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BIOLOGY AND PHENOLOGY OF *AMBLYGASTER SIRM* (CLUPEIDAE) IN NEW CALEDONIA, A SARDINE OF THE CORAL ENVIRONMENT

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ABSTRACT

The biology of the sardine, *Amblygaster sirm,* is studied from fish caught in the lagoons around New Caledonia. About 500 fishing hauls were carried out between 1980 and 1983. This sardine is a fast-growing, medium sized fish (L_{max}: 24 cm) with a short lifespan. Reproduction takes place from October to December. First maturity is attained when fish reach 1 year of age and at this time their size is about 16–17 cm. Mortality is high and most fish die before the age of 2 years. This phenology compared with other seasonal spawners indicates a tendency towards semelparity.

A study of the resources of small pelagic fishes from the lagoon of New Caledonia was conducted by the Centre ORSTOM of Noumea from 1980 to 1983 (Conand, 1988). About 20 species of small pelagics occur regularly in the catches. They are mostly Engraulids, Clupeids, Atherinids and Carangids. Five or six species do not exceed 10 cm (TL) and have no commercial interest apart from their use as bait for tuna pole and line fishing. Juveniles of the larger species can be used as bait and adults for human consumption. One of these species *Amblygaster sirm* (Walbaum, 1792) is a sardine which can reach 25 cm. It is common and is often the dominant species of the catch. This tropical species inhabits coastal waters in the Indian Ocean and in the Pacific Ocean eastward of the Samoa Islands. Some studies have been conducted on its biology: in the Red Sea (Rafail, 1970; 1972; Sanders and Kedidi, 1984), on Sri Lankan coasts (Dayartne and Gjosaeter, 1986), in Indonesia (Sadhotomo and Atmadja, 1985) and in the Philippines (Ingles and Pauly, 1984). I present results obtained in the lagoons of New Caledonia on growth, reproduction and mortality of the species. The life cycle and phenology are then considered.

MATERIAL AND METHODS

From March 1980 till June 1983, 18 fishing cruises, each lasting 2 weeks were made every other month, in the lagoons around New Caledonia (Fig. 1). Fish were attracted with a light, and caught with a "boke ami" (a Japanese lift-net). The most commonly used net was 11 m wide and 13 m deep and the mesh size was 5 mm. Usually two sets were made: the first in the middle of the night and the second before sunrise. In addition, Dumbea Bay near Noumea, was visited monthly from July 1981.

The whole catch was weighed, a sample was taken to determine the species and weight composition of the catch and length frequency distributions were computed for each species (total length to the lower half centimeter). Then, samples of each species were frozen and brought back to the laboratory for reproductive studies.

Biometric relationships were adjusted with a balanced number of individuals per size class. Linear relations describe the relationships among standard length, fork length and total length. The length-weight relationship $W = aL^n$ has been fixed according to the principal axis of the $\log_{10}$ weight-$\log_{10}$ length relationship.

For the study of growth, the mathematical expressions used are, the von Bertalanffy growth function (VBGF) and a modified version of this function with a sinusoidal oscillation to simulate the seasonal growth variation (Pauly and Gaschütz, 1979). Its form is:

$$L = L_\infty\left(1 - \exp[-K(t - t_0) + a\frac{K}{\omega}\sin \omega(t + \Phi)]\right)$$

where L_∞, K, t_0 parameters from standard VBGF, a = intensity of the seasonal oscillation (between

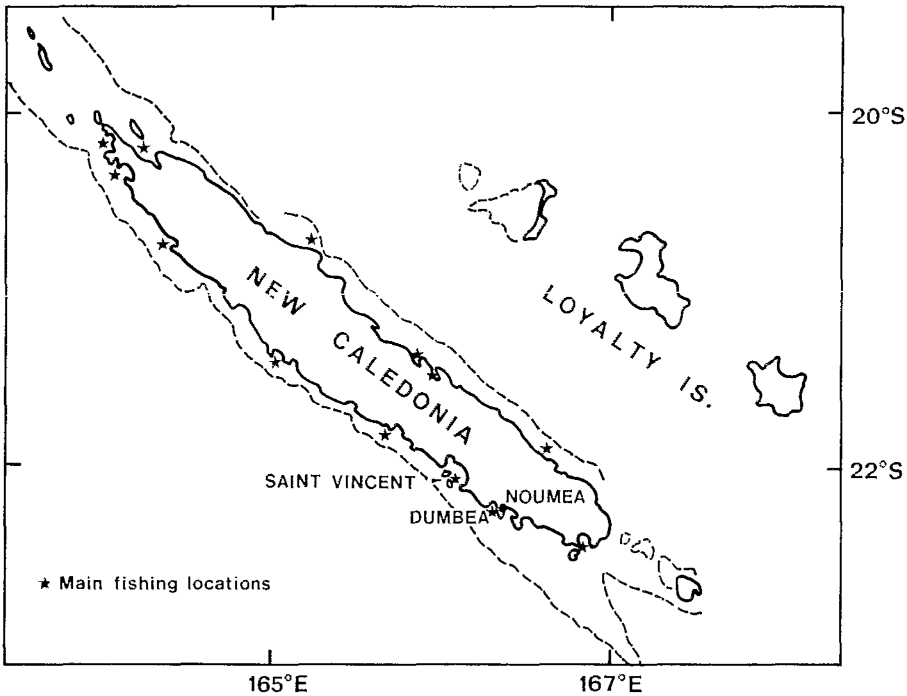

Figure 1. Map of New Caledonia showing the main fishing stations.

