Spawning biomass of the northern anchovy (*Engraulis mordax*) in the Gulf of California during 1992

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Spawning biomass of the northern anchovy, *Engraulis mordax*, in the Gulf of California during 1992, was estimated in 135 147 metric tons (cv = 0.509), using the Daily Egg Production Method (DEPM). Data are based on the ratio between the daily egg production and the specific daily fecundity of the population. Ichthyoplankton and midwater trawl samples show that the main spawning area of anchovy extends from the northern tip of Ángel de la Guarda Island through 30 nautical miles south of Tiburón Island. Northern anchovy population distributed farther north in the Gulf of California during 1992, due to the El Niño warm waters event, than it had been in 1991.
Key words: biomass, anchovy, Gulf of California, fecundity, ichthyoplankton.

Biomasa reproductiva de la anchoveta norteña (*Engraulis mordax*) en el Golfo de California en 1992

Mediante el método de producción diaria de huevos se estimó el tamaño de la biomasa reproductora de la anchoveta norteña, *Engraulis mordax* en 135 147 toneladas métricas (CV = 0.509), en el Golfo de California durante 1992. La cifra se basa en el cociente de la producción diaria de huevos y la fecundidad específica diaria de la población. Los muestreos tanto de ictioplancton como de anchovetas juveniles y adultas indicaron que la principal área de desove se extendió desde la punta norte de la isla Ángel de la Guarda hasta 30 millas náuticas al sur de isla Tiburón. Debido a la presencia de un evento El Niño, la población de anchoveta norteña se distribuyó más al norte durante 1992 en comparación con 1991.
Palabras clave: biomasa, anchoveta, Golfo de California, fecundidad, ictioplancton.

Introduction

Until l985 the northern anchovy, *Engraulis mordax* (Girard, 1856), was distributed in the northwest Pacific from Queen Charlotte Island, British Columbia, to Cabo San Lucas, Baja California Sur, Mexico (Reid, 1966; Baxter, 1966). During the 85/86 fishing season (October 1985 to May 1986) the purse seine fleet in the Gulf of California caught 2 071 metric tons (t) of northern anchovy and its distribution area extended to the Gulf of California (Hammann and Cisneros-Mata, l989). Further, Green-Ruiz and Acal-Sánchez (1987) found anchovy larvae in the ichthyoplankton study of April of 1985.

Ichthyoplankton investigations in the Gulf of California showed major changes in relative abundance of Pacific sardine and northern anchovy: between 1985 and 1989, sardine was the dominant species and between 1990 and 1992, Pacific sardine decreased and anchovy increased (Green-Ruiz and Aguirre-Medina, l988[1], 1989[2]; 1990[3]; Hammann *et al*., 1991; Green-Ruiz *et al.*, 1992[4]).

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The northern anchovy in the Gulf of California is considered to be an important potential resource, especially in light of sharp declines in the Pacific sardine fishery such as the one experienced in the early 1990s. Over the recent years anchovy commercial landings have varied greatly: reported catch in the 86/87 season was only 39 t, increasing to 777 t during 87/88 and 7 693 t in 88/89. In 90/91 northern anchovy represented the third most important catch in Mexico (5.4%; 12 768 t) and during the 91/92 season catch was fifth (4.9% with 5 169 t). However, in 92/93 the catch fell to 1 606 t and in 93/94 this species was not caught, although in the following two seasons, the catch increased again to 1 039 t in 94/95 and 4 217 t in 95/96 (Nevárez-Martínez *et al.,* l992[5]; Cisneros-Mata *et al*., l989; Cisneros-Mata *et al*., 1997).

Daily egg production method (DEPM) was developed to estimate the spawning biomass of northern anchovy off California (Parker, 1980; Stauffer and Picquelle, 1980; Lasker, 1985; Bindman, 1986) and since then it has been used worldwide to estimate spawning biomass of small pelagic fish populations: in Peru (Santander *et al.,* 1984), Spain (Uriarte and Motos, 1991[6]; García *et al*., 1992) and Portugal (Cunha *et al*., 1992). Alheit (1993) provided a review and evaluation of the DEPM applied to clupeoid fishes. In 1991 the DEPM was first applied in Mexico by the Instituto Nacional de Pesca (INAPESCA) (Cotero-Altamirano and Green-Ruiz, 1997).

