Pheromone Traps for Detecting Incipient Outbreaks of the Spruce Budworm, *Choristoneura fumiferana* (Clem.)

C.J. Sanders

1996

NODA • EDNO
CANADA ONTARIO
Northern Ontario Development Agreement
Entente de développement du nord de l'Ontario
Forestry • Foresterie

Funding for this report has been provided through the Northern Ontario Development Agreement's Northern Forestry Program.

Canadian Cataloguing in Publication Data

The National Library of Canada has catalogued this publication as follows:

Sanders, C.J.

Pheromone traps for detecting incipient outbreaks of the spruce budworm, *Choristoneura fumiferana* (Clem.).

(NODA/NFP Technical report; TR-32)
Includes an abstract in French.
Includes bibliographical references.
"Funding for this report has been provided through the Northern Ontario Development Agreement's Northern Forestry Program."
ISBN 0-662-24951-8
DSS cat. no. Fo29-42/32-1996E

1. Spruce budworm—Control—Ontario, Northern.
2. Pheromones—Ontario, Northern.
3. Insect traps—Ontario, Northern.
4. Forest insects—Control—Ontario, Northern.
I. Great Lakes Forestry Centre.
II. Title.
III. Series.

SD945.S7S36 1996 634.9'7526781 C96-980391-5

Catalogue No. Fo29-42/32-1996E
ISBN 0-662-24951-8
ISSN 1195-2334

Copies of this publication are available at no charge from:
Publications Services
Natural Resources Canada
Canadian Forest Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Microfiche copies of this publication may be purchased from:
Micro Media Inc.
Place du Portage
165, Hotel-de-Ville
Hull, Quebec J8X 3X2

This report was produced in fulfillment of the requirements for NODA/NFP Project No. 4217 "Predicting budworm outbreaks with pheromone traps".

Sanders, C.J. 1996. Pheromone traps for detecting incipient outbreaks of the spruce budworm, *Choristoneura fumiferana* (Clem.). Nat. Resour. Can., Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. NODA/NFP Tech. Rep. TR-32. 8 p. + appendices.

ABSTRACT

Sex pheromone traps are an efficient and convenient method for monitoring low-density populations of spruce budworm. This report describes the recommended type of trap, lure, and insecticide, and provides guidelines for deployment and handling of the traps. Data from northern Ontario show that a catch of 100 moths corresponds to a density of 25 second instar larvae per 10 m^2 of branch surface. Below this density larval sampling is impractical. Therefore a catch of 100 moths per trap can be used as a threshold; above this, more intensive larval sampling is appropriate.

RÉSUMÉ

Les pièges sexuels à phéromone représentent une méthode efficace et pratique de surveiller les populations peu denses de la tordeuse des bourgeons de l'épinette. Ce rapport décrit les types de piège, d'attractif et d'insecticide recommandés et formule des conseils pour la mise en place et la manipulation des pièges. D'après les données obtenues dans le nord de l'Ontario, la capture de 100 papillons correspondrait à une densité de 25 larves au deuxième stade sur 10 m^2 de surface de branche. Lorsque la densité est inférieure, l'échantillonnage des larves n'est pas pratique. Par conséquent, la capture de 100 papillons par piège peut servir de seuil: lorsque les captures sont plus abondantes, un échantillonnage plus intensif des larves est approprié.

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PHEROMONE TRAPS FOR DETECTING INCIPIENT OUTBREAKS OF THE SPRUCE BUDWORM, *CHORISTONEURA FUMIFERANA* (CLEM.)

INTRODUCTION

The spruce budworm (*Choristoneura fumiferana* [Clem.]) is a major factor in the dynamics of the boreal forests of North America, influencing stand composition, stand succession, and wood supply. A predictable and dependable wood supply is essential for the maintenance of a healthy forest industry, but this can be jeopardized by reduced growth rates and tree mortality caused by the budworm (MacLean 1990). Long-term solutions to the budworm problem involve silvicultural treatments that will change stand composition and reduce the vulnerability of the forest. However, many millions of hectares of existing forest are highly vulnerable. For these, the only alternatives are to reduce damage by spraying the feeding larvae with pesticides or to ameliorate the impact of the budworm by preemptive harvesting of the most vulnerable stands; i.e., removing the threatened trees before they are seriously damaged.

Integrated resource management systems, which will involve the judicious use of pesticides together with planned harvesting, are now being developed for coping with the budworm problem (MacLean and Porter 1995). An essential component of any such management system is knowledge of the pest numbers and predictions of future damage.

In contrast to most forest insect pests, which cycle approximately every 10 years, the spruce budworm oscillates on much longer cycles, averaging at least 35 to 40 years between outbreaks in any one location (Royama 1984). Because of the enormous areas of forest involved, most surveys of budworm population status have been carried out from aircraft by mapping areas of visible defoliation. By the time defoliation is visible from the air, however, budworm densities are already high and the opportunity for preemptive action has been lost. During the troughs between outbreaks, budworm populations sink to very low densities, possibly only one or two larvae per tree. Monitoring changes in budworm density during these endemic phases of the population cycle is difficult. Currently, the most widely used technique is to sample the overwintering larval populations. This involves collecting branches from the host trees using pole pruners, soaking the foliage in a caustic solution to wash the larvae from their hibernacula, and then filtering off the debris and examining the filter paper for the small larvae. This is time-consuming, messy, and expensive. The development of sex pheromone traps provides a technique for monitoring changes in low-density populations that is efficient, effective, and easy to use. Sex pheromone traps have been used to monitor spruce budworm populations in eastern North America for over 10 years, and experience has shown that while they have limitations at higher densities they can reliably detect changes at low densities (Allen et al. 1986, Sanders 1988). This report describes the use of such traps for monitoring endemic populations and discusses how trap catches can be used to alert forest pest managers to the need for more intensive sampling using conventional techniques.

What are Pheromones?

Pheromones are chemicals released by one organism that cause a behavioral response in another individual of the same species. Most insect species communicate by pheromones and the spruce budworm is no exception. When a female budworm moth is ready to mate she releases a chemical that attracts male moths to her. The sex pheromone causes the male moths to fly upwind, which in effect results in the male flying to the female. Each species of moth uses a unique blend of chemicals, so that only males of the same species are attracted to the females. Pheromones are also extremely potent; a female moth releases only a few nanograms of pheromone each hour.