0 and 1), ω = period (here 2Π) and Φ = phase (the beginning of the growth oscillations with respect to T = 0). Multifan software (Fournier et al., 1989) has been used for estimating growth parameters. Multifan utilizes a likelihood method based on the approach of Schnute and Fournier (1980) and Fournier and Breen (1983) to simultaneously analyze several length frequency samples. Several estimates were made either cumulating the size distribution frequency on a monthly basis for the whole of New Caledonia, or with observations of one night per month in one bay. The growth of young fish between 30 and 80 mm has been studied by counting increments on otoliths observed with an optical microscope. Although the readings have not been validated by rearing or tagging experiments, it was assumed that for young fish each increment corresponds to one day.

Specimens brought to the laboratory for reproductive work were measured (TL, mm) and the body (g) and the gonad weighed (cg). The sex and maturity stage of the gonads were noted using the Fontana (1969) scale which comprises 7 stages (1: immature; 2: resting; 3: maturing; 4: prespawning; 5: spawning; 6: post-spawning; 7: involution). The gonad index (GI) given by the relation:

$$GI = \text{gonad weight} \times 100/\text{total weight}$$

has been calculated and the variation of its monthly mean, analyzed. Natural mortality can be inferred from the catch curve (Ricker, 1975). To develop this curve, the monthly mean of the number of fish caught per fishing haul has first been calculated for each size class. Then, considering the consistency of the variations of the yield and the sizes, during the 3 years, observations were grouped per month on a yearly basis. Finally, with the back calculated ages the catch curve has been established.

Using the natural mortality, the length-weight relationship and the growth function, it is possible to estimate the theoritical evolution of the instantaneous biomass of a cohort, from the relation:

$$B_t = N \cdot e^{-Zt} W_t$$

where B_t = biomass at time t, N = starting abundance in numbers, Z = total mortality, and W_t = mean weight of a fish at time t.

Results

Annual Variations of Abundance.—The variation during the year of the mean monthly catch of this sardine, in weight and in number of individuals, (Fig. 2)

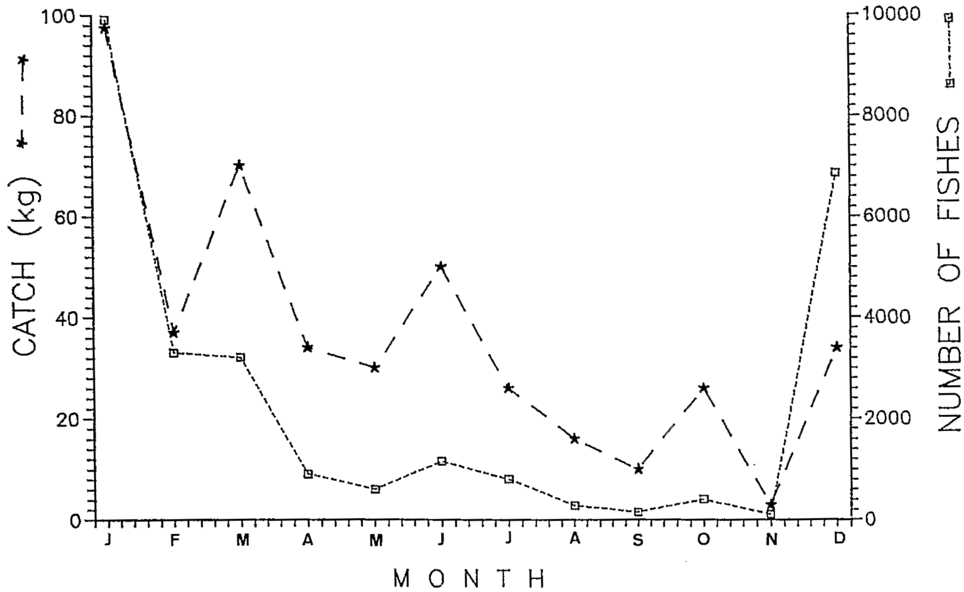

Figure 2. Mean monthly catch per fishing set.

clearly shows that recruitment starts in December at the end of southern hemisphere spring. Catch is highest in January then gradually decreases until November.

Biometric Relationships.—Relations amongst fork length (FL), total (TL) and standard length (SL), calculated from 66 individuals with a TL between 59 and 201 mm are:

$$FL = 0^{\circ}86\ TL + 3^{\circ}92 \quad (r = 0^{\circ}998)$$

and

$$SL = 0^{\circ}81\ TL + 2^{\circ}74 \quad (r = 0^{\circ}998)$$

The length-weight functions:

$$W = aL^n,$$

given in Table 1 were established for males, females, and a balanced sample of juveniles and adults of both sexes. The function adjusted for males or females only takes into account fishes larger than 80 mm. The slope is higher for the function adjusted from the sample including juveniles.