The spawning biomass estimate in the DEPM is the ratio between daily egg production and daily specific fecundity (eggs by day per metric t) of the adult fish population. Daily egg production is estimated from an egg mortality curve using egg densities at age computed from ichthyoplankton survey data. Adult reproductive parameters are estimated from adult fish sampled with midwater trawls. Adult fish parameters included in daily specific fecundity are: individual fecundity, sex ratio, proportion of females that spawn each night, and mature female weight. In the DEPM biomass estimates are based on biological parameters and are independent of stock assessment models that require indices of relative abundance, and the precision of parameters and biomass can be estimated (Hewitt, 1985).

In this paper we provide an estimate of the spawning biomass stock of *E. mordax* in the Gulf of California using DEPM and identify the main spawning area and boundaries of the spawning schools during 1992.

Materials and methods

Study area

During the northern anchovy's peak reproduction season in the Gulf of California, two simultaneous research cruises were conducted from January 17th to February 8th 1992 to collect adults (R/V BIP XI) and obtain eggs (R/V Antonio Alzate), and record temperatures at the sea surface and 10 m depth. The survey design was described in Cotero-Altamirano and Green-Ruiz (1997).

The study area (Fig. 1a) was located between lines 140 (29° 30' N and 114° W) and 440 (26° N and 109° W), and covered 30 survey lines oriented perpendicular to the Gulf coasts; distance between lines was 10 nautical miles (nm), and on each line, distance between stations was 5 nm according to the station plan of the Small Pelagic Fish National Program of INAPESCA.

At each ichthyoplankton station, a vertical haul was made with a CalVET net from a depth of 70 m (Lasker, 1985). The net characteristics were: 0.25 m in diameter at the mouth, 1.5 m long, with a mesh opening of 0.333 mm; a flowmeter was installed in the mouth of the net. Samples were collected day and night and fixed with 5% Formalin solution neutralized with sodium borate. Sea surface and 10 m depth temperatures were recorded using Nansen bottles and reversible thermometers.

Based on the same station plan, 16 lines perpendicular to the coastline were sampled, with 20 nm between lines (Fig. 1b). On each line,

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adult anchovies were collected by trawls with a 4 panel midwater net, 47 m long, 27 m mouth width, and 2.5 cm mesh. Trawl tows had 30 minute duration and were conducted between 18:00 and 06:00 hr, principally in inshore areas. Echo sounder and sonar were used to search for fish schools yet trawls were done with and without acoustic evidence for the presence of schools (Picquelle and Stauffer, 1985; Smith and Hewitt, 1985). In addition, day time trawls were made (30 to 50 nm offshore) to locate the reproductive schools and define the boundary of the spawning schools. For each trawl, sea surface temperature was recorded *in situ*.

Anchovy specimens were randomly sampled from the trawl catches, sex and standard length (SL) were recorded from the first 50 fish. The total weight, gonad-free body weight, and maturity were determined by macroscopic examination. In most cases, gonad-free body weight and maturity were determined from the first 25 mature females (Picquelle and Hewitt, 1983). Additional females with hydrated ovaries were selected to increase the number of females for fecundity estimates, but these fish samples were not included in the estimate of spawning fraction.

Data processing

Egg production (Po), Egg Mortality (Z) and Area (A).

The ichthyoplankton was separated from all the zooplankton samples, anchovy eggs and larvae were identified, and eggs were staged using the Moser and Ahlstrom (1985) descriptions. To each egg its age was assigned by day category based on sea temperature at 10 m depth and collection time, according to a model for temperature-dependent northern anchovy egg development (Lo, 1985).

The standard length of preserved larvae (SLP) was measured to 0.5 mm with an ocular micrometer. Only larvae smaller than 7.0 mm were considered, since the catch of larger larvae with the CalVET net is not regarded as representative of the available larval stock at sea (Lo, 1983).

