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The confusion tactics as a means to study the migration of the larch bud moth, *Zeiraphera diniana* (GN.) (Lep., Tortricidae), in the Engadin Valley[1]

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Aerial application of the microencapsulated synthetic sex attractant of the larch bud moth, *Zeiraphera diniana* (GUENÉE), *E*11–14:Ac, was used to evaluate the influence of immigration on the growth of local populations in the Engadin (Switzerland) during the minimum phase of a population cycle. Two test areas of 70 and 230 ha were selected to be treated for three successive generations just prior to the beginning of the local moth flight. After the first treatment a significant difference in population density in the Val Bever site was observed as compared to the control, but subsequently to the second application moth immigration on the regional scale had contributed to differences in local population growth. In the 3rd year of the experiment, mass immigration by long range dispersal swamped the entire Engadin area, levelled out all differences in local densities and lead to an unprecedented 40-fold population increase. The experiment reveals that the pheromone treatment had been effective temporarily, but continuous immigration on a regional scale and accidental mass immigration by long range dispersal negate the successful application of the confusion tactics against the larch bud moth.

INTRODUCTION

Very low population numbers are an important condition to apply the confusion technique for pest control successfully. The extreme amplitude of the fluctuation of the larch bud moth (LBM in the text), *Zeiraphera diniana* (GUENÉE), provokes the application of this method during the minimum phase of the population cycle. Several small scale field experiments had been carried out prior to 1977 in the Engadin Valley to collect information on the feasibility of the confusion technique against the LBM (BALTENSWEILER & DELUCCHI, 1979). Results obtained in the course of these experiments confirmed previous observations that continuous immigration of LBM adults occurs into the upper regions of subalpine mountain valleys (BALTENSWEILER & FISCHLIN, 1979). It seemed therefore necessary to quantify this immigration before investing further funds in a technique which might prove inefficient. A preliminary report of a large scale pheromone application to three successive LBM generations in 1977–1979 was published in 1979 (BALTENSWEILER & DELUCCHI, 1979). This paper summarizes the final results.

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MATERIAL AND METHODS

Experimental areas

Test areas were selected within the Oberengadin among the so-called "Frühtypus" areas (AUER, 1961) where the LBM exhibits generally the fastest population growth. Two sites in orographically different situations were chosen (see Fig. 1 in BALTENSWEILER & DELUCCHI, 1979):

- the Sils area, 3.5 km in length in SE exposure of the main valley; 70 ha, pure larch forest between 1800 and 2000 m asl.
- the Val Bever represents an isolated lateral valley running E-W, 5 km in length, but rising only very slightly from 1700 m to 1850 m at the valley bottom; 230 ha of mixed larch-cembran pine forest between 1700 and 2000 m asl. The test area was subdivided into 3 sections running across the valley, termed front, middle and interior section, and using the river to separate each section into a left and a right bank subsection.

The Sils area is considered to be a typical area for moth convergence (BALTENSWEILER & FISCHLIN, 1979) whereas the interior section of the deeply entrenched Val Bever has to be considered as being in greatest possible isolation from the main valley. In the neighbourhood of each test site areas exhibiting similar ecological characteristics were defined as reference areas of the first order whereas the entire Oberengadin valley with its 6000 ha of subalpine larch-cembran pine forest served as a reference area of second order. The larval densities in the treated areas are compared against the densities of the entire untreated Oberengadin (Tab. 1) whereas for the moth flight catches are compared between the test sites and the control areas situated in their immediate neighbourhood, i.e. the control areas of first order (Tab. 2).

Application of the pheromone

The males of the larch form, the host race living on larch (*Larix decidua* MILLER), respond maximally to the *trans*-11-tetradecenyl acetate (*E* 11–14: Ac) (BALTENSWEILER *et al.*, 1978). Technical *E* 11–14: Ac (CHEMSAMPCO, Inc., Columbus, Ohio), formulated in gelatine based microcapsules (60–250 μm ∅; APPLETON PAPERS INC., Dayton, Ohio), was applied at a dosage of 7 to 9 g/ha by helicopter. The pheromone was applied immediately after the first male moths were caught in pheromone sticky traps in three successive generations (1977, 1978, 1979). The distribution of the capsules as well as their emission rate was monitored. After 60 days the capsules contained in either south or north exposure above the crown canopy 13.3% and 41.5% respectively of their initial pheromone content.

