The History of Insecticide Resistance

Dodd 2024-
History of Insecticide Resistance
Tuesday, January 30, 2024
Module 1

Alden Estep & Neil Sanscrainte

USDA ARS
Center for Medical Agricultural &
Veterinary Entomology

Mosquito & Fly Research Unit

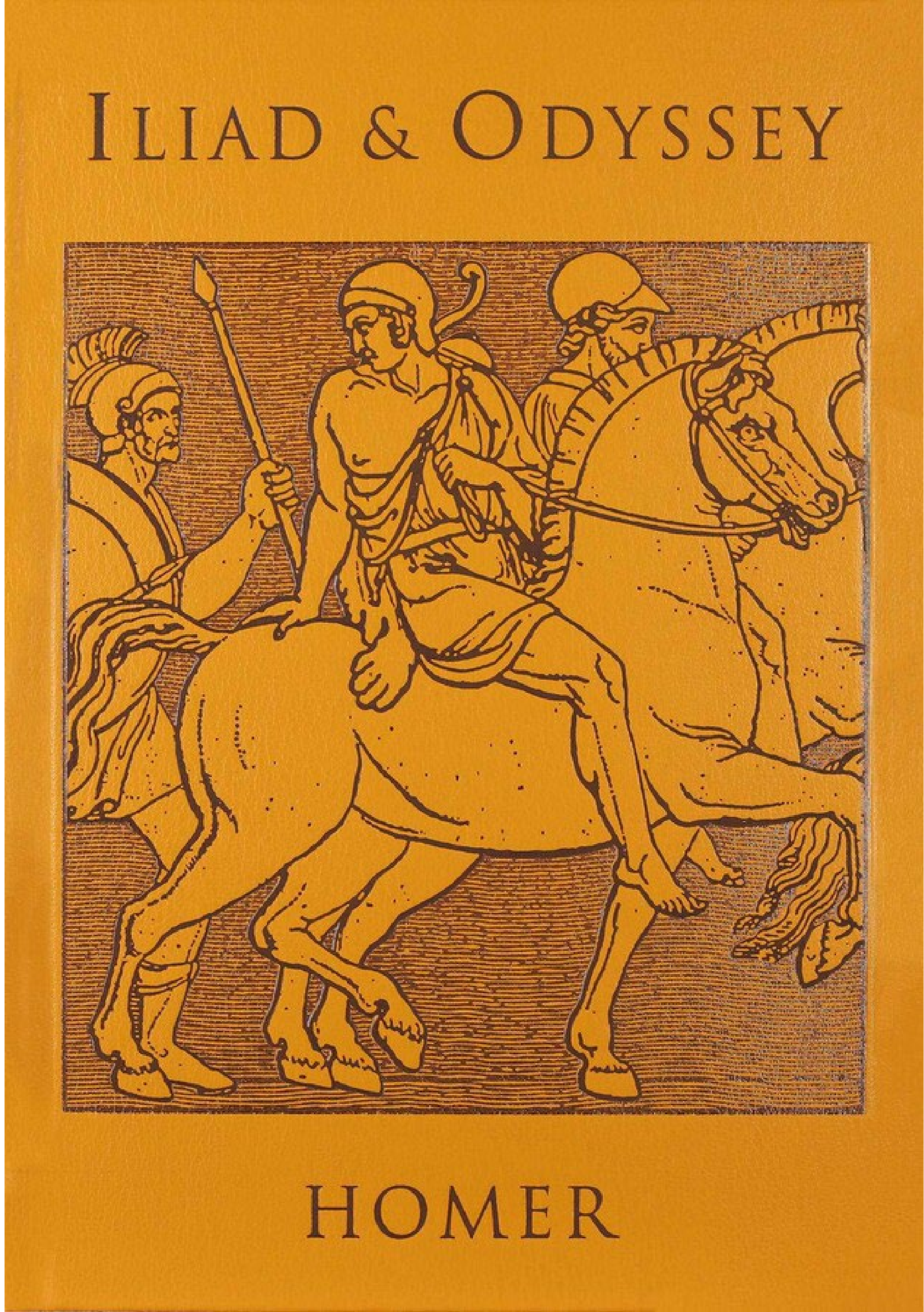
Credit: Malaria Control in War Areas Report 1942-1943

Timeline of Insecticides

<1000BC

Early chemical interventions:

- Smoke
- Inorganic sulfur
  - Memorialized by Homer
  - A cleansing ritual used against lice
- Botanicals
  - Early use in China and Persia
  - Extracts of several plants



Timeline of Insecticides

<1000BC

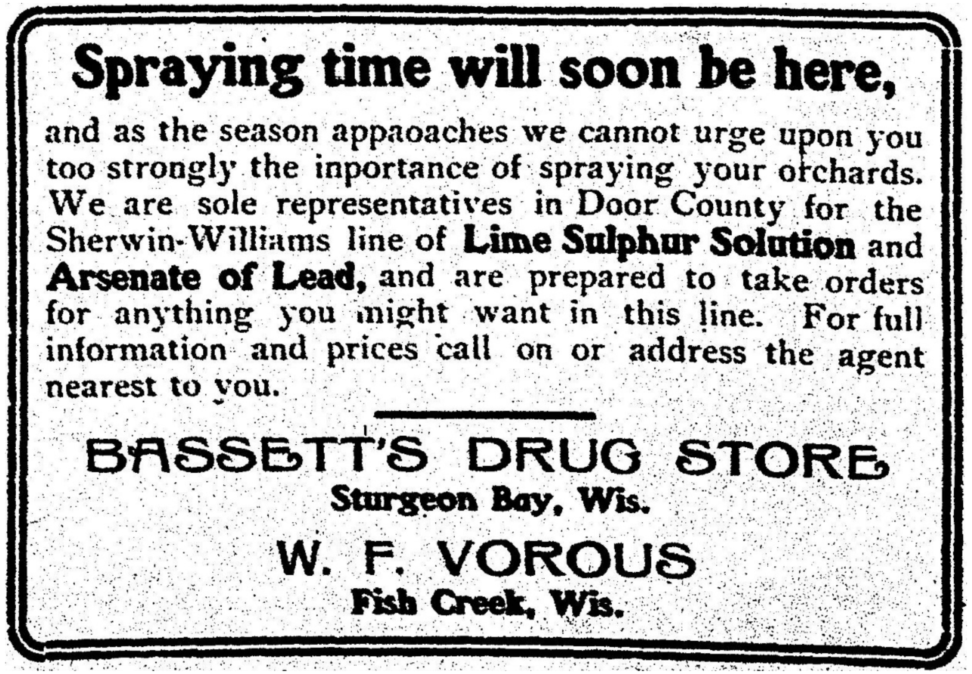
Early chemical interventions:

- Smoke
- Inorganic sulfur
  - Memorialized by Homer
  - A cleansing ritual used against lice
- Botanicals
  - Early use in China and Persia
  - Extracts of several plants

Timeline of Insecticides

<1000BC

900



Spraying time will soon be here,

and as the season appaoaches we cannot urge upon you too strongly the inportance of spraying your orchards. We are sole representatives in Door County for the Sherwin-Williams line of **Lime Sulphur Solution** and **Arsenate of Lead,** and are prepared to take orders for anything you might want in this line. For full information and prices call on or address the agent nearest to you.

BASSETT'S DRUG STORE
Sturgeon Bay, Wis.

W. F. VOROUS
Fish Creek, Wis.

Heavy metal compounds:

- Arsenic compounds
- Lead compounds
- Copper compounds

- Remained in use until the modern pesticide era
- Extremely long-lasting
- Many sites of pre-1950 orchards are still contaminated

Timeline of Insecticides

<1000BC

900

1700s

1842

1700s

- Persian dust introduced into Europe
- Dried and ground chrysanthemums
- Contained pyrethrum

1842

- Johann Zacherl
    - Formulated pyrethrum into a consumer product
    - Industrialization of pesticides- Vienna, Austria-1855

Timeline of Insecticides

<1000BC
900
1700s
1842
1867

1867

- Paris Green
- Initially a pigment used by painters - 1814
- Widely considered the first insecticide
- 1870s- wide use against Colorado Potato Beetle
- Pesticide for eradication efforts through 1945

By Georges Seurat - The Art Institute of Chicago, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2993756

Timeline of Insecticides

<1000BC
900
1700s
1842
1867

1867

- Paris Green
- Initially a pigment used by painters - 1814
- Widely considered the first insecticide
- 1870s- wide use against Colorado Potato Beetle
- Pesticide for eradication efforts through 1945

By Georges Seurat - The Art Institute of Chicago, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2993756

https://ae-files.s3.amazonaws.com/ArticleImages/c3e28b01-7ce7-4b7d-9633-b0850d0ea1be.JPG

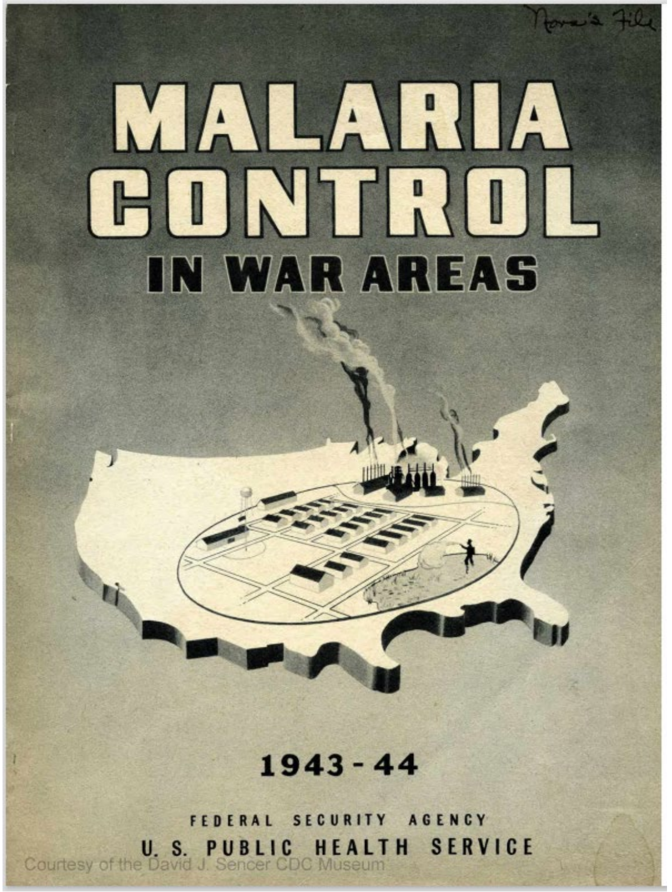
Power Dusting to Control Shoreline Breeding

