RESULTS OF THE EXPLORATORY CRUISES OF THE ALEJANDRO DE HUMBOLDT IN THE GULF OF CALIFORNIA[a]

C. P. MATHEWS[b], J. L. GRANADOS and J. ARVIZU
FAO/UNDP and Instituto Nacional de Pesca
Apartado M-10778, Mexico (1), D.F., Mexico

ABSTRACT

During the year April 1971–March 1972, R/V ALEJANDRO DE HUMBOLDT operated by the Mexico/FAO Research and Development Project of the United Nations Development Program, carried out preliminary cruises in the Gulf of California to evaluate the potential fishery resources.

A stock of hake, *Merluccius* sp., found principally north of Isla Tiburon and along the east coast of the Gulf as far south as Guaymas was surveyed in three cruises between June 1971 and March 1972. The abundance was greatest in February and March, with a total estimated biomass in the northern Gulf at that time of 28000 metric tons.

Langostino[1] or squat lobster, *Pleuroncodes planipes,* was found to be widely distributed in the Gulf south of Isla Tiburon, with the major part of the population north of Guaymas.

South of the latitude of Bahía de Yavaros the trawls brought up samples of sediments and other material with evidence of active anaerobic decay. The depth at which this occurred decreased southward to the mouth of the Gulf, and the greatest depth yielding appreciable amounts of groundfish decreased in the same way. Measurements of dissolved oxygen indicated that these conditions prevailed where the sea floor was within the oxygen minimum layer.

In spite of this limitation of space available to groundfish, a potential annual yield to a fishery was estimated to lie between about 70000 and 190000 metric tons. The total annual bycatch in the shrimp fishery was found by calculation to lie within this range.

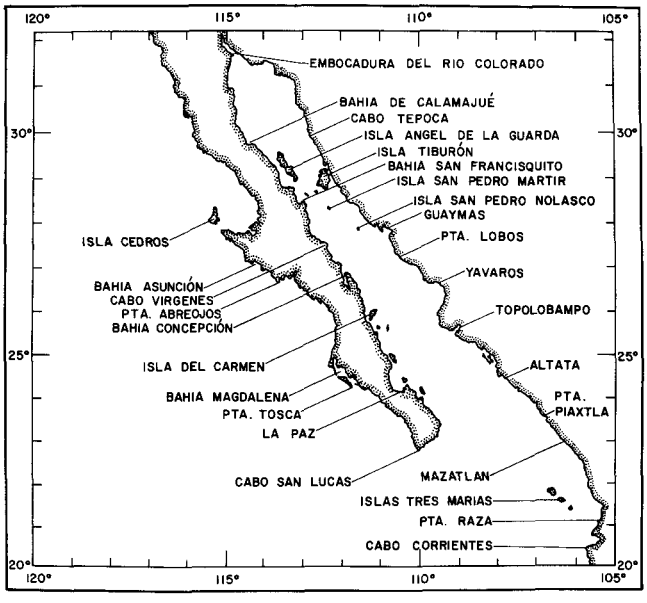

Figure 1. Map of Gulf of California.

INTRODUCTION

During the year April 1971–March 1972 the R/V ALEJANDRO DE HUMBOLDT, operated by the Mexico/FAO Research and Development Project of the United Nations Development Programme, carried out extensive exploratory and prospective cruises in the Gulf of California. The chronology and areas covered are shown in Table 1 and Figure 1.

The early cruises, April through June 1971, attained three main objectives: exploratory fishing throughout the Gulf, shaking down the ship, and educating the crew and scientists in conducting operations. After this period the crew and scientists could handle the fishing gear as deep as 1000 m, the limit imposed by the equipment available. Subsequently because of mechanical difficulties fishing was confined to depths less than 600 m.

Preliminary study of the results led to setting up several long term objectives: concentrating effort on the eastern shelf and slope which is more favorable for trawling than the narrow and rocky western shelf; investigating the population of large hake, *Merluccius* sp., in the northern Gulf; investigating the stock of langostino, or squat lobster, *Pleuroncodes planipes,* in the area between Isla Tiburon and Bahía de Yavaros; and obtaining additional data on the

TABLE 1

Chronology of operations by R/V ALEJANDRO DE HUMBOLDT under the Mexico/FAO Research and Development Project of the United Nations Development Program from April 1971–October 1972

Date	Area of operations	Shown in figures[1]
1971		
April, May	Mazatlán to Yavaros, coast of Sinaloa, and La Paz	13, 23
May, June	Yavaros to R. Colorado, coast of Sonora and northern Gulf	3, 9
July	I. Angel de la Guarda to C. San Lucas, coast of B. California	3
July	Mazatlán to C. Corrientes, coast of Nayarit	22
August	Northern Gulf, north of I. Tiburón	4
August	I. Tiburón to Guaymas, coast of Sonora	4, 10
September	Northern Gulf, north of I. Tiburón	4
November	Transects across shelf, Mazatlán to C. Corrientes	24
Nov, Dec	Transects across shelf, Mazatlán to Yavaros	14
December	Transects across shelf, near I. San Pedro Nolasco	11
1972		
Feb, March	Northern Gulf, to I. San Pedro Nolasco	5, 12
October	Pacific coast of Baja California	--

[1] All areas shown in figure 1.

[a] This is not necessarily the view of FAO.

[b] Present address: Department of Fisheries Oceanography
Unidad de Ciencias Marinas, UABC
Apartado Postal 453
Ensenada, Baja California

[1] The currently accepted name for *P. planipes* appears to be langostilla.

extent and effects on fish of oxygen-deficiency and anaerobic conditions in the deeper waters and floor of the Gulf. No other ground fish stock seemed sufficiently large or important to justify any special investigation, but some fishing effort was expended on the mixed groundfish stock in the course of other work. As a result a considerable volume of data on these stocks was obtained.

Methods and Equipment

The ALEJANDRO DE HUMBOLDT is a 450 gross ton stern trawler, provided with biological and hydrographic laboratories. The fishing equipment used during this study was an otter trawl, provided with otter boards to keep the net mouth open. Figure 2 shows a schematic representation of the fishing equipment used. The mesh size of the wings was fairly small (<10.0 cm) while that of the cod-end varied: until June 1971 a material of 5.5 cm mesh was used, while from July onwards a 4.5 cm mesh cod-end was substituted. The ratio of warp out to depth was usually 3.0:1 to 3.5:1; this was increased to around 5.0:1 in February 1972. For depths greater than 500 m, lower ratios were used. The speed at which the net was hauled along the bottom varied from 2.0 knots at depths over 450 m to 4.0 knots in very shallow waters, but most hauls were carried out at from 3.0 to 3.5 knots.

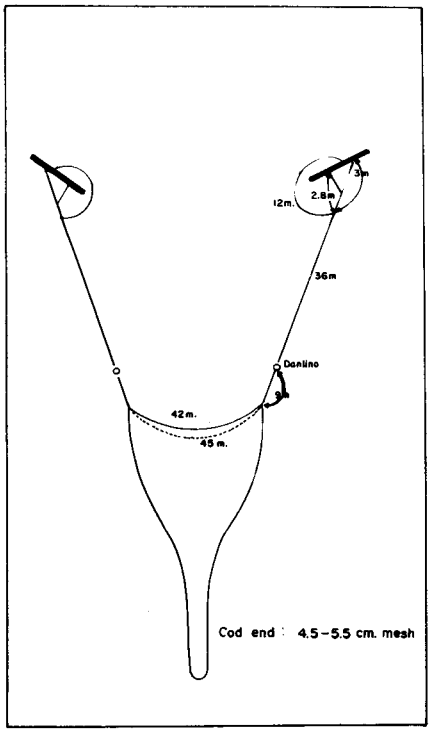

Figure 2. Schematic drawing of the otter trawl used, not be scale.

