

Mean Monthly Distribution, Abundance and Production of Anchoveta Eggs off Peru (4-14°S), 1964-1971 and 1972-1986*

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Abstract

This contribution is based on the detailed analysis (resolution: half-degree squares) of 90 maps of anchoveta (*Engraulis ringens*) egg standing stock off Peru (4-14°S), published in 1987 by H. Santander (IMARPE, Callao, Peru). It pertains to surveys conducted from 1964 to 1986. Monthly means were computed for each half-degree square using 3x3x3 running averages, i.e., involving all adjacent squares of a given month and square, and the adjacent squares of the preceding and following months. Monthly maps of egg distribution are presented, averaged over the periods 1964 to 1971 and 1972 to 1986, which are the phases preceding and following the 1972-1973 El Niño and the coincident stock collapse, respectively.

It is shown that the center of gravity of anchoveta egg production has shifted to the south along the coast. Also, the relationship between the two egg production seasons (August-October, January-March) has changed: egg production was much higher in spring than summer from 1964 to 1971, but was, from 1972 to 1986, slightly higher in summer. Overall, mean daily egg production was reduced from about 3.13×10^{13} in 1964-1971 to about 2.2×10^{13} in 1972-1986.

Resumen

Esta contribución se basa en un análisis detallado (resolución: cuadrado de medio grado) de 90 mapas de producción de huevos de anchoveta (*Engraulis ringens*) frente a Perú (4-14°S), publicados en 1987 por H. Santander (IMARPE, Callao, Perú). Estos se refieren a prospecciones realizadas de 1964 a 1986. Los promedios mensuales fueron calculados para cada cuadrado de medio grado usando promedios móviles de 3x3x3; esto es, involucrando todos los cuadrados adyacentes de un determinado cuadrado y mes, y los cuadrados adyacentes del mes precedente y siguiente. Se presentan mapas mensuales de distribución de huevos, promediados para los períodos 1964 a 1971 y 1972 a 1986, que son las fases precedente y siguiente al Niño 1972-1973 y el coincidente colapso del stock, respectivamente.

Se muestra que el centro de gravedad de la producción de huevos de anchoveta se ha desplazado al sur. Asimismo, la relación entre las dos estaciones de producción de huevos (Agosto-October, Enero-Marzo) ha cambiado: la producción de huevos fué mucho mas alta en primavera que en el verano de 1964 a 1971, pero fue ligeramente mas alta en el verano de 1972 a 1986. En general, el promedio diario de producción de huevos se redujo de alrededor de 3.13×10^{13} en 1964-1971 hasta alrededor de 2.2×10^{13} en 1972-1986.

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Introduction

The anchoveta (*Engraulis ringens*) once supported off Peru the largest single-species fishery of the world (Tsukayama and Palomares 1987). The collapse of this fishery, coincident with the 1972-1973 El Niño, has been, in earlier years, attributed to this hydrographic anomaly but the data presently available suggest that the purse seine fishery was the main culprit (see Muck, this vol.). The need to better manage this resource makes it particularly important to identify the key factors which determine recruitment of anchoveta. The present study is concerned with a process most likely to belong to these factors: the apparent rate of production of eggs by the anchoveta stock. The word "apparent", which will be omitted henceforth, refers to the fact that the rates of egg production derived and presented further below do not account for egg mortality, which is covered by Pauly and Soriano (this vol.).

Also, the geographical distribution of this egg production will be presented. However, due to limitations of the available data, the pertinent maps will refer only to monthly 'climatological' averages for two periods - 1964 to 1971 and 1972 to 1986. This division of the available data into two sets was chosen to cover two crucial phases: one of high anchoveta biomasses, lasting from the beginning of egg survey work to the 1972-1973 El Niño, and of generally low, but highly variable biomasses, lasting from 1972 to 1986 (see Pauly and Palomares, this vol.).

Materials and Method

The present contribution, extracted from Senocak (1988), is based entirely on the 90 maps of egg distribution in Santander (1987), pertaining to the area off Peru comprised between 4 and 14°S and based on surveys conducted from 1964 to 1986. Santander (1987) provides details on these surveys. Of this information, only the map number, the year and the month are reported here (Table 1). Sampling was performed from 50 m to the surface with a Hensen net 175 cm long, 70 cm aperture diameter and 300 µm meshes.

Table 1. Within- and between-year availability of anchoveta egg distribution maps used for this contribution.^a
 Tabla 1. Disponibilidad dentro de años y entre años, de mapas de distribución de huevos de anchoveta usados en esta contribución.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total No. of maps
1964			1	2		3			4			5	5
1965			6	7			8				9		4
1966		10			11				12		13		4
1967					14				15		16		3
1968		17							18			19	3
1969	20						21		22				3
1970					23				24	25	26		4
1971					27			28			29		3
1972		30					31/32	33	34/35	36		37	8
1973	38		39			40/41	42	43	44		45		8
1974		46			47			48	49		50		5
1975		51						52	53			54	4
1976	55						56	57			58		4
1977			59	60			61	62/63		64/65			7
1978				66			67			68		69	4
1979		70					71		72		73		4
1980	74								75				2
1981		76		77					78	79			4
1982		80							81			82/83	4
1983													0
1984									84			85	2
1985		86	87					88	89				4
1986					90								1
Total No. of Maps	4	9	5	5	6	3	9	9	17	6	9	8	90

^a Numbers for different months and years refer to the map numbers in Santander (1987).

The original station records were not accessible to the authors; hence, this work is based on the maps of egg abundance assembled since 1964 by H. Santander and colleagues at IMARPE, of which all had been redrawn at ICLARM, Manila, using a base map and standardized labeling schemes (Table 2).

The surveys documented through Santander's maps did not all cover the investigation area as defined in Fig. 1. However, no large-scale interpolation or extrapolation were undertaken here to compensate for this deficit. Rather, strict rules were applied for small-scale (within half-degree square) interpolations (Fig. 2), i.e., larger areas not covered during a given survey were not included in any of the analyses.

