PHYTO-ECOLOGICAL BASIS OF MOSQUITO CONTROL: CARTOGRAPHY OF LARVAL BIOTOPES [1]

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The characterization of a biotope, that is to say, the plain and concise expression of its physiognomy, limits and dynamics, is one of the major difficulties of ecology, particularly in its application to the study of vectors, intermediary hosts and virus reservoirs. Nevertheless, such an expression is highly desirable, indeed indispensable, particularly in the case of epidemiological inquiries when it is necessary to give an accurate interpretation of limiting factors and of evolutive cycles. This expression is even more needed when it comes to planning, in space and time, the control operations proper. With this practical proposition in mind, our purpose is to set forth the motives which lead us to adopt the plant cover as an ecological indication of the larval habitats of Culicidae.

This method has been applied in the south of France since 1963 for all of the coastal areas of the Languedoc-Roussillon region (27,800 square kilometers) Figs. 1 and 2. It allowed us to draw up an ecological map, at the scale of 1/5,000 (Figs. 3 and 4), the value of which increased with each successive season.

REVIEW OF THE MAIN BIOTOPES OF CULICIDAE OF SOUTHERN FRANCE

Before approaching the specific cartographic problems, it seems advisable to review briefly the characters of the main larval habitats of Culicidae observed in the "Midi" (south) of France. Schematically it is possible to distinguish two principal categories of habitats: urban and rural.

URBAN HABITATS (anthropogen) are essentially settled by *Culex pipiens*, s.l. They include hypogean biotopes, rich in organic matter (flooded cellars, pits), in which the autogenous and homodynamic forms develop and epigean biotopes (ponds, ditches, open drains. . .), in which the anautogenous and heterodynamic forms are found.

RURAL HABITATS are usually natural. Their dynamics allow them to be divided into two broad ecological groups, permanent and temporary:

a. Permanent biotopes [7] are generally found in fresh, sometimes slightly brackish waters. In the Mediterranean "Midi," the waters richest in organic matter are colonized by the anautogenous form of *Culex pipiens*, the others by *Culex molestus*, *Anopheles maculipennis*, *Anopheles labranchiae atroparvus* and *Anopheles hyrcanus*. Finally, *Culiseta subochrea* and *Anopheles algeriensis* live in slightly brackish habitats.

b. Temporary biotopes are settled by a series of species, some of which present striking adaptive characters. Their eggs, particularly those laid on humic soil, can remain quiescent for a long time. They hatch out during a humid period only if certain physico-chemical conditions are fulfilled (temperature, pH, relative humidity). The larval development is then very often explosive (cycle of less than 6 days for *Aedes caspius*).

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[7] The concept of the permanent habitat is evidently bound to the behavior of the species; a rice paddy can be a permanent habitat during the statge of full activity.