Table 1. Length weight relationship; weight in grams, total length in millimeters; N, number; L_{min} and L_{max}, observation interval

	N	L_{min}	L_{max}	r	a × 10^{-6}	N
Males	192	91	218	0.994	2.62	3.225
Females	248	80	229	0.998	2.47	3.237
Males, Females, Juveniles	397	42	229	0.999	3.49	3.123

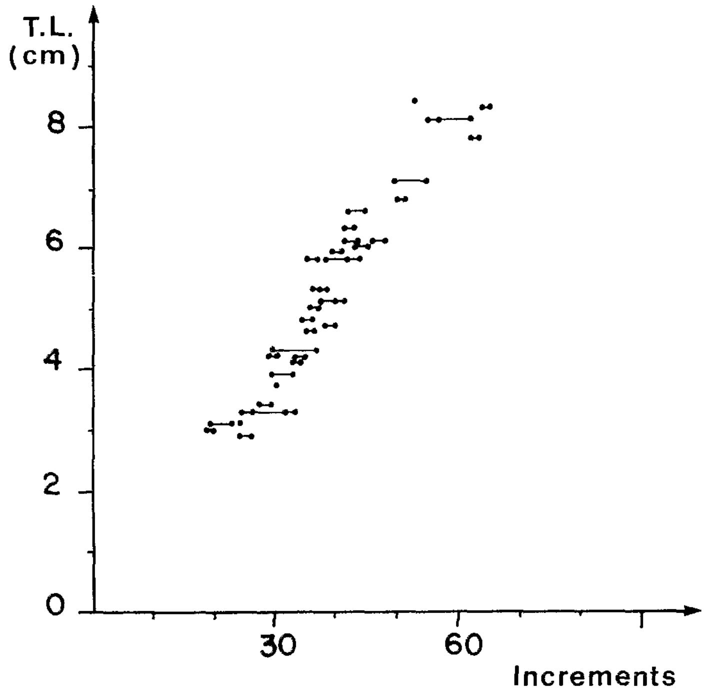

Figure 3. Relationship between otolith increment count and total length for young fish. (Dots for right and left otolith are linked with a line.)

Growth.—Increment counts for 30 to 80 mm fish are presented in Figure 3. They show that 1-month-old sardines measure between 30 and 40 mm and those 2 months-old between 70 and 80 mm. VBGF adjustments were made, on monthly samples from Dumbea Bay in 1982, on Saint Vincent Bay samples from 1980 to 1982 and the monthly grouping of all the observations made in New Caledonia. Histograms and back calculated modal length are given in Figure 4. Parameters of the functions and back calculated age-length values are given in Table 2. With slight variations according to places and years, *A. sirm* in New Caledonia reaches about 12 cm in 6 months, 17 cm in 1 year and 20–21 cm in 2 years.

The modified VBGF was used for Dumbea Bay station which has been sampled very regularly and may be said to have its own population. Adjustment is more precise and reflects a fast growth near March–April at the end of the hot rainy season and a slow growth between September and November at the end of the maturation and during spawning.

Table 2. Parameters of the growth equation and back calculated length. (S): modified function with sinusoidal oscillation

Location, year	Parameters of the equations					Back calculated length age			
	L_∞ (mm)	K (yr^{-1})	t_0 (yr)	α	Φ	3 mth	6 mth	1 yr	2 yrs
Dumbea 1982	211.3	1.58	0.001			69	116	168	202
Dumbea 1982 (S)	216.8	1.35	−0.033	0.499	0.255	69	122	157	201
St Vincent 80-81-82 (S)	232.1	1.10	−0.135	0.084	0.056	100	122	162	209
New Caledonia	221.5	1.58	−0.003			73	122	176	212