An exponential curve was fit to the age and daily egg production data to estimate the daily egg production (Po) and mortality rate (Z). To compare estimates for 1991 (Cotero-Altamirano and Green-Ruiz, 1997) and 1992 (present work),

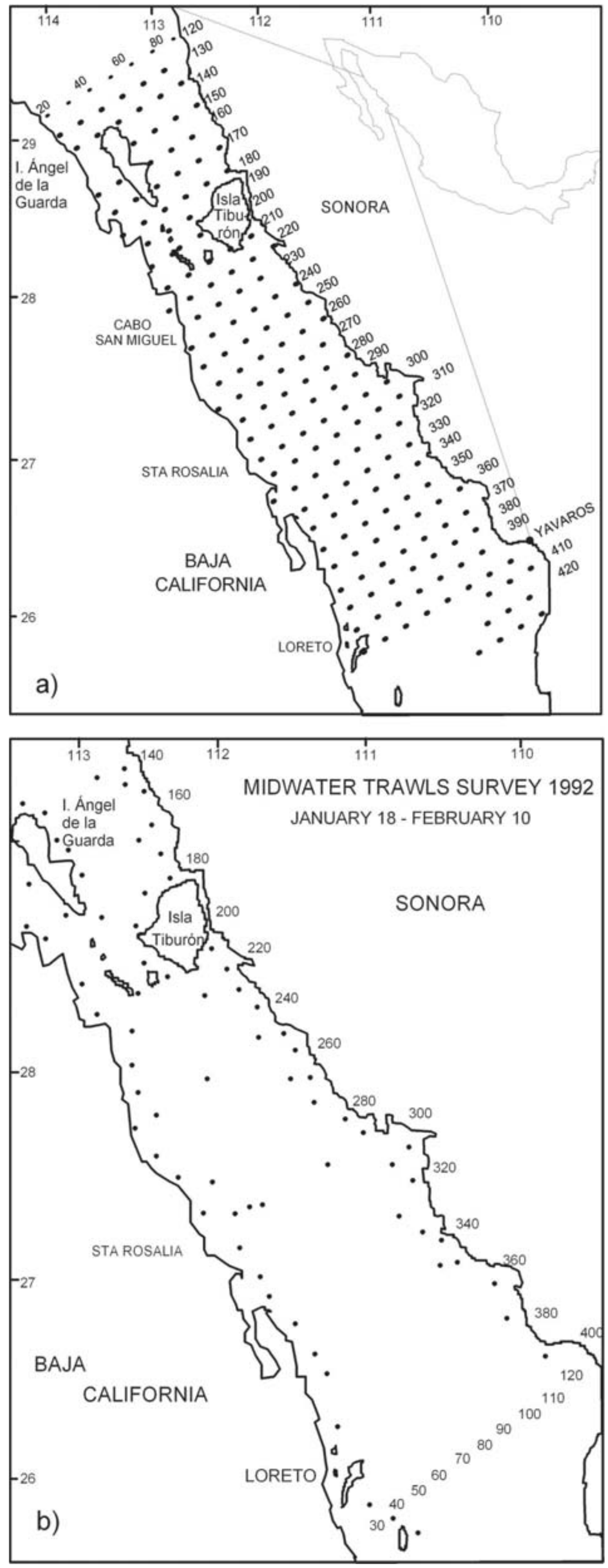

Fig. 1. Study area and station pattern for 1992 (*a*) Plankton and (*b*) Adults cruises. The dots are the stations.

we used the Single Equation Model (SEM) of Lo (1986). The model estimates the daily egg production and mortality rate assuming that eggs and yolk-sac larvae (larvae <5 mm SLP, Zweifel and Lasker, 1976) mortality rates are the same. We made corrections for bias due to temperature dependent incubation time, yolk-sac growth rate, larval retention, extrusion, and avoidance (Lo, 1983; Lo *et al.,*1989; 1996). The area (A) surveyed for eggs was post-stratified: Stratum 1 was the area where eggs were found and Stratum 0 where no eggs were collected. For biomass estimation, model *Po* is multiplied by *A*.

Adult parameters

Preserved gonads from both sexes were weighted to the nearest milligram. A sample was obtained from the central part of each gonad and processed for histological examination; the 5-7 micron sections were stained using traditional Hematoxylin and Eosin histotechnique (Humason, 1979). Each gonad was classified histologically to estimate the fraction of females and males that were mature and to measure spawning rate (Hunter and Golberg, 1980; Hunter and Macewicz, 1985; Cotero-Altamirano, 1987).

