PERUVIAN HAKE FISHERIES FROM 1971 TO 1982[1]

MARCO A. ESPINO
Instituto del Mar del Perú
Apartado 22
Callao, Perú

CLAUDIA WOSNITZA-MENDO
Programa Cooperativo Peruano-Alemán de Investigación Pesquera
Deutsche Gesellschaft für Technische Zusammenarbeit
Instituto del Mar del Perú
Apartado 22
Callao, Perú

ABSTRACT

Past estimates of Peruvian hake biomass calculated by the swept-area method have left some doubts about the size of the stock. With the available monthly catch statistics from 1971 onwards, quarterly age-length keys, and estimates of natural mortality, we applied a cohort analysis that shows much lower biomass estimates than those obtained by the swept-area method. This cohort analysis indicates that spawning stock biomass has been in serious decline since especially heavy exploitation in 1978. Peruvian hake stocks are expected to recover after the 1982-83 El Niño because of light exploitation and possibly good recruitment. A yearly catch of about 100,000 metric tons is proposed; this is much lower than previous estimates of sustainable yield. A yield-per-recruit analysis supports this contention.

RESUMEN

Las estimaciones de biomasa de la merluza peruana obtenidas en los últimos años mediante el método de area barrida han dado resultados dudosos con respecto a la dimensión del stock. En base a la estadística disponible de la pesca mensual desde 1971 en adelante y las claves tamaño-edad, además de los estimados de mortalidad natural, se aplicó el análisis de cohortes que mostró una biomasa mucho menor que aquella obtenida por el método de área barrida. Este análisis de cohortes muestra que la biomasa del stock desovante ha declinado peligrosamente desde la excesiva explotación del año 1978. Se espera que el stock de la merluza peruana se restablezca después de El Niño 1982-83, debido a la escasa explotación y posiblemente al buen reclutamiento. Se propone una pesca anual de 100.000 tons que es mucho menor que las estimaciones anteriores del rendimiento sostenible. Además un análisis de rendimiento por recluta corrobora esta suposición.

INTRODUCTION

The Peruvian hake *(Merluccius gayi peruanus)* is distributed over the continental shelf and farther offshore to more than 500-m depth. As the most abundant demersal species in the Peruvian coastal ecosystem, hake is important both commercially and ecologically. Furthermore, the dynamics and life history of the Peruvian hake may have parallels with the Pacific hake *(Merluccius productus)*.

The Peruvian hake grows slightly faster and attains a larger size than the Pacific hake. The Peruvian hake spawns in the austral winter-spring months of August to October over the continental shelf. Fish are recruited to the fishery at age 2 and mature at about age 3 (35 cm). Juveniles are pelagic. However, in contrast to the Pacific hake, adults are demersal and are fished with bottom trawls, whereas Pacific hake are fished mostly with midwater trawls (Bailey et al. 1982).

Before 1972, Peruvian hake was harvested mainly by the coastal demersal fleet off Paita in northern Peru (about 5°S), and catches fluctuated around 20,000 metric tons (MT) annually. In 1973 an intensive fishery by foreign high-seas fleets began (Table 1). Catches of hake reached their highest levels (303,000 MT) in 1978, when the stock apparently changed its habitat from demersal to semipelagic and became accessible to the national purse seine fisheries as well.

In past years, various estimates of Peruvian hake biomass have been made from bottom trawl surveys but have left doubts about the results.

To obtain a better estimate, we applied cohort

TABLE 1
Catches of Peruvian Hake

	Paita (N. Peru) *Coastal fleet* (Metric tons)	Total Peru *Including high-seas fleet* (Metric tons)
1971	24,000	26,000
1972	7,695	12,580
1973	36,386	132,856
1974	20,862	109,318
1975	14,307	84,898
1976	10,230	92,872
1977	5,833	106,799
1978	10,645	303,495
1979	8,163	92,954
1980	8,165	159,376
1981	14,581	64,026
1982	—	33,000*

*Preliminary data

[Manuscript received November 5, 1985.]

[1]Publication No. 25 of the Cooperative Peruvian-German Fisheries Research Project (PROCOPA)

analysis (Pope 1972) using catch data from the 12 years between 1971 and 1982.

METHODS

The equations used to calculate stock in number *(N)* and fishing mortality rate *(F)* were the following (Pope 1972):

$$N_i = (C_i + N_{i+1}e^{M/2})\, e^{M/2} \quad (1)$$

$$F_i = \ln\left(\frac{N_i}{N_{i+1}}\right) - M \quad (2)$$

where C = catch in number, and
where M = natural mortality rate.

The number of the oldest year class was calculated as:

$$N_t = \frac{C_t}{F_t/(F_t/M)}$$

Natural mortality *(M)* was estimated using the equation from Pauly (1980):

$$\mathrm{Log}_{10}M = -0.0066 - 0.279\ \mathrm{Log}_{10}\ L_\infty + 0.6543\ \mathrm{Log}_{10}K + 0.4634\ \mathrm{Log}_{10}\bar{T}$$

where L_∞ is the asymptotic length (total length, in cm),
K is a growth constant of the von Bertalanffy growth equation; and
$\bar{T}$ is the annual mean temperature (°C) of the water in which the stock lives.

