Dynamics of the populations of the maize stem borer, *Eldana saccharina* Walker (Lepidoptera: Pyralidae), in Côte d'Ivoire.
I- Borer abundance.

Pascal Moyal

ORSTOM, B.O. 26, Giza, Cairo, EGYPT.

Running title: *Eldana saccharina* abundance in Côte d'Ivoire.

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Mots-clés: *Eldana saccharina*, foreur du maïs, Afrique de l'ouest, dynamique des populations.

Moyal Pascal.

Dynamics of the populations of the maize stem borer, Eldana saccharina Walker (Lepidoptera : Pyralidae), in Côte d'Ivoire : 1. Borer abundance 2. Influence of some abiotic and biotic factor.

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Abstract

Populations of the stem borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) were monitored in maize crops in Côte d'Ivoire from 1982 to 1989. In the Guinean zone (southern half of the country), where several maize cycles can be grown throughout the year, populations were low during the first cycle (planting from March till May), rose to a peak in October-November during the second cycle (planting from June till August), and decreased during the third cycle (planting in September-October) and the dry season (from December to February). The abundance of the pest in the various ecological regions was studied during the second maize cycle, which can be grown in most of Côte d'Ivoire. Population density proved to be low (less than 1 borer per stem) in the Sudanese zone (northern half of the country) and in the western highlands and high in the Guinean zone (3 to 10 borers per stem). It is concluded that *E. saccharina* is a major pest of the second and third maize cycles in the Guinean zone of Côte d'Ivoire, where it caused crop losses lying in most cases between 25% and 65%.

Résumé

Les populations du foreur de tiges *Eldana saccharina* Walker (Lepidoptera: Pyralidae) ont été suivies dans des cultures de maïs en Côte d'Ivoire de 1982 à 1989. Dans la zone guinéenne (moitié sud du pays), où plusieurs cycles de maïs peuvent être cultivés au cours de l'année, les populations ont été faibles au cours du premier cycle (semis de mars à mai), se sont accrues durant le second cycle (semis de juin à août) atteignant un pic en octobre-novembre, puis ont décru durant le troisième cycle (semis en septembre-octobre) et la saison sèche (de décembre à février). L'abondance du ravageur dans les diverses régions écologiques de Côte d'Ivoire a été étudiée au cours du second cycle de culture, qui peut être réalisé dans la plus grande partie du pays. La densité de population est apparue faible (moins de 1 foreur par tige) dans la zone soudanienne (moitié nord du pays) et dans la région montagneuse de l'ouest et forte dans la zone guinéenne (3 à 10 foreurs par tige). Il a été conclu que *E. saccharina* est un ravageur majeur des second et troisième cycles dans la zone guinéenne, où cette espèce a été à l'origine de pertes de récolte allant dans la plupart des cas de 25% à 65%.

Introduction

The maize stem borer, *Eldana saccharina* Walker (Lepidoptera: Pyralidae), is a major pest of cereal crops in most African countries south of Sahara (Betbeder-Matibet, 1983). Whereas it is mentioned mainly as a pest of sugarcane in South Africa (Atkinson, 1980), this borer is generally reported as a maize pest in eastern Africa (Uganda and Tanzania - Girling, 1978) and western Africa (Ghana, Benin, Nigeria - Girling, 1980; Atachi, 1989; Bosque-Pérez & Mareck, 1990).

Infestations of maize crops by this pest generally begin at anthesis (Bosque-Pérez & Mareck, 1990 and 1991). Oviposition occurs on debris on the soil (Atkinson, 1980), on the hairy margins of maize leaf sheaths, and on cob husks (Tran, 1981; Cochereau, 1985). Generally larvae enter the stem little after hatching, but sometimes feed first a few days on the leaf sheaths.

In Côte d'Ivoire, the fluctuations of populations of the pest in maize crops were first studied in two localities of the southern and central regions (Pollet *et al.*, 1978; Dabiré, 1980). Borer populations were also studied in sugarcane crops and compared with those observed in adjacent maize crops (Cochereau, 1982 and 1985). In the present study, *E. saccharina* populations were monitored in maize crops during eight years. The paper reports on the abundance of the species in the different ecological regions of Côte d'Ivoire and on the fluctuations of populations throughout the growing seasons of maize.

Material and Methods

The abundance of *E. saccharina* in maize crops of Côte d'Ivoire was studied yearly from 1982 to 1989. The country is divided into two main ecological regions: the Guinean zone in the south and the Sudanese zone in the north (Fig. 1) (Guillaumet & Adjanohoun, 1971; Monnier, 1978). The Guinean zone, which is mainly a forest area, is divided into three sectors:

forest sector, which is a forest-savannah mosaic region; and between both, the Mesophil sector, which is a region of semi-deciduous rain forest. The Sudanese zone, which is a savannah area, is divided into two sectors: the Sudanese sector, which is restricted to a little fringe in the north of the country, and the Sub-sudanese sector between the latter and the

Guinean zone. Altitude is low in most of the country (less than 400m above sea level) except in the western regions: from Man to Boundiali (Fig. 1) it lies between 500m and 900m, with peaks of more than 900m around Man (Avenard, 1971).

The maize growing seasons per sector vary, depending on rainfall. The timing and duration of rainy seasons are due to the movements of the Inter-Tropical Convergence Zone (ITCZ) (Eldin, 1971). In the Sudanese zone only one rainy season occurs, generally from May till October, and only one maize crop is grown in a year. In the Mesophil and Ombrophil sectors of the Guinean zone, only one rainy season may also occur, from February-March till November, but usually a short dry season occurs in July-August because the ITCZ generally reaches a sufficiently high latitude degree at this time. Two rainy seasons are then observed, before and after this short dry season, which permit the growing of maize twice a year. In the Pre-forest sector of the Guinean zone, one or two rainy seasons occur depending on the maximum latitude degree reached by the ITCZ.

In the whole of the country three rainfed maize cycles can thus be grown. The first cycle, which is planted from March till May, is generally grown in the Guinean zone. The second cycle is planted from June till August: it is the only cycle grown in the Sudanese zone and in the mountainous region around Man, and it can also be grown in most other regions. The third cycle, which is planted in September or October, can be grown during the second rainy season in the Mesophil and Ombrophil sectors of the Guinean zone.

E. saccharina populations were monitored in maize crops grown on research stations of the Institut des Savanes (IDESSA) (Bouaké, Ferké, Gagnoa, and Man), a private firm (Roussel-Uclaf) (Bouaké and Brobo), and on observation sites of the Development Services (other localities) (Fig. 1). Rainfed maize crops were grown during the different rainy seasons. In addition, irrigated crops were grown during the dry season in Bouaké (Fig. 1).

The maize variety used was 'Composite Jaune de Bouaké', the most widely distributed variety in Côte d'Ivoire (CIDT, 1984). It has a growing season of about 100 days from sowing to harvest, and a maximum yield of 6,200 kg/ha (IDESSA, 1982). Planting was done at a spacing of 0.80m between rows and 0.20m between plants. 300 kg/ha N-P-K (10-18-18) fertilizer were applied at planting and 75 kg/ha urea at male flowering.

During the first three years, *E. saccharina* abundance was studied in the cotton-growing region, which includes the Sudanese zone, the Preforest area of the Guinean zone, and stretches to Daoukro in the east of the Mesophil sector of the Guinean zone (Fig. 1). From 1985 to 1989, borer populations were studied mainly in localities of the Guinean zone.

Random samplings were made every 20 days, except in 1982 when, in most cases, only one sampling was done 80 days after seedling emergence. Plant samples were taken either in observation plots (samples of 100 plants) or in the control plots of agronomic experiments (samples of 25 to 50 plants, depending on the number of replications). The sampled plants were dissected and borer numbers recorded.

Results and discussion

Attacks by *E. saccharina* commenced generally between 50 and 60 days after seedling emergence (DAE), at the beginning of grain filling period. However earlier attacks, which began about 20 DAE, were observed rarely (in Béoumi and Daoukro only). Population densities generally increased up to a maximum observed between 80 DAE and 100 DAE. Table 1 presents the average borer abundance at 80 DAE and 100 DAE in the different ecological sectors of Côte d'Ivoire.

Very low borer densities were observed in the Sudanese zone. In the Sudanese sector no borer at all (in Tengrela) or densities close to 1 borer per stem (in Ferké) were recorded. In the northern part of the Sub-sudanese sector (Boundiali, Dianra, Korhogo) very low populations (less than 10 borers per 100 stems) were also observed. Populations were slightly higher in the western area of the Sub-sudanese sector (Touba), and increased in the central area (Niakara, Dabakala), up to two borers per stem in Niakara in 1984.

In the Guinean zone borer densities were generally high. They varied from a minimum of 1-2 borers per stem in June plantings (Bouaké, 1983 and 1986) to a maximum of more than 14 borers per stem in August plantings (Bouaké, 1987). In most crops, the maximum observed density in the preforest and mesophil sectors was between 3 and 8 borers per stem. Populations were lower only in Daoukro (eastern part of the Mesophil sector) (about 2 borers per stem in 1984 and 1989) and in the western highlands (Man) were they were in most years less than 1 borer per stem.

In the Ombrophil sector, the collected data showed a decrease in borer densities southwards. In Binao (center part), close to the limit between the Mesophil and Ombrophil sectors, 3 borers per stem were found and only 1 borer per stem in San-Pédro (western part), along the Atlantic cost.

Fluctuations of population densities throughout the year were studied from 1986 to 1989 in two localities, Gagnoa and Bouaké. In Gagnoa three rainfed maize cycles were grown throughout the year, and in Bouaké irrigated crops were planted during the dry season in addition to the rainfed cycles grown each year. Population densities in each crop at 60, 80 and 100 DAE are presented in figure 2. Population fluctuations were very similar in both localities. The first maize cycle (planting from March to May), grown during the first rainy season, was very little attacked by *E. saccharina*, with generally less than 10 borers per 100 stems. Borer abundance increased during the following months up to most high densities during the second cycle (6 to 14 borers per stem in October-November). Then, population densities decreased during the third cycle (3 to 4 borers per stem in Gagnoa) and reduced regularly during the dry season, down to the low densities observed in the first cycle. The density minima were observed in May-June, during the first rainy season. Similar fluctuations were observed in other localities of the Mesophil sector like Bongouanou (eastern part).

The observed fluctuations are consistent with Dabiré's observations (1980) in Bouaké. Similar annual cycles of *E. saccharina* were also noticed in the forest region of Nigeria (Bosque-Pérez and Mareck, 1990) and of Ghana (Girling, 1980). It can then be concluded that such fluctuations are likely the usual case in the Guinean zone. In the last two cases however the authors, who studied population densities in the first and third maize cycles, indicated that the third one can be a complete loss as a consequence of attacks by *E. saccharina*. The present investigation in Gagnoa, in the same ecological region, showed nevertheless that the crops planted in September suffered much less from attacks by the borer than the second maize cycle. During the third cycle the annual graph of population densities was in a decreasing phase: 3 to 4 borers per stem were observed, which could not result in a destruction of the crop (Moyal, 1996).

Fluctuations of *E. saccharina* populations can also be compared to those of the Noctuids *Poeonoma serrata* (Hampson) and *Sesamia botanephaga* Tams and Bowden at Kumassi, in the forest region of Ghana (Bowden, 1976). Populations of these borers are lowest at the end of the dry season (February and March) and are rising to maximum numbers from August to October. This cycle is similar to the annual march of humidity but quite different from rainfall, which is bi-modal with peaks from April-June and September-October. In Côte d'Ivoire, rainfall is similar to that of Kumassi in Gagnoa whereas in Bouaké the second peak occurs earlier, in August-September. However the lowest populations of *E. saccharina* were observed in Bouaké during the first rainy season, in May-June, and the peak of density occurred at the end of the second rainy season, in October-November. Fluctuations of the populations of *E. saccharina* are then delayed in comparison with those of *P. serrata* and *S. botanephaga* and are likely not so dependent on relative humidity.

The study of abundance of *E. saccharina* during the second cycle showed clearcut differences between regions of Côte d'Ivoire. In the Sudanese zone and in the western highlands of the Guinean zone populations never rose to high numbers. In contrast high densities were observed in the central and eastern areas of the Guinean zone. The present investigation enables therefore to estimate the crop loss risk in the different regions using the model developed by Moyal (1996). Thus, the maximum percentage of crop loss in the Sudanese zone and in the region of Man, caused by infestations of 1 large borer per stem 80 DAE, is about 8.0%. In the Guinean zone, attacks by 3, 5, and 10 large borers per stem 80 DAE resulted respectively in 23.0%, 37%, and 65% crop loss. Population densities observed in the course of the present study showed then that *E. saccharina* was a regular cause of severe crop losses in maize crops of the second and third cycles in most of the Guinean region. In contrast, in the Sudanese zone, in the western highlands, during the first cycle, and during the dry season, populations of *E. saccharina* were low and did not result in economic damage to maize crops.