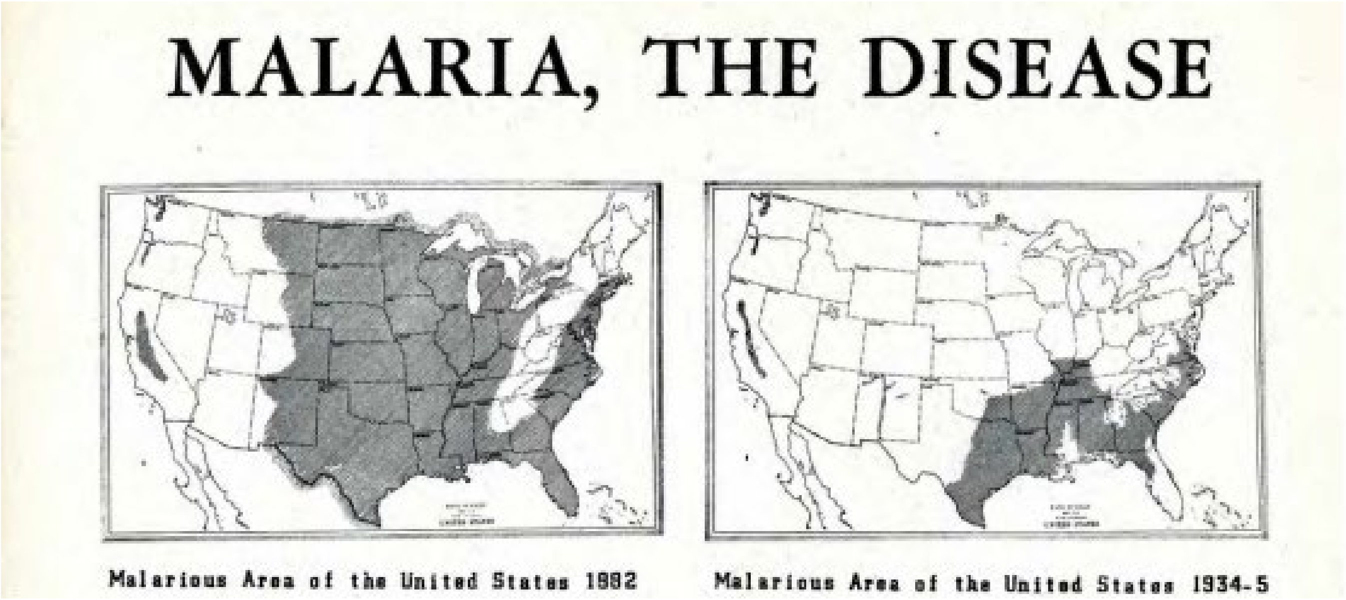
Timeline of Insecticides

- <1000BC
- 900
- 1700s
- 1842
- 1867

1867

- Paris Green
- Huge impact on eradication programs
  - Example: Malaria Control in Wartime Areas Program



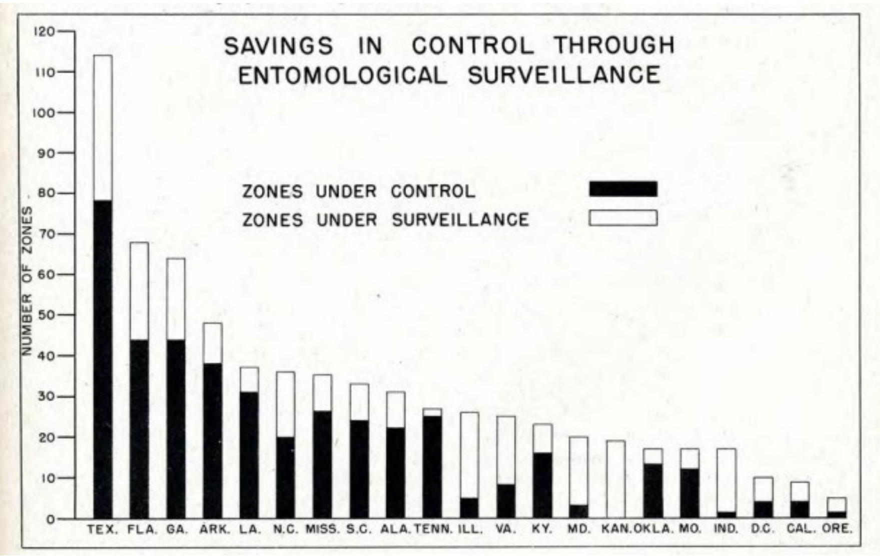


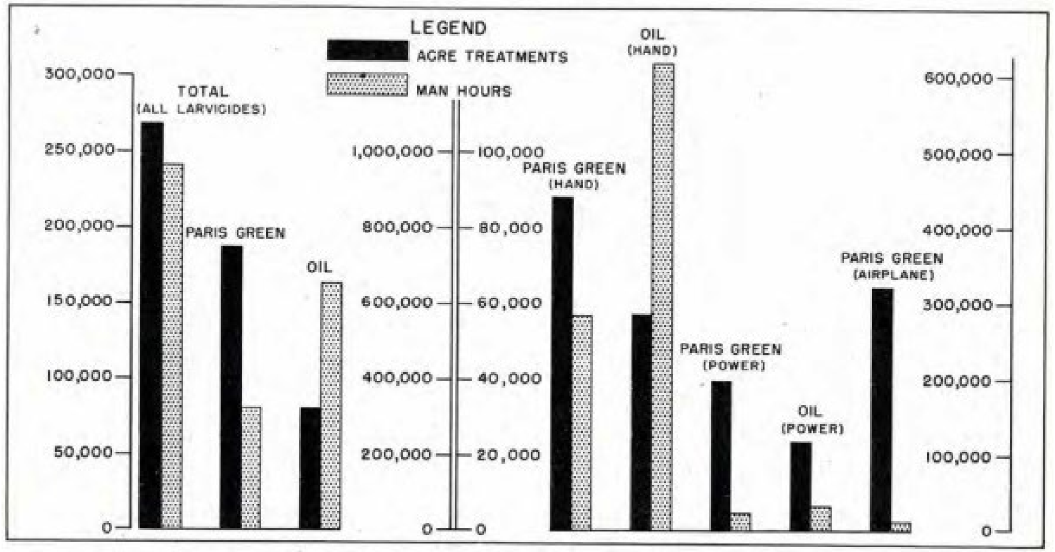
Timeline of Insecticides

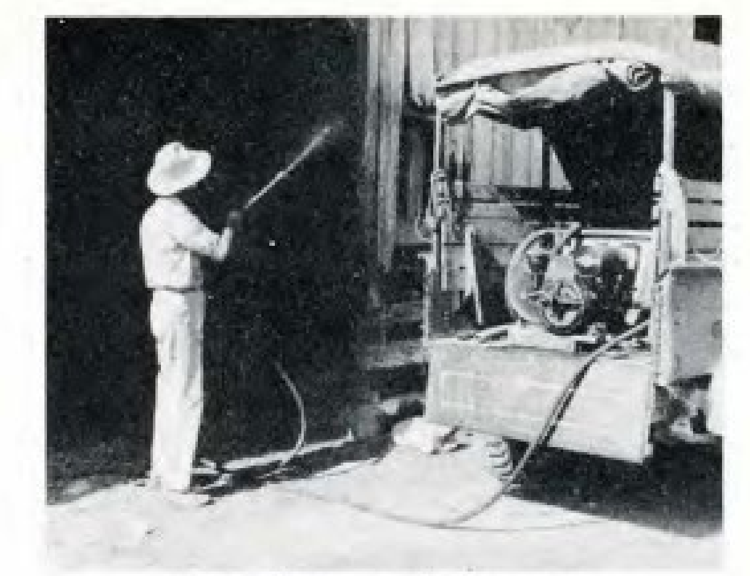
- <1000BC
- 900
- 1700s
- 1842
- 1867

1867

- Paris Green
- Huge impact on eradication programs
  - Example: Puerto Rico
  - 340,000 gal/month of larviciding oil
  - Required an oil tanker sailing every week
  - Replaced by 4.5 tons/month of Paris Green







Adult Mosquito Destruction

Timeline of Insecticides

<1000BC
900
1700s
1842
1867
1874

1867

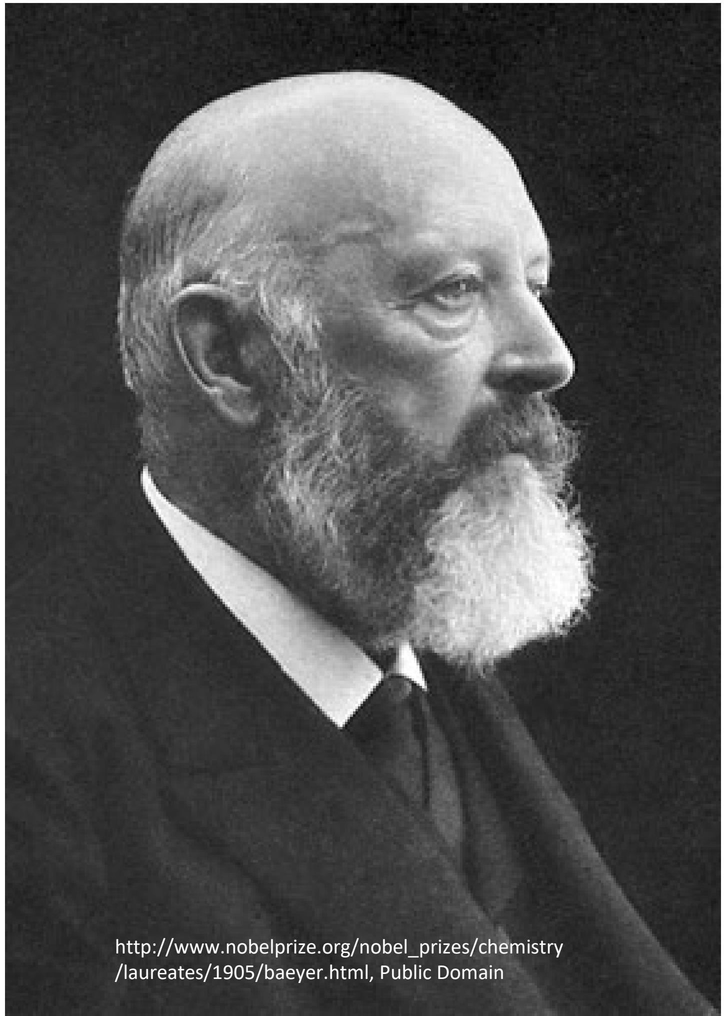
- Paris Green
- Initially a pigment used by painters - 1814
- Widely considered the first insecticide
- 1870s- wide use against Colorado Potato Beetle
- Pesticide for eradication efforts through 1945

1874

- Synthesis of DDT by Othmar Zeidler
- Doctoral student at University of Strasbourg

Adviser: Adolf von Baeyer

1905 Nobel Prize



Timeline of Insecticides

<1000BC
900
1700s
1842
1867
1874
1936
1939

1936

- Gerhard Schrader
- Synthesized several organophosphates
- His work was corrupted to create nerve agents

1939

- Paul Hermann Muller
- Discovers insecticidal properties of DDT
- Colorado potato beetle – Switzerland
- 1943- USDA Insects Affecting Man Laboratory

Timeline of Insecticides

<1000BC
900
1700s
1842
1867
1874
1936
1939
1944
1945
1948

1944

- Scrub typhus outbreak in Naples, Italy
- Ticks and chiggers transmit *Orientia tsutsugamushi*
- **First time: Disease cycle stopped with DDT**

1945

- Approved for use in US – October 1945
- Pushed for agricultural & household use
- Quickly began to replace Paris Green

1948

- Paul Hermann Muller awarded Nobel Prize

https://www.treehugger.com

Timeline of Insecticides

<1000BC
900
1700s
1842
1867
1874
1936
1939
1944
1945
1948

1944

- Scrub typhus outbreak in Naples, Italy
- Ticks and chiggers transmit *Orientia tsutsugamushi*
- **First time: Disease cycle stopped wi**

1945

- Approved for use in US – October 19
- Pushed for agricultural & household
- Quickly began to replace Paris Green

1948

- Paul Hermann Muller awarded Nobel Prize

https://www.treehugger.com

Timeline of Insecticides

<1000BC
900
1700s
1842
1867
1874
1936
1939
1944
1945
1948
1949
1950s
1970s

1949

- Synthesis of first pyrethroid - allethrin
- Schechter, Green & LaForge 1949
- USDA Bureau of Entomology

1950s

- Widespread use of organophosphates
- Widespread use of carbamates

1970s

- Widespread use of pyrethroids

used to investigate more fully these rearrangements.

