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Ecology of Larval Mosquitoes, with Special Reference to *Anopheles arabiensis* (Diptera: Culcidae) in Market-Garden Wells in Urban Dakar, Senegal

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ABSTRACT The urban area of Dakar, Senegal, contains >5,000 market-garden wells that provide permanent sites for mosquito larvae, in particular *Anopheles arabiensis* Patton, the major vector of malaria. A study of the bioecology of mosquito larvae was conducted over 1 yr with a monthly visit to 48 of these wells. Overall, 9,589 larvae were collected of which 80.1% were Culicinae and 11.9% Anophelinae. Larvae from stages III and IV (n = 853) were identified to 10 species. *An. arabiensis* represented 86% of the anophelines collected and *An. ziemanni* Grunberg 14%. The most common Culicinae species included *Aedeomyia africana* Neveu-Lemaire, *Culex quinquefasciatus* Say, and *Mimomyia splendens* Theobald. Maximum anopheline abundance was observed at the end of the dry season in June, whereas maximum Culicinae abundance was observed at the end of the rainy season in September. Most wells (67%) did not harbor any *An. arabiensis* larvae and in the remaining 33% the larval abundance was low, averaging 0.54 larvae in stages III–IV per tray sample. To identify factors that determine the abundance of larvae in these wells, a co-inertia (multivariate) analysis was carried out to account for physicochemical variables (depth, turbidity, temperature, pH, conductivity, Na^+, Cl^-, HCO_3^-, CO_3^{--}, and NO_3^- concentrations) and biological variables (abundance of mosquito species, predators [e.g., fish, Dytiscidae, Notonectidae, odonates], molluscs [*Bulinus* and *Biomphalaria*], and surface plants [water lettuce, *Lemna*, and filamentous algae]). The co-inertia analysis indicated that the abundance of *An. arabiensis* was associated with *Cx. quinquefasciatus* and *Cx. decens* for the physiochemical data but was not associated with other mosquito species for floro-faunistic data. The conditions associated with abundant *An. arabiensis* were warm temperature (28–30°C), clear and not too deep water (<0.5 m), elevated concentrations of HCO_3^- and CO_3^{--}, low concentrations of NO_3^- and NaCl, low populations of larvivorous fish and invertebrate predators (notably odonates), the presence of water lettuce, and an absence of *Lemna*. These results indicate that many contributing factors influence the ecology of the immature stages of *An. arabiensis*.

KEY WORDS *Anopheles arabiensis*, larvae, ecology, multivariate analysis, Senegal

THE RELATIONSHIPS AMONG hydro-agricultural development, mosquitoes, and malaria are particularly close, especially for rice (Lacey and Lacey 1990). Market-gardening also constitutes an agricultural practice that requires water to be available in good supply in immediate proximity to crops located within or outside tropical African towns. The towns are ideal for selling these products, and urban farming appears to be economically significant (Niang 1996).

In Dakar, Senegal, *Anopheles arabiensis* Patton, a species in the *An. gambiae* complex, is the only malaria vector and the most abundant anopheline. Adult populations present important seasonal variations, with minimal densities in the dry season from March to June, sharp increases after the first rain in July, maxima in August–September, and decreases abruptly after the last rain in October–November (Vercruysse and Jancloes 1981, Trape et al. 1992). Anopheline larvae use 3 main habitats: niayes that are large, permanent marshes due to the emergence of the water table along offshore bar dunes; pluvial pools and ponds present during the rainy season and the beginning of the dry season; and market-garden wells that are the only type of habitat addressed by the current study. No data exists on the relative importance of these wells, although >5,000 have been counted in the lowlands, where the water table is easily accessible. The term "céane" is used locally to denote these rudimentary wells that are not reinforced with cement. The water mainly is used to irrigate allotments and usually is drawn twice a day by laborers equipped with 2 watering cans. Wells are permanent; if necessary, they are dug deeper when the water table recedes. They are shallow (usually <2 m) and sunlit, and the water is relatively clean. These wells provide potential breeding places for many mosquitoes. *Gambusia* were introduced into the Dakar area during the 1930s and are very common in market-garden wells where their presence is recommended by the National Hygiene