During the whole year's observations only three otter trawl nets were available; by the end of this period these nets had suffered very considerable distortion, and the vertical distance separating footline from headline may have been as little as 2–3 m, when it should have been 3–4 m. Such distortion of the equipment is likely to result in lower than normal catches being obtained and, if no correction is made, calculated abundances would be likely to err on the low side, particularly in February–March, 1972.

The depth during each trawl was monitored continuously by means of an echosounder, and whenever possible the ship's course was adjusted so as to keep trawling at a constant depth. If a considerable change in depth was unavoidable (>10% of the initial depth) the haul was usually ended; for most hauls depth did not vary by more than 2–3%. The ship's speed was recorded at the beginning and the end of each trawl. The swept area technique was used for conversion of the catch in kilograms to abundance in kilograms per hectare (kg/ha), and the following assumptions were made: (i) that the otter boards and danlinos were effective in startling fish and so made all fish between the otter boards accessible to the net; (ii) that the otter boards were 60 meters apart during trawling (this was based on measurements of a simple scale model); (iii) that, because of escapement around and through the net, only 50% of the accessible fin fish were caught; (iv) that no adjustment owing to escapement was necessary for *Pleuroncodes planipes*.

The catch per unit area, C_a, is calculated from the measured catch C as follows.

$C_a = C/K$ kilograms per hectare (kg/ha)

where K is the area swept.

$$K = \frac{60 \times 1853 \times Vt}{10000} = 11 \times Vt \text{ hectares}$$

where 60 is the distance between the otter boards in meters

1853 is the number of meters in a nautical mile

V is the average ship's speed during the haul in knots

t is the duration of the haul in hours

10000 is the number of square meters in a hectare

The abundance of fin fish, that is, the total biomass living on unit area, assuming 50% escapement, is estimated as,

$A = 2C_a$

The abundance of langostino is estimated as $A = C_a$.

The hydrographic work was carried out with a Bisset-Berman Salinity/Depth/Temperature Recorder (STD), model 9060, which was calibrated from time to time. Nansen bottles and reversible thermometers were used to obtain samples for oxygen and salinity determination and for checking STD observations. The methods used were those standardized by the U. S. Hydrographic Office (U.S. Naval Oceanographic Office, 1970).

RESULTS

1. HAKE (*Merluccius sp.*)

Hake were first caught in quantity in June. Figure 3 shows the locations of hauls and the calculated abundances. More than half (60) of the 105 exploratory hauls were made on the shelf or delta sediments where the depth to the seafloor was less than 180 m (100 fm), and 52 of these hauls caught no hake or only negligible quantities. Out of the 45 hauls at greater depths, the catches in twelve hauls were equiv-

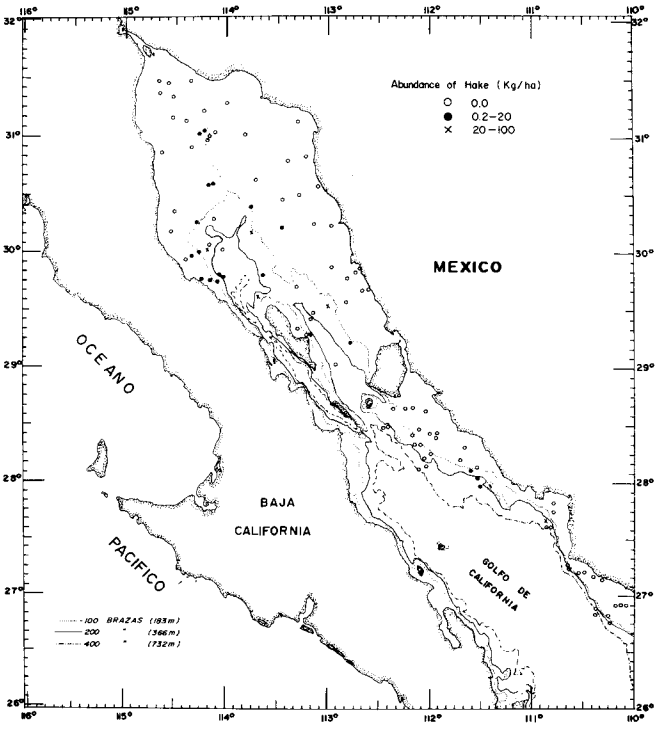

Figure 3. Location of hauls and abundance of hake in the northern Gulf of California, June 1971.

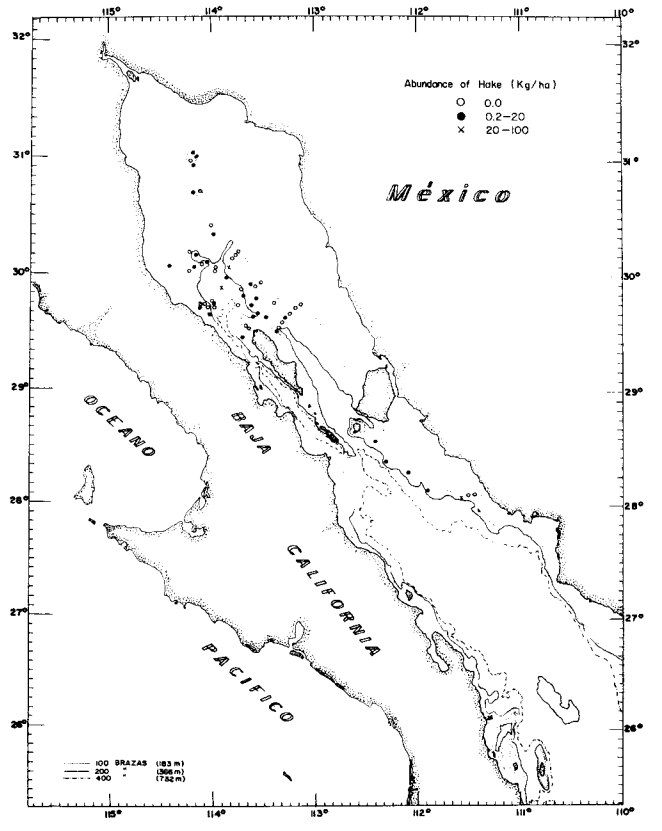

Figure 4. Location of hauls and abundance of hake in the northern Gulf of California, August–September 1971.

alent to abundances between 0 and 20 kg/ha and in five hauls to abundances between 20 and 100 kg/ha. All but four of these productive hauls were north of Isla Tiburón and Isla Ángel de la Guarda. The remaining four were on the slope near Isla San Pedro Nolasco and Guaymas. Figure 6 shows that while hake were taken at all depths from 105 m (at night) or 160 m (daytime) to 540 m, the bulk of the fish were caught between about 180 and 400 m.