CHEMISTRY DEPARTMENT
COLUMBIA UNIVERSITY
NEW YORK 27, N. Y.
LOIS M. NASH
T. I. TAYLOR
W. v. E. DOERING

RECEIVED FEBRUARY 21, 1949

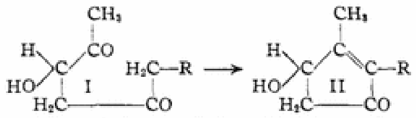
THE SYNTHESIS OF CYCLOPENTENOLONES OF THE TYPE OF CINEROLONE

Sir:

Henze[1] has studied 3-hydroxy-2,5-hexanedione and 2-hydroxy-1-phenyl-1,4-pentanedione. Hunsdiecker[2] has shown that aliphatic 1,4-diketones cyclize to cyclopentenones only if a $—CH_2—$ group is present in position 5.

We have prepared six hydroxy diketones of formula I by the reaction of pyruvaldehyde with aqueous solutions of alkali salts of beta-keto acids[3] at room temperature and about *p*H 8, under what may be considered "biological" conditions. On completion of the reaction, the products are extracted and distilled (60–75% yields). We have found that these hydroxydiketones could be cyclized to the cyclopentenolones of formula II by agitation with aqueous alkali (usually 2%) at room temperature, the products being then extracted and distilled (50–65% yields).

$CH_3COCHO + RCH_2COCH_2COONa \longrightarrow$



(a) $R = —n\text{-}C_4H_9$; (b) $R = —CH_2CH{=}CHCH_3$; (c) $R = —CH_2CH{=}CH_2$; (d) $R = —CH_2C(CH_3){=}CH_2$; (e) $R = —CH_2CH_2CH{=}CH_2$; (f) $R = —CH_2CH{=}C(CH_3)_2$.

Hydroxydiketones[4]: Ia, $C_{10}H_{18}O_3$ 1.4514, 64.48, 9.74, 64.10, 9.56; Ib, $C_{10}H_{16}O_3$, 1.4679, 65.19, 8.76, 64.75, 8.79; Ic, $C_9H_{14}O_3$, 1.4657, 63.51, 8.29, 62.82, 8.05; Id, $C_{10}H_{16}O_3$, 1.4687, 65.19, 8.76, 65.28, 8.38; Ie, $C_{10}H_{16}O_3$, 1.4675, 65.19, 8.76, 65.01, 8.52; if, $C_{11}H_{18}O_3$, 1.4715, 66.64, 9.15, 66.80 8.75.

Cyclopentenolones[4]: IIa, $C_{10}H_{16}O_2$, 1.4945, 71.39, 9.59, 71.10, 9.64; IIb, $C_{10}H_{14}O_2$, 1.5143, 72.26, 8.49, 71.75, 8.40; IIc, $C_9H_{12}O_2$, 1.5141, 71.02, 7.95, 70.23, 8.07; IId, $C_{10}H_{14}O_2$, 1.5120, 72.26, 8.49, 72.48, 8.18; IIe, $C_{10}H_{14}O_2$, 1.5089, 72.26, 8.49, 71.88, 8.35, IIf, $C_{11}H_{16}O_2$, 1.5100, 73.29, 8.95, 73.44, 8.71.

Compound IIb, although having the same structure, is not identical with natural *dl*-cinerolone. However, its dihydro derivative is identical with compound IIa, and with *dl*-dihydrocinerolone. A similar lack of identity of synthetic 2-(2-butenyl)-3-methyl-2-cyclopenten-1-one with *dl*-cinerone has been reported[5] and attributed to geometric isomerism in the side chain.

The cyclopentenolones of formula II have been acylated with natural *d*-chrysanthemum monocarboxylic acid, and IIc with the *dl-cis-trans* synthetic acid, to furnish esters analogous to cinerin I.

All of these, except the ester of IIa, exhibit high toxicity and knockdown to flies, those of IIc and IId exceeding the "pyrethrins" in toxicity. These synthetic esters are more stable than the pyrethrins and cause no irritation when applied as sprays or aerosols.

The above synthesis of cyclopentenolones opens the way to the technical production of esters of the pyrethrin type since the synthesis of chrysanthemum monocarboxylic acid has been improved[6] and a more suitable substitute for this acid may yet be discovered.

Details of this research will be published later.

(5) Harper, *J. Chem. Soc.*, 892 (1946).
(6) Campbell and Harper, *J. Chem. Soc.*, 283 (1945).

BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE
AGRICULTURAL RESEARCH ADMINISTRATION
U. S. DEPARTMENT OF AGRICULTURE
BELTSVILLE, MD.
MILTON S. SCHECHTER
NATHAN GREEN
F. B. LAFORGE

RECEIVED FEBRUARY 17, 1949

What is insecticide resistance?

Card & Smith 1897 definition: (from Forgash 1984)

- It became evident a year or two ago that something was wrong in the generally accepted doctrines in regard to this insect [codling moth, *Laspeyresia pomonella* (L.)]. At the experiment station here and among growers in the state (Nebraska) it gave much trouble, in spite of spraying as commonly advised and practiced.—The larger worms simply dig their way into the apple without eating, tearing out and throwing down the pieces of apple. Probably the same holds true of the small ones, which makes the fight more discouraging. (2)

  Washes that easily destroy the San Jose scale in California are ridiculously ineffective in the Atlantic states. This very scale is changing its life history and habits in the east materially in several directions. (3)

Schoof 1959 definition:

- Before continuing with this discussion, it is desirable to define the term "resistance." As interpreted here, it is the ability of an arthropod population to survive exposure to dosages of a toxicant to which it formerly was highly susceptible. This definition excludes a population which never displayed a susceptibility to an insecticide. Such strains or populations have been considered by some authors to be naturally resistant or refractory to the chemical involved.

What is insecticide resistance?

Functional definition:

- Phenotypic loss of efficacy
- Change from previous
- Variation in baseline susceptibility

Card & Smith 1897 definition: (from Forgash 1984)

- It became evident a year or two ago that something was wrong in the generally accepted doctrines in regard to this insect [codling moth, *Laspeyresia pomonella* (L.)]. At the experiment station here and among growers in the state (Nebraska) it gave much trouble, in spite of spraying as commonly advised and practiced.—The larger worms simply dig their way into the apple without eating, tearing out and throwing down the pieces of apple. Probably the same holds true of the small ones, which makes the fight more discouraging. (2)

  Washes that easily destroy the San Jose scale in California are ridiculously ineffective in the Atlantic states. This very scale is changing its life history and habits in the east materially in several directions. (3)

Schoof 1959 definition:

- Before continuing with this discussion, it is desirable to define the term "resistance." As interpreted here, it is the ability of an arthropod population to survive exposure to dosages of a toxicant to which it formerly was highly susceptible. This definition excludes a population which never displayed a susceptibility to an insecticide. Such strains or populations have been considered by some authors to be naturally resistant or refractory to the chemical involved.

How does insecticide resistance develop?

Melanger 1914:

JOURNAL

OF

ECONOMIC ENTOMOLOGY

OFFICIAL ORGAN AMERICAN ASSOCIATION OF ECONOMIC ENTOMOLOGISTS

VOLUME 7, 1914

Editor
E. Porter Felt

Associate Editor
W. E. Britton

Business Manager
A. F. Burgess

Advisory Board

C. P. Gillette	W. E. Hinds
L. O. Howard	S. A. Forbes
H. T. Fernald	Herbert Osborn

JOURNAL OF ECONOMIC ENTOMOLOGY PUBLISHING CO.
Concord, N. H.
1914

originally intended for a local experiment but is now an Adams project under Doctor Hinds, Auburn, Ala., and this paper is presented with his permission.

Mr. W. E. Hinds: I wish to bring out one point which I think is of interest. In the applications that have been made we found indications of a shedding due to the direct arsenical effects of the spray. Some of the fruit that was shed from treated trees had certain characteristics by which it could be distinguished from fruit shed from untreated trees. The question has been brought up in connection with these experiments as to the extent of this shedding due to arsenical application. The percentage varies considerably when the neutral and acid forms of arsenate of lead are used. As far as I know this point has not been considered heretofore. I would suggest at this time to those who have arsenate spraying projects under way that they see whether any way could be found to offset the shedding of unpunctured fruit.

Mr. W. M. Scott: Was there any difference noted as to the effect of different forms of arsenate of lead on the foliage?

Mr. W. E. Hinds: We had practically no injury. There were a few burned areas but not enough to be of economic importance.

President P. J. Parrott: Mr. A. L. Melander will present the next paper entitled, "Can Insects become Immune to Spraying?"

CAN INSECTS BECOME RESISTANT TO SPRAYS?[1]

By A. L. Melander, *Entomologist, Washington Agricultural Experiment Station*

There is a prevalent feeling in some districts that sulphur-lime is less efficient now than formerly in controlling San José scale, or orchard aphides, or the brown mite. This has been largely ascribed to the general adoption of the factory-made clear solution which is popularly regarded as subject to a mysterious adulteration.

There seems to be no question but that some years and in some places sulphur-lime is a rapidly acting insecticide. In Piper's elaborate experiment at Wawawai, Washington, in 1902, he repeatedly found all the scales dead a week after the application. The same is true of some Wenatchee scales I examined two years ago. At the same time that these Wenatchee scales were counted, specimens from Clarkston, Washington, sprayed two weeks before, showed 90 per cent alive. Even with 26° sulphur-lime, ten times stronger than a normal application, 74 per cent of the scales were still alive.

In the experiment of 1902 Piper discovered that sulphur-lime was

[1] Contribution from the Entomological Laboratory of the Bussey Institution, Harvard University, No. 75.

How does insecticide resistance develop?

IR Mechanisms:

- Variation between strains
- Suggested inheritance
- Broad vs. narrow resistance

Melanger 1914:

JOURNAL

OF

ECONOMIC ENTOMOLOGY

OFFICIAL ORGAN AMERICAN ASSOCIATION OF ECONOMIC ENTOMOLOGISTS

VOLUME 7, 1914

Editor
E. Porter Felt

Associate Editor
W. E. Britton

Business Manager
A. F. Burgess

Advisory Board

C. P. Gillette
L. O. Howard
H. T. Fernald
W. E. Hinds
S. A. Forbes
Herbert Osborn

JOURNAL OF ECONOMIC ENTOMOLOGY PUBLISHING CO.
Concord, N. H.
1914

originally intended for a local experiment but is now an Adams project under Doctor Hinds, Auburn, Ala., and this paper is presented with his permission.

