THE LESSONS OF THE PERUVIAN ANCHOVETA FISHERY

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ABSTRACT

The outstanding features of the Peru upwelling system are high productivity and great variability. No large changes in the parameters of the anchoveta population were detected in the fishery and survey data analyzed in studies done before 1972, but because of deficiencies in the data such changes may have occurred and gone undetected. These studies might have been adequate in a less variable fishery, and even in the anchoveta fishery were useful in that they prevented an excessive increase in fishing effort. But because they did not allow for the possibility of large changes in the behavior of the population, they were of little value when recruitment failed in 1972. The stock's collapse in that year and its apparent failure to recover since are still not understood. In the light of this experience, future studies and management of anchoveta fisheries should take into account the potential for large changes in the parameters of the fish populations and in the meaning of the usual fishery statistics and survey data.

INTRODUCTION

Because of upwelling, the coastal waters of Peru are among the world's most productive. The chief direct consumer of this immense planktonic production is the Peruvian anchoveta, *Engraulis ringens* Jenyns, and it in turn is the chief forage item of the region's higher level consumers, including fish, birds, and marine mammals. In some years the normal processes of production and consumption are interrupted when upwelling ceases and warm surface waters advance to the coast with lethal effects on the native biota, a phenomenon called El Nino.

In the absence of a large market, no large scale fishery developed to exploit Peru's marine production until the second world war, when high demand and low supplies in the United States and elsewhere offered large profits from the export of canned tuna and bonito. After the war, as normal fishing operations resumed in the former belligerent countries, Peruvian exports were steadily displaced from foreign markets by cheaper domestic products, and in Peru the boats and factories that had been built during the war were increasingly idle.

Reduction plants had been installed in the canning factories to make fish meal from the leavings of the canning process, and beginning about 1950 some factory owners resorted to buying anchoveta for reduction to cut their losses when the canning lines were idle. This incidental activity soon became profitable in itself as world demand for fish meal increased and other supplies declined, in particular the California sardine. As new boats and plants entered the industry, the catch of anchoveta grew exponentially, doubling each year from 100,000 tons in 1955 to 3.3 million tons in 1960 (Boerema and Gullard, 1973).

At this point the Peruvian government, with technical assistance from the Food and Agriculture Organization of the United Nations (FAO), began to collect fishery statistics and conduct fishery investigations with the aim of rationally managing the resource. The first assessment of the fishery, done in 1965, showed that the stock was fully exploited, or nearly so, by the current annual catch of 8 million tons, and for the next few years the catch was limited to approximately this amount by closed seasons and quotas. Later studies, done after the population of fish eating birds had been reduced by some 75% during the 1965 El Nino, showed that the anchoveta stock could yield 10 million tons per year on the average. The quota was consequently raised in 1968, and the annual catch was around 10 million tons through 1971. While the annual quotas prevented excessive increases in the catch, they did not prevent and in fact encouraged excessive increases in the industry's capacity (catching and processing) since the companies with the largest capacities obtained the largest shares of the quota. As a result, the industry by 1971 was heavily overcapitalized.

At the end of 1971, the anchoveta fishery appeared to be a model of successful management, by biological standards if not economic ones. But then, within months, the population suffered two catastrophes. First it became clear early in 1972 that recruitment had practically failed, and after that the adult stock, crowded against the coast by the severe 1972 El Nino, was greatly depleted, either by heavy fishing or by a combination of heavy fishing and extraordinary mortality due to the extreme environmental conditions that then prevailed. By the middle of 1972 only a small part of the former stock appeared to have survived.

The stock of anchoveta did not recover rapidly after the collapse of early 1972, and since then the fishery has operated at a low level. After catching about 4.5 million tons in the first months of 1972, the fishery in effect remained closed until March 1973 when about 2 million tons were caught during a brief open season, but acoustic surveys and the composition of the catch showed that recruitment was again poor and the stock was still small. The fishery was again closed for the remainder of the year. In 1974 conditions were somewhat better and a catch quota of 4 million tons was filled. So far in 1975, a quota of 3 million tons has been taken in the first part of the year, and an additional 2 million may be allowed in the last few months. Acoustic surveys continue to show a stock size well below the average observed before 1972.

