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BIBLIOGRAPHY OF SEQUENTIAL SAMPLING PLANS IN INSECT PEST MANAGEMENT BASED ON WALD'S SEQUENTIAL PROBABILITY RATIO TEST

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ABSTRACT

This paper contains 65 references dealing with the development of sequential sampling plans in insect pest management based on Wald's Sequential Probability Ratio Test (SPRT), 25 in forest entomology and 40 in agriculture entomology. The insect(s) sampled, whether the decision procedure was based on one or two SPRTs, and the mathematical distribution and probabilities of Type I (α) and Type II (β) errors used to develop the SPRTs are also given for each sequential sampling plan.

Sequential analysis includes all of those statistical procedures in which the sample size is not fixed prior to sampling. In sequential hypothesis testing, the number of observations taken in a given sample depends on the conclusiveness of evidence collected, observation by observation, for or against the null hypothesis or standard being tested. In other words, the final pattern and number of observations are not determined prior to sampling. The problem is to test the simple null hypothesis against some simple alternative hypothesis. The sample size is a random variable and is based on some stopping rule.

Test procedures based on sequential techniques require, on the average, a much smaller sample size, i.e., only 40–60% as many observations, than is required by equally reliable procedures based on fixed sample size techniques. When observations are expensive, time consuming, or destructive, sequential procedures seem to have a distinct advantage. Sequential hypothesis testing can be used to classify populations or to accept or reject a specific standard. They are especially useful in surveys.

Much of the theoretical literature in sequential hypothesis testing deals with Wald's Sequential Probability Ratio Test (SPRT) (Ghosh 1970; Wald 1943, 1945, 1947; Wetherill 1975). For literature reviews of the early work in sequential analysis, see Jackson (1960) and Johnson (1961). SPRT sampling plans have been used in insect pest management to aid in monitoring insect populations or their damage since Stark (1952) developed the procedure for sampling the lodgepole needleminer, *Recurvaria milleri* Busck.

To develop the decision boundaries of the SPRT, the critical population levels for classification or decision-making (simple null and alternative hypotheses), probabilities (risk levels) for making Type I (α) and Type II (β) errors, and underlying distribution of the variable or characteristic of interest are predetermined. Almost all SPRT insect sampling plans are based on the binomial, negative binomial, normal, and Poisson distributions.

In this paper, we review agriculture and forest entomology applications of the SPRT.

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Table 1. Sequential probability ratio sampling plans for monitoring forest insect populations or their damage.

Insect	No. of SPRTs	α, β values[a]
Binomial Distribution		
Larch sawfly (Ives 1954)	2	d
Larch sawfly (Ives and Prentice 1958)	2	d
Hemlock sawfly (Hard 1971)	1	a,d,e
Pine leaf adelgid (Dimond 1974)	2	d
Nantucket pine tip moth (Waters 1974)	1	a,d
Negative Binomial Distribution		
Spruce budworm (Morris 1954)	2	d
Spruce budworm (Waters 1955)	2	d
Forest tent caterpillar (Connola et al. 1957)	1	c
Red pine sawfly (Connola et al. 1959)	1	d
Spruce budworm (Cole 1960)	2	d
Spruce beetle (Knight 1960a)	1,2	d
Mountain pine beetle (Knight 1960b)	2	d,e
Cone and seed insects (Kozak 1964)	2	?
White grubs (Ives and Warren 1965)	1,2	d
Mountain pine beetle (Knight 1967)	2	c,d,e
Douglas-fir tussock moth (Mason 1969)	1	a,d
Spruce budworm (McKnight et al. 1970)	3	d,e,g
Roundheaded borers (Safranyik and Raske 1970)	2	d
Forest tent caterpillar (Shepherd and Brown 1971)	2	d
Jack pine sawfly (Tostowaryk and McLeod 1972)	2	d
Pine leaf adelgid (Dimond 1974)	2	d,f
Spruce budworm (Waters 1974)	2	d
Normal Distribution		
Lodgepole needleminer (Stark 1952)	2	b,d
Lodgepole needleminer (Stevens and Stark 1962)	3	d
Pine leaf adelgid (Dimond 1974)	2	d
Poisson Distribution		
Winter moth (Reeks 1956)	2	d
Spruce budworm (Cole 1960)	1	d
Saddled prominent eggs (Grimble and Kasile 1974)	1	c

[a]a=0.05, 0.05; b=0.05, 0.10; c=0.10, 0.05; d=0.10, 0.10; e=0.20, 0.20; f=0.30, 0.30; e=0.40, 0.40.

PEST MANAGEMENT APPLICATIONS

Numerous sampling plans based on the SPRT for classifying various insect populations have beeen published in the entomology literature (Fowler and O'Regan 1974, Pieters 1978). At the present time, at least 65 applied articles have been published in insect pest management, 25 in forest entomology and 40 in agriculture entomology.

