1935	2 851	4 098	575
1936	1 692	2 821	719
1937	1 209	5 383	453
1938	1 204	6 940	610
1939	1 611	6 763	530
1940	1 764	11 808	448
1941	2 463	14 442	618
1942	2 069	6 152	521
1943	1 681	3 268	526
1944	1 263	3 720	558
1945	720	2 385	400
1946	566	1 625	225
1947	405	1 667	118
1948	740	3 875	172
1949	793	4 261	308
1950	780	3 690	321
1951	277	290	132
1952	136	397	12
1953	202	972	15
1954	239	1 197	73
1955	170	382	71
1956	108	264	42
1957	90	588	28
1958	177	1 586	110
1959	122	905	46
1960	88	288	35
1961	54	111	25
1962	27	74	6
1963	21	56	5
1964	11	11	6
1965	3	–	1

[a] Catch given for each year refers to a season running from June of that year through May of the next year.

only modestly larger than the amount required to replace the spawning stock in the absence of fishing, at all observed levels of stock size. Simulations incorporating the observed mean and variance of net recruitment showed that the stock would have declined at an average fishing mortality rate as low as $F = 0{\cdot}25$, lower than the natural mortality rate of 0·4 and substantially lower than the calculated fishing mortality rates during most years of the fishery. The eventual collapse of the stock can thus be interpreted as the consequence of overfishing, while the pattern of the decline resulted from variations about the average in reproductive success. These variations were correlated, good and bad years coming in runs.

On the other hand, the steady contraction of the stock after 1945 and the very long run of unsuccessful spawnings since 1958 suggest an environmental change unfavourable to the northern sardine stock, and the irregular appearance of sardine scales in anaerobic sediments representing the last few millennia shows only occasional periods of sardine abundance. Thus, while no environmental mechanism has been identified, it is possible that natural causes contributed to the demise of the stock.

As the northern sardine stock was declining after the Second World War, the anchovy stock in the same region was growing rapidly, from an estimated 165 000 t in 1951 to 3·3 million t in 1966. Competition with the anchovy may have been the reason for the lack of a response by the sardine stock to its own low density in the later years of the fishery and, conversely, the growth of the unexploited anchovy stock may have been the result of reduced competition with sardines. Or the replacement of sardines by anchovies may have been the result of an environmental change. But sardine and anchovy scale deposits in anaerobic sediments off California show no correlation, positive or negative, so it is not at all certain that any simple ecological or environmental process was at work.

Management

The fishery was never regulated in any way until directed fishing for sardine was prohibited in 1966. Under state law in California, no fishery will be allowed until the spawning stock rebuilds to 18 000 t.

ANCHOVY (*Engraulis mordax*)

There are three stocks of anchovy in the California Current region: a northern stock from British Columbia to central California, a central stock off southern California and northern Baja California, and a southern stock off southern Baja California. The central stock is larger than the other two combined, and has been the main object of commercial interest and scientific study in Mexico and the USA in recent years.

Fish of this stock reach an age of at least six years, but individuals older than three years are rare (Spratt, 1972). A majority of fish, although not a large majority, are sexually mature at two years of age (Baxter, 1967). The rate of natural mortality is close to 1·0 (MacCall, 1974).

The fisheries

Apart from a small bait fishery in California, taking a few thousand tonnes per year, anchovy catches were negligible until after the Second World War, when some California purse seiners landed anchovies as a

Table 2. California: Spawning stock size and catches of the central stock of northern anchovy

	Spawning stock[a] ('000 t)	USA catch[b] ('000 t)	Mexico catch[b] ('000 t)	Total catch ('000 t)
1951	164	8	c	8
1952	142	32	c	32
1953	464	45	c	45
1954	698	25	c	25
1955	769	26	c	26
1956	441	32	c	32
1957	1 065	22	c	22
1958	1 345	9	c	9
1959	1 376	8	c	8
1960	1 400	7	1[d]	8
1961	1 054	9	1[d]	10
1962	2 706	7	1	8
1963	3 867	6	1	7
1964	2 637	7	5	12
1965	4 235	8	9	17
1966	3 247	34	13	47
1967	–	37	20	57
1968	–	21	14	35
1969	2 726	66	4	70
1970	–	93	50[d]	143
1971	–	47	36[d]	73
1972	2 530	68	55[d]	123
1973	–	106	11	117
1974	–	114	42	156
1975	3 275	150	60	210
1976	–	117	79	196

[a] As of 1 March, estimated from ichthyoplankton surveys. Data from MacCall (unpublished MS).

[b] Including small amounts from northern and southern stocks; 1951–1959 figures for USA from Baxter (1967), 1960–1973 figures from MacCall et al. (1976), 1974–1976 figures from FAO Yearbook of Fishery Statistics, Vol. 42 (1977).

[c] No reliable data on Mexican catches in the years 1951–1959 are available, but these were small, i.e., less than 1000 t/yr.

[d] Estimated in various ways by MacCall et al. (1976).

substitute for the rapidly declining sardine. Commercial landings were 20000–40000 t per year during 1952–1957, but then decreased to a few thousand tonnes per year until 1966, when fishing for reduction began in Mexico and the USA. In recent years annual catches have been 100000–200000 t (Table 2), and while further increases in the USA are, for the time being, prevented by a quota, the Mexican fishery is still developing.

The stock

Ichthyoplankton surveys carried out since 1951 with the original purpose of monitoring the sardine stock showed a tremendous growth in the anchovy stock, from 165000 t in 1951 to 3·3 million t in 1975. MacCall (1980) has fitted a logistic growth curve to the time series of stock-size estimates, taking account of catches, and this curve describes the points fairly well. He has also inferred from the parameters of the curve that the maximum average yield of the stock is around 500000 t, with the proviso that management for maximum yield would be uneconomic owing to the large natural variability of the stock.

As a maximum average yield, the estimate of 500000 t seems low by conventional standards. The asymptote of the logistic growth curve is about 3·5 million t, so with $M = 1{\cdot}0$, Gulland's yield equation $Y_{max} = 0{\cdot}5\, M B_0$ gives an estimate of 1·75 million t. The difference may result from a failure of the assumption on which the logistic growth curve is based, i.e., that the parameters of the curve were constant since 1951. If in fact the environment was gradually becoming more favourable to the anchovy, the fitted curve would necessarily underestimate the growth rate parameter r. On the other hand, the difference could also result from a failure of the assumption on which the Gulland estimate is based, i.e., that the maximum sustainable yield will be taken when $F = M$ and biomass is reduced to half the asymptotic level. If in fact the maximum yield occurs with $F < M$, as it appears would have been true for the California sardine and may be true for other pelagic stocks, then the Gulland estimate may be too high by a wide margin.

As in the case of the sardine stock, it is not possible to distinguish the relative importance of environmental, ecological, and density-dependent factors in the observed recent history of the anchovy stock, but scale deposits in anaerobic sediments show considerable natural fluctuations in the more distant past. These records indicate a stock at the beginning of this century of about twice the asymptotic size estimated by MacCall, which then declined to a fairly low level around 1925 and recently has made a modest recovery.

Management

Scientists in the USA have long advocated a substantial anchovy fishery, partly in the hope that holding down the abundance would lead to a recovery of the sardine stock. Sport fishermen in the state of California have opposed a commercial anchovy fishery, however, and the state government has tried to balance commercial and recreational interests by allowing a fishery but limiting it to a low annual quota of around 100000 t.

The debate in California has of course become increasingly academic as the Mexican fishery on the same stock has developed. Mexico plans to increase its catches to at least 500000 t per year by 1982, and more if possible, so the stock will be exploited much more heavily and there will be an empirical test of its productivity under present environmental conditions. Mexico and the USA have not yet established a joint management regime, although the two countries are collaborating on scientific research.

PACIFIC MACKEREL (*Scomber japonicus*)

Mackerel are distributed throughout the region of the California Current. Morphometric studies have shown some significant differences among fish from different places, particularly between fish from the Gulf of California and southernmost Baja California and fish farther north; but the existence of distinct stocks is not certain. Most fish mature at age one (Kramer, 1969). Mackerel school by size, and the age at recruitment to the purse-seine fishery decreased as the stock declined, from age two to zero (Parrish, 1974). Fish as old as eleven years have been reported, but owing to exploitation fish older than five or six years were rare in catches (Parrish and Knaggs, 1971). The rate of natural mortality has been roughly estimated to be 0·6–0·7 (Parrish, 1974; MacCall et al., 1976).

The fishery

Mackerel were first caught in quantity for canning in the 1920s in California. The record catch of about 66000 t was taken in 1935 after a few years of very large recruitments; after 1935 the stock and catches decreased to a lower level which persisted, with large fluctuations, until about 1963. Catches were usually in the range 20000–40000 t/yr. Since 1963 there has not been a good recruitment and the fishery in California has collapsed. Directed fishing for mackerel has been prohibited in California since 1970, although recreational fishing continues there and some mackerel are caught incidentally in other commercial fisheries. Small commercial landings are also still made in Mexico (Table 3).

The stock

Parrish (1974) and MacCall et al. (1976) published graphs (not tables) showing the size of the stock from 1932 onwards as calculated by cohort analysis. The estimates differ somewhat, presumably because of the different natural mortality rates adopted for the computations, but the pattern is the same. There were four successive years of very large recruitment in the early 1930s, each year class being two to four times the size of the largest year class ever observed after this period. From about 1935 to 1963 recruitment was highly variable but with no trend. Since 1963 there has not been a good recruitment. The total stock size has varied accordingly, from perhaps 500000 t in the early 1930s to the range 100000–200000 t in the early 1940s, after which it varied between 25000 and 100000 t before dropping to the present very low level in the 1960s.

Table 3. California: Commercial landings of Pacific mackerel[a]

	USA ('000 t)	Mexico[b] ('000 t)	Total ('000 t)
1926	2	–	–
1927	2	–	–
1928	16	–	–
1929	26	–	–
1930	8	–	–
1931	6	–	–
1932	6	–	–
1933	32	–	–
1934	52	–	–
1935	67	–	–
1936	46	–	–
1937	28	–	–
1938	36	–	–
1939	37	–	–
1940	55	–	–
1941	36	–	–
1942	24	–	–
1943	34	–	–
1944	38	–	–
1945	24	–	–
1946	24	(1)	–
1947	21	(3)	–
1948	18	(0)	–
1949	23	(2)	–
1950	15	(4)	–
1951	15	(2)	–
1952	9	(2)	–
1953	3	(2)	–
1954	12	5	17
1955	11	10	21
1956	23	13	36
1957	28	(16)	–
1958	13	(1)	–
1959	17	(1)	–
1960	17	(3)	–
1961	20	6	26
1962	22	3	25
1963	18	10	28
1964	12	9	21
1965	3	9	12
1966	2	5	7
1967	1	1	2
1968	1	0	1
1969	1	0	1
1970	0	0	0
1971	0	1	1
1972	0	0	0
1973	0	0	0
1974	0	0	1
1975	0	2	2
1976	0	2	2

[a] Figures for 1926–1966 from Kramer (1969), for later years from FAO Yearbook of Fishery Statistics, Vol. 42 (1977).
[b] There are no records of Mexican landings before 1946. Parenthesized figures for years after 1946 refer to combined landings of mackerel and jack mackerel.