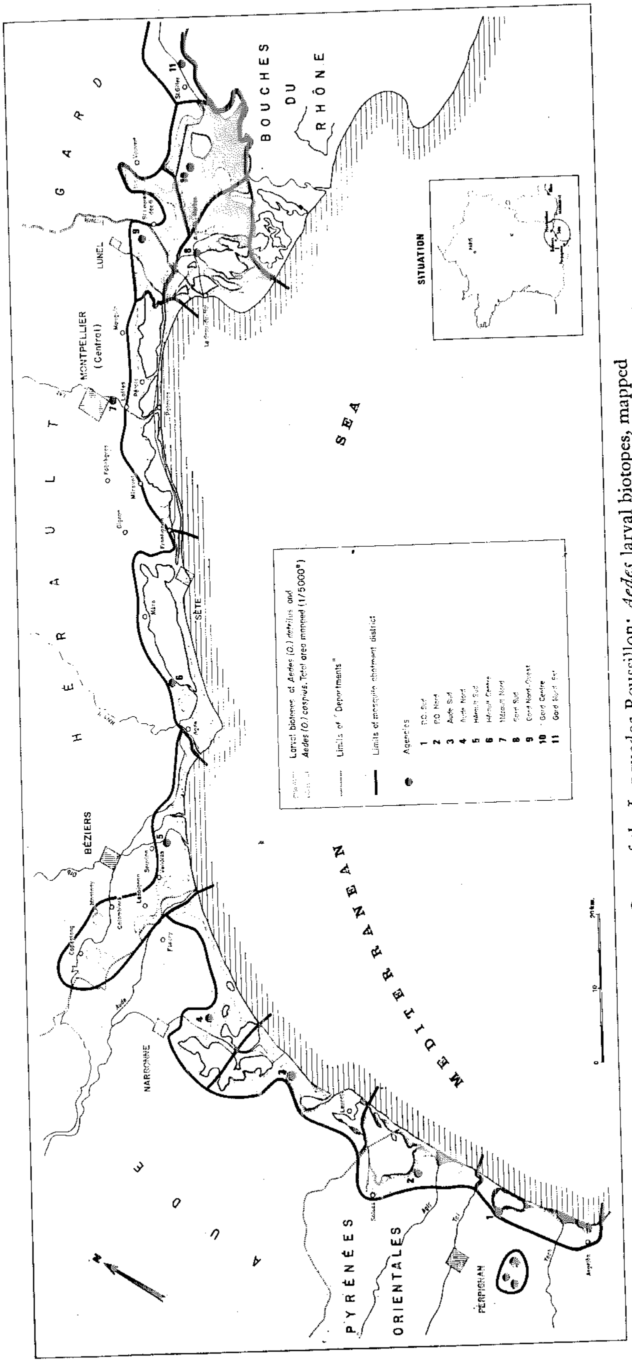

FIG. 1.—Coast of the Languedoc-Roussillon: *Aedes* larval biotopes, mapped

FIG. 2.—Precision operation on an *Aedes detritus* biotope within a *Salicornia fruticosa* community (in the vicinity of Montpellier, Hérault, France.)

The temporary fresh-water biotopes are poorly represented in the lowlands of the Mediterranean coast. In the bottomland meadows are to be found the habitats of *Aedes vexans;* in the rock cavities along the water courses we find *Aedes vittatus,* and in tree holes, the habitats of *Anopheles plumbeus, Aedes geniculatus, Aedes berlandi, Aedes pulchritarsis* and *Orthopodomyia pulchripalpis.*

The temporary salt-water biotopes, main object of the present study, occupy, on the contrary, a very wide area. Within the coastal region it is possible to distinguish two types: sub-littoral rock pools, the habitat of *Aedes mariae,* and the brackish marshes of the low alluvial plains, which are the sources of *Aedes caspius* and *Aedes detritus.*

From the ecological point of view, *Aedes detritus* and *Aedes mariae* behave like halobian species, that is to say, species adapted to the heavily salted waters (10 to 150 g. of NaCl per litre). The eggs of *Aedes detritus* hatch out from September to April. *Aedes caspius,* more ubiquitous, may be regarded as merely halophilous, adapting to a much wider range of brackish biotopes. *A. caspius* develops during the warm season from March to October with two swarming peaks, vernal and autumnal.

VEGETATION AS AN ECOLOGICAL TRACER

Although it is not difficult to delimit and, finally, to map the permanent aquatic media, the same is not true for temporary and, more particularly, the unstable lagoon environments. Here the physico-chemical as well as the topographical data tend to become less significant, owing to the important seasonal and even daily fluctuations which characterize them. On the other hand, the phyto-ecological method, based as it is on the study of the spermatophytic vegetation, furnishes valuable criteria, some of which possess great practical implications.

Fig. 3.—An aerial view photo interpreted (salt works of Villeneuve-les-Maguelonne, Herault, France). Solid fine line: maintained limits; solid thick line: added limits; broken line: abandoned limits.

The vegetation is a vital part of the environment and often influences it appreciably (pedogenesis, microclimate). In return, the environment bears an influence on the plants (texture, structure, and hydromorphy of the soils; rhythm and duration of submersion), selecting the best adapted species and shapes, in a way determining the vegetal landscape.