Each half-degree square included in the analysis was divided up into 100 subunits and the egg abundance (d) estimated for each subunit, based in class means in Table 2.

Table 2. Class limits and assumed class means of anchoveta egg abundance maps in Santander (1987), in eggs/m².

Tabla 2. Límites de clase y clase media asumida de los mapas de densidad de huevos de anchoveta presentados por Santander (1987), en huevos/m².

First group of maps		Second group of maps ^a	
Class intervals	Means	Class intervals	Means
		1 - 100	50
1 - 500	250	101 - 500	300
501 - 1000	750	501 - 1000	750
1001 - 4000	2500	1001 - 2000	1500
>4000	5000 ^b	>2000	3000

^a Refers only to map nos. 8, 20-24, 28, 31 and 40.

^b Used here instead of 5013 in Santander (1987).

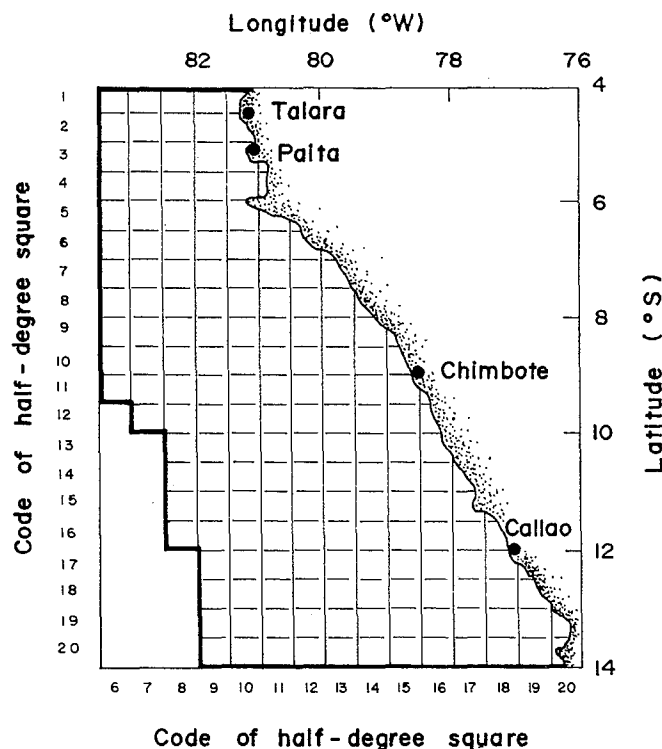


Fig. 1. Investigation area off Peru (4-14°S) showing towns mentioned in the text and numbering system for the 182 half-degree squares used to digitize information in the 90 egg distribution maps of Santander (1987). Area includes only half-degree squares covered during at least one egg survey from 1964 to 1986.

Fig. 1. Área de investigación frente a Perú (4-14°S), mostrando los lugares mencionados en el texto y el sistema de numeración para los 182 cuadrados de medio grado, usados para registrar la información de los 90 mapas de distribución de huevos reportados por Santander (1987). El área incluye sólo a los cuadrados de medio grado donde se realizó por lo menos una prospección de huevos de 1964 a 1986.

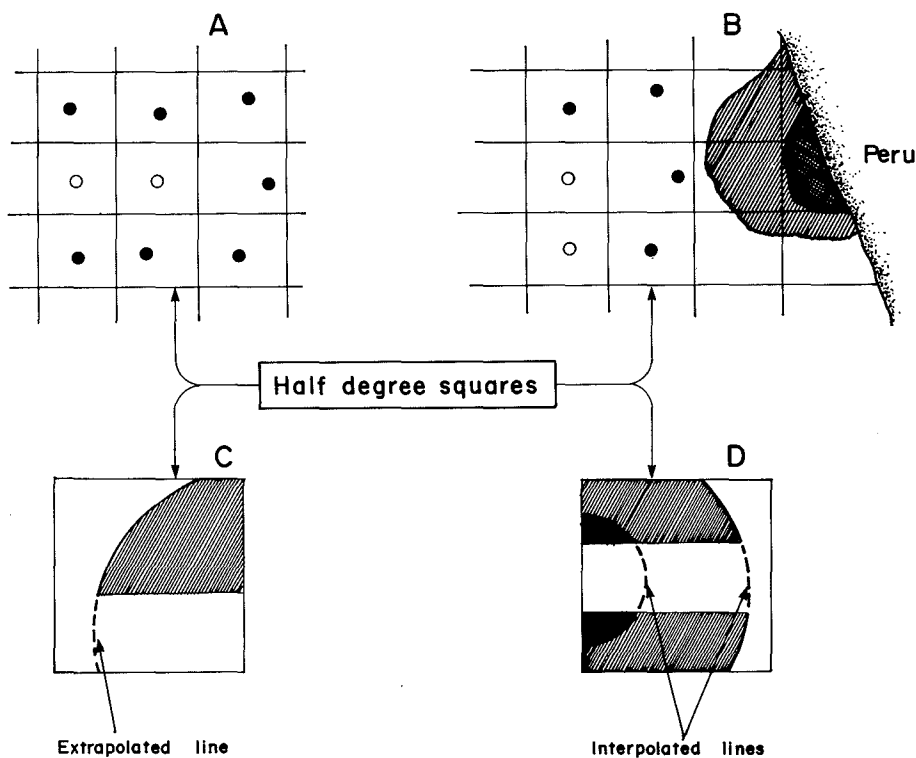


Fig. 2. Schematic representations of rules for interpretation of maps in Santander (1987). A: In cases where half-degree squares without observation (o) were surrounded by zero observation (•), the encircled squares were assumed to also contain a zero observation. B: When isolines of egg densities along the coast were clearly delimited by zero values, seaward squares without observations were assumed to contain no eggs. C and D: Interrupted isolines in maps, due to missing stations, were extrapolated or interpolated by eye, following the trend of the lines within the half-degree squares.