Mr. W. E. Hinds: I wish to bring out one point which I think is of interest. In the applications that have been made we found indications of a shedding due to the direct arsenical effects of the spray. Some of the fruit that was shed from treated trees had certain characteristics by which it could be distinguished from fruit shed from untreated trees. The question has been brought up in connection with these experiments as to the extent of this shedding due to arsenical application. The percentage varies considerably when the neutral and acid forms of arsenate of lead are used. As far as I know this point has not been considered heretofore. I would suggest at this time to those who have arsenate spraying projects under way that they see whether any way could be found to offset the shedding of unpunctured fruit.

Mr. W. M. Scott: Was there any difference noted as to the effect of different forms of arsenate of lead on the foliage?

Mr. W. E. Hinds: We had practically no injury. There were a few burned areas but not enough to be of economic importance.

President P. J. Parrott: Mr. A. L. Melander will present the next paper entitled, "Can Insects become Immune to Spraying?"

CAN INSECTS BECOME RESISTANT TO SPRAYS?[1]

By A. L. Melander, *Entomologist, Washington Agricultural Experiment Station*

There is a prevalent feeling in some districts that sulphur-lime is less efficient now than formerly in controlling San José scale, or orchard aphides, or the brown mite. This has been largely ascribed to the general adoption of the factory-made clear solution which is popularly regarded as subject to a mysterious adulteration.

There seems to be no question but that some years and in some places sulphur-lime is a rapidly acting insecticide. In Piper's elaborate experiment at Wawawai, Washington, in 1902, he repeatedly found all the scales dead a week after the application. The same is true of some Wenatchee scales I examined two years ago. At the same time that these Wenatchee scales were counted, specimens from Clarkston, Washington, sprayed two weeks before, showed 90 per cent alive. Even with 26° sulphur-lime, ten times stronger than a normal application, 74 per cent of the scales were still alive.

In the experiment of 1902 Piper discovered that sulphur-lime was

[1] Contribution from the Entomological Laboratory of the Bussey Institution, Harvard University, No. 75.

Timeline of Insecticide Resistance

1867

1897

1908

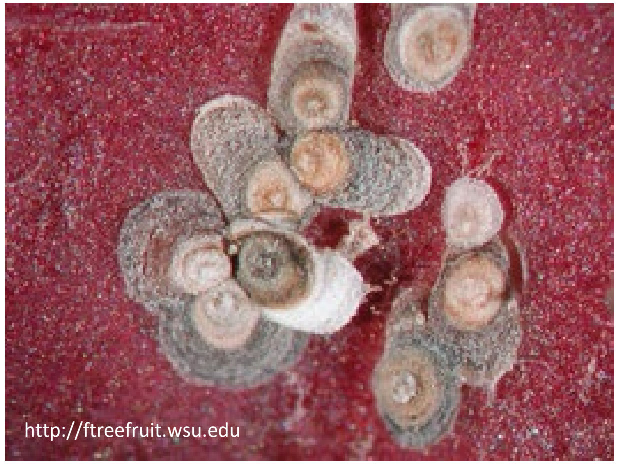
1945

1950s

1970s

1897

- Nebraska - Codling Moth
- Washington - San Jose Scale
- Resistance to sulfur pesticides



1908

- San Jose Scale
- Considered the first report of IR

Timeline of Insecticide Resistance

1867

1897

1908

1910-25

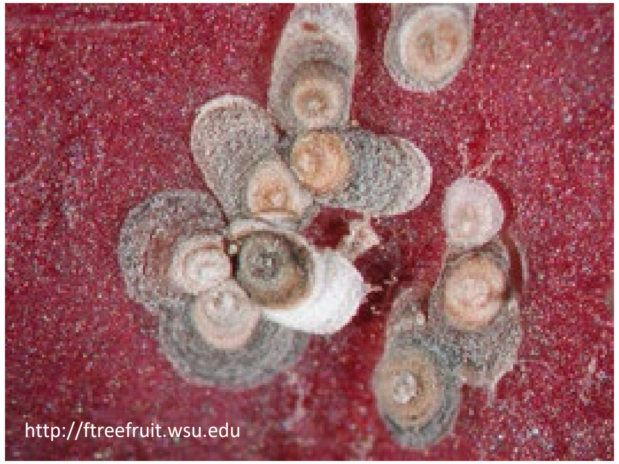
1945

1950s

1970s

1897

- Nebraska - Codling Moth
- Washington - San Jose Scale
- Resistance to sulfur pesticides

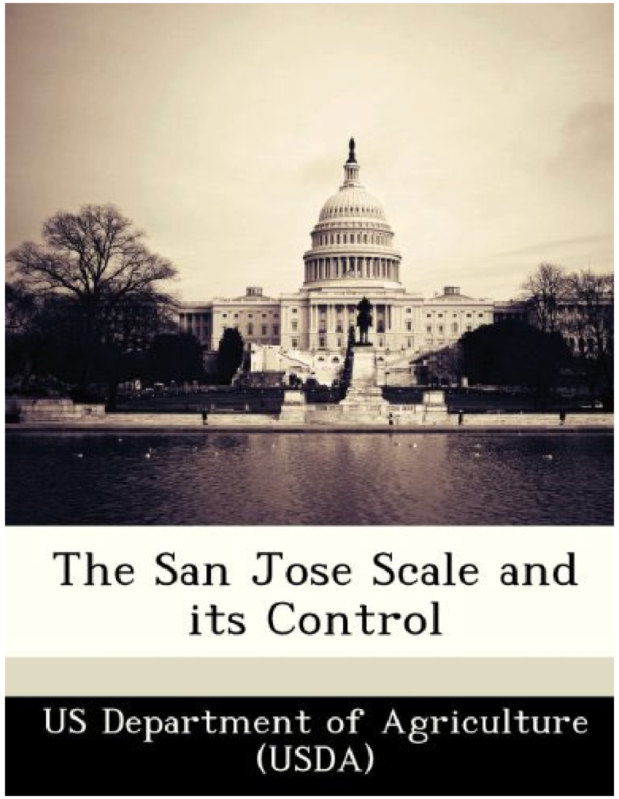


1908

- San Jose Scale
- Considered the first report of IR

1910-1925

- 3 reports from scale insects
- IR to cyanide class



Timeline of Insecticide Resistance

1867
1897
1908
1910-25
1928
1938-43
1945
1950s
1970s

1928

- Codling Moth
- Resistance to arsenates

1935

- Southern Cattle Tick
- Resistance to arsenates

1938-1943

- Blue tick – IR to arsenates
- Thrips – IR to tartar emetic
  (MoA Class 8E- non-specific inhibitor)


Photo courtesy of USDA ARS


By Daiju Azuma - Own work, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=1111495

Timeline of Insecticide Resistance

1867

1897

1908

1910-25

1928

1938-43

1945

1946

1947

1950s

1970s

1946

- IR to DDT in houseflies
- Induced by experimentation
- Confirmed in 1947 by USDA

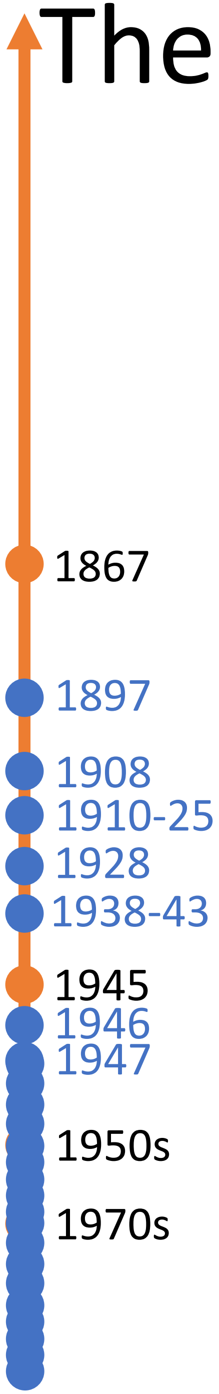
1947

- DDT IR in field in Italy
- DDT IR in New York
- First reports in mosquitoes
  - *Aedes sollicitans/taenies* - Florida
  - *Culex pipiens* - Italy
- Bedbugs - Hawaii

Photo courtesy of Library of Congress

Photo courtesy of AP Photo

The Insecticide Resistance Explosion



IR in Florida Salt Marsh Mosquitos

- August & September 1946 testing

COMPARATIVE TOXICITY OF DDT AND SOME OF THE NEWER INSECTICIDES TO ADULTS OF SALT-MARSH MOSQUITOES [1]

J. A. FLUNO, E. S. RAUN, C. C. DEONIER, AND FRANK FAULKNER [2]
U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine

- Published in 1949

- Three species:
  - *Aedes taeniorhynchus*
  - *Aedes sollicitans*
  - *Ps. confinnis*

- Three locations:
  - Mosquito Lagoon – New Smyrna Beach
  - Banana River – Cocoa Beach
  - Indian River – Oakhill & Shiloh

The Insecticide Resistance Explosion

1867

1897

1908

1910-25

1928

1938-43

1945

1946

1947

1950s

1970s

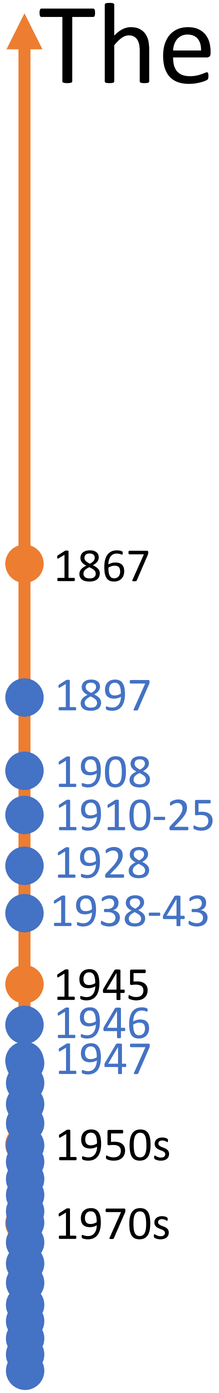
IR in Florida Salt Marsh Mosquitos

- Paired aerial sprays over 4 weeks
- DDT vs other adulticides
- Landing counts at 2, 6, 10 & 24 hours
- 2 quarts/acre, 110 ft swath
- Standard underwing spray bars
- Spray at daylight

By Palmer, Alfred T., photographer. Public Domain, https://commons.wikimedia.org/w/index.php?curid=8026429

Naval Aircraft Factory N3N-3

The Insecticide Resistance Explosion



IR in Florida Salt Marsh Mosquitos

- Paired aerial sprays over 4 weeks
- DDT vs other adulticides
- Landing counts at 2, 6, 10 & 24 hours

TABLE 1. Comparative effectiveness of sprays containing DDT and other insecticides when applied by airplane for the control of adult salt-marsh mosquitoes. Delivery rate 2 quarts per acre; 5 per cent solutions in fuel oil unless otherwise indicated.