The sex pheromone of the spruce budworm was identified in the 1970s as E- and Z-11-tetradecenal, 14-carbon chain aldehydes with one site of unsaturation (Sanders and Weatherston 1976). Once it was identified and synthesized it was then used to make lures, which are special formulations that protect the chemicals from degradation and release them at a constant, slow rate over the several weeks that the moths are flying. These lures can be placed in a trap so as to catch the moths that are attracted. After the moth flight period the traps can be collected and the moths counted. The numbers of moths caught provides an indication of population density.

Protocols for the use of sex pheromone traps for monitoring spruce budworm populations were first published 10 years ago (Allen et al. 1986). However, since then changes have been made and the following discussion brings the recommendations up to date.

MATERIALS

There are three components to an effective pheromone trap: the trap itself, a lure, and a killing or restraining agent. Registration is not required for the use of the trap and lure in either Canada or the United States, but if an insecticide is used in the trap then it requires registration in the appropriate country.

Trap

There are numerous trap designs commercially available. After several years of laboratory and field testing (Sanders 1986, Jobin et al. 1993) the Multi-pher I® trap was selected as the standard for the spruce budworm monitoring program (Fig. 1). These traps are manufactured by le Groupe Biocontrôle, Ste-Foy, Quebec, but are available through a number of suppliers. The Unitrap® (International Pheromone Systems, Wirral, United Kingdom) performed equally well and is an acceptable substitute. These traps have the capacity to hold several thousand moths without losing their effectiveness, which is a necessary requirement for monitoring a wide range of population densities. The designs allow moths to enter the traps easily, but prevent escape (Fig. 2).

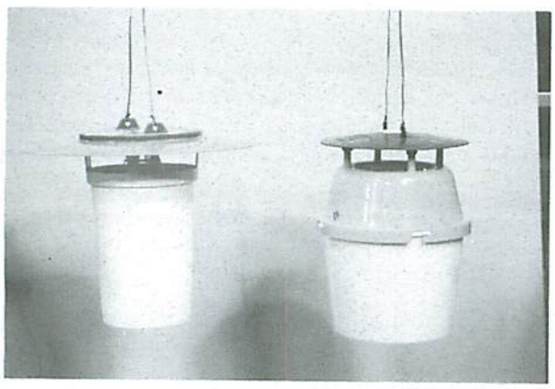

Figure 1. Multi-pher I® trap (left) and Unitrap® (right) recommended for use in the spruce budworm pheromone monitoring program.

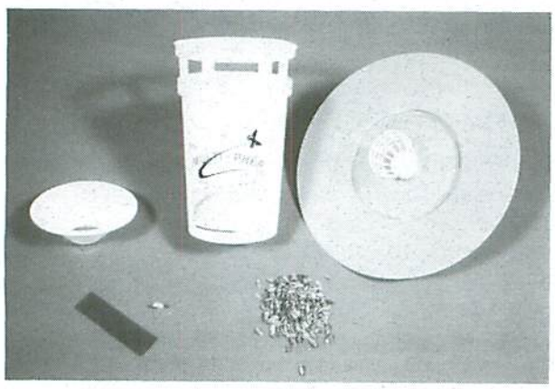

Figure 2. Exploded view of a Multi-pher I® trap, showing the component parts: the lid (right) with the shuttlecock inserted; the bucket (center); the baffle or funnel (left) that fits inside the bucket; and the Vaportape II® insecticide strip (bottom left).

Lure

As with trap design, there are numerous types of lures available, and again many have been tested for the spruce budworm monitoring program (Sanders 1981, 1992; Sanders and Meighen 1987). The necessary criteria are: protection of the synthetic pheromone from chemical degradation (usually oxidation, which is hastened by exposure to UV radiation), and release of the synthetic pheromone at a predetermined, constant rate that spans the flight period of the budworm plus a few weeks to permit the lures to be deployed in advance.

The release rate selected for the spruce budworm monitoring program is 100 nanograms per hour, which is slightly higher than the maximum rate at which the natural pheromone is released by a female moth (Silk et al. 1980, Morse et al. 1982). This is sufficient to catch some males at very low densities, and yet it causes no aberrant behavior in the males, which is a possibility at excessively high release rates. The duration of release is specified to be at least 8 weeks. This spans the flight period, which is about 3 weeks in any one location, and provides a margin of a few weeks to allow for errors in predicting moth flight. It also permits deployment of the traps during larval sampling, which may occur 3–4 weeks before moth flight. Provided the physiochemical properties of the lure formulation do not change from batch to batch, it can be assumed that the release rate will not change.

The lures in current (1995) use are Biolures®, (Consep Membranes Inc., Bend, Oregon) with a loading of 2.8 mg synthetic pheromone per lure. Biolures® consist of two layers of plastic with a bubble in between that contains a substrate impregnated with the synthetic pheromone. The pheromone evaporates from the substrate and saturates the air space in the plastic bubble, thereby forming a constant pressure gradient across the plastic regardless of the amount of pheromone remaining. This results in a relatively constant release rate over time (Sanders 1992), which can be controlled by the use of plastics with different properties and different thicknesses. Each Biolure® measures approximately 3 cm x 4 cm, and has a sticky patch on one surface so that it can be stuck to the underside of the trap lid. The lures are individually wrapped, thereby reducing the risk of contamination.

The number of moths captured can be greatly affected by the chemical composition of the synthetic blend and its release rate from the lures. Therefore, steps must be taken to ensure that these properties are the same for all batches of lures.

Supplies of the synthetic pheromone, which should be checked for purity before a new batch of lures is made up, should meet the following specifications:

a) purity should be >98 percent Δ-11-tetradecenals;

b) isomer ratio should be 95 percent E- : 5 percent Z-isomer (± 0.5 percent);

c) the material should contain no Δ-11-tetradecenyl acetates or alcohols; and

d) the material should contain no aldehyde in the form of trimers.

Currently, chemical analyses are carried out at the Canadian Forest Service, Great Lakes Forestry Centre laboratory. Relevant data on chemical purity and the concentration of the synthetic pheromone are available to all users upon request. Purity and ratios of the pheromone components are determined by gas chromatography on appropriate columns, with appropriate calibration to determine the concentration. The amount of trisomerization is determined by thin layer chromatography.

Insecticide

In contrast to many traps used for the detection and timing of moth flight, the Multi-pher® traps and Unitraps® have no sticky surfaces. Moths entering the buckets are trapped by the funnel shaped entrance. If they are not immobilized in some way, the moths will fly around inside the trap, damaging themselves and others. In turn, this makes them difficult to identify and count. Therefore, the moths are killed by using an insecticide, for which registration is required. The insecticide selected for this purpose is the fumigant dichlorvos (DDVP). There are several products on the market that provide DDVP impregnated in plastic. Only one is registered for use in pheromone traps in Canada: namely, Vaportape II®, (Hercon Environmental Corp., Emigsville, Pennsylvania; Canadian Registration No. 21222; US Registration EPA No. 8730-32). Plastic strips measure 3 cm x 10 cm and are 2 mm in thickness (Fig. 2). They are sold individually wrapped, which eliminates the danger of exposure in handling. The packets should be opened in the field and dropped into the bucket at the time the trap is deployed.