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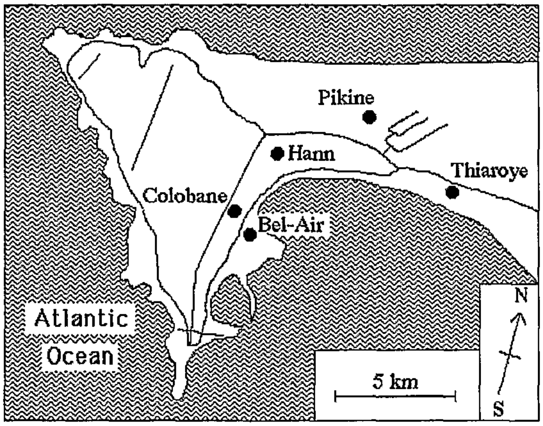

Fig. 1. An urban area in Dakar, Senegal, showing the 5 study districts.

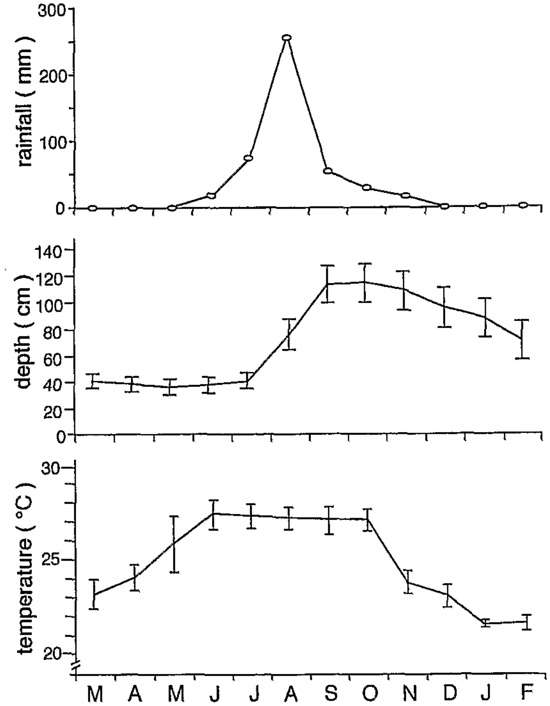

Fig. 2. Monthly rainfall, mean water depth in the wells, and the mean water temperature (bar indicates standard error).

Service. Market-gardeners are held responsible and may be fined if fish are absent from their wells.

The purpose of our project was to study the ecology of mosquito larvae and to identify the factors that influence the abundance of larvae in market-garden wells. Knowledge of these factors would improve our understanding of the regulation of the adult population and may aid in the discovery of new methods for control of the larval stages. Particular attention was paid to the malaria vector *An. arabiensis.*

Materials and Methods

Study Site. Five districts of the urban area of Dakar were selected: Bel-Air, Colobane, Hann, Pikine, and Thiaroye. Distances between 4 of 5 districts exceed mean adult dispersal within the urban environment (Fig. 1). In each district 10 wells were selected with the consent of the market-gardeners. At Bel-Air the market-gardening period is from January to May; at Colobane and Thiaroye from January to June; and at Hann and Pikine it is continuous, although reduced between July and October. Out of season, the wells are neglected. Wells were always <1 m below ground level, except at Bel-Air where they average 3.5 m in depth. Water constantly is exposed to the sun, except at Bel-Air due to the depth of the wells and at Hann where they were shaded by bushes.

Weather. The study area has a Sahelian climate influenced by its position near the Atlantic Ocean. Two seasons are distinguishable: a hot and rainy season from mid-June to mid-October and a dry season for the rest of the year (Fig. 2). The dry season is mild between November and April and warm from May to the beginning of the rainy season. During the study year, a total of 448 mm of rain fell between May 1995 and December 1995 on 39 d of rain (1961–1990 period averages 406.8 mm). The average monthly ambient temperature during the rainy season varied between 23 and 29°C, reaching a peak in October 1995.

Collection of Mosquitoes and Associated Fauna and Flora. Once a month, between March 1995 and February 1996, 10 dips were taken in each well (5 from the edge and 5 from the middle) with a tray (21 cm long by 11 cm wide with a capacity of 500 ml per dip). Mosquitoes were identified as 3rd and 4th instars, or from emerging adults. The species of the *An. gambiae* complex were determined from a DNA sample taken from one leg of an adult by using the polymerase chain reaction (PCR) technique (Scott et al. 1993). The presence and relative abundance per dip sample of associated fauna and flora also were recorded. Among the associated fauna, species were considered to be potential predators of mosquitoes based on Service (1977).