Fig. 2. Representación esquemática de reglas para la interpretación de los mapas de Santander (1987). A: En los casos donde el cuadrado de medio grado sin observación (o) está indicado por observación cero (•), se asume que el cuadrado circunscrito también contiene observación cero. B: Cuando las isolíneas de densidades de huevos a lo largo de la costa están claramente delimitadas por valores cero, se ha asumido que los cuadrados hacia la costa y sin observaciones tampoco contiene huevos. C y D: Las isolíneas interrumpidas en los mapas, debido a estaciones ausentes, fueron extrapoladas o interpoladas al ojo, siguiendo la tendencia de las líneas dentro del cuadrado de medio grado.

The mean abundance of eggs per m^2 (E_j) in a given half degree during a given survey and square (j) was then estimated from:

$$E_j = (\sum n_1 d_1) N_j^{-1} \quad \dots 1)$$

where N_j is the number of subunits in square (j), n_1 the number of subunits of a given egg abundance level (see Table 2), and d_1 the mean number of eggs per m^2 for that group of subunits. Note that directly under the coast, squares with $N < 100$ were rather frequent (see Fig. 1).

The estimated development time of anchoveta eggs were taken, for the years 1964-1982 from Table 3 in Santander (1987). For the following period, which lasted to the end of 1986, development time (D, in days) was estimated from

$$\log_{10} D = 6.953 - 4.09 \log_{10} (T + 26) \quad \dots 2)$$

where T is the sea surface temperature (SST, in $^{\circ}C$), and which was derived by Pauly (1987) from equation (5) in Pauly and Pullin (1988) and from empirical data in Santander and Sandoval de Castillo (1973). The temperature used to represent the Peruvian coast from 4 to $14^{\circ}C$ south for the years 1982-1986 are means of the monthly temperatures for Talara, Paita, Chimbote and Callao (see Table 2 and Figs. 3 and 4).

Table 3. Mean monthly sea surface temperature at Talara, Paita, Chimbote and Callao (Peru), 1984-1986, in °C.^a

Tabla 3. Promedios mensuales de la temperatura superficial del mar en Talara, Paita, Chimbote y Callao (Perú), 1984-1986 (en °C).

Month	Talara		Paita		Chimbote		Callao					
	1984	1985	1984	1985	1984	1985	1984	1985				
Jan	(19.9)	(18.9)	20.8	19.9	18.9	21.5	20.5	19.5	20.0	16.0	15.0	14.7
Feb	(23.5)	(21.0)	23.5	23.5	21.0	22.3	20.2	18.8	21.2	16.2	15.2	17.0
Mar	(22.5)	(22.7)	19.6	22.5	22.7	20.7	19.7	20.3	20.0	17.0	15.6	15.9
Apr	(19.8)	(19.5)	18.8	19.3	19.0	18.1	19.9	18.5	19.5	18.0	15.0	15.4
May	(18.0)	16.3	18.9	17.4	16.0	18.0	18.8	17.6	18.3	16.3	14.9	15.3
Jun	(17.6)	18.1	17.9	17.0	17.8	16.9	17.8	17.6	17.8	15.6	14.9	15.5
Jul	(17.1)	16.9	19.1	16.5	16.4	17.9	18.9	17.1	17.8	15.5	15.1	15.5
Aug	(16.9)	16.6	18.5	16.3	15.7	17.5	18.0	17.1	18.7	15.3	14.7	16.1
Sep	(17.1)	16.7	17.2	16.5	15.9	16.0	18.0	17.5	18.6	14.7	14.5	15.7
Oct	(17.1)	16.9	18.9	16.5	16.1	18.4	18.8	18.2	18.0	14.6	14.6	15.0
Nov	(17.6)	16.7	20.0	17.0	16.7	19.6	19.0	18.3	20.3	15.1	14.3	15.8
Dec	(17.6)	18.7	20.5	17.0	18.1	20.0	19.3	19.1	21.5	14.8	14.7	16.5

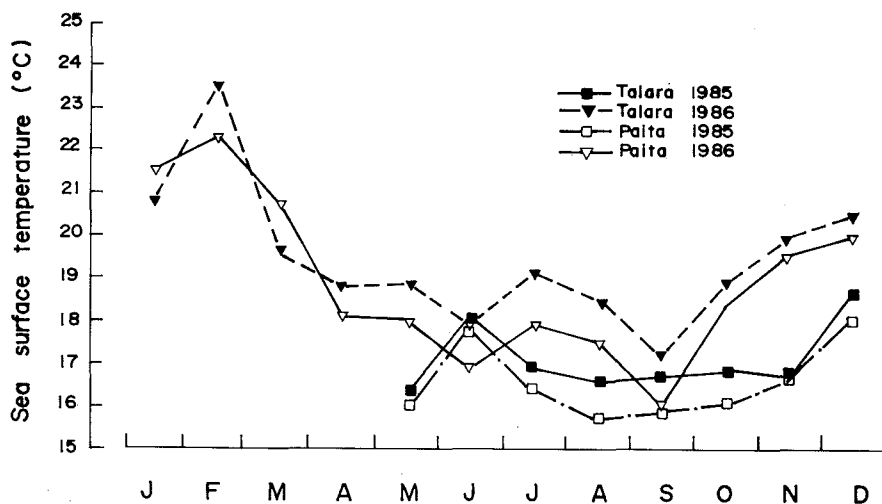
^a Estimates in brackets derived from regression in Fig. 4 and from Paita values; values for 1983 were not needed, given the absence of egg maps in that year.

Fig. 3. Mean monthly sea surface temperature at Talara and Paita, Peru, 1985 and 1986 (from IMARPE, unpublished data).