In many ways the history of the mackerel stock is similar to that of the sardine. Parrish (1974) found almost no density dependence in recruitment, but a great variation in spawning success at all observed stock sizes. Like the sardine, the mackerel went through runs of years when spawning success was either consistently good or consistently bad, and for the most part the years of high sardine spawning success were also good for mackerel, specifically the early 1930s, the late 1940s, and the years 1953–1954. The last years of relatively high recruitment of sardine were 1958 and 1959, and of mackerel, 1960–1963. The time series of total stock sizes of sardine and mackerel are very similar except for the difference in scale.

Management

In California, except for some size limits and area closures, there was no regulation of the mackerel fishery until it was prohibited in 1970 (Kramer, 1969). At present the California fishery is limited by a quota determined as a fixed proportion of the excess of spawning stock size over 10000 short tons. Since the spawning stock was increased by the good 1974 and strong 1976 year classes, the fishery was reopened in 1977 and the quota raised in 1978 (MacCall, personal communication).

There is no mention of Mexican regulations in any of the papers cited.

JACK MACKEREL (*Trachurus symmetricus*)

Jack mackerel are distributed from the Gulf of Alaska to the southern tip of Baja California, but are most abundant off southern California and northern Baja California, approximately the same section of coast occupied by the central stock of anchovy. No evidence of subpopulations has been reported (Mac Gregor, 1966).

About half the fish are mature at age two and all at age three. The commercial purse-seine catch consists primarily of fish two to four years old with some five- and six-year-old fish. But much larger and older specimens, some of them twenty-five to thirty years old, predominate in survey catches taken several hundred miles out to sea (Blunt, 1969). There are no estimates of natural mortality, but it cannot be very high, at least among larger fish.

The fishery

Landings were small (a few thousand tonnes or less) until after the Second World War, when sardines became scarce. Since 1950, annual catches, used for canning and reduction, have varied between 8000 and 64000 t, depending on demand (Table 4).

Table 4. California: Recent catches of jack mackerel[a]

	Total catch ('000 t)
1950	64
1951	43
1952	69
1953	27
1954	8
1955	22
1956	41
1957	41
1958	11
1959	17
1960	36
1961	46
1962	44
1963	57
1964	44
1965	34
1966	25
1967	20
1968	27
1969	25
1970	24
1971	30
1972	25
1973	10
1974	10
1975	13
1976	17

[a] Figures for 1950–1973 from MacCall et al. (1976) include commercial and recreational catches in Mexico and USA. Figures for 1974–1976 from FAO Yearbook of Fishery Statistics, Vol. 42 (1977), covering commercial landings only.

The stock

A partial survey of the spawning area produced an average estimate of 320000 t of spawners in the years 1955–1957. The average spawning biomass in the entire CalCOFI area in the years 1964–1966 was estimated to be 1·3–2·0 million t. Tagging experiments in 1972 showed an exploited stock of 0·6–1.4 million t (MacCall et al., 1976).

The rate of fishing mortality on the stock as a whole is undoubtedly low, but after several years of relatively large catches in the late 1940s and early 1950s, the mean age in the catches, which consist of younger fish, decreased considerably (Blunt, 1969). In view of its great longevity, the jack mackerel may have a low rate of natural turnover, and the high stock-size estimates may simply reflect a large reservoir of older fish which will not persist if recruitment to it is greatly decreased by fishing on the younger age groups near the coast.

Management

There are no regulations for jack mackerel.

OTHER SPECIES

SAURY (*Cololabis saira*)

The saury is an oceanic species, distributed far to seaward throughout the California Current region and most abundant off central and southern California and northern Baja California. On the basis of plankton surveys, Smith et al. (1970) estimated the average spawning stock in the basic CalCOFI survey area (central California to central Baja California) to be about 180000 t during the years 1950–1966. Outside the basic survey area, occasional observations indicated at least another 170000 t farther offshore and about 155000 t off northern California and Oregon. Saury eggs were very rare off southern Baja California.

BONITO (*Sarda chiliensis*)

Although catches were small, bonito were common off California in the 1920s and 1930s. Various indices of abundance showed a near disappearance of the species after 1941, followed by a return and re-establishment of a spawning population off California in 1956–1957. Since 1958 the total annual catch off California and Mexico has varied between 3000 and 15000 t (MacCall et al., 1976).

FISH STOCKS AND ENVIRONMENT IN THIS CENTURY

The nearly corresponding runs of good and poor recruitments of sardine and mackerel off California suggest an environmental influence on recruitment. Usually a series of good recruitments occurred during years of above average sea temperatures (Marr, 1960), but Murphy (1966) did not find a close and consistent relationship between temperature and reproductive success during the years 1932–1959.

Svetovidov (1953) believed that spectacular changes in the abundance of several pelagic stocks – Hokkaido-Sakhalin herring (*Clupea pallasi*), Far Eastern sardine (*Sardinops melanosticta*), and California sardine – resulted from long-term changes in the temperature regime of the Pacific. He noted that the development of sardine fisheries in Asia and North America followed a large-scale warming of the Pacific that began after the First World War, and the decline and eventual collapse of these stocks occurred when the oceans cooled again in the 1940s. There are of course no fishery data for estimating the abundance of sardines off California before the First World War.

LONG-TERM RECORDS

Soutar and Isaacs (1969, 1974) have estimated the historical relative abundance of several pelagic species off southern California and central Baja California from the frequency of scales deposited in stratified anaerobic sediments in deep basins. For the last two hundred years off southern California, these records show that sardines were relatively abundant in the years 1845–1865, 1890–1905, and 1915–1925, with periods of low abundance from 1865 to 1890 and since 1950. For most of the last two centuries anchovies have been considerably more abundant than sardines, although the anchovy stock has been much smaller since 1925 than it was previously, despite the increase since 1950. The scale records indicate only a two- to threefold increase in anchovy stock size between 1950 and 1966, as compared with the twentyfold increase shown by plankton surveys. Mackerel scales are scarce, even absent during several periods, but indicate a higher relative abundance around 1830, 1890, and 1930. Other interesting features are that Pacific hake (*Merluccius productus*) were much more abundant between 1885 and 1920 than they have been since, and that brief, dramatic increases in saury abundance occurred in 1815–1825 and 1940–1955. As a group, these species have been considerably less abundant since 1930 than at any other time in the last two hundred years (except perhaps for 1875–1880). The scale deposits from off central Baja California are qualitatively similar in most respects, but they show a low abundance of sardines for the entire period except 1920–1935, and a low and fairly stable abundance of hake.

Over the last 1800 years, scale deposits show the sardine to have been absent off southern California as often as it was present, and to have been about equally abundant during all of its appearances. The anchovy was consistently present, but appears to have declined steadily in abundance over the last 1500 years, by a factor of four or so.

Fitch (1969) found sardine otoliths in Indian middens left 3000–7000 years ago, but no fossil sardine otoliths in excavations of sediments that were below the sea surface off California during the Pleistocene and Pliocene (100000–10000000 years ago). Anchovy otoliths were present in both the Indian middens and sediments.

DISCUSSION

It appears from the long historical record as well as from the intensive studies of the last few decades that large, natural long-term and medium-term variations take place in the abundance of pelagic stocks off California and, perhaps to a lesser extent, Baja California.

In the case of sardine and mackerel, it is fairly clear that density-independent changes in reproductive success (i.e., recruits per spawner), with either good or bad conditions persisting for several years at a time, have had a major effect on fluctuations in abundance during the last forty years, while the fishery was probably responsible for the long-term decline of the stocks. As a result of the absence of a density-dependent response, both stocks showed a lower productivity (i.e., potential yield per unit biomass) at intermediate levels of abundance than would be expected in light of their natural rates of turnover, and thus declined at rates of exploitation that *a priori* would not have been considered excessive. A logistic model of the growth of the central stock of anchovy also shows a relatively low potential productivity.

From a scientific viewpoint, the causes of varying reproductive success, including the absence of density dependence, remain as important ecological questions. Detailed field and laboratory studies of anchovy larvae (e.g., Lasker, 1975) are now providing some direct insights into the autecology of that species, and the rapidly developing anchovy fishery should in effect provide a test of the importance of competition between anchovies and sardines.

For management purposes, however, it may be sufficient to know, at least for the mackerel and the sardine, that net recruitment is highly variable and roughly proportional to spawning stock size. In this situation a sound strategy for conserving the stock would be to maintain a fairly large spawning biomass to capitalize on good years when they occur, even after a run of several bad years. A similar strategy, although derived in a different way, seems appropriate for the anchovy as well. The disadvantage of such a management strategy is that the catch of each species allowed to the fishery would be highly variable, but the variability of the total catch could of course be greatly reduced if the fleet and the industry were prepared to shift among species at short notice.

THE PERUVIAN ANCHOVY FISHERY

The history of the fishery can be divided into three periods: the explosive development from less than 100000 t in 1955 to nearly 9 million t in 1964; a period of apparent stability, with catches in the 8–12 million t range from 1964 to 1971; and the period of crisis since 1971, during which catches have been generally less than 4 million t. In virtually all the available statistics the fish used for fish meal have all been recorded as anchoveta (*Engraulis ringens*), but in fact the catches have always included a proportion of other pelagic species, e.g., sardine (*Sardinops sagax*). Recently, with the collapse of the anchoveta the relative quantities of other species in the catches have increased, and possibly the absolute quantities have also; however, the quantities remain small compared with anchovy (probably no more than 10%). In addition to incidental catches in the fish-meal fishery several pelagic species (mackerel, jack mackerel, etc.) are also taken for direct human consumption, but the quantities are much smaller (between one and two orders of magnitude) than the fish-meal catches.

STUDY OF THE FISHERY

Because of its importance, the anchoveta fishery has been well studied. During the first two periods, study along simple classical lines appeared to describe adequately the events in the fishery. Application of the Schaefer model using catch and effort data with adjustments for the more obvious improvements in the fishing methods (echo-sounding, fish pumps, etc.) gave a good fit, with a maximum yield in the 10–12 million tonne range, at a level of fishing effort around that reached by the fishery in 1964. A modification to include predation by birds (Schaefer, 1970) gave perhaps a more realistic description of the system in which the fishery operated, but did not significantly alter the conclusions. The production model analyses were supported by yield-per-recruit calculations but, because of uncertainties in age determination, the latter were not soundly based on a good separation of fishing and natural mortalities. There was, however, even in 1971 some suspicion that the situation was not quite so simple and satisfactory (Anon., 1972).

Any complacency was removed by the crisis of 1972. This was brought about by two things. First, the recruitment that entered the fishery early in 1972 from the spawning in the middle of 1971 was a failure. Secondly, the unusual environmental conditions – "El Niño" – in 1972 concentrated the fish in a narrow belt along the coast where very good catches were taken in March and April 1972; this good fishery removed most of the older fish spawned before 1971. As a result by the middle of 1972 the stock had been reduced to a very low level. Since 1972 recruitment and adult stock have been carefully monitored by acoustic surveys carried out by IMARPE[1]. There seems to have been a gradual rebuilding of the stock, but with both spawning stock and recruitment much lower than before 1972. However, the recruitment from the spawning in 1976 (which appeared to be another year of abnormal oceanographic conditions) was very poor, and the stock is now apparently at a very low level.