Date applied	Insecticide	Pretreatment counts (number per man per minute)	Per cent reduction at indicated time following treatment: 2 hours	6 hours	10 hours	24 hours
1946						
August 8	DDT	97	99	99	99	90
	Benzene hexachloride, gamma isomer 6 per cent	107	99	94	92	29
14	DDT	90	48	57	57	71
	Benzene hexachloride, gamma isomer 6 per cent	103	64	67	37	46
14	DDT [1]	107	85	93	94	94
	Benzene hexachloride [1], gamma isomer 12 per cent	103	86	94	94	68
August 22	DDT	38	85	92	97	87
	Chlorinated camphene	88	17	42	59	27
22	DDT	40	85	92	97	87
	Technical chlordane	80	59	..	85	70
Sept. 11	DDT	292	48	59	77	59
	Technical chlordane	296	38	41	57	50

[1] 10 per cent solution.

The Insecticide Resistance Explosion

1867
1897
1908
1910-25
1928
1938-43
1945
1946
1947
1950s
1970s

IR in Florida Salt Marsh Mosquitos

- Paired aerial sprays over 4 weeks
- DDT vs other adulticides
- Landing counts at 2, 6, 10 & 24 hours

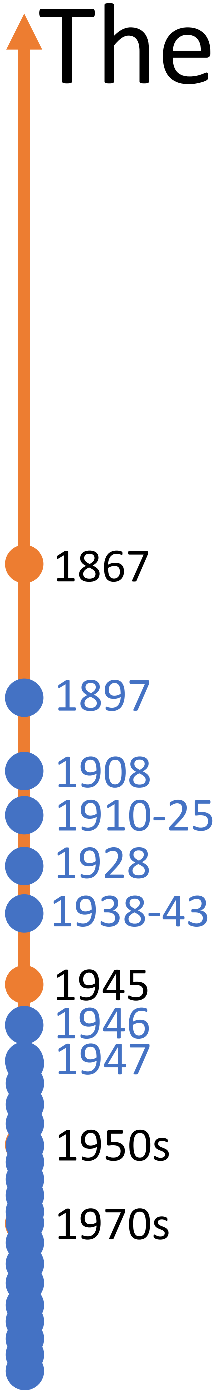
TABLE 1. Comparative effectiveness of sprays containing DDT and other insecticides when applied by airplane for the control of adult salt-marsh mosquitoes. Delivery rate 2 quarts per acre; 5 per cent solutions in fuel oil unless otherwise indicated.

Date applied	Insecticide	Pretreatment counts (number per man per minute)	Per cent reduction at indicated time following treatment: 2 hours	6 hours	10 hours	24 hours
1946						
August 8	DDT	97	99	99	99	90
	Benzene hexachloride, gamma isomer 6 per cent	107	99	94	92	29
14	DDT	90	48	57	57	71
	Benzene hexachloride, gamma isomer 6 per cent	103	64	67	37	46
14	DDT[1]	107	85	93	94	94
	Benzene hexachloride[1], gamma isomer 12 per cent	103	86	94	94	68
August 22	DDT	38	85	92	97	87
	Chlorinated camphene	88	17	42	59	27
22	DDT	40	85	92	97	87
	Technical chlordane	80	59	..	85	70
Sept. 11	DDT	292	48	59	77	59
	Technical chlordane	296	38	41	57	50

[1] 10 per cent solution.

>95% reduction

<61% reduction



The Insecticide Resistance Explosion

IR in Florida Salt Marsh Mosquitos

- Paired aerial sprays over 4 weeks
- DDT vs other adulticides
- Landing counts at 2, 6, 10 & 24 hours

TABLE 1. Comparative effectiveness of sprays containing DDT and other insecticides when applied by airplane for the control of adult salt-marsh mosquitoes. Delivery rate 2 quarts per acre; 5 per cent solutions in fuel oil unless otherwise indicated.

Date applied	Insecticide	Pretreatment counts (number per man per minute)	Per cent reduction at indicated time following treatment: 2 hours	6 hours	10 hours	24 hours
1946						
August 8	DDT	97	99	99	99	90
	Benzene hexachloride, gamma isomer 6 per cent	107	99	94	92	29
14	DDT	90	48	57	57	71
	Benzene hexachloride, gamma isomer 6 per cent	103	64	67	37	46
14	DDT[1]	107	85	93	94	94
	Benzene hexachloride[1], gamma isomer 12 per cent	103	86	94	94	68
August 22	DDT	38	85	92	97	87
	Chlorinated camphene	88	17	42	59	27
22	DDT	40	85	92	97	87
	Technical chlordane	80	59	..	85	70
Sept. 11	DDT	292	48	59	77	59
	Technical chlordane	296	38	41	57	50

[1] 10 per cent solution.

>95% reduction

36% loss of DDT efficacy over one month

<61% reduction

The Insecticide Resistance Explosion

1867
1897
1908
1910-25
1928
1938-43
1945
1946
1947
1950s
1970s

IR in Florida Salt Marsh Mosquitos

- Revisit the IR situation in 1949

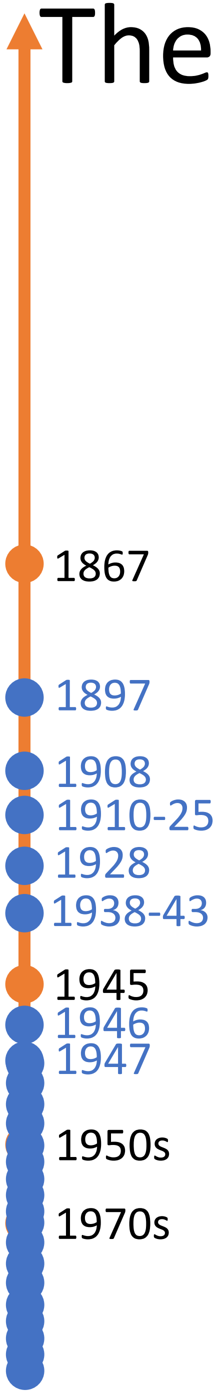
RESISTANCE OF SALT-MARSH MOSQUITOES TO DDT AND OTHER INSECTICIDES [1]

C. C. DEONIER AND I. H. GILBERT [2]

U. S. D. A., Agricultural Research Administration, Bureau of Entomology and Plant Quarantine

- Noticeable loss of efficacy during 1949 treatments

Studies by members of the Orlando, Fla., laboratory in the Cocoa Beach area of Brevard County, Fla., in the summer of 1949 indicated that aerial applications of DDT at the rate of 0.2 pound per acre and higher were not giving such good control of salt-marsh mosquitoes (*Aedes taeniorhynchus* (Wied.) and *A. sollicitans* (Walk.)) as in previous years. Apparently



The Insecticide Resistance Explosion

IR in Florida Salt Marsh Mosquitos

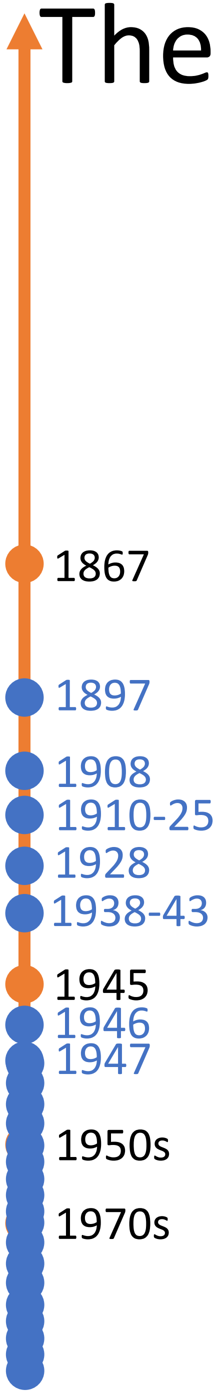
- Revisit the IR situation in 1949
- Noticeable loss of efficacy during 1949 treatments
- Comparison of treated vs. untreated areas
- Comparison of DDT to several other AIs
- Larval assay

TABLE 2.—Toxicity of several insecticides in acetone suspensions to fourth-instar larvae of salt-marsh mosquitoes taken from different locations in Brevard County, Fla. (Average of 2 beakers of 25 larvae each; number of larvae that pupated before end of test shown in parentheses.)

Marsh ocation	*Treatment*	*Percent mortality in 48 hours* *DDT*	*TDE*	*Toxaphene*	*Dieldrin*	*Lindane*	*Chlordane*	*Parathion*
		0.005 p.p.m.						
oder [1]	Heavy	0	...	64	46	58	40	100
ocoa Beach	do.	16	0	72	56	80	100	100
Haulover	Occasional	90	72	46	52	64	74	100
hiloh	do.	90	96	64	70	54	90	100
itusville	None	100	100	100	100	100	100	100
		34 (33)	...	0 (0)	74 (13)	34 (33)	84 (8)	100
		0.01 p.p.m.						
oder [1]	Heavy	18	...	86	82	100	92	100
ocoa Beach	do.	44	4	88	100	100	100	100
Haulover	Occasional	86	92	98	100	96	100	100
hiloh	do.	96	92	98	100	80	100	100
itusville	None	100	100	100	100	100	100	100
		80 (10)	...	22 (39)	90 (5)	88 (6)	100	100
		0.025 p.p.m.						
oder [1]	Heavy	26	...	98	100	100	100	...
ocoa Beach	do.	76	8	100	100	100	100	...
Haulover	Occasional	98	98	100	100	94	100	...
hiloh	do.	100	100	100	100	96	100	...
itusville	None	...	...	...	...	...	...	...
		92 (4)		88 (6)	100	78 (11)	94 (3)	98 (1)

[1] *Aedes sollicitans* larvae. All others were *A. taeniorhynchus*.

The Insecticide Resistance Explosion



IR in Florida Salt Marsh Mosquitos

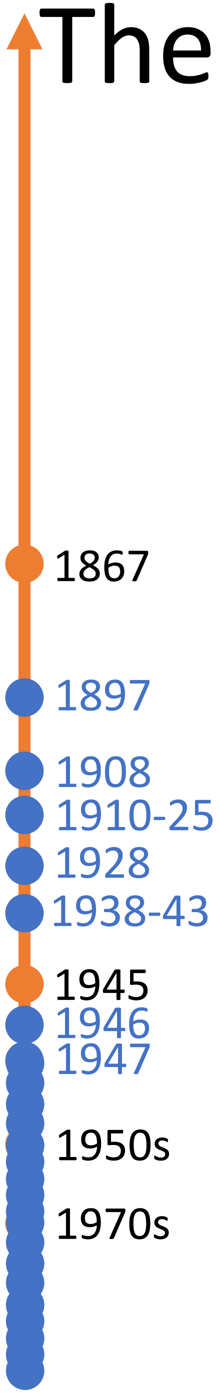
- Revisit the IR situation in 1949
- Noticeable loss of efficacy during 1949 treatments
- Comparison of treated vs. untreated areas
- Comparison of DDT to several other AIs
- Larval assay

TABLE 2.—Toxicity of several insecticides in acetone suspensions to fourth-instar larvae of salt-marsh mosquitoes taken from different locations in Brevard County, Fla. (Average of 2 beakers of 25 larvae each; number of larvae that pupated before end of test shown in parentheses.)