Fig. 3. Promedios mensuales de temperatura superficial en Talara y Paita, Perú, 1985 y 1986 (de IMARPE, datos no publicados).

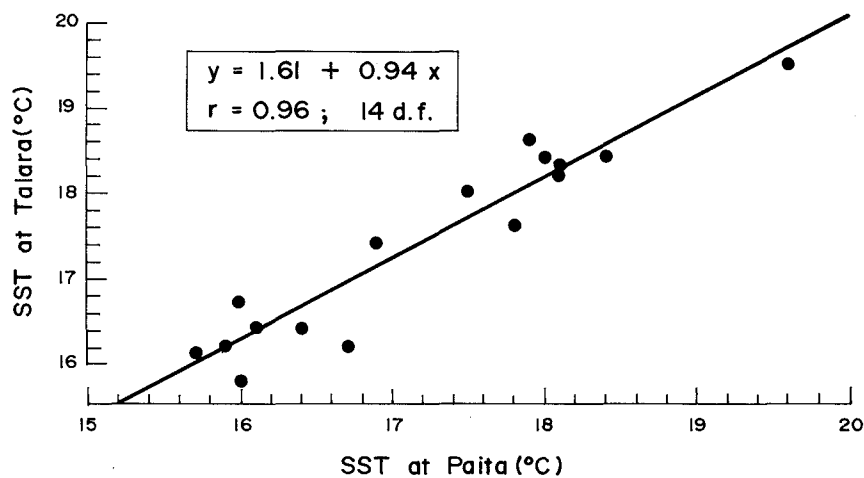


Fig. 4. Regression of sea surface temperature at Talara vs. sea surface temperature at Paita (May-December 1985 and May-December 1986), as used to predict missing SST values for Talara.

Fig. 4. Regresión de la temperatura superficial del mar en Talara vs. temperatura superficial del mar en Paita (Mayo-Diciembre 1985 y Mayo-Diciembre 1986), utilizada para predecir los valores ausentes de la temperatura superficial del mar de Talara.

Daily anchoveta egg production per m² (P_{dj}) was then computed, for each half-degree square (j) and each survey/month using

$$P_{dj} = E_j * D_{-1} \quad \dots 3)$$

The resulting maps turned out to have numerous gaps and were rather difficult to interpret. Therefore, a 3x3x3 interpolation scheme (see Fig. 5) was used to smoothen the data. This resulted in the elimination of gaps while simultaneously leading to the emergence of interpretable spatial patterns. Without missing values, the smoothing scheme in Fig. 5 will not lead to biased means, but to reduced variance (Sager 1971).

After smoothing, the monthly values of P_{dj} were averaged for the periods 1964 to 1971 and 1972 to 1986.

Santander's maps were Mercator projections, i.e., the east-west extent (e.g., in km) of a one-degree "square" changes with latitude (see Table 4). These values were used to convert the smoothed egg production estimates per m² within each half-degree square into production estimates per total area.

Finally, the geographic center of gravity of the anchoveta egg production was computed for each of the 12 months in the two periods by multiplying the production in each half-degree square by the latitude and longitude of its center, then computing the (weighted) average latitudes and longitudes by month.

Table 4. Relationship between degree of latitude and km equivalent at 4-14°S.^a
 Tabla 4. Relación entre grado de latitud y su equivalencia en km de 4-14°S.

Latitude (°South)	Km. equivalent of one degree longitude
4	112.04
5	110.89
6	110.70
7	110.48
8	110.23
9	109.95
10	109.63
11	109.27
12	108.89
13	108.47
14	108.02

^a From Klein (1894).

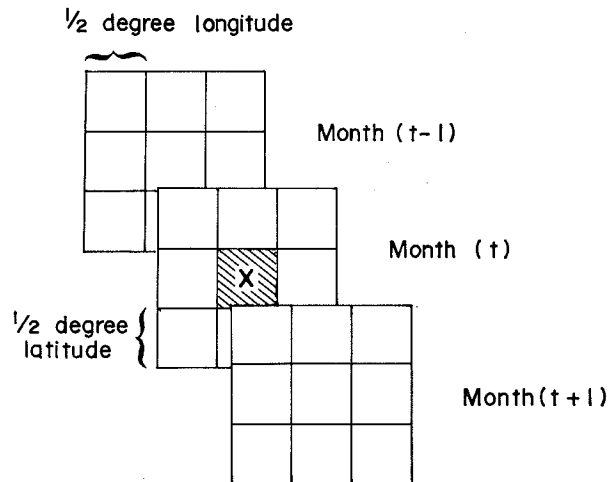


Fig. 5. Schematic representation of 3x3x3 smoothing scheme in space and time. This scheme was also used for interpolation of missing values, but only when observations were available for at least 2 out of the 27 half-degree squares.

Fig. 5. Representación esquemática del arreglo emparejado de 3x3x3 en el espacio y tiempo. Este esquema también fue empleado para interpolar valores ausentes, pero sólo cuando se dispuso por lo menos de observaciones en 2 de los 27 cuadrados de medio grado.

Results and Discussion

The smoothed "climatological" maps of monthly anchoveta egg production obtained here for the periods 1964 to 1971 and 1972 to 1986 are presented here in Figs. 6a, 6b, 6c and 6d. As might be seen, maximum egg production generally occurs in a single band right along the coast, although there are indications in certain months (e.g., February or October, first and second period) of two distinct spawning "centra" (*sensu* Mathisen, this vol.), one at about 8°S, the other at about 13°S.