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Table 1. Average number of *Eldana saccharina* larvae per 100 stems at 80 and 100 days after emergence (**80** and **100**, respectively) in the ecological sectors of Côte d'Ivoire from 1982 till 1989. Cycles 1 to 3: rainfed maize cycles. Cycle 1: maize emergence from 01 March till 15 May; cycles 2a and 2b: second maize cycle. Cycle 2a: maize emergence from 16 May till 30 June; cycle 2b: maize emergence from 01 July till 15 August; cycle 3: maize emergence from 16 August till 30 September; cycle SS1: first cycle of dry season, maize emergence from October till the end of December; cycle SS2: second cycle of dry season, maize emergence from January till the end of February.

Sector	1982		1983		1984		1985		1986		1987		1988		1989	
	80	**100**	**80**	**100**	**80**	**100**	**80**	**100**	**80**	**100**	**80**	**100**	**80**	**100**	**80**	**100**
Sudanese	0	0	0	0	-	-	-	-	-	-	-	-	111	104	58	-
Sub-Sudanese																
North	0	0	0	0	5	8	-	-	-	-	-	-	-	-	-	-
center	64	-	29	8	150	205	-	-	-	-	-	-	-	-	-	-
West	50	-	8	13	3	3	-	-	-	-	-	-	-	-	-	-
Pre-forest																
Cycle 1	-	-	-	-	-	-	0	-	17	51	130	111	7	7	-	-
Cycle 2a	96	-	53	159	-	-	4	-	96	128	-	-	-	-	-	-
Cycle 2b	-	-	-	-	778	303	-	-	817	371	-	-	274	1198	596	716
Cycle 3	-	-	-	-	-	-	60	-	-	-	1348	1452	-	-	-	-
Cycle SS1	-	-	-	-	-	-	-	-	20	90	304	169	82	133	33	13
Cycle SS2	-	-	-	-	-	-	0	-	14	28	40	83	-	-	113	43
Mesophil																
East																
Cycle 1	-	-	-	-	-	-	-	-	-	-	-	-	8	20	-	-
Cycle 2a	671	-	-	-	220	185	-	-	-	-	45	227	2	80	43	168
Cycle 2b	-	-	-	-	-	-	-	-	-	-	-	-	1064	326	-	-
Cycle 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Center																
Cycle 1	-	-	-	-	-	-	4	-	3	17	300	794	41	150	3	-
Cycle 2a	-	-	-	-	-	-	-	-	288	132	-	-	455	370	220	538

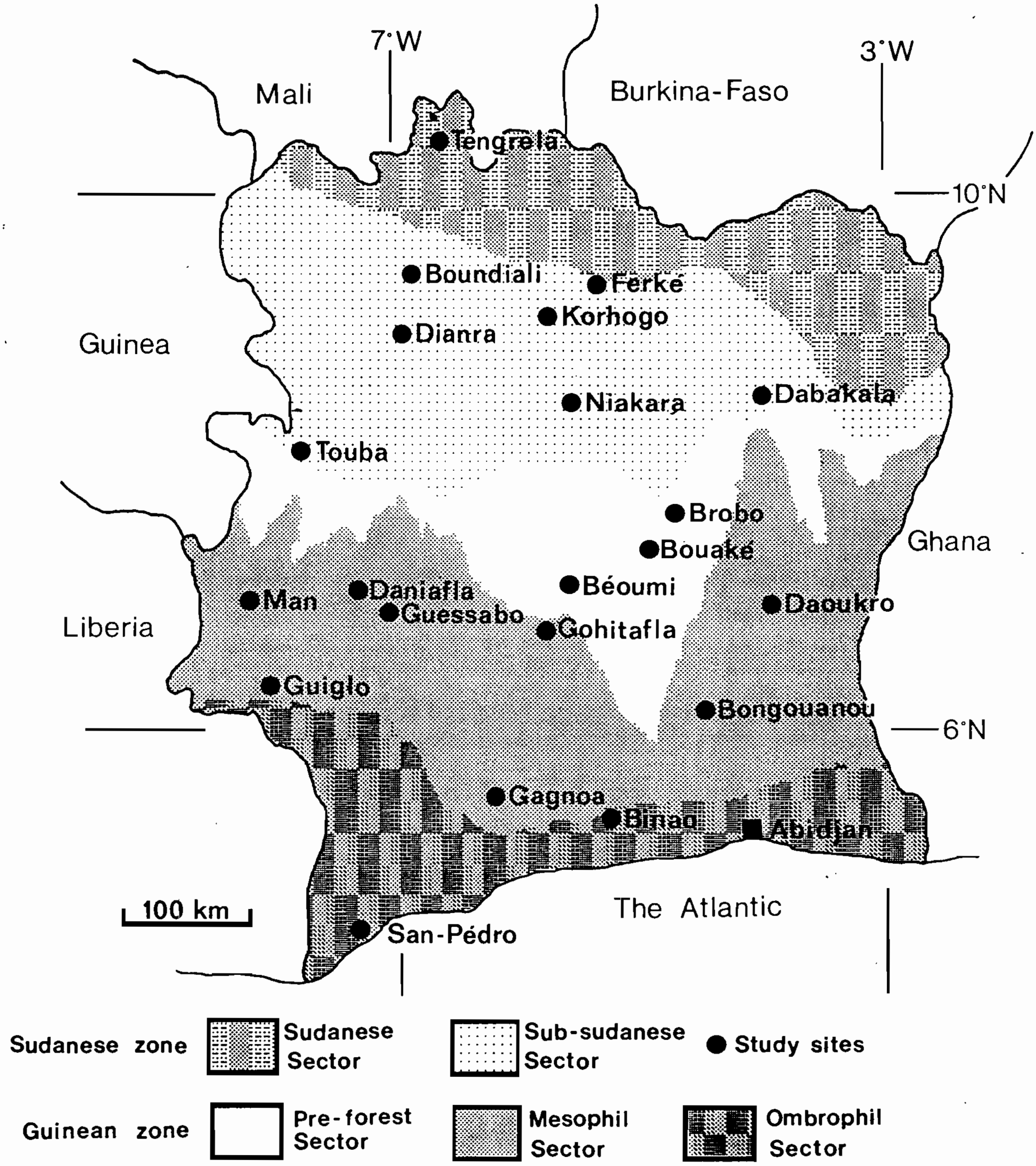
Cycle 2b	348	-	246	676	-	-	-	-	-	-	605	678	816	-	364	-
Cycle 3	-	-	-	-	-	-	-	-	200	101	272	228	182	419	48	346
West																
Cycle 2a	-	-	-	-	-	-	-	-	60	99	14	72	131	336	-	-
Cycle 2b	-	-	-	-	-	-	-	-	-	-	-	-	320	-	34	60
Ombrophil																
East																
Cycle 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cycle SS1	-	-	-	-	-	-	-	-	200		-	-	-	-	-	-
Center																
Cycle 2a	-	-	-	-	-	-	-	-	-	-	-	-	106	340	-	-
West																
Cycle 2a	-	-	-	-	-	-	-	-	-	-	-	-	95	-	-	-
2b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

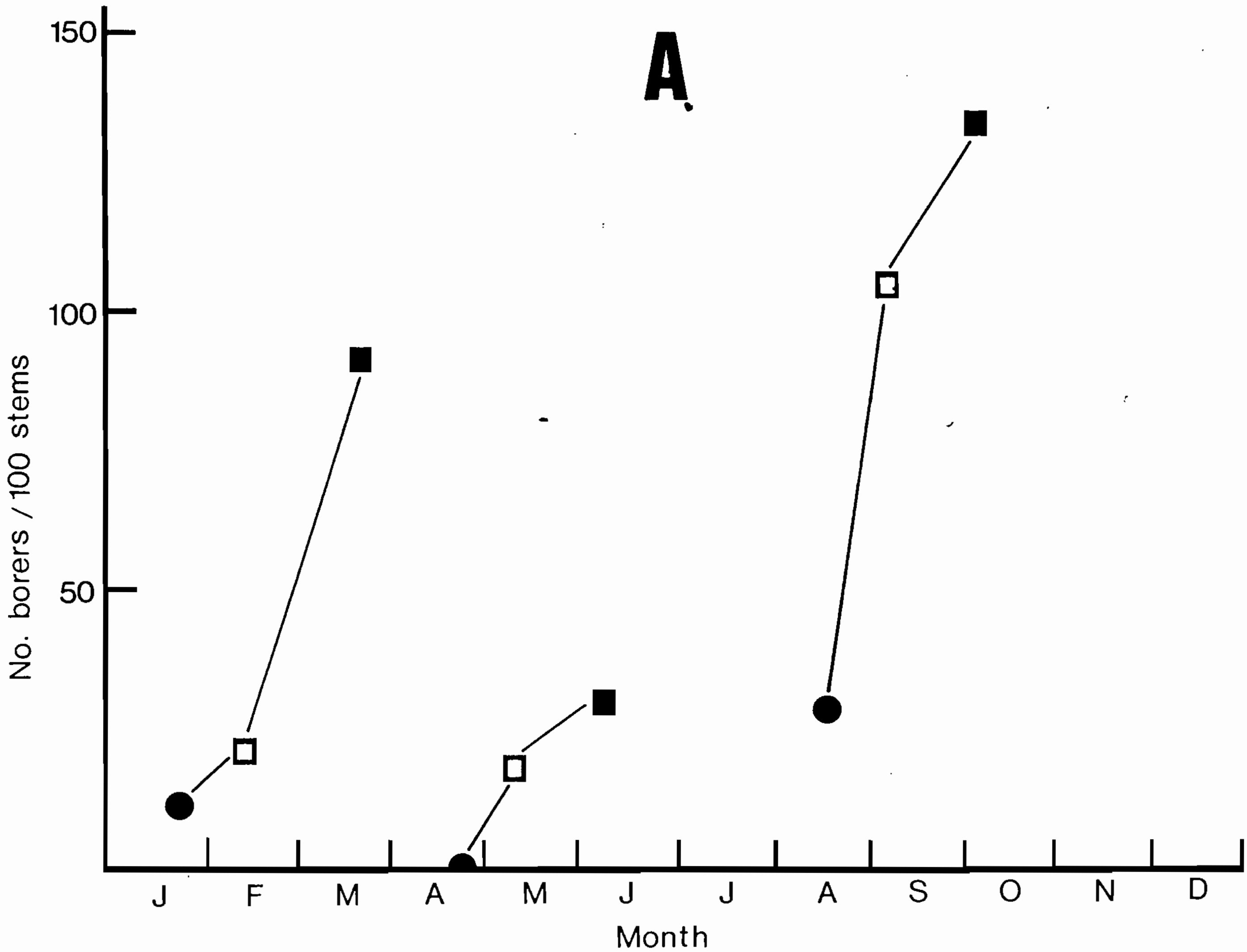
Figure captions

Fig. 1. Map of Côte d'Ivoire showing the ecological zones and sectors.

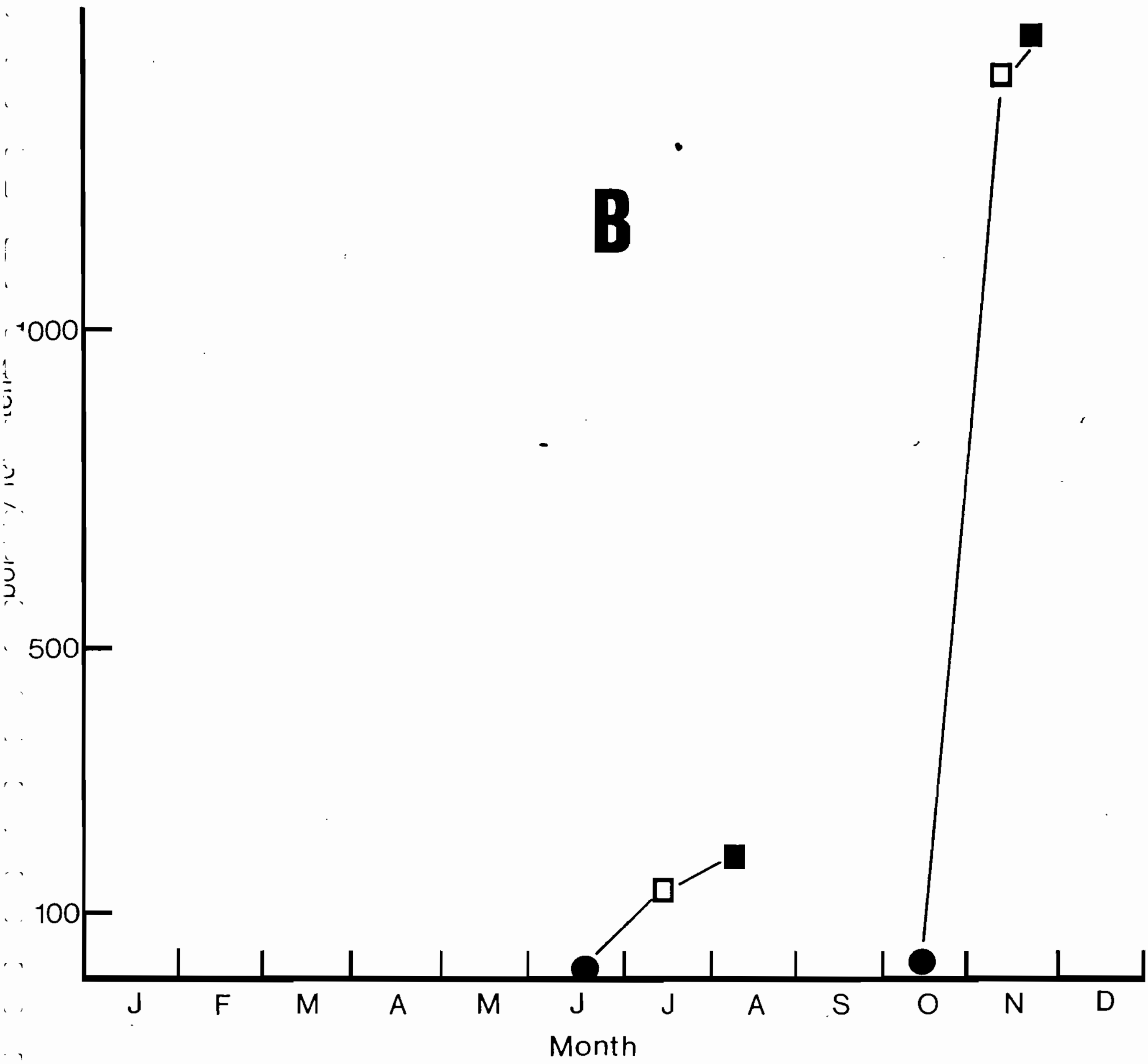
Fig. 2. Borer densities in Bouaké throughout the year. A: 1986; B: 1987; C: 1988; D: 1989.