Changes in the stocks of other species seem to have occurred, although the data base in most cases is poor. The bonito (*Sarda chiliensis*) stock, which used, before 1960, to support large catches (ca. 100000 t) for

[1] Instituto del mar del Perú.

human consumption, seems to have decreased. Certainly catches fell to only 4000 t in 1976, though there may have been a switch away from bonito fishing to the (at least initially) more profitable anchoveta fishery. The decrease seems to have occurred throughout the history of the anchoveta fishery, although there was a sharp drop from 1972 (64000 t) and 1973 (35000 t) to 1974 (7000 t). A somewhat similar history has been shown by the population of guano birds. These appear to be vulnerable to El Niño conditions, decreasing sharply on each occasion; but since the development of the anchoveta fishery they have failed to show the recovery that had seemed to occur after each El Niño on earlier occasions.

On the other hand, several other pelagic species (e.g., sardine) seem to have increased, although the relative importance of real increases in abundance, greater attention by fishermen, and more detailed collection of statistics, in the recorded increases of catch is not clear. The results of acoustic surveys suggest that the total biomass of sardines was around 6 million t in 1976/1977 (IMARPE internal reports). The decrease in anchoveta biomass between the start of the fishery (or even around 1970) to the low point of perhaps 2–3 million t early in 1977 was more than this.

MANAGEMENT

Although large (up to 1 million t) catches of anchoveta are taken in northern Chile, the Peruvian anchoveta can be and has been managed as a stock under single national jurisdiction. In fact the fish in southern Peru may form a stock separate from those in the rest of Peru, but related to those in Chile. The southern Peruvian stock has at times been managed separately. As a result it has been possible for the Peruvian Government to apply management measures earlier, and more vigorously, than has often been the case when stocks are shared, and measures have to be agreed by several countries. The earlier measures (Valdez-Zamudio, 1973) controlled the quality of the fish by closed seasons first (in 1965) during the peak spawning season (August/September) when the quality was poor – and also when catch rates were low. Later a closed season was established in February/March when newly recruited small fish (*peladilla*) were particularly abundant. By 1969 additional measures were needed to limit the total amount of fishing, first by prohibiting fishing on certain days of the week, and later by closing the season completely once a predetermined total catch was reached. At first there were no controls on the capacity of the fishing fleet, or of the processing plants, leading to an enormous and economically nonsensical over-capacity (Anon., 1970). The crisis in the fishery due to the collapse of the stock led to the nationalization of the fishery in 1973 (Valdez-Zamudio, 1973), and to the rationalization of the catching and processing capacity. The basic management procedure is now the setting of allowable catches based on scientific advice (especially that from the estimates of biomass from acoustic surveys), but it also involves other regulations as to how, where, and by whom the catches are taken.

CONCLUSIONS

The history of the Peruvian anchoveta is not a happy one. A fishery which a decade ago made Peru the biggest fishing country in the world (in terms of weight) and supplied a third of the country's exports has been reduced to a fraction of its former level – even though this is still large by most standards. However, even with the benefit of hindsight it is not easy to point out obvious errors in the scientific advice or in the action taken. Perhaps the most obvious concerns the danger of the excess capacity that existed in 1972; this resulted in the fishing-out of the stock of surviving older fish at a rate that made it difficult for the Government to detect and react quickly enough to the failure of the spawning in 1971.

More generally, the events of 1971 and later illustrate the inadequacies of most simple models. The Schaefer model failed to provide a warning, or even much of a *post facto* explanation, of the events since 1971, which suggested that the environment could have a disastrous effect on the fishery. Equally, and this is not always appreciated, there does not seem to be a simple "environmental" explanation. Since the fishery began there have been three major El Niño-type events, in 1965, 1972, and 1976. They have been accompanied by very different events in the fishery: no major change in 1965/1966 (though the bird population dropped by something like three quarters); a failure of the 1971 spawning (i.e., before the El Niño); and a failure of the 1976 spawning (i.e., during the El Niño).

There appear to have been differences in the oceanographic conditions, both physical and biological, in the three seasons, but equally the fish stocks were very different. In 1964/1965, the stock was fished down to only a moderate extent; in 1971 the spawning stock was low, but because of a good survival from the 1970 spawning there was a large stock of fish just below the age of maturity, which would have added to the predation pressure on the eggs and larvae produced; in 1976 all sizes of fish were moderately scarce. In addition any explanation of the events since 1971 should take account of the low, but apparently increasing, stock abundance between 1972 and 1976. One promising approach is the extension of the Ricker stock/recruit model to take account of changes in distribution (essentially density) brought about by environmental effects (Csirke, 1980).

THE INDIAN OIL-SARDINE AND MACKEREL FISHERY

Writing about a century ago Day (1878) noted that the oil sardine, which at that time were used to produce large quantities of oil, were "abundant in some years [but] they occasionally forsake their haunts for several consecutive seasons, returning again in enormous quantities". He also noted that catches of mackerel were highly variable. His remarks also apply to more recent years. Statistics are available since 1925 (Raja, 1969, Table VIII, and FAO Yearbooks of Fishery Statistics). During this period the pattern of fishing which is concentrated along the southwest coast of India, from about 17°N south to Cape Comorin, has remained much the same. It is mostly carried out by small unpowered boats operating close to the shore with beach seines, boat seines, and gill nets, although recently a small purse-seine fishery has started. Most of these gears can switch from one species to the other. Effort data are scanty, but the trends in catch probably reflect natural changes in abundance or availability, rather than in effort.

Examination of the fifty-year period of statistics suggests a different pattern of fluctuation for the two species. Mackerel catches show high year-to-year differences, with peaks in the catches at intervals of around five years, but with no longer period changes, i.e., periods of ten or more years of very high or very low catches. Sardine catches, while showing about the same year-to-year variability, also show longer periods (of the order of a decade), when catches are unusually high or low. Average annual catches (t) in selected periods are shown below:

Years	Sardine	Mackerel
1925–1933	9 600	84 200
1934–1942	19 300	33 500
1943–1949	500	74 500
1950–1956	26 900	58 000
1957–1967	185 500	49 300
1968–1976	165 600	99 400

Since the years were grouped according to the sardine catches, the difference between sardine and mackerel is probably exaggerated, but mackerel have not shown sustained periods of very low catches comparable to those of sardine from 1943 to 1949.

Estimates of biomass are scarce. Banerji (1973), examining the data from 1955 to 1965, i.e., near the beginning of the recent period of high catches, estimated average fishing and natural mortality coefficients as $F = 0{\cdot}75$, $M = 0{\cdot}67$ respectively. This implies the average biomass is about 1·3 times the annual catch. Since 1972 estimates of biomass have been made by the FAO/UNDP Pelagic Fisheries Project based in Cochin from a variety of surveys. The number of schools was estimated from sightings from aircraft and from sonar surveys, and multiplied by school size estimated from fishing, to give total biomass. Estimates were also obtained from integrated acoustic survey results. Some doubts surround each of these methods, and the results have been highly variable, although this could be a reflection of the real variation in the stock. Estimates of biomass have ranged from 50000 up to 700000 t. With average catches of around 150000 t these would imply values of F from 0·2 upward in broad agreement with Banerji's results.

The causes of the fluctuations and the possibility of forecasting them have received attention for a long time. Bearing in mind that nearly all the catches are taken in an extremely narrow coastal strip, the fluctuations in catch could be due to variations in the availability to the fishery of a stock of fairly constant abundance. The variability of the biomass estimates from the survey suggests this is probably not the case. Further, the consistent appearance of good or bad year classes in successive years (e.g., Banerji, 1973, Table II) shows that a major cause of the fluctuations must be variations in year-class strength. Although the sardine fishery is based on very young fish, three year classes (0-, 1-, and 2-year-old fish) are found in significant numbers.

The picture for mackerel is less clear. Catches are of virtually all one year class, so that there is little internal evidence of year-class fluctuations. However, the survey data again suggest real fluctuations in abundance, and hence almost certainly in recruitment (there is little evidence of major growth changes). Examination of the fluctuations in catches since 1925 shows that peaks in mackerel catches do not, in general, coincide with peaks in sardine catches, either in the same year or, allowing for the slight difference in age composition, with a one-year delay. Therefore the factors determining year-class strength in each species are not the same, and probably not simply related to smaller-scale phenomena. For sardine it has long been considered that catches are related to rainfall (Hornell, 1910), and Raja (1973) established a close correlation between rainfall in June-August with later catches for the period 1956 to 1972. It remains to be seen how well this correlation is maintained in later years, and what are the mechanisms involved. It may well be that both rainfall, and favourable conditions for sardine larvae are correlated with year-to-year differences in the pattern of the southwest monsoon. Certainly the monsoon has a dominant effect on the seasonal pattern of conditions in the area inhabited by young sardines.

Apart from environmental effects on individual year classes it might be expected that there is some interaction between the sardine and mackerel, as well as between these species and other pelagic species (e.g., *Anchoviella* spp., which the surveys have shown to be abundant). Raja (1969) emphasizes this possibility and quotes Hornell (1910) to the effect that the two species were scarcely ever abundant in the same year. A certain degree of inverse relationship is apparent in the text table, where the changes in average catch from one period to the next are always of opposite sign for the two species. This is suggestive, but the relation does not seem to be as simple as a constant total for the two species.

At present these stocks appear to be in a healthy condition, and questions of management are not urgent; indeed the present governmental policy is to encourage expansion, especially by larger vessels working outside the narrow coastal strip exploited by the traditional fishery. This situation may not last. The past history of the sardine fishery and the history of other sardine fisheries suggest that a period of low catches can be expected at some indeterminate time in the future. Then the question of management measures would be urgent. Measures were applied between 1943 and 1947, but it is not known to what extent they were effective in reducing the fishing mortality, or in speeding up the recovery of the stock. Even less is it understood whether more drastic measures, applied some years earlier, would have been successful in preventing the decline, or whether similar measures should be introduced if the stocks begin to show signs of entering a new period of decline.

THE PELAGIC FISHERY OF NAMIBIA

The Benguela Current system is one of the major upwelling areas of the world. Highest plankton productions have been recorded in that region (Cushing, 1969), where two sectors of particularly intense upwelling are distinguished. The first one lies north of the Cape while the second extends along the Namibian shores from the mouth of the Orange River to the port of Lüderitz. Two large pelagic fisheries, whose combined production reached a peak of almost 2 million tonnes in 1967, have developed in the vicinity of these two centres of high productivity.

The Cape and Namibian fisheries have a number of features in common, both in their structure, that is in the composition of their catches and of their fleets, and in their history, including that of the management policies applied to them. Like several other large pelagic fisheries of the world, the Cape fishery, rapidly followed by its Namibian counterpart, started after the Second World War in response to the high demand for canned products at that time. Initially the fishery was essentially directed toward the pilchard (*Sardinops ocellata*) and, to a lesser extent, for the Cape fishery only, toward the horse mackerel (*Trachurus trachurus*). But progressively, in an effort to offset the decline in pilchard catches, fishing operations extended to the anchovy (*Engraulis capensis*), the mackerel (*Scomber japonicus*), the round herring (*Etrumeus teres*) and occasionally even the myctophids. Simultaneously a growing proportion of the landings was used for industrial purposes.

The Cape fishery is the best documented, but only the Namibian fishery, which is economically more important and also apparently simpler in its species base, will be considered here.