PROTOCOLS FOR HANDLING AND DEPLOYMENT OF TRAPS

Assembly of Traps

First, if not already assembled, a wire hanger is attached to the lid of the trap through the holes provided. Then a Biolure® is removed from its envelope, the paper backing is peeled away, and the lure is stuck to the underside of the lid. When applied to a Multi-pher® trap, one corner of the Biolure® should overlap the central ring of the lid, into which the shuttlecock is then snapped. The shuttlecock impedes the flying moth and increases the probability that it will fall into the bucket; it also anchors the corner of the Biolure®, a safeguard in case high humidity causes the adhesive to loosen. Next the funnel is fitted securely into the bucket. Care should be taken to ensure that it is fully inserted and will not move if the trap is knocked during handling. The bucket is then fastened to the lid, and examined to ensure that it is positioned squarely and that all the fasteners have interlocked. Finally, at the time of deployment, the Vaportape II® plastic strip is removed from its wrapper and dropped into the bucket. It is recommended that each trap be held up to the light as it is being deployed in the forest so as to confirm that it contains a Vaportape II® strip. (This will show up as a shadow inside the trap.)

Handling of Traps, Lures, and Insecticide

Multi-pher® and Unitraps® are made of rigid plastic and require no special care in handling. The plastic does however absorb some pheromone, which remains active from one year to the next and makes the trap slightly attractive even without a lure. The chemicals are very persistent and cannot be removed completely by washing, but the quantities absorbed are small and do not affect the number of spruce budworm moths caught in the trap when it contains a fresh lure the following year. As such, this contamination is not a serious problem. However, it is possible that the absorbed chemicals may have biological effects on other insects. For instance, spruce budworm and jack pine budworm (*Choristoneura pinus pinus* [Freeman]) are repelled by each other's pheromone. Therefore, traps that have been used with the pheromone of one species should not be used at a later date for another species because contamination may reduce catches. It is recommended that traps be marked so that they are always used for the same species.

The pheromone itself has no known toxic affects on humans or other animals and no safety precautions need to be taken when handling the lures. However, again there is a potential problem with contamination of the traps, and this may affect catches. It is important to avoid touching the surface of the lure where the pheromone is being released. For those who are handling large numbers of lures it is recommended that rubber or vinyl gloves be worn. Again, to avoid contamination of traps and equipment, each Biolure® should be unwrapped and fixed to the trap in the field when the trap is deployed. Lures of any type should be stored in a freezer, and be kept as cool as possible during transit to avoid high rates of release and possible contamination of other equipment.

The insecticide DDVP is potentially toxic, and direct contact with the insecticide strip or inhalation of the vapor should be avoided. The strips are packaged in tinfoil, which virtually eliminates any leakage of the vapor. As a

further precaution, it is recommended that they be kept refrigerated during storage, but not in a refrigerator that is used to store food. Each Vaportape II® strip is wrapped individually, and with care it is not necessary to touch the strip itself when placing one in a trap. However, for those individuals handling large numbers of the insecticide strips, rubber or vinyl gloves are recommended. Exposed strips should never be kept in a confined space, such as the interior of a car, for any length of time. When the traps are collected and dismantled at the end of the season, both the lures and the insecticide strip should be removed and immediately disposed of in a sanitary landfill.

Selection of Trapping Sites and Deployment of Traps

To ensure that trap catches are representative of budworm populations, certain protocols must be met. Traps should be deployed in mature forest stands (a minimum of 10 ha in area) containing at least 50 percent white spruce (*Picea glauca* [Moench] Voss) and/or balsam fir (*Abies balsamea* [L.] Mill.). For convenience of handling, traps are deployed at eye level. Traps placed higher in a tree will catch more moths, but catches can be more variable and special techniques are necessary to place and retrieve such traps. Catch is affected by airflow around the trap, which is in turn influenced by obstructions. Living foliage of the host tree may in itself provide some attraction to the moths and may influence catches. Therefore, each trap should be hung on a dead branch, at least 50 cm from the stem of the tree. Traps should also be free from any obstruction that might prevent them from swinging freely in case they become snagged at an angle that could allow moisture to enter and cause the moths to rot. As suggested by Jobin et. al. (1993), hinged brackets can be fastened to trees in permanent sample plots. This provides the added advantage of having traps in exactly the same position each year. Finally, traps should be positioned at least 40 m from the edge of the forest stand.

Traps placed at eye level, at least 40 m apart, show little evidence of interference between neighboring traps (Houseweart et al. 1981). Therefore, one trap will give almost as reliable an estimate as will a group of traps spaced >40 m apart. The use of one trap is quicker and cheaper than using multiple traps, but provides no estimate of variation. Also, traps are occasionally vandalised or damaged by bears. If only one trap is deployed, loss of that trap means no data for that location. As a compromise, a configuration of three traps arranged in an equilateral triangle with 40 m between traps is recommended. To make it simpler to deploy the traps and to ensure that they are placed in the same location each year, it is recommended that both the trail and the trees, from which the traps are to be hung, be permanently marked.

Timing

The synthetic pheromone tends to build up on the surface of the lures while they are sealed inside their wrappers. As a result, initial release rates can be quite high after the lures are unwrapped. Therefore traps should be deployed several days in advance of expected moth flight. Because the lures have an effective life of at least 8 weeks, traps may be deployed several weeks early. This enables flexibility in the time of deployment and allows for a visit to the site well before moth flight.

Collection of Traps

Traps should be collected when it is certain that the moth flight is over, but allowing a little extra time can be beneficial in case there is an invasion of moths from an area where insect development has been slower. At the time of collection, the Vaportape II® strip should be removed and kept for disposal in a sanitary landfill. If there are only a few moths they can be counted at the site. If this is not convenient, the moths can be emptied into a paper bag for counting later. Each bag should be marked with the date, location, and trap number, and the open end should be folded over and then closed with staples. These bags can be stored in a cold, dry location for several weeks if necessary. However, care should be taken to ensure that rodents, especially mice, cannot reach them.