Finally, as a true indicator, the vegetation represents the more balanced and stable expression of the various ecological factors. It is, in the words of Charles Flahaut, "the mirror of the environment." Mapping the vegetation tends to give substance to the various factors of the environment, physico-chemical as well as biotic.

Vegetation and Culicidae Biotopes

In certain cases vegetation is the direct substrate for the culicine larvae. This is true in particular for the species of the genus *Mansonia,* bound as they are to the presence of certain aquatic plants (*Typha, Phragmites*). In the same way, for the dendrolimnic fauna (*Orthopodomyia, Anopheles plumbeus*), the tree is, in itself, the biotope.

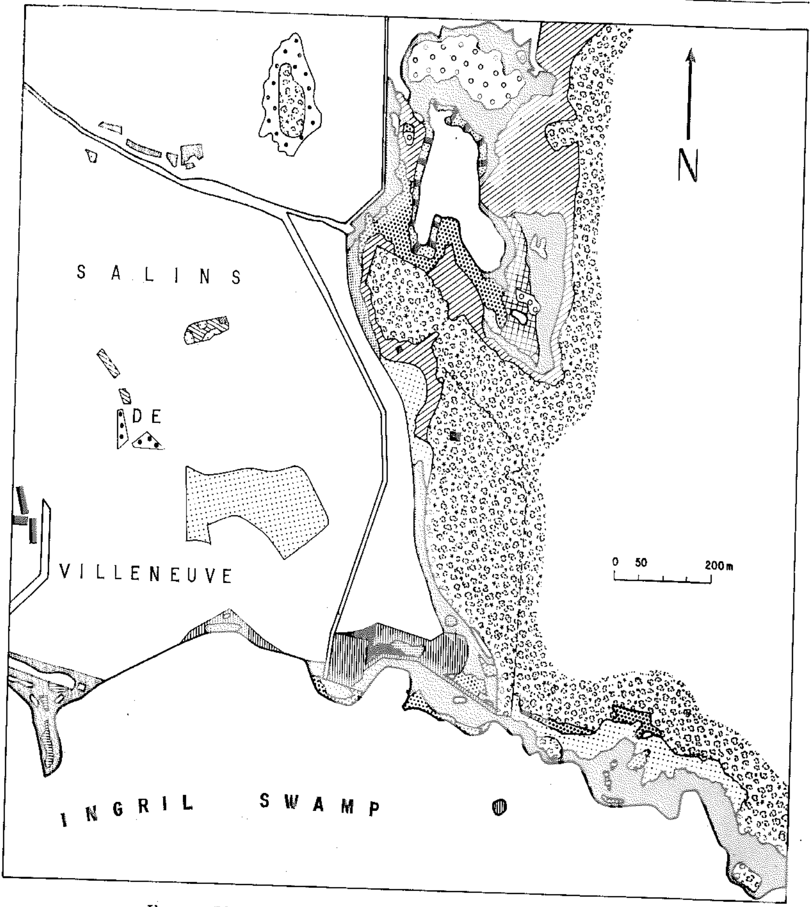

FIG. 4.—Phyto-ecological map based on the preceding photograph.

LEGEND

- *Schoenus nigricans* & *Agropyrum acutum* community
- *Suaeda fruticosa* & nitrophiles community
- *Agropyrum acutum* & *Daucus carota* community
- *Agropyrum acutum* & *Obione portulacoides* community
- *Suaeda fruticosa* & *Obione portulacoides* community
- *Triglochin maritimum* & *Juncus maritimus* community
- Cultures
- *Inula crithmoides* & *Juncus maritimus* community
- *Arthrocnemum glaucum* community
- *Salicornia fruticosa* community
- *Salicornia fruticosa* community, *Plantago coronopus* variant
- *Salicornia fruticosa* community, *Juncus subulatus* variant
- *Salicornia fruticosa* & *Arthrocnemum glaucum* community
- *Spartina versicolor* community
- *Phragmites communis* & *Scirpus maritimus* community

However, when the "biotope-vegetation" correlation is not so obvious, for example in certain lagoons, it is necessary to carry the inquiry further. Thus, our search for eggs of *Aedes* in the soil on the Mediterranean coasts, following the technique of Horsfall and Craig (1956), provided unequivocal evidence of the relationships between larval habitat and spermatophytic vegetation.