Number of eggs in a spawning batch (batch fecundity) was calculated using an estimate of the number of hydrated oocytes in the ovary (Hunter and Macewicz, 1985). Each hydrated female obtained in the adult survey was used to estimate batch fecundity. Both right and left lobes of the ovary from each female were examined histologically to identify females that had begun to ovulate and spawn. Ovaries containing both hydrated oocytes and new postovulatory follicles were eliminated from analyses to avoid underestimates of batch fecundity. Three random subsamples from left or right ovary were taken to estimate batch fecundity, since Cotero-Altamirano and Green-Ruiz (1997) found that the sample location was not significant. We estimated mean batch fecundity from data of 204 hydrated females and then determined the relation between batch fecundity and gonad-free weight by linear regression.

For estimation of adult parameters: average weight of the females (W), batch fecundity (F), spawning fraction (S), and sex ration (R) from anchovies caught by mid-water trawl we used a weighted sample mean and their variance estimators using the next equation in each case (Picquelle and Stauffer, 1985):

$$\bar{\bar{y}} = \frac{\sum_{i=1}^{n} m_i \bar{y}}{\sum_{i=1}^{n} m_i} \qquad \text{Eq. 1}$$

$$\hat{Var}(\bar{\bar{y}}) = \frac{\sum_{i=1}^{n} m_i^2 (\bar{y} - \bar{\bar{y}}_i)^2}{(\sum_{i=1}^{n} \frac{m}{n_i})^2 n(n-1)} \qquad \text{Eq. 2}$$

Where

$\bar{\bar{y}}$ = weighted simple mean

m_i = number of fish subsampled from the *i*th trawl

n_i = number of positive trawl

$\bar{y}_i$ = average for the *i*th trawl = $\sum_{j=1}^{mi} \frac{y_{ij}}{m_i}$

y_{ij} = observed value for the *j*th fish in the *i*th trawl

Biomass model

For the spawning biomass (B), the ichtioplankton and adult parameters were applied in the model developed by Parker (1980) and Stauffer and Picquelle (1980), the variance was calculated using the delta method (Picquelle and Hewitt, 1983; Parker, 1980; Bindman, 1986).

The spawning biomass is defined as the quotient of the daily eggs production in the sea and the daily fecundity (per ton of spawners) of the population:

$$B = \frac{kPoAW}{RSF} \qquad \text{Eq. 3}$$

Where

B = spawning biomass estimate in metric tons;

Po = daily egg production rate in number of eggs per day per 0.05 m^2 of sea surface;

A = area of survey in m^2;

W = average weight of mature females;

R = average weight of mature females in grams;

F = batch fecundity in number of eggs;

S = fraction of mature females spawning per day;

K = conversion factor from grams to metric tons (10^{-6} t/g)

Results

Oceanography and distribution of anchovy

Sea surface temperature in 1992 varied between 16.3 °C and 23.2 °C, and was on average 2.5 °C higher than in 1991, due an El Niño event (Green-Ruiz and Hinojosa-Corona, 1997). Temperatures increased gradually from north to south.

Of 320 plankton stations, 24% were positive for anchovy eggs (Fig. 2). The main spawning area was detected between the northern tip of Ángel de la Guarda Island and 30 nm south of Tiburón Island across the full width of the Gulf. Only a few eggs were observed in the southern portion of the Gulf during 1992. Stratum 1 covered 89% and Stratum 0 only 11% of the total area surveyed.

Of 70 midwater trawls for adults, 14 (20%) were positive. Schools of spawning anchovy were distributed mainly in the region of the large islands (Ángel de la Guarda and Tiburón), along both coasts on line 280; along the coast of Sonora between lines 320 and 340; and to the south, along the coast of Baja California Sur in the vicinity of Loreto (Fig. 3). Adult anchovies were located in water with temperatures between 16.5 °C and 21.3 °C.

