TESTS OF MOSQUITO REPELLENTS IN ALASKA [1]

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ABSTRACT. The repellent systems tested in Alaska (1970–1972) were designed to protect individuals or small groups of people. Mosquitoes were not repelled by a commercial "electronic mosquito repeller." Nor were mosquitoes repelled by four chemicals, *N,N*-Dimethyloctanamide, 2-[(*p*-Methoxybenzyl)oxy]-*N,N*-dipropylacetamide, *tertiary*-Butylsulfenyldimethyldithiocarbamate, and Benzyl benzoate, applied on vermiculite to one acre or one-half acre plots. The other chemicals tested were applied to fabric nets of wide- or narrow-mesh fashioned into hooded jackets. Deet-treated jackets gave effective protection (biting rate not greater than 10% of the control rate) for 8 days. Except for an unexplained lapse on the 2nd day, jackets treated with two experimental chemicals, *o*-Ethoxy-*N,N*-dipropylbenzamide and *o*-Ethoxy-*N,N*-diethylbenzamide, gave effective protection for at least 10 days.

INTRODUCTION. Although adult mosquito suppression by means of aerial or ground application of insecticides has been done with some success in Alaska (Mount *et al.* 1969), this method and the other two traditional techniques—larviciding and source reduction—of mosquito management are generally impractical. Much of the summer landscape of Alaska is highly productive of mosquitoes (Hopla 1964–65). Widely scattered over that landscape are small enclaves of people who would doubtless enjoy being protected from mosquito attack, but no practical means of achieving that happy end has been discovered. The human popula- is too small and too scattered to cope with mosquitoes in any organized way. Protection from mosquito attack has therefore become a matter of individual ingenuity in the use of topical repellents and protective clothing.

MATERIALS AND METHODS. Reported here are the results of tests of candidate area repellents, repellent-impregnated fabrics, and an "electronic mosquito repeller." The latter (Skeeter Skat™) was purchased from Sports Alliance, Inc., Los Angeles, CA. Lists of chemicals tested and mosquitoes encountered are given in Tables 1 and 2.

TABLE 1. Chemicals tested.

USDA ENT number	Chemical definition
26660-X	*N,N*-Dimethyloctanamide [a]
22542	*N,N*-Diethyl-*meta*-toluamide [b]
19083	*o*-Ethoxy-*N,N*-dipropylbenzamide [c]
20297	*o*-Ethoxy-*N,N*-diethylbenzamide [c]
20573-a	2-[(*p*-Methoxybenzyl(oxy]-*N,N*-dipropylacetamide [d]
25031	*tertiary*-Butyl sulfenyldimethyldithiocarbamate [e]
523	Benzyl benzoate [f]

[a] Hallcomid M 8–10®, donated by the C. P. Hall Company of Illinois, Chicago.
[b] Deet, Federal Stock Number 6840–753–4963.
[c] Provided by the U. S. Naval Medical Field Research Laboratory, Camp Lejeune, NC.
[d] Donated by McLaughlin Gormley King Company, Minneapolis, MN.
[e] Rotran, R-55™ Repellent Concentrate 25E, donated by Phillips Petroleum Company, Bartlesville, OK.
[f] Federal Stock Number 6840–281–2062.

Changes in mosquito populations were evaluated by means of sweep samples (10 vertically oriented, figure-8 sweeps with an insect net 11 inches diameter), landing counts (5 minutes, bare forearm), biting counts (5 minutes, bare forearm, proboscis inserted), and penetration counts (number passing through a wide-mesh net during 30 minutes). Additional procedural information is given in the pertinent sections below.

The area repellent tests and part of the repellent-impregnated fabric tests were done at Eielson Air Force Base (64°40'N, 147°6'W), a taiga locality, in 1971 and 1972. The sound repellent tests and most

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TABLE 2. Composition of the mosquito fauna.