Within the limits of our study, this technique allowed us to show a close correlation between the characteristics of standing vegetation and relative intensity of mosquito egg deposition. For example, the *Juncus maritimus* or *Salicornia fruticosa* swamps give cover to a considerable number of eggs, while neighboring plant communities often shelter only a few.

The following transect, carried out in the Camargue at the "Mas Astouin" site on April 20, 1965, is a good example of the case:

Station No. 1: Upper edge of the habitat
Vegetation: *Agropyrum acutum*
Density of eggs: 0/8 m2*

Station No. 2: Slope 20 cm below the level of No. 1
Vegetation: *Juncus maritimus*
Density of eggs: 65/ dm2

Station No. 3: Lower edge of the *Juncus* border
Vegetation: thin *Juncus maritimus* + *Suaeda maritima*
Density of eggs: 4/ dm2

Station No. 4: Hollow 20 cm lower than No. 3
Vegetation: crust of blue-green algae (Myxophyceae)
Density of eggs: 0/ dm2

The samples from the center of the habitat are all negative. As a matter of fact, in this biotope, more than 100 meters wide, the eggs of *Aedes* are strictly localized in the fringe of *Juncus maritima*, with a width of only 30 to 50 cm.

Aedes detritus (Hal.).

PHYTO-ECOLOGICAL CARTOGRAPHY

CHOICE OF THE INDICATORS. The wide variety of methods proposed for the cartographical study and recording of vegetation illustrates the obvious difficulties of the task.

In the phyto-sociological method (Braun-Blanquet *et al.*, 1951), more frequently utilized in western Europe, the source of information is the composite of data obtained through the quantitative sampling of an area, homogeneous and extensive enough to be representative of the phytocoenose. The composite, often including many species, is augmented by a series of environmental data (geographical and geomorphological situation, pedology, geology . . .). The comparison of composites from similar phyto-coenoses allows us, by the means of tables, to extrapolate the corresponding vegetal association.

The method of the ecological-statistical group (Gounot, 1958) is now very much in use.[8] It appears to offer greater precision, for the ecological group represents a combination of species "with a similar ecological behavior" and sociological affinities defined from the statistical point of view.

The "method of transect" based on the linear sampling of the vegetation allows one to follow the variations of the plant cover as well as the variations of the ecological factors (e.g., microtopography, superficial moisture textures, fluctuations of the water level). Although very useful in the interpretation of vegetation-substrate relationships, it is of limited utility in developing the map proper.

For several reasons, the main ones of practical order, and taking into account the data given above, we adopted an eclectic method based, essentially, upon the vegetal physiognomy. In our phyto-eco-

[8] The conception of Gounot is a synthesis of the notion of ecological groups, in the sense of Duvignaud and of the auto-ecological studies of Ellemberg.

logical map each community is defined by one or several plants which are conspicuous at first sight. If desired, the indication of some companion species lends precision to other ecological variations such as hydromorphy, halomorphy and soil structure. We were able, in this way to sort out some thirty communities forming four broad units:

(1) The "sansouires," (Fig. 5) [9] fundamentally halomorphic
(2) The reed swamps, hydromorphic
(3) The rush marshes
(4) The salt meadows, with slight hydromorphy and halomorphy.