The center of gravity for both series (1964 to 1986) and all months combined is 9°42'S, which is very close to the value of 9°48'S that can be estimated from Table 2 of Santander (1987). This implies that Santander's large-scale extrapolation of limited surveys (and maps) to

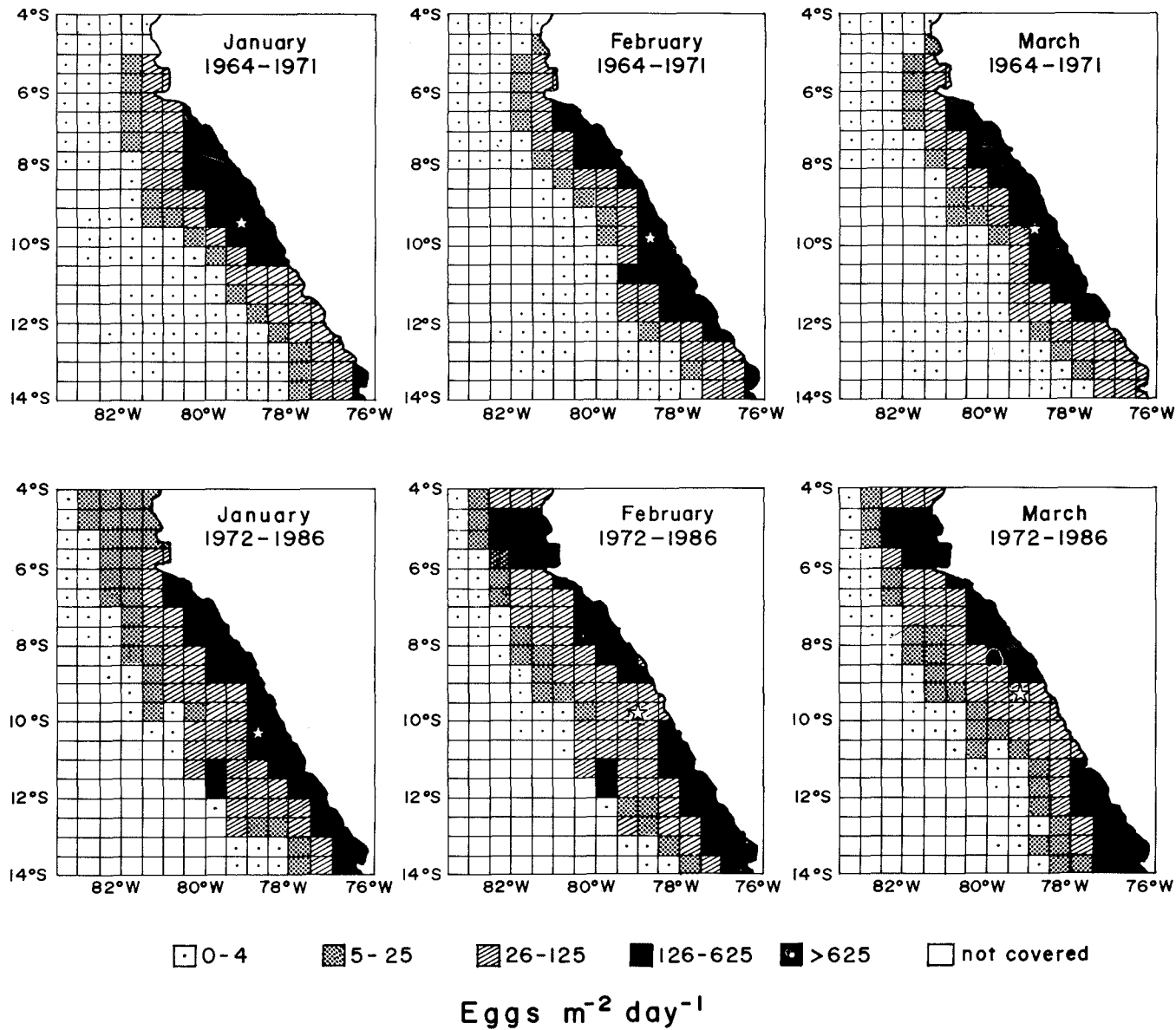


Fig. 6a. Geographic distribution of mean monthly anchoveta egg production ($\text{eggs/m}^2/\text{day}$) for the months of January, February and March during two periods (above 1964-1971; below 1972-1986). The large white star indicates center of gravity of the production values.

Fig. 6a. Distribución geográfica de los promedios mensuales de producción de huevos de anchoveta ($\text{huevos/m}^2/\text{día}$) para los meses de Enero, Febrero y Marzo, durante dos períodos (arriba 1964-1971; abajo 1972-1986). La estrella blanca indica el centro de gravedad de los valores de producción.