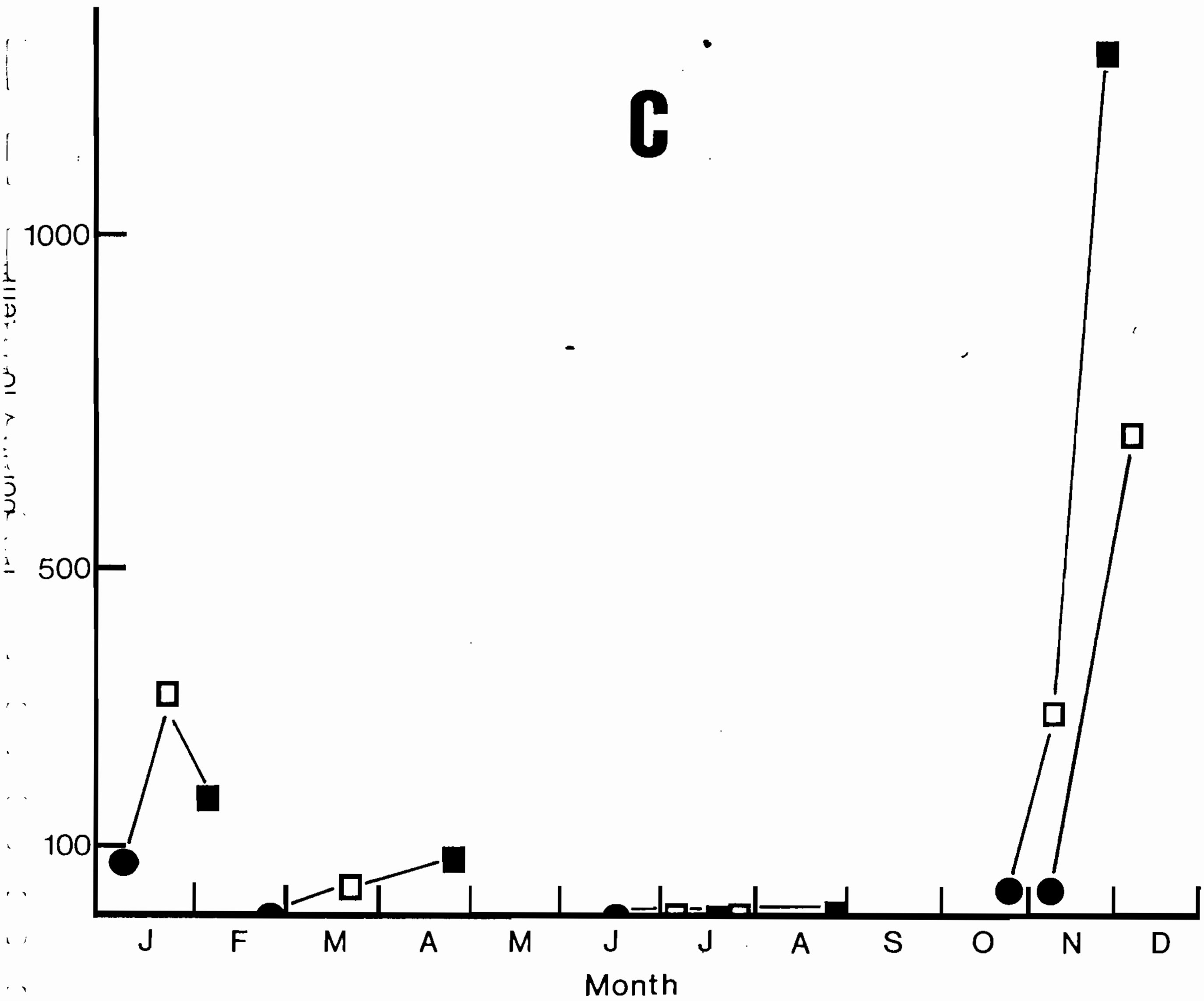
Fig. 3. Borer densities in Gagnoa throughout the year. A: 1986; B: 1987; C: 1988; D: 1989.

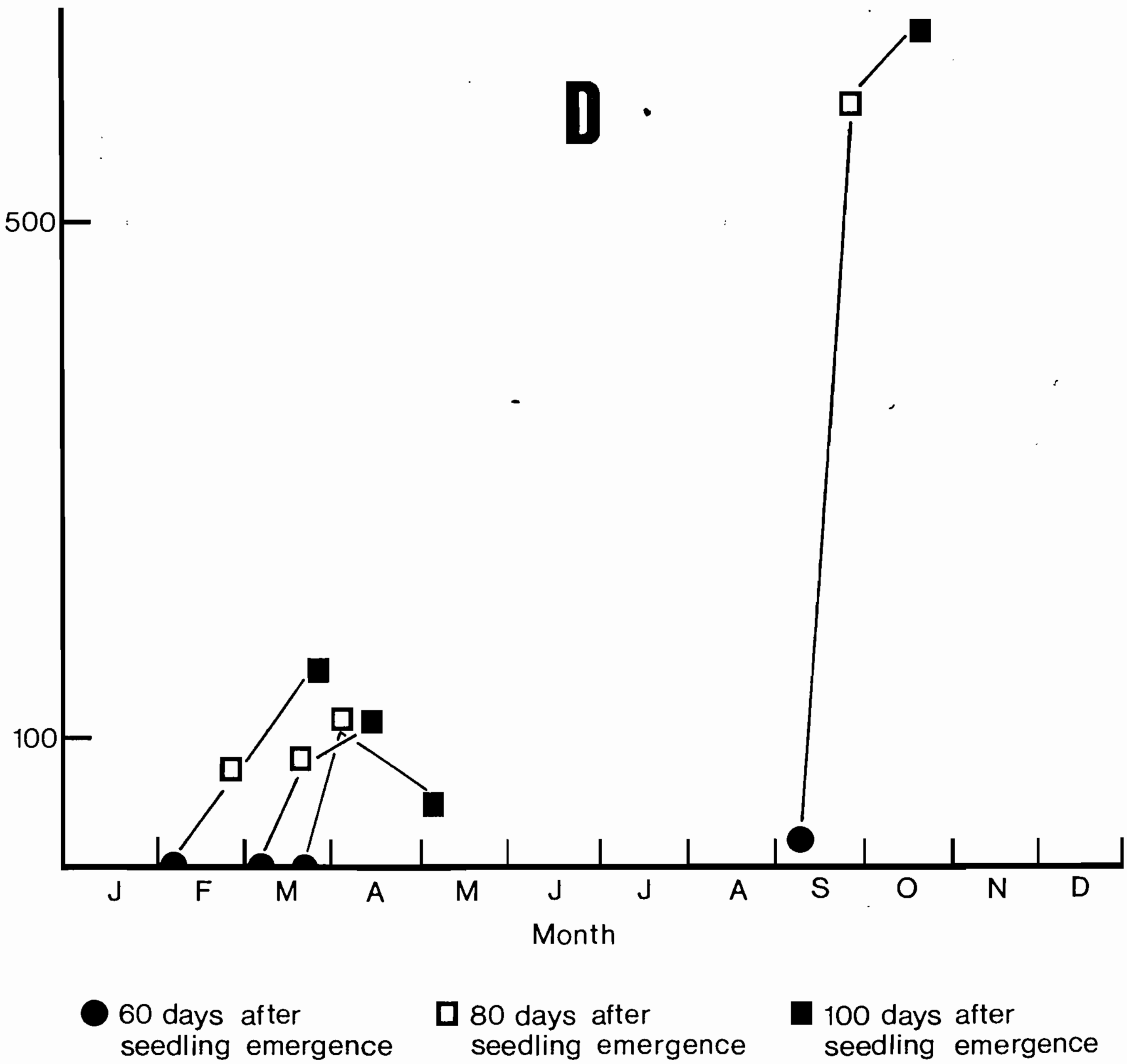

7°W
3°W
Mali
Burkina-Faso
Guinea
Liberia
Ghana
10°N
6°N
Tengrela
Boundiali
Ferke
Korhogo
Dianra
Niakara
Dabakala
Touba
Brobo
Bouaké
Béoumi
Man
Daniafla
Guessabo
Gohitafla
Daoukro
Guiglo
Bongouanou
Gagnoa
Binao
Abidjan
San-Pédro
100 km
The Atlantic
Sudanese zone
Sudanese Sector
Sub-sudanese Sector
Study sites
Guinean zone
Pre-forest Sector
Mesophil Sector
Ombrophil Sector