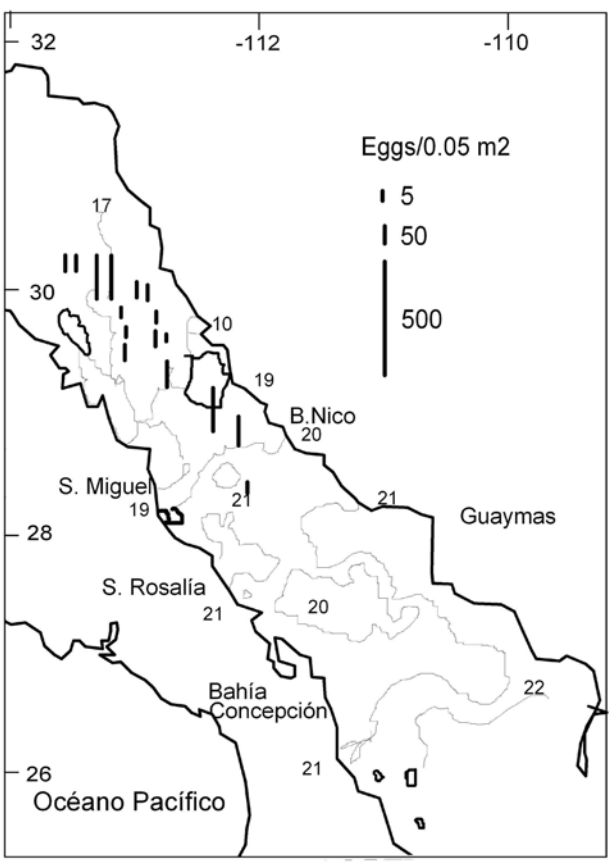

Fig. 2. Distribution and abundance of Northern anchovy eggs in relation to temperature for 1992 cruise.

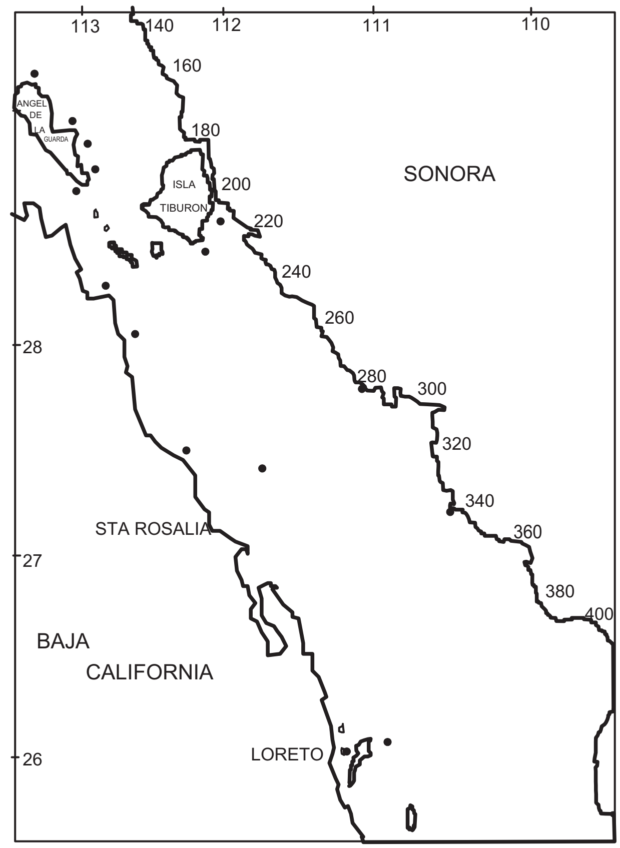

Fig. 3. Distribution of positive trawls (square dots) of reproductive adults for 1992 cruise.

Daily egg production

The daily egg production (PO) was 4.7 eggs/0.05 m²/day (CV = 0.45) and the estimated daily embryonic mortality rate (z) was 0.32/day (CV = 0.29) (Fig. 4, Table 1).

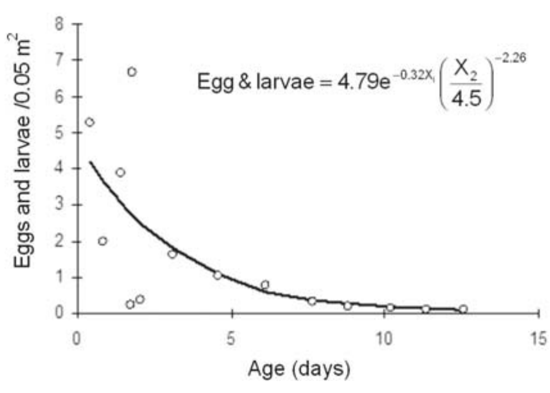

Fig. 4. Embryonic mortality curve for northern anchovy (*Engraulis mordax*) eggs and yolk sac larvae from the 1992 daily egg production method survey. Observed (open circles) and estimated (line).