Physicochemical Analysis of Water. Once every 2 mo, data on the following physicochemical parameters of the water were collected: depth, temperature, turbidity (by extinction of a white disk progressively immersed), pH, conductivity, Na^+ concentration (by atomic absorption spectrometry on a Varian A-20 [Mulgrave, Victoria, Australia]), and Cl^-, HCO_3^-, CO_3^{--}, and NO_3^- concentrations (by capillary ion analysis on Waters materials [Milford, MA]). The first 3 parameters were measured in the field and the other 7 in the laboratory from a water sample to which 2 drops of chloroform was added.

Multivariate Analysis. The relationships among the mosquito species, the physicochemical variables, and the floro-faunistic environmental components were analyzed by co-inertia analysis (Dolédec and Chessel 1994). Co-inertia analysis belongs to the family of table

Table 1. Total number of mosquito larvae collected during monthly visits from March 1995 to February 1996 in 10 tray dip samples per month per well at the market-garden wells in 5 districts of an urban area in Dakar, Senegal

	District					Total	%
	Bel-Air	Colobane	Hann	Pikine	Thiaroye		
No. of wells	10	9	10	10	9	48	
Anophelinae	149	662	11	219	107	1,148	11.9
Culicinae	2,340	5,281	196	518	106	8,441	88.1
Total	2,489	5,943	207	737	213	9,589	100

coupling methods, such as canonical correlation analysis or canonical correspondence analysis, and analyzes the relationship between 2 data tables. The factor scores of co-inertia analysis have the property of maximizing the covariance with all the variables in both data tables, as is the case for canonical correlation analysis, and the corresponding factor maps therefore describe relationships between tables. The 1st step of co-inertia analysis applies one of the basic multivariate analysis methods on each of the 2 data tables (i.e., principal component analysis for quantitative variables, correspondence analysis for count tables, or multiple correspondence analysis for qualitative variables). The 2nd step computes and analyzes the table obtained by crossing the 2 initial analyses, and interpreting the factor maps. The main advantage of co-inertia analysis is that it maximizes the covariance instead of the correlation. In canonical correlation analysis, a high correlation can be obtained between axes with low variance, that often are hard to interpret. To achieve a high covariance, co-inertia axes must have both a good correlation and a high variance (for axes t and u, $\mathrm{cov}(t,u) = \mathrm{cor}(t,u)\sqrt{\mathrm{var}(t)\ \mathrm{var}(u)}$), thereby allowing an easier interpretation for each of the 2 tables.

Three co-inertia analyses were conducted in pairs to study the relationships among the numbers of mosquitoes, the floro-faunistic environment, and the water physicochemical variables. The physicochemical quantitative variables first were analyzed by a normed principal components analysis. The relative abundance of each mosquito species, the associated fauna and surface plants were assigned to 4 groups as follow. For mosquito species, only 3rd–4th instars were considered: group 0 (absent), group 1 (1–3 larvae per 10 dips), group 2 (4–9), and group 3 (≥10); for associated fauna: group 0 (absent), group 1 (<50 per 10 dips), group 2 (50–120), and group 3 (>120); and for surface plants: group 0 (absent), group 1 (present in places), group 2 (continuous monolayer), and group 3 (mat). Some rare species of mosquitoes and associated fauna such as veliids or geriids were excluded from the analysis. The mosquito data and the floro-faunistic environmental variables were analyzed by 2 separate centered principal components analyses. The 3 preliminary principal components analyses describe the main structures of these tables, and they are useful to understand the co-inertia analysis. The principal components analysis of physicochemical data showed that some variables are highly correlated (for example Na^+, Cl^-, and conductivity, or carbonates, bicarbonates, and pH), but that multicolinearity among variables did not cause problems in the interpretation of the principal components and co-inertia analyses (e.g., nitrates, turbidity, depth, and temperature are not highly correlated).