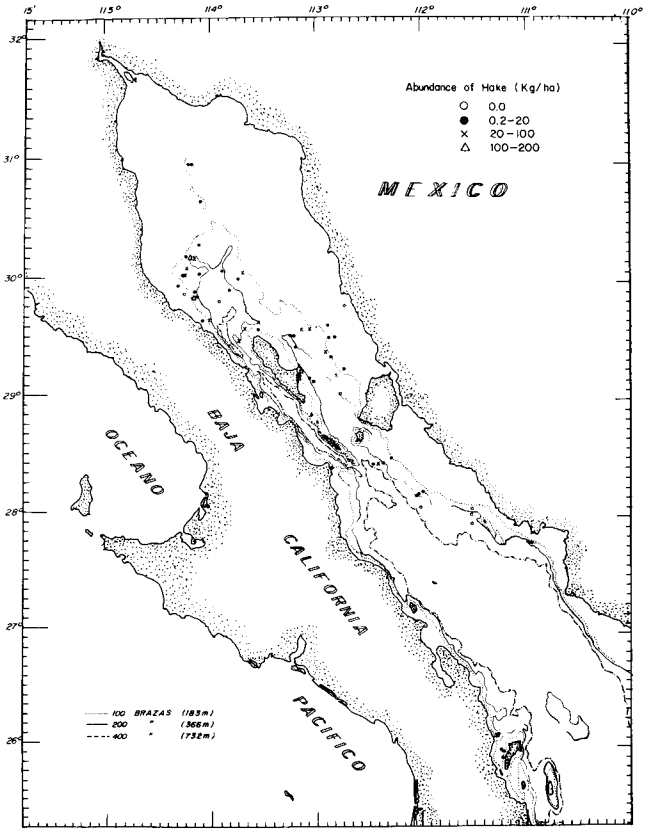

Figure 5. Location of hauls and abundance of hake in the northern Gulf of California, February–March 1972.

During the August–September cruise, in order to conserve effort while attempting an approximate estimate of the total biomass of hake in the northern Gulf, all hauls were made in the areas which had proved productive in June, namely, those below the 180 m level marking the edge of the shelf and delta deposits (Figure 4). Out of the 60 hauls, the catches in 27 were

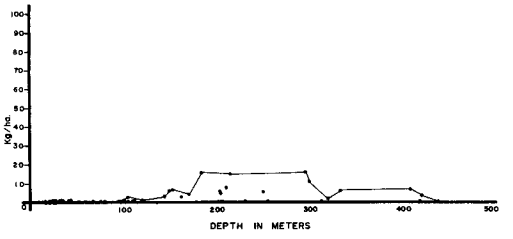

Figure 6. Depth of hauls and abundance of hake in the northern Gulf of California, June 1971.

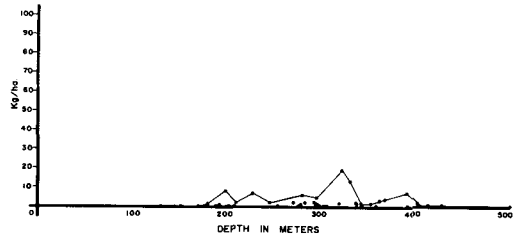

Figure 7. Depth of hauls and abundance of hake in the northern Gulf of California, August–September 1971.

equivalent to abundances between 0 and 20 kg/ha and in three hauls to abundances between 20 and 100 kg/ha. Figure 7 shows that the bulk of the fish were taken between about 200 and 400 m.

During the February–March 1972 cruise, most hauls were made below the edge of the shelf (Figure 5). Out of the 63 hauls, the catches in 37 were equivalent to abundances between 0 and 20 kg/ha, in 14 hauls between 20 and 100 kg/ha, and in three hauls between 100 and 200 kg/ha. Figure 8 shows that the productive catches were made within roughly the same depth range as in previous months, and corresponded to a considerably higher average abundance.

During other cruises, hake were caught as far south as Bahía de Yavaros off the Sonora coast and Isla del Carmen off the Baja California coast, but in abundances never greater than 4 kg/ha.

Table 2 summarizes the hauls and corresponding abundances of hake in the northern Gulf. On the sea floor at depths below 180 m, the mean abundance was considerably higher in February–March 1972 than during the preceding summer. Mathews (in preparation) proposes a migration pattern consistent with this fact. Table 3, showing the catch rates (kg/h) for large hake (more than 45 cm in total length) during this exploratory fishing, suggests that during February–March it might support a commercial fishery.

TABLE 2

Frequency of occurrence of catches corresponding to different abundances of hake in the northern Gulf of California

Abundance level (kilograms per hectare)	June 1971	Number of catches: June 1971 eliminating 60 hauls at less than 180m	August–September 1971	February–March 1972
None	80	28	30	9
0.2–20	20	12	27	37
20–100	5	5	3	14
100–200	0	0	0	3
Total	105	45	60	63

TABLE 3

Catch of hake more than 45 cm in total length

	Catch rate (kilograms per hour)	Maximum length (centimeters)
June 1971	80.7	94
August 1971	11.1	84
February–March 1972	343	107

The total biomass of hake in the northern Gulf during each cruise period can be estimated by multiplying the mean abundance in each depth zone by the area of sea floor in that zone. Table 4 shows the results of such a calculation. Since the mean abundance as shown above is highest at depths between about 180 and 370 m, most of the hake biomass in the northern Gulf appears to occur between these depths.

However, reviewing the whole body of data while writing this paper, and noting that in February–March out of ten hauls made at or above 180 m, eight yielded abundances of 0.2–20 kg/ha, it seems possible

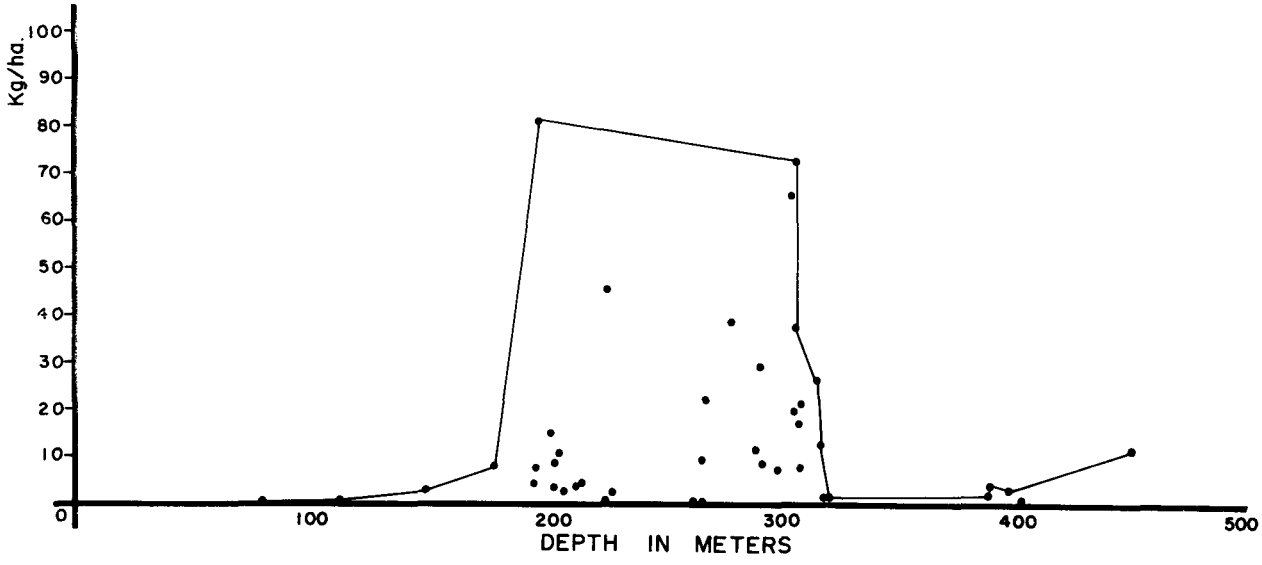

FIGURE 8. Depth of hauls and abundance of hake in the northern Gulf of California, February–March 1972.

that further testing of the productivity of the shallow portions of the shelf is warranted.