Table 1
List of eggs and larvae 1992 data witch estimated daily egg producction (Po) and instantaneous mortality rate (Z)

Size (mm)	*Age (Days)*	*No. Eggs or larvae•0.05 m⁻²*
E	0.433	5.24
E	0.871	1.985
E	1.415	3.85
2.67	1.74	0.2316
E	1.82	6.67
3.12	2.06	0.3702
3.69	3.12	1.6397
4.24	4.59	1.0353
4.79	6.11	0.7702
5.32	7.67	0.3127
5.85	8.84	0.1841
6.37	10.22	0.1175
6.89	11.36	0.1055
7.40	12.55	0.0812

E: eggs.

Adult parameters

The standard length of female adults ranged from 72 to 121 mm ($\alpha = 0.05$), and male adults from 78 to 119 mm. The mean for both sexes combined was 100 mm with CV = 0.07 (Fig. 5). The length of first maturation, when 50% of individuals are mature (Cotero-Altamirano and Green-Ruiz, 1997), was 99.6 and 99.4 mm SL ($\alpha = 0.05$) for females and males respectively (Fig. 6).

Before estimating average female weights, we corrected the weight of hydrated females in the sample for bias due to the presence of females with hydrated ovaries (Picquelle and Stauffer, 1985). We adjusted weights with a regression of whole-body weight on ovary-free weight estimated for females without hydrated ovaries:

$$W = 1.035\omega + 0.609 \qquad \text{Eq. 4}$$

where ω is the ovary-free weight ($r^2 = 91\%$). The estimated average female weight was 11.12 g, with a CV of 0.026.

The batch fecundity for each mature female was estimated by regressing batch fecundity on ovary-free weight for a sample of 204 hydrated females (without new postovulatory follicles) taken during the survey.

The relation between female ovary-free weight (W) and batch fecundity (F) was:

$$F = -1170.1 + 775.25W \qquad \text{Eq. 5}$$

with $r^2 = 55\%$; female ovary-free weight ranged from 5.6 to 18.2 g (Fig. 7).

Using Eq. 5 to estimate batch fecundity for all mature females from each trawl, we obtained a mean of 6 847 oocytes per mature female (CV = 0.036).

The spawning fraction (average fraction of females spawning per day) was 0.115•day (CV = 0.274), estimated from females that spawned the night before capture.

The sex ratio (fraction of females in the anchovy stock based on fish weight) for anchovy in our survey was 0.49 (CV = 0.067).

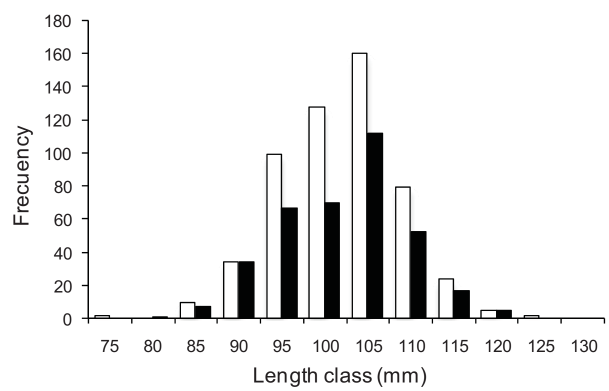

Fig. 5. Standard length distribution for northern anchovy (*Engraulis mordax*) taken in all trawls. Females (open bars) and males (filled bars).

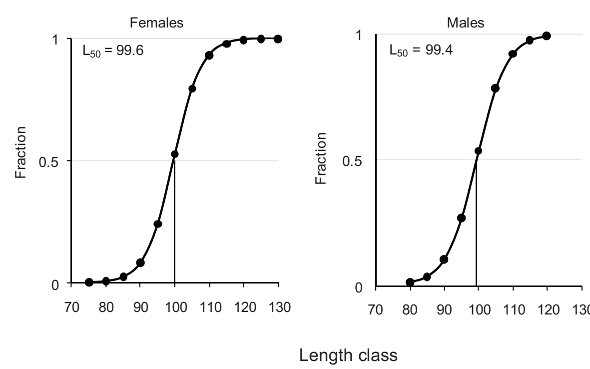

Fig. 6. Fraction of northern anchovy (*Engraulis mordax*) females and males that were sexually mature as a function of standard length (mm). L_{50} are estimated length at which females and males were mature.