In each of these units the communities were classified according to decreasing order of the hydromorphy:

(1) In the "sansouire" unit it is possible to distinguish:

Ruppia maritima community in brackish swamps, almost permanently flooded
Salicornia herbacea community
Salicornia radicans community
Arthrocnemum glaucum communnity (erect form)
Salicornia fruticosa community, *Juncus subulatus* variant
Salicornia fruticosa community, *Juncus maritimus* variant
Salicornia fruticosa community, s.st.
Salicornia fruticosa and *Arthrocnemum glaucum* community
Salicornia fruticosa and *Aeluropus littoralis* community
Salicornia fruticosa community, *Plantago coronopus* variant
Arthrocnemum glaucum community (prostrate form)
Inula crithmoides and *Juncus maritimus* community
Suaeda fruticosa and *Obione portulacoides* community
Suaeda fruticosa and nitrophiles community

(2) In the reed swamps unit composed of species appreciably less halophilous, and even of fresh water species, we can distinguish:

Phragmites communis and *Typha angustifolia* or *Typha latifolia* community in nonsaline, deep, stagnant waters
Phragmites communis and *Scirpus lacustris* community in place of the former in fresh, running, or at least better exposed water
Phragmites communis and *Scyrpus maritimus* community, in stagnant, slightly salted water
Phragmites communis and *Juncus maritimus* community
Phragmites communis and *Aster trifolium* community
Phragmites communis and *Bonjeania recta* community in fresh, renovated water (rivers, swamps, forest)
Scirpus maritimus and *Aeluropus littoralis* community in place of the former in slightly halophilous zones

(3) In the unit "rush marshes," less homogeneous from the ecological point of view, it is possible to distinguish:

Juncus maritimus, pure community
Juncus subulatus and *Aeluropus littoralis* community
Juncus maritimus and *Triglochin maritimum* community
Juncus maritimus and *Schoenus nigricans* community, in place of the former on sandy soils
Juncus maritimus and *Aeluropus littoralis* community

(4) The "salt meadows" unit follows, generally, the "rush marshes." It is possible to distinguish in this unit the following vegetational types:

Spartina versicolor community

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[9] On the French Mediterranean coast, west of Marseille, and more particularly in the Rhone delta, the so-called "sansouires" are salt marshes inhabited by a low vegetation, essentially composed of Chenopodiaceae pertaining to the genera *Arthrocnemum, Salicornia, Suaeda, Kochia, Salsola,* and *Obione.*

FIG. 5.—A herd of livestock going over a "sansouire" in the Camargue (Rhone delta, France). (*Salicornia fruticosa* and *Arthrocnemum glaucum* community). In the foreground a border of *Tamarix gallica* and *Juncus maritimus*. *Aedes detritus* and *Aedes caspius* biotope.

Agropyrum acutum and *Juncus maritimus* community

Agropyrum acutum and *Schoenus nigricans* community in place of the former on sandy soils

Glyceria festucaeformis and *Lotus decumbens* community, variant with *Obione portulacoides*

Glyceria festucaeformis and *Lotus decumbens* community

Trifolium maritimum and *Agropyrum acutum* community

Tragopogon pratensis and *Trifolium pratense*

Agropyrum acutum and *Obione portulacoides* on the edge of the nonflooded areas

Agropyrum acutum and *Daucus carota* community

Dorycnium gracile and *Schoenus nigricans* community in place of the former in sandy soils

CHOICE OF THE SCALE: PHOTO-INTERPRETATION; GRAPHICAL EXPRESSION. At the interpretation stage, one of the major problems which presents itself to the cartographer is, undeniably, that of the representation scale. This was also true in our case. With regard to the habitats of Culicidae, a large scale had a chance of being not sufficiently manageable; inversely, the drawing had to be accurate enough to allow the easy spotting of an area of less than 20 square meters. Finally, after several trials, we elected a scale of 1/5000 which, in addition to being manageable, allowed the utilization of complementary symbols.