Estimates of mortality based on approximately 900 pairs of otoliths taken between June 1971 and March 1972 indicate that natural mortality (M) is about 0.29

TABLE 4

Estimated biomass of hake north of Isla Tiburón and Isla Ángel de la Guarda

Depth (meters)	Mean abundance (kilograms per hectare) June 1971	Aug–Sept 1971	Feb–Mar 1972	Area (thousands of hectares)	Biomass (metric tons) June 1971	Aug–Sept 1971	Feb–Mar 1972
147–183	1.6	0.6	4.6	312	500	200	1,400
184–366	10.6	4.4	36.2	679	7,200	3,000	24,600
367–549	3.8	2.6	7.0	305	1,200	800	2,100
Total	--	--	--	--	8,900	4,000	28,100

for females and 0.47 for males. Assuming that harvesting would occur mainly in the season of maximum biomass (February–March, Table 4) and that the maximum yield would be obtained when the fishing mortality is adjusted to equal the natural mortality (Gulland 1970, p. 2) then the maximum would be between:

$$0.29 \times 0.5 \times 28000 = 4060 \text{ metric tons.}$$
$$\text{and } 0.47 \times 0.5 \times 28000 = 6580 \text{ metric tons.}$$

The mean of about 5000 tons is the best available estimate pending further study of the stock.

2. LANGOSTINO *(Pleuroncodes planipes)*

Langostino was widely distributed in the Gulf south of Isla Tiburón, but has not been found north of the island. The highest concentrations were found off the coast of Sonora between Isla San Pedro Mártir and Guaymas (Figures 9–12). From Guaymas to Bahía de Topolobampo catches were smaller. From Bahía de Topolobampo to Mazatlán, usually less than 50 individuals were obtained in a catch and south of Mazatlán, catches were very low. Figures 13 and 14 show the distribution in April–May and November respectively from Bahía de Yavaros to Mazatlán.

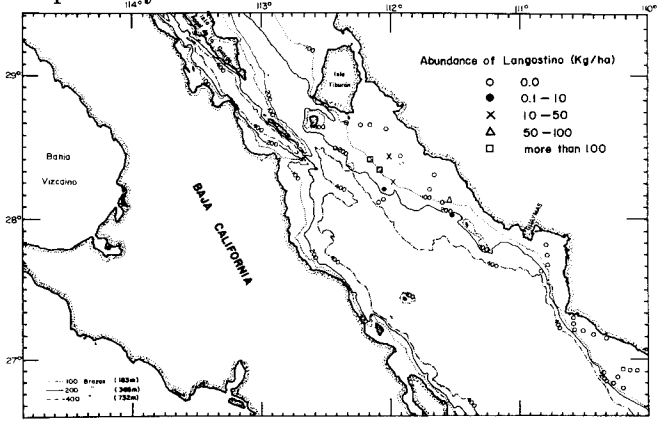

Figure 9. Location of hauls and abundance of langostino between Isla Tiburón and Guaymas, June 1971.

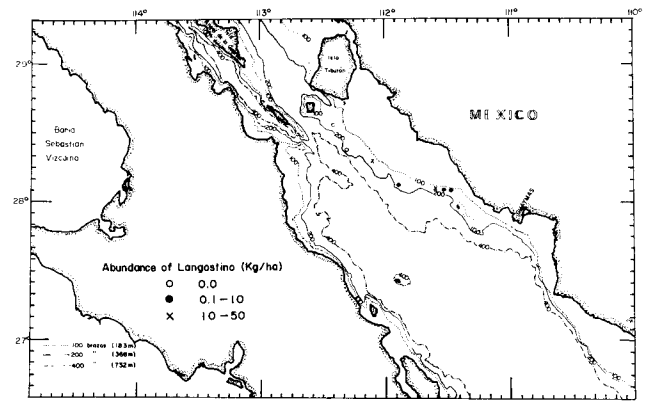

Figure 10. Location of hauls and abundance of langostino between Isla Tiburón and Guaymas, August 1971.

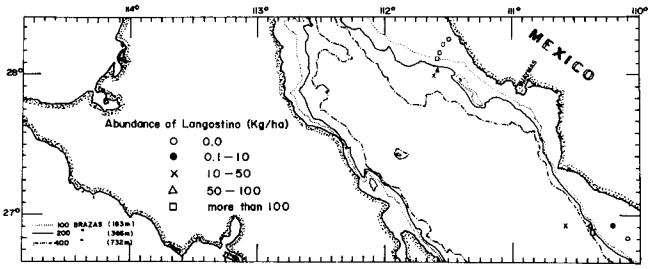

Figure 11. Location of hauls and abundance of langostino near Guaymas, December 1971.

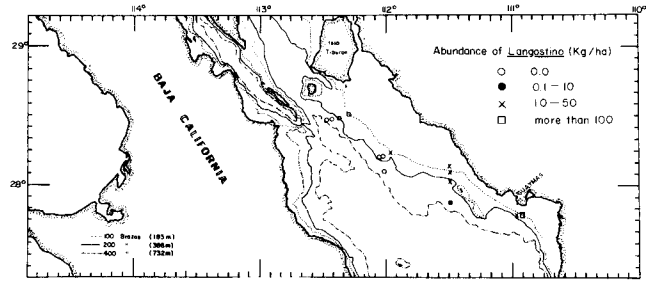

Figure 12. Location of hauls and abundance of langostino between Isla Tiburón and Guaymas, February–March 1972.

Table 5 shows the calculated abundances corresponding to catches made at different depths in each of the seasonal cruises in the area between Isla Tiburón and Bahía de Yavaros. The largest number of catches yielding large abundances were made in December and June. In December and June, 10 catches were made (out of a total of 14 productive hauls) yielding abundances greater than 70 kg/ha. No catch was made in any other month yielding an abundance greater than 27 kg/ha. Only in December did the catches suggest large populations at depths greater than 370 m. One catch (abundance between 10 and 50 kg/ha) in December was made at more than 700 m. In January 1972 a single catch in shallow water (75 m) corresponded to an abundance of more than 400 kg/ha. Further work is necessary to define the depth distribution of langostino. In the area south of Bahía de Yavaros only four catches were made

corresponding to abundances greater than 10 kg/ha. All were at depths less than 370 m (Figures 13 and 14).

In Figures 13 and 14, positions are also plotted at which the trawl brought up solid material or objects, such as sediment, waterlogged and decaying wood and decaying bones accompanied by readily evident hydrogen sulfide. Figures 15, 16 and 17 show hydrographic data, including temperature, salinity, and dissolved oxygen concentration in December along a section northwest of Isla San Pedro Nolasco (Figure 11). Between the surface and the sea floor at 500 m the temperature decreases a great deal, and the rate of decrease is especially rapid between about 50 and 100 meters, showing that vertical mixing at this level is slow. Partly as a result, the dissolved oxygen concentration below 300 m is very low, less than 0.5 ml per liter of sea water. The numbers along the sea floor are related to the abundance of langostino

TABLE 5

Numbers of catches and abundances of langostino between Isla Tiburón and Bahía de Topolobampo at different depths and seasons [1]

Depth (meters)	June 1971 (36 hauls) 0–180	180–370	370–730	September 1971 (7 hauls) 0–180	180–370	370–730
Abundance (kilograms per hectare)						
Negligible	22	3	4	0	2	0
0.1–10	0	1	1	0	3	0
10–50	1	1	0	0	2	0
50–100	1	0	0	0	0	0
More than 100	1	1	0	0	0	0

Depth (meters)	December 1971 (10 hauls) 0–180	180–370	370–730	Feb–March 1972 (14 hauls) 0–180	180–370	370–730
Abundance (kilograms per hectare)						
Negligible	2	0	1	1	3	3
0.1–10	1	0	0	0	0	1
10–50	0	0	2	2	2	1
50–100	0	0	1	0	0	0
More than 100	1	2	0	0	1	0

[1] For locations see Figures 9, 10, 11 and 12.