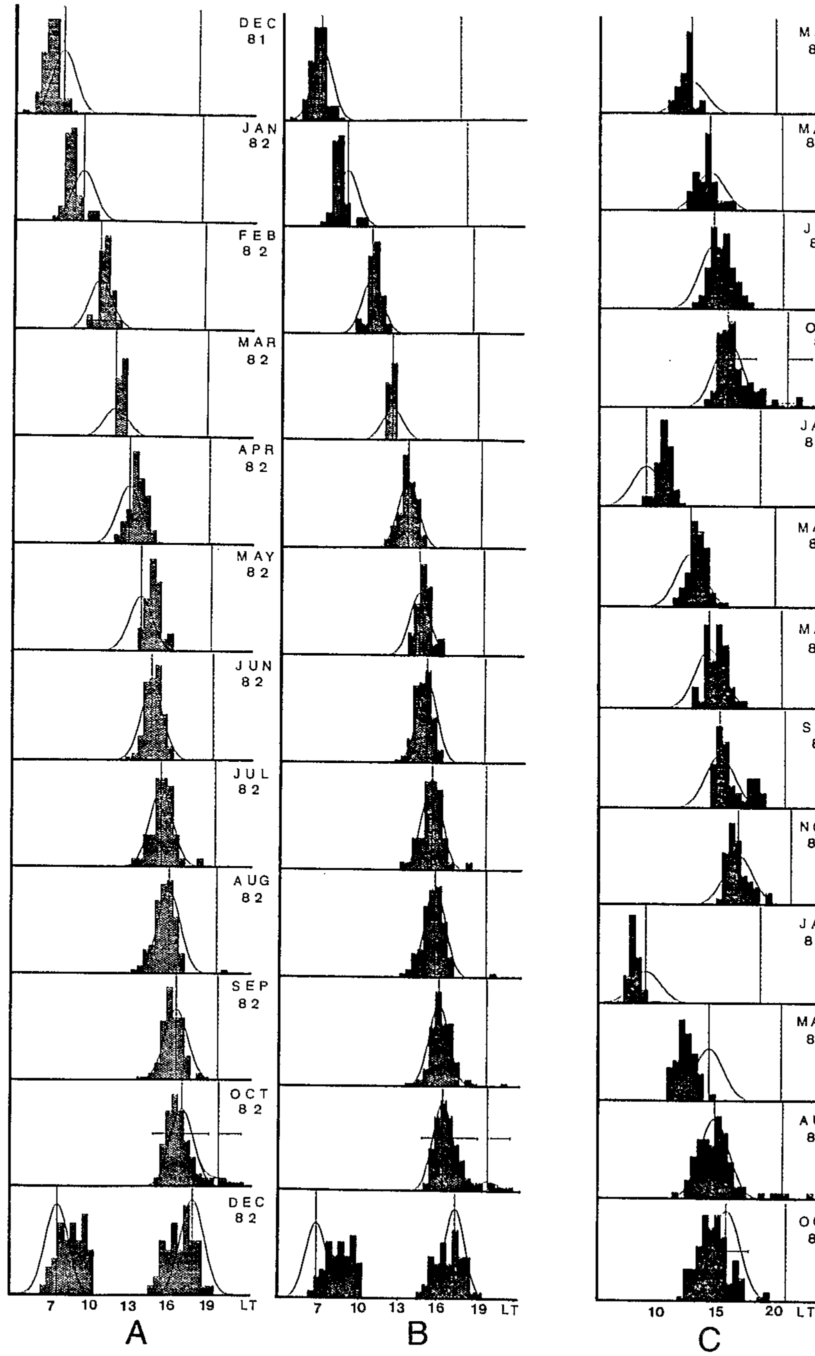

Figure 4. Length frequency histograms and back calculated size from von Bertalanffy growth functions; A) Dumbea Bay in 1982; B) Dumbea Bay in 1982 with the modified function (note the improvement in the adjustment); C) Saint Vincent Bay from 1980 to 1982, with the modified function.

Table 3. Distribution of sexes per fishing set and per size class (TL in mm)

Set	Males	Females	Size	Males	Females
1	39	61	12	0	1
2	42	58	13	0	2
3	66	34	14	13	11
4	28	77	15	32	20
5	28	38	16	59	79
			17	42	80
			18	27	36
			19	20	21
			20	6	8
			21	2	5
			22	2	3
			23	0	2

Reproduction.—Studies of sex-ratio were limited to a few observations (Table 3). They show that one sex is often dominant in a fishing haul, which could result from the dominance of one sex in a school. Observations also show that females are less abundant amongst small fish, but more abundant than males amongst large ones.

The variations of the GI from 1980 to 1982 (Fig. 5) clearly shows that the sexual cycle of *A. sirm* in New Caledonia is regular and annual with a peak occurring in the fourth quarter. This allows the calculation of a mean on a monthly basis of the 3 years of observations. Figure 6 gives the annual cycle of: (a) the monthly proportion of males, females and individuals undetermined by eye observation; (b) the monthly proportion of the maturity stages for males and females; (c) the female gonad index. In January and February, almost all sardines are small juveniles, and gonads develop gradually from March till September. Between October and December, all the fish are mature and spawning.