Applying this formula and using the growth parameters from Misu and Hamasaki (1971), we got $M = 0.2$ for females and $M = 0.4$ for males. Using the former estimates, we obtained biomass values for males two times higher than for females.

Because these figures seemed to be unrealistic, and because equal natural mortality for both sexes (at least in the younger age-groups) should be assumed, we used the mean value of $M = 0.3$. This value led to more balanced abundances in age-group II, although some differences remained (Table 2). A value of $M = 0.3$ is similar to values used for other hake stocks around the world (Francis 1983; Terré 1984).

We determined ages by reading otoliths collected from the Paita area. It should be mentioned, however, that for the first years of the study relatively few otoliths existed. Therefore, we established quarterly age-length keys for each year of investigation, taking them as representative of the age distribution of the monthly catch. We also assumed that the high-seas fleet catch had the same age composition as the Paita fleet catches; this assumption appears to be acceptable based on existing length frequencies of the high-seas fleet catches. The annual catch by age for the two sexes is demonstrated in Figure 1. N and F matrices were calculated separately for each sex because of their different growths and terminal lengths.

Preliminary runs indicated a fishing mortality rate of 1.0 for females of age-group V and VI. From this we chose a provisional terminal F of 0.5 and 1.0 for females and males, respectively, supposing that the older age-groups suffer less fishery mortality (Beverton and Holt 1957, p.81).

RESULTS (Table 2)

Biomass, Number of Spawning Stock, and Recruits

Until 1978, there is a continuous increment in biomass; later it diminishes (Figure 2). The total biomass fluctuates between a maximum of 630,500 MT in 1978 and a minimum of 130,000 in 1982; the latter is possibly an underestimation due to the scarce landings made in this El Niño year.

Observing the number of two-year-old recruits (Table 3), we note very low values in the last three years despite a certain underestimation of the 1982 value as explained above. The very good recruitment of the 1974 year class was probably due to the more favorable environmental conditions for hake following the 1972 El Niño (Wosnitza-Mendo and Espino. The impact of "El Niño" on recruitment in the Peruvian hake [*Merluccius gayi peruanus*]. In review.)

Analysis of the Instantaneous Rate of Fishing Mortality (F)

The mean F value for both males and females was low in the first two years (Figure 3), when the stock was being exploited only by the coastal fleet. From 1973 on, with the beginning of the heavy fishery, F for males increased until 1978, at which time it reached 2.08. F diminished in 1979 (1.30) and reached its maximum values in 1980 (2.35) and 1981 (2.48). The latter values are a result of a fishery on a depleted stock at levels higher than sustainable equilibrium yields. In the case of the females, F was maintained between 0.51-0.96 until 1979; in 1980 it reached its maximum (2.14). The F's in females are due, fundamentally, to their higher longevity and presumably to the larger individuals concentrated in deeper water. Analysis of the variation of F values in each year (Figures 4 and 5) shows that in the first two years (1971-72) the main fishing effort was on age-group V (males). Because of the intensive fishery from 1973 on, and the depletion of

TABLE 2
Cohort Analysis of Peruvian Hake

M = 0.3; F_t = 0.5 (females) F_t = 1.0 (males)