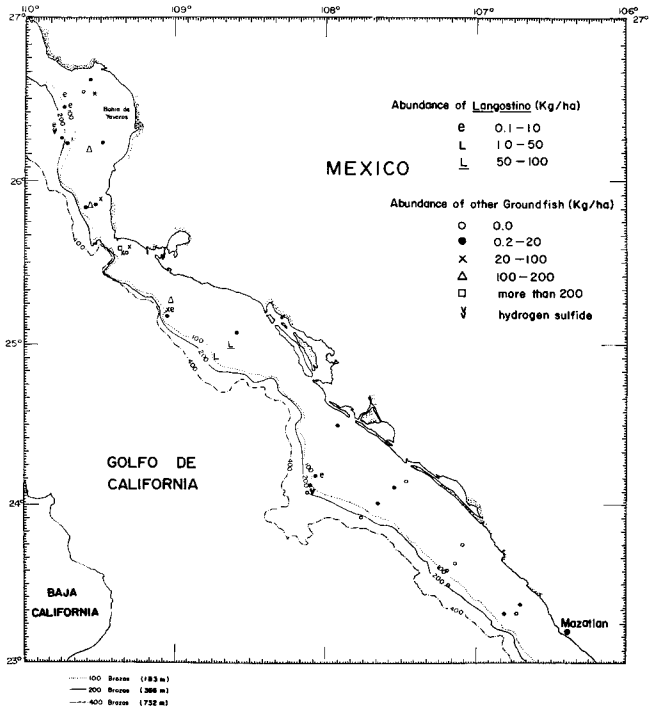

Figure 13. Location of hauls and abundance of mixed groundfish and langostino, Bahía de Yavaros to Mazatlán, April and May 1971.

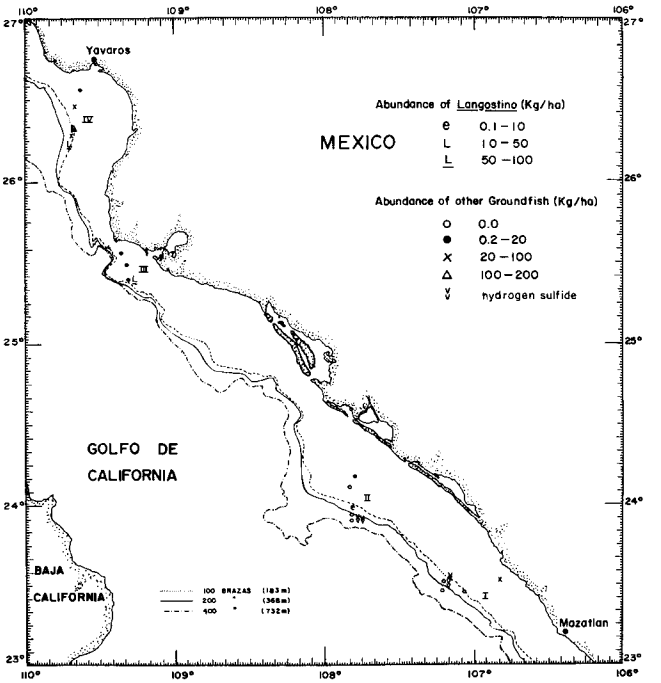

Figure 14. Location of hauls and abundance of mixed groundfish and langostino, Bahía de Yavaros to Mazatlán, November–December 1971.

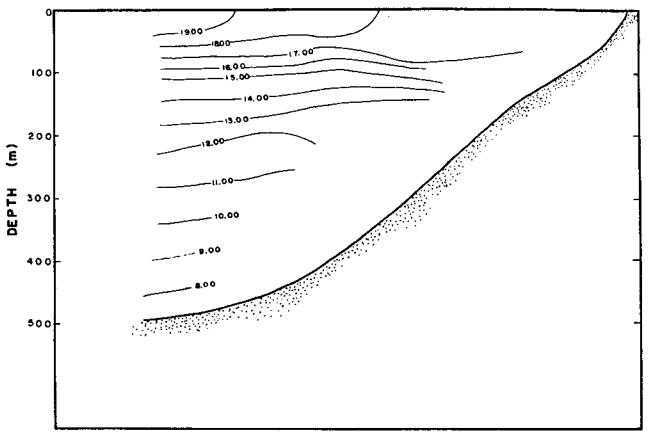

Figure 15. Temperature (centigrade) in a section northwest of Isla San Pedro Nolasco (see Figure 11) December 1971.

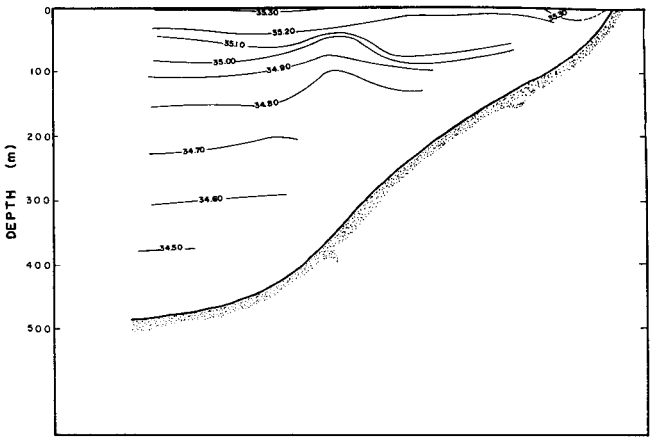

Figure 16. Salinity (parts per thousand) in a section northwest of Isla San Pedro Nolasco (see Figure 11) December 1971.

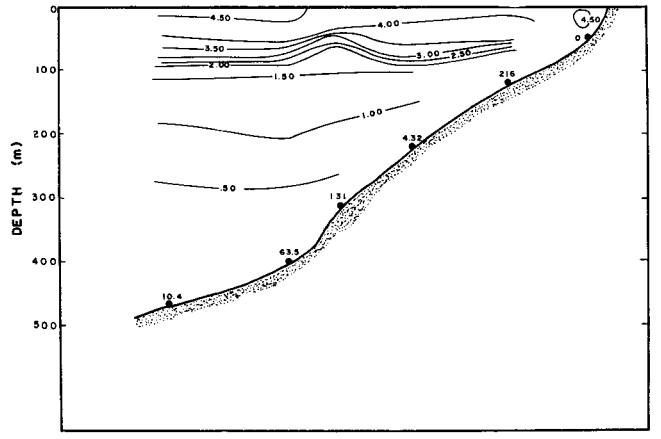

Figure 17. Dissolved oxygen (milliliters per liter) in a section northwest of Isla San Pedro Nolasco (see Figure 11) December 1971. Numbers on the sea floor show abundance of langostino, kg/h.

derived from those catches. The abundances in this set of catches are largest at intermediate depths and oxygen concentrations. The range of salinities is small and unlikely to be critical. The temperature range is large and the temperature at both the least and the greatest depths may be unfavorable and may therefore in part control the depth distribution of langostino. It is also natural to regard the very low oxygen concentrations as limiting. However, as Figures 13 and 17, and Table 5 show, catches of langostino were made at depths greater than 370 m in the southern Gulf (see also Figures 9, 11, and 12). Oxygen concentrations as low as 0.1 ml per liter have been observed in a considerable body of water between 400 and 800 m between the latitudes of Bahía de Yavaros and Guaymas (Roden 1964, Mathews and Granados, in preparation). This is discussed further below. It seems possible that langostino tolerates oxygen concentrations much lower than do many other organisms.