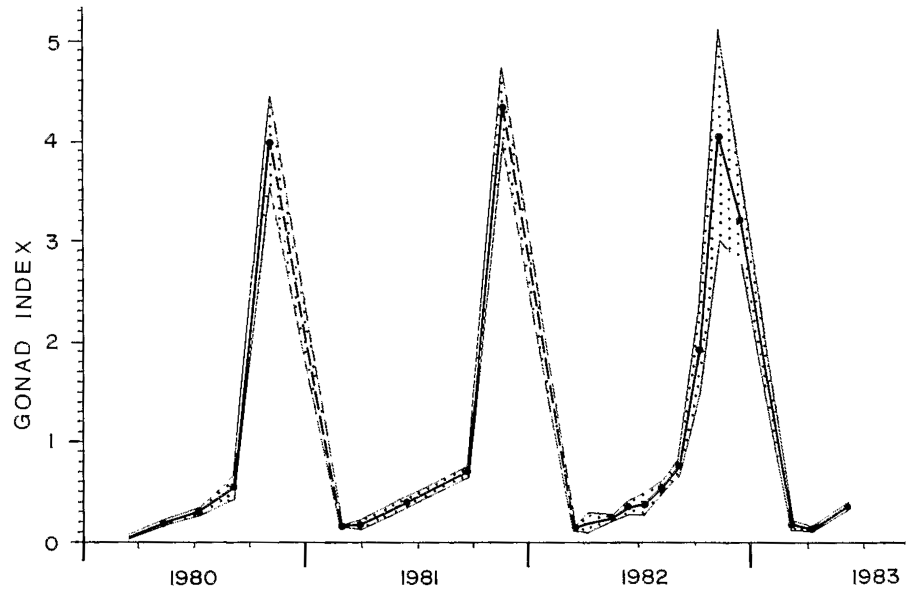

Figure 5. Three consecutive years of female gonad index: mean gonad index computed per fishing cruise; shaded area for 95 p. cent confidence interval.

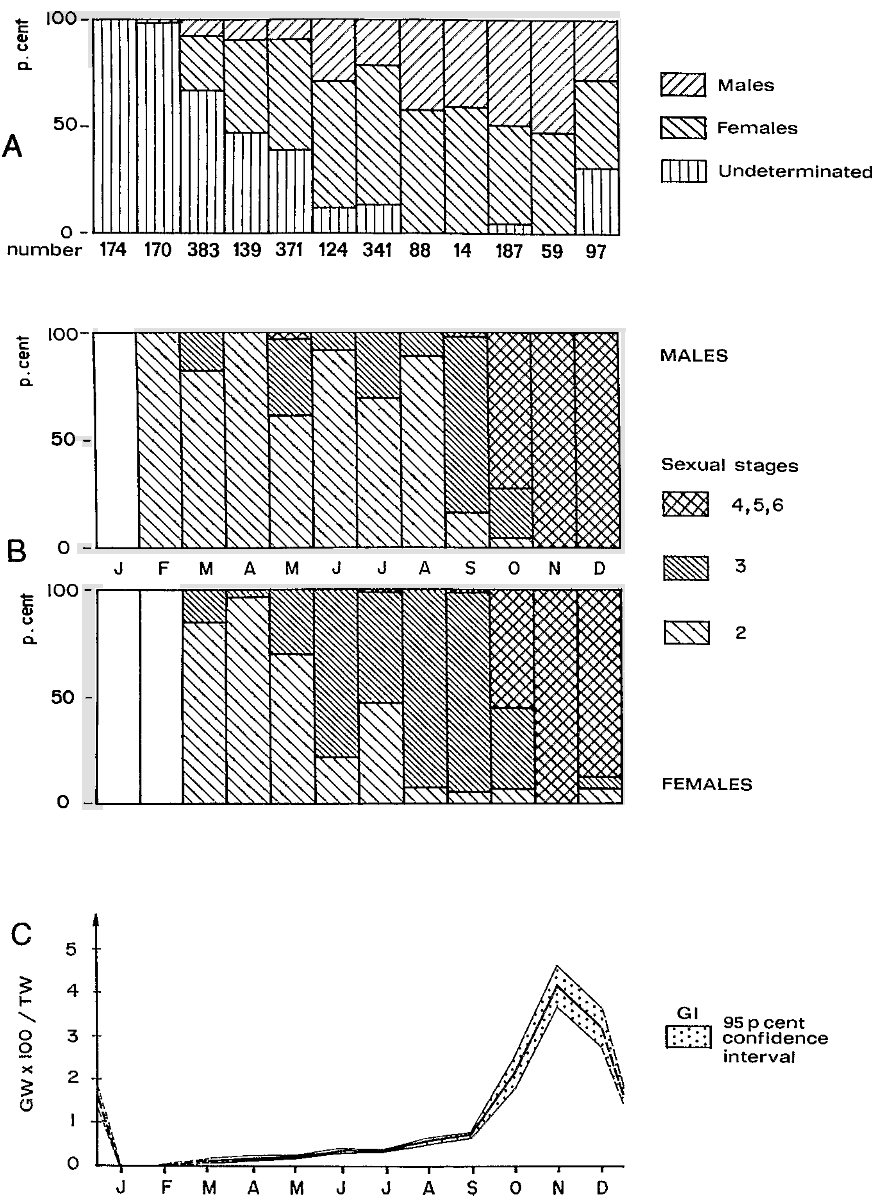

Figure 6. Reproduction of *A. sirm*. Mean of 3 years of observations: A) monthly proportion of males, females and undetermined; B) monthly proportion of maturity stages for males and females; C) GI as a function of month for females.

All fish reach maturity in October and at that time they are 10 to 12 months old. Smallest specimens are 12 cm but the mode is 16 cm and this value represents the mean size at first maturation.