Stock in Number (10^6)												
Females	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
II	161.7	171.2	146.2	165.2	192.2	460.3	222.8	187.4	116.0	80.1	76.1*	78.1*
III	73.9	119.8	126.8	100.1	122.2	141.8	340.7	161.7	137.5	81.4	58.1	19.4
IV	34.9	53.0	87.5	80.4	75.3	82.4	98.0	239.3	72.9	88.6	43.9	39.0
V	13.3	19.6	27.4	20.7	10.2	16.6	20.7	17.9	18.1	13.1	13.3	8.9
VI	10.2	7.8	7.2	3.8	3.9	2.4	4.4	7.5	6.3	5.2	1.2	1.3
VII	2.9	6.9	2.8	1.2	1.6	2.7	1.1	2.5	3.7	1.0	0.1	0.2
VIII	—	1.6	4.5	0.8	0.4	1.0	2.0	0.5	1.5	1.4	—	—
	296.9	379.9	402.4	380.2	405.8	707.2	689.7	616.8	356.0	270.8	192.7	146.9
Males												
II	244.8	271.1	233.1	203.5	220.6	616.4	298.6	295.9	211.8	129.6	94.3*	119.9*
III	63.7	181.3	200.8	172.3	150.1	162.8	456.0	215.5	215.8	154.5	94.9	36.9
IV	58.4	45.5	130.6	133.4	113.7	102.5	103.4	316.1	89.0	110.2	60.4	53.7
V	7.8	31.2	11.5	19.2	25.5	14.0	4.4	4.2	3.5	23.7	1.8	1.4
	374.7	529.1	576.0	528.4	509.9	895.7	862.4	831.7	520.1	418.0	251.4	203.9
Fishing Mortality Rates												
Females												
II	0.0003	—	0.0012	—	0.004	0.04	0.011	0.01	0.005	0.03	0.001*	0.02*
III	0.01	0.001	0.05	0.08	0.01	0.05	0.08	0.50	0.10	0.34	0.07	0.04
IV	0.30	0.13	1.13	1.12	1.33	1.36	1.31	2.60	1.03	1.85	1.59	0.82
V	0.37	0.17	1.10	1.88	0.94	1.38	0.91	0.76	0.73	1.84	2.58	1.41
VI	0.29	0.12	0.98	0.83	0.14	0.01	0.48	0.48	0.64	3.38	2.11	0.56
VII	0.29	0.12	0.98	0.83	0.14	0.01	0.48	0.48	0.64	3.33	2.11	0.56
F(III-VII)	0.25	0.11	0.85	0.95	0.51	0.56	0.65	0.96	0.63	2.14	1.69	0.68
Males												
II	—	—	0.0003	0.001	0.006	—	0.008	0.007	0.002	0.001	0.002*	0.002*
III	0.01	—	0.04	0.05	0.12	0.03	0.12	0.54	0.34	0.55	0.30	0.18
IV	0.68	0.21	1.86	1.42	1.67	2.03	2.62	4.45	2.56	4.77	4.38	1.21
V	1.40	0.28	0.68	1.26	0.42	0.94	1.16	1.24	0.99	1.73	2.77	1.00
F(III-V)	0.70	0.16	0.86	0.91	0.74	1.00	1.30	2.08	1.30	2.35	2.48	0.80
Biomass (10^3 MT)												
Females												
II	55.1	58.4	49.9	56.3	65.5	157.0	76.0	63.9	39.6	27.3	26.0*	26.6*
III	30.1	48.8	51.7	44.1	49.8	57.8	138.8	65.9	56.0	34.4	23.7	7.9
IV	19.8	30.1	49.6	45.6	42.7	46.7	55.6	135.7	41.3	50.2	24.9	19.4
V	11.3	16.6	23.2	17.5	8.6	14.1	17.5	15.2	15.3	11.1	11.3	6.7
VI	18.0	13.8	12.7	6.7	6.9	4.2	7.8	13.2	11.1	9.2	2.1	2.6
VII	6.9	16.5	6.7	2.9	3.8	6.5	2.6	6.0	8.9	2.4	0.2	0.5
VIII	—	4.6	13.8	2.5	1.2	3.1	6.1	1.4	4.6	7.4	5.0	—
	141.2	188.8	207.6	175.6	178.5	289.4	304.4	301.3	176.8	142.0	93.2	63.7
Males												
II	70.3	77.9	67.0	58.5	63.4	177.1	85.8	85.0	60.9	37.2	27.1*	32.2*
III	24.1	68.5	76.0	65.2	56.8	61.6	172.5	81.5	81.6	58.4	35.9	11.4
IV	27.7	21.6	62.0	63.2	54.0	48.7	49.1	150.2	42.3	52.4	28.7	22.0
V	4.6	18.4	6.8	11.3	15.0	8.2	2.6	2.5	2.1	14.0	1.1	0.7
	126.7	186.5	211.8	198.2	189.2	295.6	310.0	319.2	186.9	162.0	92.8	66.3

*Preliminary data

Continued on next page

TABLE 2 (continued)
Cohort Analysis of Peruvian Hake

$M = 0.3$; $F_t = 0.5$ (females) $F_t = 1.0$ (males)

Biomass (10^3 MT) (continued)												
Females + males	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
II	125.4	136.3	116.9	114.8	128.9	334.1	161.8	148.9	100.5	64.5	53.1*	58.8*
III	54.2	117.4	127.7	109.3	106.6	119.4	311.3	147.4	137.6	92.8	59.6	19.3
IV	47.5	51.7	111.6	108.8	96.7	95.4	104.7	285.9	83.6	102.6	53.6	41.4
V	15.9	35.0	30.0	28.8	23.0	22.3	20.1	17.7	17.4	25.1	12.4	7.4
VI	18.0	13.8	12.7	6.7	6.9	4.2	7.8	13.2	11.1	9.2	2.1	2.6
VII	6.9	16.5	6.7	2.9	3.8	6.5	2.6	6.0	8.9	2.4	0.2	0.5
VIII	—	4.6	13.8	2.5	1.2	3.1	6.1	1.4	4.6	7.4	5.0	—
	267.9	375.3	419.4	373.8	367.7	585.0	614.4	620.5	363.7	304.0	186.0	130.0

*Preliminary data

older fish, the F values in age-group IV increased, showing extremely high peaks in 1978, 1980, and 1981. However, mesh size regulations were increased from 70 to 90 mm in 1980, and thus since 1981 F has increased on older ages.