Size frequency distributions were obtained on two samples of langostino taken from catches in June 1971. The samples were small and the size frequency distribution irregular but the modal body length in both samples was close to 54 mm. During February–March 1972 collections were made off the Pacific coast of Baja California between Bahía de Asunción and

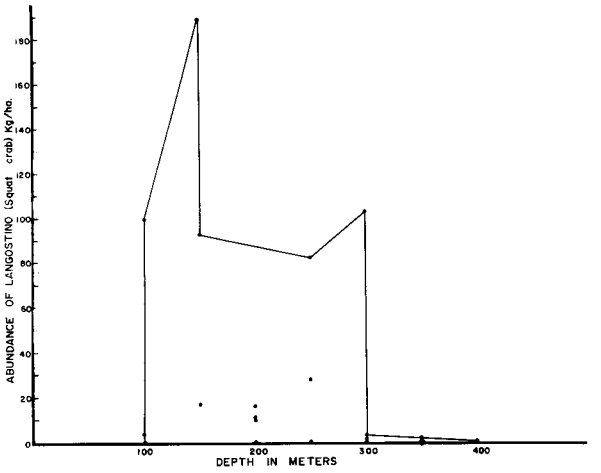

Figure 18. Depth of hauls and abundance of langostino in Pacific waters between Bahía de Asunción and Cabo San Lucas, February and March 1972.

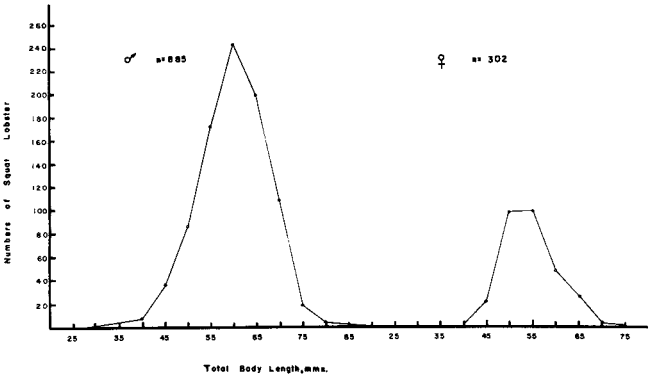

Figure 19. Size frequency distribution of male and female langostino taken in Pacific waters, February and March 1972.

Cabo San Lucas. Figure 18 shows that abundances were high and all of the productive catches were in water no deeper than 300 meters. The size distribution frequency for males and females separately was obtained on samples of all catches as shown in Figure 19. The modal length for males appears to be 60 mm, and for females it lies between 50 and 55 mm. The modal length for the Gulf samples and the mean of the two modal lengths for the Pacific samples are close. The sex ratio for the Pacific catches was 2.8 males to 1 female in January–February and nearly the same in October.

3. GROUNDFISH

Groundfish other than hake or langostino were taken throughout the length of the Gulf in considerable quantities. Tables 6, 7, and 8 show the abundances obtained at different seasons and depths in the north-

TABLE 6

Estimated biomass of groundfish other than hake and langostino north of Isla Tiburón, June 1971

Depth (meters)	Number of hauls	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
0–183	44	23	3,230	74,500
184–366	16	16.2	679	10,800
367–549	5	7.4	305	2,300
Total	65	--	--	87,100

TABLE 7

Estimated biomass of groundfish other than hake and langostino north of Isla Tiburón, August 1971

Depth (meters)	Number of hauls	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
0–146	0	--	2,918	67,300[1]
147–183	7	33.8	312	10,500
184–366	38	13.8	679	9,400
367–549	10	15.8	305	4,800
550–914	1	11.4	79	900
Total	56	--	--	92,900

[1] Assuming that the abundance at 0–183 m equalled that in June (23 kg/ha).

ern Gulf. The highest abundances were found in February–March and were concentrated in the shallowest areas. Table 9 summarizes the information for the other areas surveyed. In general abundances were lower than in the northern Gulf, especially in deeper water. South of Bahía de Yavaros the decline in catches in deep water is especially noticeable. In Figures 13, 14, 20, 21, and 22 the locations of hauls and abundances of groundfish are indicated.

For the areas south of Isla Tiburón, where mixed groundfish abundance varies little with season and for which few data are available, an average figure has been chosen to represent abundance the whole year round. Table 9 shows the calculated total biomass for these areas. The total biomass in the areas listed in Table 9 was 62000 mt, of which 59000 were concentrated in the first 183 m.

TABLE 8

Estimated biomass of groundfish other than hake and langostino north of Isla Tiburón, February–March 1972

Depth (meters)	Number of hauls	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
0– 78	0	--	1,790	174,000[1]
79–183	5	97.8	1,440	140,000
184–366	33	28.6	679	19,500
367–549	6	7.8	305	2,400
Total	44	--	--	335,900

[1] Assuming that the abundance at 0–78 m equalled that at 79–183 m.

TABLE 9

Estimated biomass of groundfish other than hake and langostino in the Gulf of California

Area	Depth (meters)	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
Isla Tiburón to Guaymas	0–183	20	480	9,600
	184–366	10	206	2,100
	367–549	2	206	400
Guaymas to Bay of Yavaros	0–183	20	686	13,700
	184–366	10	69	700
	367–549	2	103	200
Topolobampo shelf	0–183	30	206	6,200
Topolobampo shelf to C. Corrientes	0–183	10	2,813	28,100
	184–366	0	412	0
	367–549	0	--	0
Bay of La Paz	0–183	10	137	1,400
	184–366	0	69	--

Total biomass (metric tons) in various depths:

0–183 m	59000
184–360 m	2800
367–549 m	600
Total	62400

No data are presently available for estimating any of the population parameters of the mixed groundfish stock; in the absence of such data it is suggested that the sustainable yield is unlikely to be less than 0.2 or more than 0.5 of the biomass. Using these

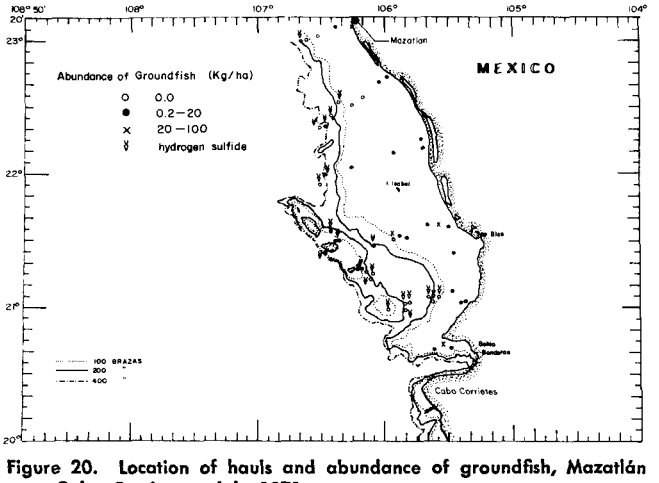

Figure 20. Location of hauls and abundance of groundfish, Mazatlán to Cabo Corrientes, July 1971.

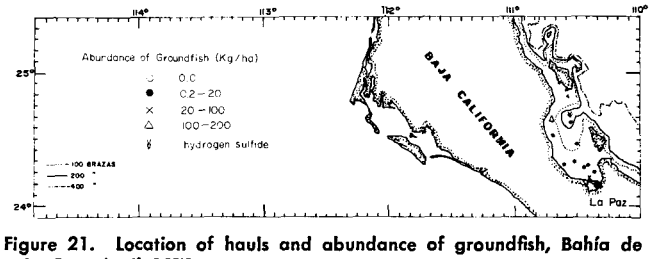

Figure 21. Location of hauls and abundance of groundfish, Bahía de La Paz, April 1971.