Marsh ocation	Treatment	DDT	TDE	Toxaphene	Dieldrin	Lindane	Chlordane	Parathion
		Percent mortality in 48 hours						
		0.005 p.p.m.						
oder [1]	Heavy	0	...	64	46	58	40	100
ocoa Beach	do.	16	0	72	56	80	100	100
laulover	Occasional	90	72	46	52	64	74	100
hiloh	do.	90	96	64	70	54	90	100
itusville	None	100	100	100	100	100	100	100
		34 (33)	...	0 (0)	74 (13)	34 (33)	84 (8)	100
		0.01 p.p.m.						
oder [1]	Heavy	18	...	86	82	100	92	100
ocoa Beach	do.	44	4	88	100	100	100	100
laulover	Occasional	86	92	98	100	96	100	100
hiloh	do.	96	92	98	100	80	100	100
itusville	None	100	100	100	100	100	100	100
		80 (10)	...	22 (39)	90 (5)	88 (6)	100	100
		0.025 p.p.m.						
oder [1]	Heavy	26	...	98	100	100	100	...
ocoa Beach	do.	76	8	100	100	100	100	...
laulover	Occasional	98	98	100	100	94	100	...
hiloh	do.	100	100	100	100	96	100	...
itusville	None	...	...	...	...	...	...	...
		92 (4)		88 (6)	100	78 (11)	94 (3)	98 (1)

[1] *Aedes sollicitans* larvae. All others were *A. taeniorhynchus*.

The Insecticide Resistance Explosion



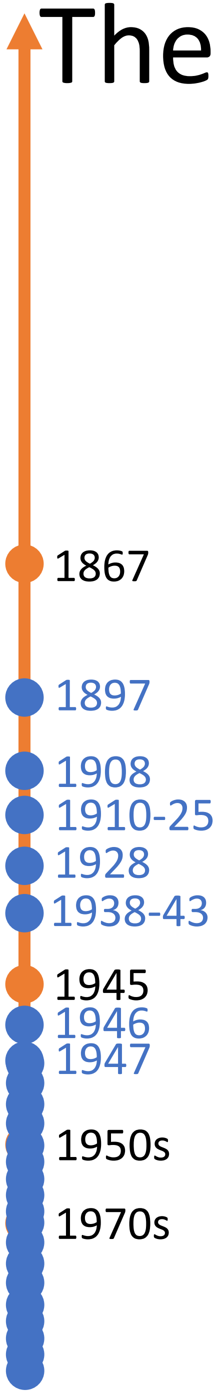
IR in Florida Salt Marsh Mosquitos

- Revisit the IR situation in 1949
- Noticeable loss of efficacy during 1949 treatments
- Comparison of treated vs. untreated areas
- Comparison of DDT to several other AIs
- Adulticiding

TABLE 3.—Comparative mortalities obtained in space-spray tests with DDT against adult salt-marsh mosquitoes from different sources. (Exposure of 10 seconds unless otherwise shown.)

Date	Species and location	Average number of mosquitoes per test	Concentration (percent) and sex: 0.25 Male	0.25 Female	0.5 Male	0.5 Female	1.0 Male	1.0 Female	2.0 Male	2.0 Female
	Marshes in treated area									
	Aedes taeniorhynchus									
July 18	Yoder marsh (both sexes)	22	..		..		..		91	
	Yoder marsh (both sexes, 60-second exposures)	33	54		62		94		92	
Aug. 5	Yoder marsh	75	15	35	39	6	31	20	64	52
Sept. 1	South Causeway	180	..	..	8	2	51	7	67	11
Aug. 20	Sarasota	115	28	4	38	10	85	27	84	51
	A. sollicitans									
July 18	Yoder marsh (both sexes)	55	..		..		..		42	
	Yoder marsh (both sexes, 60-second exposures)	32	30		38		46		73	
Aug. 5	Yoder marsh	115	32	13	21	13	63	19	89	[illegible]
	Untreated marshes									
	A. taeniorhynchus									
Aug. 5	Titusville Beach	195	93	37	96	62	93	65	97	[illegible]
	North Volusia County	140	96	71	91	58	100	89	100	[illegible]
Sept. 1	Titusville Beach	365	..	..	98	84	100	96	98	93
	Laboratory colony									
	A. aegypti (both sexes)	81	51		94		100		100	

The Insecticide Resistance Explosion



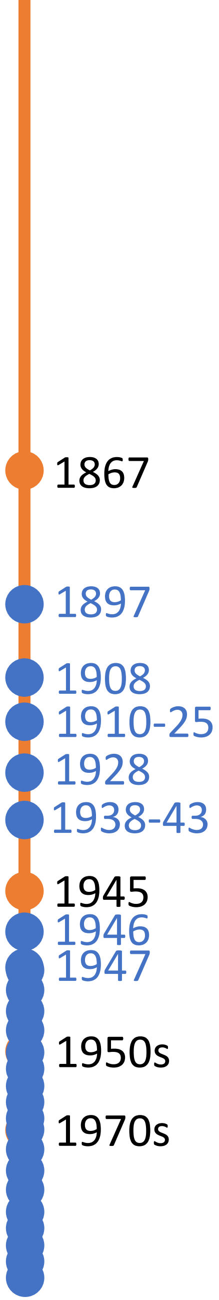
IR in Florida Salt Marsh Mosquitos

- Revisit the IR situation in 1949
- Noticeable loss of efficacy during 1949 treatments
- Comparison of treated vs. untreated areas
- Comparison of DDT to several other AIs
- Adulticiding

TABLE 3.—Comparative mortalities obtained in space-spray tests with DDT against adult salt-marsh mosquitoes from different sources. (Exposure of 10 seconds unless otherwise shown.)

Date	*Species and location*	*Average number of mosquitoes per test*	*Concentration (percent) and sex* 0.25 *Male*	0.25 *Female*	0.5 *Male*	0.5 *Female*	1.0 *Male*	1.0 *Female*	2.0 *Male*	2.0 *Female*
	Marshes in treated area									
	Aedes taeniorhynchus									
July 18	Yoder marsh (both sexes)	22	..		..		..		91	
	Yoder marsh (both sexes, 60-second exposures)	33	54		62		94		92	
Aug. 5	Yoder marsh	75	15	35	39	6	31	20	64	52
Sept. 1	South Causeway	180	..	..	8	2	51	7	67	11
Aug. 20	Sarasota	115	28	4	38	10	85	27	84	51
	A. sollicitans									
July 18	Yoder marsh (both sexes)	55	..		..		..		42	
	Yoder marsh (both sexes, 60-second exposures)	32	30		38		46		73	
Aug. 5	Yoder marsh	115	32	13	21	13	63	19	89	[illegible]
	Untreated marshes									
	A. taeniorhynchus									
Aug. 5	Titusville Beach	195	93	37	96	62	93	65	97	[illegible]
	North Volusia County	140	96	71	91	58	100	89	00	[illegible]
Sept. 1	Titusville Beach	365	..	..	98	84	100	96	98	[illegible]
	Laboratory colony									
	A. aegypti (both sexes)	81	51		94		100		100	

The Insecticide Resistance Explosion



1959

Resistance in Arthropods of Medical and Veterinary Importance—1946-58

H. F. Schoof[1]

- Increasing number of IR species

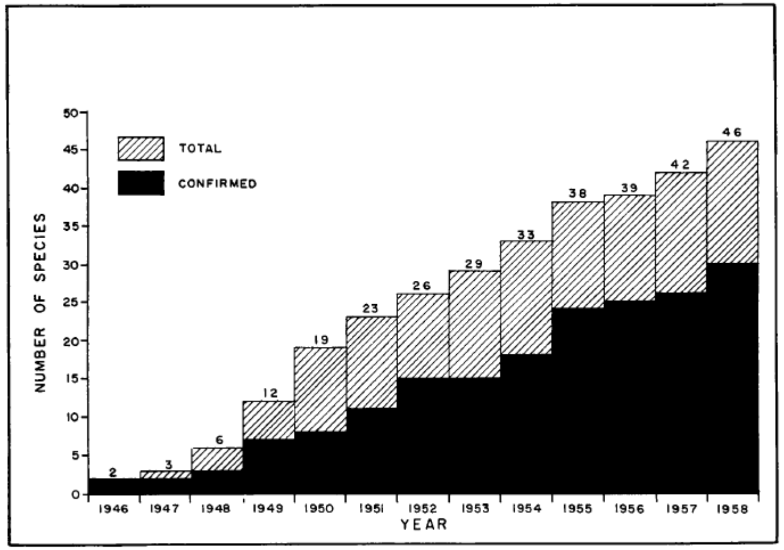
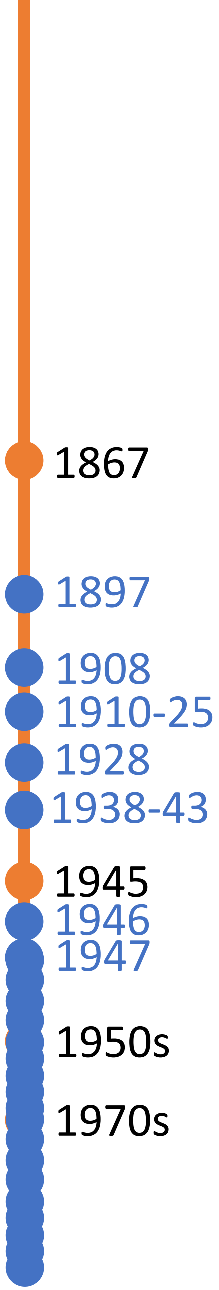
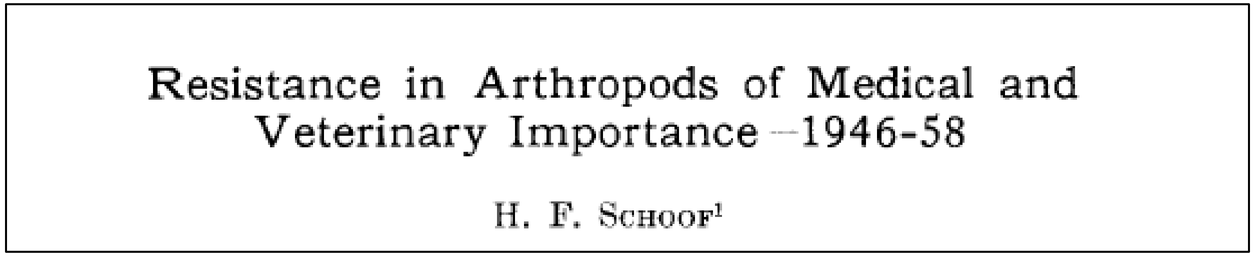


Fig. 1.—Cumulative number of arthropods of public health importance physiologically resistant to insecticides, 1946–58.