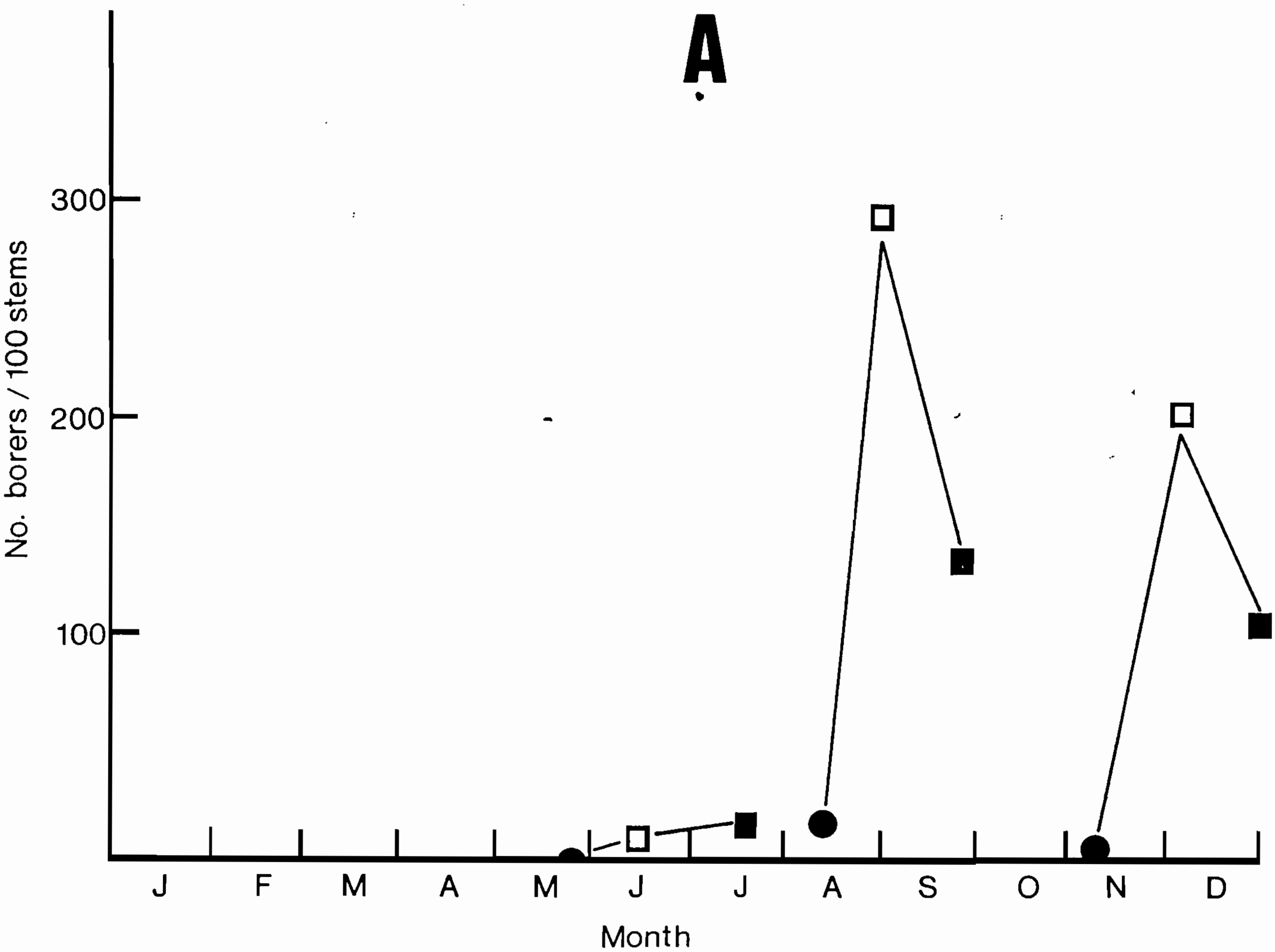


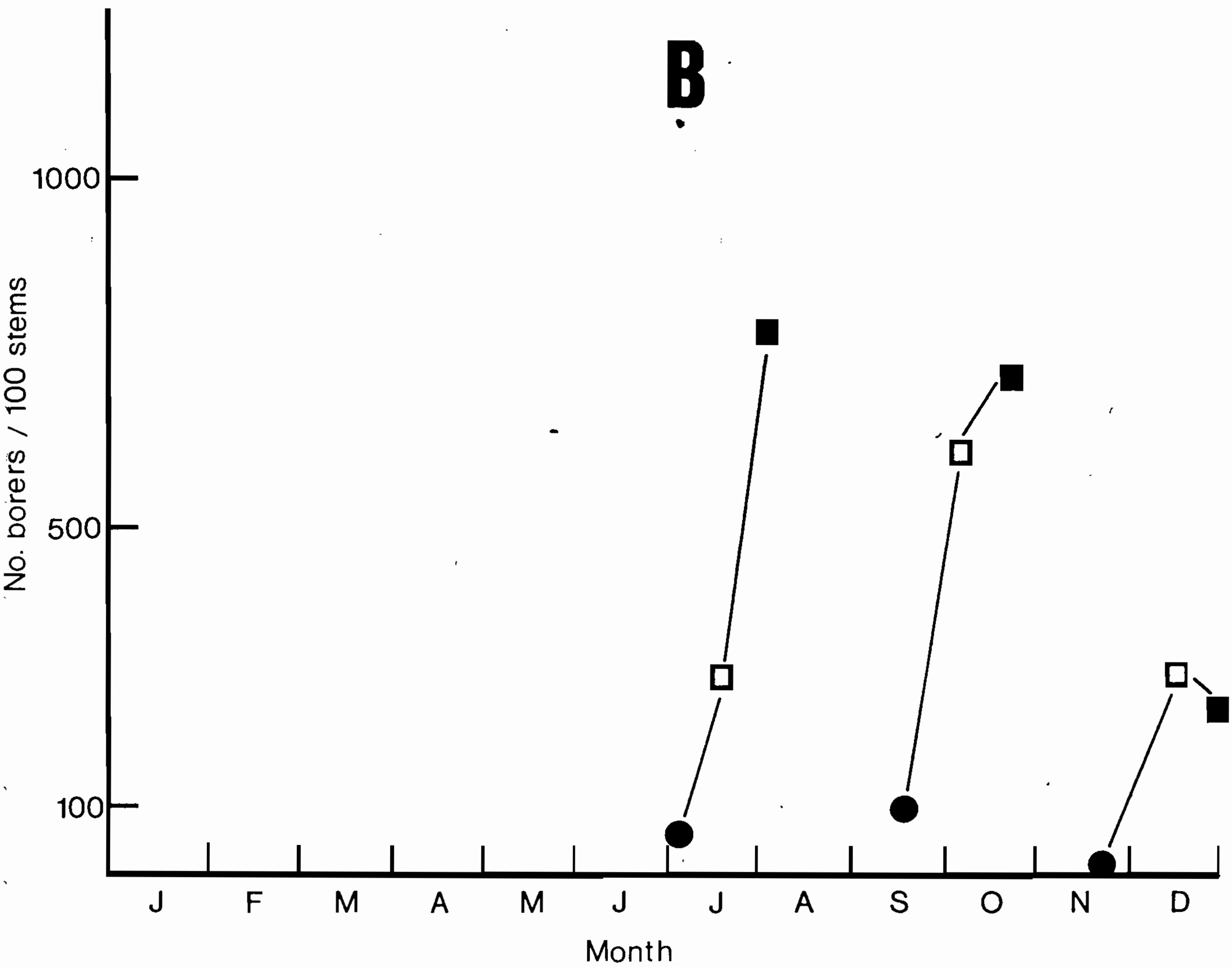
A
150
100
50
No. borers / 100 stems
J
F
M
A
M
J
J
A
S
O
N
D
Month


B
1000
500
100
J
F
M
A
M
J
J
A
S
O
N
D
Month


C
1000
500
100
J
F
M
A
M
J
J
A
S
O
N
D
Month


D
500
100
J F M A M J J A S O N D
Month
60 days after seedling emergence
80 days after seedling emergence
100 days after seedling emergence


A
300
200
100
No. borers / 100 stems
J
F
M
A
M
J
J
A
S
O
N
D
Month


B
1000
500
100
No. borers / 100 stems
J
F
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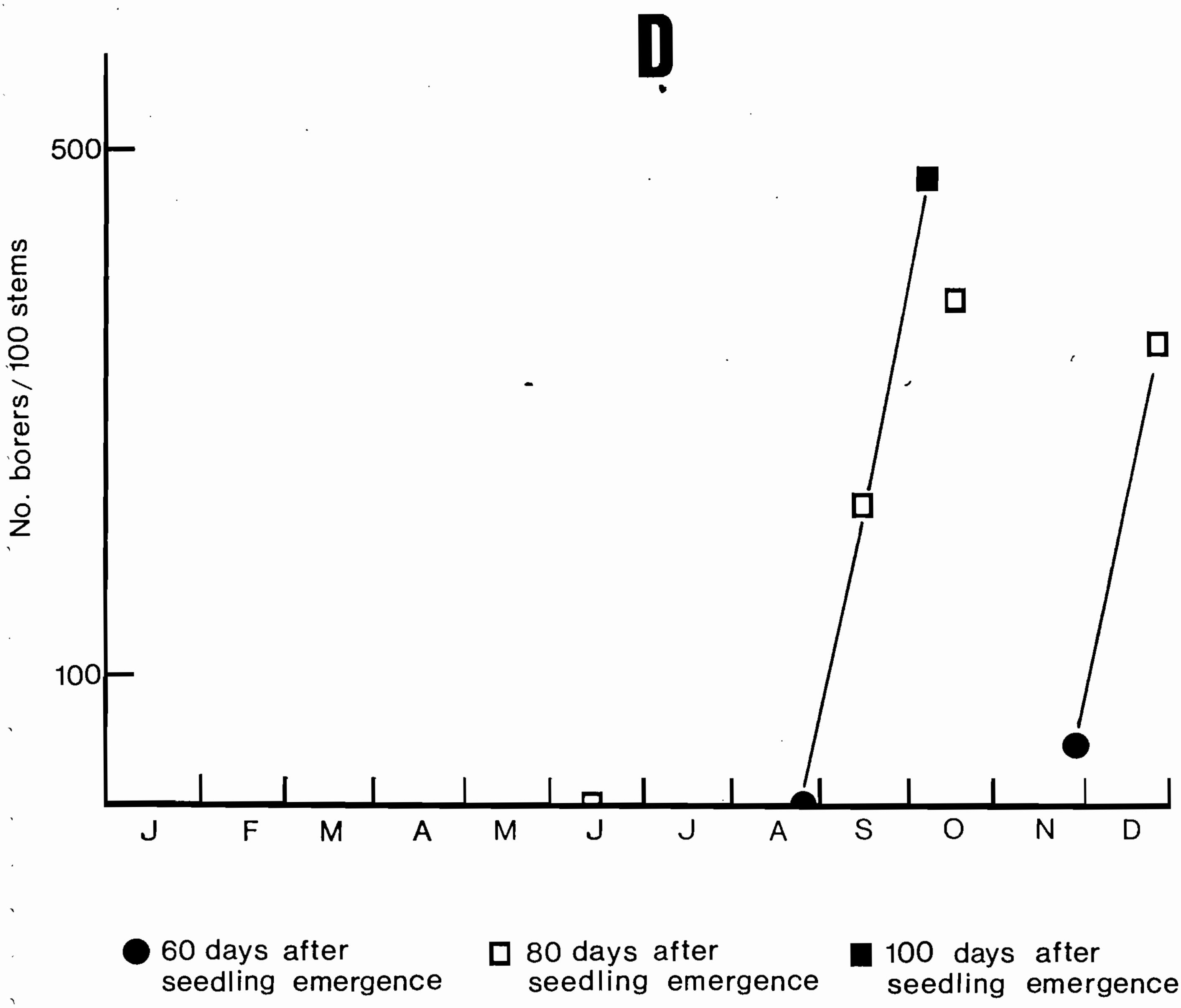
Month



D
500
100
No. borers/100 stems
J
F
M
A
M
J
J
A
S
O
N
D
60 days after seedling emergence
80 days after seedling emergence
100 days after seedling emergence

Dynamics of the populations of the maize stem borer, *Eldana saccharina* Walker (Lepidoptera: Pyralidae), in Côte d'Ivoire.

II- Influence of some abiotic and biotic factors.

Pascal Moyal

ORSTOM, B.O. 26, Giza, Cairo, Egypt.

Running title: Factors influencing *Eldana saccharina* dynamics in Côte d'Ivoire.

Key-words: *Eldana saccharina*, *Busseola fusca*, maize borer, West Africa, population dynamics, parasitism, model.

Mots-clés: *Eldana saccharina*, *Busseola fusca*, foreurs du maïs, Afrique de l'ouest, dynamique des populations, parasitism, modèle.

Abstract

The influence of abiotic factors on the population density of the maize stem borer, *Eldana saccharina* Walker (Lepidoptera: Pyralidae), was studied in Côte d'Ivoire during the second maize cycle (planting from June till August), which is the most infested. Two factors, the temperature sums and rainfall from the beginning of the year till 20 days before sampling, and their interaction, explained 81% of the observed variation in density. Two egg parasitoids and eight parasitoids of larvae and pupae were collected. The average rate of the larval and pupal parasitism in each ecological sector was less than 4% in all maize cycles. Egg parasitism increased throughout the year up to a peak of about 80% in November. The early attacks by another major borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), made the crop less attractive to *E. saccharina*. The influence of those different factors on the population dynamics of the borer is discussed.

Résumé

L'influence des facteurs abiotiques sur la densité de population du foreur des tiges de maïs, *Eldana saccharina* Walker (Lepidoptera: Pyralidae), a été étudiée en Côte d'Ivoire durant le deuxième cycle de culture (semis de juin à août), qui est le plus attaqué. Deux facteurs, les sommes de températures et la pluviométrie depuis le début de l'année jusqu'à 20 jours avant la date d'échantillonnage, ainsi que leur interaction, expliquent 81% de la variation de densité observée. Deux parasites d'oeufs et huit parasites de larves et nymphes ont été récoltés. Le taux moyen de parasitisme des larves et nymphes dans chaque secteur écologique n'a pas excédé 4% quelque soit le cycle de maïs. Le taux du parasitisme des oeufs s'est accrû au long de l'année jusqu'à atteindre un pic d'environ 80% en novembre. Les attaques précoces d'un autre foreur, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), ont rendu les cultures moins attractives à *E. saccharina*. L'influence de ces divers facteurs sur la dynamique des populations du foreur est discutée.

Introduction

Eldana saccharina Walker (Lepidoptera: Pyralidae), is a major borer of maize in many African countries south of the Sahara desert (Girling, 1978 and 1980; Atachi, 1989; Bosque-Perez & Mareck, 1990). Monitoring of that pest in Côte d'Ivoire during eight years (Moyal, 1997b) showed that population densities were low until June-July, increased from this time until October-November, and then decreased. The peak of density observed in October-November was high (8 to 10 borers per stem) in the Pre-forest and Mesophil sectors of the Guinean zone. It decreased northwards and southwards. Populations were generally low in the western highland region.

Little is known about the factors involved in the changes in population density of *E. saccharina*. The main studies on that topic were conducted in sugarcane crops in South Africa, where the effect of weather and host-plant nitrogen on borer densities was studied (Atkinson and Carnegie, 1989; Atkinson and Nuss, 1989). The only published work conducted in maize crops (Girling, 1978) stressed the importance of predatism of eggs and young larvae by ants in a locality of Uganda.