To estimate batch fecundity, the ovocytes of the last mode of their size distribution were counted for 24 females measuring between 168 and 215 mm caught in October and November. Fish were at stage 4. The relation between batch fecundity and weight (in grams) is:

Table 4. Catch per unit effort (number of individuals per fishing set). Monthly value and total, per size class

Class midlength	Month												Total
	01	02	03	04	05	06	07	08	09	10	11	12	
35	78	0	0	0	0	0	0	0	0	0	0	150	228
45	145	43	0	0	0	0	0	0	0	0	0	818	1.006
55	814	103	0	0	0	0	0	0	0	0	0	2.513	343
65	2.286	466	31	2	0	0	0	0	0	0	5	1,429	4.219
75	1,940	856	153	6	0	0	0	0	0	0	2	946	3.903
85	1,729	450	251	7	0	0	0	0	0	0	0	288	2.725
95	915	393	320	11	0	0	0	0	0	0	0	161	1.800
105	1.483	306	265	165	0	0	0	0	0	0	0	0	2.219
115	525	473	331	163	11	6	0	1	0	0	0	0	1.510
125	22	213	506	192	56	157	1	3	0	8	0	0	1.158
135	0	13	570	216	65	361	12	20	0	33	0	0	1.290
145	0	0	420	69	115	284	115	35	6	54	0	0	1,098
155	0	0	222	17	153	161	186	82	23	81	0	2	927
165	0	0	113	3	91	109	155	73	46	91	0	4	685
175	0	0	33	0	42	63	117	13	34	44	8	10	364
185	0	0	28	0	14	26	77	3	16	17	18	11	210
195	0	0	7	0	7	6	35	2	6	14	6	6	178
205	0	0	7	0	1	6	20	3	4	12	0	1	54
215	0	0	4	0	0	0	9	0	1	17	0	0	31
225	0	0	2	0	0	0	0	1	0	6	0	1	10
235	0	0	0	0	0	0	0	0	0	1	0	0	1
245	0	0	0	0	0	0	0	0	0	1	0	0	1

$$F = 300W - 132$$

with a standared variation of 83 and $r = 0.97$. It has not been possible to establish how many batches of eggs are laid in a spawning season, so, the total fecundity is still unknown.

Mortality, Theoretical Evolution of a Cohort.—From monthly observations of size frequency and CPUE, expressed in number of fish per fishing haul, a CPUE per size class for each month and for the year is inferred (Table 4). From this value and the growth function it is possible to calculate the catch per age (Annex 1), to draw the catch curve (Fig. 7) and to estimate the total mortality:

$$Z = 2.9 \pm 0.1$$

As there is almost no fishery for sardine in New Caledonia the total mortality is also the natural mortality.

The theoretical evolution of the biomass of a cohort of 100,000 fish at 1 month, (age of the recruitment) is shown in Figure 8. The maximum biomass occurs at 7 months and this critical size is attained slightly before the first maturity.

Life Cycle.—In New Caledonia the sardine *Amblygaster sirm* reaches maturity as it approaches 1 year of age. The spawning season occurs from October to December, before the hot, rainy season. There are probably several spawnings (most Clupeids are serial spawners) (Hunter and Goldberg, 1980; Alheit, 1988). The lifespan is short and the fish usually die after spawning or at least if it survives, before reaching the next spawning season.

Discussion

Results on growth, from several studies, are summarized in Table 5. Early studies (Rafail, 1972; Burhanuddin et al., 1974; Sanders and Kedidi, 1984) prob-

Annex I. Showing the steps for the construction of the catch curve of *Amblygaster sirm* with L_{∞} = 221.5 (TL in mm), K = 1.58 (yr^{-1}), t_0 = −0.003 (yr), Dt, time spend in the size class; N, number of fish

Class limits		Age						
Lower	Upper	In	Out	Dt	N	N/Dt	Log_eN/Dt	Mean age
30	40	0.089	0.123	0.034	228	6,706	8.81	0.106
40	50	0.123	0.159	0.036	1,006	27,944	10.24	0.141
50	60	0.159	0.197	0.038	3,432	90,316	11.41	0.178
60	70	0.197	0.237	0.040	4,219	105,475	11.57	0.218
70	80	0.237	0.281	0.044	3,903	88,704	11.39	0.259
80	90	0.281	0.327	0.046	2,725	59,239	10.99	0.303
90	100	0.327	0.377	0.050	1,800	36,000	10.49	0.352
100	110	0.377	0.431	0.054	2,219	41,093	10.62	0.404
110	120	0.431	0.491	0.060	1,510	25,167	10.13	0.461
120	130	0.491	0.557	0.066	1,158	17,545	9.77	0.523
130	140	0.557	0.630	0.073	1,290	17,671	9.78	0.592
140	150	0.630	0.713	0.083	1,098	13,229	9.49	0.670
150	160	0.713	0.808	0.095	927	9,758	9.18	0.759
160	170	0.808	0.921	0.113	685	6,062	8.71	0.862
170	180	0.921	1.057	0.136	364	2,676	7.89	0.985
180	190	1.057	1.232	0.175	210	1,200	7.09	1.138
190	200	1.232	1.473	0.241	89	369	5.91	1.341
200	210	1.473	1.870	0.397	54	136	4.91	1.641
210	220	1.870	3.159	1.289	31	24	3.18	2.230
220	230	3.159			10			

ably underestimated sardine growth when they adjusted a VBGF giving sizes of 10 to 11 cm at 1 year and 15 to 17 cm at 2 years. On the other hand, estimates of growth based on otolith readings with the assumption of the formation of one increment per day (Gjosaeter et al., 1984; Dayartne and Gjosaeter, 1986) give a size of 16 to 17 cm at 6 months and 20–21 cm at 1 year and might be overestimated. Several studies of otolith increments were made with checks on free or cultured tagged fish. They show that on some species, on some days, no increment is formed (Jones, 1986), or the increment is very thin and below the detection power of the light microscope (Campana and Neilson, 1985). VBGF adjustments made by Ingles and Pauly (1984) and Sadhotomo and Atmadja (1985) correspond, up to the second year, to those observed in New Caledonia and are within the interval of the variation observed according to the locations and the years.