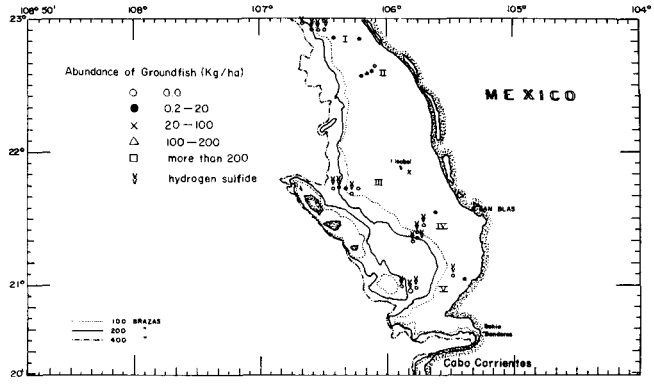

Figure 22. Location of hauls and abundance of groundfish, Mazatlán to Cabo Corrientes, November 1971.

figures, it is possible to estimate the yield from the Gulf of California groundfish. It is assumed that any fishery would be concentrated on these stocks during the period of highest abundance. It is further assumed that an estimated yield of less than 1000 mt would be of no commercial interest; this assumption holds if the groundfish are principally intended for reduction, but may require revision if a substantial fraction of the fish caught could be destined for human consumption. Table 10 shows that the total yield is likely to lie between 73000 and 186000 mt. Of this nearly 90% would be obtained from the area north of Isla Tiburón.

TABLE 10

Estimated potential yield of the Gulf of California groundfish other than hake and langostino (metric tons per year)

	North of Isla Tiburón	Isla Tiburón to Guaymas	Guaymas to Yavaros	Topolobampo Shelf	Topolobampo to Cabo Corrientes
Biomass above 183 m	314,000[1]	9,600[2]	13,700[2]	6,200[2]	28,100[2]
Minimum estimated yield	62,000	1,900	2,700	1,200	5,600
Maximum estimated yield	157,000	4,800	6,900	3,100	14,000
Minimum estimate for the whole Gulf	--	73,000	--	--	--
Maximum estimate for the whole Gulf	--	186,000	--	--	--

[1] Season of maximum biomass (February to March) from Table 8.
[2] From Table 9.

It is instructive to compare the figures given in Table 10 with the commercial production of groundfish in the Gulf of California. Attention is drawn to the largest component, i. e. to the bycatch. An extensive study of the bycatch of the Gulf of California shrimp fishery (Anon) is available based on 1117 trawls carried out in the months of July and August. Of these trawls 80% were carried out from 0–36 meters and the rest from 36–90 meters; only a very few were carried out below 73 meters, which may be regarded as the usual limit for the commercial shrimp fishery in the Gulf of California. As a result of this study, Chávez (personal communication) suggests that the best estimate of the ratio of the bycatch to the shrimp catch is 5:1 by weight. In 1971, statistics provided by the Secretaría de Industria y Comercio show that shrimp landings in Baja California and Sonora totalled 8300 mt and landings in Sinaloa and Nayarit totalled 15300 mt. Using Chávez's ratio, the corresponding bycatches are shown in Table 11.

TABLE 11

Geographical distribution of calculated bycatches and estimated potential yields of groundfish other than hake and langostino (metric tons per year)

Calculated bycatches		Estimated potential yields		
			minimum	*maximum*
B. Calif. and Sonora	41,500	North of Yavaros	66,600	169,000
Sinaloa and Nayarit	76,000	Topolobampo and south	6,800	17,100
Total (rounded)	117,000		73,000	186,000

The calculated bycatch for the whole Gulf is well within the range of the estimated yields. However the ratio of the bycatches separately calculated from the shrimp landings in the northern and southern Gulf states does not compare well with the estimated potential yields in the northern and southern Gulf (Table 11). This disparity suggests that a considerable fraction of the landings in southern parts may have been taken in the northern Gulf, or alternatively altogether outside of the Gulf.

DISCUSSION

As previously noted, in the southern section of the Gulf, many hauls brought up from the sea floor decaying organic matter smelling of hydrogen sulfide. Hydrographic samples from deep water had low concentrations of dissolved oxygen. Table 12 shows in a

TABLE 12

Abundance of groundfish, presence of hydrogen sulfide in sediments, and oxygen content of water at different depths (samples taken along section V in Figures 23 and 24)

Soundings (meters)	Hydrogen sulfide in sediments	Abundance of groundfish (kilograms per hectare)	Oxygen concentration	
			Sample depth (meters)	milliliters per liter
57	–	1.5	40	2.62
146	+	0	140	0.3
270	+	0	243	<0.3
341	+	0	340	<0.3
457	+	0	433	<0.3

+ present.
– absent.

section off Pta. Raza (see section V in Figure 22) that at 40 meters the oxygen concentration was 2.6 ml/liter and at 140 meters and below, it was not more than 0.3 ml/liter (the lowest value that could be

read with the available equipment). Figure 23 shows that the oxygen concentration decreased sharply from above 4.0 ml/liter at 20 to 40 meters to less than 1.0 ml/liter at 70 to 80 meters. Figure 24 shows one of the hydrographic features related to this distribution, namely a temperature decrease of 10°C in the upper 60–70 meters. Since the salinity changed only 0.4‰ in this layer, the temperature drop was necessarily accompanied by a great increase in density with

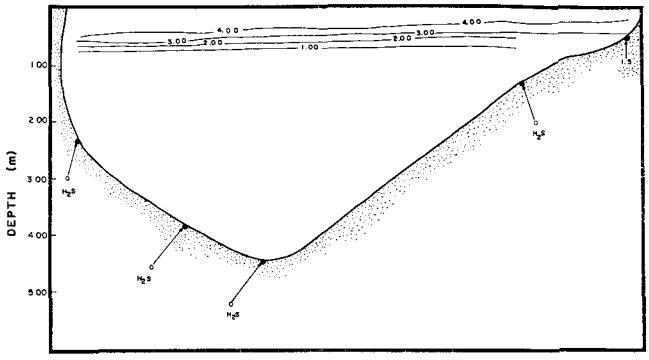

Figure 23. Dissolved oxygen (milliliters per liter) in a section off Pta. Raza (section V in Figure 22). The number and dot on the sea floor indicate the abundance (kg/ha) of groundfish found at that depth. The other labels indicate the presence of hydrogen sulfide in material from the sea floor.

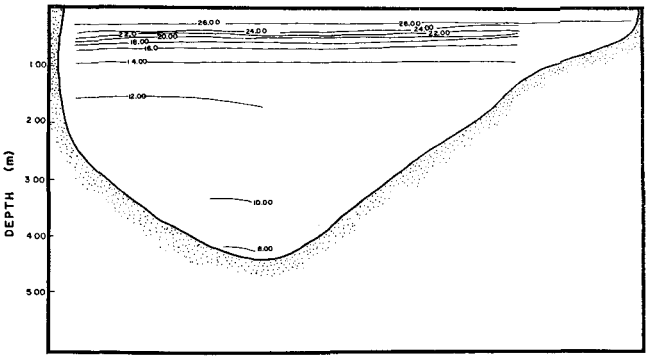

Figure 24. Temperature (centigrade) in a section off Pta. Raza (section V in Figure 22).

depth, and hence by very slow vertical mixing. The other important hydrographic feature is the water in the depths of the southern Gulf, which is part of a great body of such cool and oxygen-poor water in the eastern tropical Pacific (Roden 1964, Wyrtki 1966).