The present paper is devoted to the study of the influence of climatic factors and of pre-imaginal parasitism on the population density of *E. saccharina* in maize crops of Côte d'Ivoire. The effect of the damage caused by another major borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), on the attractiveness of the crop to *E. saccharina*, is also investigated.

Material and Methods

Côte d'Ivoire is divided into two main ecological regions, the Guinean zone and the Sudanese zone (Moyal, 1997b). This division, which is based on botanical features (Guillaumet & Adjanohoun, 1971), is related to climatic differences (Eldin, 1971).

In table 1 are presented the main climatic characteristics of the different ecological zones (after Eldin, 1971). The annual rainfall varies between 1100 and 1800mm in all regions but the Ombrophil sector of the Guinean zone and the highland western region, where it is about 600 mm higher on average. Distribution of rainfall throughout the year varies, depending on the region. In the Sudanese zone there is a short rainy season and a long dry season, which lasts at least 7 months. The annual water deficit (Potential evapotranspiration minus rainfall) is high. In the Guinean zone the dry season is shorter (5 months on average) and the water deficit much lower. However a period of low rains usually occurs towards August in that region (Moyal, 1997b). The average air temperature varies little throughout the year, ranging between 23 and 30°C in all regions (Berron, 1978). The range between the diurnal maximum and the night minimum increases however from south northwards. In January, when it is maximum, it is less than 10°C, about 15°C and 20°C respectively in southern, central and northern Côte d'Ivoire. Relative humidity decreases slightly from south northwards: 85% in the Ombrophil sector of the Guinean zone, 75 to 80% in the other sectors of this zone, and 65 to 70% in the Sudanese zone (Berron, 1978).

The maize plants were sampled every 7, 10, or 20 days in the different experimental sites (see Moyal, 1997b, for information about the experimental sites, the conducted trials and the agronomic features of maize crops) and taken to the central laboratory of Bouaké where they were dissected. The collected eggs and insects were afterwards reared in the laboratory (at 22±2°C and 70±5% RH). The percentage of parasitism was estimated at each dissection date for eggs and 100 DAE for larvae and pupae. The collected parasitoids were sent to specialists for identification (see acknowledgements). Voucher specimens were deposited at the Museum National d'Histoire Naturelle (antenne ORSTOM) in Paris and at the Natural History Museum in London.

The influence of early infestation of maize crops by *B. fusca* on the subsequent attacks by *E. saccharina* was studied in an experiment conducted in Bouaké, center Côte d'Ivoire, in 1989. This trial was arranged in a split-plot design with three replications. Artificial infestations with newly hatched larvae of *B. fusca* were done at three different dates, respectively 10, 17 and 24 DAE. Three infestation levels were used for each date, respectively 0, 3 and 5 larvae per plant.

Results

Influence of abiotic factors

The study of the abundance of *E. saccharina* in Côte d'Ivoire (Moyal, 1997b) showed that pest density was low during the first maize cycle (planting from March to May), increased more or less highly, depending on the region, during the second cycle (planting from June till August), and then decreased during the third cycle (planting from September till

October) and the dry season (November till February). A precise study of the relationship between climatic factors and population density of the pest was difficult because of the low number of study years and of the lack of meteorological records in several localities. The available data enabled however to get a first insight into this relationship, particularly during the second maize cycle, which is the most infested by the borer.

Figures 1-3 present the fluctuations of relative humidity, average temperature, and rainfall in Bouaké, Gagnoa and Man from 1987 to 1989. They show that little change in relative humidity occurred in a given locality year by year, except during the dry season in Bouaké and Man. Such small fluctuations were unlikely the cause of the important differences observed in the borer population density. The differences between average temperatures for a given month were less than 2°C. However some years were regularly hotter, for instance 1987, whereas others were colder all the year round, like 1989 in Man and Bouaké. The addition of these fairly small differences in temperature for several months could then result in high differences in temperature sums. Rainfall was very variable year by year, with great differences in time and intensity of peaks and drought.

The relationship between the two latter abiotic factors and population density of *E. saccharina* in the three sites during the second maize cycle was investigated through a regression analysis. The developed model (Table 2) explains 81% of the observed variation in population density. The significant explanatory variables used were temperature sums from the beginning of the year till 20 days before sampling (temperature base=10.6°C, according to Shanower *et al.*, 1993), total rainfall during the same period, and interaction (viz. product) between both. Locality was introduced as a factor: Gagnoa and Bouaké, which proved to be not significantly different, were joined (coding=-1) and compared to Man (coding=1). The model shows that for a same combination of temperature and rainfall the population density of the borer was less in Man than in the other localities. The significant interaction between climatic factors shows that they have a combined effect on population densities, and this effect was similar in the three localities, since there was no significant interaction between locality and climatic factors.

Pre-imaginal parasitism

Egg-parasitism

Two egg parasitoids were collected: *Telenomus applanatus* Bin and Johnson (Hymenoptera: Scelionidae) and *Trichogrammatoidea eldanae* Viggiani (Hymenoptera: Trichogrammatidae). The former was highly dominant (between 70 and 100% of the parasitized eggs) in all cases but one when it killed only 50% of the parasitized eggs. The percentage of egg-parasitism (number of parasitized eggs*100/total number of eggs) in the trials where eggs were found is presented in table 3: it was close to zero during the first cycle, increased during the second cycle (21% in Gagnoa at the end of August 1986; at the end of September, 17.3% in Daniafla in 1987 and 38% in Brobo in 1986), and grew up to more than 75% towards the end of October (Bouaké, 1987).

Larval and pupal parasitism

The average rate of larval and pupal parasitism in each ecological sector, estimated 100 DAE, was less than 4% (Table 4), with local peaks up to 7%. It generally increased slightly throughout the year. This parasitism was mainly due to one species, *Syzeuctus sp. nov.* (Hymenoptera: Ichneumonidae) (81.9% of the parasitized borers). This species was misidentified as *Syzeuctus cribrosus* Kriechbaumer in a previous work (Dabiré, 1980) and its description is currently under way (Zwart , Agricultural University of Wageningen, and Delobel, ORSTOM, pers. comm.). Most collected parasitoids belonged to Hymenoptera. The percentages of the parasitized borers killed by these species were respectively: 8% by the three Ichneumonids *Venturia sp.*, *Enicospilus sp.* and a genus close to *Isotima spp.*; 1.7% by the Bethylid *Goniozus spp.*; 2.6% by the pupal parasitoid *Tetrastichus atriclavus* Waterston (Eulophidae). Two other parasitoids were collected: *Sturmiopsis parasitica* (Curran) (Diptera: Tachinididae) and a nematod belonging to Mermithidae, which killed respectively 4.3% and 1.5% of the parasitized insects. The latter species as well as *Syzeuctus sp. nov.* were found all over the country. The Bethylid and the Tachinid were found in the Pre-forest sector of the Guinean zone, the Bethylid only during the dry season. The remaining species were found in the other sectors of that zone.

Influence of infestation by B. fusca

Table 5 shows that the plants artificially infested by larvae of *B. fusca* were less attacked by *E. saccharina* than the plots free of the former species. The difference increased with the rate of infestation by *B. fusca* and decreased with the date of infestation.

Discussion

The developed model shows that temperature sums and rainfall from the beginning of the year till 20 days before sampling and their interaction explained a great part of the variation in densities of *E. saccharina* during the second maize cycle. Simulations using different sets of data within the limits of the observed sums of temperature and rainfall show that borer density increases with rainfall for a given temperature sum. This is true when both variables are transposed only when rainfall is greater than about 1200 mm. Below this limit population density decreases when temperature sums increase. Simulation with the observed data shows furthermore that, when two crops were planted at an interval of 15 days in a given locality, the estimated borer density is accurate generally only for one crop, either the first or the second one. Population density in the experiments generally increased highly during those close plantation dates when rainfall and temperature sums changed little. For instance in Bouaké in 1988 population density increased from 274 to 656 borers per 100 stems in 15 days during which no rain occurred. In this case the model estimates accurately the borer density in the second crop (681 insects) but overestimates that in the first one (648). Temperature sums and rainfall are then not sufficient to explain such high changes in a little period of time. A possible explanation might be that additionnal egg-layings due to adults emerged from the first crop occurred in the second crop. The model should then be considered as a first step towards a better knowledge of the influence of abiotic factors on population density of *E. saccharina*. The fluctuations of temperature sums and rainfall explain the observed variations in average borer density year by year but do not explain the quick changes between two close plantation dates in a given locality.

The regression analysis also showed that there was a significant effect of locality. Borer density was thus lower in Man for a given combination of the explanative variables although a change in the abiotic factors resulted in a similar change in borer density in all localities (no interaction between locality and other variables). This may be explained by the fact that the commencement of population increasing after the dry season was delayed in western highlands because of lower temperatures. Indeed the developmental period and the fecundity of the borer are respectively increased and reduced when temperature is lower (Shanower *et al.*, 1993). Since rainfall was heavier in Man, population then began to increase at a higher rainfall sum.

The present investigation revealed that borer population density increased with rainfall for a given temperature sum. This result is contradictory with what was observed in South Africa (Atkinson and Carnegie, 1989) where borer density was higher during dry years in sugarcane crops. In contrast they are consistent with previous results that showed that maize crops suffering from water stress were less infested by *E. saccharina* in Côte d'Ivoire (Moyal, 1995). The variable "rainfall during the two months preceding the sampling date" was however not significant when introduced in the model, although it was not far from being so ($P(>|t|)=0.08$). This lack of significance might have resulted from the low number of available data. Such a difference in behaviour between populations of western and southern Africa and the fact that maize crops are little infested by *E. saccharina* in South Africa (Atkinson, 1980) suggest that there are likely great genetic differences between both populations.

The combined influence of temperature and rainfall on population density enables to explain the low density observed in the Sudanese zone as well as the fact that densities were higher in eastern Côte d'Ivoire (Bongouanou) for a given rainfall. In the Sudanese zone a long dry season occurs (Table 1). Rainfall is low until July (for instance between 250 and 400 mm less in Ferké than in Bouaké or Gagnoa during the first six months of 1988 and 1989) and rains stop early, which prevents high increase of populations. In the Bongouanou region the average monthly temperature is regularly higher than that of Bouaké or Gagnoa by 1°C (Berron, 1978), which results in a faster development of populations.

Larval and pupal parasitism were low. This confirms what was previously observed in Côte d'Ivoire (Pollet *et al.*, 1978; Dabiré, 1980) as well as in other countries of West Africa (Jerath, 1968). Such a parasitism cannot have a great influence on the dynamics of borer populations. The main egg parasitoid was *T. applanatus*, which confirms Cochereau's results (1982, 1985). This author, who planted maize crops along sugarcane, found high rates of egg parasitism in maize crops throughout the year (Cochereau, 1985). This is probably related to the closeness of the sugarcane crop and is different from what was observed in the present study. The results hereabove presented showed that egg parasitism was increasing with borer density up to a peak of about 80% at the beginning of the dry season. Such a high percentage had likely a great part in the quick reduction of borer densities observed from November.

The study showed that early attacks of maize crops by *B. fusca*, which result in dead-hearts and in a reduction of stand density, made the crop less attractive to *E. saccharina*. This may explain the low densities of *E. saccharina* observed some years during the second cycle in the eastern part of the Mesophil sector (Daoukro and Bongouanou). Thus, in 1984 and 1989, the maximum population density of *B. fusca* in this region was about 5 insects per stem versus 2 to 3 insects per stem during the other years (Moyal, 1997a) and densities of *E. saccharina* moved in the opposite direction (Moyal, 1997b). These results show that, in contrast with what was observed in Uganda (Girling, 1978), some kind of interspecific competition between both borers occurs in Côte d'Ivoire.

Conclusion

In the present investigation, the population density of the maize stem borer, *E. saccharina*, in Côte d'Ivoire was low until June. It increased highly from July till November in the Pre-forest and Mesophil sectors of the Guinean zone, slightly less in the Ombrophil sector. The increase in borer density was low in the Sudanese zone and in the western highlands.

The combined influence of rainfall and temperature explained a great part of the observed fluctuations. The dynamics of populations and the factors that influence it can be summarized as follows. During the dry season, the low abundance of host-plants results in a gathering of borers in the wet areas and in a reduction, little by little, of borer density. The first rains result in a quick increase in host-plant abundance. Borers then disperse and their density gets lower in the maize crops because of the great abundance of wild and cultivated host-plants at this time. The long dry season in the Sudanese zone as well as the low temperatures in the western highlands delay this process. Borer populations increase during the second maize cycle in relation with the combined influence of rainfall and temperature. The delay in population development in the Sudanese zone in addition with an early stop of rains does not enable a high increase in density. In the western highlands, the long rainy season enables borer populations to increase in late plantings. In the other sectors of the Guinean zone, populations of *E. saccharina* increase highly, particularly in the East where temperatures are higher. Some factors reduce the attractiveness of maize crops to the pest, like for instance infestations by the other major borer, *B. fusca*, and periods of drought. The egg parasitism increases highly during the second cycle. The combined effect of this parasitism and of rain reduction results in a quick decrease in population density during the third maize cycle, in December. This reduction continues then throughout the dry season.