For the females, we note a uniform exploitation rate on age-groups IV, V, VI, and VII in the first three years (Figure 5). Between 1974 and 1979, the exploitation rate is very high on age-groups IV and V, especially for age-group IV in 1978. After 1980 the pattern changes because of the increase in mesh size and increasing F values for age-groups V, VI, and VII.

Yield per Recruit

Results of the cohort analysis make it possible to calculate the yield per recruit by taking the F value of

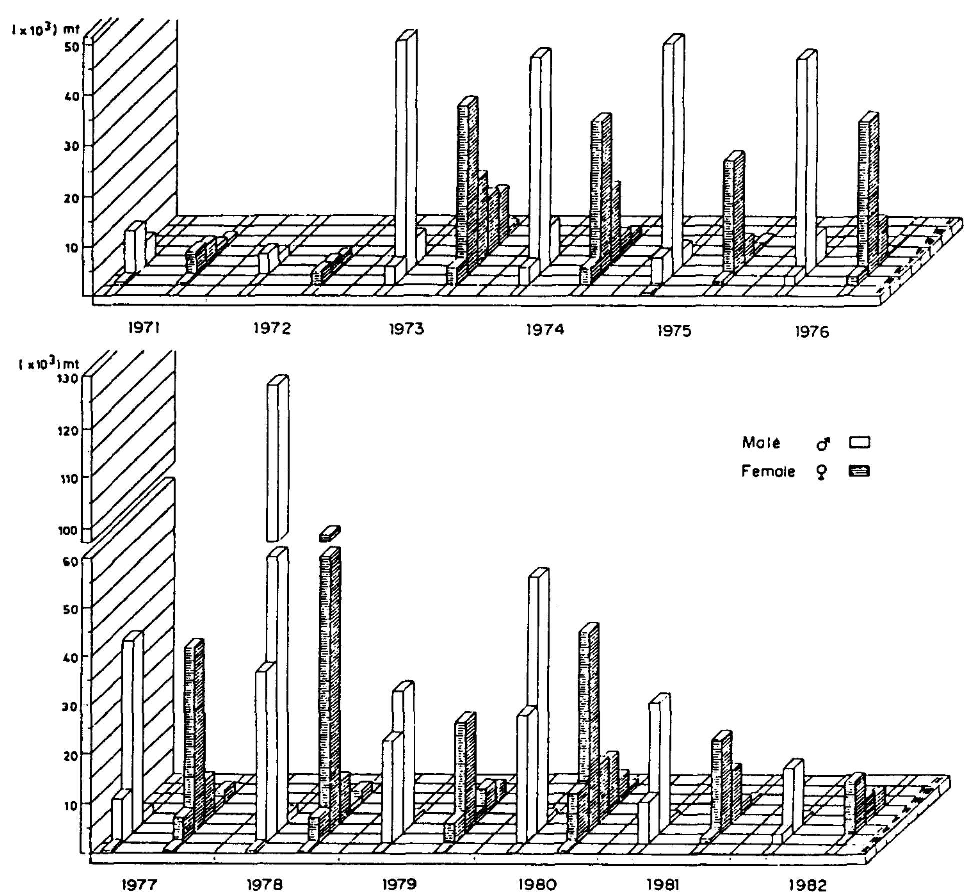

Figure 1. Annual catch by age distribution by sexes of Peruvian hake (*Merluccius gayi peruanus*).

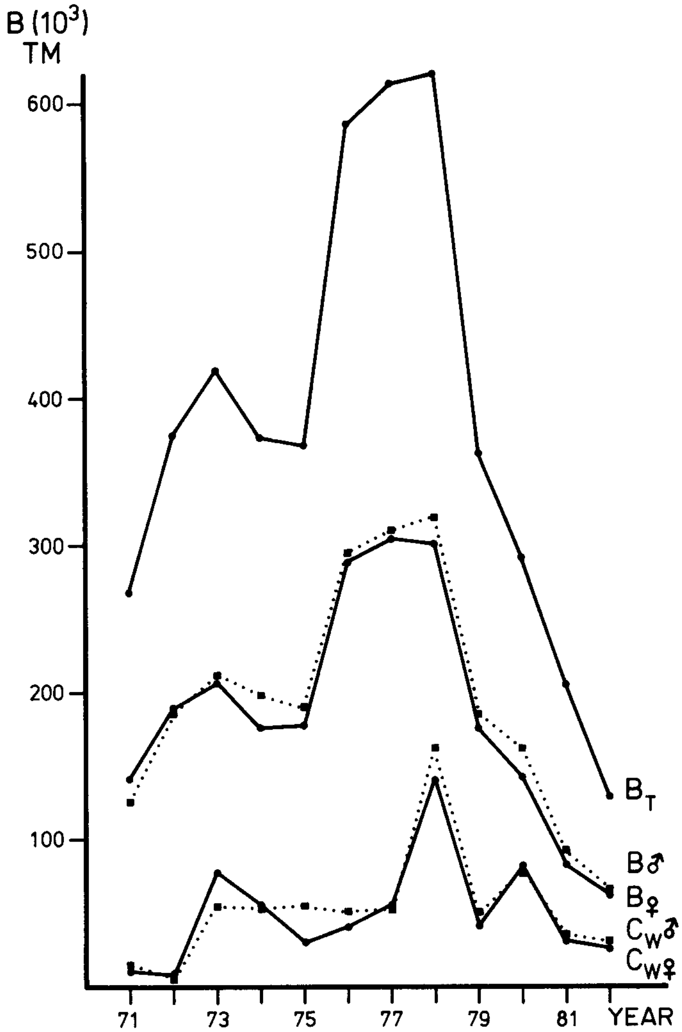

Figure 2. Variation of catches (Cw) and biomass (B) of Peruvian hake, 1971-82.