The record of anchoveta fishery can be interpreted in various ways. One is that the stock and its usual behavior were adequately described by the assessments done before 1972. In this case, the recruitment failure of 1972 was a freak event whose consequences were needlessly exacerbated and prolonged by excessive catches in 1972 and since. Another interpretation is that these assessments for one reason or another did not accurately represent the condition or behavior of the stock. In this case, there is no sure way to infer from the available data whether the catches before or after 1972 were too high or too low, or what should be the strategy for managing the fishery now.

The choice between these interpretations is still open. This paper will briefly describe the upwelling system and the natural history of the anchoveta, relate the ways in which the fishery was studied and managed, discuss the questions still outstanding, and finally draw from the Peruvian experience some advice for studying and managing other anchovy fisheries that may have some similar features.

THE UPWELLING ECOSYSTEM

Upwelling and Primary Production

The rate of upwelling along the coast of Peru varies seasonally with the strength of the southeast trade winds that blow nearly parallel to the coast. During the southern winter (June to September), when the winds are strongest, the upwelling is most vigorous and the zone of cold water along the coast is widest. During spring and summer upwelling slows and the zone of cold water narrows as the winds subside, usually to a minimum in March (Bjerknes, 1961).

In some years an extreme relaxation of the trade winds results in a virtual cessation of upwelling. The zone of cold water disappears along most of the Peruvian coast which is then subjected to tropical conditions causing major disruptions. This event, which is called El Nino, is simply the extreme case since the summer minimum of upwelling. It is not a well defined phenomenon, since the summer minimum can fall anywhere in the whole range of conditions between relatively strong upwelling and almost no upwelling. While the designation of El Ninos is therefore arbitrary in some cases, the most severe occurrences in this century have been roughly periodic, falling 6 to 8 years (or some multiple thereof) apart. Bjerknes (1966) proposed a mechanism of interaction between the oceanic and atmospheric circulations of the Pacific to account for the apparent cycle.

Up to a point, the rate of primary production and the density of phytoplankton vary inversely with the rate of upwelling, being lowest in winter and highest in spring and summer, although low values can also occur at the height of summer when upwelling is very weak. The low rates of primary production observed in winter presumably result from the deeper mixing caused by the strong winds in that season (Guillen, Rojas de Mendiola, and Izaguirre de Rondan, 1971).

Upwelling consists of the emergence from depth of distinct water parcels rather than a steady flow. Parcels well up across a zone extending several kilometers or tens of kilometers from shore, and each parcel is the site of a distinct biological succession as it moves offshore and gradually mixes with surrounding waters (Strickland, Eppley, and Royas de Mendiola, 1969). Succession does not proceed at the same rate in all parcels since plankton growth rates within an upwelled parcel depend on the concentration of organic chelators that sank from the surface layer into the parcel before it welled up (Barber *et al.,* 1971).

Because of the seasonal and annual differences in upwelling strength, and the patchiness of the plankton, the environment occupied by the Peruvian anchoveta is quite variable in both time and space, on both large and small scales. Moreover, its most extreme variations are as yet unpredictable, which will be important in considering the population dynamics of the fish and the performance of the fishery.

Life History of the Anchoveta

On a large scale, the distribution of anchoveta schools varies seasonally as upwelling strength varies. In winter, when the layer of cold upwelled water along the coast is relatively wide and deep, schools are usually small and scattered across a zone extending 200 km or more offshore and at depths to 80 m. In summer the schools are larger and restricted to a much narrower and shallower layer of water whose dimensions depend on the degree to which upwelling weakens. In most summers this layer is around 100 km wide, but in summers of weak upwelling it contracts to 20–40 km, and during severe El Ninos it disappears entirely along much of the coast (Jordan, 1971; Murphy, 1974). In summer the distribution of schools is often very contagious, large expanses of water being nearly devoid of fish while a few small areas contain great numbers of schools in varying proximity (Instituto del Mar del Peru, 1974a).