A second problem, of general order too, arises from difficulties in spotting the limits of communities. When surveying for the purpose of mapping in flat country, the investigator finds himself quite often in the center of a dense overgrowth (*Phragmites communis,* for example) which hides the topographical landmarks and makes his drawing inaccurate. To avoid these difficulties we utilized, from the beginning, aerial photographs, either directly or after photo-interpretation. On a photograph at the scale of 1/5000, it is very easy to distinguish the various physiognomic types of vegetation by their characteristics of structure (smooth, granular, striated), shape, relief, and color. The study of stereoscopic pairs furnishes, on the other hand, numerous supplementary details.

In the graphical expression proper, particularly when it comes to the choice of colors, we complied with the classical recommendations of the botanists. So the red shades are reserved for the phyto-ecological units of the more dry and saline "sansouires"; the blue shades for the more flooded and fresh water units (reed swamps), the intermediate shades allowing numerous combinations: the purple, for instance, represents the *Scirpus maritimus* areas, less flooded than the *Phragmites communis* areas (blue) and less alomorphic than the *Salicornia fruticosa* zones (red).

From the practical point of view, the development of the phyto-ecological map at the scale of 1/5000 requires the following operations, with results as shown in figures 3 and 4.

Centralization of information (map, aerial photographs, hydrological, phytosociological and pedological (soil classification) documents).

Photo-interpretation proper—The photographs concerning a test zone are covered with a tracing sheet, transparent and rigid (Kodatrace). The outlines of the units are then drawn, using a mirror stereoscope with 3 to 5 magnification.

Physiognomic significations of the units are sorted out on the photographic document. This operation, of great practical value, is carried out in the field by means of transects made during the propitious season.

Extension of the photo-interpreted units to the whole of the zone to be mapped.

Rectification in the field of the questionable areas and definitive proofing of the photo-interpreted units by means of some chosen transects.

Transfer of the outlines to the final map.

Choice of colors.

Eventual "offset" printing.

DIVISION OF THE PHYTO-ECOLOGICAL MAP. CONCEPT OF ECOLOGICAL UNITY. The operational necessities of the antilarval action have compelled us to divide the phyto-ecological map into a number of independent sectors or "ecological unities," similar to the hydrological basins of our rivers, in which the phytocoenoses react in the same way towards the submersions and the dampenings. The differences in the application of various ecological units lie essentially in the geomorphological heterogeneity of the coast, from the standpoint of inflow as well as the drainage.

Some of the main causes of this heterogeneity are: the uneven distribution of the pools due to the localization of rain storms, the differences in orientation of the coast with respect to the maritime inputs (winds from the east and the south), the dissociations of the floods from one river to another, and the heterogeneity of the soils (quick vertical drainage of the sandy soils, runoff or stagnation on heavy ground).

The individualization of these units allowed us, considering the practical side of the question, to improve the techniques of locating habitats and performing antilarva and anti-imago treatments. Engineering, too, profited materially from these concepts.

USE OF THE PHYTO-ECOLOGICAL MAP. PRACTICAL APPLICATIONS. The vegetation map, at the scale of 1/5000, has proved a valuable working instrument for the evaluation of programs as well as for the management of the operations. When it comes to planning operations it allows one, by simple planimetry, to compute the area of potential mosquito sources and to estimate *ipso facto* the mean requisites for insecticides, spreading materials, and personnel. At the inspection stage, it allows one to follow, without undue difficulty, the fluctuations of the water level and, consequently, to determine within a few hours the location and extent of "hatching zones." [10]

At the operating stage it allows one to make decisions concerning the various methods of action, including the insecticide formulations and equipment to be used. For example, aerial application would likely be indicated for extensive and open larval habitats. Ground application by means of cross-country vehicles would be the method of choice on smaller areas. Granulated insecticides would be used in preference to emulsified sprays for application in areas with dense vegetative cover.

Moreover, the phyto-ecological map provides information of value in planning for drainage operations. It also offers a guide to possible future land use, as it indicates not only the salinity of water but also the texture and micro-topography. So a *Schoenus nigricans* community indicates a sandy soil, easily drainable; on the contrary, a *Molinia coerulea* or *Salicornia fruticosa* community indicates a heavy, very impermeable soil which will be more difficult to improve by drainage (possible location for rice growing or urbanization).