Counting should be done in a fumehood or in a well ventilated area so as to avoid the inhalation of moth scales, which can cause allergic reactions. A face mask should be used to provide additional protection. Several techniques are available to speed up the counting of large numbers of moths. First the moths should be spread out, and large insects other than budworm should be removed. Then one, or preferably more, subsamples can be counted out and either weighed or measured volumetrically. By dividing the weight or volume into that of the whole catch, the total count can be estimated.

STANDARDIZATION OF TRAP CATCH

Before comparisons can be made between catches, it is essential to ensure that the data are comparable. Errors can occur in the synthesis of the pheromone and in the manufacture of the lures. Either of these can affect the potency of the lures. Before 1992, a fresh supply of synthetic chemical was obtained each year, often from different suppliers. The different batches varied considerably in purity and potency. In 1992 several hundred grams of high-purity pheromone were obtained from Bedoukian Research Inc., Danbury, Connecticut, and aliquots of this have been used for the manufacture of Biolures® in subsequent years. This has reduced differences between various batches of lures. However, it is still possible that minor

changes due to ageing of the pheromone in storage or changes in the lure manufacturing process could cause differences in potency. Therefore, some form of calibration must be carried out between different batches of lures. Where necessary, correction factors are applied to the trap catch data.

In the province of Québec, where traps are deployed by le Ministère des Ressources naturelle, corrections are made by using second instar larval (L_2) populations as a standard (Boulet 1992). For the analyses carried out by the Canadian Forest Service, Great Lakes Forestry Centre, calibrations are based on data collected in north central Ontario. For the years 1986 through 1988, when polyvinyl chloride pellets were used as lures, corrections were made by using L_2 populations as a standard. This was similar to the technique used by le Ministère des Ressources naturelle in Québec (Boulet 1992). For 1989 and subsequent years, correction factors have been obtained by deploying lures from successive batches at the same time and in the same place over a range of population densities. Catches from the new batch are then plotted against the old, and a regression analysis is carried out. This is used as the correction factor, utilizing the 1992 data as the standard.

Appendix A shows the relationships between moth catch and overwintering second instar (L_2) larval densities in northwestern Ontario for each year from 1986 through 1993. The year 1993 is the last one in which L_2 samples were taken in conjunction with the pheromone traps.

Appendix B shows the relationships between successive batches of lures for the years 1989 through 1995, and explains how the correction factors were derived for each year.

Appendix C shows the relationship between moth catch and L_2 densities for the years 1989 through 1993 after corrections have been applied to the moth catches. These are the only 5 years in which the data are appropriate for this purpose, because in other years the relationship itself between L_2 and moth catch was used to correct the moth catches. There are no significant differences among the regressions for the 5 years, which lends confidence to the correction factors, and also supports the use of the relationship between moth catch and L_2 densities as a method of correcting moth catches in other years.

The correction factors are shown in Table 1. The relationships between corrected moth catches and L_2 densities for the pooled data from 1989 through 1993 are shown in Figure 3.

Table 1. Correction factors applied to moth catches for the years 1986 through 1995 to allow for differing potencies of lures.

Year	a	b
1986	1.3165	0.7848
1987	1.4943	0.7426
1988	2.1921	0.5742
1989	1.6278	0.6340
1990	1.5159	0.7398
1991	0.8171	0.7639
1992	standard year, no correction needed	
1993	0.0188	1.0215
1994	Bio93 lures used in 1994, therefore correction is the same as for 1993	
1995	-0.0007	1.0806

These factors are based on the equation:

$\log_{10}(1 + \text{corrected catch})$ for $\text{year}_i = a + b \log_{10}(1 + \text{actual catch})$ for year_i.

For 1988 and before, corrections were made using correlations between moth catch and L_2 as the method of calibration. Using this method, regressions of corrected catch against L_2 are the same as the 1992 regression.

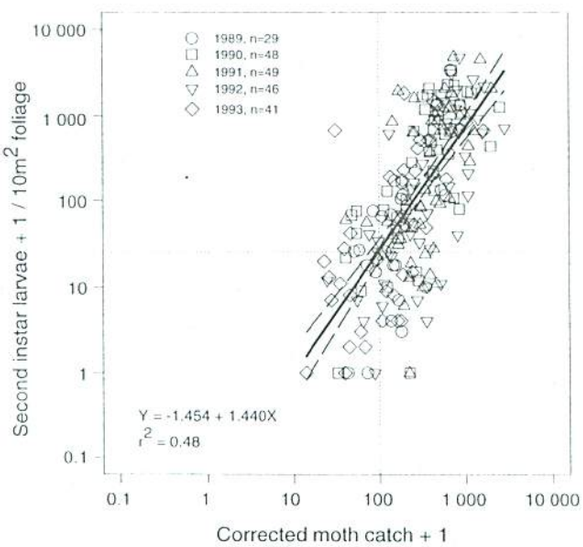

Figure 3. Relationship between moth catch and subsequent overwintering second instar larval populations. The regression line is for the pooled data for the years 1989 through 1993 after corrections were made for differences in lure potency (see appendices). From this it is concluded that a catch of 100 moths corresponds to a density of about 25 larvae per 10 m^2 of foliage surface, or about 3 larvae per 45-cm branch tip.

INTERPRETATION OF RESULTS

Use of Traps as a Trigger for Larval Sampling

Currently, predictions of budworm density for the following year are made by sampling L_2 densities. This involves washing branches in a caustic solution (*see* Sanders 1980). This is an inefficient and inaccurate method at densities below 10 to 20 larvae per 10 m^2 of branch surface area, which corresponds to one or two larvae per branch. One of the major potential uses of pheromone traps is to monitor low-density populations so as to indicate when population densities rise to a level that is measurable by conventional second instar larval sampling (about 20 larvae per 10 m^2 of branch surface area). The regression in Figure 3 indicates that a catch of 100 moths corresponds to a density of 25 second instar larvae/10 m^2 of branch surface area, or about three larvae per branch, in the subsequent generation. Therefore, a trap catch of 100 can be used as a trigger to initiate more intensive larval sampling.

Note that these data are for mature mixedwood stands in north central Ontario (the area between Lake Nipigon and the Québec border), and are representative of boreal mixedwood stands in Ontario and western Québec. This relationship will change in different forest types. Trap catch is a reflection of the number of insects per unit area of forest. Given the same densities of larvae per branch, pure stands of mature white spruce in Alberta or balsam fir in the Maritimes will probably carry far higher populations of spruce budworm per hectare than will a mixedwood stand with only 50 percent spruce and fir. Catches will reflect this. Therefore, in other stand types threshold catches will have to be established based on relationships between larval density and trap catch.