The catch rates of anchoveta purse seiners fluctuate seasonally as the distribution of schools changes. Fishing success is relatively low in winter, and usually high in summer when the fish are concentrated.

The first fish to approach the coast and concentrate in large schools after the winter dispersion are evidently the spawners, since the spring catches typically consist almost entirely of maturing and spawning fish despite the presence of a large number, even a majority, of immature fish in the population. The recruits produced in the spring spawning, which takes place roughly from August to October, usually first enter the catches in early summer (December or January). A second spawning, variable in strength and timing among years, produces a second smaller recruitment that normally appears in the catches between March and May (Chirinos de Vildoso and Alegre de Haro, 1969). It is not known how many times an individual may spawn each year.

At the time of first vulnerability to capture, and later during the following spring spawning, some recruits apparently school separately from mature fish, since schools caught in summer sometimes consist entirely of recruits (Saetersdal and Valdivia, 1964) and schools caught in spring consist entirely of mature fish. With those exceptions, anchoveta do not school by age, or by sex.

Some spring spawned recruits participate in the spring or summer spawning of the following year (when 1 year old), but their participation is highly variable among years. Clark (1975) found summer spawned recruits do not spawn until the year after (at the age of 2 years less a few months). The oldest fish in the catches are usually around 3 years old (Chirinos de Vildoso and Chuman, 1968) and 17 cm long, although older and larger fish also occur rarely.

Tagging studies (Jordan, 1972) and some anatomical differences (Rojas de Mendiola, 1971) indicate a division of the anchoveta off Peru into two stocks, with a boundary near 15°S, which also marks the transition from the oceanographic regime of northern Chile and southern Peru to the somewhat different regime further north. The southern stock provided 10–15% of Peruvian catches before 1972.

Predators of the Anchoveta

The major known consumers of anchoveta are fish, birds, and sea lions. Other animals such as squid may also feed on anchoveta, but no instances have been observed and reported.

Among the pelagic fish that prey on anchoveta, the most important commercially is the bonito, *Sarda chiliensis.* Annual catches of this fish rose steadily from a few thousand tons in 1940 to 100,000 tons in 1960, and have since fallen by half. Catch per effort has also declined recently, most sharply after the 1965 El Nino (Instituto del Mar del Peru, unpublished figures). It appears that the bonito population has been substantially reduced by fishing.

The fish eating birds that consume anchoveta have a long and colorful history, since their dried excrement, or guano, is a fine fertilizer which has been mined from the island rookeries off and on since Inca times. Partly owning to human activity (including the disruption of breeding by 19th Century operations and the enlargement of breeding grounds by fencing off headlands in this century) and partly to periodic mass mortalities during El Ninos, the size of the bird populations has varied greatly in the last few centuries. In the most recent period, the number of birds fell from an unprecedented maximum of 25 million in 1955 to 6 million after the 1957 El Ninos, recovered rapidly to 18 million in 1963 dropped to 4 million after the 1965 El Ninos, and then increased slowly to 6.5 million just before the 1972 El Ninos, which left between 1 and 2 million survivors (Jordan and Fuentes, 1966; Murphy, 1974).

Because the decline of the bird population is a mirror image of the increase in anchoveta catches during the same period, it has been argued that the fishery inhibited the growth of the bird populations by reducing the abundance of anchoveta (e.g., Ricker, 1970). But the changes in the total numbers of birds have resulted mostly from changes in the numbers of the historically most important species, the guanay, *Phalacrocorax bougainvillei.* This bird is a cormorant that unlike the other species chases fish underwater, including fish trapped in a purse seine, and since fisherman often locate anchoveta schools by sighting birds feeding, it is plausible that the guanay's poor performance in recent years is the result of mortality incidental to fishing operations rather than of scarce prey. In 1973 when anchoveta were certainly scarce but the fishery was closed almost the entire year, the population of birds increased (Instituto del Mar del Peru, 1974b).

The Biological Effects of El Nino

When upwelling ceases and warm oceanic water replaces cold nutrient rich water in the surface layer along the Peruvian coast, the density and productivity of the plankton fall to very low levels. Planktonic and nektonic species from the tropics invade the pelagic zone (Instituto del Mar del Peru, 1972). Anchoveta schools are hard to find near the surface, although dense concentrations may occur in places where some weak or sporadic upwelling persists (Jordan, 1959; Jordan and Fuentes, 1966).