Acknowledgements

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Table 1. Main climatic characteristics of the ecological zones.

Ecological Zone	Annual Rainfall (mm)	Annual water Deficit[a] (mm)	Duration of the long dry season (Months)	Average Annual Temperature and range of extrema (°C)
SUDANESE ZONE				
Sudanese Sector	1100 to 1700	≥850	≥8	27 (15 to 37)
Sub-sudanese Sector	1100 to 1700	600 to 850	7 to 8	26 to 27 (16 to 36)
GUINEAN ZONE				
Pre-forest Sector	1100 to 1600	400 to 600	5 to 6	25 to 28 (19 to 34)
Mesophil Sector	1200 to 1800	250 to 400	4 to 5	25 to 28 (19 to 33)
Ombrophil Sector	1600 to 2500	150 to 250	3 to 4	26 to 27 (21 to 33)
West Highlands	1700 to 2500	<300	4 to 5	20 to 25 (12 to 30)

[a] Potential Evapotranspiration minus Rainfall

Table 2. Regression analysis of the number of *E. saccharina* per 100 plants on climatic factors.

Explanatory Variable	Regression Coefficient	$P(>\|t\|)$[a] (%)	Intercept	Residual Standard Error	R^2
Rainfall	-5.5329	4.25			
Temperature sum	-1.8865	3.23	6451.75	184.308	0.8107
Interaction	0.0017	2.20			
Locality	-284.9531	0.85			

[a]Level of significance of the Student *t*-test.

Table 3. Percentage of parasitized eggs.

Locality	Date	Days after emergence	average Number of eggs per plant	Parasitism Percentage
Bouaké	09 Jun 1987	54	0.54	0
	15 Jun 1987	60	0.39	0
	22 Jun 1987	67	0.61	0
	20 Oct 1987	62	13.7	79.5
	28 Oct 1987	70	24.1	75.9
	28 Dec 1987	60	1.49	81.0
	06 Jul 1988	57	0.15	0
	07 Oct 1988	53	0.11	100
Brobo	16 Jun 1986	72	0.38	0
	23 Jun 1986	79	0.23	0
	30 Sep 1986	56	4.20	38.3
Gagnoa	21 Aug 1986	66	0.68	21.0
	30 Oct 1987	38	0.11	0
Man	16 Sep 1986	74	0.36	0
Daniafla	30 Sep 1987	58	0.18	17.3
Guessabo	31 Aug 1988	58	0.08	0

Table 4. Percentage of larval and pupal parasitism.

Ecological Zone	Year	Maize Cycle	Percentage of parasitism
SUDANESE ZONE			
Sudanese Sector	1988	2nd	0
	1989	2nd	0
GUINEAN ZONE			
Pre-forest Sector	1986	Dry season	0
		1st	0
		2nd	0
	1987	1st	0.50
		2nd	0
	1988	Dry season	0
		1st	0
		2nd	0
	1989	Dry season	0
		2nd	0.8
Mesophil Sector	1986	1st	0
		2nd	0.4
		3rd	0
	1987	1st	0.1
		2nd	1.9
		3rd	3.0
	1988	1st	0.6
		2nd	1.2
		3rd	2.0
	1989	1st	0
		2nd	3.0
		3rd	3.4
Ombrophil Sector	1988	2nd	0.6

Table 5. Influence of artificial infestation of maize crops by *B. fusca* on the subsequent natural infestation by *E. saccharina* 80 days after emergence.

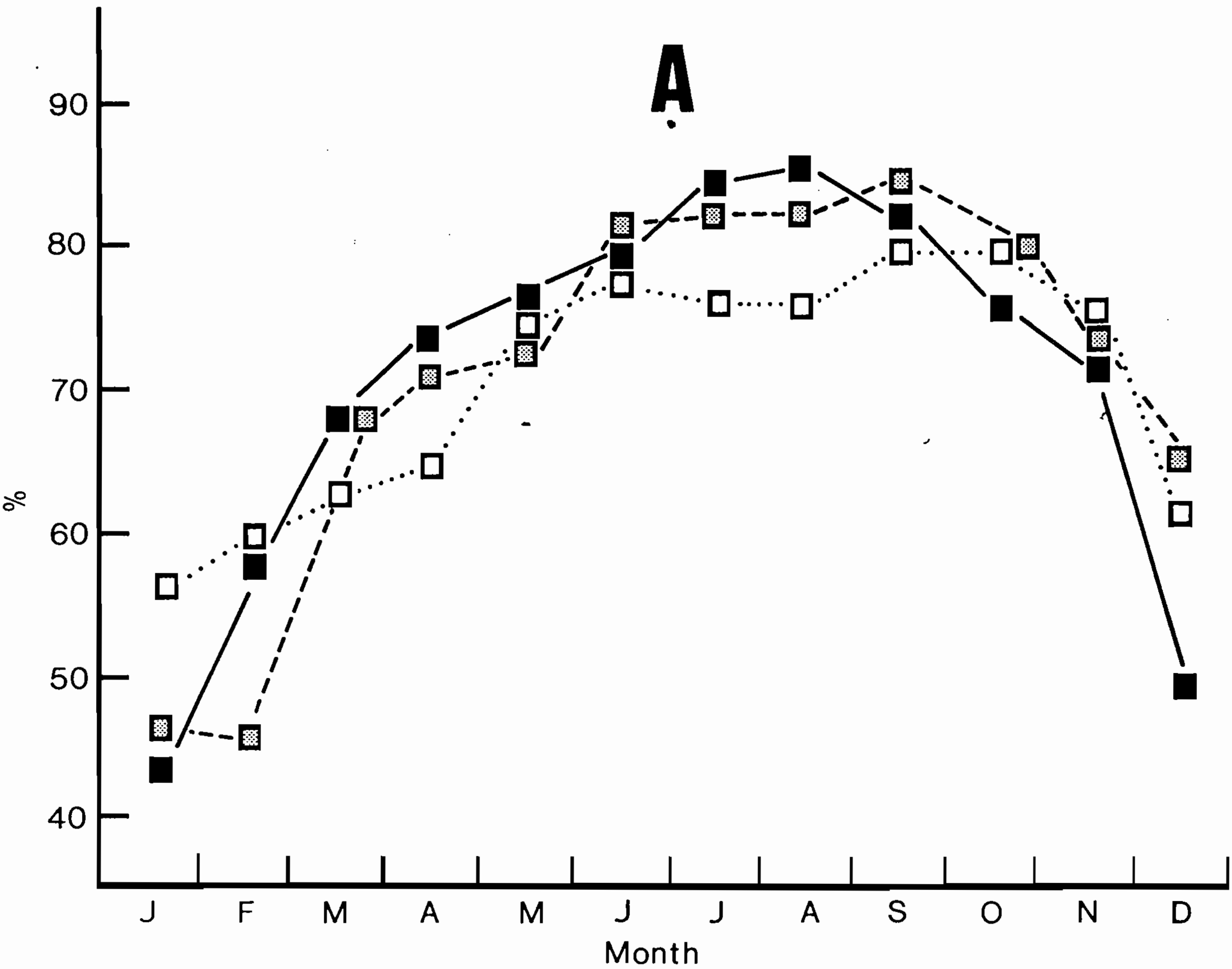
Infestation Date (days after emergence)	Number of *B. fusca* larvae per plant	Number of plants per hectare at harvest	Number of *E. saccharina* in 100 stems	Standard Error
10	0	37500	989	250
	3	20833	404	180
	5	15833	526	115
17	0	44167	606	222
	3	19167	404	229
	5	26667	366	282
24	0	51667	498	229
	3	42500	612	166
	5	39167	440	120

Figure captions

Fig. 1. Fluctuations of relative humidity from 1987 to 1989 in Bouaké (A), Gagnoa (B) and Man (C).

Fig. 2. Fluctuations of average temperature from 1987 to 1989 in Bouaké (A), Gagnoa (B) and Man (C).

Fig. 3. Fluctuations of rainfall from 1987 to 1989 in Bouaké (A), Gagnoa (B) and Man (C).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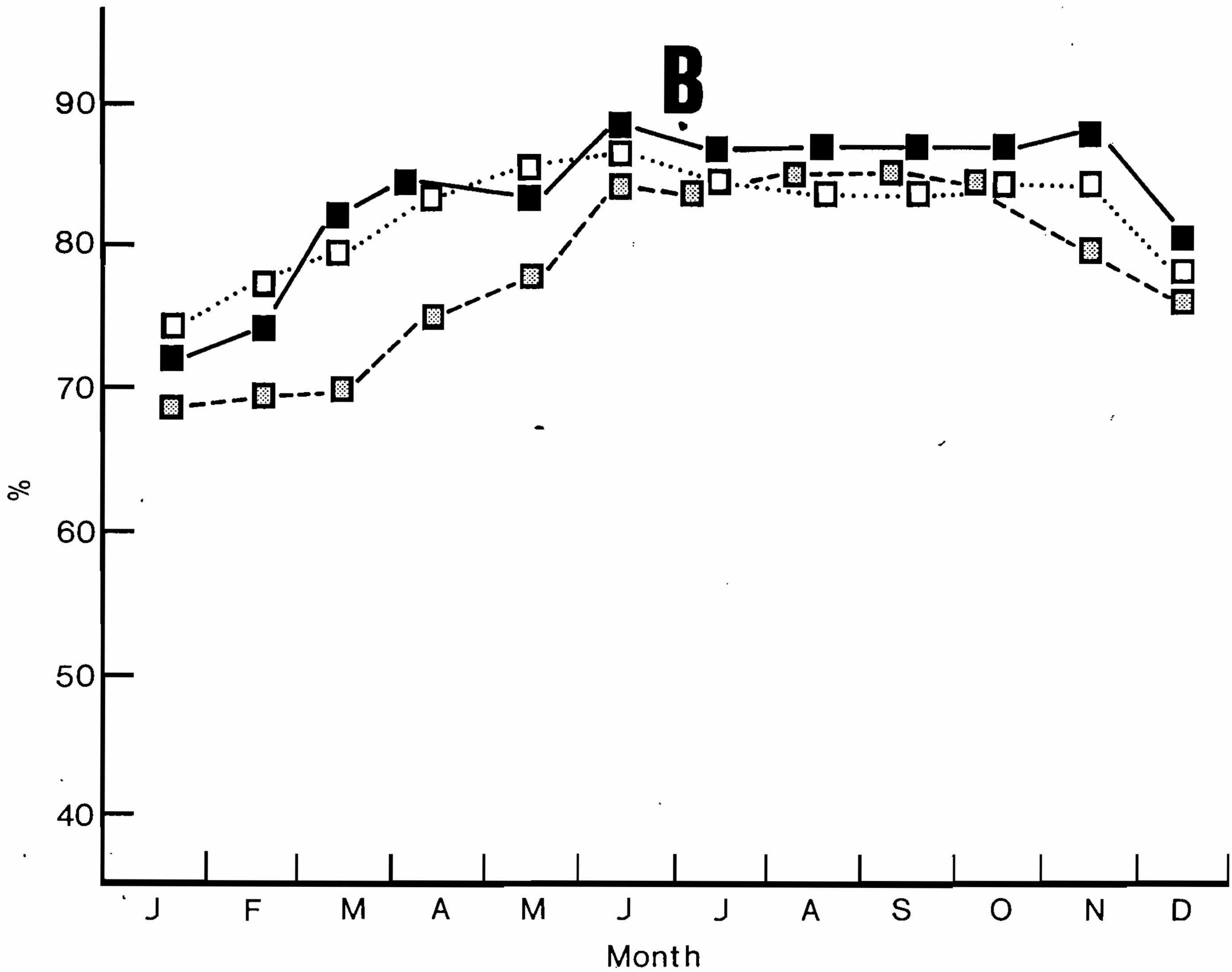