Last, the phyto-ecological map is looked upon as a powerful research tool, providing a sound foundation from which highly significant work can be undertaken.

[10] The eggs of *Aedes* hatch out only in the areas which have been subjected to periods of desiccation followed by flooding. Locating the permanent water level is of particular value to inspection teams at the time of floods. Within a given ecological unit this is applicable for all similar communities.

SUMMARY

The authors propose a method for the detection and representation of the larval habitats of Culicidae in saline environments. This method is based on the utilization of the perennial vegetation as an ecological indicator for these biotopes.

The practical application of this concept to mosquito control in the south of France made it possible to establish an operating organization in a rational manner and to attain a good level of efficiency in a short time.

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References

BRAUN-BLANQUET, J. 1953. Essai sur le classement des biocenoses. Station Intern. Geobot. Med. Alp. Montpellier Comm. 118:8–12.

BRAUN-BLANQUET, J., ROUSSINE, N., and NEGRE, R. 1951. Les groupments végétaux de la France Méditerraneénne. Monogr. C.N.R.S. 297 p.

BULLOCK, H. R. 1960. Chorionic pattern of *Aedes* eggs by sump method. Trans. Am. Micros. Soc. 79:167–170.

CLARKE, G. L. 1954. Elements of ecology. J. Wiley and Sons, Inc., Chapman and Hall, Ltd. 534 p.

CLEMENTS, A. N. 1963. The physiology of mosquitoes. Pergamon Press. 393 p.

COLWELL, R. N. 1967. Remote sensing as a means of determining ecological conditions. Bioscience 17:444–449.

CORRE, J. J. 1961–1962. Une zone de terrain salé en bordure de l'Étang de Mauguio. Étude du milieu et de la végétation. Bull. Carte Phytogeogr., S.B. 6:105–151 and 7:11–48.

CRAIG, G. B., and HORSFALL, W. R. 1958. Taxonomic and ecological significance of eggs of aedine mosquitoes. Proc. Tenth Inter, Congr. Ent., Montreal 3:853–857.

GOUNOT, M. 1958. Contribution à l'étude des groupements végétaux messicoles et rudereaux de la Tunisie. Ann. Serv. Bot. Agr., Tunisie, 31, 152 p.

HORSFALL, W. R., and CRAIG, G. B. 1956. Eggs of floodwater mosquitoes IV. Species of *Aedes* common in Illinois (Diptera:Culicidae). Ann. Entomol. Soc. Amer. 49:368–374.

LOPP, O. V. 1957. Egg sampling as an index of mosquito breeding. Proc. Forty-Fourth Ann. Meet. New Jersey Mosq. Exterm. Ass. pp. 60–63.

ODUM, E. P. 1959. Fundamentals of ecology. W. B. Saunders Co. 546 p.

REY, P. 1957. L'interprétation des photographies aerriénnes. Bull. Serv. Carte Phytogeogr., S.A. 11:5–44.

REY, P. 1965. Photographie aérriénne et vegetation. Conf. UNESCO, Toulouse. Sept. 1964.

RIOUX, J. A. Les *Culicides* du "Midi" Méditerraneén. Lechevalier, Paris. 303 p.

RIOUX, J. A., CROSET, H., GRAS, G., and JUMINER, B. 1964. Priorité aux méthodes antilarvaires dans la lutte contre les *Aedes* halophiles en Languedoc–Roussillon. (Principes logistiques generaux et application pratique). Arch. Inst. Pasteur Tunis 41:386–395.

RIOUX, J. A., CROSET, H., GRAS, G., and JUMINER, B. 1965. Les bases théoriques et pratiques de la lutte contre *Culex pipiens pipiens* L., dans le sud de la France. Arch. Inst. Pasteur Tunis 42:473–503.

ROSSETTI, C. 1964. Utilisation de la photographie aérriénne à grande échelle pour l-étude de la vegetation ouverte. Conf. UNESCO, Toulouse. Sept. 1964.