Use of Traps to Monitor Trends in Population Density

The onset of future outbreaks can be predicted by following population trends during the endemic phase of the population cycle. Simmons and Elliott (1985) demonstrated the use of data from light traps for predicting outbreaks, and the same can be done with pheromone traps (Sanders 1988). By plotting catches from single locations or a group of locations over successive years, population trends can be detected. These can then be projected ahead to provide predictions of when populations will reach damaging densities. The value of this approach has been demonstrated by le Québec Minstère des Forêts (Boulet 1992), where trap catch data predicted the onset of defoliation in western Québec. Figure 4 shows an example of trend data for Black Sturgeon Lake in northwestern Ontario.

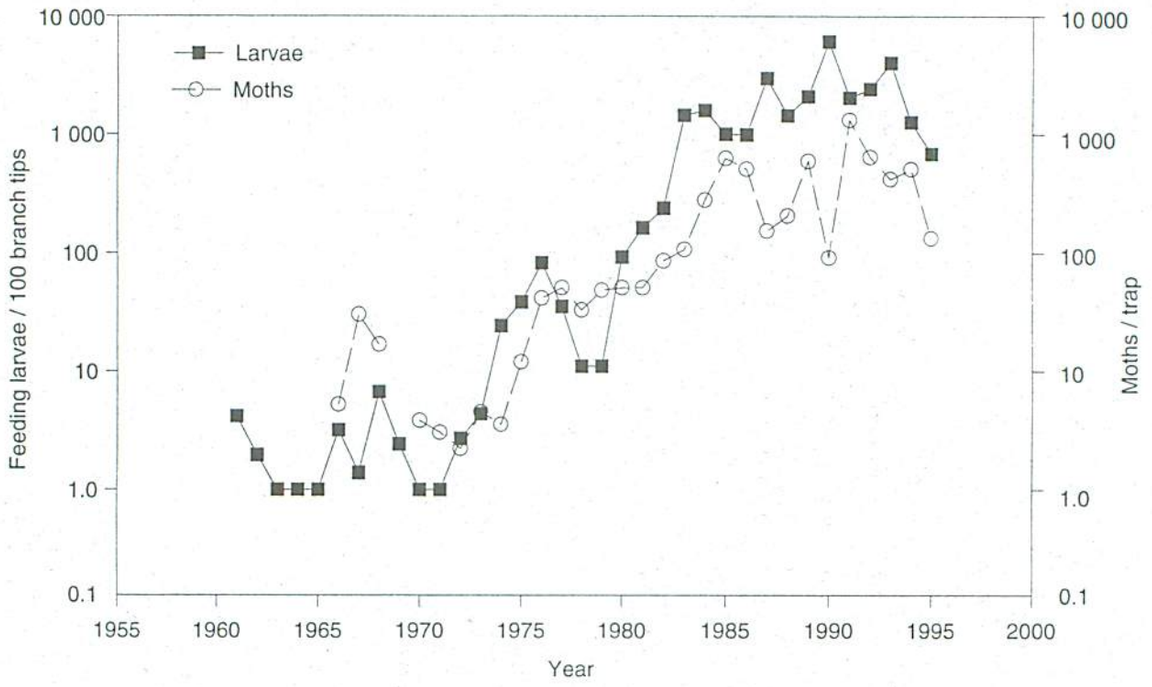

Figure 4. Relationship between population densities of feeding larvae (ca fourth and fifth instar) and subsequent catches of moths in pheromone traps over the period 1966 through 1995 near Black Sturgeon Lake in northwestern Ontario. Noticeable defoliation first occurred in the area in 1983. (Figure updated from Sanders [1988].)

Application to Regional Decision Support Systems

The limitation of trap catch data for showing regional trends in population density is that they are point-source data. For geostatistical analyses, such as geographic information systems (GIS), continuous coverage maps are required. If traps are deployed at regular intervals throughout a region, the results can be used to generate maps of budworm density that can be analyzed by GIS. Various techniques are available for generating such maps. The one selected for analyzing spruce budworm trap catches is a geostatistical analytical process called kriging (Liebhold et al. 1993). The resulting maps can be used for various purposes: a) by overlaying successive maps, further maps can be generated that show where significant changes in density are taking place; b) they can be used in conjunction with other data to modify predictions of future defoliation; and c) they can be used to provide an overview of budworm status throughout its whole range across North America. With computer software now available[1], maps can be generated almost immediately. This should make it possible to have them available by early fall of the current year.

Details of the geostatistical techniques used for generating the maps are described in a companion report.[2]

ACKNOWLEDGMENTS

The development of the geostatistical techniques for analyzing the trap data was supported by the Northern Ontario Development Agreement, Northern Forestry Program; the Forest Pest Management Alternatives/Minor Use Fund; and the Decision Support System Network (DSS) component of the Integrated Forest Pest Management Program under Canada's Green Plan.

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Appendix A. Relationships Between Moth Catches and Larval Densities.

Figure A1 (a–h) shows the relationships between the actual, uncorrected moth catches and the subsequent densities of overwintering second instar (L_2) larvae for the years 1986 through 1993 from north central Ontario. The plot locations were selected to provide a wide range of densities. Logarithmic transformations were carried out to normalize the variances and all analyses were based on counts of (n + 1), so as to remove the problem of zero counts.