The most conspicuous victims of El Nino are the fish eating birds which routinely suffer a 75% mortality when the anchoveta disappear. Whether the anchoveta or other fish are also subject to extraordinary mortality during El Ninos is unknown. The severe El Ninos and minor disturbances in the summers of 1957, 1963, and 1965 were all followed in the next summer by an extreme scarcity of adult fish in the catches, consistent with a heavy mortality during the disturbances, and Clark (1975) inferred from a study of virtual populations, and the changes in catch composition in 1971 and 1972, that the recruits of 1971 had perished as a group during the 1972 El Nino. On the other hand changes in catch composition could have been the result of some process (e.g., changes in selection according to age by the fishery) other than previous extraordinary mortality, and no masses of dead fish have been observed during or after any of the recent disturbances.

STUDY AND MANAGEMENT OF THE FISHERY

In 1960 when the catch of anchoveta was still growing rapidly, the Peruvian government established the Instituto del Mar del Peru (called the Instituto de Investigaciones de los Recursos Marinos until 1964) to conduct studies of Peru's fish resources and particularly the anchoveta fishery. Since 1960 the Instituto has been advised and assisted in its task of monitoring the fishery and training technical personnel by FAO which under various projects has provided visiting consultants, equipment, and formal instruction as well as resident advisors.

Since its beginning the Instituto has kept monthly records of the anchoveta fishery, including the size, composition, and activity of the fleet as well as the size and composition of the landings (by length, age, sex, and reproductive condition). It has also conducted synoptic surveys of the upwelling zone. Known by the general name EUREKA surveys, these have consisted of synoptic acoustic coverage of large parts of the coastal zone by chartered fishing vessels which in the course of traversing their transects sometimes made test sets to determine stock composition and collected plankton samples. Other surveys have been performed by the Instituto's research vessels.

The monthly fishery records collected by the Instituto served as the basic data for several studies and assessments of the fishery by personnel of the instituto and foreign experts.

Saetersdal, Tsukayama, and Algre (1965) did the first studies on fishing power and standardization of effort. They found that the catch per vessel trip increased with gross vessel tonnage, but that both the slope and intercept of the regression line varied seasonally. In particular, they noted a steep and nearly proportional relationship in months of good fishing, and a less steep and distinctly nonproportional relationship during months of poor fishing. Despite these variations, they recommended gross tonnage as an index of fishing power, and in subsequent assessments fishing effort was computed as the sum of products of gross registered vessel tonnage (GRT) and some measure of fishing time (either months of operation or number of trips).

Boerema *et al.* (1967) concluded from changes in catch per unit effort and catch composition that the fraction of deaths caused by fishing had increased from less than ¼ in 1961 to about ⅔ in 1964. They did not diagnose overfishing, but advised that further increases in effort would not substantially increase and might decrease the catch which was then around 8 million tons per year.

Murphy (1967, 1973), Schaefer (1967, 1970), and Gulland (1968) all fitted various surplus production functions to the records of catch and effort, and found the maximum sustainable yield of stock, to the fishery and the guano birds combined, to be around 10 million metric tons. The same result was obtained with longer series of data by a succession of panels of experts convened later under FAO sponsorship (Ricker, 1970, 1972).

There were other indications that the stock was at or near full exploitation after 1964. Several different computations (Boerema, *et al.*, 1967; Gulland, 1968) showed the fraction of deaths caused by fishing was around 0.5, considered to be the optimum. The composition of the catch in numbers also changed from a preponderance of adults to a preponderance of recruits, which raised fears that the spawning stock was becoming dangerously small.

On the basis of all these results, the government in 1965 imposed a catch quota and thereafter began to close the fishery in certain seasons for the purposes of limiting the total catch and, in summer, postpone for a month or two the capture of recruits. As mentioned earlier, these measures limited the catch without limiting the capacity of the fishing fleet and the processing plants which by 1971 were only about 50% utilized in catching and processing the quota.