THE FISHERY

Main stocks

Although the species, and fleet composition of the fishery, tended to become more complex in recent years, the history of the Namibian fishery is essentially that of the exploitation of pilchard by local purse seiners. From the location of the spawning and fishing areas, two stocks of pilchard and one of anchovy are supposed to occur (O'Toole, 1977). They are all geographically distinct from the corresponding Cape stocks. The southern stock of pilchard, which supports the bulk of the exploitation, seems to spawn earlier than the northern one (August-November and February-March respectively). Within their respective areas of distribution, pilchard stocks apparently have similar migration patterns. Spawning takes place in the southernmost part of each area, from which the eggs and larvae drift northward in such a way that the recruits are found in the northernmost sector of the distribution area. From there they progressively move toward the southern spawning sectors (Schülein, 1971; and Crawford, *In* Newman, 1977). The distribution and migration pattern of the anchovy stock is less clear.

The three stocks are mainly exploited by the Namibian purse-seine fishery. However, during certain years the stocks migrate further north than usual and become partially available to the purse seiners based in southern Angola which normally fish the Cunene horse mackerel (*Trachurus trachurus trecae*). In the 1960s Soviet vessels, operating in more offshore waters with midwater trawl, have also caught varying relatively low quantities of pilchard, amounting to 6 percent of total catch on average.

The Soviet trawlers mainly fish for the Cape horse mackerel (*Trachurus trachurus trachurus*), as regards coastal pelagic species. The structure and distribution of horse mackerel stocks, as well as their migrations and role in the ecosystem, are poorly understood. Off Namibia, trawl catches are supposed to consist mainly of Cape horse mackerel, whereas off Angola the purse seiners would mainly catch the more tropical inshore Cunene species. From the respective decline in catch rates, Draganik (1977) assumes that the populations harvested off Namibia are distinct from those caught in adjacent northern and southern areas.

Volume and species composition of the catches

Initially the fishery developed at a moderate rate (Table 5, Fig. 1) but, after 1962, when 400 000 t were caught, the expansion accelerated under the combined effect of the still-growing activity of the land-based fleet, the entry into the fishery of two offshore fishing expeditions and the rise in anchovy catches following the progressive adoption, from 1964 onwards, of purse seines with 13 mm mesh size. In 1968 the overall pelagic yield from the region exceeded 1·6 million t, of which 1·4 million t of pilchard and 0·16 of anchovy were caught by the purse seiners alone.

In 1970, however, the production dropped suddenly as a result of a severe decline in the catch rate for pilchard and of the departure, in 1970/1972, of the two factory vessels and their catchers. In 1971 the total catch was 660 000 t, of which only 325 000 t consisted of pilchard. The anchovy catch was not affected by that collapse; from 1968 to 1978 it remained stable at a level equal on average to 200 000 t.

From 1971 to 1974, a moderate recovery of the pilchard catch was noted (600 000 t in 1974), but the improvement did not last and in 1978 only a third

Table 5. Namibia: Annual catches ('000 t) of coastal species

	Pilchard		Anchovy[c]	Mackerel[c]	Horse mackerel		Other coastal pelagic species[c]	Total (including trawl-caught horse mackerel)
	Namibian purse seiners[a,b]	Other fleets[a]			Namibian purse seiners[a,d]	Non-local (trawl) fleets[c]		
1950	47	–	–	–	–	–	–	47
1951	127	–	–	–	–	–	–	127
1952	226	–	–	–	–	–	–	226
1953	262	–	–	–	–	–	–	262
1954	251	–	–	–	–	–	–	251
1955	227	–	–	–	–	–	–	227
1956	228	80	–	–	–	–	–	302
1957	228	147	–	–	–	...	–	385
1958	229	40	–	–	–	...	–	289
1959	274	5	–	–	–	...	–	309
1960	283	10	–	–	–	...	–	333
1961	344	7	–	–	–	47	–	398
1962	397	14	–	–	–	23	–	434
1963	555	53	...	–	–	21	–	629
1964	636	82	+	–	–	71	–	789
1965	666	114	1	–	–	126	–	907
1966	720	57	3	–	–	100	–	880
1967	926	44	22	–	–	72	–	1 064
1968	1 387	14	161	–	–	69	–	1 631
1969	1 110	11	267	–	–	47	2	1 437
1970	514	51	189	–	1	51	1	807
1971	325	3	185	3	140	73	5	734
1972	374	73	137	3	22	51	2	677
1973	408	24	296	5	12	259	5	1 072
1974	562	35	249	2	30	168	3	1 049
1975	561	15	186	4	14	187	12	979
1976	452	11	88	43	22	462	(4)	1 082
1977	200	...	133	–	–	–	–	–

[a] From: Newman (1978). Table 8.
[b] From: Schülein et al. (1977). Table 1.
[c] From: Report of the 1977 session of the ICSEAF Standing Committee on Statistics, Annex C, Tables 6, 7 (i). Figures for anchovy later revised based on information kindly provided by D. S. Butterworth.
[d] From: Villiers, G. de (1977). A preliminary review of trends in South African catches and abundance of horse mackerel (*Trachurus trachurus capensis*). ICSEAF Coll. Sc. Pap., 4: 99–104.
( ) preliminary estimates; ... data not available; + less than $^1/_2$ unit; – nil or negligible.

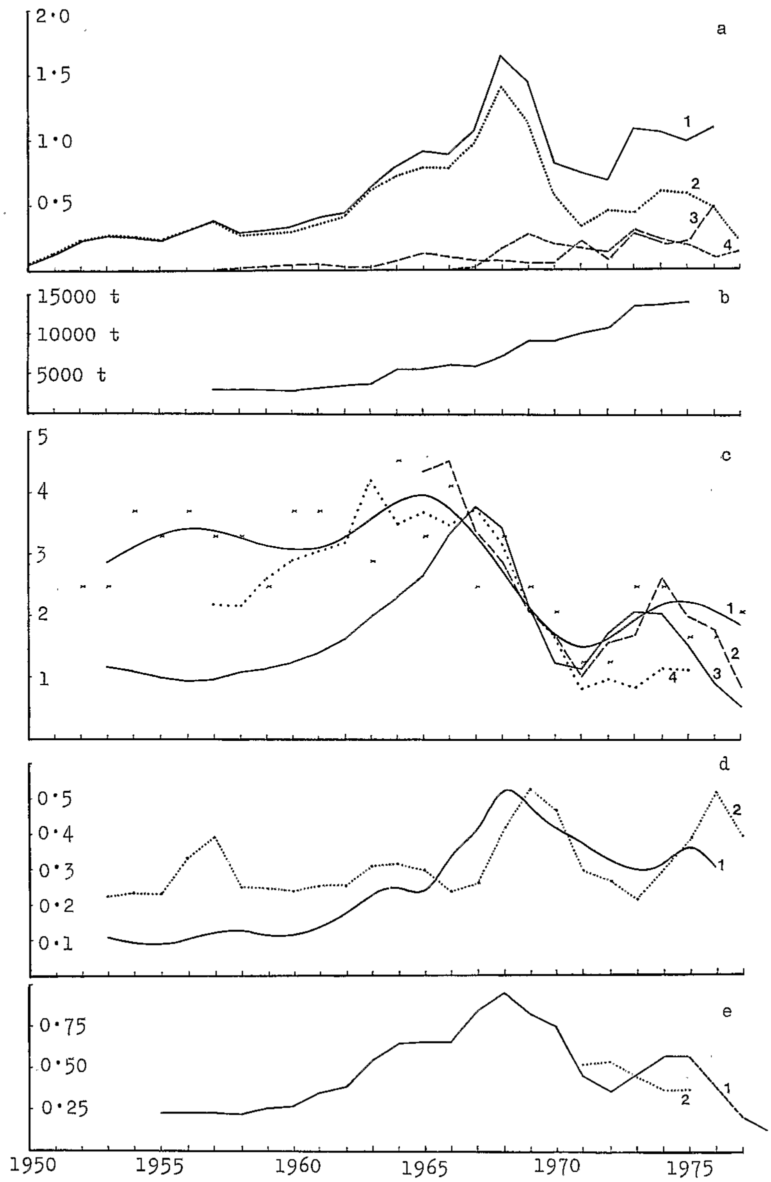

Figure 1. Trends of the main parameters in the Namibian purse-seine fishery. (a) Total catch (10^6 t). 1) All pelagic species. 2) Pilchard. 3) Horse mackerel (purse seine and trawl). 4) Anchovy. (b) Total hold capacity. (c) Biomass estimates (10^6 t). 1) Guano production. 2) Landings/fuel consumed. 3) VPA. 4) t/fleet hold capacity. (d) Fishing mortality estimates. 1) Guano production. 2) VPA. (e) Catch quotas. 1) Pilchard. 2) Anchovy.

of the quota was caught although it had to be substantially reduced in the course of the fishing season (down to 125000 t).

Unlike its Cape counterpart, the Namibian fishery has only partially succeeded in compensating for the drop in the target species (pilchard and anchovy) by a widening of its species base. Even with the capture of 140000 t of young horse mackerel in 1971 and of 43000 t of mackerel in 1976, the contribution of other species has so far remained sporadic and negligible on average.

Only the catches of horse mackerel by midwater trawlers have risen notably during recent years. Several countries, such as Bulgaria, Cuba, and Poland, have, like the USSR, initiated fishing operations aimed at that species. As a result the horse mackerel catch which was between 50000 and 100000 t during the late 1960s reached almost 500000 t in 1976. The development of these operations, following the increase of anchovy catches some years earlier, has enabled the overall yield (all pelagic species, all gear) to remain at about one million tonnes so far, a level which practically corresponds to the mean production for the last ten years.

The fleets

Statistics on the Namibian fleet of purse seiners are incomplete. From 1962 to 1975, the overall hold capacity went up from 3000 to about 14 300 t (Table 6, Fig. 1b). The number of boats (99 in 1975) did not increase as rapidly as their average tonnage (Newman, 1977). Their range of operations also increased and, consequently, the area regularly scouted and exploited has been since 1972, about four times wider than in 1965/1966. Recent data (Schülein et al., 1977) also show that, from 1972 until 1977, the searching time expended by the Namibian purse-seine fishery has significantly increased. The effect on fishing power of the adoption of technological innovations (sonar, fish pump, power-block, etc.) has not been assessed in the Namibian fishery. In its Cape counterpart, Newman (1977) showed that, from 1964 until 1972, the fishing effort developed by the purse seiners increased by 250 percent. This percentage does not take account of the effect of other devices such as aerial scouting. This increased effort is essentially due to the adoption of the above-mentioned innovations, for during the same period the fleet tonnage did not increase by more than 20 percent. As the two fisheries are very similar in their structure as well as in their development, one can assume that the gain in efficiency has been comparable in both.

From 1966 to 1971, with an interruption in 1970, two factory vessels – ex-whalers converted – participated in the fishery. They were supplied by 27 catchers fishing the same stocks as the land-based purse seiners, outside the 12 nm limit.

Table 6. Namibia: Purse-seine fishery (total fish hold capacity)[a]

	Total tonnage		Total tonnage
1957	3 000	1967	6 018
1958	3 022	1968	7 320
1959	2 990	1969	9 263
1960	2 822	1970	9 265
1961	3 204	1971	10 247
1962	3 554	1972	10 915
1963	3 795	1973	13 783
1964	5 610	1974	13 955
1965	5 683	1975	14 280
1966	6 179		

[a] From: Newman (1977). Table 19.