Evaluation of the confusion effect

The efficacy of the treatment was evaluated (1) by the number of male moths caught in traps baited with virgin females or 10 μg *E* 11–14: Ac and (2) the density of larvae in the following generation as compared to the reference areas.

The traps used were metal-plates (50 cm square, covered on both sides with Bird Tanglefoot (the TANGLEFOOT COMPANY, Grand Rapids, Michigan, USA) and pulleyed 5–10 m into the larch crowns and fixed so they could not turn in the wind. The virgin females, exposed in mesh covered plastic cages, or the rubber caps with the pheromone were placed in the center hole (10 cm ∅) of the

Tab. 1. Larval densities in the treated areas of Bever and Sils, and the untreated Oberengadin (= OE control). 1, number of sample trees. 2, total amount of foliage analyzed (kg). 3, number of larvae per kg foliage: x ± SE.

Location	1977				1978				1979				1980			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Bever	72	171	2	0.012 ± 0.008	122	321	4	0.013 ± 0.006	100	300	48	0.160 ± 0.031	100	200	1942	9.710 ± 0.485
Sils	28	58	3	0.052 ± 0.052	42	102	2	0.020 ± 0.014	29	87	45	0.517 ± 0.098	20	40	1150	28.750 ± 3.765
OE control	419	526	12	0.023 ± 0.007	479	705	34	0.048 ± 0.010	105	305	75	0.246 ± 0.035	72	147	1412	9.605 ± 0.794

Tab. 2. Catches of larch bud moth males by sticky traps baited with either virgin females, 10 μg *E* 11–14: Acetate, or blank as a control. 1, number of traps. 2, trap-days = number of traps x number of days. 3, number of males caught. 4, number of males per trap per day. 5, suppression of male catch in % of control.

Location	Trap type	1977					1978					1979				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Bever	LF-female	12	204	6	0.0294	-	6	264	1	0.004	99.4	6	332	46	0.139	89.8
	E 11-14:Ac	36	1824	1	0.0005	64.3	22	956	0	< 0.001	> 91.7	19	1313	141	0.107	86.8
	blank	-	-	-	-	-	4	144	0	< 0.007	-	4	276	10	0.036	79.3
Control Bever+Samedan	LF-female	-	-	-	-		1	42	29.	0.690		1	56	76	1.357	
	E 11-14:Ac	12	702	1	0.0014		4	168	2	0.012		9	594	482	0.811	
	blank	-	-	-	-		-	-	-	-		1	69	12	0.174	
Sils	LF-female	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	E 11-14:Ac	10	620	0	< 0.002	> 88.2	15	710	3	0.004	> 99.2	12	801	62	0.077	93.1
	blank	-	-	-	-	-	2	70	0	< 0.014	-	2	133	2	0.015	-
Control Sils Fiuors	LF-female	-	-	-	-		-	-	-	-		-	-	-	-	
	E 11-14:Ac	6	300	5	0.017		6	312	161	0.516		6	438	487	1.112	
	blank	-	-	-	-		-	-	-	-		-	-	-	-	

plate. The traps were controlled at weekly intervals or more frequently depending on the moth catch. In 1979, two mercury vapor lamps were operated continuously in the Val Bever (located in the middle section, left bank) and in Zuoz during the moth flight. In addition 35 moth populations were caught alive by means of mobile mercury lamps in 13 nights spread over the whole flight season and subsections for monitoring the sex-ratio, the mating status and the fecundity of the females.

Larval density was monitored by collecting 3 kg of larch twigs and foliage per sample tree, 1 kg from each of three levels within the crown at the time of the L4/L5 instar. In 1980 the sample was reduced to 2 kg.