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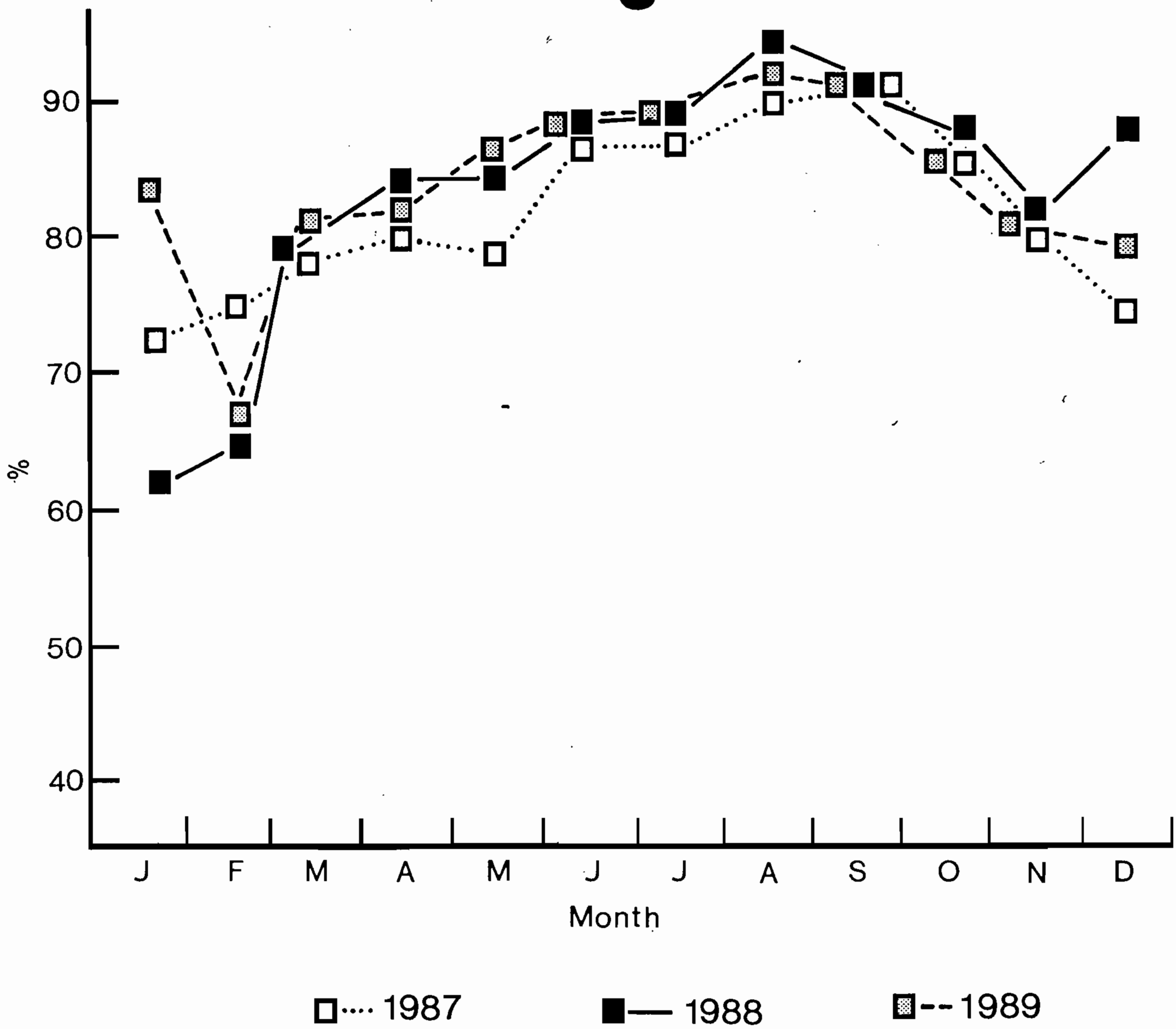

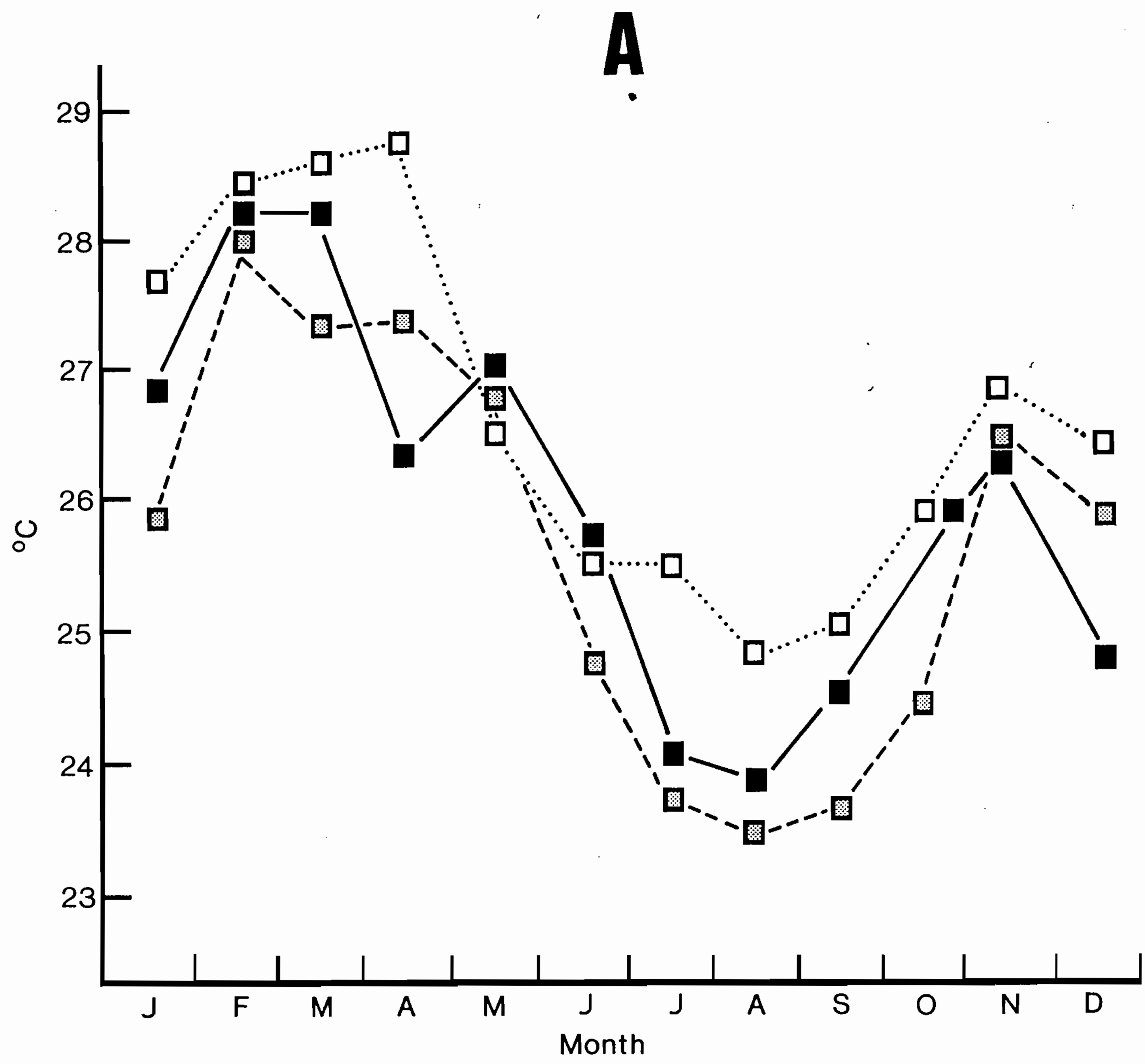

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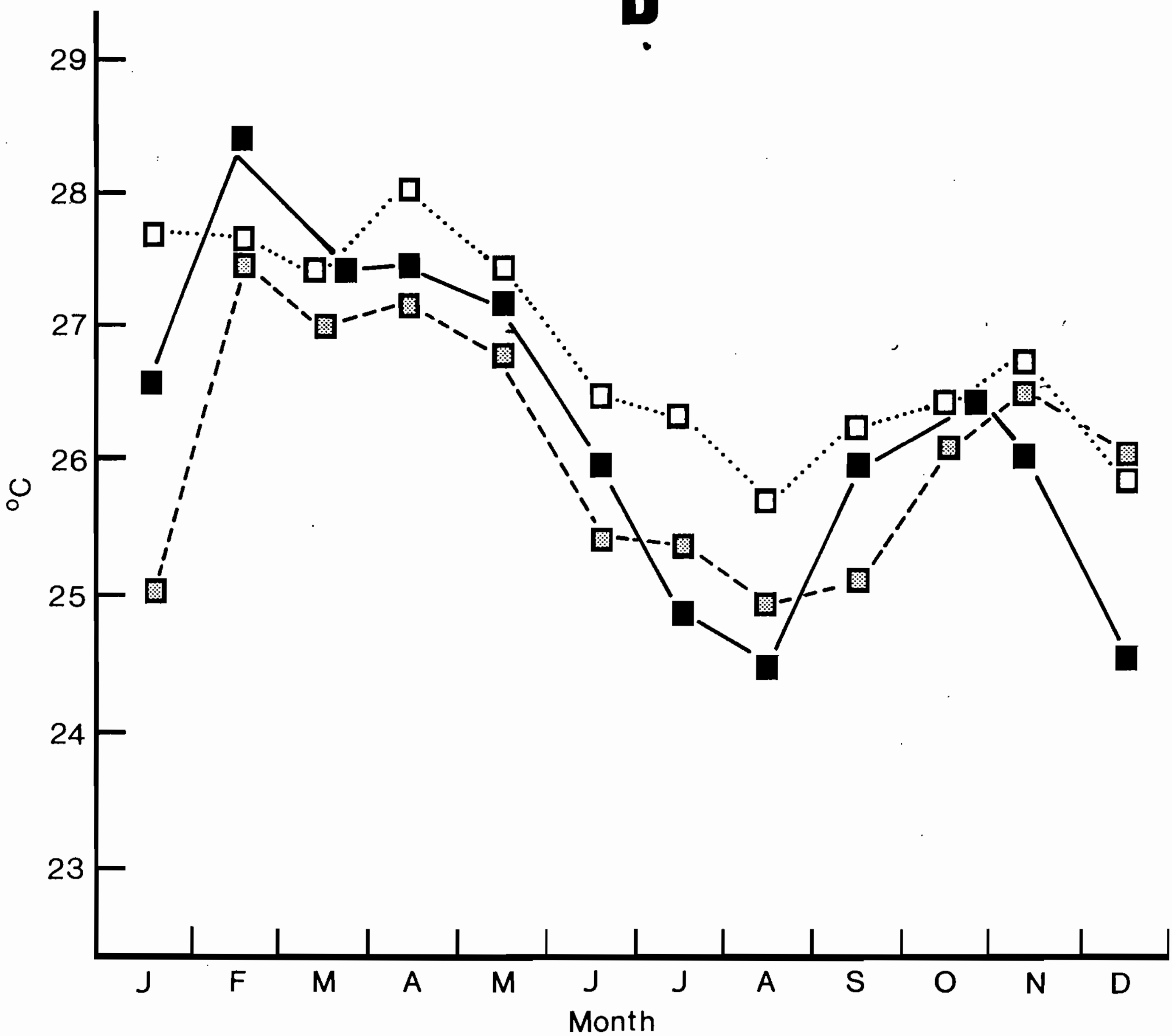