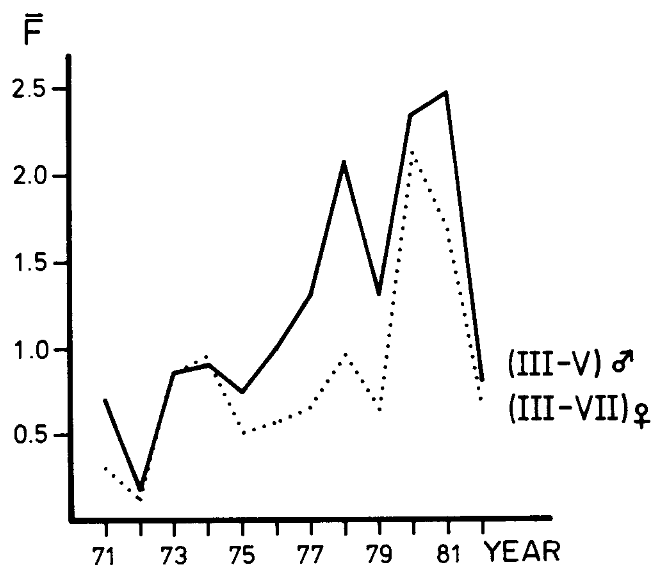

Figure 3. Annual variation of fishing mortality (F̄) for Peruvian hake, 1971-82.

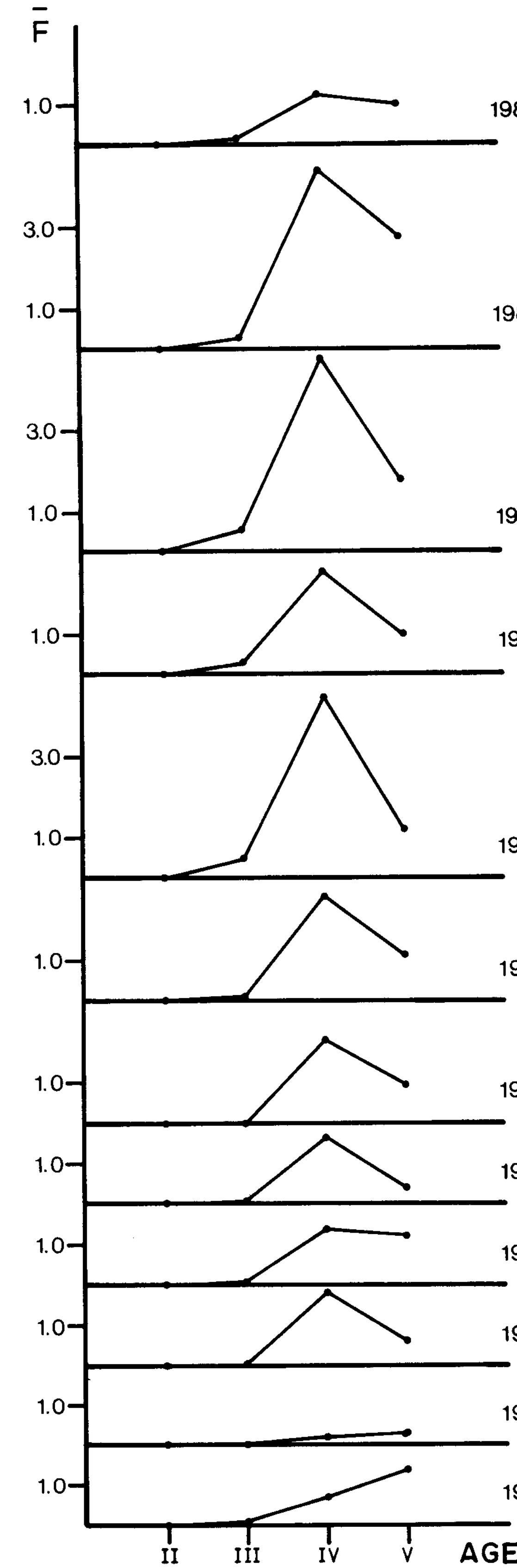

Figure 4. Variation of fishing mortality rate (F̄) for males, 1971-82.