Data on fishing seasons, duration and precise location of fishing operations conducted by midwater trawlers fishing for horse mackerel are rare and incomplete. Only the Soviet data can provide some indications of the trends in stock abundance as it is only recently that other countries have begun operations specially directed to that species.

STOCK ASSESSMENT

Pilchard

Biomass

Several estimates of pilchard biomass – absolute and relative – derived from aerial and acoustic surveys (Cram, 1977), egg and larval surveys (King, 1974), tagging experiments (Newman, 1970), catch per unit of effort (Newman, 1977; Schülein et al., 1978), and cohort analysis (Schülein et al., 1978; Butterworth, 1978) have been published (Table 7). They all contain some bias of unknown importance. For example, the findings of cohort analysis still have to be considered as preliminary: age determination does not yet have the desired accuracy; no age–length key is available for the years before 1966; total landings are suspected of having been under-recorded for certain years, and their breakdown by species lacks reliability; last, no reliable estimate is available for natural mortality, although the figure 0·5 gives final results which compare best with other observations on the stock. In addition, Newman (1977) observed that the production of guano – annual statistics referring to the artificial platforms erected near Walvis Bay are available (after Crawford, *In* Newman, 1977) – should be related to the abundance of pilchard, for this species constitutes the main prey of the guano-producing cormorants (*Phalacrocorax capensis*).

All biomass estimates referring to long historical series have been plotted on the same scale (Fig. 1c). For the period subsequent to 1967, the guano curve fits well with the other two, after it has been shifted two years (correlation with biomass estimates derived from cohort analysis: $r = 0{\cdot}73$). This is in line with the difference in the age of exploitation of pilchard by cormorants and by purse seiners. Cormorants are said to feed mainly on juvenile pilchards (Newman, 1977) whereas the cohorts were essentially fished from age two to five in the 1960s and from age zero to three in the 1970s (Butterworth, 1978).

The various estimates are in good agreement for the decade: in 1971 the stock was at about a quarter of its 1966/1967 level; it came back to about half this size in 1974 before falling again to reach in 1977 its lowest level ever observed (only the catch per hold capacity is not in agreement with this description for recent years). Additional evidence has been published which

Table 7. Namibia: Pilchard biomass indices

	Cohort analysis (10^6 t)[a]	Landing/ fuel consumed (kg/1)[b]	Landing/ hold capacity (t/t)[c]	Guano production ('000 t)[b]
1950	–	–	–	0·6
1951	–	–	–	0·6
1952	–	–	–	0·9
1953	1·2	–	–	0·8
1954	1·1	–	–	0·9
1955	1·0	–	–	0·8
1956	0·9	–	–	0·8
1957	1·0	–	0·076	0·6
1958	1·1	–	0·075	0·9
1959	1·1	–	0·091	0·9
1960	1·2	–	0·101	0·8
1961	1·4	–	0·106	0·7
1962	1·6	–	0·111	1·1
1963	2·0	–	0·146	0·8
1964	2·3	–	0·122	1·0
1965	2·7	0·103	0·128	0·6
1966	3·3	0·107	0·121	0·8
1967	3·8	0·080	0·130	0·6
1968	3·4	0·068	0·110	0·5
1969	2·2	0·049	0·074	0·3
1970	1·2	0·040	0·057	0·3
1971	1·1	0·024	0·028	0·6
1972	1·7	0·037	0·034	0·6
1973	2·1	0·040	0·029	0·4
1974	2·0	0·062	0·040	0·4
1975	1·5	0·047	0·039	0·5
1976	0·9	0·042	–	–
1977	0·5	0·020	–	–

[a] From: Butterworth, D. S., (1978). See also footnote no. 3.
[b] From: Newman (1977). Table 18.
[c] From: Newman (1977). Tables 9 and 19.

confirms the collapse of the stocks at the turn of this decade; Cram (1977) and King (1974) estimated by means of aerial, acoustic, as well as egg and larval surveys that the pilchard biomass was between 2 and 3 million t during the period 1971/1973, whereas Newman (1970) calculated from tagging experiments two estimates of six million t for the periods 1957/1959 and 1963/1966. While it is recognized that the figure of 6 million t is probably too high (tagging mortality was unknown and not accounted for in the estimation), the difference between the two successive series of estimates is in line with the occurrence of a strong decline in stock size between 1968 and 1971. Prior to 1965, however, the three available abundance estimates diverge significantly. According to the guano index, the stock would have increased only slightly from 1952 to 1966, its size remaining, during the whole period, larger than it has been since. On the other hand, cohort analysis indicates that the stock would have been at a low level prior to 1961 (at a level comparable to that in 1971). The catch per unit effort (t/unit hold capacity) lies in between, although closer to the guano index.

The precise function which relates the guano production to the stock size remains to be investigated[2]. In addition, the stock-size estimates from guano data are relatively scattered (partly because the available statistics are given with one significant figure only). The guano/pilchard biomass relationship, however, is most likely to remain stable with time but not necessarily with the pilchard and bird population biomasses. Saturation (the platforms being too narrow to accommodate the bird population) may occur in periods of high cormorant population. Should this be the case, it could explain part of the discrepancy observed between the estimates of biomass before 1965. A lag between the fluctuations in population size of birds and pilchards can be expected, particularly when variations are rapid. A varying loss of guano may occur according to the average distance between the feeding grounds and the platforms, etc. It seems, however, that such likely distortions have played a minor role as the biomass derived from guano statistics had followed rather closely – though apparently more slowly – the other two indices during the apparent strong decline of pilchard (1968/1971), that is, throughout the largest and fastest variation in pilchard biomass ever observed.

On the other hand the catch per unit effort/biomass relationship is not likely to stay stable with time; the effect of innovations has not been accounted for in the computation of the catch per unit effort, and, in the Cape fishery, these innovations, which probably resulted in doubling the fishing efficiency, were introduced in the period 1955/1968, i.e. when the three available biomass estimates differ most. No adjustment was made either for the increase in dead time resulting from the extension of the scouted area, which is said to have increased five times from 1965 to 1972. Depending on the rate of intermingling within the stock, biomass estimates derived from cohort analysis are likely to have been underestimated for years when fishing operations were restricted to a portion only of the whole area of distribution of the stock, that is, before the rapid increase in catches took place[3].

[2] Detailed statistics available on guano yields, bird population censuses, and estimates of pelagic fish stock biomass in the Cape and Namibian fisheries, as well as an interesting discussion of the possible relationships between these various parameters, have been published since the present paper was written. For more information, readers should therefore refer to the following study: Crawford, R. J. M., and Shelton, P. A. 1978. Pelagic fish and seabird interrelationships off the coasts of South West and South Africa. Biol. Conserv., 14: 85–109.

[3] After this paper had been written, the following comments were received from D. S. Butterworth. "Butterworth (1978) used an age-length key relevant to the 1970s for the whole period in the cohort analysis. In fact, tag returns in the 1960s indicate that pilchards lived much longer than they apparently do now;

For all these reasons and until additional information is collected to investigate the true significance of these various indices, more importance should be attached to the biomass estimates derived from guano production figures.

Rate of exploitation

The variation, throughout the history of the fishery, of fishing mortality can be followed from the ratio Y/B. For B, only the estimates drawn from cohort analysis and from the guano production statistics have been considered here, for the third one, that is the one derived from catch per unit effort, lies between the first two during the period of discrepancy. Several observations can be made when one compares the curves in Figure 1d. The stock was heavily exploited in 1967/1969 – at least by comparison with the levels observed throughout the history of the fishery; this period of intensive fishing corresponds to the operation of the two offshore fleets, working outside the quota regulation. Another period of heavy exploitation, almost equivalent to the previous one according to cohort analysis findings, but somewhat lighter if guano production figures are considered, would have started in 1974. According to the fishing mortality coefficients derived from cohort analysis, the exploitation rate has been high since the initiation of the fishery and, apart from three short period increases, has only slightly increased later. The exploitation rates derived from the guano production are substantially lower for the 1950s. They rapidly increased in the mid-1960s and remained high during the entire decade. This trend gives more cause for concern, the stock size being definitely lower after the fishery had developed.

It could be argued against this interpretation that the rate of exploitation has never attained exceptional levels similar, for instance, to those observed in demersal stocks. In practice, fishing mortality values have at most equalled the natural mortality coefficient. Because of our limited knowledge of the resilience to exploitation of pelagic stocks and because estimates of mortality coefficients remain partly speculative for this stock, less importance should however be given to this optimistic interpretation of the data.

inspection of modal progressions also indicates a slower growth rate for pilchards before the 1970s. These effects result in an underestimate of the biomass for the 1950s and 1960s by VPA". Rough calculations made by Butterworth to take into account these observations indicate that during the period mid-1950s–mid-1960s, the stock would have increased from 2·5 million t in 1955/1956 to 3·9 million t in 1966. Although still uncertain, these figures are substantially higher than those given in Table 7 and Figure 1c, and in better agreement with the estimates derived from the guano statistics.

Stock and recruitment

The only available data are those derived from cohort analysis published by Schülein et al. (1978) and later revised by Butterworth (1978). Because of the limitations already noted in the original data, these findings must still be considered as preliminary. Butterworth concludes his analysis with the following remarks:

"There is clearly no exact functional relationship (between the strength of the 0+ group and the parental biomass) though there is a definite trend indicating 0+ group strength is an increasing function of biomass over the biomass range considered. This then suggests that with the present low biomass, prospects for very good year classes in the immediate future are low and short-term large-scale recovery of the fishery is unlikely" (until, independently of the stock size, good conditions for recruitment again prevail).

It is essential to note that, from Schülein, Butterworth, and Cram's computations, the stock-recruitment curve seems to be lightly convex with successive runs of good and poor recruitments (Fig. 2). Although, as underlined by Butterworth (personal communication), the apparent correlation in the strength of successive recruitments may partly result from errors in age determination of cohorts entered into the fishery prior to 1970, this pattern suggests that density-independent factors predominate, and, consequently, that the stock stability is low, as well as is the recruitment surplus, on average. In 1977, recruitment was apparently the lowest ever observed.

Other pelagic stocks

By comparison, the state and potential yield of the other pelagic stocks are poorly known. Information on their role in the ecosystem is practically non-existent. As happened in the Cape fishery, the increase in the landings of anchovy coincided with the introduction – partial in 1964, complete in 1968 – of purse seines with a 13 mm mesh size which were better adapted for the capture of anchovy. This observation obviously invalidates the theory of replacement of the pilchard by the anchovy, as well as its corollary according to which it might be possible to promote the re-establishment of the pilchard stock by fishing the anchovy more fully. Centurier-Harris (1977) studied this possibility in the Cape fishery where similar events occurred but was unable to detect any correlation between the biomasses of the two stocks.