The Insecticide Resistance Explosion



1959



Resistance in Arthropods of Medical and Veterinary Importance—1946-58

H. F. Schoof[1]

- Increasing number of IR species
- 16 of 30 confirmed IR are in US
- 20 of 30 species are mosquitoes
- DDT was losing efficacy

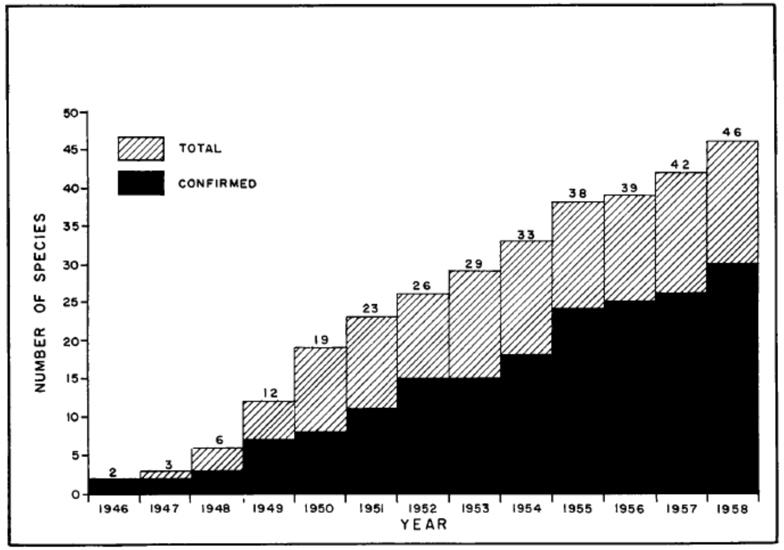
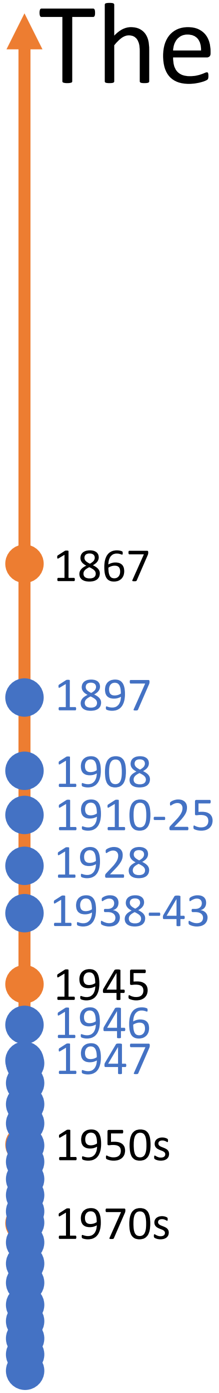


Fig. 1.—Cumulative number of arthropods of public health importance physiologically resistant to insecticides, 1946–58.

The Insecticide Resistance Explosion



1959

Resistance in Arthropods of Medical and Veterinary Importance—1946-58

H. F. Schoof[1]

- Increasing number of IR species
- 16 of 30 confirmed IR are in US
- 20 of 30 species are mosquitoes
- DDT was losing efficacy

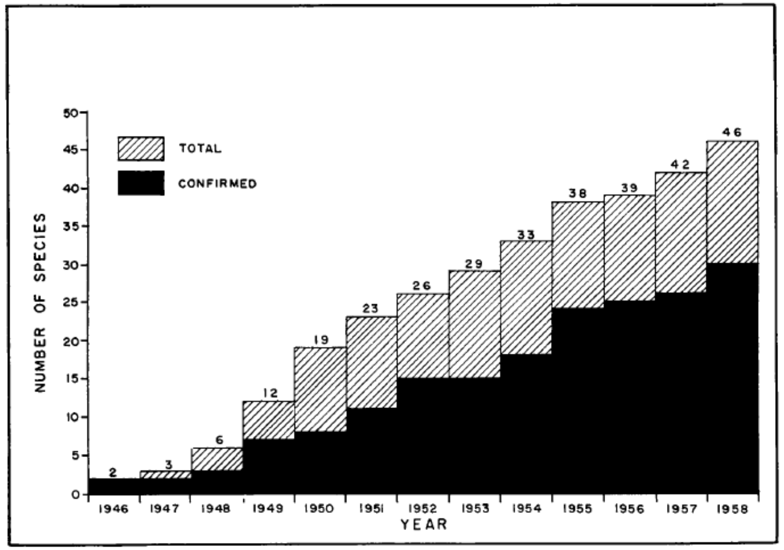


Fig. 1.—Cumulative number of arthropods of public health importance physiologically resistant to insecticides, 1946–58.

- Conclusion:

In our control of arthropods of medical and veterinary importance today, we are confronted with a resistance problem of ever increasing magnitude. To cope with this difficult situation, extensive research and investigation on a broad spectrum is an absolute necessity. Knowledge, persistence, and, to be frank, a certain amount of fortuity are the only means by which we can hope to solve the enigma facing us.

The Insecticide Resistance Explosion

1867
1897
1908
1910-25
1928
1938-43
1945
1946
1947
1950s
1970s

1984

History, Evolution, and Consequences of Insecticide Resistance*[,1]

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

- Over 400 resistant species (1908-1980)
- 61% ag pests & 39% public health pests
- IR has high economic & social cost
  - Production loss & increased labor
  - Increased disease & lost output

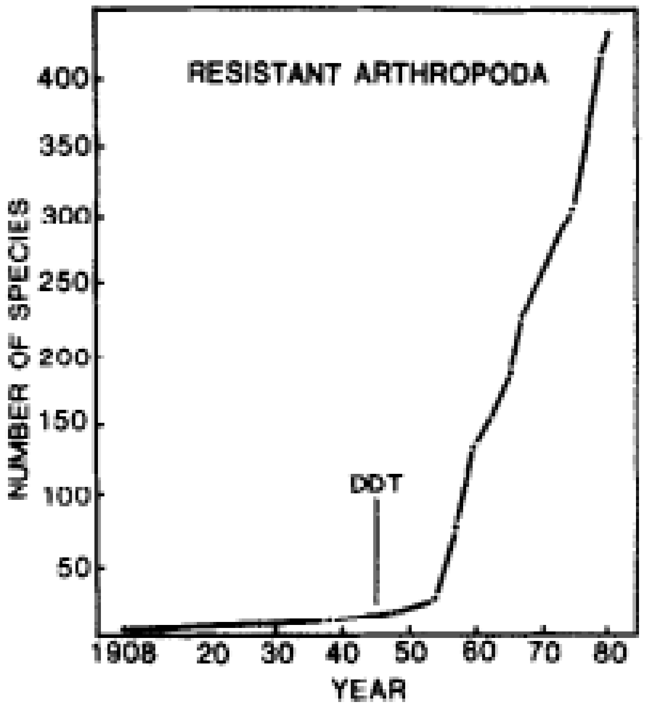


FIG. 1. *Numbers of resistant species of arthropods from 1908 to 1980.*

The Insecticide Resistance Explosion

1867
1897
1908
1910-25
1928
1938-43
1945
1946
1947
1950s
1970s

1984

History, Evolution, and Consequences of Insecticide Resistance*,[1]

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

- Over 400 resistant species (1908-1980)
- 61% ag pests & 39% public health pests
- IR has high economic & social cost
  - Production loss & increased labor
  - Increased disease & lost output

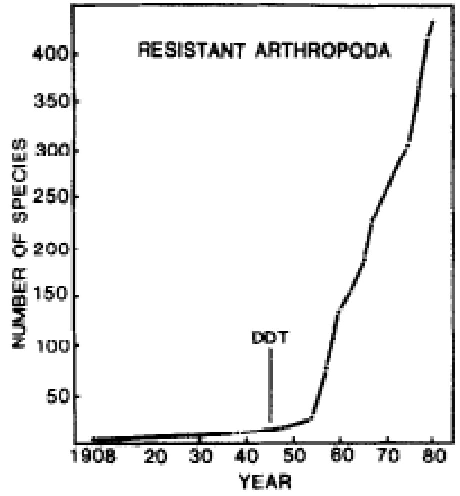
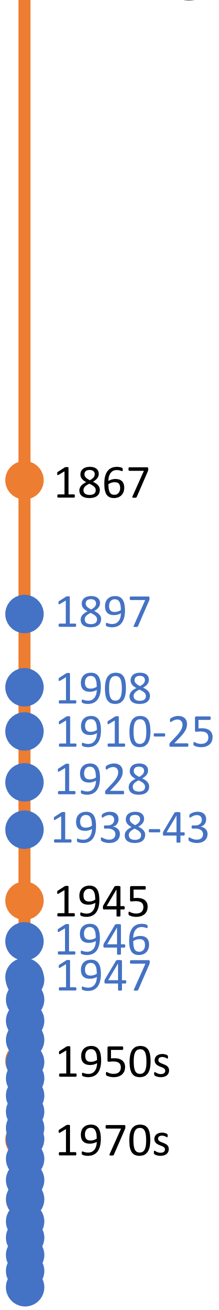


FIG. 1. *Numbers of resistant species of arthropods from 1908 to 1980.*

- Increased rate of IR after introduction of synthetics
  - Before 1945: <1 species/year
  - By 1960: >12 species/year

The Insecticide Resistance Explosion



1984

History, Evolution, and Consequences of Insecticide Resistance*[,1]

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

- Time to develop IR can be very short ~1-4 years

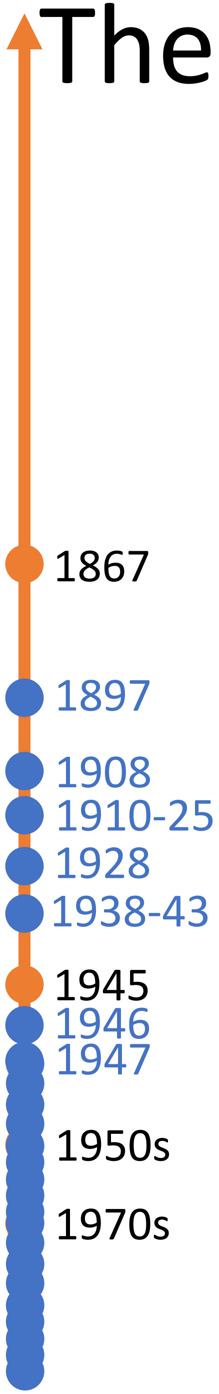
TABLE 7

An Abbreviated Chronology of Colorado Potato Beetle Resistance to Insecticides in Long Island, New York[a]

Insecticide	Year introduced	Year first failure detected
Arsenicals	1880	1940s
DDT	1945	1952
Dieldrin	1954	1957
Endrin	1957	1958
Carbaryl	1959	1963
Azinphosmethyl	1959	1964
Monocrotophos	1973	1973
Phosmet	1973	1973
Phorate	1973	1974
Disulfoton	1973	1974
Carbofuran	1974	1976
Oxamyl	1978	1978
Fenvalerate[b]	1979	1981
Permethrin[b]	1979	1981
Fenvalerate + piperonyl butoxide[b]	1982	—

[a] Modified from Gauthier *et al.* (12).
[b] Semel, personal communication (13).