TABLE 3
Number of Two-Year-Old Recruits

	N (II) (Millions)
1971	406.5
1972	442.3
1973	379.3
1974	368.7
1975	412.8
1976	1,076.7
1977	521.4
1978	483.3
1979	337.8
1980	209.7
1981	170.4
1982	198.0

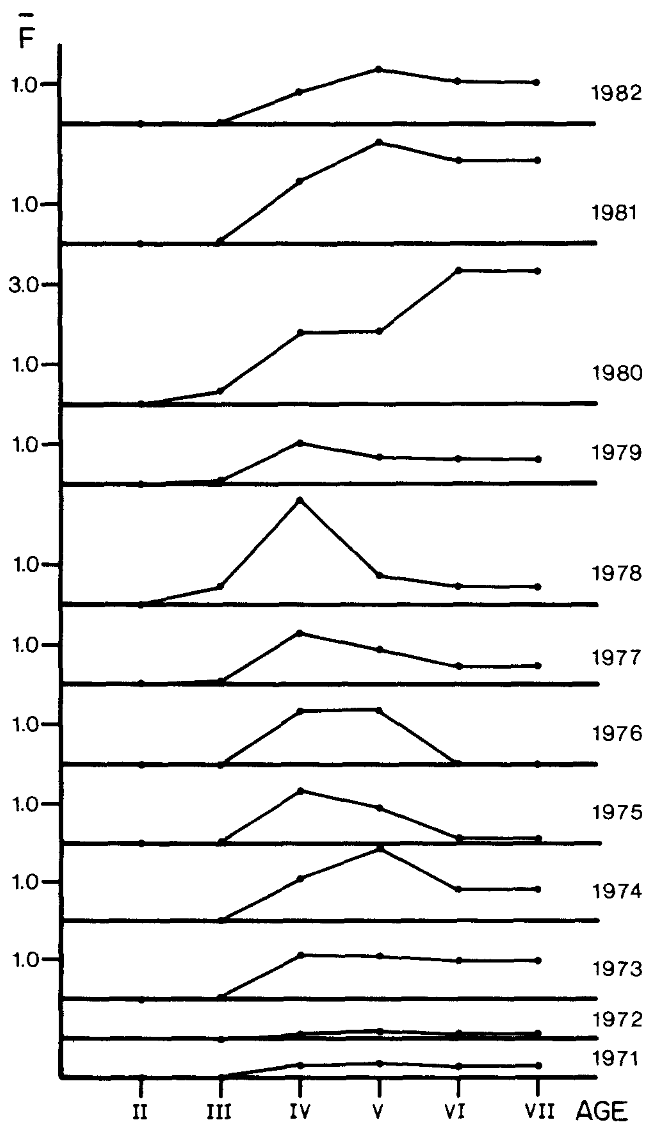

Figure 5. Variation of fishing mortality rate (F̄) for females, 1971-82.

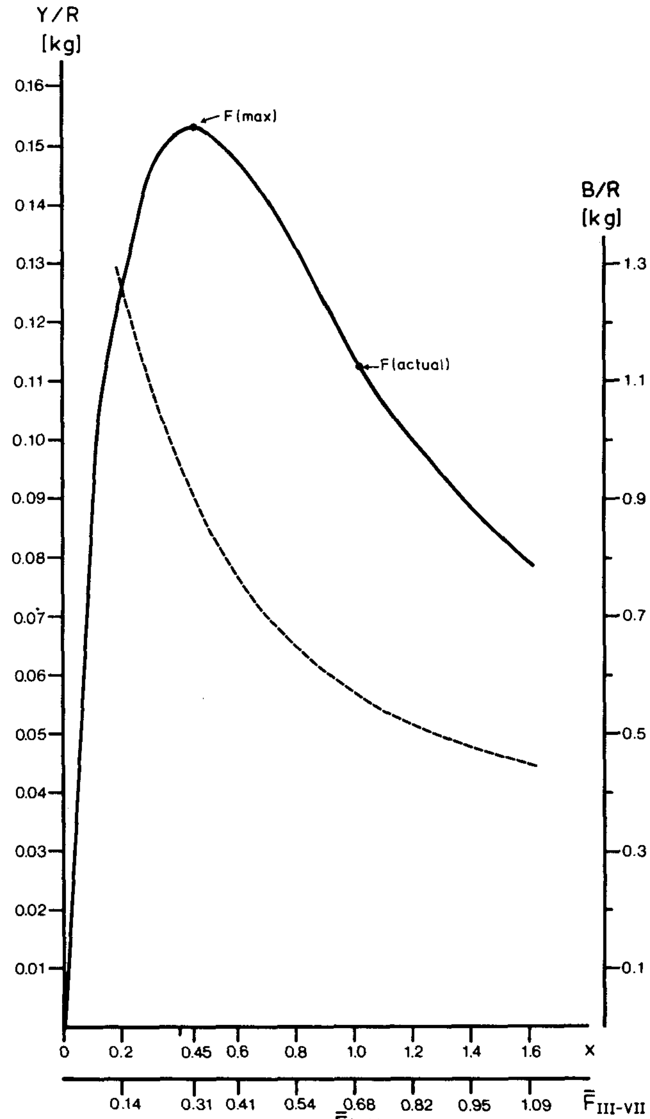

Figure 6. Yield per recruit for females (———). Biomass per recruit for females (-----).

the last year (1982) for each age-group as 100%. M is a constant of 0.3. The calculations were made with a unit of 1,000 recruits, leading to yield per recruit for different values of F (Figures 6 and 7). In both sexes, we observe that the actual (1982) F value is much higher than the value needed to obtain the maximum yield. The actual F value for males is 0.80 (age-groups III-V), whereas the optimal F should be 0.48, which would mean a 40% decrease in fishing effort. For females, the actual F is 0.68 (age-groups III-VII) and should be 0.31 (55% lower).