In an attempt to divert excessive effort away from pilchard and, thus, to help its recovery, anchovy quotas (Fig. 1e) were always set well above the most

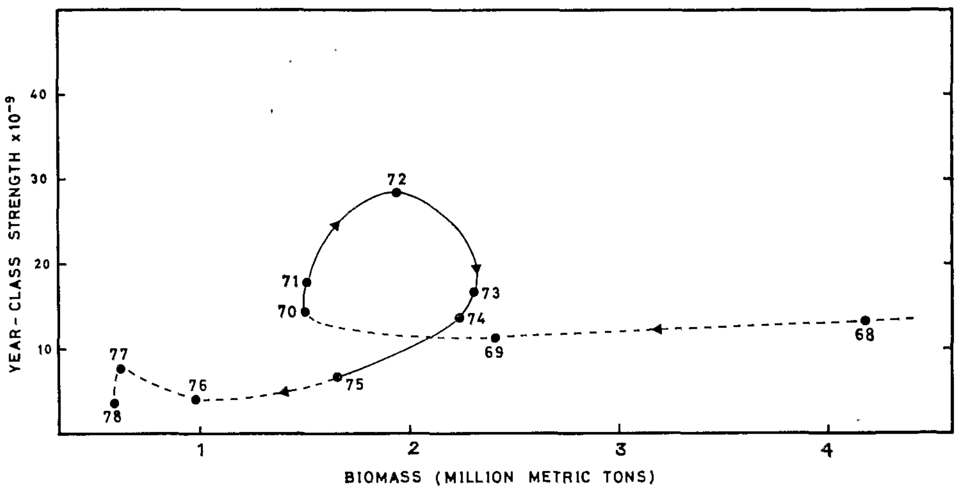

Figure 2. Namibian pilchard: Relationship between the 0-group year-class strength and the adult biomass estimate, as derived from VPA with $M = 0{\cdot}5$ (after Butterworth and le Clus, 1979).

recent catches. However, they were never filled. From 1968 to 1977 the catches fluctuated between 90000 and 300000 t, around an average of 190000 t. It was only in 1978 that the catch reached a maximum of 355000 t. This was in large measure owing to the diversion of effort away from pilchard caused by the poor abundance and availability of the latter and an exceptional contribution of very young fish (Butterworth and le Clus, 1979). Comparison of past trends in catches and quotas suggests that the stock was already intensively exploited before 1978. Preliminary virtual population analysis (Butterworth and le Clus, 1979) leads to the same conclusion. Biomass estimates show that by 1977/1978 the stock size had declined to about one third of its 1968 level. Using these biomass estimates and C/B as an index of fishing mortality and assuming that stable conditions prevail within the environment and in recruitment, a production curve was drawn from which it seems unlikely that the stock can sustain annual yields higher than 240000 t (ICSEAF, 1979).

So far, mackerel have appeared in significant quantities only during one year (1976) in the catches of the Namibian purse seiners.

The status of horse mackerel in the Namibian coastal pelagic ecosystem is not clearly understood. By cohort analysis, Newman and Centurier-Harris (1977) showed that the stock had remained stable at about 500000 t until 1971. Then, following excellent recruitments in 1970 and 1971, it went rapidly up to about 2·3 million t. This trend in biomass is in agreement with the Soviet catch per unit effort. Catches increased from 50000 to 200000 t in the period 1970–1975 to 500000 t in 1977. However, thanks to the simultaneous increase in recruitment, the rate of exploitation remained roughly stable. The stock would probably be unable to support the present catches for long periods, should recruitment fall to its earlier level.

FISHERY MANAGEMENT

Gertenbach (1973) and Newman (1977) have reviewed the management policy which has been applied to the Cape and Namibian purse-seine fisheries.

The first management actions were taken as early as 1952, when the stocks were still only lightly exploited. The number of plants was controlled and fishing forbidden from November – later from September – till February. It has not been demonstrated that the establishment of a closed season had a beneficial effect on recruitment. However, since at that time the fish were in poor condition and the oil yield low, it is reasonable to concentrate in that period the limitation on fishing mortality.

Since 1955, the tonnages that the plants were allowed to process as well as the total hold capacity of the fleet (Fig. 1b,d) have also been controlled. The catch quota was maintained between 225000 and 270000 t until 1960. As the stock was thought to be able to bear higher catches, in 1964 the quota was progressively increased up to 650000 t and kept at that level for three years. But with the entry in 1966 of the two offshore fleets, fishing outside 12 nm and the national management scheme, it became impossible to justify the restrictions imposed on the land-based boats. The quota was again increased, reaching 960000 t in 1969.

Such expansion could not continue indefinitely.

Actually in 1970, for the first time in the history of the fishery, the quota was not filled, although it was slightly reduced. In order to reduce fishing pressure, the offshore fleets were persuaded to leave the fishery. Then in 1971, in an attempt to divert part of the fishing effort away from the pilchard stock, two separate quotas were established: for anchovy the fleets were given a generous 525000 t and for pilchard a more restricted 425000 t. Unfortunately this policy failed; although the anchovy quota has been substantially reduced on several occasions in successive years, it was never attained. The pilchard quota had to be further reduced. In 1972 it was set at only 370000 t. In 1973/1975, with a slight improvement in catch rate, the catch limitation was slightly relaxed but the decline started again. In 1977 and 1978 the quotas originally adopted had to be further reduced during the fishing season. In 1978 the quota was finally set at 125000 t, but only 46000 t could be taken.

DISCUSSION

Although the balance of this long succession of initiatives may appear disappointing, it is not fully negative. By comparison with other pelagic fisheries in the world, the policy has definitely been successful in maintaining the investments in fishing, as well as in processing capacities, within reasonable limits. It should also be observed that this policy was largely empirical, in the sense that it has hardly ever been based on proper estimates of the average potential yield of the stock, and of the current trends in its biomass.

The first consequence of this situation was that actions were always taken after some delay with respect to the stock-size fluctuations. This lag is obvious when one compares the timing of the variations in stock abundance, in the annual quotas, and in the achieved rate of exploitation (Fig. 1c,e,d). Between the former and the latter two years have elapsed on average. Although apparently moderate, this lag resulted in substantial losses as catches could have been higher in periods of stock increase (i.e., until the mid-1960s), and because the efficiency of the management measures was reduced by their delayed enforcement (in 1968/1971, for instance). At worst, the delayed action tended to amplify the natural fluctuations of stock size, as the rate of exploitation increased when the stock biomass began to fall (in 1967/1969, for example) and decreased after several good recruitments had strengthened the stock (1971/1973). This practice contributed to reducing further the natural productivity of the stock and, in periods of intensive fishing, increased the risk of collapse. It could be observed that such a pattern is more likely to occur in stocks where good and bad recruitments come in runs and where the number of year classes in the population is limited.

The successive quotas have apparently been based on the past fishing performances of the fleet rather than on accurate estimates of the current stock size and of its surplus capacity. This approach has probably resulted in slowing down the increase in the exploitation rate, but has been insufficient to maintain it within satisfactory limits. From the timing of events which followed one another in the fishery, the entry of the two offshore fleets seems to have had a special responsibility in triggering off the stock collapse. In two years, the total catch, which had until then been maintained below one third of the stock size, increased to half this size. Catches have since remained between these two limits, while the stock was going through a succession of worsening states.

A production model (Gulland's technique, exponential function, functional relationship) has been applied to the biomass estimates derived from guano yields and to the annual catches. Indices of fishing effort were obtained by dividing annual catches by the corresponding guano yields. In spite of the appreciable scatter of the points, this computation (Fig. 3) shows that:

- Fishing had an undeniable effect on the stock ($r = -0{\cdot}53$).
- Under the observed conditions, the equilibrium yield curve passes through a maximum slightly below 600000 t.

Actually, from 1962 to 1966, i.e., before the arrival of the factory vessels, the catch, which at that time was exclusively made up of pilchard of higher commercial value, remained regularly at just over 600000 t. After 1970 when the factory vessels had left the area the catches did not exceed 425000 t on average, a figure to which, however, should be added 300000 t of other species of lower commercial value. Meanwhile, the total hold capacity of the fleet had doubled as, most likely, did its unit (per hold capacity) efficiency.

It can be concluded that the stock was grossly overexploited from 1967 to 1976. Because of the low level to which it has fallen in recent years, the present quotas, although low in comparison with the past performances of the fishery, still appear capable of generating excessive levels of exploitation. In 1977, the catch seems to have come closer to the surplus yield. However, this conclusion may still be overoptimistic, for the other two indices (c.p.u.e. and VPA) suggest that the stock could be appreciably lower than indicated by the guano data (Fig. 1c).

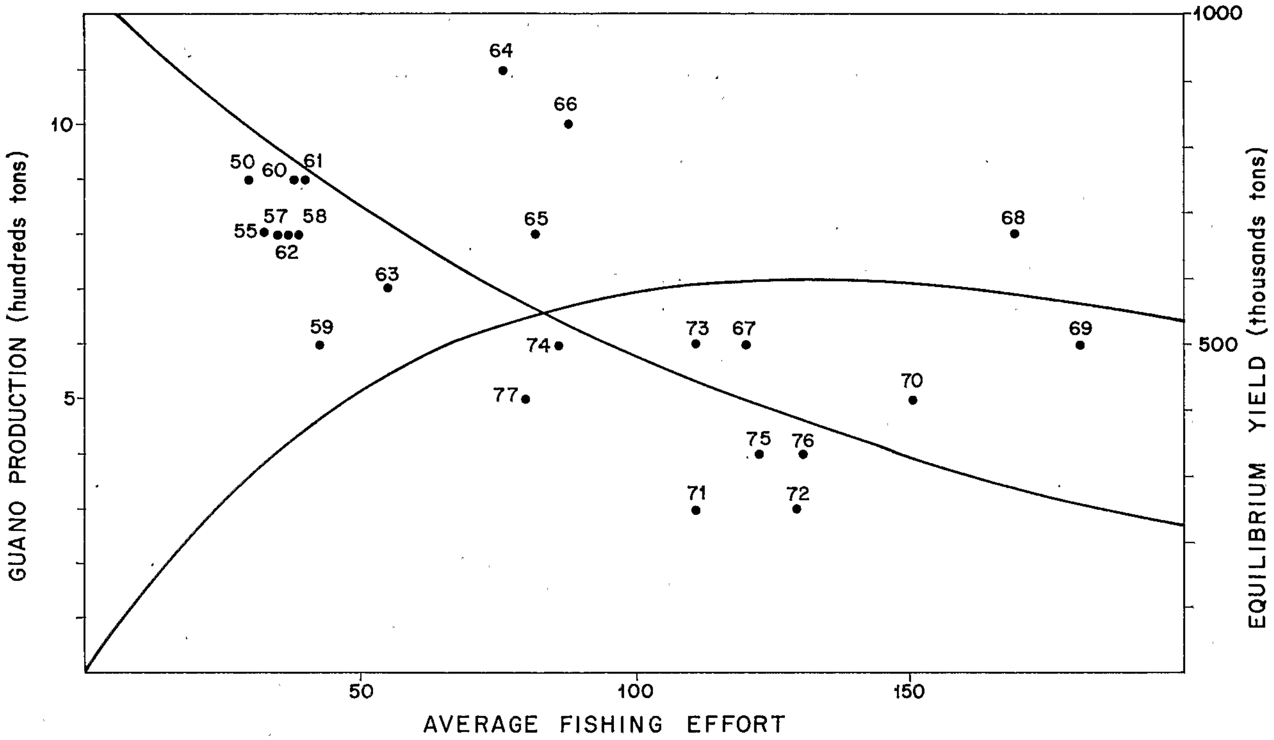

Figure 3. Namibian pilchard: Relationship between guano production (taken as an index of pilchard biomass) and corresponding fishing effort estimates (3-year average until 1966, 2 years after 1966) and resulting equilibrium yield curve.