In addition to the stock assessments by catch and effort methods cited above, on which the government's regulations were based, two histories of the fishery have been prepared by virtual population methods. Burd and Valdivia reconstructed the population in each month from the catch histories of individual recruit groups, choosing likely values for a constant rate of natural mortality and the rate of fishing mortality in the last month in which fish of a particular group appeared in the catch. Clark (1975) treated the virtual population in each month as an index of population size on the assumption that natural and fishing mortality varied proportionally. Both studies showed that the fishery was strongly selective with respect to age, and that the relative vulnerabilities of different age groups had changed after the 1965 El Nino. Neither study shed any light on the potential yield of the stock or the possible reasons for its collapse in 1972, except for Clark's inference that the El Nino of that year had caused a mass mortality of year old fish.

OUTSTANDING QUESTIONS

The Meaning of the Collected Data

By now there are several fairly long series of data on the anchoveta fishery, but known and suspected biases and errors in the data continue to frustrate attempts to infer confidently from fishery statistics the effects of fishing on the stock. The problems are the following:

(i) The reported landings have been treated as estimates of the total catch. But since small fish are often pulverized and lost in pumping operations at sea and in port, and are often under reported even if they do reach the plants, the reported landings are certainly less than the total catch. The ratio of true catch to reported landings is not known for any period, nor can it be assumed to have been constant when there were large changes in catch composition.

(ii) The length composition of the landings is biased because, for various reasons, small fish were less likely to be sampled than larger ones. The age composition of the landings, which was estimated by subsampling the length sample, shares this bias; in addition, the age data suffer from suspected inaccuracies in the otolith readings on which they are based.

(iii) A more serious problem for the purposes of current assessment and management is that, owing to differences in vulnerability to capture among age groups, the composition of the landings does not reflect the composition of the population. Nor do changes in the composition of the landings necessarily indicate changes in the composition of the stock, since the relative vulnerabilities of different age groups, while often consistent, can vary greatly among seasons and years. These variations are clear enough in virtual population studies, but such studies necessarily follow events by some years.

(iv) The catch per gross registered vessel tonnage (GRT) trip or GRT month has been treated as an index of stock abundance in the anchoveta fishery, but not without grave doubts discussed by Gulland (1968), Murphy (1973), Clark (1975), and the fourth panel of experts convened by FAO and the Instituto del Mar del Peru (Murphy, 1974). It is very likely that the catch per GRT trip is strongly influenced by factors other than total stock abundance. These factors include the areal distribution of the stock (including total area occupied, school size, and contagiousness of distribution), the incidence of vessel saturation, the proportion of the stock unavailable to the fleet, the distance at which the fishermen can detect schools, and the degree of cooperation among vessels. All of these are known or suspected to have varied greatly among seasons and years in Peru. On the other hand, the catch per trip is certainly buffered against changes in stock density, since low catch rates can be at least partly compensated by longer trips. For both reasons, it is doubtful that the accumulated series of catch per effort records can be regarded as an accurate record of changes in stock abundance.

(v) The observations collected during acoustic and plankton surveys are not affected by the peculiarities of the fishery, and in principle could provide unbiased estimates of stock size. In practice, however, it is a large and difficult task to estimate stock size, or even changes in stock size, by counting the eggs in the sea. The Peruvian survey results, and the present knowledge of the anchoveta's spawning habits, are certainly not adequate to the task.

Acoustic survey results probably provide the most trustworthy measures of stock size (Johannesson and Losse, 1973), but even these may be subject to error because of incorrect calibration of the equipment, or changes in the distribution and behavior of anchoveta, or changes in the abundance of other species in the pelagic zone.

Further work on acoustic surveys is now being done by FAO in Peru, and this work offers the best hope for devising a reliable, practical, and timely method of monitoring the abundance of the stock.