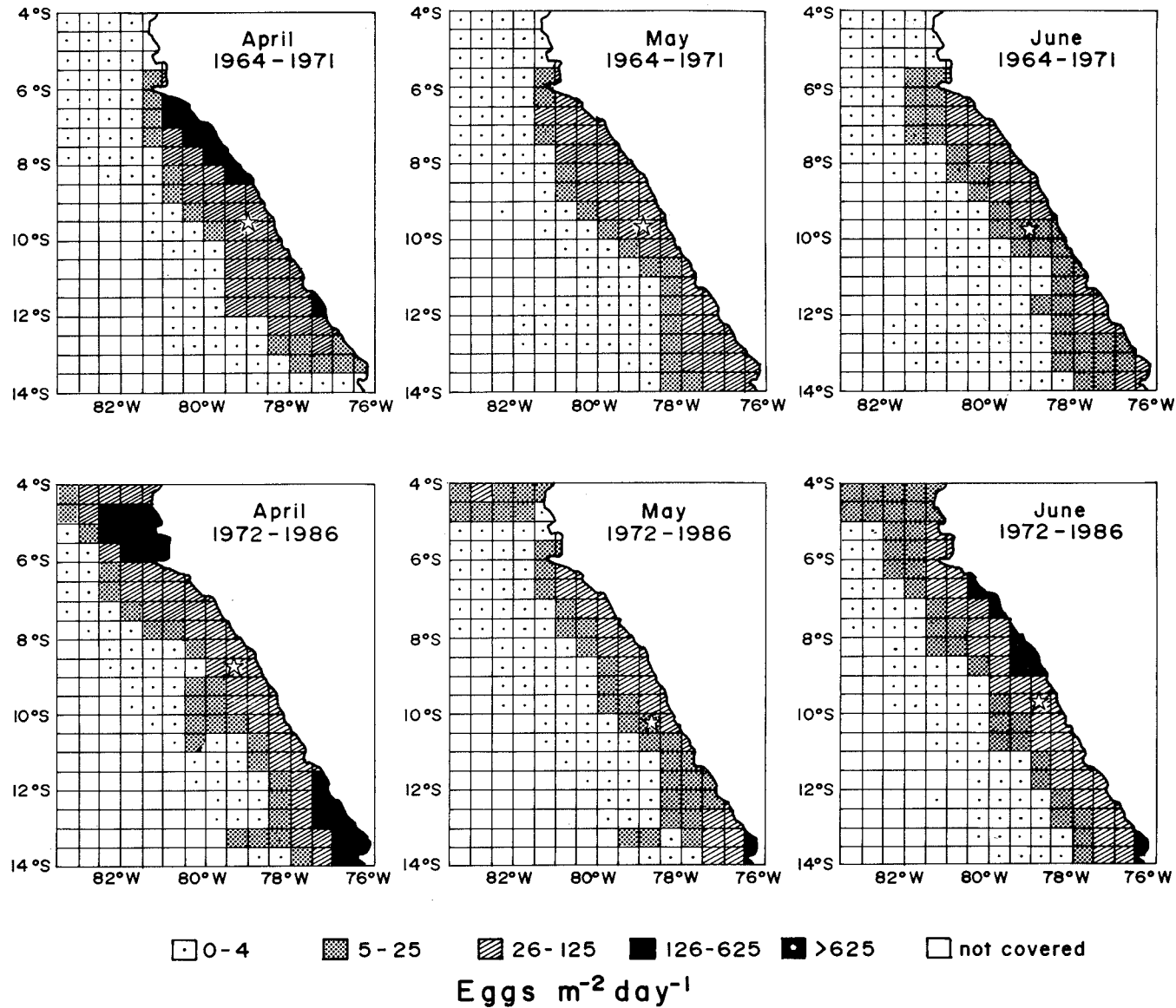


Fig. 6b. Geographic distribution of mean monthly anchoveta egg production ($eggs/m^2/day$) for the months of April, May and June during two periods (above 1964-1971; below 1972-1986). The large white star indicates center of gravity of the production values.

Fig. 6b. Distribución geográfica de los promedios mensuales de producción de huevos de anchoveta ($huevos/m^2/día$) para los meses de Abril, Mayo y Junio, durante dos períodos (arriba 1964-1971; abajo 1972-1986). La estrella blanca indica el centro de gravedad de los valores de producción.