Table 12 and Figure 23 show at 57 m a modest catch of groundfish, with negligible catches below, while at each of the greater depths the trawl brough up matter smelling of hydrogen sulfide. Absence of fish, low oxygen concentrations in the water, and anaerobic decay in the sediments (producing hydrogen sulfide) are correlated throughout the Gulf. Table 13 shows the greatest depths at which hauls for groundfish were successful in localities surveyed, from the area north of Isla Tiburón to the area between Mazatlán and Cabo Corrientes. Proceeding from north

TABLE 13

Greatest depths at which groundfish were taken in localities from north to south in the Gulf of California

Locality	Date	Maximum depth (meters)
North of Isla Tiburón	June 1971	not less than[1] 400
North of Isla Tiburón	Aug–Sept 1971	not less than 550
North of Isla Tiburón	Feb–Mar 1972	not less than 400
Isla Tiburón to Guaymas	June 1971	not less than 400
Isla Tiburón to Guaymas	Sept 1971	not less than 300
Isla Tiburón to Guaymas	Feb–Mar 1972	not less than 400
Guaymas to Bahía de Yavaros	May 1971	not less than 450
Bahía de Yavaros	May 1971	not less than 200
Topolobampo shelf	May 1971	not less than 100
Altata to Mazatlán	April 1971	not less than 200
Pta. Piaxtla to Pta. Raza	Nov 1971	not less than 100
Mazatlán to Cabo Corrientes	July 1971	not less than 800[2]
Bahía de La Paz	April 1971	not less than 100

[1] "Not less than" means that catches were made down to this depth, but no deeper hauls were attempted. In all other cases, hauls were made at greater depths but catches were negligible.
[2] Catches were negligible between 200 and 700 meters. Moderate catches were made at 700 and 800 meters, and a haul at 1000 meters was unproductive.

to south the trend is upwards, that is fish are taken only in shallower and shallower water. This trend also appears in Table 9 where the abundances of groundfish decrease to the south, especially below 183 meters. While during the November and December cruises there was some trouble in measuring low oxygen concentrations aboard ship, the results were consistent with information on the distribution of dissolved oxygen in the Gulf available from other sources (Roden 1964, Scripps Institution 1965). Table 14 summarizes a pertinent aspect of this distribution as observed during four months in 1957. It is clear that the upper limit (defined as <1.0 ml per liter, Wyrtki, 1966) of the layer of oxygen-poor water slopes upward toward the mouth of the Gulf. During the cruises of the ALEJANDRO DE HUMBOLDT it was observed that in no case where the water close to the sea floor was found to have an oxygen content significantly higher than 0.3 milliliter per liter was hydrogen sulfide detected in a trawl in the same locality.[a]

As shown by Roden (1964) and the 1957 cruises by Scripps ships (Scripps Institution 1965) in the southern Gulf over a considerable area, a layer several hundred meters thick, e.g., between the depths of 400 and 800 m) contains less than 0.1 milliliter per liter of oxygen. Below this, slightly higher concentrations are found. While langostino can perhaps tolerate conditions within the layer, and there were observed in the present surveys two small to moderate catches of groundfish at 700 and 800 m (Table 13), for fishes valued commercially at the present time, the deeper waters of the southern Gulf do not appear promising.

[a] Since writing this paper one of us (CPM) has participated in a cruise on the R/V ALEXANDER AGASSIZ during which 10 trawls were carried out with a small otter trawl net, the foot rope of which was ~ 11 feet (3.35 m) long. Hydrocasts were taken at some localities where trawls were carried out. The results obtained confirmed the correlation between low O_2 concentrations and very low or zero fish catches. Sediment samples were taken with a box core by Mr. A. Soutar, and showed that H_2S did not appear in the sediments above depths of ~ 30–35 cm, nor did it appear outside of the zone where the O_2 minimum intersected the bottom.

TABLE 14

Least depth at which dissolved oxygen was less than 1.0 ml/liter

Station lines		Scripps Institution of Oceanography cruises 1957							
Number	Location (approximate)	February 5702	[a]	April 5704	[a]	June 5706	[a]	August 5708	[a]
108	N. of I. de la Guarda	--	--	--	--	X500	1	--	--
109	N. of I. de la Guarda	--	--	X200	1	--	--	X200–300	3
110						X250	1		
113	Between I. de la Guarda	--	--	X800	1	--	--	X100–700	4
114	and I. Tiburón	--	--	--	--	X1000	1	X800	1
115				X300–800	2				
116	S. of I. Tiburón	600	1	--	--	--	--	--	--
117	S. of I. Tiburón	X200–250[b]	3	--	--	--	--	--	--
121	S. of Guaymas	150–200	3	--	--	--	--	--	--
127		150–400	4	150–300	5	200–300	5	300	3
139	N. of I. del Carmen	75–200	4	100–150	4	200–250	5	250–300	5
145	Opposite La Paz	75–150	4	--	--	--	--	--	--
151	Opposite Altata	75–150	6	75–150	6	75–150	6	150–200	6
157	N. of Mazatlán in the	--	--	75–150	5	50–100	5	100–150	5
160	open Pacific	75–100	5	75–150	5	--	--	--	--

[a] These columns show the number of stations occupied on that line in that month. When there was more than one station occupied in a line, the two numbers show the shallowest and deepest observations. There was a tendency for the surface of the layer of low oxygen content to be shallower on the east side of the Gulf, so that the number on the left usually characterizes the area trawled.

[b] The X indicates that at all depths down to the greatest depth (or depths) sampled, as shown, the oxygen content was greater than 1.0 milliliter per liter.

ACKNOWLEDGEMENTS

We are particularly grateful to Mr. R. C. Lockerman of the U.S. National Oceanographic Data Centre of N.O.A.A., for his advice and assistance; we are also very grateful to Mr. B. C. Bedford, Fisheries Laboratory, Lowestoft, for much advice and invaluable assistance during work both at sea and in the laboratory. Biol. H. Chávez has also been very helpful to us.

Of course we are responsible for any errors this work may contain. Of the many others who helped us carry out our work we wish to single out Captain F. Hernández Ascencio of the R/V ALEJANDRO DE HUMBOLDT, and Ingeniero Adolfo Torres May of the Superintendencia de Buques in Mazatlán. Without their invaluable support most of what we did would not have been done.

We also wish to acknowledge the assistance of Dr. G. L. Kesteven, then Project Manager, and Dr. M. Ruivo, Fisheries Division at FAO in Rome, whose efforts made it possible to carry out this work.

REFERENCES

Anon. 1969. Informe de desarrollo de trabajo. *Inst. Nat. Inv. Biol. Pesq.*, (2). *Programa de Fauna de Acompañamiento de Camarón.*

Gulland, J. A. 1970. *In* J. A. Gulland (ed.) The fish resources of the ocean. *FAO Fish. Tech. Pap.*, (97). Food and Agriculture Organization of the United Nations, Rome.

Roden, Gunnar I. 1964. Oceanographic aspects of Gulf of California, p. 30–58. *In* T. H. van Andel and G. G. Shor, Jr. (eds.) Marine geology of the Gulf of California. *Am. Ass. Petrol. Geol., Memoir*, (3) : 1–408.

Scripps Institution of Oceanography of the University of California. 1965. Oceanic observations of the Pacific: 1957. Univ. Calif. Press, Berkeley.

U.S. Naval Oceanographic Office. 1970. Instruction manual for obtaining oceanographic data. 3rd ed. *U.S. Govt. Print. Off., Wash., D.C.* v.p.

Wyrtki, Klaus. 1966. Oceanography of the eastern equatorial Pacific Ocean, p. 33–68. *In* Harold Barnes (ed.) Oceanography and marine biology: an annual review, *4*. George Allen & Unwin Ltd., London.