In Sri Lanka, Dayartne and Gjosaeter (1986) have observed *A. sirm* sardines, maturing in February and they found them to be totally mature from April to June. These observations from the northern hemisphere agree with those of New Caledonia with a 6 months shift. Knowledge of batch fecundity has limited interest as this fish is probably a serial spawner and spawns a number of batches during the season. Studies carried on several species of Clupeids and Engraulids, using Hunter and Goldberg (1980) method, show a spawning frequency varying usually between 2 and 8 days. By another way, Thorrold (1989) has shown, with otolith daily increments analyzed for *Herklotsichtys castelnaui,* a sardine from Queensland estuaries, that spawning occurred mostly twice per lunar month, at neap tides. These two techniques could give interesting information on the real fecundity of *A. sirm.*

The mortality rate estimated in New Caledonia is higher than those given by Ingles and Pauly (1984) and Sadhotomo and Atmadja (1985) who observe growth rates similar to ours for the first 2 years. For Ingles and Pauly (1984) 4- or 5-year-old fish would not be exceptions. From our study it seems that in New

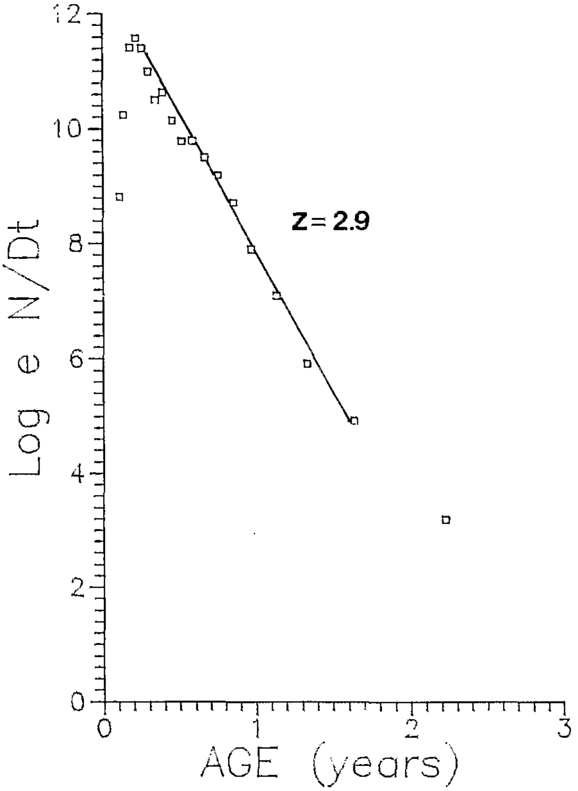

Figure 7. Catch curve used to infer mortality; points are means for all areas.

Caledonia, 2-year-old fish are few and it would be very unusual for a fish to reach 3 years. Size dispersion around the mean let even suppose that the largest specimens were in fact only 2 years old.

Conclusion

Amblygaster sirm in New Caledonia is a fast growing fish of medium size with a short lifespan. The reproductive season is well defined and lasts 2 or 3 months and first maturity is reached when fish attain their first year. Mortality is high

Table 5. Comparison of the results on growth and mortality of *A. sirm* from studies in various region of the Indo-Pacific

Reference	Location	Length (cm age)			L_∞ (cm)	K (yr^{-1})	M (yr^{-1})
		6 mth	1 yr	2 yrs			
Rafail (1972)	Egypt	6	11	17	22.6	0.65	1.45
Sanders and Kedidi (1984)	Egypt	—	10	15	26.1	0.37	1.49
Gjosaeter et al. (1984)	Mozambique	16	20	—	22.0	2.5	3.41
Dayartne and Gjosaeter (1986)	Sri Lanka	17	21	—	22.9	2.38	—
Burhannudin et al. (1974)	Indonesia	6	17	23	24.3	0.59	1.34
Sadhotomo and Atmadja (1985)	Indonesia	11	17	23	25.2	1.17	2.08
Ingles and Pauly (1984)	Philippines	10	16	23	27.3	0.86	1.66
Present study	New Caledonia	12	17	21	22.2	1.58	2.9