The significance of the relationships highlighted by the co-inertia analysis between each pair of tables was tested by means of Monte-Carlo permutation tests (Good 1993). Computations and factor map displays were carried out using ADE-4 software (Thioulouse et al. 1997) that is available for free on the Internet (http://pbil.univ-lyon1.fr/ADE-4/).

Results

In total, 9,589 mosquito larvae were collected from 48 wells in 5 districts (Table 1). Culicinae and Anophelinae comprised 88.1 and 11.9% of the fauna, respectively. The number of larvae collected varied greatly among the districts. Although *Anopheles* larvae were observed during every month, 90% was collected from May to September (Fig. 3). Culicine populations underwent marked seasonal variation, with minima in

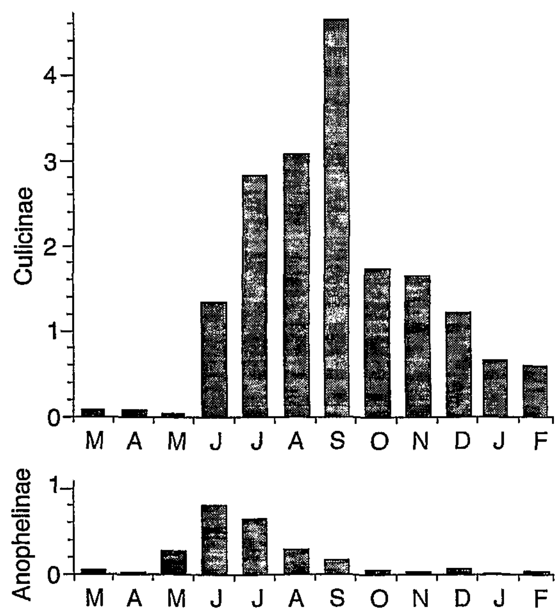

Fig. 3. Mean per dip per month of Anopheline and Culicinae larvae collected from 48 market-garden wells in an urban area in Dakar, Senegal.

Table 2. Number of 3rd and 4th instar mosquitoes collected from the market-garden wells in 5 districts of an urban area in Dakar, Senegal

	District					Total	%
	Bel-Air	Colobane	Hann	Pikine	Thiaroye		
Anopheles arabiensis	45	151	3	27	15	241	86.1
Anopheles ziemanni	0	0	0	36	3	39	13.9
Total Anophelinae	45	151	3	63	18	280	100
Aedeomyia africana	252	98	2	10	2	364	42.7
Aedes aegypti	1	0	1	0	0	2	0.2
Culex quinquefasciatus	1	222	7	36	0	266	31.2
Culex decens	2	34	3	2	2	43	5.0
Culex tritaeniorhynchus	0	17	0	0	0	17	2.0
Culex striatipes	0	3	0	0	0	3	0.4
Mimomyia splendens	24	28	43	47	15	157	18.4
Mansonia africana	1	0	0	0	0	1	0.1
Total Culicinae	281	402	56	95	19	853	100

May and maxima in September. Overall 1,133 third and 4th instars were identified to 10 species comprised in 6 genera (Table 2).

Anopheles gambiae s.l. was found in all 5 districts and represented 86% of the identified anopheline larvae. They were most frequent in the Colobane wells (62.6%), where demographic pressure was greatest and houses were nearest (≈200 m) to the wells, and rarest in Hann, where only 3 larvae were identified. Mean abundance was 0.16 immature mosquitoes per tray sample. All 85 *An. gambiae* s.l. (including 3rd–4th instars [55] and adults [30] emerging from larvae collected in the wells) captured in different districts on different dates were identified by the PCR technique as *An. arabiensis*. Therefore, all *An. gambiae* s.l. will be considered to be *An. arabiensis*.

Culicinae were most abundant in the wells at Bel-Air and Colobane. *Aedeomyia africana* Neveu-Lemaire mainly colonized wells at Bel-Air, whereas *Culex* were present at Colobane (83.3%). *Mimomyia splendens* Theobald regularly was found in the wells in all 5 districts, especially at Pikine and Hann. Very few *Aedes* and *Mansonia* were collected in wells.

Environmental Factors. The anopheline larvae in Bel-Air, Colobane, and Hann (districts where Anophelinae larvae were all *An. arabiensis*) were found in wells with temperatures ranging from 18 to 32°C. Greatest abundance was observed between 28 and 30°C.