RESULTS

Larval census

Larval densities per kg larch branches are presented for the test sites Sils and Bever and for 4 successive generations in comparison to the untreated Engadin valley (Fig. 1; Tab. 1). In 1978, the year after the first treatment, the larval

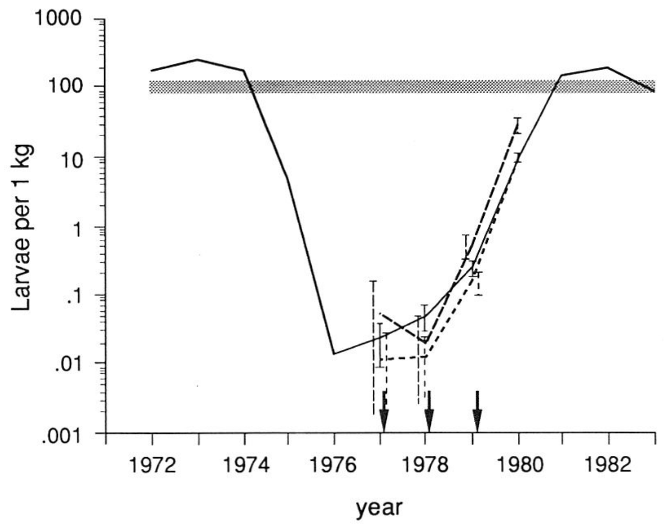

Fig. 1. Densities with confidence limits (95%) for the two test sites Bever (dotted line) and Sils (dashed line) from 1977 to 1980 as compared to the population cycle in the Oberengadin (solid line). The Oberengadin values of the years 1972–1976 are from AUER (1977), those of 1977–1983 from BALTENSWEILER & FISCHLIN (1988).

density in the Sils site was lower by a factor three as compared to 1977, it was stagnant in Bever but significantly lower as compared to the untreated area which had doubled its density. Thereafter the densities increased in all three areas at about the same rates and transgressed simultaneously the defoliation level in 1981. From 1978 to 1979 the Sils test site increased 50-fold and exhibited afterwards even significant higher densities than the control area. The isolated Val Bever site showed in 1978 a rather homogenous density (Fig. 2). In the following year, 1979, the local densities clearly had increased significantly faster in front of the valley than in its interiour, yet in 1980 the densities were again very homogenous throughout the valley.

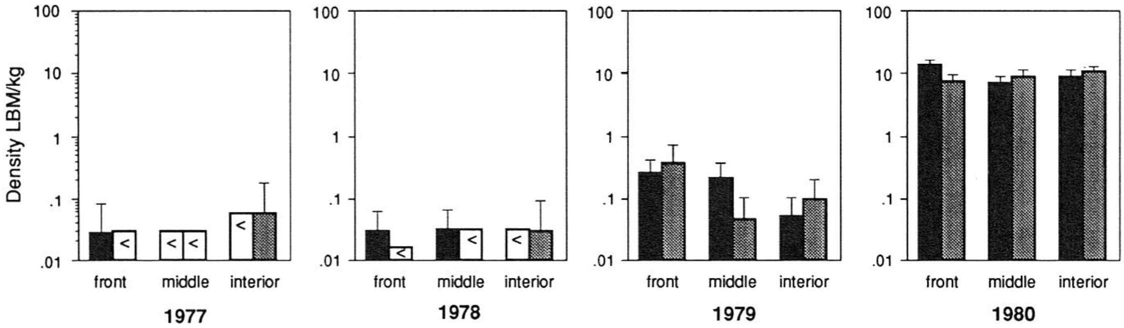

Fig. 2. Val Bever test site: Larval densities from 1977 to 1980 for the front, middle, and interior section of the valley. Black columns: left bank subsections; grey columns: right bank subsections. <: density of larvae is less than 1 larva per total sample in a subsection.

Moth flight

The number of males caught in *E* 11–14: Ac traps increased steadily from one generation to the next, irrespective whether the area had been treated or not (Tab. 2), however, the catch in the control areas was in general 10 times higher, except for the Bever site in 1977.