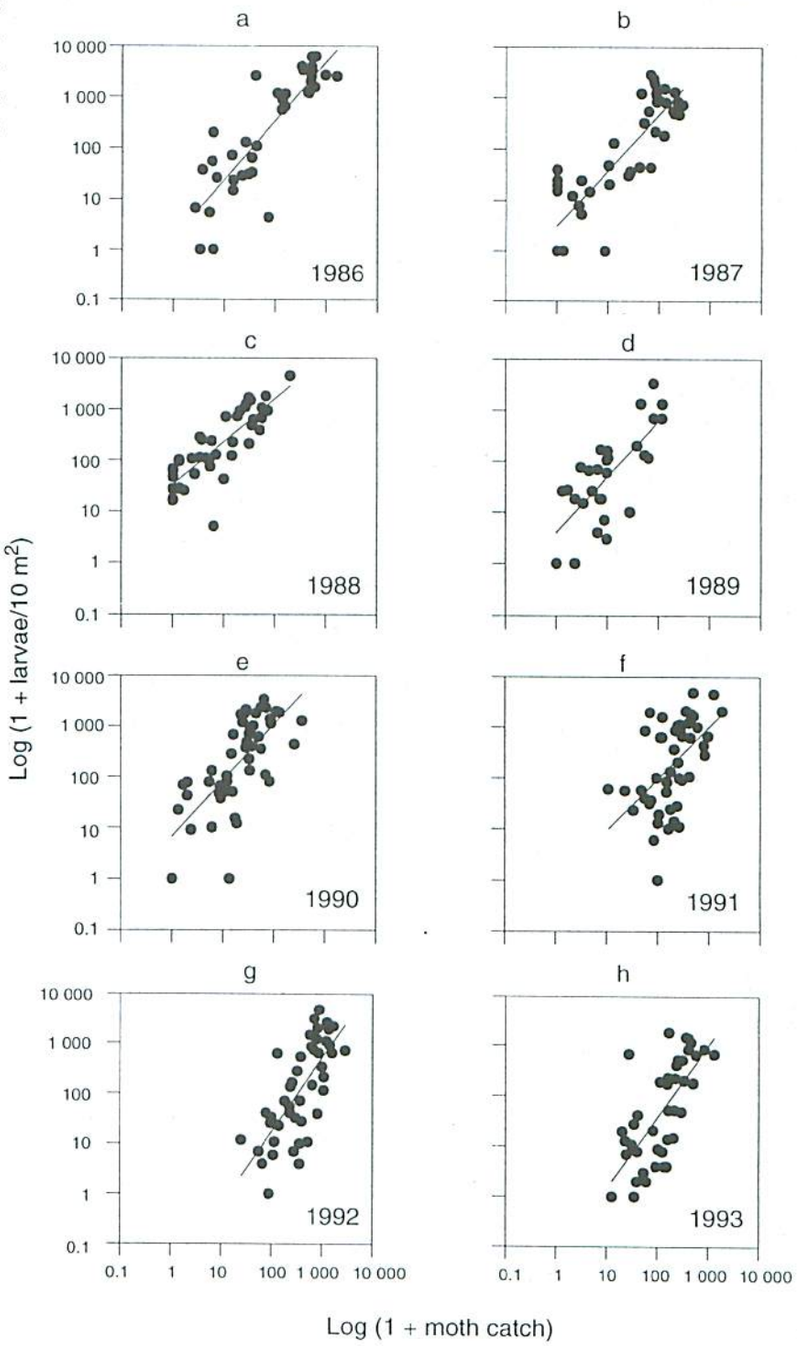

Figure A1. Relationships between moth catch and overwintering larval populations in northwestern Ontario. The data were obtained each year from sites between Thessalon in the east and Thunder Bay in the west. Sites were selected to span a wide range of budworm densities.

Appendix B. Relationships Between Moth Catches and Larval Densities after Corrections for Variations in the Potency of Lures.

Figure B1 (a–h) shows the same data as used in Appendix A, after correction of the moth catches to allow for variations in the potency of the lures from year to year. Figure B1 (i) shows the regressions for the years 1989 through 1993 on the same graph. These are the years when corrections were made by calibrating each batch of lures against those from 1992 by placing lures from successive batches in the field in the same location and at the same time. Note the close relationship obtained after corrections had been made. Figure B1 (j) shows the combined regression for the pooled data of 1989 through 1993. It illustrates that a moth catch of 100 corresponds to a larval density of log 1.422, which equals 26.4.

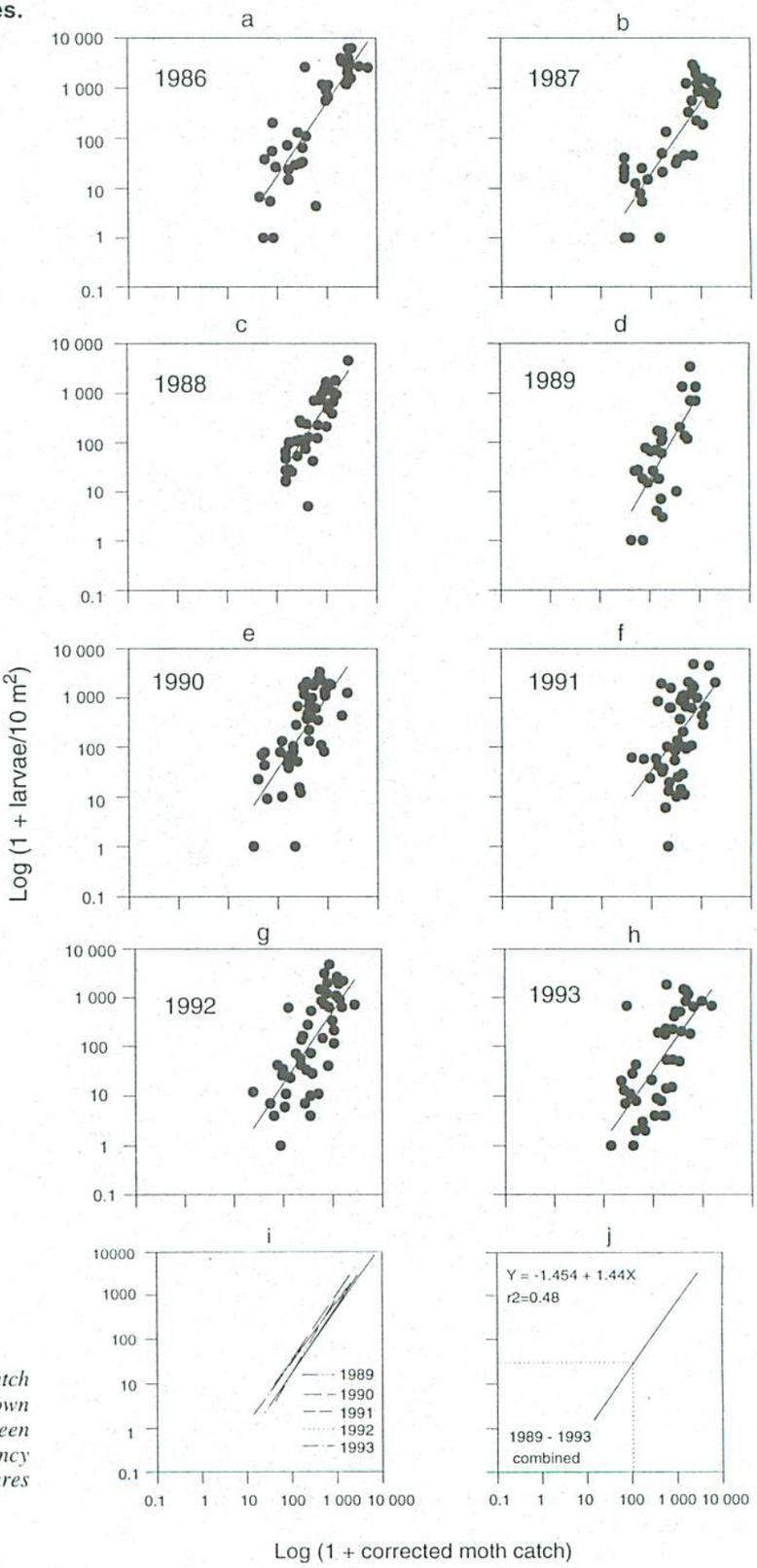

Figure B1. Relationships between moth catch and overwintering larval populations shown in Figure A1, after corrections have been made to allow for differences in potency among different batches of pheromone lures (see Appendix C).