The average turbidity of the water was 30 cm (range, 2–100 cm) (Table 3), with a minimum in July (mean ± SE, 24 ± 10) and a maximum in January (35 ± 12). The average pH of the water was 7.31 (range, 6.33–9.53). The pH of the wells with immature *An. arabiensis* ranged between 6.7 and 8.2, of which 86% was between pH 7 and 8. The conductivity of the water principally was associated with seasonal concentrations of Na^+ and Cl^-. During the dry season (January–June), the NaCl concentration increased due to evaporation (see the water level of the wells, Fig. 2), until reaching a mean of 6.3 g/liter and an extreme value of 247 g/liter in one well at Colobane. Salinity decreased considerably during the rains, with a mean of 1.1 g/liter in September. The maximum concentrations in wells with mosquitoes were 3.4 g/liter with *An. arabiensis*, 9.4 g/liter with nonidentified 1st–2nd instars of Anophelinae, and 199 g/liter with *Cx. quinquefasciatus* Say.

Potential predators, including fish (*Gambusia* spp. and *Tilapia* spp.), amphibians (tadpoles), Coleoptera (Hydrophilidae, Dytiscidae), Hemiptera (Nepidae, Notonectidae), and odonates, frequently cohabited with mosquito larvae. Relative fish abundance per dip did not show marked seasonal variation in all the wells, except the one with a maximum NaCl concentration. Apart from fish, tadpoles and odonates were most abundant, particularly during the rainy season, when the anopheline abundance decreased after June.

Table 3. Mean ± SE of the physicochemical parameters of the water at the market-garden wells in 5 districts of an urban area in Dakar, Senegal

	District					Mean
	Bel-Air	Colobane	Hann	Pikine	Thiaroye	
Depth, cm	60 ± 27	73 ± 11	79 ± 35	76 ± 34	68 ± 31	71 ± 34
Turbidity, cm	31 ± 16	23 ± 3	32 ± 10	35 ± 8	30 ± 8	30 ± 11
Temp, °C	24.2 ± 2.6	26.3 ± 3.2	24.0 ± 1.9	24.3 ± 1.7	25.4 ± 2.3	24.7 ± 2.5
pH	7.35 ± 0.25	7.98 ± 0.42	7.06 ± 0.21	7.21 ± 0.31	7.02 ± 0.27	7.32 ± 0.40
Conductivity, μmhos/cm	3,180 ± 1,190	14,340 ± 15,500	980 ± 550	3,370 ± 900	1,770 ± 670	4,630 ± 4,120
Na^+, mg/liter	348 ± 109	5,187 ± 7,430	116 ± 69	415 ± 126	172 ± 77	1,183 ± 1,672
Cl^-, mg/liter	836 ± 374	7,966 ± 11,255	236 ± 148	647 ± 207	350 ± 158	1,918 ± 2,565
HCO_3^-, mg/liter	235 ± 101	625 ± 200	92 ± 54	369 ± 190	161 ± 75	296 ± 204
CO_3^{--}, mg/liter	12 ± 11	33 ± 26	9 ± 10	14 ± 11	8 ± 10	15 ± 13
NO_3^-, mg/liter	69 ± 69	16 ± 25	9 ± 11	353 ± 172	130 ± 95	114 ± 132

During the rainy season, when the water lettuce formed a thick mat covering the entire surface of most of the wells, *Ad. africana* and to a lesser extent *Mi. splendens*, colonized the wells.

Market-gardening, which is especially intense between January and June, was another essential factor regulating mosquito abundance in the wells. Market-gardeners keep the surface of the wells clear from vegetation to facilitate the filling of watering cans. Large amounts of water are removed daily: between 400 and 1,600 liters (measured number of filled watering cans multiplied by mean watering-can volume) according to the size of the allotment and the requirements of the crops. This amount equated to the approximate well volume of 500 liters during dry season, indicating that wells were resupplied from the water table when watering occurred. Presumably mosquito larvae also were removed with the water and eliminated from sampling. However, this was not the case in some districts during the rainy season when cultivation ceased, and the wells were abandoned between July and December.