Fig. 3 exemplifies the daily catch per trap during the flight period in 1979 for the Val Bever and the two control sites situated on either side of the mouth of Val Bever into the main valley. The moth flight had started in the control sites about

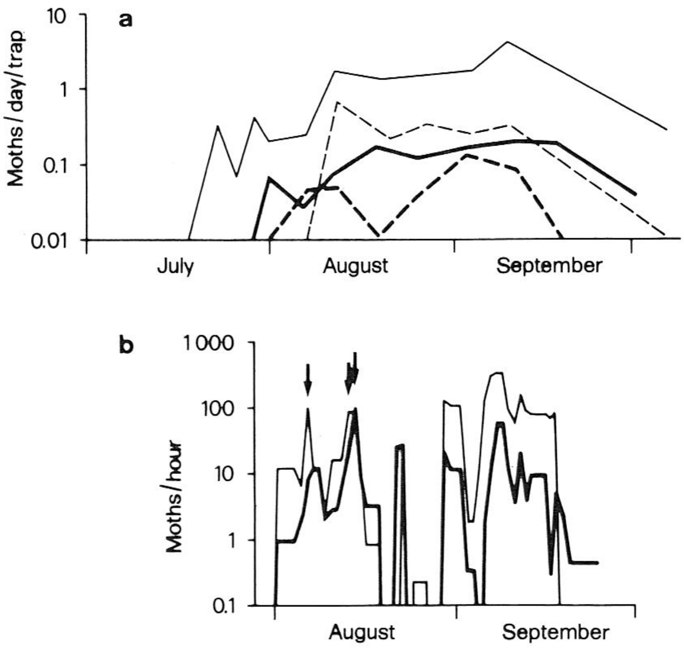

Fig. 3. a: Catches of male moths by sticky traps baited with 10 μg *E* 11–14: Ac in 1979 in Val Bever (thick lines) and the neighbouring control area (thin lines). Solid lines: traps with *E* 11–14: Ac; dashed lines: blanks. b: Moth catches in the two permanent light traps in the test site Val Bever (thick line) and the control in Zuoz (thin line) during the flight season 1979. The arrows indicate peaks on August 7th, 14th, and 15th coinciding with weather pattern conducive to immigration.

10 days earlier than in the Val Bever proper and reached a general plateau of 1.7 males per day per *E* 11–14: Ac trap on August 11, 1979, i.e. 8 days earlier before the plateau was reached in the treated area with 0.18 males only. Traps with virgin females attracted in the test areas somewhat more males than the *E* 11–14: Ac traps (Tab. 2). The empty check traps captured between August 8 to 12 a maximum of 0.6 males in the control area and 0.05 males in the treated area per day and trap. During this same period males were caught in empty traps at several other, untreated sites. Moth catches in the permanent light traps in Val Bever and the control in Zuoz resembled each other in the course of the entire flight season very closely (Fig. 3b). Peak catches during the beginning of the flight occurred in both sites on August 7 and again August 14 & 15. The second peak coincided just about with the emergence period of the local population in the front section of Val Bever whereas in the interiour emergence began after August 23 only. From the females caught in the permanent light traps in the treated area of Val Bever and in the control area of Zuoz, 96 resp. 104 individuals were analysed for their content of spermatophores. With 85.4%, resp. 97.1% mated females, both populations exhibited a high mating status. Another 280 females caught in mobile light traps in Val Bever were reared in the laboratory without a male subsequently to their catch. Only 45.0% of them were mated as determined by their laying of an additional complement of 53.4 ± 4.1 eggs (n=126). This low mating status cannot be attributed to rearing conditions since among 31 females collected as larvae in Val Bever and Sils and reared individually together with a male under identical conditions, 93.5% laid an average of 97.4 ± 16.5 eggs (n=29). The obvious difference in the mating status between the two Val Bever populations stemming from the permanent and the mobile light traps must remain unexplained.