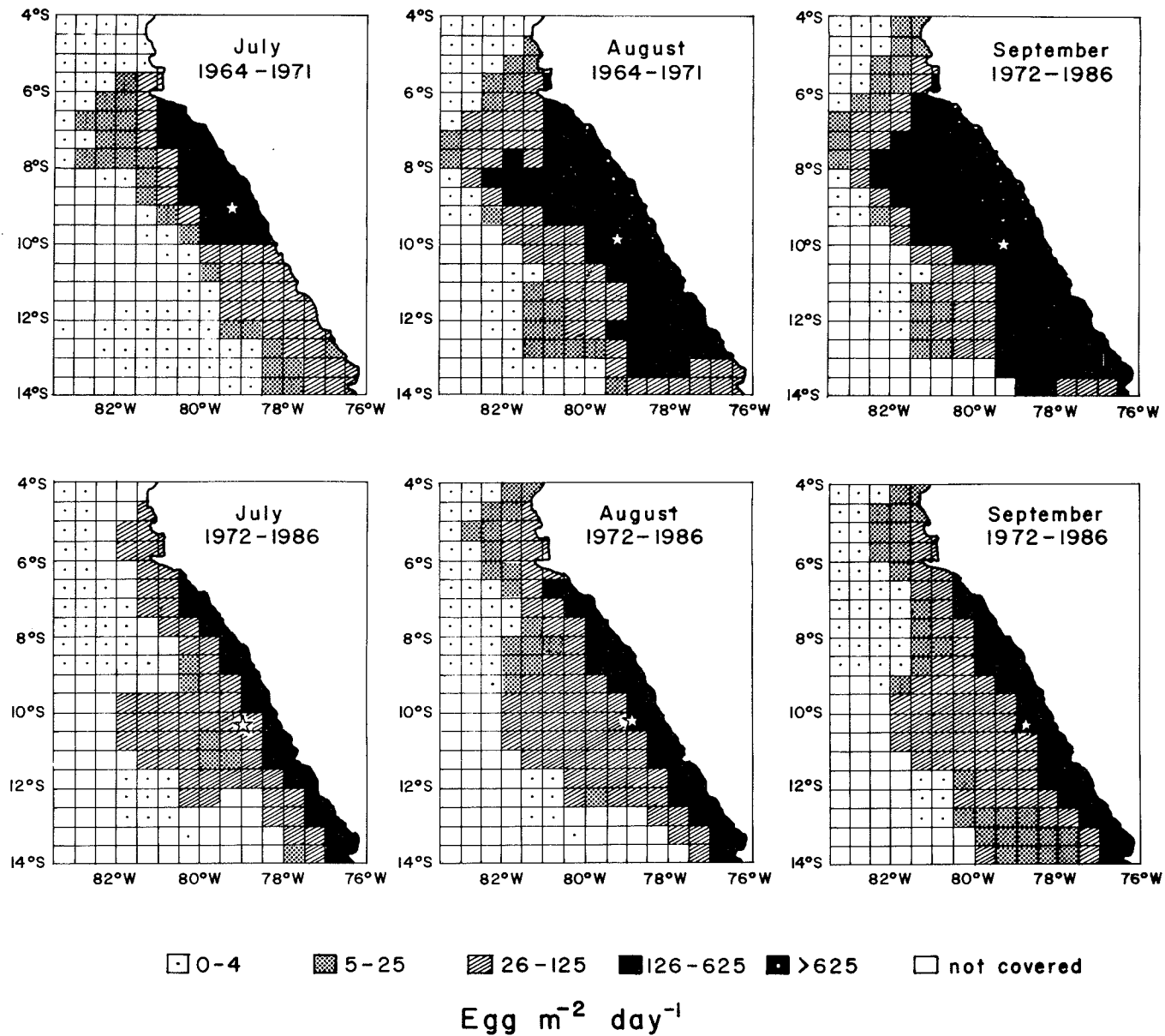


Fig. 6c. Geographic distribution of mean monthly anchoveta egg production (eggs/m²/day) for the months of July, August and September during two periods (above 1964-1971; below 1972-1986). The large white star indicates center of gravity of the production values.

Fig. 6c. Distribución geográfica de los promedios mensuales de producción de huevos de anchoveta (huevos/m²/día) para los meses de Julio, Agosto y Septiembre, durante dos períodos (arriba 1964-1971; abajo 1972-1986). La estrella blanca indica el centro de gravedad de los valores de producción.

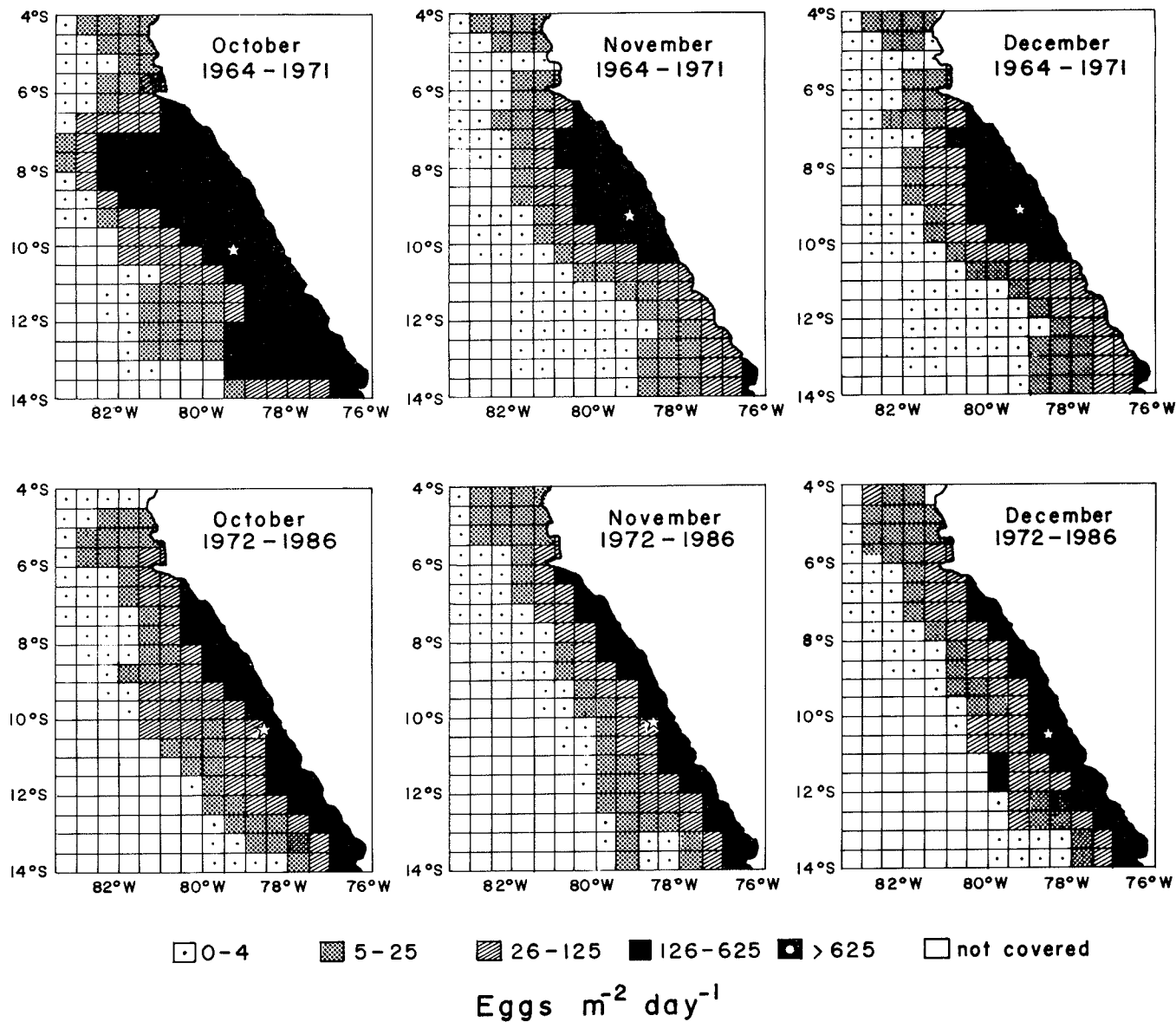


Fig. 6d. Geographic distribution of mean monthly anchoveta egg production ($\text{eggs/m}^2/\text{day}$) for the months of October, November and December during two periods (above 1964-1971; below 1972-1986). The large white star indicates center of gravity of the production values.

Fig. 6d. Distribución geográfica de los promedios mensuales de producción de huevos de anchoveta ($\text{huevos/m}^2/\text{día}$) para los meses de Octubre, Noviembre y Diciembre, durante dos períodos (arriba 1964-1971; abajo 1972-1986). La estrella blanca indica el centro de gravedad de los valores de producción.

the whole of the northern-central coast of Peru ($4-14^{\circ}\text{S}$) did not lead to any bias that would shift the north-south balance.