Appendix C. Calibration of Annual Catches.

The potency of different batches of pheromone lures can vary. As a result, catches of moths may be higher or lower than expected, and give a false reading of population density. There are several reasons for this variation in potency, but these can be accommodated and/or allowances can be made for them.

1. Different types of lures (polyvinyl chloride pellets, rubber septa, plastic tapes, hollow fibers, etc.) have different release rates and may lose potency at different rates during the flight season. Problems with this can be prevented by using the same formulation each year. After several years of testing, Consep Membrane Biolures were selected as being operational because they had the most consistent release rates over time.
2. The purity of the chemical composition of the synthetic pheromone may vary with different syntheses. Some chemicals that are closely related chemically to the spruce budworm pheromone are known to have inhibitory effects on catches of male budworm. These can be removed during synthesis, but there can be numerous other minor impurities whose biological activity is unknown. These problems can be controlled by obtaining a stock solution of high purity that is sufficient to supply lures for many years. Aliquots of this are then used to formulate lures each year, so that successive batches are of identical composition.
3. The synthetic pheromone may break down during storage, principally by oxidation. This may result in biologically active by-products. Also, in the case of aldehydes, the pheromone may polymerize, which depletes the amount of active material. Both these effects can cause potential problems if a large supply of pheromone is kept for several years. These problems can be minimized by storing the pheromone under deep freeze (-60°C or colder), and by flushing the bottle that contains the pheromone with nitrogen after it has been opened in order to remove the oxygen.

In spite of these precautions, the possibility that differences in potency may occur still exists. Therefore, some form of calibration is required to determine if different batches of lures are of equal potency, and, if they are not, to provide a correction factor to make the catches comparable. There are two methods of doing this. The first involves cross-calibration, i.e., placing lures from different batches in traps at the same time in the same locations over a wide range of budworm densities and checking the correlation between catches obtained by the different batches. The second method involves correlating moth catches against some other measure of budworm density, such as overwintering L_2 larval densities. The problem with this method is that there may be high variability in larval densities. Therefore, cross-calibration is the preferred method.

At present, cross-calibrations have been carried out by staff of the Canadian Forest Service, Great Lakes Forestry Centre, but users of the traps are encouraged to conduct calibrations in their own juridictions. For a meaningful calibration it is essential that traps be deployed over a wide range of population densities. Experience has shown that at least ten locations are required, but more are preferable.

Calculation of Correction Factors

Figure C1 (a–e) shows the relationships between moth catches with different batches of lures on which the correction factors used in Appendix B are based. The need for calibration was not realized until 1988, when very anomalous catches occurred. From 1989 to the present, successive batches of lures have been cross-calibrated each year. For 1986, 1987, and 1988, calibration was done by using the correlations with L_2 larval densities. For the years 1989 to the present correction factors have been calculated from calibration data.

In each of the years 1989, 1990, and 1991, different batches of synthetic pheromone were used. In 1992 a single large (200 g) batch of synthetic pheromone was obtained from Bedoukian Research Inc., (Danbury, Connecticut) and this was used for the subsequent lures. Fresh batches of Biolure® were made up in 1992, 1993, 1995. In 1994 lures from the 1993 batch, which had been stored at -80°C, were used.

Note that the 1989 and 1990 lures were very similar in potency (*see* Figure C1[a]), but that they were considerably less potent that the 1992 lures which were taken as the standard (Figure C1[b]). The 1991 lures were slightly less potent than the standard 1992 lures (Figure C1[c]). The 1992, 1993, and 1995 lures were very similar in potency (Figures C1[d] and C1[c]), which is encouraging, because they were made from the same batch of synthetic pheromone. For most purposes, catches for the years 1993, 1994, and 1995 require no correction.

The following shows the calibrations obtained between years and the correction factors that should be applied to catches each year, using 1992 as the standard.