DISCUSSION

Although it is known that a high percentage of moth catch suppression, as measured in 1978 (Table 2), does not prove conclusively that the resident females remain unfertilized, the low larval population densities in 1978 had provided the necessary stimulus to proceed with the experiment (BALTENSWEILER & DELUCCHI, 1979). However, larval densities in 1979 revealed that population increase had not been successfully checked by the two previous treatments. A detailed analysis of the local densities in Val Bever suggests immigration of gravid females from the main valley into the interior of Val Bever in 1978 (Fig. 2) and the 50-fold increase of the local population in Sils confirms the specific characteristics of this place as a convergence site for moths (BALTENSWEILER & FISCHLIN, 1979). Thus these results reflect the effects of regional migration. Conversely the 40-fold population increase from 1979 to 1980 in the entire Engadin (Tab. 1) can only be explained by mass-immigration. The potential exodus area is found in the southwestern French Alps, where in June 1979 large tracts of subalpine larch forests had been defoliated (BALTENSWEILER & RUBLI, in prep.). Weather patterns conducive to long range dispersal (BALTENSWEILER & VON SALIS, 1975) and influx into the Engadin area had occurred on August 6 and again on August 14 & 15, 1979. Furthermore the considerable numbers of moths caught by light and pheromone trapping just prior to the emergence of local populations in 1979, the catch of males in empty traps, indicating a disorientated behaviour as observed after transit flight (BALTENSWEILER & VON SALIS, 1975), and the extraordinary homogeneity of local densities within the Val Bever site in 1980 are also in agreement with the assumption of immigration by long range dispersal. Finally, a 50-fold increase in population density for an area as large as the entire Engadin had never been measured since 1949. Life table information indicates that population growth of this magnitude is impossible without considering immigration of moths. Conversely the reduction in larval population density in the Val Bever site in 1978, the moth catch suppression (Tab. 2; Fig. 3a) as well as the large proportion of 55% of unmated moths in 1979 suggest nevertheless some efficacy of the pheromone treatment. The experiment reveals, however, that continuous regional and/or stochastic long range dispersal impede that the confusion tactics as a control method against the LBM will ever be feasible. Furthermore, the experiment contributes to the explanation why parasitoids are not able to impede the onset of a new population cycle in the optimum area (DELUCCHI, 1982).

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ZUSAMMENFASSUNG

Die sogenannte Verwirrungstaktik versucht durch das Ausbringen des artspezifischen Sexuallockstoffes das Auffinden der weiblichen Falter durch die Männchen zu verhindern und damit die Vermehrung einer Population zu hemmen. Weil diese Taktik vor allem bei sehr niedriger Populationsdichte wirksam ist, benutzten wir sie, um die aus der Phänologie des Falterfluges abgeleitete Immigration des Lärchenwicklers (*Zeiraphera diniana* GUENÉE) in subalpine Areale zu untersuchen. Mittels Helikopter wurde das synthetische Sexualpheromon *E* 11–14: Ac in mikro-enkapsulierter Formulierung in den beiden topographisch unterschiedlichen Versuchsarealen von Val Bever (230 ha) und Sils (70 ha) ausgebracht. Die Behandlung erfolgte während dreier aufeinanderfolgender Generationen unmittelbar nach Beginn des lokalen Falterfluges. Nach der ersten Behandlung zeigte sich in der Val Bever eine signifikant geringere Populationsdichte als im Oberengadin (= Kontrolle). Nach der zweiten Anwendung führte regionale Einwanderung zu beträchtlichen Unterschieden im lokalen Populationswachstum. Im dritten Versuchsjahr wurde das Engadin durch eine Massen-Einwanderung von Faltern überflutet, welche die lokalen Dichte-Unterschiede aufhob und zu einem unerwarteten, 40fachen Populationsanstieg führte. Der Versuch zeigt, dass die Verwirrungstaktik vorübergehend wirksam war, aber laufende Einwanderung von Faltern sowohl durch regionale wie auch zeitweise grossräumige Migration zu einer starken Vermehrung von lokalen Populationen im subalpinen Raum beiträgt. Damit dürfte auch eine erfolgreiche Anwendung dieser Bekämpfungsmethode gegen den Lärchenwickler nicht in Frage kommen.

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