Multivariate Analyses. Principal components analyses were carried out on 3 sets of data: (1) the number of the different species of mosquitoes, (2) the physicochemical variables of water (depth, turbidity, temperature, pH, conductivity, Cl^-, Na^+, HCO_3^-, CO_3^{--}, and NO_3^- concentrations), and (3) the floro-faunistic environment, including predators (fish, tadpoles, Dytiscidae, Notonectidae, odonates), molluscs (*Bulinus* spp. and *Biomphalaria* spp.), and surface plants (*Pistia stratiotes* L. [water lettuces], *Lemna* spp. [duckweeds], and filamentous algae).

The principal components analysis of the physicochemical variables highlighted a primary factorial axis opposing Cl^-, Na^+, and conductivity versus NO_3^-, and a secondary factorial axis opposing depth and turbidity versus water temperature. The principal components analysis of the numbers of mosquitoes highlighted a direct relationship among *An. arabiensis, Cx. quinquefasciatus* and *Cx. decens*. In contrast, *Ad. africana* was not associated with these other mosquitoes. The study per district, or in relation to the season, agreed with the trends described above. The principal components analysis of the floro-faunistic environment demonstrated the importance of 2 groups: water lettuce–odonates, and *Bulinus–Biomphalaria*–tadpoles. To a lesser extent, *Gambusia, Tilapia,* and *Lemna* also grouped together. The numbers of other species did not indicate particular structure. Seasonal variations were evidenced in the group of *Bulinus–Biomphalaria*–tadpoles, which abounded in the rainy season and in the group of odonates–water lettuce, which abounded at the beginning of the dry season.

The co-inertia analysis conducted between the numbers of mosquitoes and the physicochemical variables of the water showed that *An. arabiensis* and *Cx. quinquefasciatus* and, to a lesser extent, *Cx. decens,* had physicochemical affinities that were comparable and different from those of *Ad. africana. An. arabiensis, Cx. quinquefasciatus,* and *Cx. decens* were associated with values for nitrates, and warm, transparent, and shallow water. *Ad. africana* was associated with water that presented high turbidity and low nitrates. *Mi. splendens* was associated with deep water (Fig. 4a). The co-inertia analysis conducted between the numbers of mosquitoes and data of the floro-faunistic environment documented a strong relationship between *Ad. africana* and water lettuce; a positive, although somewhat weaker relationship with water lettuce existed for *An. arabiensis* and *Mi. splendens* (Fig. 4b). The co-inertia analysis conducted between data of the floro-faunistic environment and physicochemical variables has shown a strong relationship between water lettuce and turbidity, between Notonectidae and salinity and also overall tadpoles-*Bulinus–Biomphalaria* with nitrates (Fig. 4c).

The Monte Carlo permutation tests revealed the existence of significant relationships among the 3 sets of data. These relationships were particularly strong between mosquitoes and the floro-faunistic environment ($P < 10^{-5}$) and between the floro-faunistic environment and physical-chemistry ($P < 10^{-5}$), but were less intense between mosquitoes and physical chemistry ($P = 0.01$).

Discussion

Market-garden wells constitute an important larval habitat for the malaria vector *An. arabiensis* in urban Dakar, although abundance was low in all districts. Considerable variability was observed in mosquito larval abundance in the market-garden wells of urban Dakar. Many factors were associated with the abundance of the different mosquito species, but none independently determined the larval phenology of *An. arabiensis.* Complex interaction among these factors regulate its larval population size. Conditions favoring the larval *An. arabiensis* were warm temperature (>27°C), water ≤40 cm in depth, high carbonate concentration, high pH, and presence of water lettuce. Conditions unfavorable were a high nitrate concentration, numerous larvivorous fish, numerous odonates, murky water, and *Lemna.*

Warm water temperature essential for immature *An. arabiensis* was related to seasonal and diel variations in ambient temperature and solar impingement. The seasonal variations in temperature may explain, in part, variations in larval abundance. The decrease in anopheline abundance from July to October was counterintuitive, because temperature, nitrate concentration, and the growth of water lettuce seemed favorable. However unfavorable factors, such as increase in depth, turbidity, predators (particularly odonates and tadpoles), and mats of *Lemna* predominated; furthermore, at this time, other potential breeding places exist, especially temporary pluvial pools and ponds which may be more attractive for gravid females searching oviposition sites.