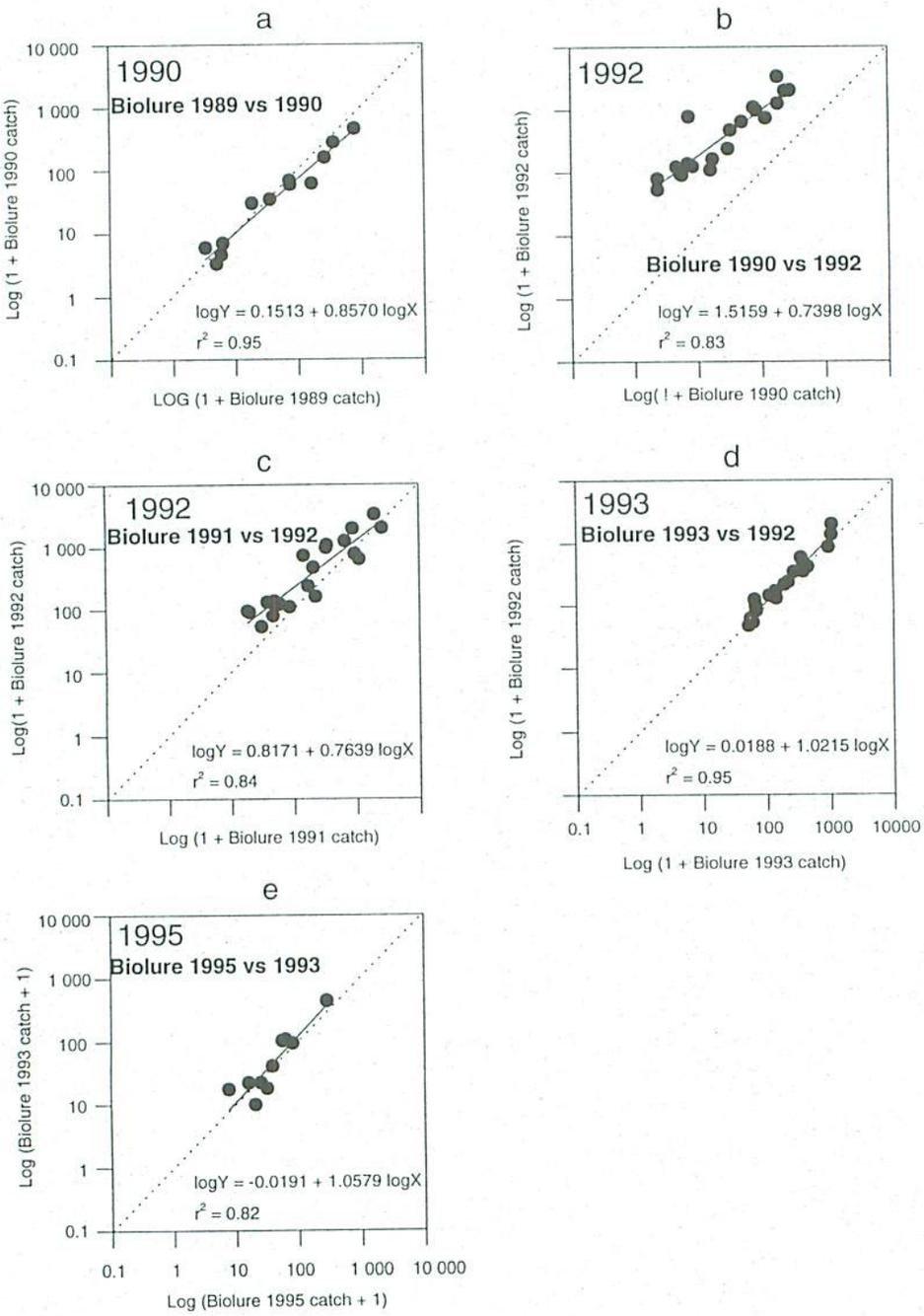

Figure C1. Relationships between catches of moths using different batches of lures. Lures from different batches were placed in traps that were then deployed side by side in the same stands in the same year. Correction factors to allow for the differences were then calculated from these regressions (see *text*).

1986

Corrected log (PVC86 + 1) = 1.3165 + 0.7848*log (PVC86 + 1)

Based on the following calculation:

log ($86L_2$ + 1) = 0.2405 + 1.1489*log (PVC86 + 1) (Figure A1[a]), and

log ($92L_2$ + 1) = -1.6869 + 1.4640*log (Bio92 + 1) (Figure A1[g]).

Therefore, if it is assumed that the 86 L_2s and the 92 L_2s are true estimates, substitution can be made as follows:

-1.6869 + 1.4640*log (corrected PVC86 + 1) = 0.2405 + 1.1489*log (PVC87 + 1),

or corrected (log PVC86 + 1) = ([1.6869 + 0.2405] + 1.1489*log [PVC86 + 1]) / 1.4640, and

corrected (log PVC86 + 1) = 1.3165 + 0.7848*log (PVC86 + 1).

1987

Corrected log (PVC87 + 1) = 1.4943 + 0.7426*log (PVC87 + 1)

Based on the following calculation:

log ($87L_2$ + 1) = 0.5007 + 1.0871*log (PVC87 + 1) (Figure A1[b]), and

log ($92L_2$ + 1) = -1.6869 + 1.4640*log (Bio92 + 1) (Figure A1[g]).

Therefore, if it is assumed that the 87 L_2s and the 92 L_2s are true estimates, substitution can be made as follows:

-1.6869 + 1.4640*log (corrected PVC87 + 1) = 0.5007 + 1.0871*log (PVC87 + 1),

or corrected (log PVC87 + 1) = ([1.6869 + 0.5007] + 1.0871*log [PVC87 + 1]) / 1.4640, and

corrected (log PVC87 + 1) = 1.4943 + 0.7426*log (PVC87 + 1).

1988

Corrected log (PVC88 + 1) = 2.1921 + 0.5742*log (PVC88 + 1),

Based on the following calculation:

log ($88L_2$ + 1) = 1.5222 + 0.8406*log (PVC88 + 1) (Figure A1[c]), and

log ($92L_2$ + 1) = -1.6869 + 1.4640*log (Bio92 + 1) (Figure A1[g]).

Therefore if it is assumed that the 88 L_2s and the 92 L_2s are true estimates, substitution can be made as follows:

-1.6869 + 1.4640*log (corrected PVC88 + 1) = 1.5222 + 0.8406*log (PVC88 + 1),

or corrected (log PVC88 + 1) = [(1.6869 + 1.5222) + 0.8406*log(PVC88 + 1)] /1.4640, and

corrected (log PVC88 + 1) = 2.1921 + 0.5742*log (PVC88 + 1).

1989

Corrected log (Bio89 +1) = 1.6278 + 0.6340 log*(Bio89 + 1).

Based on the following calculation:

In 1990 the Bio89 were calibrated against the Bio90, yielding the following regression:

corrected log $(Bio89 + 1)_{90}$ = 0.1513 + 0.8570*log (Bio89 + 1) (Figure C1[a]).

Based on the correction for Bio90 in terms of the standard Bio92 (Figure C1[b]),

corrected log (Bio89 +1) = 1.5159 + 0.7398 (0.1513 + 0.8570*log [Bio89 + 1])

= 1.5159 + 0.1119 + 0.6340*log (Bio89 + 1)

= 1.6278 + 0.6340*log (Bio89 + 1)

1990

Corrected log (Bio90 +1) = 1.5159 + 0.7398*log (Bio90 +1) (Figure C1[b]).

1991

Corrected log (Bio91 +1) = 0.8171 + 0.7639*log (Bio91 +1) (Figure C1[c]).

1992

Standard year, no correction needed.

1993

Corrected log (Bio93 +1) = 0.0188 + 1.0215 log*(Bio93 +1), (Figure C1[d]).

1994

Bio93 lures used in 1994, therefore correction is same as for 1993.

Corrected log (Bio94 +1) = 0.0188 + 1.0215 log*(Bio94 +1).

1995

Corrected log (Bio95 + 1) = -0.0007 + 1.0806*(Bio95 + 1),

based on the following calculation:

log*(Bio93 + 1) = -0.0191 + 1.0579 log*(Bio95 + 1) (Figure C1[e]),

and because:

corrected log*(Bio93 +1) = 0.0188 + 1.0215 log*(Bio93 +1) (Figure C1[d]),

then by substituting for log (Bio93 + 1) in Figure C1(e):

corrected log*(Bio95 + 1) = 0.0188 + 1.0215(-0.0191 + 1.0579 log*[Bio95 + 1])

= 0.0188 - 0.0195 + 1.0806 log*(Bio95 + 1), and

= -0.0007 + 1.0806*log (Bio95 + 1).