Species	Eielson AFB		Sagwon	
	Landing %	Sweep %	Biting %	Sweep %
Aedes				
species A	...	...	48.0	49.0
cataphylla	...	...	<1	<1
cinereus	0	<1	...	...
communis	19.8	15.6	3.3	2.7
diantaeus	<1	<1	...	...
excrucians	19.8	8.2	...	...
fitchii	35.1	11.0	...	...
hexodontus	3.0	7.4	38.5	37.6
impiger	<1	<1	1.9	<1
implicatus	<1	0	...	...
intrudens	7.8	42.0	...	...
nigripes	...	...	1.0	5.8
pullatus	<1	0	2.5	1.1
punctor	6.5	6.6	<1	<1
riparius	<1	<1	...	...
species	7.8	5.6	4.6	2.8
Culiseta				
alaskaensis	<1	<1	...	...
impatiens	<1	0	...	...

of the repellent-impregnated fabric tests were done at Sagwon (69°22'N, 148°54' W), a tundra locality, in 1970 and 1972. Both localities have been described elsewhere (Gorham 1972a, b).

I worked alone during all the Sagwon tests. This circumstance obviously prohibited simultaneous pursuit of experimental and control procedures and simultaneous testing of the several repellent treated fabrics. All procedures were conducted as rapidly as possible in sequence, and the sequence was intentionally varied from series to series.

The circumstances of the test situation prohibited completely independent tests. There was some transfer of repellent from the fabric to the skin of the forearm. The effect of this undesirable residual was immediately noted during preliminary control counts. Thorough washing of the forearm with liquid detergent and water, followed by a rinse with 70% ethanol and complete drying, was routinely practiced between each test to counteract the residual effect. However, this procedure also made the forearm less attractive to mosquitoes. The washing was done in a small stream which originated from melting ice nearby in the tundra. I assume that the drastic lowering of skin temperature occasioned by the washing in ice water accounted for the diminished attractivity of the skin surface to mosquitoes. A further refinement of technique was therefore introduced, namely, a brisk massage of the forearm, to restore a normal temperature to the skin surface; this appeared to achieve the desired effect.

The variability of biting count results under "control" conditions is a frustrating circumstance that tends to undermine confidence in the whole procedure. In an effort to convey more precisely an understanding of the intensity of mosquito activity at the time of each test, I have computed a "Background Activity Index." Sweep sample and biting counts associated with each series of tests (and, in a separate calculation, with all tests of all series) were averaged. The average biting count was added to the average sweep count and the largest sum thus obtained was equated with 100. The remaining lesser sums were entered in Table 3 as some proportion of 100.

AREA REPELLENTS. One of the major drawbacks of adulticidal and larvicidal

TABLE 3. Protection (shown in %) provided by repellent devices, with associated environmental conditions at Sagwon in July 1972.

Test or Observation	Dates															Average
	6	6–7	7	7–8	8	8–9	10	10–11	11	12	12	13–14	14	15	15	
Fine-weave net jackets:																
Deet	100	100	100	100	100	100	100	100	...	100	100	98.3	64.6	90.7	30.5	85.1
Wide-weave net jackets:																
Deet	100	91.3	100	100	100	98.2	100	100	...	100	100	89.8	45.4	58.1	39.5	84.3
19083	100	65.2	93.3	97.8	96.9	99.4	91.6	97.5	...	100	100	100	100	93.0	98.1	97.9
20297	100	39.1	97.8	98.9	93.9	98.2	97.6	98.1	...	97.8	96.3	100	92	90.7	91.8	95.5
Bednet:																
20573	...	...	...	...	...	...	...	99.3	92.9	90.5	...	98.2	86.5	50	...	89.8
Skeeter																
Skat	−57	−413	−262	+58.7	−388	−92.1	−152	...	...	...	...	...	...	...	...	−194
Background activity index	30	34	23	67	29	94	80	100	47	35	33	62	68	33	91	53.7
Biting count average	51.6	11.5	44.6	92	32.8	165	84	159	117.5	45.5	82	117.7	99	43	188.5	83
Sweep sample average	63.3	122	45.5	168	80	197.5	223.5	227	65.5	90.3	44	121.6	165.3	85	161	124.2
Time	0715–1510	2256–2455	0737–0947	2217–2430	0649–0946	2224–2421	0731–1026	2148–2427	2150–2315	0748–1043	2225–2355	2127–2406	2030–2321	0700–0956	1839–2022	... ...
Temperature range (° F)	47–64	34–52	52–55	41–55	51–60	42–65	52–65	45–60	46–60	59–66	44–50	40–54	51–69	61–69	67–72	...
Relative humidity range (%)	43–85	70–88	69–75	70–91	65–86	56–90	47–76	65–89	65–88	55–64	82–92	72–90	51–78	51–62	44–61	...