Because fishing mortality is directly correlated with fishing effort, this would indicate a considerable decrease in fishing effort. But a direct reduction of effort would cause serious socioeconomic consequences; we therefore recommend that the minimum mesh size

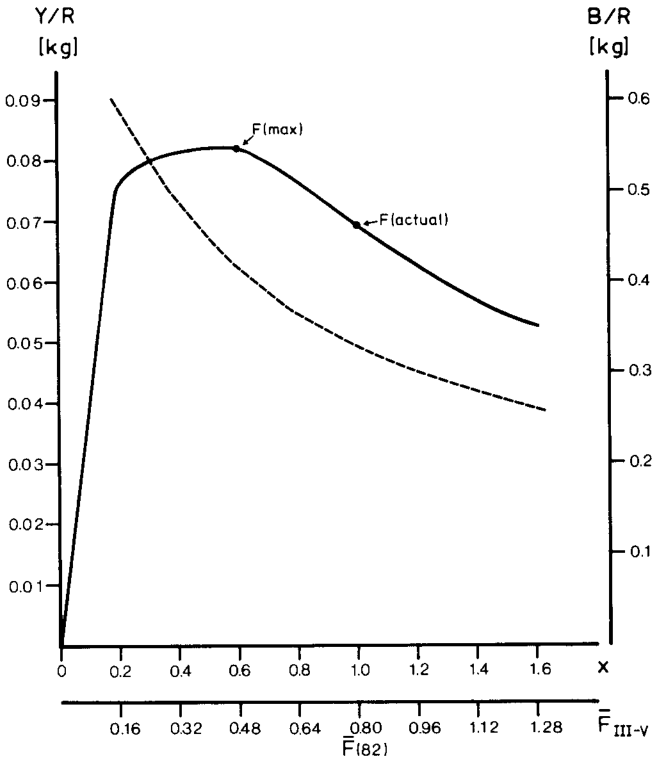

Figure 7. Yield per recruit for males (———). Biomass per recruit for males (-----).

be increased to at least 110 mm. A similar measure was taken in the South African hake fishery in 1974 (Wysokinski 1976). Environmental conditions like El Niño may also act to preserve the stock. In 1982-83 the stock was apparently unavailable to the fishery, because landings did not exceed 33,000 MT.

Exploitation Rate

Because we find very different distribution and concentration of fish stocks off Peru during so-called normal and abnormal years of El Niño, existing production models are not so useful for estimating the equilibrium yield. Therefore, we have taken the catches of "normal" years (1973-76 and 1979) from Table 1 to calculate an average equilibrium yield of 103,300 MT and a biomass of 454,000 MT. This gives us an equilibrium exploitation rate of "*E*" calculated as $\bar{C}/\bar{B}$ of about 0.25 with 95% confidence limits between 0.16 <"*E*" <0.36.

The variation of "*E*" (Figure 8, Table 4) shows low values for the first two years and excessive exploitation in 1978 and 1980. The high exploitation rate in 1978 is a result of the purse seine fishery of the anchovy fleet off Chimbote (9°S); in July and August this fleet concentrates in the spawning area. The high 1980 "*E*" value reflects an effort too high in relation to the already overfished stock.

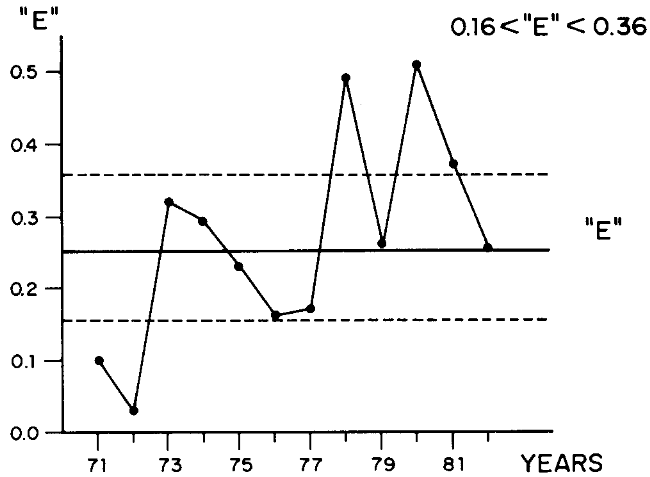

Figure 8. Variation of equilibrium exploitation rate "E" from 1971 to 1982.