The Insecticide Resistance Explosion



1984

History, Evolution, and Consequences of Insecticide Resistance*,1

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

- Time to develop IR can be very short
  ~1-4 years

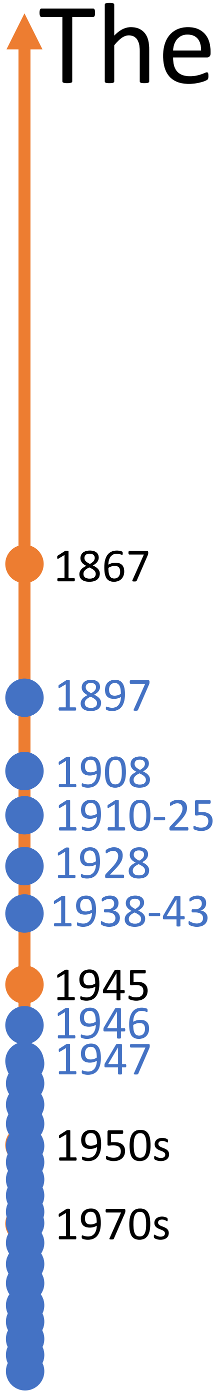
- More time equals more IR in more species

TABLE 3

Numbers of Arthropod Species Resistant to Different Pesticide Types from 1967 to 1980

Pesticide type	Number of resistant species: 1967[a]	1975[b]	1980[c]
Cyclodiene	140	225 (61)[d]	269 (20)
DDT	98	203 (107)	229 (13)
Organophosphate	54	147 (172)	200 (36)
Carbamate	3	36 (1100)	51 (42)
Pyrethroid	3	6 (100)	22 (267)
Fumigant	3	9 (200)	17 (89)
Other	11	19 (73)	41 (116)
Total for all pesticide types	312	645 (107)	829 (29)
Number of resistant species	224	364 (63)	428 (18)

The Insecticide Resistance Explosion



1984

History, Evolution, and Consequences of Insecticide Resistance*,[1]

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

How do organisms become resistant?

- Pre-adaptive: IR factors naturally exist in the population
- Early exposure: IR factors segregate nearly independently
- Building phase: IR factors begin selecting for efficiency
- Rapid phase: IR factors rapidly increase in population

The Insecticide Resistance Explosion

1867

1897

1908

1910-25

1928

1938-43

1945

1946

1947

1950s

1970s

1984

History, Evolution, and Consequences of Insecticide Resistance*[,1]

ANDREW J. FORGASH

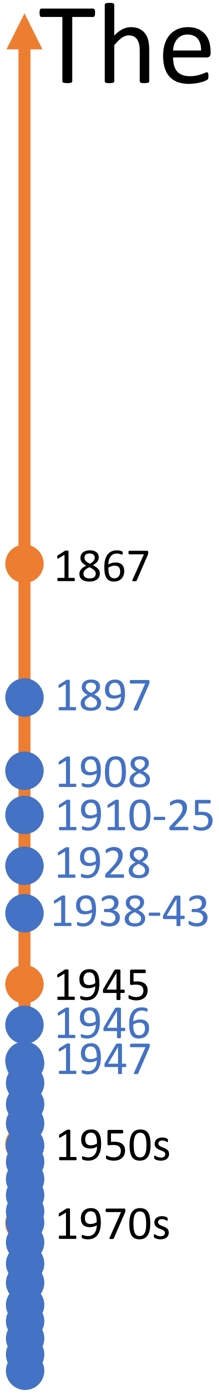
Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

How do organisms become resistant?

- Pre-adaptive: IR factors naturally exist in the population
  baseline susceptibility
- Early exposure: IR factors segregate nearly independently
  susceptibility- slight IR
- Building phase: IR factors begin selecting for efficiency
  gradual increase in IR
- Rapid phase: IR factors rapidly increase in population
  rapid increase in IR

The Insecticide Resistance Explosion



1984

History, Evolution, and Consequences of Insecticide Resistance*,1

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

Nine elements that select for IR development

A *residual closely related* to a previous AI

AI *persistent* in the environment

Slow-release formulations

Application at a low threshold of population density

Treatment reaches and kills a high percentage of population

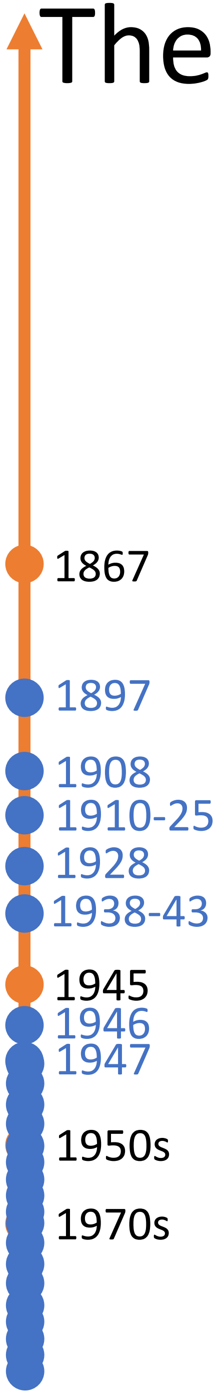
Selection against larvae or against both life-stages

Thorough application

Coverage of large geographical areas

Application of AI to every generation

The Insecticide Resistance Explosion



1984

History, Evolution, and Consequences of Insecticide Resistance[*,1]

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

Nine elements that select for IR development

A *residual closely related* to a previous AI

AI *persistent* in the environment

Slow-release formulations

Application at a low threshold of population density

Treatment reaches and kills a high percentage of population

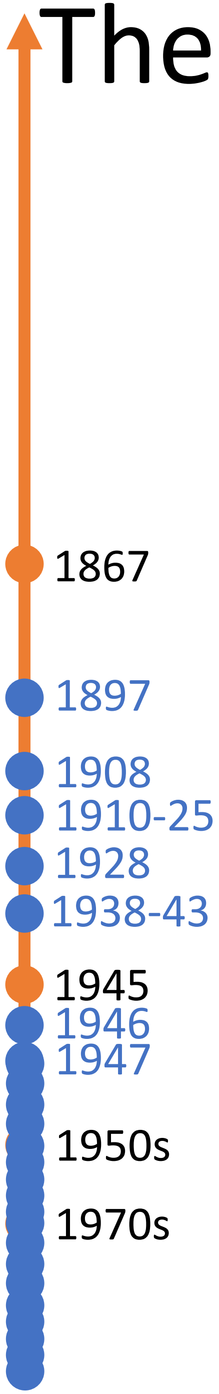
Selection against larvae or against both life-stages

Thorough application

Coverage of large geographical areas

Application of AI to every generation

The Insecticide Resistance Explosion



1984

History, Evolution, and Consequences of Insecticide Resistance*[,1]

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

Nine elements that select for IR development

A *residual closely related* to a previous AI

AI *persistent* in the environment

Slow-release formulations

Application at a low threshold of population density

Treatment reaches and kills a high percentage of population

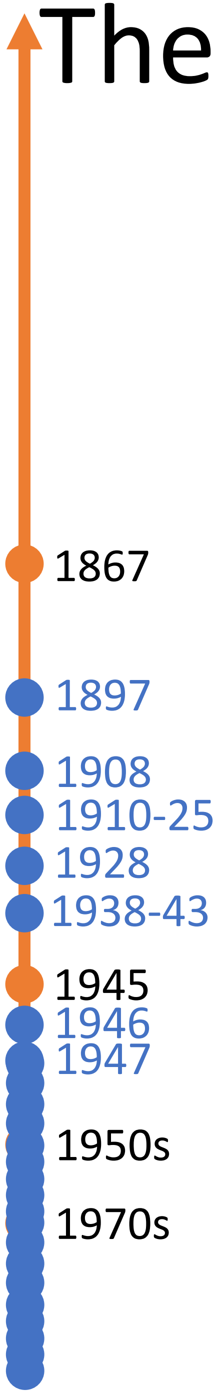
Selection against larvae or against both life-stages

Thorough application

Coverage of large geographical areas

Application of AI to every generation

The Insecticide Resistance Explosion



1984

History, Evolution, and Consequences of Insecticide Resistance[*,1]

ANDREW J. FORGASH

Department of Entomology and Economic Zoology, Cook College, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey 08903

Accepted February 23, 1984

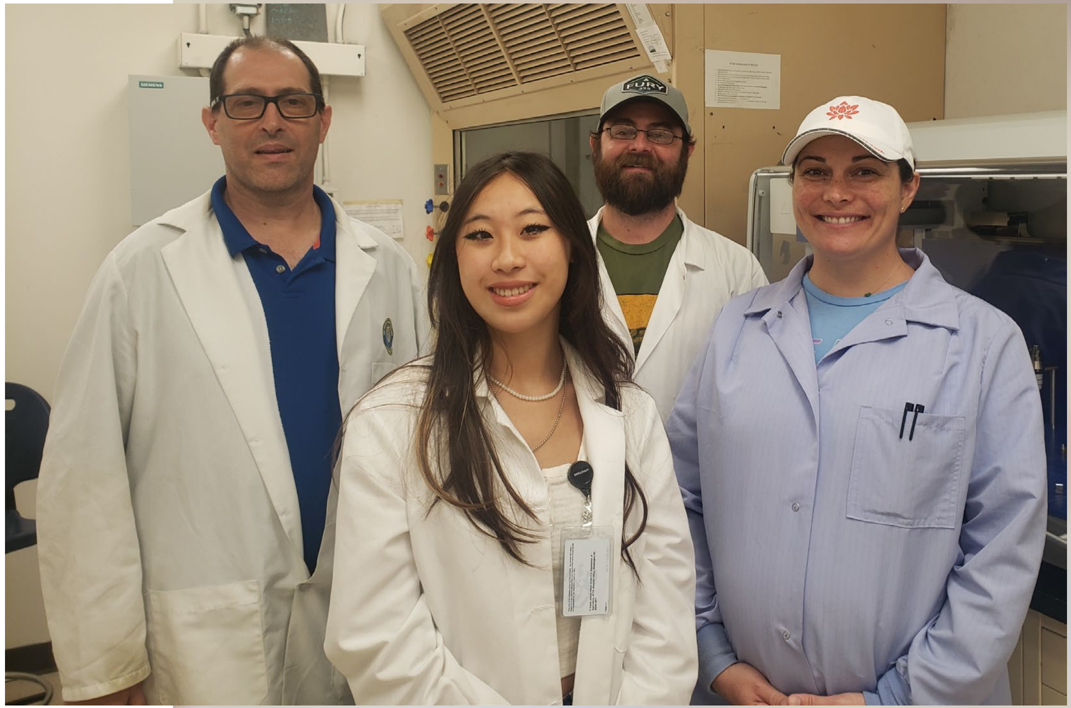
What is the future of insecticide resistance?

Whatever the causes, the fact is that we are rapidly running out of control materials for the <insert pest name here> in certain <insert area here> . There may be new types of compounds on the horizon that will be able to satisfy immediate needs,

but eventually there probably will be the same old question once again— "Where do we go from here?"

Thank you!

Questions?



Just reach out…

[*alden.estep@usda.gov*](mailto:alden.estep@usda.gov)

[*neil.sanscrainte@usda.gov*](mailto:neil.sanscrainte@usda.gov)

Alden Estep – Research Entomologist
Neil Sanscrainte – Molecular Biologist

USDA ARS Center for Medical Agricultural & Veterinary Entomology

Required Disclaimers:

"The findings and conclusions in this presentation are those of the author(s) and should not be construed to represent any official USDA or U.S. Government determination or policy."

"Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture."

"The U.S. Department of Agriculture prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. USDA is an equal opportunity provider and employer.