TABLE 4. Area repellent tests at Eielson AFB.

Candidate repellent	Plot size (acres)	Rate of appl. per acre: Chemical (quantity)	Vermiculite (pounds)	Average landing count: Control Before	Control After	Treatment Before	Treatment After	Average sweep sample: Control Before	Control After	Treatment Before	Treatment After
Benzyl benzoate (90%)	0.5	2 gallons	36	66	78	..	71	34.5	38	..	40
Hallcomid M 8–10 (100%)	1.0	6 gallons	33	102.5	80.3	61	65	51.5	28	41	24.7
Rotran (25%)	0.5	2 gallons	36	66	78	..	100	34.5	38	..	37.5
20573-a (100%)	0.5	592 grams	72	..	66	81	88	..	34.5	69.5	36.5

treatments, especially in Alaska, is prompt migration and reinfestation from surrounding areas. An effective area repellent would be a welcome and desirable solution to this problem. The idea of area repellency and the results of small field trials have been discussed by Horsfall (1959), Lopp and Buchanan (1959), Berry *et al.* (1965), and Langford *et al.* (1966).

Four candidate repellents were applied to vermiculite and spread over 0.5 or 1.0 acre plots in a spruce forest. None of the candidate chemicals showed any appreciable repellency to mosquitoes (Table 4).

The manufacturers of Rotran, a rodent repellent, do not claim that it has any repellent action for mosquitoes. Hallcomid M 8–10 belongs to a chemical family (caprilic acid lower alkyl amides) which has been patented as an insect repellent but has never been commercially produced for that purpose. During the course of mixing and spreading M 8–10, some of the chemical contacted the inner surfaces of my forearms. At every point of contact the skin reddened and I distinctly felt a burning sensation. Five days later the affected surfaces cracked and peeled, and during the course of a few subsequent days gradually returned to a normal condition.

SOUND REPELLENT. The electronic mosquito repeller was tested on seven occasions during the period 6–10 July 1972. No significant repellent effect was noted, but on one occasion the number of bites was 58.7% less than the corresponding control biting count average. In the other six tests the biting rate varied from 57% to 413% greater than the corresponding control biting count average (Table 3). Claims of the effective repellency by means of sound as stated by promoters of the Skeeter Skat and by Greenlee (1970) for a similar device were not supported in this series of tests.

REPELLENT-IMPREGNATED FABRICS. The dense populations of mosquitoes so often encountered in Alaska make it highly desirable to have some sort of protection. Headnets are helpful but visibility suffers. During the course of other field work my assistant and I used repellent-treated jack-

ets to protect us from mosquito attack. I considered these uses of the jackets to be informal tests conducted under very practical conditions.

At Sagwon a cotton-net, camouflage pattern, hooded jacket (24 meshes/inch), treated with two ounces of 75% deet (0.45 gram deet/gram of net), gave complete protection (no bites through net) for 45 hours (intermittent use spread over a 7-day period), but repellency rapidly decreased thereafter (Gorham 1972b).