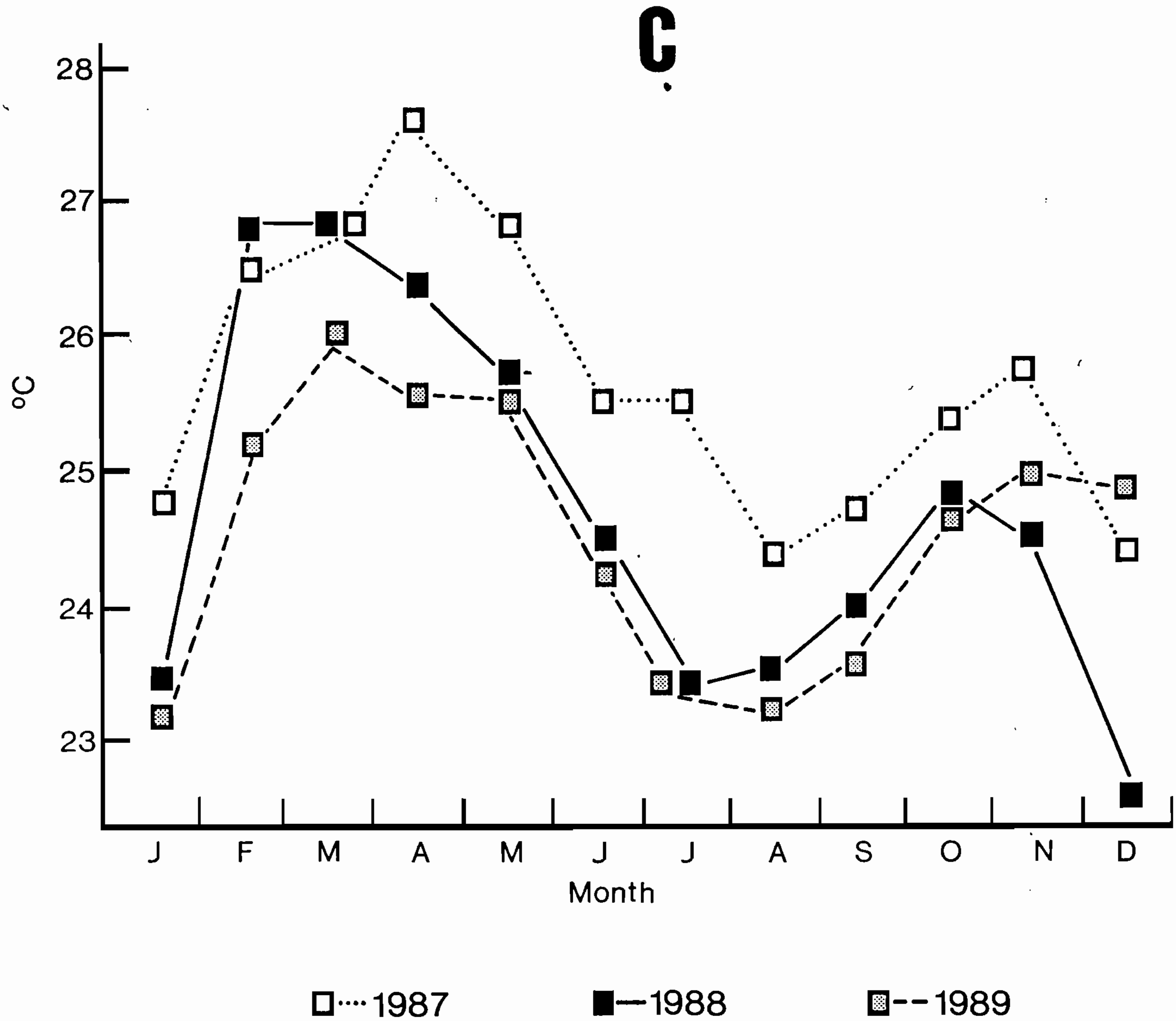
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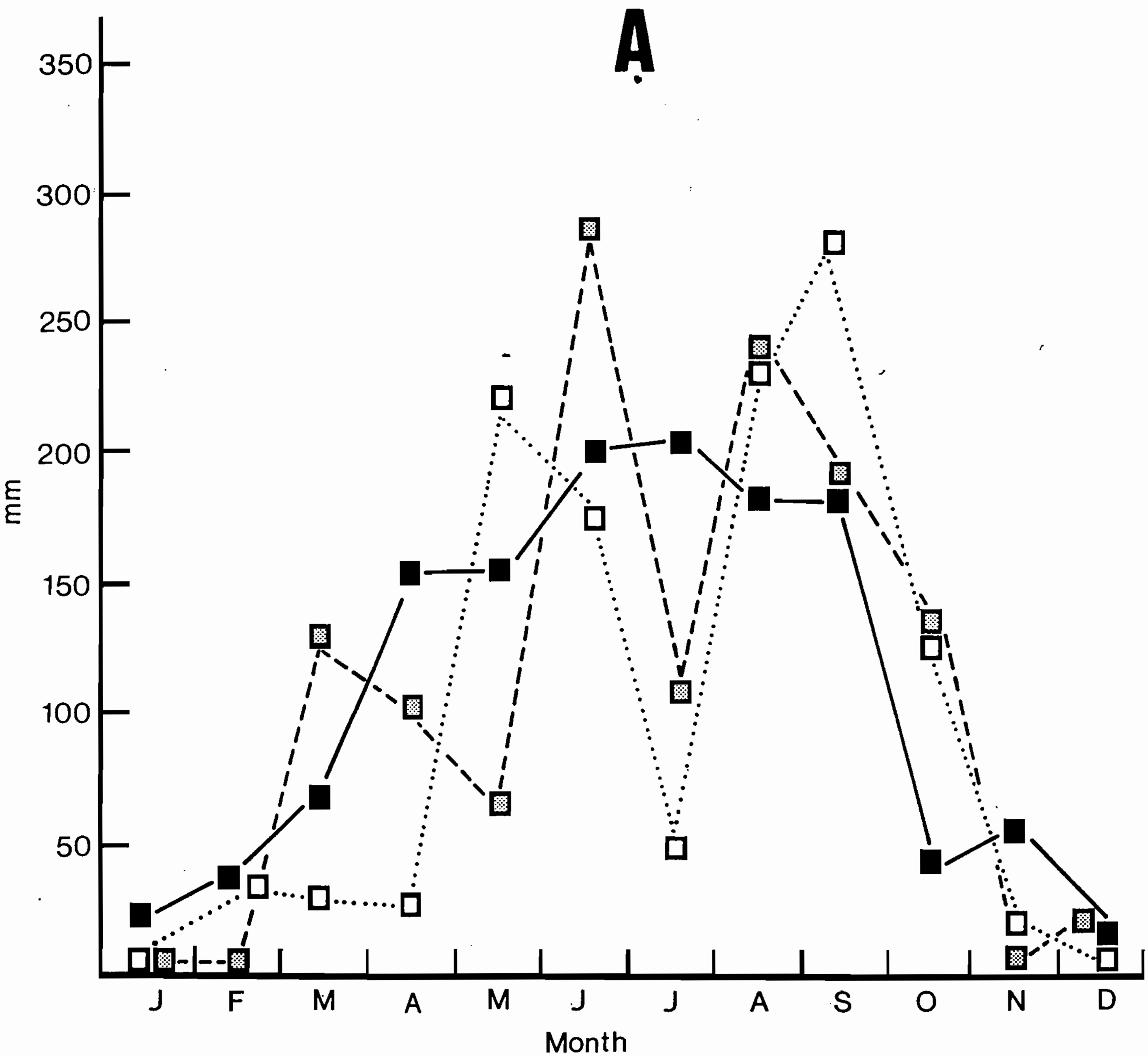

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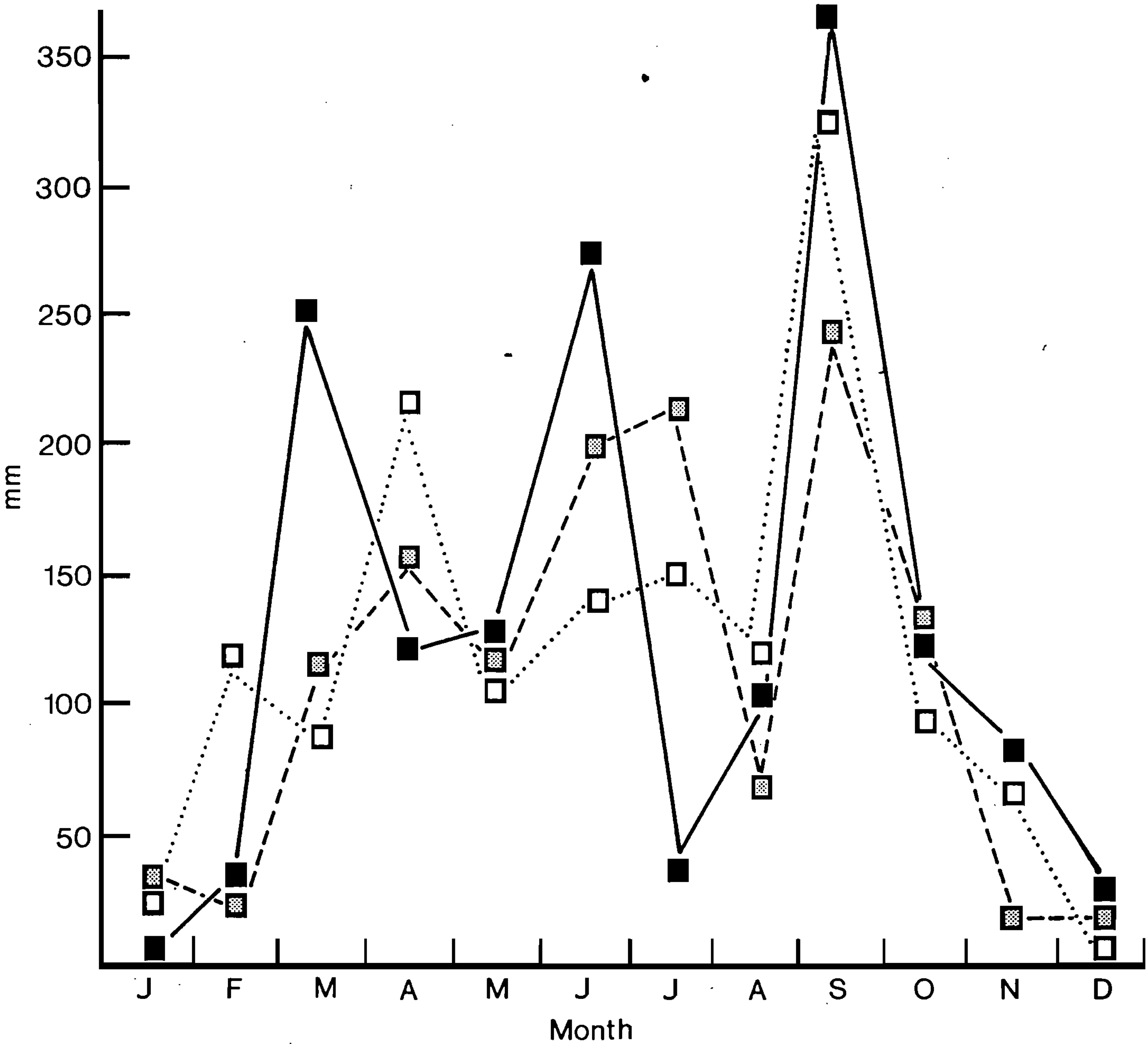

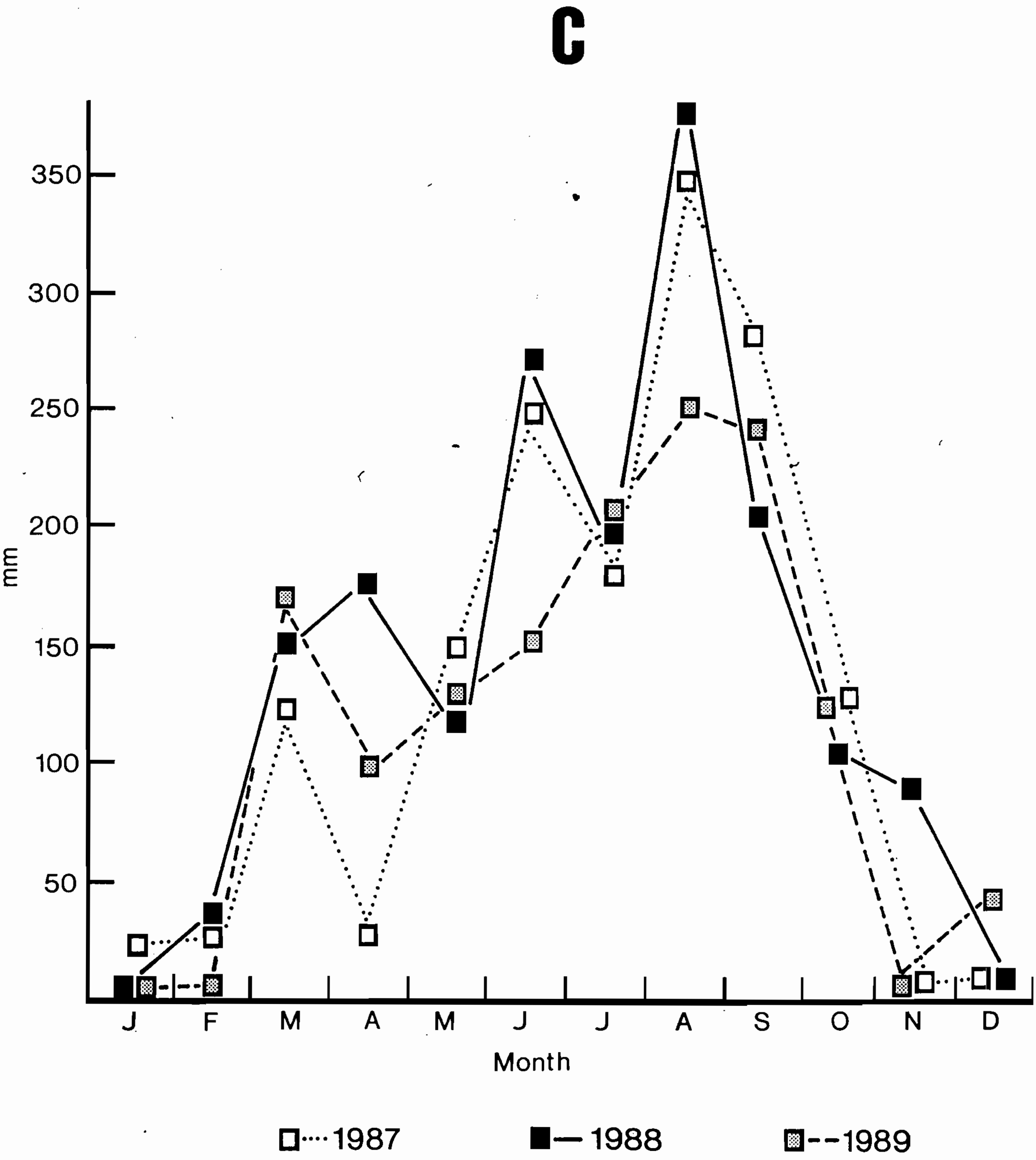

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