Fig. 7. Linear regression of batch fecundity on ovary-free weight fitted to females with hydrated eggs.

Biomass estimate

The spawning biomass of the anchovy, *E. mordax*, of the Gulf of California estimated by the DEPM for 1992 was 135147 t (CV = 0.509). Estimates of egg production, rate of egg mortality, adult parameters and comparisons to 1991 are presented in *table 2*.

Table 2

Estimates of rates and adult reproductive parameters for spawning biomass of northern anchovy, *Engraulis mordax*, in the Gulf of California for 1992, using daily egg production method. The numbers in parenthesis are the coefficient of variation

Parameters		*1991*	*1992*
Daily egg production (1012 eggs /day) by area	PoA	7.49 (0.44)	4.7 (0.45)
Average female weight (g)	W	13.64 (0.019)	11.12 (0.026)
Batch fecundity (no. eggs/ batch per mature female)	F	8,220 (0.079)	6,847 (0.036)
Spawning fraction (no. spawning females per mature female)	S	0.174 (0.206)	0.115 (0.274)
Sex ratio (no. females/ total).	R	0.68 (0.027)	0.49 (0.067)
Spawning biomass (103 t)	B	105,079 (0.445)	135,147 (0.509)
Egg mortality rate	Z	0.35	0.32
Average temperature (°C)		17.6	20.0
Average Temperature of positive stationts (°C)		16.4	18.5
Positive Stations (%)		21.0	24.4

Discussion

The estimated spawning biomass of northern anchovy in the Gulf of California increased (28%) from 1991 (105 079 t) to 1992 (135 147 t). The population of anchovy in 1992 may have been higher if there had not been an El Niño event. This had a negative effect on reproduction, in comparison to the previous year.

The average weight of the female in 1992 was less than in 1991, causing a decrease of the number of eggs per spawning female, low estimated batch fecundity and a decrease in the fraction of spawning females. As a result of this, estimate of the biomass was low 1 606 t and in 1993-1994 this species was not caught and a concealment of the possible population growth. However, if 1992 had been a normal year, the anchovy biomass may have increased in a significant way.

Fiedler (1984) and Fiedler *et al.* (1986) studied the effects of the 1982-1984 El Niño on northern anchovy, reporting that the spawning range as indicated by distributions of eggs had moved far to the north and offshore in 1983 relative to 1980-1982. They also found that several 1983 spawning parameters appear anomalous and that the average female weight was lower in 1983, but El Niño seemed to have had no net effect on the egg production that year. We found that the 1992 El Niño in the Gulf of California had an effect on distribution, warm waters causing northern anchovy to move to the north accompanied by lower average female weight and daily egg production.

On the other hand, even though we are talking about different environments (enclosed and small area versus open and large areas), the population level of anchovy in the Gulf of California was below that of anchovy of the Pacific ocean of California when the population was in the process of decline (between 309 000 and 870 000 t for the period of 1980-1984) and in Peru (1 204 191 t in 1981). The anchovy population in the Gulf of California was similar to the estimates of northern anchovy in California, prior to the establishment of a fishery (between 180 and 500 t for 1951 and 1953).

Estimates of the spawning biomass of the Gulf of California anchovy by DEPM should continue to improve understanding of this population which is not only a potentially exploitable fishery resource, but also plays a decisive role in the ecological relationship that is developing in the Gulf of California.

The DEPM is one of most effective methods and gives a lot of biological information needed for application of other methods like population matrix. Methods such as the daily fecundity reduction (DFR) method for demersal fishes should be used to estimate spawning biomass of some small pelagic fish. Both methods can be used if data on fish-egg stages, duration, and abundance, plus the reproductive output of adult fishes are available (Lo *et al*., 1993; Moser *et al*., 1994; Lo, 2007).

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