At Eielson AFB my assistant tested a wide-mesh, deet-treated garment, the No-Skeet-O Jacket, purchased pre-treated and ready to use from Entomology Research Institute, Lake City, MN. The jacket was worn a total of 20 hours over a period of 20 days (it was kept in a plastic bag when not in use). There were eleven separate exposure periods. Although mosquitoes were always present in large numbers, none succeeded in biting through the treated fabric. Testing was suspended before the first bite was received, but during the final hour of exposure I noted that mosquitoes were beginning to rest momentarily on the jacket. Experience from other tests indicates that this behavior pattern is soon followed by probing and then by successful insertion of the proboscis. It would have been very instructive to have included this jacket in the tests described below, but the jacket was stolen before that plan could be effected.

BEDNET TESTS. A standard-size, cotton-fiber bednet (0.25 inch mesh), provided by the U. S. Naval Medical Field Research Laboratory (Camp Lejeune, N.C.) was treated with ENT-20573-a at the rate of 0.125 gram per gram of net. This small dosage, one-fourth the usual rate (Grothaus *et al.* 1974), was dictated by two rigid parameters—the weight of the net and the quanity of available chemical. The net was treated on 13 June 1972 and held in a sealed plastic bag until 6 July. It was then placed out of doors on a suitable frame. A plastic cover protected it from rain and dew. Six tests of 30 minutes each were done between 10 and 15 July. The protection rate was calculated as a percentage based on the difference between the penetration count and the corresponding average 5-minute biting count (multiplied by six to match the 30-minute test period).

The bednet tests were difficult to carry out, working alone, and the results are difficult to evaluate (Table 3). No untreated control net was available and the penetration counts were not precisely comparable with the biting counts. With these reservations in mind, it is probably best to conclude that the results are equivocal and the ENT-20573 merits further testing at a higher dosage rate, with adequate controls, under conditions of intense mosquito attack.

NET JACKETS. One garment, a fine-weave jacket described above, was treated with 2 ounces of 75% deet on 4 July 1972. The other three jackets, all wide mesh, were provided by the U. S. Naval Medical Field Research Laboratory, Camp Lejeune, NC. Two were pre-treated there with ENT-19083 and ENT-20297. The third was treated with 2 ounecs of 75% deet (0.35 gram of deet/gram of net) on 5 July 1972. The jackets were removed from airtight storage on 5 July and placed on hangers in an outdoor shelter that provided only protection from rain and dew; air circulated freely through the shelter. The jackets were maintained in that fashion for the duration of the test program.

The fine-weave, deet-treated jacket gave complete protection for 8 days and permitted only 2 bites on the 9th day; protection declined erratically thereafter (Table 3). This was a much better performance than the same jacket gave in 1970 under essentially identical ambient conditions (Gorham 1972b). That, however, was a practical test during which the jacket was worn for long periods in the field and subjected to a great deal more stress than that occasioned by a 5-minute biting count.

The deet-treated wide-mesh jacket performed almost as well as the fine-weave one during the first 8 days, but failed thereafter (Table 3). The results of these two series of tests indicate that treatment

of a cotton-net jacket with 2 ounces of 75% deet every 8 days would provide complete protection from mosquito bites (through the treated surface only) under conditions of mosquito density that are probably among the highest extant anywhere in the world. Any use-associated factors that would compromise the persistent qualities of the repellent would naturally reduce the duration of effective protection.

The jackets treated with ENT-19083 and ENT-20297 started out giving 100% protection, but failed on the 2nd day when protection dropped to 65.2 and 39.1% respectively. On the 3rd day protection levels in both instances surpassed 90% and remained above that level during the rest of the series (Table 3). The test program was terminated before any further failures occurred; therefore the actual duration of effective protection could not be determined.