It should also be remembered that recent recruitments are the lowest ever observed.

As long as no alternative resources, large enough to accommodate the excessive effort, are identified, the recovery of the pilchard stock and its fishery is dependent on the reduction and control of fishing. With such an unstable stock, the limitation of effort seems at first sight to offer the proper solution, inasmuch as a stabilized fishing mortality would keep the rate of exploitation constant.

However, even when the average surplus yield that all the stocks can generate is assessed, such a management approach alone is unlikely to provide a fully satisfactory answer. The gains in efficiency, which each boat can be expected to develop within the limits fixed in the management scheme, will have to be properly monitored and regularly offset. In order to overcome that difficulty, it has been suggested that the same goal could be achieved through the allocation of catch quotas to processing plants. It is thus expected that the plants which already possess the majority of vessels will aim at minimizing the harvesting costs and will therefore endeavour to keep the size and equipment of their fleet at the minimum compatible with their quotas.

The advantage of simplicity which can be expected from effort limitation would be lost with such a scheme, since each year a quota likely to keep the fishing mortality constant would have to be assessed. In addition, this method alone would not permit the stock fluctuations to be kept within certain limits. As will be discussed later, such an objective is likely to provide a more efficient and safe strategy for the exploitation of highly fluctuating stocks such as pilchard. Finally the mere allocation of catch quotas to plants would entirely neglect the problem – better known than solved in practice – of the distribution of effort among various stocks which are simultaneously exploited (pilchard, anchovy, horse mackerel, mackerel, etc.) and probably biologically interrelated. Some intervention is likely to be desirable to prevent overconcentration of effort on the pilchard which, since it is used for canning, benefits from higher prices.

The limitation of effort through quota allocation to the processing plants would also leave unsolved the question of the control of effort applied by the independent fishermen. To the extent that their interests do not coincide with those of the plants, it can be expected that the former will react differently to the management measures.

In this connexion, the Namibian and Cape fisheries give an interesting example of the unexpected effects that management policies can sometimes generate. It was on the initiative of the independent fishermen, who owned the majority of the vessels in the beginning, that the fleet size was frozen (Gertenbach, 1973). This action incidentally demonstrates that, in a fishery operated by a single homogeneous community, the fishermen are likely to cooperate in the successful implementation of an effort-limitation scheme, provided it appears to be in the direct, long-term interest of their community. Unfortunately, in the Cape and Namibian fisheries, the scheme ultimately contributed to depriving them of their boats. As it became profitable to operate purse seiners with larger hold capacity and wider operating range, the fleet size limitation made it necessary to pool together several licences when old boats had to be replaced. This increased the minimum investment requirements and resulted in a progressive purchase of the vessels by the processing companies whose liquid assets were probably greater than those of the individual fishermen.

Table 8. Ghana and Ivory Coast: Total annual catches (t) of coastal pelagic species

	Round sardinella[a]	Flat sardinella[d]	Mackerel	Anchovy
1963	7 960[b]	–	–	–
1964	40 330[b]	–	–	–
1965	8 200[b]	–	–	–
1966	15 774[b]	11 009[c]	–	–
1967	47 130[b]	18 812[c]	–	–
1968	8 241[b]	32 785[c]	–	–
1969	29 804[b]	11 363[c]	–	–
1970	30 411[b]	9 915[c]	–	–
1971	35 830[b]	33 427[c]	2 398[b,e]	41 318[b]
1972	94 742[b]	30 483[c]	8 264[b]	26 780[b]
1973	5 818[b]	22 511[c]	3 577[b]	14 578[b]
1974	1 698[b]	30 198[c]	612[b]	33 441[b]
1975	2 021[b]	28 328[c]	844[b]	32 173[b]
1976	15 541[c]	28 833[c]	93[c]	28 657[c]

[a] These figures do not include some 1 000–2 000 t caught annually as bait for tuna fishing boats.

[b] From: Rapport du Groupe de travail sur la sardinelle des côtes ivoiro-ghanéennes, Abidjan (1976).

[c] From: Data reported to FAO (FAO Yearbooks of Fishery Statistics and CECAF Statistical Bulletin No. 1).

[d] Estimated as total sardinella catch (FAO statistics) – round sardinella catch (Working Group Report).

[e] Ivory Coast only.

THE SARDINELLA FISHERY OFF GHANA AND THE IVORY COAST

From July until October and to a lesser extent in the early part of the year, upwelling occurs along the coasts of Ghana and the Ivory Coast. The increased productivity associated with this upwelling has a significant effect on the abundance of the coastal pelagic resources and distinguishes this zone from other less productive areas of the Gulf of Guinea.

In Ghanaian waters, the round sardinella (*Sardinella aurita*) stock has for some centuries been the object of an active fishery. In the early 1960s, two fleets of purse seiners, one based in the Ivory Coast, the other in Ghana, were added to the traditional canoes. For several years, the combined catches of these three fleets fluctuated around 25 000 t without showing any clear trend. In 1972, the catch suddenly rose to 95 000 t and fell immediately thereafter to a lower level for three successive years when catches ranged between 5800 and 1700 t (Table 8).

At about the same time, there was a population explosion of the triggerfish (*Balistes capriscus*). Because of its normally low density and the difficulties in utilizing this species, *B. capriscus* had hitherto been considered as devoid of all economic interest. Within a few years, it became one of the most important species in the trawl catches. Other significant changes, such as the drop in both the mean abundance of zooplankton and the catches of mackerel, were also noted for several consecutive years from 1973 onwards. The apparent simultaneity of these phenomena suggested that they were related and that the drop in sardinella and mackerel stocks was largely due to natural causes.

The state of the round sardinella stock was specially assessed by an *ad hoc* working group which met in Abidjan in June/July 1976. A large part of the information which follows is extracted from the report of this meeting (FRU/CRO, 1976), which can be consulted for further details.

THE FISHERY

The sardinella stock extends over the continental shelf between 4°30′W and 1°30′E approximately. It is geographically distinct from stocks of the same species found north of Sierra Leone and south of Gabon, i.e., in the areas where the seasonal effects of the upwellings associated with the Canary and Benguela current systems are felt. The migrations of the central stock are closely linked to the upwelling cycle, as are the biological characteristics of the fish and the fishery. Throughout the first half of the year, before the upwelling starts, the adult population of round sardinella overwinters close to the bottom at depths of 50–80 m between the longitudes of Three Points Cape and Accra. When the upwelling starts, at the beginning of July, the stock moves towards the coast and the surface. Individual growth rate increases as abundant food is available in the form of *Calanoides carinatus*, which starts to reproduce rapidly as it approaches, also with the upwelling, the surface and the coast. The fish breed throughout the year, but spawning reaches a peak during this period. As the upwelling season progresses the stock extends along the eastern half of the Ivory Coast and reaches as far as the Togolese boundary in the east.

At the end of the upwelling season, towards October, the area over which the stock is distributed begins to diminish and by December the population is once again confined within its deep-water wintering zone. Similar movements towards the surface and the coast occur during the periods of minor upwelling in the early part of the year, but these displacements are, like the upwellings, much less marked in that period of the year. The juveniles do not participate initially in these migrations and are usually found relatively close to the shore.

Fishing takes place for the most part during the main upwelling season, as at that time the stocks of fish reach the coastal and surface waters and become accessible to the canoes and nets of the artisanal fleet (traditionally encircling gillnets of little depth). Because of their greater range of action and their deeper nets the seiners have a longer fishing season. Despite these advantages, however, the canoes take more than half of the total catch, the Ghanaian and Ivorian seiners catching on average one quarter and one fifth of the total respectively.

The influence of the upwelling on stock availability is reflected in the correlation observed between catch per unit effort and the intensity of upwelling, and explains the even better relation between total production in any one season and an index which integrates the duration and intensity of the upwelling. The particularly good catches of the years 1964 and 1967 correspond with years of strong upwelling. However, 1972, when catches attained the record level, was not a particularly cold year, the marine climate having remained rather constant between 1969 and 1973, and 1971 for example having been slightly colder than 1972.

The history of the catches can be traced over the last fifteen years (Table 8). Before 1963, records are lacking for certain fleets. After this date their accuracy is variable, being less for the earlier years and also for the canoe fishery where the volume and species composition of the catch are more difficult to estimate. Actually, the statistics given in the working group report (FRU/CRO, 1976) and those reported to FAO do not correspond precisely. From 1963 to 1971, the catches of the round sardinella ranged between 8000 and 47000 t. Following the record catch of 95000 t in 1972, catches fell to nearly nothing (around 3000 t) for the following three years. The catch of 15500 t in 1976 and of 56000 t (including the flat sardinella, *S. maderensis*, caught by Ghana) indicates that the stock is beginning to recover.

The round sardinella is not the only pelagic species which is exploited in this upwelling zone. Off the Ivorian coast, the flat sardinella is normally caught in larger quantities than the round one. As the former is available for a greater part of the year and over a longer stretch of the coast, its importance for local seiners is greater than that of the round sardinella. With a mean production of about 10000 t, the local population seemed to be fully exploited (Marchal, 1971). In Ghana, the flat sardinella initially played a secondary role in the catches. Fishing was concentrated in the east of the country around the mouth of the Volta River. However, during these later years, catches have increased remarkably, from 1400 t in 1970 to about 18000 t, at which level they have remained stable since 1974.

The mackerel (*Scomber japonicus*), which occupies the same habitat as the round sardinella, is mainly exploited by Ghanaian boats. Its fishing season is concentrated towards the end of the upwelling period. In Ghana and the Ivory Coast, the catches dropped at the same time as those of the round sardinella but, in contrast to that species, remained low in 1976 and 1977 (Table 8).

The anchovy (*Engraulis guineensis*) is only caught in appreciable quantity off Ghana. Possibly this reflects a difference in fishing practices. In contrast to the previous species, catches have stayed more or less stable throughout the last few years.

THE EFFECTS OF FISHING ON THE STOCK

A GENPROD model has been applied to the catches per unit of effort of the Ivorian purse-seine fleet and to the total catch. To eliminate the effects of upwelling on the availability of fish, the annual catches per unit of effort were weighted by a yearly upwelling index. Until 1971, the stock showed a classic response to the increase in effort. Based on these observations – it should be noted that these are few (6) and refer to a fleet which fishes the least directly on the stock – the potential was estimated at about 40000 t. An earlier analysis (FAO, 1974) based on yield per recruit computations for the cohorts exploited between 1966 and 1971 suggested a potential which was notably less, about 30000 t. Before 1972, the stock was therefore probably at most only slightly overexploited. But, by 1972, the catches had probably reached a level of about three times the maximum potential yield. Under these conditions there would have been a severe overexploitation likely to reduce the standing stock to an extremely low level. This conclusion is in agreement with the catches per unit effort observed during the three following years (1973, 1974 and 1975), which were abnormally low for the corresponding effort. It can also be noted that the catches were equally low in 1965 and 1968 which followed strong upwelling years in which catches in excess of 40 000 t were achieved.