We summarize the applications in forest and agriculture entomology in tables 1 and 2, respectively, to include (1) the insect(s) sampled, (2) whether one or two SPRTs were used to develop a two-decision procedure (e.g., control versus no control) or a three-decision procedure (e.g., light versus medium versus heavy infestations), respectively, and (3) the mathematical distribution and values of α and β used to develop the SPRT(s). Of the 28 SPRT sampling plans found in the 25 references in forest entomology,

Table 2. Sequential probability ratio sampling plans for monitoring agricultural insect populations or their damage.

Insect	No. of SPRTs	α, β values[a]
Binomial Distribution		
Green peach aphid, sugar beets (Sylvestor and Cox 1961)	1	f
Corn earworm, corn (Wolfenbarger and Darroch 1965)	1	f
Cotton fleahopper, cotton (Sterling and Pieters 1973)	3	f
Cotton fleahopper, cotton (Pieters and Sterling 1974)	1	f
Cotton arthropods, cotton (Sterling and Pieters 1974)	1	?
Bollweevil and *Heliothis* spp., cotton (Pieters and Sterling 1975)	2	f
Cotton arthropods, cotton (Sterling and Pieters 1975)	1	?
Cotton arthropods, cotton (Sterling 1976)	1	?
Mexican bean beetle, soybeans (Bellinger and Dively 1978)	1	e
Mexican bean beetle, soybeans (Bellinger et al. 1981)	1	b
Negative Binomial Distribution		
Green peach aphid, sugar beets (Sylvestor and Cox 1961)	1	f
Antestia, coffee trees (Rennison 1962)	1	c
Cabbage looper, cauliflower (Harcourt 1966a)	1	f
Imported cabbageworm, cauliflower (Harcourt 1966b)	2	f
Hylema brassicae (Bouché), cauliflower (Harcourt 1967)	1	f
Bollworm, cotton (Allen et al. 1972)	1	k
Boolworms, cotton (Ingram and Green 1972)	1	f
Lygus bugs, cotton (Sevacherian and Stern 1972)	1	f
Cabbage looper, cauliflower (Shepard 1973)	1	f
Alfalfa weevil, alfalfa (Stevens et al. 1976)	1	a,b,f
White grub, grain sorghum (Teetes and Sterling 1976)	1	?
Culex tarsalis Coquillett, rice (Mackey and Hoy 1978)	3	?
Hairy chinch bug, turfgrass and sod (Liu and McEwen 1979)	1	f
Cereal aphids, barley (Ba-Angood and Stewart 1980)	1	f
Corn rootworms, corn (Foster et al. 1982)	1	d
Tomato fruitworm, tomatoes (Nilakhe et al. 1982)	1	f,h,k
Japanese beetle, turfgrass and sod (Ng et al. 1983)	1	d,f
Alfalfa blotch leafminer, alfalfa (Harcourt 1983)	1	f
Normal Distribution		
Tomato pinworms, tomatoes (Wolfenbarger et al. 1975)	1	?
Poisson Distribution		
Asiatic rice borer, rice (Torii 1971)	2	?
Aeneolamia varia saccharina (Distant), sugar cane (Evans 1974)	1	f
Southern potato wireworm, potatoes (Onsager 1974)	1	i
Nabis spp., soybeans (Waddill et al. 1974)	2	f
Geocoris spp., soybeans (Waddill et al. 1974)	2	f
Wireworms, potatoes (Onsager et al. 1975)	2	g
Tomato pinworm, tomatoes (Wolfenbarger et al. 1975)	1	?
Eurygaster integriceps Put., winter wheat (Viktorov 1975)	1	f
Green cloverworm, soybeans (Hammond and Pedigo 1976)	1	f
Alfalfa weevil, alfalfa (Harcourt and Guppy 1976)	1	f
Velvetbean caterpillar, soybeans (Strayer et al. 1977)	2	f
Redbacked cutworm, peppermint (Danielson and Berry 1978)	1	j,l
Potato leafhopper, alfalfa (Luna et al. 1983)	1	d

[a]a = 0.001, 0.001; b = 0.01, 0.01; c = 0.025, 0.025; d = 0.05, 0.05; e = 0.05, 0.01; f = 0.10, 0.10; g = 0.125, 0.125; h = 0.15, 0.15; i = 0.20, 0.05; j = 0.20, 0.10; k = 0.20, 0.20; l = 0.40, 0.10.

5, 17, 3, and 3 were based on the binomial, negative binomial, normal, and Poisson distributions, respectively. Of the 42 SPRT sampling plans found in the 40 references in agriculture entomology, 10, 18, 1, and 13 were based on the binomial, negative binomial, normal, and Poisson distributions, respectively.

The proliferation of SPRT applications in the literature in recent years indicates widespread consideration of sequential sampling plans in insect pest management. In developing such plans, the sampler should be aware of the approximate nature of the decision process of Wald's SPRT due to overshooting errors and how such errors affect Wald's operating characteristic (*OC*) and average sample number (*ASN*) equations (Wald 1947). The errors caused by modifying the decision process, and the simultaneous operation of two or more SPRTs in a composite sampling plan should also be considered. For detailed discussions of these errors and how the sampler might adjust for them, see Fowler (1978, 1983, 1985).

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