The cause of the 2nd-day failure has eluded me. The failure occurred at the time when the control biting counts were the lowest of the entire series; complete protection should therefore have been easily achieved. At first I attributed the failure to the low ambient temperature (42° F for 19083; 46° F for 20297) and postulated that the volatization rates of the repellents were sensitively related to temperature. However, the record revealed instances of complete protection with 19083 in the 45–49° F range, and greater than 90% with 20297 in the 42–48° F range. I can only suggest that biting activity at the time was unpredictable: two control biting counts yielded no mosquitoes at 34 and 36 F; two others produced counts of 20 and 26 mosquitoes biting at 34 and 52° F, respectively; the sweep samples yielded 188 mosquitoes at 52° F, and 56 at 36° F. In short, mosquitoes were flying actively but biting erratically.

DISCUSSION. The duration of acceptable protection levels achieved in the deet tests was much shorter than that reported in tests done elsewhere (Catts 1968; Grothaus *et al.* 1974). In the series of tests with 20297 there was some indication that protection levels declined after 8 days, but were still greater than 90% when the tests were terminated at 10 days. The data do not permit a firm conclusion, but the results suggest that an acceptable level of repellency of 20297 would not have lasted as long as other reports have indicated (Grothaus *et al.* 1974). I cannot explain the modest performance of these repellents in Alaska, but I can suggest that the results might be attributed to marked differences in three parameters of the Alaska situation, in contrast to that of the contiguous states: the mosquitoes species are different; the density of mosquitoes is much higher; and the ambient temperatures associated with mosquito attack are generally much lower.

The need for wide-mesh bednets is not as compelling in arctic and subarctic regions as it is in the warmer parts of the world. A repellent-treated, wide-mesh bednet provides the user with protection from mosquitoes while permitting air circulation (more, at least, than a fine-mesh net) where warm ambient temperatures prevail (Grothaus *et al.* 1974). In those regions of the higher latitudes which, in season, are highly productive of mosquitoes, daytime temperatures in the 60–90° F range are common, but "nighttime" temperatures drop to levels that are more associated with heat conservation than heat dispersion. Protection from mosquito attack is still required, since tundra mosquitoes may actively seek blood at temperatures ranging upward from 34° F, but a fine-mesh bednet accomplishes that even without a repellent. At this point, however, simuliids and ceratopogonids, also troublesome denizens of some high latitude regions, enter the picture; no recent repellent work concerning these groups has been done in Alaska.

The comfort factor associated with repellent-treated wide-mesh bednets was deliberately introduced to promote acceptance and regular use, two keys to the prevention of mosquito-transmitted diseases. This is a compelling objective in the lower latitudes but in the arctic and subarctic,

mosquitoes have attracted far more attention as nuisances than as vectors. However, with the belated discovery of California encephalitis virus in Alaskan mosquitoes, the vectoral role of our mosquitoes has at last been recognized, but beyond an incomplete list of hosts (based on viral and antibody identifications) nothing is known of the epidemiology of California encephalitis in Alaska and the Yukon (Feltz *et al.* 1972; McLean *et al.* 1972; Sudia *et al.* 1971).

The foregoing comments about bednets cannot be fully extended to repellent-treated net jackets. I am not convinced that such garments for Alaskan use need to be wide-weave nets; the durability, acceptability and effectiveness of the repellent chemical are probably far more important criteria than the design of the jacket. However, it would be convenient to have a standard mesh-fabric-repellent combination that could be used universally. In that case the mesh would have to be wide to satisfy comfort considerations in warmer climates. Such a net jacket could be used under all ambient conditions during which mosquitoes are active in the higher latitudes.

There is more, however, to the nuisance factor of mosquito attack than the bites received. The cloud of noisy, gyrating mosquitoes which surrounds one's person in mosquito country is in itself a constant source of annoyance and is anything but conducive to productive human activity. Although the use of any of the jackets mentioned above prevents bites on the surfaces it covers (usually, also, on the face when the hood is in place), mosquitoes continue to control the surrounding air space, to land momentarily on the face, and to probe all surfaces not treated with repellents. The repellent-treated net jacket represents an important and welcome advance in personal protection from mosquito attack, but there is still ample room for innovation—more effective ("long-distance") space repellents, more practical protective clothing (for use with and without repellents), and area repellents for use on small foci of intense human activity.

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