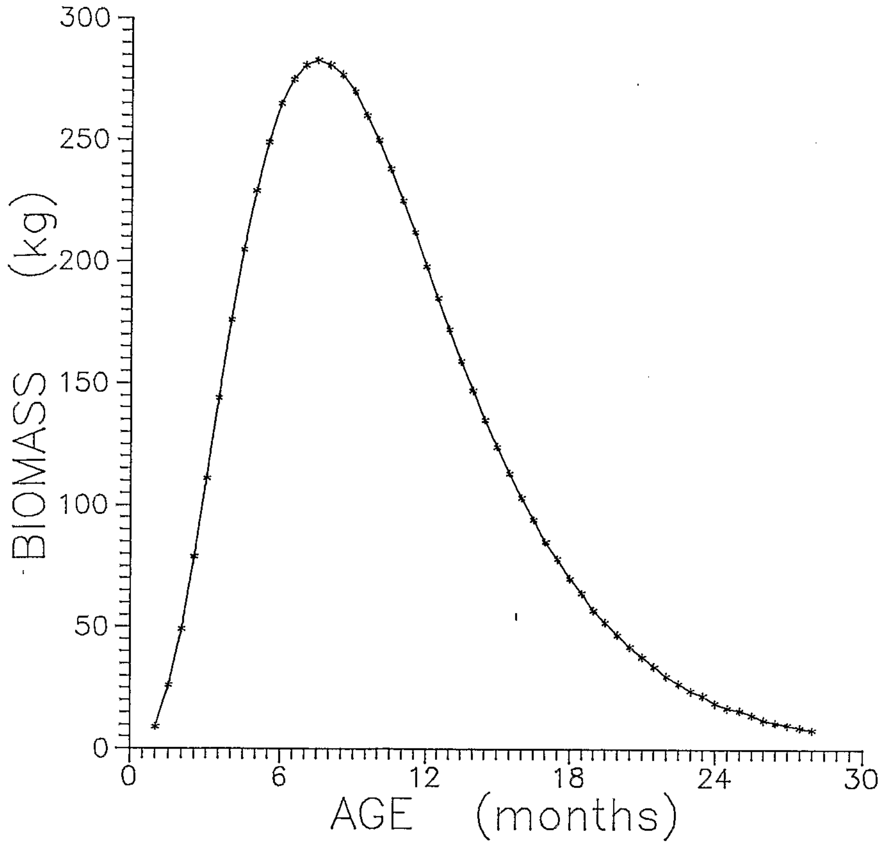

Figure 8. Theoretical form of the instantaneous biomass of a cohort of 100,000 one month old individuals.

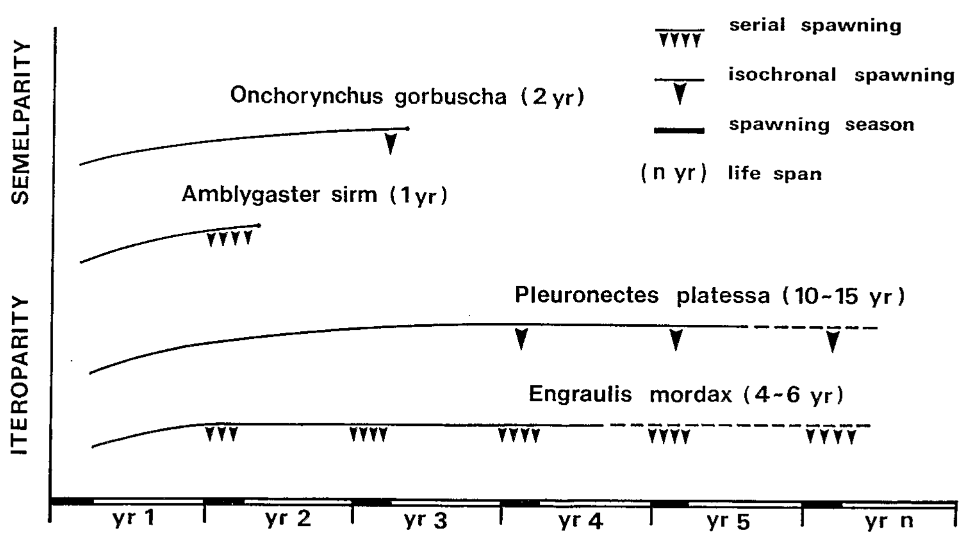

Figure 9. Example of four reproductive strategies of fish with seasonal spawning period.

and fish usually die before the second year, however some individuals can have a second spawning season. This phenology is compared with other seasonal spawners (Fig. 9). Isochronal spawners like for example *Pleuronectes platessa* in temperate waters (Simpson, 1951) or serial spawners like *Engraulis mordax* (Hunter and Goldberg, 1980) have a limited annual spawning season which repeats for several years. With adults dying after they have spawned, *Onchorhynchus gorbuscha*, a Pacific salmon, is on the opposite typically semelparous (Mann and Mills, 1979). *A. sirm* appears intermediate and shows a tendency towards semelparity as it dies after a unique breeding season which lasts 2 or 3 months, during which it spawns several times. "Semelparity is an option for a short lifespan with a high reproductive effort and fecundity" (Mann and Mills, 1979). But it requires a strategy ensuring that the population maintains itself if unfavorable conditions, occuring during larval or juvenile life lead to a recruitment failure. The intermediate strategy of *A. sirm* combines the advantage of high reproductive effort and the increase of survival probability with several cohorts.

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