DISCUSSION

The Peruvian hake stock between 1971 and 1982 showed marked variability in abundance from highs of 614,000 and 620,000 MT in 1977 and 1978 to lows of less than 200,000 MT in recent years. Whereas the high levels of stock biomass appear to be due to strong recruitment, the decline in biomass seems to result from overexploitation of the resource and relatively poor recruitment. Recruitment dynamics of Peruvian hake are quite marked, varying by some sixfold over a 12-year period. This pattern of great changes in recruitment from year to year is also observed in the Pacific hake (Francis 1983). Strong year classes are especially important to the fishery, as exemplified by the 1974 year class, which constituted about 50% of the stock biomass in 1977-78.

There are several sources of potential error in this study. The cohort analysis may underestimate stock biomass if the initial *F* values are too large. But we believe that using monthly runs minimizes the error. We have done some simulations and found that applying monthly runs and using, for example, F_t = 1.0

TABLE 4
Biomass and Equilibrium Yield for Peruvian Hake (in 1,000 Metric Tons)

	Biomass	Yield (*C*) (from Table 1)
1973	419.4	132.9
1974	373.8	109.5
1975	367.7	84.9
1976	585.0	92.5
1977	614.4	106.8
1979	363.7	92.9
	$\bar{B}$ = 454.0	$\bar{C}$ = 103.25

"*E*" = $\bar{C}/\bar{B}$ = 0.23

instead of 0.5 yields an underestimate of the biomass of 7.4% in the first year and less than 1% in the following years. Applying annual runs yields an underestimate of about 38.5% in the first year, and about 8% and 4% in later years (Wosnitza-Mendo, in prep.)

A second source of underestimation of biomass might be a smaller M than the real one (Terré 1984). Apart from applying Pauly's method, we used the production model of Csirke and Caddy (1983) as described in Espino and Wosnitza-Mendo (1984) in order to determine M values that are independent from growth parameters. Because in the first two years of investigation (1971 and 1972) only the coastal fishery and no open-sea fishery existed, we assumed that the Z values for these years approached natural mortality (M). M for these years was about 0.3, indicating that our former estimate of M is realistic. Another source of potential error would be a difference in age composition of the foreign high-seas catch and the coastal demersal catches; however, from bottom trawl surveys, we believe that little difference exists.

Our results indicate that the previous estimates of hake abundance based on swept-area methods are very likely too high. The last surveys resulted in estimates of 1-2 million MT (except for "Humboldt" cruise 8103-04 which resulted in an estimate of 600,000 to 800,000 MT using a catchability coefficient for the net of 0.75). The former estimates did not determine confidence limits, did not employ stratification for the area, and used extremely low catchability coefficients of 0.25. From these results it is apparent that FAO's (1978) proposed potential production of 200,000 to 250,000 MT of Peruvian hake cannot be attained. With the expected recovery of the hake stock after the 1982-83 El Niño, we recommend a yearly catch of 100,000 MT assuming "normal" conditions. This could be slightly raised later on and will unavoidably diminish during other El Niño events.

ACKNOWLEDGMENTS

We want to thank Kevin Bailey for review of the biological aspects of this manuscript, and an anonymous scientist for review of the cohort analysis.

LITERATURE CITED

Bailey, K.M., R.C. Francis, and P.R. Stevens. 1982. The life history and fishery of Pacific whiting, *Merluccius productus*. Calif. Coop. Oceanic Fish. Invest. Rep. 23:81-98.

Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. Ser. II 19:533.

Csirke, J., and Caddy, J.F. 1983. Production modeling using mortality estimates. Can. J. Fish. Aquat. Sci. 40:43-51.

Espino, M., and C. Wosnitza-Mendo. 1984. El uso del modelo de Csirke/Caddy para la merluza peruana (*Merluccius gayi peruanus*). Bol. Inst. Mar Perú-Callao 8(5):191-205.

FAO. 1978. Report of the technical consultation on the Latin American hake industry, held in Montevideo, Uruguay, 24-28 October 1977, FAO Fisheries Report 203.

Francis, R.C. 1983. Population and trophic dynamics of Pacific hake (*Merluccius productus*). Can. J. Fish. Aquat. Sci. 40:1925-1943.

Misu, H., and S. Hamasaki. 1971. Age and growth of Peruvian hake, *Merluccius gayi* (Guichenot). Bull. Seikai Reg. Fish. Res. Lab. 41:93-106.

Pauly, D. 1980. On the interrelationship between mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Conseil 39(2):175-192.

Pope, J.G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northeast Atl. Fish. Res. Bull. 9:65-74.

Terré, J. 1984. Some aspects of the Cape hake stock in ICSEAF division 1.5. ICSEAF 1984 (Part II). Colln. Scient. Pap. Int. Commn SE Atl. Fish. 11:61-73.

Wysokinski, A. 1976. Revised estimates of equilibrium yield for the hake stock using the Beverton-Holt method. ICSEAF, 1976 Colln. Scient. Pap. Int. Commn. SE Atl. Fish 3:187-193.