The Proper Strategy for Managing the Anchoveta Fishery

In the anchoveta fishery, and most others, the aim of management is to obtain something fairly close to the maximum surplus production by maintaining the stock at some optimum size, which can be achieved by regulating fishing. But surplus production is the difference between growth and recruitment on one hand and natural mortality on the other, and in Peru the determinants of this difference may change greatly in both the short term and the long term in response to factors other than stock size. It is very likely that the rate of natural mortality varies somewhat with oceanographic changes from year to year, and during El Ninos may be heavy, at least among some age groups. Aside from oceanographic effects, the rate of natural mortality has probably decreased since the start of the anchoveta fishery as a result of reductions in the populations of predators (guano birds, bonito, and other food fish). Clark (1975) concluded from a comparison of virtual stock sizes and acoustic estimates in the same months that natural mortality was negligible after 1965 until 1972, although it must have been quite high before the start of the fishing. Despite fairly steady recruitment before 1972, the recruitment failure of that year shows that reproductive success also can change greatly. The summer of 1971–72 may have been a rare exception; on the other hand, while the spawning stock did not decrease and probably increased from 1965 to 1971, the results of plankton surveys during the spring spawnings of those years, for what they are worth, show a steep and persistent decline in egg production (Murphy, 1974); and the recruitment failure of 1972 had already occurred before El Nino set in.

The potential for large changes in the parameters of the anchoveta population independent of stock size does not imply that stock size has no effect. Rather it implies that the effect of stock size depends on environmental and perhaps behavioral factors, so that different stock sizes would be optimum (i.e., most productive) in different conditions. At present, however, the factors other than stock size that influence natural mortality and reproductive success are largely unknown, and until these factors can be identified and predicted, it will not be possible to manage the fishery rationally.

The event of 1971–72 provides a case in point. By March 1972, when the fishery reopened after a 2 month summer closure, it was apparent to the

Instituto del Mar del Peru that there would be little recruitment. The instituto recommended that the fishery remain closed to conserve the spawning stock, but the government allowed the fishery to operate until June, by which time the stock was reduced to a very low level. It seems from this record that the adult stock was simply fished out. On the other hand, the stock was very large during 1971, and during that year the catch was restricted by quota. As a result, a large adult population was present at the start of the 1972 El Nino. If natural mortality did in fact drop close to zero after 1965, the adult stock present in late 1971 may have been substantially larger than at the start of earlier El Ninos, and this excess may have been indirectly responsible in part for the collapse of the stock when the plankton disappeared during the 1972 El Nino. In this case, the collapse of the stock resulted as much from insufficient fishing in 1971 as from excessive fishing in 1972.

To manage the stock properly under all the environmental conditions that occur in Peru, particularly during the next El Nino, the Peruvian authorities would need to be able to predict environmental changes and their effects on the stock. Variations in upwelling strength along the coast of Peru result from large scale changes across the Pacific Ocean, and may soon be predictable from leading indicators elsewhere, which could be monitored by satellites (Miller and Laurs, 1975). Learning the effects of such variations on the stock of anchoveta will, however, require a careful monitoring of the size and composition of the stock under all conditions. Does weak upwelling have any effect on natural mortality? Does the effect differ among age groups (eggs, larvae, juveniles, adults)? Is it density dependent? How do environmental conditions affect spawning activity?

ADVICE FOR A DEVELOPMENT ANCHOVY FISHERY

The doubts and questions that remain in Peru can serve to guide the study and management of anchovy fisheries elsewhere.

The first lesson to be drawn is that while it is essential to collect the basic fisheries data (catch, effort, and catch composition), it is also essential to find out what these data mean. In a purse seine fishery for a species that inhabits a variable environment, catch per effort and catch composition may be heavily influenced by variable factors other than stock size and composition, and these factors will need to be investigated and monitored to make the collected fishery statistics useful for purposes of assessment. This effort will periodically require some independent measure of the size and composition of the stock, e.g., systematic acoustic surveys with test fishing.

A second lesson is that the productivity of the stock may vary greatly, randomly or systematically, with factors other than stock size and composition. In this situation it will not be meaningful to estimate the usual population parameters and relationships from observations made in different periods; the values may have changed, and their averages may be useless or even dangerous for management purposes. Instead, an attempt should be made to relate population performance to environmental conditions as well as stock size from the start, so that eventually the fishery can be managed rationally as environmental conditions change.

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