The exceptional catch in 1972 resulted from an abnormal availability of the stock with respect to the correlation already observed with the intensity of upwelling. During the first half of the year, i.e., before the start of the upwelling season, the Ivorian boats regularly obtained good catches. These became exceptional at the beginning of the upwelling season, the three fleets having succeeded in landing more than 70 000 t in July and August alone. Then the catch rates became poor, even before the upwelling season drew to a close, an observation which supports the hypothesis of an extreme reduction of the stock.

STOCK AND RECRUITMENT

The available information does not permit precise determination of the shape of the stock-recruitment curve. Cohort analysis indicates that recruitment was average in 1970, excellent in 1971, and very poor in 1972. Since catches in 1972 were made very early, before the main spawning season, the year classes, including the 1971 one, which were likely to breed, may well have been decimated before having time to reproduce. This hypothesis is not entirely confirmed by available estimates of the abundance of larvae. Breeding was apparently reduced in 1972 as well as in 1973, but was reduced only to 20–30% of the 1969/1971 mean level. Only in 1974 and 1975 did it truly collapse (3% of the 1969/1971 level).

From all available indices (cohort analysis, catches per unit of effort of recruits for the Ivorian fleet), recruitment fell to an extremely low level in 1973 and remained low until 1975. Recently recruitment seems to have increased as evidenced by the larger yield obtained in 1976 and 1977.

POSSIBLE CHANGES IN THE ECOSYSTEM

The assumption can be made that an appreciable decrease in the amount of available forage contributed to the almost complete collapse of the stock after it had been seriously damaged by the exceptional catches of 1972. The same shortage of food would have also reduced to near zero the recruitment resulting from the weak, but not insignificant, spawnings of 1972 and 1973. Off the Ivory Coast from 1972 and off Ghana from 1973, and thus until 1975, which is the latest year for which data are available, the figures for the mean abundance of zooplankton for the whole year, as for the upwelling season, were about 40% less than those observed previously. At the same time, the mean density of *Calanoides carinatus*, which constitutes the main prey of the round sardinella, fell in 1973 to 30% of its mean observed value.

This fall in the abundance of zooplankton may also be responsible for a lowering of the mackerel stock or for a reduction of its availability on the fishing grounds. On the other hand, the drop in catches which has been observed since 1973/1974 may be due to the reduction of effort directed to the target stock of *Sardinella aurita* in which fishery the greater part of the mackerel is taken as a by-catch.

Other observations, which tend to relate the collapse of the round sardinella stock to profound changes in the ecosystem, have also been made. At apparently the same period, an explosion of the triggerfish (*Balistes capriscus*) population was observed in the Gulf of Guinea. This species, which has been known to exist in the region for a long time, had previously only been caught as a few isolated individuals per haul in the commercial catch and in the numerous trawling surveys which have been conducted all over the Gulf of Guinea. From 1972 onwards increased landings were recorded in Ghana and in Togo (FAO Yearbook of Fishery Statistics, Vol. 42). In 1972, the species represented 27% of the total catch made by small inshore trawlers in Ghana, a percentage which rose to 43% in 1973 and 53% in 1974 (FAO, 1976a).

However, the first signs of this sudden increase in the triggerfish population were noted well in advance of the collapse of round sardinella. For example, the species was observed as early as 1970, in growing numbers, in the landings at Elmina (Ghana). Its poor market value probably explains why it was not sold initially, and the increase in its utilization was probably related to the collapse in the landings of round sardinella.

In addition, it could be noted that the boom of the triggerfish extends over a much larger area than the upwelling zone where the round sardinella stock is distributed. For example in 1976 triggerfish appeared as a major element in the demersal catches made off Guinea during a survey conducted by the German Democratic Republic with RV "Ernst Haeckel" (Zupanovic and Cissé, 1977). A similar observation was made off Togo.

In addition to the difference in the geographical distribution of the two stocks, they also seem to belong to different ecosystems. Even though the triggerfish can be found in significant concentrations in midwater, it is, as one can infer from its buccal anatomy, essentially a demersal species. The fact remains that the expansion in biomass of triggerfish constitutes a unique example of a gross modification in a marine ecosystem, both by its magnitude and its geographical extent.

The hypothesis that the flat sardinella has, in part, substituted the round sardinella has also been put forward. This does not seem to be the case: first, because the flat sardinella is more closely related in its distribution and production to the inflow of fresh waters than is the round sardinella which is essentially an offshore and stenohaline species; secondly, because the increase in the catches of flat sardinella started in 1971, before the collapse of the round sardinella. On the other hand, it is probable that the fall in abundance of this latter species resulted in a concentration of effort on the flat sardinella.

DISCUSSION

The assessment of the causes of the collapse of the round sardinella stock is made difficult by the lack of accurate information on many of the key parameters, in particular on the level of the ichthyomass throughout the period of observation. Equally unknown are the causes of the exceptional availability of the stock during the first part of 1972. Finally, the relationships between secondary production, notably of *Calanoides carinatus*, and the magnitude of the stock and the recruitment are insufficiently documented. It does seem however that the huge catches in 1972, which were taken from a stock already fully exploited, or even slightly above, directly caused its collapse. The latter may then have been achieved by a substantial decrease in the amount of food, notably for the larvae and the pre-recruits. Compensations by density-dependent factors do not seem to have occurred, as the low spawnings in 1972 and 1973 gave rise to even weaker recruitments in subsequent years. On the other hand, explanations based on the competition between stocks and their partial replacement are unsatisfactory.

It would be extremely interesting to follow the recovery of the stock and to see whether or not this is accompanied by an increase in the secondary production, especially of *Calanoides carinatus*. The food regime of the pre-recruits also needs to be studied.

Until now the stock has not been subjected to any management measure.

CONCLUSIONS

The lack of precision in the estimates of several parameters of the fisheries under review in this paper affects the conclusions, which must be partly speculative. However, they form a coherent basis for identifying some promising lines of research and of principles for improved utilization of this kind of resource.

All stocks examined here showed a long-term variability greater than that commonly observed in demersal fisheries. However, this variability did not start with the intensification of fishing as evidenced by indicators – e.g., the scale deposits found in bottom sediments off California – of large historical fluctuations in stock biomass. The second observation is that the variations shown by stocks inhabiting the same ecosystems were largely independent. Off Namibia, South Africa, California, and southwest India no simple correlation between the biomasses of pilchard (or sardine) and of anchovy (or mackerel) has been found. This does not imply that the overall yield, which can be provided by the most diversified multispecies resources such as the community pilchard (or sardine) / anchovy / mackerel / horse mackerel / saury very frequently observed (for example, off California, Namibia, South Africa, Japan), cannot be more stable than the yield of apparently more simple multispecies stocks like the one found off Peru. If the component stocks have independent fluctuations in amplitude and frequency, the relative fluctuations of the overall production can be expected to decrease as the number of component stocks increases. In the Northwest Pacific, for example, the total pelagic catch taken by Japan, Korea, and the USSR has remained between 3·9 and 4·9 million tonnes during the last decade, while the main stocks – sardine, anchovy, mackerel, horse mackerel, and squid have always represented between 62% and 66% of the total – were undergoing considerable fluctuations (Chikuni, in preparation). On the other hand, the purely natural variability in stock biomass is not so marked in amplitude as the variations in annual catches would suggest. As has been seen for the Namibian fishery, a lag of two years, with respect to stock-size variation, in the implementation of quotas has apparently tended to increase the rate of exploitation at the beginning of each decline in stock size and, consequently, to enlarge its variations.

In addition, the difficulties encountered in correctly estimating the biomass of pelagic stocks and the fishing effort effectively exerted upon them, resulting, for example, from possible reductions in the area of distribution as the stock declines (Peru) or from a substantial and growing underestimation of the fishing efficiency, greatly increases the risk of seriously under-estimating the exploitation rate in pelagic fisheries. In several fisheries considered here (Namibia, Ivory Coast / Ghana, and probably Peru) the collapse has been triggered by an intensive, unsuspected over-exploitation and did not simply result from a natural decline in stock size. The term 'collapse' appears therefore, to be partly inappropriate insofar as it suggests the occurrence of a natural, unforeseeable, and inexplicable event. The apparent inadequacies of available methods for forecasting such events lie more in the lack of proper data, aggravated by the difficulties in correctly estimating some key parameters, such as the biomass and the fishing effort, than in the models themselves. The need to monitor more exactly the trends in biomass makes it essential to carry out periodic surveys (e.g., by means of quantitative acoustic methods), to collect more refined effort data (with provision for monitoring changes in fishing power and according to a fine grid in order to detect possible changes in stock distribution), and to employ a biomass index independent of the rate of exploitation, such as the guano statistics. To make full use of such indicators the relationship, or at least the correlation, between them and stock biomass has to be determined.

Some parameters seem to play a greater role in the dynamics of pelagic stocks than they normally do in those of demersal species. In current stock-assessment work the common practice has been to assume that they remain reasonably constant in time and for different levels of fishing effort. If such assumptions are not valid, an appreciable bias will be introduced in the assessments. For example, the area of stock distribution can apparently vary considerably with stock size (Peru) or with time, possibly as a result of long-term climatic changes (California). Similar remarks apply to stock availability which can change appreciably with seasons or from year to year (Ivory Coast/Ghana).

The review of the Californian, Ivorian–Ghanaian, Namibian, and Peruvian fisheries has shown the key role of the stock/recruitment relationship in the variability of pelagic stocks. The Namibian pilchard stock and the Californian sardine and mackerel stocks appear to have reached their levels of maximum average production at rates of exploitation which do not seem exceptionally high in comparison with most demersal stocks. The stocks started to decline when fishing mortality reached a value about equal to the estimated natural mortality coefficient. This peculiarity appears to be related to the roughly linear form of the stock/recruitment relationship, which seems to be a common characteristic of clupeids and engraulids. The extremely low recruitments produced by reduced, but not insignificant, spawning recorded during the collapse of the sardinella stock off Ghana/Ivory Coast is in agreement with the observations made on California stocks that good or bad recruitments come in runs. This low density dependence in recruitment, that is, the lightly convex shape of the stock/recruitment curve, as observed for instance for the Namibian pilchard, could be the reason for the relatively lower productivity of coastal pelagic stocks. These are almost exactly the conclusions reached by Cushing (1971) in his study of the characteristics of the stock/recruitment relationship in herring-like fishes and of their consequences for stock stability.

Several conclusions regarding ways to improve the management of coastal pelagic stocks can be drawn from the observations given above on their dynamics. The first one is that instead of trying to keep the annual catches approximately constant, one should aim at maintaining the biomass within certain limits as close as feasible to those corresponding to the maximum surplus recruitment and to fish more or less according to the size of successive recruitments. Such a strategy will necessarily lead to large fluctuations in annual catches. It is therefore essential to have a flexible fishery able to shift its effort from one stock to another. The example of the Japanese pelagic fishery in home waters shows that this is possible though not necessarily easy. In case such flexibility cannot be fully achieved or appears too costly, some reduction in the average long-term yield, below the theoretical maximum of stock productivity, will have to be accepted.

Finally, it is essential to reduce to a minimum the delay between the assessment of the current biomass of each major constituent stock and the determination of corresponding permissible catches on the one hand and the enforcement of decisions on the other. The need to manage coastal pelagic stocks in real time provides another argument in favour of a more frequent use of biomass surveys. For the same purpose a formula for fixing the optimum (corresponding to the management strategy adopted for each fishery) rate of removal according to the biomass observed could usefully be agreed upon in advance.

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