Predation influences the population dynamics of anophelines (Laird and Miles 1985) and may be the most important single factor determining population

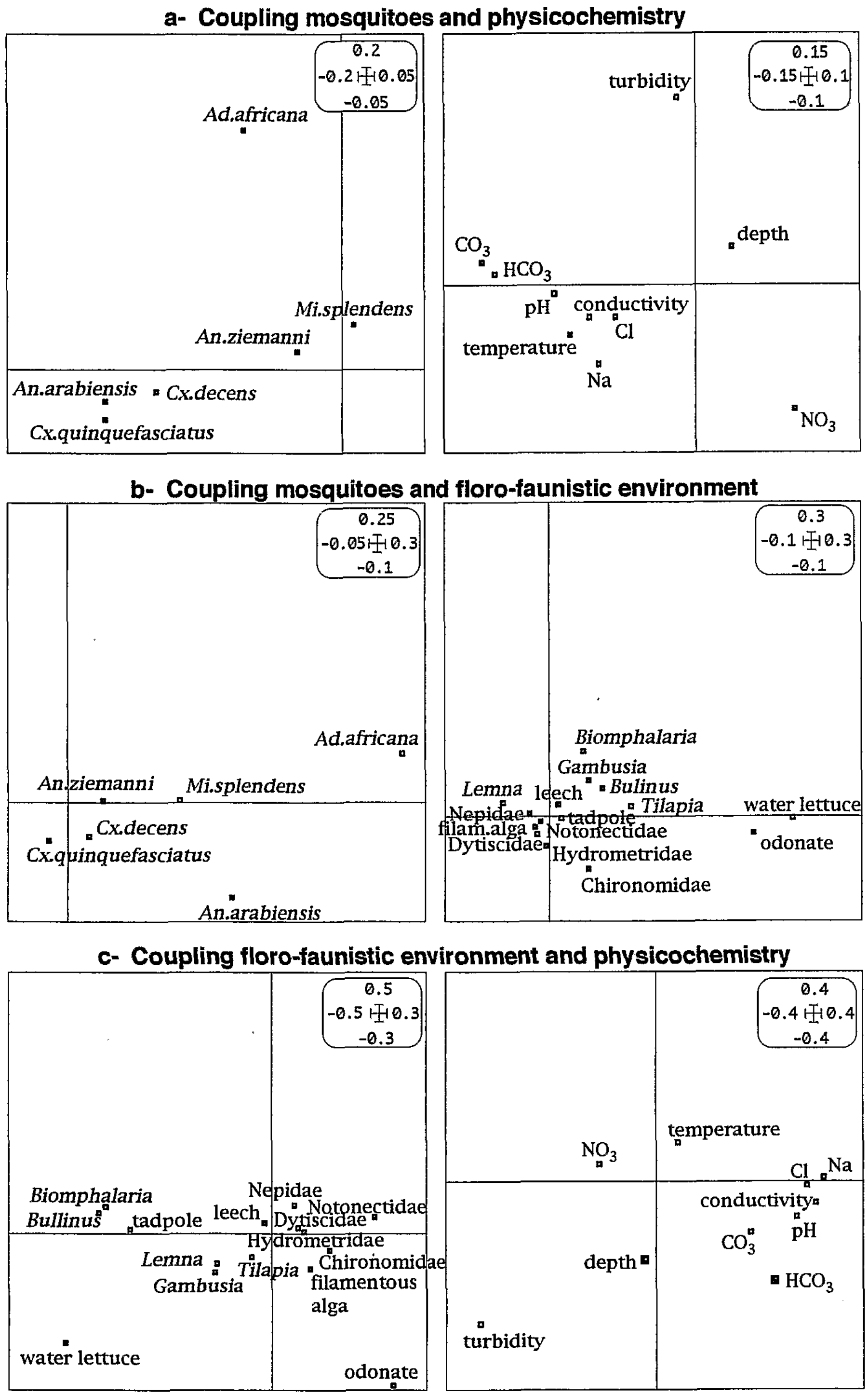

Fig. 4. Factorial plans resulting from the co-inertia analysis. In each pair of graphs the variables located in a same direction in relation to the origin can be considered as positively associated, whereas the variables located in opposite directions can be considered as antagonists. Variables plotted near the origin cannot be interpreted. The interpretation of the factor maps of the co-inertia analysis must take into account the properties of the factor scores. For example in the 1st analysis (mosquitoes and water physicochemistry), the 1st factor score maximizes simultaneously the covariance with the mosquitoes species and with the water physicochemical variables. Consequently, in "a," the 3 mosquitoes species *An. arabiensis, Cx. quinquefasciatus,* and *Cx. decens* can be considered as associated to high values of carbonates, bicarbonates, pH, temperature, and conductivity and negatively associated to NO_3^- and depth. On the 2nd axis, *Ad. africana* is associated to high values of turbidity.