Fig. 7 presents the center of gravity of anchoveta egg production off Peru on a monthly basis, for each of the two periods distinguished here. As might be seen, spawning of anchoveta in 1972-1986 involved more seasonal changes than it did in 1964-1971.

Also, a shift southward along the coast appears to have occurred. This may be in line with the "southernization" hypothesis of Palomares et al. (1987), which states that *Engraulis ringens* off northern/central Peru have become, over the last decades, more similar to their southern counterparts - in terms of various aspects of their biology - than they were earlier.

Fig. 8 presents, finally, monthly averaged estimates of total anchoveta egg production off Peru ($4-14^{\circ}\text{S}$) for the two periods considered here. The similarity between the two curves involves:

- i) evidence of two peaks per year, one lasting from January to March ("summer"), the other from August to October ("spring") and

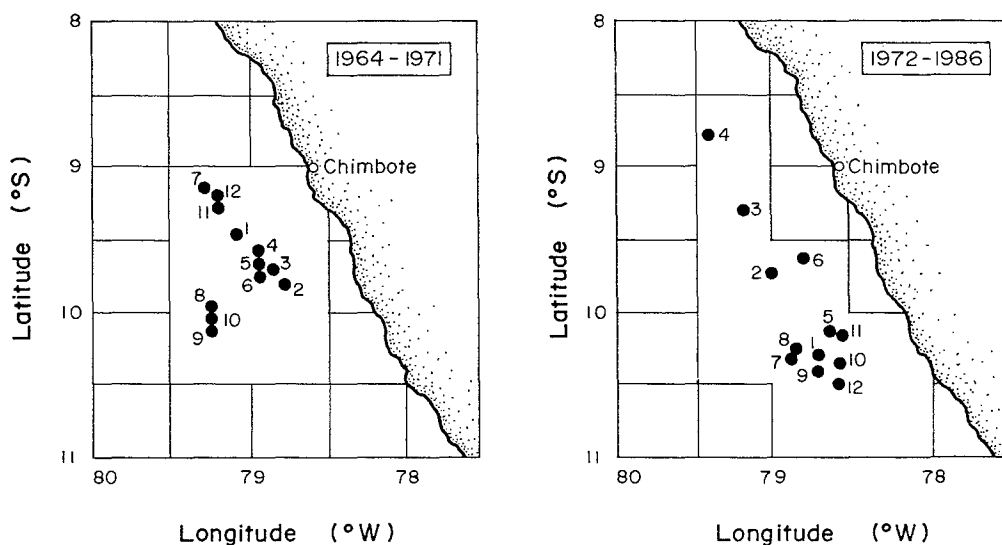


Fig. 7. Location changes of center of gravity of anchoveta egg production along the Peruvian coast, $4-14^{\circ}\text{S}$ (1-12 = January-December). Left: monthly changes from 1964 to 1971. Right: monthly changes from 1972 to 1986. (Note wider range and southeastern shift in later period.)

Fig. 7. Cambios en la ubicación de los centros de gravedad de producción de huevos de anchoveta a lo largo de la costa peruana, $4-14^{\circ}\text{S}$ (1-12 = Enero-Diciembre). Izquierda: Cambios mensuales de 1964 a 1971. Derecha: Cambios mensuales de 1972 a 1986. (Nótese para los últimos años una mayor amplitud y un cambio hacia el sur).

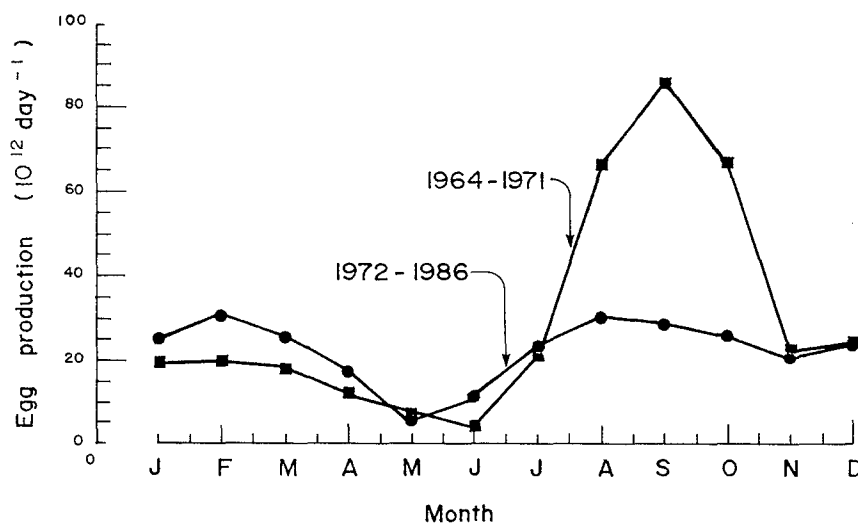


Fig. 8. Mean monthly egg production of anchoveta off Peru ($4-14^{\circ}\text{S}$) for the periods before and after the 1972/1973 El Niño. (Note marked difference in the September peak.)

Fig. 8. Promedios mensuales de producción de huevos de anchoveta frente a Perú ($4-14^{\circ}\text{S}$) para los períodos anterior y posterior al Niño 1972/1973. (Nótese la marcada diferencia en el máximo de Septiembre).

ii) a production minimum in May-June ("fall").

However, it is the difference between these two curves which strikes us most. In the first period (1964-1971), the spring peak was much larger than the summer peak, while both peaks are more or less equal in the second period (1972-1986).

A number of hypotheses could be presented to explain this large difference (Senocak 1988). However, as pointed out in the Introduction, the egg production rates estimated here are *apparent* rates, i.e., they do not account for egg mortality. We shall, therefore, abstain from suggesting here a cause for the change reflected in Fig. 8. The reader is invited, however, to consult Pauly and Soriano (this vol.) for a follow-up on anchoveta egg production and mortality.

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