fields, larval mortality was estimated to be ≈98% and has been attributed mainly to invertebrate predators (Mogi et al. 1984, 1986). In Kenyan rice fields, larval mortality of *An. arabiensis* has been estimated at 93% (Service 1977). In California, predation by aquatic beetles was a main cause of larval mortality in *Cx. tarsalis* in small ponds (Walton et al. 1990). In wells, which are permanent stagnant water, the importance of predators has been recognized (Gillies and De Meillon 1968). During our study, many predators of mosquito larvae were observed in all the market-garden wells. In several wells in Dakar not part of this study, abundance of *An. arabiensis* as high as 10–100 larvae per dip was recorded in the presence of invertebrate predators (Nepidae, Dytiscidae, Notonectidae), but in the absence of larvivorous fish (H.P.A.-A. and V.R., unpublished data). This indicates that most predation may be by fish (*Gambusia, Tilapia* or both). Our results emphasized the importance of odonates as mosquito predators, an observation also made in water-filled tree holes (Fincke et al. 1997). It is speculated that predators were hampered during the rainy season by the growth of water lettuce that provided larval refuges (Linden and Cech 1990) but not by the growth of *Lemna* or filamentous algae. *Lemna* may not hide the larvae from the predators, and filamentous algae do not occupy the air-water interface where anopheline larvae spend the most time. Contrary to what was observed for the larvae of *An. albimanus* and *An. pseudopunctipennis* in southern Mexico (Rejmankova et al. 1991), filamentous algae were not an important factor in the ecology of larval *An. arabiensis* in Dakar.

Water lettuce is reputedly favorable to numerous anopheline larvae (Zetek 1920, Unti 1943) by providing shelter from predators. However, Bernet (1950) noted that in the rainy season the development of thick rafts of this plant that entirely cover the surface of the wells, makes them unfavorable to anophelines. During the rainy season in Dakar, water lettuce proliferates but the Bernet's assessment was not observed. Under these conditions, *Ad. africana* and *Mi. splendens* showed greatest abundance. Human activity, especially market-gardening, regulates the water lettuce population.

Market-gardening influences larval populations of mosquitoes in at least 3 ways. First, the wells regularly are cleared of all excess vegetation during use. Second, large quantities of water are drawn daily to water crops, which accelerates the renewal of the water in the wells from the water table and removes an unknown proportion of the larvae. Third, market-gardeners restock the wells with fish, the predator most commonly used for mosquito control (Hoy et al. 1972). Furthermore these wells are maintained and are indispensable for market-gardening in any season. Market-gardening occurs mainly during the dry season. It is possible, but not profitable during the rainy season, which explains the seasonal abandonment of the wells.

Apart from *An. arabiensis,* the only other collected anopheline was *Anopheles ziemanni* Grunberg. It was limited to the districts of Pikine and Thiaroye where the wells often contained long grass favoring this anopheline. *An. ziemanni* is not known to play a significant role in the transmission of malaria (Hamon et al. 1956, Gillies and De Meillon 1968).

Our study focused on factors of the aquatic environment that influence the abundance of larval mosquitoes in market-garden wells. From a global point of view on the mosquito ecology in the town of Dakar, other aspects not studied herein should be considered. For instance, alternate larval habitat, and the oviposition behavior of gravid females are certainly involved in the presence or absence of each mosquito species in the various surface water habitats. Maximal abundances was observed in June for larval *An. arabiensis* in the wells and in August–September for adults (Vercruysse and Jancloes 1981, Trape et al. 1992); these asynchronous dynamics may provide a clue as to the low importance of wells for adult production relatively to alternative sources. Consequently, further research may be needed to determine if market-garden wells constitute a priority target for malaria vector control in urban Dakar.

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